ESR 94-08

REGIONAL METALLOGENIC EVALUATION OF ALBERTA

PREPARED BY

R.A. OLSON CONSULTING LTD.

R.A. Olson, Ph.D., P. Geol.

M.B. Dufresne, M.Sc., P. Geol.

M.E. Freeman, M.B.A., P. Geol.

and

THE ALBERTA GEOLOGICAL SURVEY
OF THE ALBERTA RESEARCH COUNCIL

R.J.H. Richardson, M.Sc., P.Geol.

D. R. Eccles, B.Sc.

March, 1994

REGIONAL METALLOGENIC EVALUATION

OF ALBERTA

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

TABLES

APPENDICES

FIGURES AND MAPS

REGIONAL METALLOGENIC EVALUATION

OF ALBERTA

ABSTRACT

Alberta's geology is both complex and diverse. Proterozoic to Tertiary sedimentary and, locally, volcanic rocks overlie Proterozoic and Archean metamorphic and granitoid rocks. In general, the province can be broadly divided into (a) the northeastern Precambrian Canadian Shield, (b) the Plains Region, and (c) the Rocky Mountains and Foothills. To the west in the Cordillera, fault and fold structures are common. Although most of this faulting is related to the Laramide Orogeny which produced the Rocky Mountains and Foothills, there are also several other faults and fault zones that are related to older tectonic events. To the east, in the Plains Region, faults are uncommon but they do exist in a few places. As well, there are a number of other anomalous structural features, such as the Steen River Anomaly, the Eagle Butte Anomaly, and numerous collapse structures related to dissolution of the Phanerozoic evaporites in the Plains Region. Igneous rocks are uncommon in Alberta, but do occur locally in at least Proterozoic, Devonian, Cretaceous and Tertiary strata.

The reconnaissance metallogenic study has identified in excess of 630 mineral occurrences, or geological, geochemical or geophysical anomalies in Alberta. These occurrences comprise a diverse suite of metals and minerals including precious metals, base metals, uranium, iron and even diamond occurrences in surficial sediments or, possibly, bedrock. Although there are more known mineral occurrences in the Precambrian rocks of northeastern Alberta and in the Proterozoic to Tertiary rocks of southwest Alberta than in the Plains Region or in the central to northern Mountains and Foothills Region, this may be a reflection of a greater intensity of past exploration rather than the Plains Region or the northwestern part of the Alberta Cordillera being geologically less favourable.

Potential exists in Alberta for the discovery of a large number of diverse metallic and precious mineral deposits. These include both syngenetic and epigenetic precious metal deposits, base metal deposits, uranium deposits, and bedrock and alluvial diamond deposits. Some of the potential deposit types that may be present in Alberta include: (a) both **bonanza lode and disseminated epithermal gold deposits**; (b) **Mississippi Valley type lead-zinc deposits**; (c) **sediment hosted base metal deposits** comprised of one or more of zinc, lead, copper and nickel with, possibly, associated precious metals; (d) **volcanogenic massive sulphide base metal deposits**; (e) **granitoid-related precious metal and base metal deposits**; (f) **Olympic Dam type copper-uranium-gold-silver deposits**; (g) **magmatic-related nickel-copper deposits**; (h) **sediment hosted oolitic iron deposits**; (i) **unconformity-related, sandstone hosted or vein type uranium deposits, or uraniferous coals or conglomerates**; (j) **diamondiferous diatremes**; and (k) **various types of placer or paleoplacer deposits** with the important placer metals/minerals being gold, magnetite, diamonds or other 'heavy minerals' of economic interest.

INTRODUCTION

During early 1992, R.A. Olson Consulting Ltd. (RAOCL) prepared an unsolicited proposal entitled "Proposal for a Regional Metallogenic Evaluation Study of Alberta", which was submitted to the Alberta Geological Survey (AGS), a department of the Alberta Research Council (ARC). This proposal formed part of a Consulting Agreement that was signed between RAOCL and the ARC on May 30, 1992. Schedule A(2) to this Consulting Agreement defines the scope of the regional metallogenic evaluation. In summary, the scope included five stages: (1) plan the study methodology and acquire selected data; (2) summarize prior exploration results from publicly available assessment reports on file with the AGS; (3) compile and interpret selected data; (4) identify those geological features and targets that are of greatest potential for metallic mineral exploration, and (5) prepare a final report that documents the results of the regional metallogenic evaluation.

A metallogenic evaluation is NOT simply an inventory of metallic mineral occurrences that are known to exist in Alberta, but instead is focused on **WHAT MIGHT BE PRESENT** based on modern geological thinking about ore deposition processes. During this study, particular attention has been given to (a) the various types of metallic mineral deposits that may be present in specific rock units or structural domains in Alberta, and (b) the types of modern geological, geochemical and geophysical exploration methods that currently are available to search for the potential deposit types.

The intent of the regional metallogenic evaluation of Alberta is twofold:

1. To provide industry with data and information about selected mineral occurrences, and geological, geochemical and geophysical anomalies in order to stimulate their interest in the metallic mineral potential of Alberta.

2. To assist in the identification of those areas of Alberta that are or may be geologically favourable for metallic mineral deposits in order to guide future work.

The prospective geological rock units, structures and anomalies that were identified by the regional metallogenic evaluation are to be used as a guide in three ways for future work in Alberta. (1) Define specific anomalies, geological units or geographic areas that could be targeted by metallic mineral exploration companies for future exploration. (2) Identify selected geographic areas where the exploration potential is deemed favourable such that a more detailed metallogenic compilation to identify more specific targets would be beneficial. Lastly, (3) Identify selected geographic areas or geological units that require more detailed geological mapping or other geoscientific studies that could, in future, be performed by the AGS, the Geological Survey of Canada (GSC) or other government or private agencies.

Physiography of Alberta

Alberta can be broadly divided into three physiographic regions: (a) the exposed Precambrian Shield north and south of Lake Athabasca in northeast Alberta, (b) the Foothills and Rocky Mountains of the Canadian Cordillera in the southwest, and (c) the Alberta portion of the Interior Plains in southern, central and northern Alberta (Figure 1).

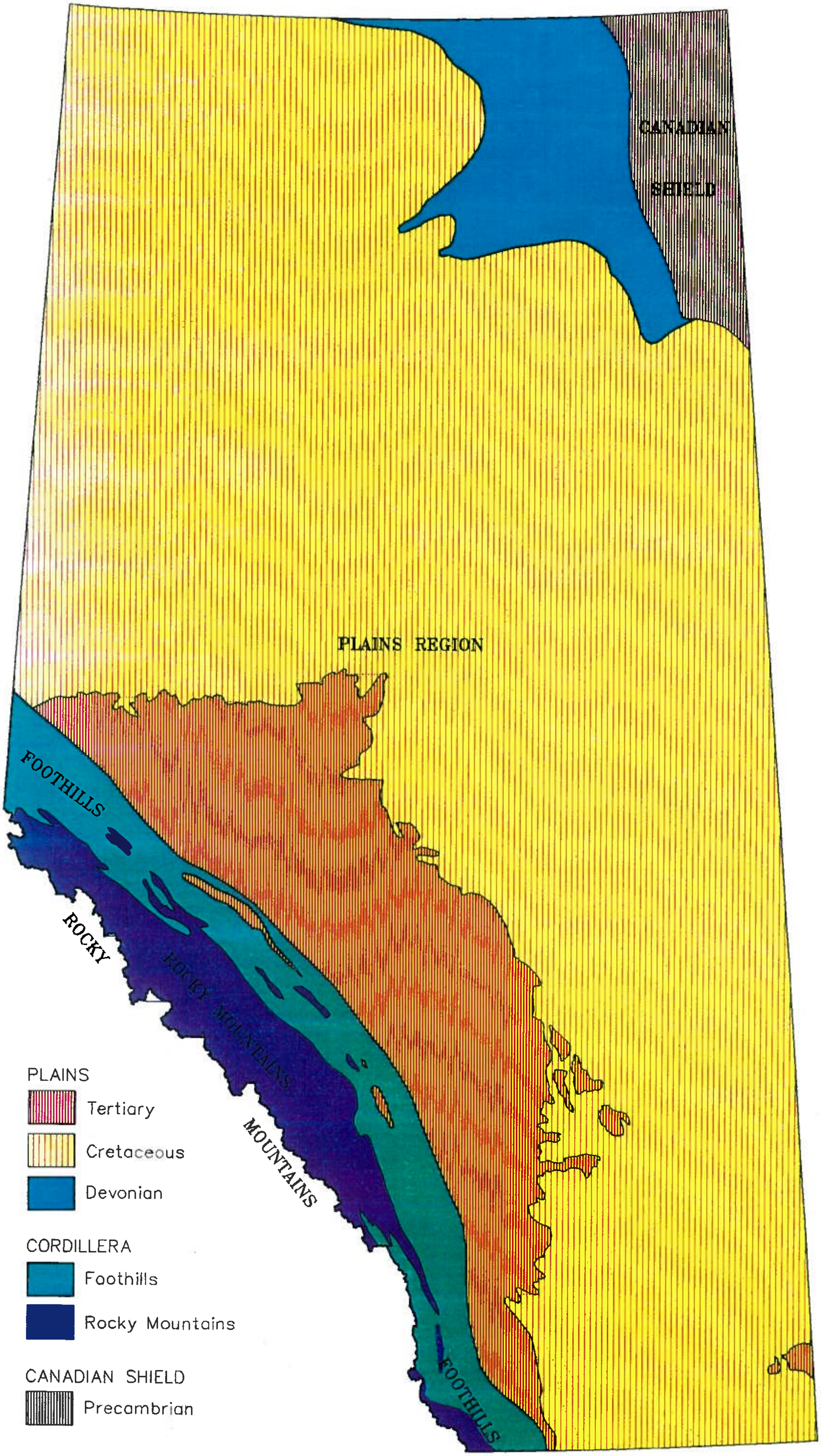


Figure 1: Regional Geology and Physiography of Alberta.

In the northeast, the Precambrian Shield is subdivided into the Kazan Upland and Athabasca Plain (Bostock 1970). North of Lake Athabasca, the western extent of the Kazan Upland is underlain mainly by massive granitoid and metamorphic rocks that form broad sloping uplands, plateaux and intervening lowlands. Bedrock exposure ranges from a few per cent to a few tens of per cent locally, and local relief is commonly up to about 50 m, with the maximum elevation reaching about 417 m above sea level (asl) northeast of Andrew Lake, Alberta. South of Lake Athabasca is the Athabasca Plain, which is underlain by Proterozoic sandstones, early- to mid-Paleozoic sedimentary rocks and Quaternary deposits that overly Precambrian basement granitoid and metamorphic rocks. Bedrock exposure is much less than one per cent in most places, and local relief is typically about 30 m or less, with the maximum elevation reaching about 665 m south of the Firebag River. Lake Athabasca and Lake Claire are the two largest lakes in northeast Alberta, and effectively divide the Precambrian Shield into two parts. Both these lakes, albeit large, are shallow and have a water surface elevation of about 213 m asl. For example, most of the Alberta-portion of Lake Athabasca has a water depth of about 10 m or less, with the maximum depth of the lake being about 17 m in its east-central part in Alberta.

The Canadian Cordillera in Alberta is subdivided into the Foothills and Rocky Mountains (Ibid). The Foothills are mainly northwesterly trending, linear ridges and hills underlain by Mesozoic sandstones, with some local mountain ranges underlain by cliff-forming Paleozoic carbonates. The Rocky Mountains comprise a series of ranges that typically are underlain by extensively folded and faulted Phanerozoic rocks to the east and Proterozoic rocks to the west. Elevation ranges from about 1,000 m in the eastern part of the Foothills, with the maximum elevation in the Alberta-British Columbia Cordillera being up to 3,954 m at Mount Robson which is in British Columbia not far west of Jasper, Alberta. Local relief in the Rocky Mountains is commonly up to several hundreds metres or more where cliff-forming units are exposed in eroded thrust fault slices.

The Interior Plains in Alberta are subdivided into the Alberta Plain in the south and the Alberta Plateau in the north (Ibid). The Alberta Plain is underlain, near surface, by flat lying to gently dipping Upper Cretaceous and Tertiary sedimentary rocks. At depth, there exist flat lying to gently dipping Paleozoic and Mesozoic strata that unconformably overlie Precambrian basement rocks. Much of the Alberta Plain is about 760 m asl in elevation, with river valleys locally entrenched up to 120 m. In places there are local highlands or plateaux, for example at Cypress Hills, Hand Hills and Swan Hills, where elevations reach 1,430 m asl. The Alberta Plateau, in its western and southern portions, is underlain near surface by Lower and Upper Cretaceous sedimentary rocks that exist in a ring of plateaux separated by the Fort Nelson and Peace River Lowlands. At depth, there exist gently westerly dipping Paleozoic rocks that unconformably overlie Precambrian basements rocks as in the Alberta Plain. To the northeast, between the Caribou and Birch Mountains and the Slave River, the region is underlain by gently dipping Devonian carbonate and evaporitic strata. Elevations in the Alberta Plateau range from about 760 m asl in the west to less than about 180 m where the Slave River enters the Northwest Territories (N.W.T.) near Fort Smith, N.W.T. Along the incised valleys of the Hay and Peace Rivers, elevations typically are less than 500 m asl whereas in the Caribou Mountains north of Fort Vermilion, Alberta, elevations locally reach 1,117 m asl.

Transportation and Other Infrastructure

In southern and central Alberta to about 56° N latitude there is an extensive road network of primary, secondary and tertiary all-weather roads. In northern Alberta, the main transportation corridors are provided by: (a) highway 63 to the Fort McMurray-Fort MacKay area in northeast-central Alberta, (b) highway 35 in northwest Alberta which extends north of Peace River through High Level to Hay River, N.W.T., (c) highway 58 which extends both west of High Level to Rainbow Lakes, and east to Fort Vemilion and beyond where via a track-trail it connects to the east with an all weather road that extends south from Fort Smith, N.W.T. into Wood Buffalo National Park in northeastern Alberta; and lastly (d) by highway 88 which runs south from Fort Vermilion to Slave Lake in north-central Alberta. In total, the road network in Alberta comprises over 150,000 km of highways or all-weather or summer- or winter--accessible roads that permit ready access to most of southern and central Alberta, and selected parts of northern Alberta. This road network is important because it facilitates mineral exploration in Alberta, including the potential for significant logistical cost savings.

In addition to the large road network in Alberta, there exist extensive networks of primary and secondary rail lines, oil and gas pipelines, and power transmission and generating stations, as well as numerous communities, and both fixed-wing and helicopter bases throughout Alberta (Alberta Chamber of Resources 1987). This extensive support infrastructure will facilitate fieldwork and reduce logistical costs for any mineral exploration or resource development that is performed in Alberta.

Metallic Mineral Rights Acquisition in Alberta

Regulatory Aspects

Prospecting by hand tools for 'metallic minerals' held by the provincial government of Alberta (hereafter referred to as the "Crown"), where such occurs without surface disturbance, is permitted throughout Alberta without any licence, permit or regulatory approval. Although unoccupied public lands may be explored without restriction, prospectors must receive consent for access from the surface owner or occupant for privately held land (Freehold land). While prospecting, the prospector may travel in a vehicle on a previously established road, trail or existing cut-line and may occupy a tent, trailer or other shelter at any location for not more than 14 days. Airborne and hand held ground geophsyical surveys, geochemical surveys or other such exploration work which does not disturb the land or vegetation cover, are permitted without any exploration approvals being required. However, to secure the rights to metallic minerals at a location in Alberta, or when exploration involves any land disturbance or use of heavy exploration equipment, the individual prospector or company is required to obtain appropriate licences, permits and approvals. For most projects, several steps are normally involved, which include: (1) acquisition of the rights to the metallic minerals in a specific location by obtaining a Metallic and Industrial Minerals Permit, (2) acquisition of an Exploration Licence, which gives a company the right to explore in Alberta and to apply for an Exploration Permit or Exploration Approval, (3) obtaining an Exploration Permit for the operation of heavy exploration equipment, and (4) obtaining an Exploration Approval where exploration activities involve or may involve environmental disturbance.

To secure the rights to metallic minerals, where such rights are held by the Crown, a person or company must apply for and obtain a "Metallic and Industrial Minerals Permit" for the desired location. The Metallic and Industrial Minerals Permit is granted under the "Mines and Minerals Act" of Alberta, and the conditions under which it may be held are governed by the "Metallic and Industrial Minerals Regulation (A.R. 66/93)". This Permit, which equates to a 'mineral claim' in other jurisdictions in Canada, does not require staking of the Permit on the ground, but instead is 'paper staking' in that an application for the Permit is made to Alberta Energy accompanied by the appropriate recording fee. The area of such a Permit ranges from a maximum of 9,216 ha (one township) to a minimum of 16 ha (one legal subdivision). Regulation 66/93 requires that assessment expenditures be performed to maintain the Metallic and Industrial Minerals Permit in good standing. These expenditures comprise: (a) at least $5.00 per hectare must be spent during the first two years of the Permit, (b) at least $10.00 per hectare must be spent during each two-year period during the 3rd to the 6th year of the Permit, and (c) at least $15.00 per hectare must be spent during each two-year period during the 7th to 10th year of the Permit. These expenditures are cumulative; that is, if more than the minimum assessment work is done in any two-year period, then the excess expenditures can be filed against the assessment work required in subsequent periods. If, however, these minimum expenditures are not made, and then filed with and found acceptable by the government of Alberta, all or a portion of the Metallic and Industrial Minerals Permit will lapse. With respect to acquisition of a location where the metallic mineral rights are held by someone other than the Crown, such acquisition is not governed by Regulation 66/93 and hence requires a contractual agreement being reached with the person or company who owns the Freehold mineral rights.

In order to develop or recover metallic minerals in Alberta, the individual or company must obtain a "Metallic and Industrial Minerals Lease", which currently also is issued under Regulation A.R. 66/93. Following the initiation of production from a metallic mineral resource, the payment of a royalty to the Crown is provided for by the "Metallic Minerals Royalty Regulation (A.R. 253/85). To assist individuals and companies in their understanding of Alberta's metallic minerals 'Royalty' regulations (i.e., A.R. 253/85), these regulations are succinctly summarized in a 'layman' document that was prepared by Alberta Energy (1986). The Royalty Regulations do not, however, pertain to those locations which are held under Freehold mineral rights. In these cases, any royalties must be negotiated with the owner of such Freehold mineral rights.

With respect to 'Land Use' regulatory aspects, any exploration project that involves the use of heavy exploration equipment or may involve environmental disturbance, including drilling, trenching, bulk sampling or other such activities, must receive additional approvals from the Crown. These approvals can be obtained from the Client and Field Services Branch, Land and Forest Services of Alberta Environmental Protection, and are provided for under Metallic and Industrial Minerals Exploration Regulation A.R. 95/91, as amended by A.R. 299/93. Normally, the individual or company contemplating work that may cause surface disturbance would need: (1) an Exploration Licence, (2) an Exploration Permit, and (3) an Exploration Approval. The Exploration Licence identifies the company or individual who will perform and/or be responsible for work having potential for environmental disturbance. This province-wide licence is not time limited, but remains in effect as long as the person or company continues to operate in Alberta. The Exploration Permit is required prior to operating heavy exploration equipment, and each unit of such exploration equipment must bear the Exploration Permit unique identifying number. An Exploration Approval allows the holder to perform the approved exploration program, including the approved surface disturbance and any restrictions on same, within a specific location. Under Regulation A.R. 66/93, an Exploration Licence and an Exploration Permit may be obtained for a fee of $50 for the licence and for each permit, and there is a fee of $100 for the processing of each Exploration Approval. These various licences, permits and approvals are obtained from the Client and Field Services Branch, Land and Forest Services of Alberta Environmental Protection. In addition to these approvals, which apply to both Crown and Freehold lands, if the surface rights are owned by someone other than the Crown, then to obtain surface access the Exploration Licensee must obtain the consent of the surface owner.

Where a property is to be brought into production, a Mineral Surface Lease must be obtained. This Mineral Surface Lease is granted under the Public Lands Act and the Mineral Surface Lease Regulation (A.R. 228/58), and its issuance is administered by the Public Lands Division of Alberta Energy. Prior to plant construction or any other pre-development work and actual production, some additional approvals must be obtained from the Crown. Details with respect to these approvals can be obtained from Alberta Energy and from Alberta Environmental Protection.

With specific reference to uranium or other radioactive elements of potential exploration interest, these resources are fully under Alberta's provincial jurisdiction and are subject to all conditions applicable to metallic minerals. However, the Atomic Energy Control Board (AECB) of the government of Canada also administers approvals for the exploration and development of uranium and other radioactive elements pursuant to the Atomic Energy Control Act and Regulation. No permission from the AECB is required to prospect for uranium or thorium in Alberta, but a person finding a deposit containing more than 0.05 per cent by weight uranium or thorium is required to report the discovery to the GSC.

Lands Available for Staking in Alberta

In Alberta, approximately 88 per cent of the province is available for the acquisition of metallic mineral rights, either from the Crown or from the 'Freehold' private owners of the mineral rights. At present, the Crown holds the majority of the metallic minerals rights and about 10 per cent of Alberta is Freehold, with most of the Freehold mineral rights being in the southern half of the province. Acquisition of metallic mineral rights is not permitted in about 12 per cent of Alberta as a result of the land being in one or more of federal or provincial parks, within the confines of cities and towns, within Military Ranges, within Indian Reserves or within selected areas governed by the Eastern Slopes Policy (Alberta Government, 1984). The major parks and prime protection areas in Alberta comprise: (a) Wood Buffalo National Park in the northeast, (b) Elk Island National Park east of Edmonton, (c) the mountain 'parks', including Jasper, Banff and Waterton National Parks, Willmore Wilderness area and Kananaskis Country, and (d) Cypress Hills Provincial Park in the southeast.

Alberta has instituted an integrated resource plan for the eastern slopes of the Foothills and Rocky Mountains area from just south of Grand Prairie in the northwest, southeast to the Canada-United States of America border. This policy defines eight "regional land use zones" where differing levels of industry activity are permitted. With respect to metallic mineral exploration and development under the Eastern Slopes Policy as of 1994, exploration for metallic minerals is not permitted within those areas designated as "Prime Protection" and "Facility". In the other six regional land use zones, mineral exploration and development are permitted, although there are some restrictions with respect to how such work is done in those areas designated as Critical Wildlife, Special Use and General Recreation.

Due to the recent interest in exploration for diamonds in western and northern Canada, and to the revisions to Alberta's Metallic and Industrial Minerals Regulation (A.R. 66/93), there has been a marked increase in the acquisition of metallic mineral rights in Alberta. That is, in early 1992 only about 800,000 ha of Crown land were held under Metallic Minerals Exploration Permit, whereas at the end of 1993 about 30 million hectares had been applied for (Figure 2).

METHODOLOGY FOR PREPARATION OF THIS REPORT

Methodology for Data Compilation

RAOCL, in consultation with selected AGS geoscientists: (a) prepared a detailed workplan for the regional metallogenic evaluation, (b) established the general format of the database tables that would be used for compilation of 'anomalies' from the existing assessment records on file at the AGS and from other sources of geoscientific data, and (c) established the map scales for compilation and final presentation of data. Numerous metallic mineral occurrences exist in northeast Alberta (NTS 74E,L,M) and in the foothills and mountains region of Alberta (NTS 82G,J,N,O and 83C,D,E,F), whereas in the remainder of Alberta there are currently few documented metallic mineral occurrences and the digital geological data is at 1:1,000,000 scale. Therefore, it was decided to compile the regional metallogenic data at various scales, comprising: (a) 1:750,000 scale for the Plains region where Precambrian basement is overlain by Phanerozoic strata in southern, central and northern Alberta, (b) 1:250,000 scale for the NTS 74E,L,M map areas in northeastern Alberta, which are underlain by the Precambrian Canadian Shield, and (c) 1:500,000 scale for the NTS 82H,J,N,O map areas in southwestern Alberta, which are underlain by Proterozoic and Phanerozoic strata. As well, (d) the location of reported metallic mineral exploration drill holes in NTS 74E,L,M map areas of northeastern Alberta were also compiled at 1:250,000 scale. However, for presentation purposes in this report, the seven maps that show 'Anomalies' have been printed as 11" by 17" colour plots, with scales ranging from about 1:540,000 to 1:2,100,000 (Maps 1994-Map 1 to 1994-Map 7). Because the data on these seven maps are in digital form, the Alberta Geological Survey can produce maps at other scales on request.

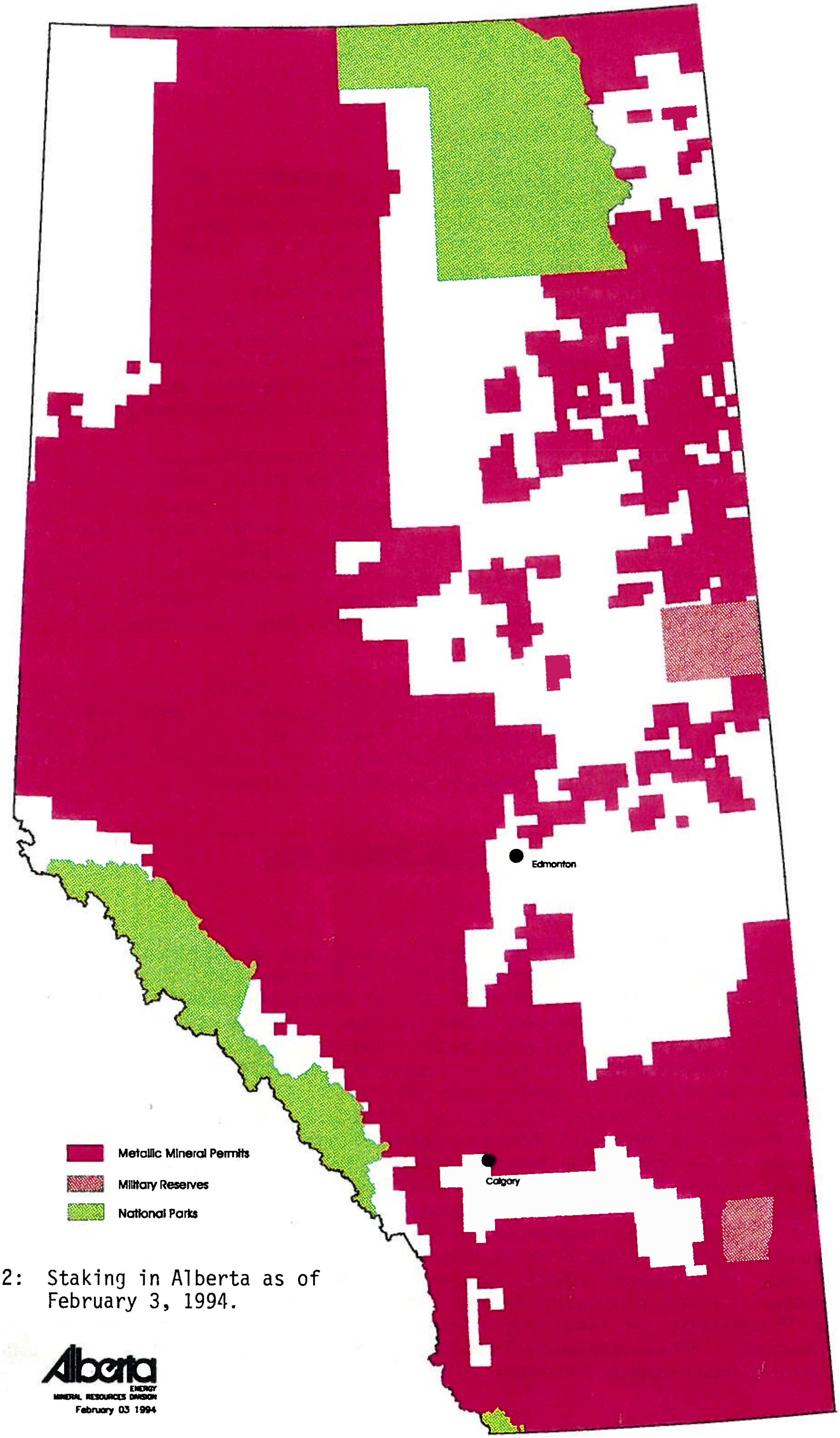


Figure 2: Staking in Alberta as of February 3, 1994.

Essentially, Maps 1 to 7 are a compilation of the mineral occurrences, and geological, geochemical, geophsyical and drilling anomalies from both published and unpublished sources for Alberta. Because Maps 1 to 7 are in preliminary Open File form, no attempt has been made to classify and present on the maps the mineral occurrences or various anomaly types with respect to the major commodity present, mineral deposit type, quality of the anomaly with respect to its potential exploration importance, or genetically associated host rock. Therefore, in strict terms Maps 1 to 7 are not "metallogenic maps", although such could be prepared in future from data currently existing or being compiled into the various GIS and other databases at the Alberta Geological Survey. Maps 1 to 7 do illustrate, however, that there is a widespread distribution of mineral occurrences and other anomalies in Alberta, and the accompanying text attempts to summarize the metallogenic variations that exist and those target lithologic units, target areas, mineral occurrences and anomalies that may be of exploration interest to companies and individual prospectors interested in the potential of Alberta for metallic and related mineral commodities.

Several database tables were created for the systematic manual capture of mineral occurrences, various types of anomalies and other information from assessment records and selected other geoscience source documents. These tables include:

Table	Title
I	Document Summary
II	Mineral Claims
III	Geochemical Anomalies
IV	Geophysical Anomalies
V	Geological Anomalies
VI	Mineral Occurrences
VII	Drilling Summary

These tables are now on file at the AGS. Much or all of these data were subsequently entered into an electronic database. To assist AGS and RAOCL geologists to compile pertinent mineral occurrence and anomaly data into Tables I to VII, RAOCL prepared a series of synoptic "metallic mineral deposit models" for 21 precious metal, base metal, uranium or other types of mineral deposits. These synoptic model summaries are included in Appendix I.

Design of the Database Tables and Output of Information

The AGS entered selected data from the above tables, as well as selected information from other geoscience sources, into a digital database. ArcCAD® was used to enter the data, and provides the foundation needed to combine a geographic information system (GIS) with computer aided design (CAD). The ArcCAD® software integrates the ARC/INFO® GIS software currently in use by the AGS's Mineral Information System and the AUTOCAD® software that was used for map production in this report. Information in the GIS may be selected and retrieved based on any combination of spatial, graphic and attribute criteria which are specified, hence allowing both spatial and relational database queries. The data entered from the manually compiled tables will be retained on digital file by the AGS's Mineral Information System group, and in future will be available to support ongoing AGS research and the activities of the mineral industry in Alberta.

The design of the ARC/INFO® database tables for the regional metallogenic study was done by Mr. R. Eccles, Mr. D. Wynne and other professional staff at the AGS. The database tables which were entered into the ARC/INFO® system were used to extract the anomaly and other mineral occurrence data shown on Maps 1 to 7. As well, selected data have been retrieved from the database and are summarized in Tables 1 to 5. Table 1 provides a listing by type of the 633 'Anomalous Sites" that were identified. Table 1 tabulates: (a) the anomaly identifier, (b) gives a

Universal Transverse Mercator (10 TM) location, and (c) specifies whether the anomaly comprises a mineral occurrence, or a geochemical, geophysical, geological or drilling anomaly. Table 2 provides a summary for each of the approximately 800 geochemical anomalies in the database; in some cases there are more than one geochemical anomaly at each Anomalous Site in Table 1. Table 3 provides a summary for each of the approximately 168 geophysical anomalies. Table 4 provides a summary of the drilling anomalies in the database. As well, the database indicates there has been a total of about 35,235 m in 835 holes drilled in Alberta for metallic minerals. Most of this drilling (at least 65 per cent) has been done in northeastern Alberta. Lastly, Table 5 summarizes selected information about the 419 mineral occurrences that exist in the metallogenic database.

Summary of the Documents Used in the Metallogenic Study

It was not the intent of the regional metallogenic evaluation to review all the geological, geochemical and geophysical maps and reports that are publicly available for Alberta. In the time available for the study, such a review is not possible because the geoscience database available for Alberta is very large. The Geoscan computerized bibliographic data system, for example, has a total of about 10,000 entries if one searches the database by 1:250,000 NTS map sheet. However, this total includes numerous duplication of references because many items encompass more than one 1:250,000 map sheet. Unfortunately, due to memory limitations on the AGS library computer it is not possible to directly eliminate all duplicates by defining the geographic area to be searched as the entire province of Alberta. By conducting a Geoscan search based on dividing Alberta into six major geographic quadrants, it was established that the Geoscan data system probably contains the references for about 5,000 unique documents. This total includes about 564 geophysical maps or reports, about 382 geological-related university theses, about 3,790 geological reports, papers, maps or other referenced publications, and about 263 non-confidential assessment reports on file with the AGS (Table 6). To further reduce this large number of references to a list that could be manageably reviewed in the time available, a 'Search Algorithm' was devised in order to identify the majority of the references which are most pertinent to the regional metallogenic study. This Search Algorithm was used to print a hardcopy listing of author-year-title references by major publishing body, which resulted in a total of 1,822 selected references (Table 6). These 1,822 references were then summarily reviewed and about 530 were selected for a more detailed review.

Another difficulty that was encountered in selecting the documents to be reviewed was with the assessment document reference listings. Geoscan, for example, as of September, 1992, had 873 assessment report entries. However, 5 of these entries are for mineral properties wholly within British Columbia. For the remaining 868 entries, a physical count of the non-confidential assessment reports on file at the AGS indicated there actually are about 263 unique assessment documents (Table 6). Hence, in excess of 600 Geoscan assessment report entries are duplicates of other entries.

During the regional metallogenic study, a total of about 790 non-confidential assessment reports, geophysical maps and reports, selected B.Sc., M.Sc. and Ph.D. theses, and other selected geoscientific publications were reviewed. As well, 13 proprietary, but non-confidential internal company reports were provided by RAOCL which documented selected exploration programs they had previously conducted in Alberta. These documents were used to compile 633 metallic mineral occurrences or geological, geochemical or geophysical 'Anomalies', which are shown in a regional summary on Figure 3 and listed in Table 1.

REGIONAL GEOLOGY OF ALBERTA

The economic importance of the Western Canada Sedimentary Basin cannot be overemphasized. Of particular importance are the oil, gas, coal and industrial mineral resources that

TABLE 6

SUMMARY OF GEOSCAN DATA SYSTEM LISTINGS FOR ALBERTA AND NUMBER OF DOCUMENTS SELECTED FOR REVIEW

Item / Remarks	Retrievable Documents	Selected for Review
Geophysical Maps and Reports	**564**	**25**
Theses	**382**	**11**
Documents selected by Search Algorithm		
Geological Survey of Canada	615	303
Alberta Research Council	217	103
Canadian Journal of Earth Science	70	13
Canadian Soc. Petroleum Geologists	701	52
American Assoc. Petroleum Geologists	115	9
Canadian Inst. Mining & Metallurgy	26	4
Other publications	78	10
Subtotal for documents from search algorithm	**1,822**	**494**
Other Documents not selected by Search Algorithm (approximate)	**1,969**	**Nil**
Assessment Reports Reviewed		
Northeastern Alberta (NTS 74E,L,M)	172	172
Southwestern Alberta (Rocky Mountains and Foothills)	48	48
Remainder of Alberta - metallic mineral permits	24	24
Remainder of Alberta - iron permits	6	6
Proprietary reports provided by RAOCL	13	13
Subtotal for assessment reports	**263**	**263**
Grand Totals	**5,000**	**793**

have been discovered within the past 50 years by intensive drilling and other exploration conducted by the resource industry. Ricketts (1989) stated "*In Alberta, Saskatchewan and Manitoba, provincial government legislation requires exploration companies to release a large proportion of the core and geophysical log data into the public domain. In Western Canada, the number of wells drilled* [to 1989] *from oil and gas exploration alone approaches 170,000 (approximately 125,000 of these being in Alberta), with the number of wells drilled for coal exploration being in excess of 50,000. Clearly, the ... Western Canada Sedimentary Basin* [is economically important], *not only in fossil fuels, but also in potash, base metals, sulphur and limestone.*"

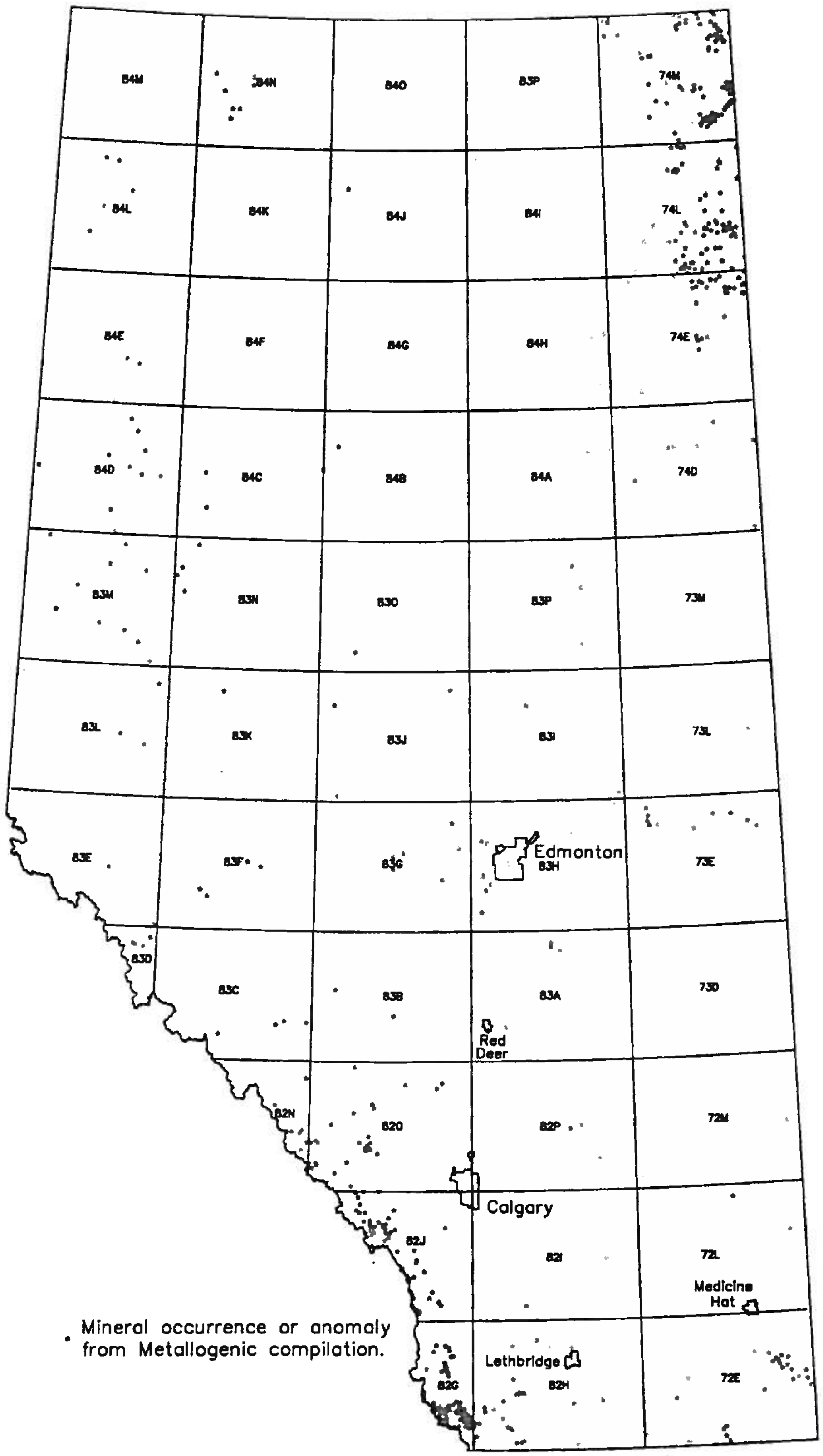


Figure 3: Regional Summary of Metallic Mineral Anomalies.

The geology of Alberta is both diverse and complex. Ages of stratigraphic units range from Archean (>2.6 Ga) to Recent. A regional correlation stratigraphic chart for the Phanerozoic strata in southern, central and northern Alberta is given in Table 7.

From northeast to southwest across the province, the geology can be divided into several broad belts. In the northeast, Precambrian Shield rocks are exposed (Figure 1, Map 3). To the southwest, Precambrian Shield rocks are overlain by a homoclinal sequence of westerly dipping Phanerozoic strata that comprise Devonian carbonate, evaporite and clastic rocks which reach a total true thickness, in places, of up to about a thousand metres. Cambrian, Ordovician and Silurian sedimentary rocks exist at depth beneath the Devonian strata in southern and southeastern Alberta, but are not exposed at surface except in the Rocky Mountains and Foothills (Maps 1 and 2). Cretaceous sedimentary rocks occur over an extensive area of Alberta, stretching from the northeast, where they unconformably overlie the Devonian rocks, to the Rocky Mountains in the west and southwest. In the southwest, the Cretaceous rocks are up to about 1,500 m in true thickness. Lower Tertiary (Paleocene) rocks, which locally reach a true thickness of about 1,500 m, overlie Cretaceous strata in a belt along the Foothills that stretches from southern Alberta, northwest to just south of Grand Prairie. As well, Oligocene to Miocene continental clastic rocks exist in a few places, such as at Cypress Hills, Hand Hills and Wintering Hills in southern Alberta, and at Whitecourt Mountain, House Mountain, Saddle Hills, Clear Hills and Caribou Mountains in northern Alberta. These middle and upper Tertiary strata tend to be thin, and typically are less than a few tens of metres thick. In the Rocky Mountains and Foothills, there is a thick sequence of sedimentary and, locally, volcanic rocks that range in age from Helikian to Tertiary. These rocks have been complexly folded and faulted as a result of the Cordilleran orogeny.

Precambrian Shield - Surface and Subsurface

The Precambrian crystalline basement rocks that are exposed in northeast Alberta and which lie buried beneath younger cover rocks in the remainder of Alberta, are an extension of the Canadian Shield. Both Burwash (1993) and Ross (1993, 1991; Ross and Stephenson 1989) subdivide the basement rocks into distinct tectonic-metamorphic domains, with ages ranging from Archean to early Proterozoic (3,278 Ma to 1,779 Ma).

Ross (1993) stated "*Major structures that segment the basement include the subsurface extensions of the Great Slave Lake shear zone* [in northwestern Alberta]*, Snowbird Tectonic Zone* [in central Alberta] *and the Vulcan Low in southern Alberta, all of inferred Early Proterozoic age (ca. 1.8-2 Ga). Southern Alberta is composed dominantly of Archean Crust (Hearne Province) that has undergone substantial modification by Early Proterozoic activity coeval with the ca. 1.8 Ga Trans-Hudson Orogen to the east. Northern Alberta is composed of a collage of Early Proterozoic age crust (2.0-2.4 Ga) that was assembled and accreted to the Archean Rae Province in the interval of 1.9-2.0 Ga.*"

Burwash (1993) agreed that "*Archean crust which was thermally overprinted during the Hudsonian Orogeny (1,850 ± 100 Ma) underlies the southeastern third of Alberta*", and further stated "*In northwestern Alberta ... intense cataclasis ... accompanied early, middle and late stages of the Hudsonian metamorphism of pre-existing Archean crust. ... Major shear zones are probably responsible for most of the strong lineaments on aeromagnetic maps. ... Hudsonian igneous complexes were emplaced in early (1,900-2,000 Ma) and later (1,750-1,850 Ma) stages. ... Hudsonian metamorphic belts related to the Wopmay Orogen and Trans-Hudson Orogen underlie parts of northwestern Alberta. ... Lower Proterozoic (?) cover rocks have been identified in several isolated drill cores from wells adjacent to the Great Slave Lake shear zone. ... Middle Proterozoic (1,200 to 1,600 Ma) cover rocks of the Athabasca Basin extend a short distance into the subsurface of northeastern Alberta. Rocks of the same age occur in the Purcell Supergroup of Waterton Park* [in southwestern Alberta, but] *between the Athabasca and Waterton Lakes area, no Middle*

Proterozoic has been recognized in drill core."

Helikian Purcell Supergroup in southwest Alberta and southeast British Columbia "*reaches a maximum thickness of 11 km* ...[and] *comprises a sequence of shallow-marine and nonmarine rocks and an underlying sequence expressed by fine grained, basinal clastic rocks in the west and platformal, clastic and carbonate rocks in the east. The base is not exposed. Facies changes are generally distinct near the northeastern limit of exposure, but become more subtle to the southwest.*" (Aitken and McMechan 1992). Hadrynian Windermere Supergroup strata are not present in southwest Alberta, but in western Alberta "*south of latitude 56° N in the central Rocky Mountains the Windermere Supergroup is represented by the Miette Group, a thick succession of fine to coarse clastic strata with locally important carbonate units*" (Gabrielse and Cambbell 1992). In British Columbia and the adjacent United States of America, the Purcell Supergroup hosts several economically important stratiform and epigenetic Pb-Zn-Ag and Cu-Ag sulphide deposits. In southwest Alberta, the Helikian strata are host to a number of stratabound copper occurrences (Hamilton and Olson, *In press*; Williamson *et al.* 1993).

In northeastern Alberta, the Helikian Athabasca Group comprises a flat-lying sequence of clastic sedimentary rocks in excess of 1,255 m thick that exists in outcrop and subcrop south and immediately north of Lake Athabasca (Wilson 1985a,b). In Saskatchewan, there are severally economically important uranium deposits spatially associated with the unconformity between Athabasca Group and the underlying Precambrian basement rocks (Sibbald and Quirt 1987; Sibbald *et al.* 1991).

Phanerozoic Strata

Regional overviews of the Paleozoic, Mesozoic and Cenozoic strata which exist in the Western Canada Sedimentary Basin and the Cordillera Orogen in Alberta, are provided by McGrossan and Glaister (1964), Douglas (1970), Ricketts (1989), Gabrielse and Yorath (1992), Mossop and Shetsen (*In press*), and Stott and Aitken (1993). Ricketts (Ibid) stated that the "*Western Canada Sedimentary Basin is the general name given to the wedge of* [predominantly] *sedimentary rocks that thickens westward from a zero-edge on the Canadian Shield to the Foreland Belt. It was an extremely long-lived depositional realm having a sedimentary record as 'youthful' as Early Tertiary, and reaching as far back in time as the Middle Proterozoic.*"

The Plains Region of Alberta is underlain by a sequence of marine to non-marine sedimentary rocks that become younger to the southwest (Maps 1 to 3). In the northeast, Devonian strata are exposed in a belt that extends from the 60th parallel, southeasterly to the Alberta-Saskatchewan border (Green 1972). Unconformably overlying these Devonian rocks is a thick sequence of Cretaceous strata that stretch the length of Alberta, from the Alberta-British Columbia-Northwest Territories juncture in the northwest, to the Canada-United States of America border in the south. Adjacent to the Rocky Mountains the Cretaceous rocks are overlain conformably to, in places, disconformably by Tertiary strata. The Tertiary rocks mainly exist in a belt that extends from near the Grande Prairie-Lesser Slave Lake area in the north to just south of the Canada-United States of America border. Tertiary strata also exist locally capping highlands in the Caribou Mountains, Clear Hills and Saddle Hills of northern Alberta, and at the Cypress Hills in southeast Alberta. In the Rocky Mountains and Foothills, the exposed rock units comprise a thick sequence of predominantly sedimentary strata that range in age from Middle Proterozoic to Tertiary. The Paleozoic to Tertiary strata are extensively mantled by Quaternary surficial materials throughout much of the Plains region.

Paleozoic

In the northeastern Alberta Plains the Paleozoic strata comprise Middle and Upper Devonian marine shale, carbonate and evaporitic lithologies (Green *et al.* 1970). The exposed thickness of the Devonian rocks in northeast Alberta is about 700 m, but in the subsurface to the west they reach a total thickness of up to about 1,175 m or greater. At or near the exposed outcrop or subcropping edge in northeastern Alberta, there has been extensive solution of the evaporitic units which has resulted in widespread brecciation of the overlying Devonian strata. In most places, the Devonian rocks are poorly exposed, with the best and most continuous stratigraphic sections occurring along the major rivers and secondary watercourses.

In the Rocky Mountains and Foothills, the exposed Paleozoic strata range in age from Cambrian to Permian (Gabrielse and Yorath 1992). Much of the Paleozoic succession in this region consists of thin to thick sequences of carbonate rocks, interlayered with predominantly marine fine- to medium-grained clastic sedimentary rocks. Numerous disconformities and unconformities exist within the Paleozoic succession, and are indicative of periods of uplift and erosion or nondepositional hiatuses.

Mesozoic

In the Plains region, Cretaceous rocks exist in outcrop or in subcrop beneath Quaternary drift over greater than two-thirds of Alberta (Green 1972). In the northeastern Plains, Lower Cretaceous marine to deltaic clastic sedimentary rocks unconformably overlie Paleozoic strata. To the south and west, the Lower Cretaceous strata are conformably overlain by Upper Cretaceous marine to continental clastic sedimentary rocks. In northern Alberta, the exposed Upper Cretaceous strata are up to about 900 m thick, whereas in southern Alberta the Lower Cretaceous succession is greater than 750 m thick and the Upper Cretaceous succession is greater than 1,650 m thick.

In the Rocky Mountains and Foothills, Triassic, Jurassic and Cretaceous rocks are exposed. The Mesozoic strata occur throughout the Foothills and Main Ranges, beginning just north of Waterton National Park and continuing into British Columbia northwest of Grand Cache, Alberta. Following the deposition of the Permian succession, there was a period of regression of the sea and nondeposition, which accounts for the Cordilleran-wide sub-Triassic unconformity. This disconformity is overlain by the Triassic system, which comprises a westward thickening marine sequence of easterly derived siliclastic and carbonate lithologies that is greater than 1,200 m thick. The Triassic period ended with uplift, regression of the sea and probable erosion (Gordey *et al.* 1992).

The Jurassic System in western Canada records the transition from an essentially passive continental margin to an active one which, in Late Jurassic time, was characterized by orogenic uplift in the west (Columbian Orogen) and an associated narrow arcuate foredeep to the east in western Alberta (Poulton 1989). In general, the Jurassic Period in Alberta was characterized by several incursions and regressions of the sea. Marine rocks are dominant in the lower part of the Jurassic succession, but interfingering of marine and continental sedimentary rocks characterizes the upper part of the Jurassic. The Jurassic succession ranges from a few metres thick in west central and southern Alberta up to a maximum of about 2,100 m in places in the Rocky Mountains.

Several major cycles of clastic sedimentary wedges, which were derived from uplift associated with the Cordilleran Orogen, characterize the Cretaceous and conformably overlying early Tertiary strata of the Western Canada Sedimentary Basin (Poulton 1989). In the southern part of the Foreland Belt, the sedimentary succession reflects uplift in the Cordillera beginning in the Late Jurassic, whereas to the northwest in the Yukon, sedimentation was not influenced by Cordilleran uplift until Late Early Cretaceous time (Yorath 1992). During the Early Cretaceous there were several cycles of Cordilleran orogenesis and associated westerly-derived clastic continental sedimentary wedges. This is in contrast to the Late Cretaceous to Paleocene period which was characterized by widespread marine flooding of the continental interior and widespread deposition of marine fine clastics and, locally, near-marine to deltaic fine- to medium-grained clastic sediments. In southwest Alberta, volcanic rocks of Late Albian Crowsnest Formation conformably overlie and are interbedded with Upper Lower Cretaceous sedimentary rocks of Blairmore Group. The Upper Jurassic-Cretaceous sedimentary strata also contain abundant coal in the Rocky Mountains, Foothills and Plains of Alberta.

Tertiary

Continental sedimentation continued without interruption through uppermost Cretaceous into Paleocene time in most of western Canada (Yorath 1992). Paleocene strata of Upper Willow Creek, Porcupine Hills, Paskapoo and Ravenscrag Formations were deposited during the last part of the uppermost Cretaceous-lowermost Tertiary clastic wedge. In the western part of the Interior Plains of Alberta, the Paleocene succession ranges in thickness from more than 1,525 m in the Porcupine Hills of southwestern Alberta to about 70 m for the Ravenscrag Formation in the Cypress Hills of southeastern Alberta (Taylor *et al.* 1964). In southwestern Alberta, Upper Cretaceous to Lower Paleocene Willow Creek Formation is overlain disconformably by Upper Paleocene Porcupine Hills Formation. Towards the north near Calgary, however, the Upper Willow Creek Formation and, possibly, the Porcupine Hills Formation grade into Paskapoo Formation. In central, western and northwestern Alberta, Paskapoo Formation conformably overlies various Upper Cretaceous rock units. In southeast Alberta, Ravenscrag Formation conformably overlies Cretaceous Frenchman Formation.

During the Miocene and Pliocene the Rocky Mountains and Interior Plains continued to be eroded as a result of earlier uplift. This Late Tertiary and early Quaternary erosion was so extensive that only small scattered patches of Miocene and/or Pliocene fluvial deposits are left in isolated preglacial valleys and on uplands. These include, for example, fluvial deposits at the Caribou Mountains, Clear Hills, Saddle Hills, House Mountain, Whitecourt Mountain, Hand Hills, Wintering Hills and Cypress Hills (Ibid). Most of these deposits range in thickness from a few metres or less up to, at most, a few tens of metres.

In southern Alberta and northern Montana there are several basic intrusions and dykes that are commonly referred to as the "Sweet Grass Intrusions". These intrusions cut Upper Cretaceous strata and have been dated at about 48 Ma (Ibid), or of Eocene age.

Quaternary

In Alberta, Quaternary glacial deposits have been geologically mapped mainly at 1:253,440 scale and, locally, at larger scales. Much of the Quaternary deposits in the northern and northwestern part of the province have not been systematically mapped, hence the type and thickness of the glacial and other surficial lithologies is either unknown or poorly known. Pertinent references for the Quaternary geology of Alberta include Barton *et al.* (1964), Prest (1970), Fenton (1987) and Fulton (1989).

The Quaternary glacial deposits in Alberta are Wisconsinan and were deposited mainly by the Laurentide Continental Ice Sheet between about 18,000 and 9,000 years ago (Fulton 1989). On occasion, Rocky Mountain Cordilleran glaciers advanced onto the Interior Plains and coalesced with the Laurentide Ice Sheet (Clague 1989). The Laurentide Ice Sheet spread into the region from the north and east, and at times reached into the Foothills and Rocky Mountains of the eastern Cordillera. During some periods of lesser glaciation, Rocky Mountain glaciers failed to reach the Interior Plains and the Laurentide Ice Sheet terminated short of the mountain front. At such times, montane outwash trains ended as deltas in lakes impounded by Laurentide ice (Ibid). Thus, ice flow and glacial transport directions are complex. In general, however, glacial transport related to the Laurentide Ice Sheet in northeast Alberta was southwesterly, and in central and southern Alberta was southerly to southeasterly where the Laurentide ice coalesced with the Cordilleran glaciers or was diverted by the Rocky Mountains. Glacial transport from the Cordilleran glaciers was generally northeasterly parallel to the trend of the major mountain valleys, and then southeasterly where Cordilleran ice coalesced with the Laurentide Ice Sheet (Fulton *et al.* 1989).

The thickness of Quaternary sediment is highly variable throughout the Interior Plains, ranging from essentially zero to, in places, at least 300 m (Fenton 1987). A thin Quaternary sequence exists on the Uplands, whereas the thickest sediment lies within pre-glacial channels or in areas of intensive glacial tectonism. The Laurentide Ice Sheet glacial deposits can be broadly subdivided into three main types: lodgment and ablation till, glaciofluvial deposits and glacial lake deposits. As well, in places the Quaternary succession includes eolian and organic deposits. However, the predominant Quaternary material is diamicton or till which was deposited directly or indirectly by glaciers. In some areas, several till units have been identified in boreholes or in outcrop. In south-central Alberta, for example, Stalker (1983) identified eight till units on the Old Man River. Some caution is required in assigning an ice advance to each till unit because glacial thrusting has, in places, caused repetition of some till units (Fenton 1987; Fulton *et al.* 1989). Fenton (1984) reviewed the evidence for at least four major glaciations that advanced across the Interior Plains. Although glacial till is common throughout much of the Interior Plains, in many places it is overlain by a thick sequence of glaciofluvial or lacustrine sediment. This overlying cover can make till sampling difficult, particularly in the northern Plains of Alberta. As well, various post-glacial effects have modified the glacial sediment. The most common post-glacial effect is selective erosion and transport of the finer fraction into low areas, which has resulted in the concentration of the coarser fraction near the tops of hills or the upper parts of slopes.

Structure

The regional structures and tectonic evolution of the Western Canada Sedimentary Basin and of Alberta have been discussed by several workers, including Webb (1964), Lorenz (1982), Cant (1988), Podruski (1988), Leckie (1989), Cant and Stockmal (1989), Osadetz (1989), McMechan and Thomson (1989), McMechan et al. (1992), Ross (1991), and Ross and Stephenson (1989).

The major structures of Precambrian age in Alberta include the Great Slave Lake shear zone in northern Alberta, the Snowbird Tectonic Zone in central Alberta, and the Southern Alberta Rift (or Vulcan Low) in southern Alberta (Ross 1993, Kanasewich 1968, 1969). These features all are inferred to be of Early Proterozoic age (ca. 2.0 to 1.8 Ga), but were periodically active to a greater or lesser degree throughout the Proterozoic and into the Phanerozoic.

Other tectonic features that were active and affected the deposition of Phanerozoic strata, from approximately oldest to youngest, include the Peace River Arch in northwest Alberta, the West Alberta Arch in western Alberta, the Meadow Lake Escarpment in central Alberta, the Sweet Grass Arch and Alberta Syncline in southern and western Alberta, the Rocky Mountain Fold and Thrust Belt, transverse, tear and normal faults in the Rocky Mountains and Foothills, and fracturing and salt dissolution in some parts of the Plains region.

Great Slave Lake Shear Zone, and Snowbird Tectonic Zone

The Great Slave Lake shear zone (GSLSZ) is a major northeast trending crustal lineament that the regional aeromagnetic data indicate extends from near Chantrey Inlet in the Keewatin District of the N.W.T., southwesterly across northern Alberta and into northeastern British Columbia (Ross 1991, 1993; Ross et. al. 1991). This crustal-scale fault zone was mainly active about 1.9 Ga (Hoffman 1987), but tectonic movement occurred along the GSLSZ until at least Middle Givetian during the late Middle Devonian (Skall 1975). In northwestern Alberta the GSLSZ is recognized by the juxtaposition of different aeromagnetic domains, and the predominant sense of movement is dextral (Ross *et. al.* 1991).

The Snowbird Tectonic Zone (STZ) is also a major northeast trending crustal lineament that extends from near Baker Lake, Northwest Territories, southwesterly to just north of the Lac La Biche area, Alberta. It splits the Churchill Province into two separate basement domains (Ross *et al.* 1989, 1991). The STZ is a prominent lineament on the aeromagnetic (GSC 1990a) and gravity (GSC 1990b) maps of Canada. Ross *et al.* (1989, 1991) infer that the STZ bifurcates into two zones below the Phanerozoic basin southwest of the Lac La Biche area. The southern zone exhibits a sinuous projection to the southwest where it appears to intersect the Foothills region of Alberta in the vicinity of Nordegg. Interestingly, some other important northeasterly trending geological features also exist in the vicinity of Nordegg. These include the axis of the doubly plunging Late Cambrian to Devonian West Alberta Arch (Verrall 1968), the Late Devonian Cline Channel (Geldsetzer and Mountjoy 1992) and the Cretaceous Bighorn Tear Fault (Verrall 1968). Further work is needed to clarify the actual position of the STZ and to document its relationship to other Phanerozoic structures which exist in the vicinity of Nordegg in the Rocky Mountains, and in the Foothills and Plains of Alberta.

Mineral occurrences and other geological anomalies which are spatially associated with the GSLSZ and the STZ are discussed under the section dealing with the resources potential of the Alberta Plains region.

Southern Alberta Rift

The Southern Alberta Rift, which also is known as the Vulcan Low, was first described by Kanasewich (1968) and Kanasewich *et al.* (1969) using deep seismic reflection, magnetic and gravity data. Kanasewich (1968) suggested the Southern Alberta Rift is traceable for 450 km from just north of Medicine Hat near the Alberta-Saskatchewan border, to the Rocky Mountains southwest of Cranbrook near the British Columbia-Idaho border. Kanasewich *et al.* (1969) suggested that the rift is Precambrian in age, penetrates the crust to the Mohorovicic discontinuity and has associated faults with vertical displacement of up to 5 km. McMechan (1981) described evidence of graben-like, synsedimentary normal faulting throughout the Precambrian Belt-Purcell Supergroup. She stated that the northeast trending St. Mary-Boulder Creek Fault near Kimberly, British Columbia and the Moyie-Dibble Creek Fault further to the southeast, were active periodically during much of the Proterozoic and that they correspond to the location of the subsurface trace of the Southern Alberta Rift identified by Kanasewich (Ibid). Regional Bouger gravity anomaly maps show significant differences in the gravity field on either side of these faults, which may mark the margins of a long-lived, crustal scale rift (Price 1981; Fountain and McDonough 1984). Examples of such rifting during Belt-Purcell, Windermere and Late Proterozoic to Early Cambrian time at the edge of the North American continent, have been described by a number of authors (e.g., Leech 1962; Stewart 1972; Lis and Price 1976; Benvenuto and Price 1979; Struik 1987; Devlin and Bond 1988; Devlin 1989).

Evidence for younger reactivation of the Southern Alberta Rift, associated with faults of lesser magnitude, has been presented by a number of authors. Price and Lis (1975), for example, described significant differences in thicknesses and facies of Upper Paleozoic rocks across the Moyie-Dibble Creek Fault. Brandley (*Pers. Comm.* 1993) suggested that increased thicknesses of Mississippian carbonates are spatially associated with the location of the Southern Alberta Rift and therefore are indicative of subsidence during that period. Pope and Thirlwall (1992) suggested that group II ultrapotassic dykes and diatremes of kimberlitic affinity in southeast British Columbia are indicative of passive margin rifting, and possibly are related to reactivation of the Southern Alberta Rift during the Permian-Triassic period. Hopkins (1987, 1988) described synsedimentary subsidence of Lower Cretaceous rocks in the Cessford hydrocarbon field and postulated this subsidence is associated with a narrow graben that reaches from the Precambrian basement into the Cretaceous section. The Cessford field is located southeast of Calgary near the inferred northern margin of the Southern Alberta Rift. Reactivation of the rift during the Lower Cretaceous is further supported by deposition of the thickest portions of the Crowsnest volcanics centred within the bounds of the rift (Pearce 1970; Adair 1986). The volcanics are trachytic to phonolitic in composition and, if compared to other trachyte and phonolite provinces, are indicative of continental rifting. The Lewis and Clark Fault System and the Great Falls Tectonic Zone, which exist in the northern United States of America, can be regarded as step-like sympathetic structures to the Southern Alberta Rift. These two fault zones are deep-seated and have a history of recurrent fault movements very similar to the Southern Alberta Rift. Episodic fault movement along the Lewis and Clark Fault System and the Great Falls Tectonic Zone has been documented from early Proterozoic to the Tertiary, and perhaps occurred as recently as the Holocene (Lorenz 1984; O'Neill and Lopez 1985; Wallace *et al.* 1990). In short, the syndepositional faults which are subparallel to the regional trend of the graben, the associated sedimentary facies changes and the locally syndepositional volcanism, indicate the Southern Alberta Rift has been periodically active over a long period of time.

Peace River Arch

The Peace River Arch exists in northwestern Alberta, and its tectonic effects encompass a large area near and westerly of Peace River (O'Connell and Bell 1990). "*In the north, the block-faulted Peace River Arch was uplifted during Cambrian time and remained a structural high until late Devonian time, when it began to subside. Subsidence continued during the Mesozoic when there may have been as much as 100-150 m of localized subsidence. By middle to late Albian time the Arch began to rise and provided structural controls on the northern depositional patterns and limits of several Cretaceous shorelines, particularly those of the Lower Cretaceous clastic wedge. During latest Cretaceous and Tertiary time, the Peace River Arch was a positive-relief feature as a result of Laramide deformation further west.*" (Leckie 1989). The Peace River Arch intersects the Rocky Mountains and Foothills just west of the Alberta border in British Columbia, but its influence on the Alberta-portion of the Rocky Mountains is uncertain. In northeastern British Columbia, however, Stelck *et al.* (1978) documented that Peace River Arch tectonics had affected sedimentary rocks in the Rocky Mountains at the Vreeland and Ice Mountain areas .

West Alberta Arch

The West Alberta Arch is a northwest-trending structure with its axis located at about the eastern limit of the Rocky Mountains (Verrall 1968). It was active from at least Silurian to Middle Devonian time as evidenced by the lack of Late Cambrian to Middle Devonian carbonates and shales, and the presence of Middle to Upper Devonian fringing reefs (Geldsetzer and Mountjoy 1992). Verrall (1968) suggested that the West Alberta Arch might have been active as early as Late Cambrian. As well, the Arch may have been reactivated during the late Paleozoic. For example, Geldsetzer and Mountjoy (1992) described the presence of debris flows, spectacular megabreccias and deep-water channels (such as the Cline Channel) within Upper Devonian carbonates, with no evidence of subaerial exposure associated with the West Alberta Arch. They suggested earthquake generated debris flows may have been responsible for these deposits. However, local grabens might also have caused the debris deposits and these structures may have been active in a few places along the West Alberta Arch during the Late Devonian, after the major uplift of the arch. As well, some evidence exists that indicate the West Alberta Arch and other structures were reactivated during the Lower Carboniferous (Brandley and Krause 1993). Verrall (Ibid) shows the West Alberta Arch as a northwest oriented doubly plunging antiformal feature with its northeast trending hinge located in the vicinity of the northeasterly trending Bighorn Tear Fault, which offsets Cretaceous thrust faults, the Upper Devonian Cline Channel and the approximate projected trend of the Snowbird Shear Zone within the crystalline basement. It has not been established whether the approximate spatial overlap of these structures is coincidence or whether they are tectonically related.

The reason for uplift of the West Alberta Arch is not known, but Bingham *et al.* (1985) reported that a conductive ridge underlies the Eastern Rocky Mountains. They suggested that in the

American Rockies similar conductive structures are correlated with high heat flow and low seismic velocities in the lower crust. They further suggested that partial melting and periodic uplift might have been associated with the conductive ridge. Perhaps partial melting during the Paleozoic beneath the present-day location of the Eastern Rocky Mountains was responsible for uplift of the West Alberta Arch.

The Meadow Lake Escarpment

The northeasterly trending Meadow Lake Escarpment is formed by the erosional edge of the Ordovician Red River Formation carbonates (van Hees and North 1964). To the east in Saskatchewan and Manitoba, the Meadow Lake Escarpment trends easterly and runs south of and parallel to the Kisseynew Lineament. Towards its western end in Alberta, the Meadow Lake Escarpment widens out and flattens. In general, the Meadow Lake Escarpment is believed to have formed as a result of broad uplift to the north, with the Meadow Lake Escarpment acting as a hinge line, during latest Silurian to earliest Devonian time. This caused erosion of the Ordovician-Silurian strata north of the Escarpment, and resulted in Devonian strata unconformably overlying Precambrian rocks north of the Escarpment whereas to the south they unconformably overlie Ordovician rocks. Some authors, however, have referred to the Meadow Lake escarpment as a "cuesta" or attribute its origin to transcurrent faulting (Douglas *et al.* 1970; Haites 1960).

Sweet Grass Arch and Alberta Syncline

"*The Sweet Grass Arch in southern Alberta and northern Montana separates the Williston Basin from the Alberta Basin. This arch is composed of several subsidiary arches, domes and northwest-trending, north-plunging, faulted folds. The arch was a positive structural feature during the Laramide Orogeny and possibly during the Jurassic. Reactivation of the Sweet Grass Arch in earliest Cretaceous time was responsible for the creation of broad uplands and deep valleys in southwestern Saskatchewan. Regional mapping indicates that the Arch was inactive during Late Cretaceous time. Plutonic intrusions that form the Sweet Grass Hills, dated at 50 to 54 Ma, occur along the axis of the Sweet Grass Arch in northern Montana and affected sedimentation of the Lower Tertiary clastic wedge in southwestern Saskatchewan and Alberta. ...*

The Alberta Syncline, situated between the Sweet Grass Arch and the deformed belt of the Rocky Mountains, is a relatively young structural feature, having been formed during Late Cretaceous to Early Tertiary time. The eastern limb of the Alberta Syncline parallels the west-dipping Precambrian basement; the western limb is formed by east-dipping strata representing the eastern margin of the Rocky Mountain Foothills." (Leckie 1989).

Rocky Mountain Fold and Thrust Belt

In the Alberta portion of the Canadian Cordillera, there are three linear belts of distinctive style: the Foothills, Front Ranges and Main Ranges. Foothills bedrock geology is characterized by thrust faults with Tertiary and Mesozoic strata in the footwall and either Mesozoic strata or Carboniferous and younger strata in the hanging wall. The Front Ranges, which are marked by the Lewis and McConnell thrusts, place Devonian to Proterozoic thick carbonates onto Cretaceous rocks. In the Main Ranges, the thrust sheets are predominantly composed of Paleozoic and Proterozoic strata where Mesozoic strata are not preserved. The structural style changes from southeast to northwest in Alberta, and into British Columbia. In the southeast, discrete overthrust faults of significant stratigraphic offset are present, whereas to the northwest there are large amplitude box and chevron style folds with little stratigraphic separation that are underlain by blind thrusts of significant stratigraphic offset (Ibid). This change in structural style from south to north coincides with a significant change in the dominant lithology of the deformed rocks. That is, it occurs where Paleozoic platformal carbonates which are characteristic of the southern Alberta Basin give way to basinal mudstone-dominated strata to the northwest (McMechan *et. al.* 1992).

In Alberta, the Rocky Mountains and Foothills are dominated by northwest-trending folds and thrust sheets that developed during accretion of land masses west of the Rocky Mountain Trench. The Lewis Thrust carried the Precambrian and some overlying Paleozoic rocks from as far west as Cranbrook, British Columbia and superimposed them on Paleozoic and younger rocks. Also present within southwestern Alberta are numerous other thrust faults as well as some normal faults which are transverse to the regional strike. The geological base maps (Maps 1, 2 and 6) which accompany this report, are simplified and only selected faults and fold structures are shown. The structural geology of the Eastern Rocky Mountains and Foothills is well-summarized by Charlesworth (1959), Shaw (1963), Bally *et al.* (1966), Dahlstrom (1970), Jones (1971) and Price (1981). Work during the 1970's and 1980's has been focused on the details of imbricate thrusting and the actual mechanisms responsible for the formation of such structures as floor thrusts, roof thrusts and duplexes (Fermor and Price 1987).

The Canadian Cordillera formed during the Laramide Orogeny, with most of the deformation occurring from the late Cretaceous to early Tertiary. However, uplift to the west is documented as early as the Jurassic by the Kootenay Group-Blairmore Formation clastic wedge (Eisbacher *et al.* 1974). Therefore, the formation of the Eastern Rocky Mountains and Foothills of Alberta was probably an ongoing process from Late Jurassic to Paleocene time, but the last major stage of uplift is thought by many authors to have occurred during Late Eocene to Oligocene. The evidence for this is the deformation of sedimentary rocks as young as Paleocene and the deposition of undeformed Eocene and Oligocene conglomerates (Shaw 1963; Bally et. al. 1966; Eisbacher *et. al.* 1974).

Transverse, Tear and Normal Faults

Northeast-trending transverse, tear and normal faults have been mapped in a few places along the Alberta Rocky Mountains and Foothills. Excellent summaries of the early mapping and geological setting of these structures are presented in Price (1967) and Dahlstrom (1970). Areas of prominent northeast-trending subvertical faults, with or without evidence of vertical movement, have been reported or mapped in the Alberta Rockies by Beach (1942), Birnie (1961), Fitzgerald (1962), Price (1967), Verrall (1968), Dahlstrom (1970), Moffat and Spang (1984), McGugan (1987) and McMechan (1988).

Large prominent tear faults which have been identified in the Alberta Rocky Mountains, include the Bighorn Tear Fault (Verrall 1968; Dahlstrom 1970), the Ghost River Fault (Fitzgerald 1962) and a possible tear fault near Moose Mountain (Beach 1942). The Bighorn Tear Fault exists along the North Saskatchewan River southwest of Nordegg, and it marks the southern termination of the Bighorn Range. Verrall (1968) suggested that the Bighorn Tear Fault exhibits vertical movement along with shearing because the south side is significantly downthrown. The major period of movement on this structure was during the Laramide Orogeny because the Bighorn Tear Fault cuts Upper Cretaceous rocks in the Cripple Creek thrust sheet, but is overridden by the McConnell thrust sheet. The poorly exposed Ghost River Fault is near vertical and exhibits at least 140 m to 185 m of vertical movement with the south side downthrown (Fitzgerald 1962). The western end of the fault appears to be overridden by the Exshaw thrust fault. Another possible tear fault has been mapped southwest of Moose Mountain by Beach (1942), although subsequent mapping by Ollerenshaw (1975) indicated that this structure may be an oblique thrust fault.

Areas where northeast trending, transverse and normal faults have been documented in the Alberta Rocky Mountains and Foothills, include Indianhead Creek, the headwaters of the Clearwater River, southwest of Banff, southwest of Canmore, the Elk, Opal and Misty Ranges east of Kananaskis Lakes, and the Mount Head area. Birnie (1961) described a series of four northeast trending normal faults that cut the Third Range thrust sheet with an average of 460 m of north side down displacement. Verrall (1968) described faults along the headwaters of the Clearwater River as right lateral shears that cut the Siffleur and Sulphur Mountain thrust sheets. He (Ibid) also described faults southwest of Banff as left lateral shears that do not cut the Sulphur Mountain thrust sheet. Moffat and Spang (1984) described transverse faults in the Sulphur Mountain and Rundle thrust sheets southwest of Canmore. They suggested the transverse faults developed during thrust movement in response to differential sheer along the moving thrust sheet. McGugan (1987) described several northeast trending transverse faults with apparent right lateral movement that cut rocks above the Lewis Thrust east of Kananaskis Lakes in the Elk Range. McGugan (Ibid) stated that at least one of the faults has an apparent displacement of 150 m, and noted that although the faults exhibit tear movement, vertical movement cannot be ruled out. McMechan (1988) has mapped dozens of northeast trending transverse faults north and east of the Elk Range along the eastern border of Peter Lougheed Provincial Park within the Opal and Misty Ranges. Many of the faults exhibit apparent right lateral displacement. Price (1967) concluded that the steep dip slip movement indicators which exist along these faults, indicate the faults formed prior to thrusting as extensional gravity faults whose orientation was controlled by the Hudsonian basement fabric. Douglas (1958) described northeast trending vertical faults in the vicinity of the Highwood River. He (Ibid) suggested that they are tear faults with up to 305 m of horizontal offset in places.

Folds, Faults, Fractures, Salt Dissolution Features and
Other Structural Anomalies in the Plains Region

In addition to the foregoing major tectonic features that affected the Western Canada Sedimentary Basin, other more local major structural elements include folds, faults, fractures, salt dissolution features, and a few problematical structures which are commonly inferred to be of astrobleme origin (Osadetz 1989).

The major folds and faults are of compressional origin and are associated with the Laramide orogeny which formed the Rocky Mountain thrust and fold belt. East of the Rocky Mountain deformed belt, faults, folds and other tectonic elements are uncommon, but do exist locally. "*Faults occur throughout* [the] *southern Interior Platform and although many reports indicate or infer their presence, their description and analysis is sparse. Faults can be subdivided into three general groups: normal faults observed or inferred to cut crystalline basement, normal faults that do not reach basement, and wrench faults that are Laramide compressive structures.*" (Osadetz 1989). As well, there are faults associated with salt dissolution collapse. "*There are many other faults inferred to explain linear facies patterns, oil field trends or surficial lineaments whose position or existence remains to be substantiated.* (Moffat and Gardner 1981) Osadetz and Haidl (1989) stated that "*faults are not commonly reported in the Interior Platform although faulting is an important component of petroleum plays in the Tippecanoe sequence* (Middle Ordovician to Lowest Devonian). *Most faults have stratigraphic offsets that terminate at the sub-Middle Devonian erosion surface. ... Some dolomitization patterns are believed to be controlled by fluids that moved through basement faults.*"

Fractures have had a profound influence on oil and gas occurrence and the quality of reservoirs in Western Canada as a result of their affect on host rock porosity (Osadetz 1989). The conditions of such fracturing are controlled by crustal stresses (Bell and Babcock 1986). "*Several regions in the Interior Platform exhibit complex and anomalous structures. Most of these are considered to be astroblemes.*" (Osadetz 1989). In Alberta, possible astrobleme structures include the Steen River structure in the north and the Eagle Butte structure in the southeast (Winzer 1972, Sawatzky 1975).

In places, folds or faults or both have formed as a result of differential compaction, by dissolution of underlying salts in the Paleozoic evaporitic successions or by other mechanisms related to post-Laramide epierogenesis. "*Large and small-scale Devonian salt dissolution features* *are a common phenomenon which occurred throughout the late Paleozoic to Tertiary. The effects of salt removal were to create topography prior to or contemporaneous with sedimentation, thus affecting depositional patterns. Salt solution may have postdated sedimentation causing the collapse of overlying sediments and creating structural-stratigraphic traps.*" (Leckie 1989).

Igneous Activity

Plutonic and volcanic rocks are common in the exposed Precambrian of northeastern Alberta (Godfrey 1986; Goff *et al.* 1986). Large areas are underlain by pluton-size granitic and granitoid rocks. Langenberg *et al.* (1993), however, stated that "*field contact relationships and bulk compositions suggest that the migmatitic granitic gneisses and high-grade metasediments were parent materials for several of the granitoid rocks during the process of partial melting (Goff et al., 1986). Consequently, the granitoids may represent Archean basement remobilized during the Aphebian.*"

Mafic to, locally, more felsic intrusive and extrusive rocks are relatively common throughout the Paleozoic succession in the northern Cordillera in the Yukon and N.W.T., but are scarce in the miogeoclinal Paleozoic strata of the southeastern Cordillera in Alberta and British Columbia (Souther 1992). In Alberta, igneous rocks are not common, but do exist at several locales. For example, the igneous intrusive or volcanic rocks include: (1) those in the Proterozoic rocks of the Clark Range in southwest Alberta (Hunt 1962, Price 1962, Goble 1974a,b, Hoy 1989), (2) the Late Early Cretaceous Crowsnest Formation near Coleman in southwest Alberta (Pearce 1970, Dingwell and Brearly 1985, Adair 1986, Peterson and Currie 1993), (3) the Early Tertiary Sweet Grass Intrusions in southern Alberta and northern Montana (Williams and Dyer 1930; Russell and Landes 1940; Irish 1971, Kjarsgaard 1994), (4) the metadiabase Crowfoot Dyke near Lake Louise (Smith *et al.* 1963), (5) a metadiabase dyke reported to cut Cambrian rocks near Jasper (Charlesworth 1967), and (6) the Mark, Cross and Blackfoot diatremes near the Alberta-British Columbia border in southeast British Columbia (Ijewliw 1987, Pell 1987a,b). The various intrusions range in age from Middle Proterozoic to Tertiary (Folinsbee *et al.* 1957, Hunt 1962, Price 1962, Pell 1987a,b).

Igneous activity in the Clark Range of southwest Alberta is of at least three types and ages. The oldest is represented by Moyie-type diorite or diabase sills and dykes that have been dated as old as 1,580 Ma and as young as 1,400 Ma (Hunt 1962; Hoy 1989). The second type is the Purcell Lavas, which are andesitic in composition and form an excellent marker horizon throughout the Belt-Purcell Supergroup. Hunt (1962) suggested that the Purcell Lavas were extruded at about 1,100 Ma. The third type of igneous activity in the Clark Range is trachytic to syenitic alkalic intrusions that straddle the Alberta-British Columbia border near the headwaters of the Castle River (Price 1962; Goble 1974a,b). Price (1962) stated that these intrusions are likely of Cretaceous or Tertiary age.

The Crowsnest Formation comprises an assemblage of alkaline trachytic to phonolitic volcanic rocks that is restricted to the eastern part of the Fernie Basin in southwestern Alberta (Dingwell and Brearly 1985, Adair 1986, Peterson and Currie 1993). The Crowsnest volcanics range up to 425 m thick locally, and are interbedded with and grade laterally into sandstone and shale of the upper Blairmore Group. The volcanic rocks are mainly pyroclastic and epiclastic deposits, with rare flows and associated intrusive rocks. Folinsbee *et al.* (1957) obtained a K-r date of 96 Ma for the Crowsnest Formation, which is late Early Cretaceous (Albian).

In southeastern British Columbia, the Howell Creek alkalic intrusions cut Lower Cretaceous strata and have yielded K-r ages that range from 112 to 72 Ma (Gordy and Edwards 1962). Souther (1992) stated that the Howell Creek intrusions include syenite and trachyte that are chemically similar to, and may be comagmatic with, the Crowsnest Volcanics. Several alkalic ultramafic diatremes and dykes have also been discovered north of the Southern Alberta Rift near the Alberta-British Columbia border between Golden and Elkford (Pell 1987a,b). Pell (Ibid) reported ages of between 348 Ma and

396 Ma for the HP pipe, which is part of the Mark diatreme cluster that straddles the Alberta-British Columbia border. The alkali ultrabasic diatreme breccias and dykes which exist in the Western and Main Ranges of the Rocky Mountains in southeastern British Columbia and, locally, in Alberta, intrude Upper Cambrian to Permian miogeoclinal rocks and were emplaced prior to Jurassic-Cretaceous deformation. "*At least one of these diatremes is a true kimberlite*" (Souther 1992).

In the Phanerozoic rocks in the Interior Plains of Alberta, the only documented volcanic rocks comprise tuffs or tuffaceous beds, or their bentonitized equivalents, that occur in strata from Jurassic to Tertiary age. The most well known of these is the Kneehills Tuff marker horizon in Late Cretaceous Edmonton Group. Most of the tuff horizons are thin, typically being a few centimetres to tens of centimetres thick, but locally they reach thicknesses of about 2 m. Although most of the tuffs probably represent wind-blown volcanic debris from far sources, it is possible that some of the tuffs may be derived locally from volcanic or diatreme activity which occurred within the Western Canada Sedimentary Basin.

Metamorphism and Metasomatism

In the Precambrian rocks of northeastern Alberta, Langenberg and Nielsen (1982) stated that there are "*two distinct cycles of metamorphism. During the Archean metamorphic cycle, metasediments were metamorphosed under high pressure granulite conditions (M1). In a second cycle, probably related to remobilization during the Aphebian, the metasediments were subjected to conditions of granulite-amphibolite transitional facies retrogressing to greenschist facies metamorphism.*"

Elsewhere in the exposed rocks in Alberta, however, metamorphic conditions are low-grade. "*Except for metamorphic culminations in ... a local area east of the Southern Rocky Mountain Trench most of the regional metamorphism in the Foreland Belt is of low-grade burial type. Precambrian rocks are commonly in greenschist facies, Paleozoic and some Mesozoic strata are mainly in prehnite-pumpellyite facies, and most Mesozoic strata are in zeolite facies. ... In the western part of the Foreland Belt, regional metamorphism appears to be stratigraphically controlled and related to depth of burial; pelitic rocks typically have a slaty cleavage. Precambrian rocks generally reach chlorite or biotite zones. ... Locally, Cretaceous and lower Tertiary sediments in the Alberta Syncline contain zeolites. Heulandite-clinoptilolite cements some sandstones of the Paskapoo and Bearpaw formations and Wapiti Group to as far north as 55°N. ... Most Cretaceous and lower Tertiary sediments of the Alberta Syncline have carbonate, illite, montmorillonite, chlorite, and interstratified clay minerals (typical of but not diagnostic of the zeolite facies), and coal ranks ranging from sub-bituminous C to high volatile bituminous B (well within the range of zeolite facies rocks).*" (Greenwood *et al.* 1992).

Dolomitization is widespread in the Paleozoic, and particularly in the Cambrian to Devonian, carbonate rocks of Alberta; most of this is probably of post-diagenetic origin (Douglas *et al.* 1970). However, Dawson (1886) reported extensive marbilization and dolomitization in southwest Alberta, and Hitchon (1993) concluded that "*the extensive dolomitization found in the Devonian of the Alberta Basin may be relatively rare in a platform-type setting such as is found in western Canada. It might be more than coincidence that many of the strongly dolomitized trends seem related to underlying basement structures.*" Recent work by Nesbitt and Muehlenbachs (1993a,b) has documented extensive pre-thrusting (likely Late Devonian), fluid flow leading to the formation of massive epigenetic to replacement dolomites with local deposition of base metals, magnesite and talc in southeastern British Columbia and the Rocky Mountains and Foothills of Alberta. This fluid event (Event 1) is characterized by a west to east flow of saline (20-25% equivalent weight % NaCl) fluids with a minimum temperature of 150 C to 200 C and high concentrations of Mg and Ca.

Known Mineral Resources of the Western Canada Sedimentary Basin

The regional metallogeny of the Cordillera has been summarized by Dawson *et al.* (1992). This (Ibid) included a brief description of the tectono-stratigraphic setting for the stratiform Zn-Pb-Ag deposits of Sullivan type, stratabound Cu-Ag occurrences in Purcell Supergroup, carbonate-hosted Zn-Pb deposits of Mississippi Valley type (MVT) in Cambrian to Devonian strata of southeastern and northeastern British Columbia, and sedimentary exhalative (Sedex) type Pb-Zn-Ag-Ba deposits in Cambrian to Mississippian strata in northeastern British Columbia and southern Yukon.

With respect to the Western Canada Sedimentary Basin, the known metallic and industrial mineral occurrences have been recently compiled and summarized by Hamilton and Olson (*in press*). They reported a total of at least 97 metallic mineral occurrences in the Phanerozoic or underlying Precambrian basement rocks in the Prairie and Cordilleran region of Western Canada, with 15 of these being in Alberta (excluding the occurrence of trace metals in the bitumen component of the Athabasca oil sands). This total includes: (a) placer gold occurrences in Recent or Preglacial river gravels in central Alberta, (b) several stratabound copper-silver occurrences in Proterozoic rocks in southwest Alberta, (c) Cu-Zn-Pb sulphide minerals in quartz-carbonate veins that cut Hadrynian to Cambrian strata in southwest Alberta, (d) Pb-Zn minerals and pyrite in carbonate rocks of Cambrian to Devonian age in southwest Alberta, (e) a gold occurrence reported in Crowsnest Formation volcanics in southwest Alberta, (f) paleoplacer titaniferous magnetite in southwest Alberta, and (g) oolitic siliceous iron-rich facies in sandstone in northwest Alberta. In addition, Carrigy (1959), Hitchon (1977, 1993) and Dubord (1987, 1988) have documented the location of at least 18 sphalerite or galena, or both, occurrences in Phanerozoic carbonate rocks in the subsurface of Alberta. As well, greater than 200 metallic mineral occurrences are reported to exist in the exposed Precambrian rocks of northeast Alberta (Edwards *et al.* 1991, Langenberg *et al.* 1993).

RESOURCE POTENTIAL OF THE PRECAMBRIAN SHIELD IN NORTHEAST ALBERTA

Prior Work and Known Mineral Resources

The Precambrian Shield in northeastern Alberta comprises a complex assemblage of igneous, metamorphic, sedimentary and volcanic rocks of Archean and Aphebian age (Godfrey 1986a). At and south of Lake Athabasca these older Precambrian rocks are overlain by Helikian sedimentary rocks that belong to the Athabasca Group (Godfrey 1970, Wilson 1985a,b, 1986).

North of Lake Athabasca the bedrock geology of the pre-Helikian basement rocks has been mapped at 1:63,360 scale or larger in 36 map-sheets by the AGS. A selected bibliography of the references for this geological mapping, as well as other pertinent geological papers and assessment reports to 1990, is given in Edwards *et al.* (1991). As well, the AGS has published several summary reports about the Alberta-portion of the Canadian Shield north of Lake Athabasca, including: (a) an aerial photographic interpretation of Precambrian Structures north of Lake Athabasca (Godfrey 1958a), (b) a synthesis of airborne radiometric survey results (Godfrey and Plouffe 1978), (c) polyphase metamorphism (Langenberg and Nielsen 1982), (d) polyphase deformation (Langenberg 1983), (e) petrology and geochemistry (Goff *et al.* 1986), (f) geophysical expression (Sprenke *et al.* 1986), (g) a summary geological map at 1:250,000 scale (Godfrey 1986a), and (h) a summation of the metallic mineral potential (Godfrey 1960, Edwards *et al.* 1991). More recently, as a result of funding provided under the Canada-Alberta Partnership on Mineral Development Agreement (Canada-Alberta MDA), the GSC has performed semi-detailed geological mapping in selected parts of northeastern Alberta (McDonough *et al.* 1993, Grover *et al.* 1993), and the AGS has re-examined and sampled selected mineral occurrences to provide more detailed information about them (Langenberg *et al.* 1993).

South of Lake Athabasca, the AGS has geologically mapped crystalline basement rocks at the Marguerite River area at 1:63,360 scale (Godfrey, 1970), and mapped the Alberta portion of the Athabasca Basin at 1:250,000 scale (Wilson, 1985a,b, 1986). Wilson (1987) summarized the geology and economic potential of the Athabasca Basin in Alberta. More recently the GSC has been studying core provided by the AGS in order to assess the potential of the western portion of the Athabasca Basin for uranium-polymetallic mineral deposits (Ruzicka 1993).

The Quaternary geology of northeastern Alberta is not well known. The existing geological mapping is at 1:250,000 scale for NTS 74E, 74L and the westernmost part of 74M (Bayrock 1971, 1972a,b). There is no readily available published maps of the Quaternary geology for NTS 74M east of the Slave River. However, during 1992 and 1993 the GSC has initiated a program under the Canada-Alberta MDA to conduct regional mapping of the Quaternary geology within NTS 74M east of the Slave River (Bednarski 1993).

During the late 1960's and 1970's at the height of the boom in exploration for uranium in Canada, the Precambrian Shield in Alberta was explored by numerous companies and was, at times, extensively staked. To 1990, the AGS reported they had at least 247 assessment reports on file that documented this work (Edwards *et al.* 1991). However, some of these assessment reports are duplicates because during this study a total of only about 170 unique assessment reports were found and reviewed. The majority of this prior exploration work was directed towards uranium exploration, but in a few cases the exploration target was base or precious metals, or rare earth elements. More recently (1992-1993) there has been renewed interest in the Precambrian of northeast Alberta for diamond exploration. Most of the assessment reports that are on file with the AGS provide few details with respect to the exploration work performed. A compilation of drilling from assessment records and from Wilson (1985a,b, 1986) show that in excess of 23,320 m in 285 holes were drilled north and south of Lake Athabasca in that area underlain by Precambrian rocks (Map 7). North of Lake Athabasca, most of this drilling (about 85% of the holes drilled) was done at four targets that were tested for uranium [Assessment reports UAF-118(1), UAF-118(3) and UAF-119(8)]. South of Lake Athabasca, the assessment records indicate that most drilling comprises isolated holes designed to provide stratigraphic information or to test specific geological, geochemical or geophysical anomalies (Map 7).

Geological Overview

Edwards *et al.* (1991) described the geology of the Precambrian Shield north of Lake Athabasca as follows:

"The exposed Shield forms part of the Churchill Structural Province and lies within the Athabasca Mobile Belt (Wilson, 1986). It consists of a north-trending belt of Archean granite gneisses intruded by an Aphebian granitoid batholithic complex.

The basement migmatitic gneissic belt consists of classic granitic gneisses with minor components of small granitoid bodies, high grade metasediments and amphibolite. The basement complex probably represents multiple cycles of sedimentation, intrusion, deformation and metamorphism; all rock units have been affected by ductile or brittle deformation.

The granitoid complex west of the gneissic belt is dominated by the Slave and Arch Lake granitoids. ... It appears that the granitoids are ultrametamorphic partial-melt derivatives from the protolithic granite gneisses. The major contact between the granitoids and the gneissic belt is intrusive, with gneissic wall wedges protruding into the granitoids.

Granitoids east of the gneissic belt include the Wylie Lake and Colin Lake Granitoids. This large band of relatively homogenous porphyroblastic biotite granites overlies the granite gneiss *complex. These [granite gneiss complex] rocks are metamorphic equivalents of highly deformed, low-grade metasedimentary and metavolcanic rocks in the Waugh Lake area. The rocks of the Waugh Lake area probably represent a sedimentary and volcanic cycle much younger than that represented by the high grade metasedimentary rocks in the granite gneiss complex*" (Edwards *et al.* 1991).

High- to low-grade metasedimentary and metavolcanic rocks exist in several places north of Lake Athabasca, particularly in the Waugh Lake area east of Andrew Lake and locally along a belt extending from Lindgren-Charles Lakes southerly to Loutit-Flett Lakes (Godfrey 1986a). At the Waugh Lake area, low-grade metasedimentary rocks, accompanied by metavolcanics, show primary sedimentary and volcanic structures, respectively (Watanabe 1961). An unconformity has been assumed between the volcanic-sedimentary sequence at Waugh Lake and the Archean granite gneisses and high-grade metasedimentary rocks. However, Langenberg *et al.* (1993) stated that the age relationship between the Waugh Lake low-grade sequence and the nearby Colin Lake Granitoids is uncertain, and the Colin Lake Granitoids may actually be intrusive into the Waugh Lake Group. To the south, "*along the north shore of Lake Athabasca the gneissic basement complex and younger granitoids are unconformably (?) overlain by low-grade metasedimentary rocks of the Burntwood Group of probable late Aphebian age*" (Edwards *et al.* 1991). The stratigraphic and age relationships between the Burntwood Group and the Waugh Lake Group are undetermined.

"*Major faults affect most of the rock units and are younger than the macroscopic fold structures in the granitoids. These faults are expressed as shear zones characterized by mylonites (Watanabe 1965). Retrograde greenschist facies minerals in the mylonitic zones suggest a late Aphebian age for this large-scale faulting, although it cannot be excluded that the ductile deformation started under higher grade conditions (McDonough et al. 1993). Extensive brecciation along most faults indicates still younger brittle fault movements at higher crustal levels*" (Langenberg *et al.* 1993). All of this faulting occurred prior to deposition of the Athabasca Group. In places, however, some basement faults affected the depositional environment of the Athabasca Group sediments, and some basement faults were reactivated and cause minor offsets of Athabasca Group strata.

"*The shoreline of Lake Athabasca in the Fort Chipewyan area approximately coincides with the erosional edge of unmetamorphosed sandstones of the Athabasca Group (Helikian age). ... A well-developed regolith has been mapped beneath the Athabasca sandstone at Greywillow Point (T 118, R 1) on Lake Athabasca.*

South of Lake Athabasca four formations of the Helikian Athabasca Group are present. From the base these formations are the Fair Point, the Manitou Falls, the Wolverine Point and Locker Lake. The siltstones and shales of the upper member of the Wolverine Point Formation are tuffaceous in nature and are believed to have been deposited under nearshore marine conditions. The other formations within the Athabasca Group were deposited in a fluvial setting (Wilson 1985b).

An angular unconformity separates the Athabasca Group from the underlying Shield rocks of the Churchill Structural Province" (Edwards *et al.* 1991). South of Lake Athabasca, the sub--Athabasca Group basement rocks are either extensively drift covered or poorly exposed, with the greatest exposure of these basement rocks being within the Marguerite River area (Bayrock 1971, 1972a, Godfrey 1970). The Marguerite River area represents a portion of a northeasterly-trending basement topographic high that existed during deposition of the Athabasca Group. This high was a major factor in controlling sedimentation at the southwest margin of the Athabasca Basin (Wilson 1985b).

"*The Fishing Creek Granitoid, Alkali Feldspar rich Granitoid, Grey Foliated Granitoid and Wylie Lake Granitoid of Wilson (1986) south of Lake Athabasca are probably all equivalent to phases* *of the Wylie Lake pluton exposed north of the lake. ... The mylonitic rocks south of Lake Athabasca are broadly equivalent to the Granite Gneisses and High Grade Metasedimentary Rocks of Godfrey (1986) north of Lake Athabasca. The mylonitic rocks south of Lake Athabasca can be divided into a mafic and a felsic type (Wilson 1986). The mafic mylonites predominate and may have been derived from a granite gneiss or High grade Metasedimentary Rocks. The felsic variety were probably derived from granitoid rocks (Wilson 1986)*" (Edwards *et al.* 1991).

"*The Athabasca Group rocks occupy an oval basin measuring over 400 km east to west and over 200 km north to south with an area of over 80,000 km^2. Approximately 10 per cent, or 8,000 km^2, lie in Alberta south of the north shore of Lake Athabasca. In Alberta, strata of the Athabasca Group consist of nearly flat-lying sandstones more than 1,255 m thick. The succession is underlain, beneath a marked angular unconformity, by predominantly gneissic rocks of the Churchill Structural Province of the Canadian Shield. ... Where the basement is covered by Athabasca rocks, a pre--Athabasca paleosol or regolith is preserved. ...*

Basement topography was a major control on Athabasca sedimentation in Alberta, at least in early Athabasca times. The main sub-Athabasca topographic feature is a broad trough oriented northeast to southwest, with its axis along the south shore of lake Athabasca (the Jackfish sub-basin of Ramaekers, 1979). Later in Athabasca times, at least one fault, probably oriented northwest to southeast, affected sedimentation between" Stone Point on the south shore of Lake Athabasca and the Saskatchewan border (Wilson, 1985b).

"*Devonian carbonates are present west of the Athabasca Basin. In the southwest these rocks overlap the Athabasca Group with sharp unconformity. Cretaceous rocks are present to the southwest, but they do not outcrop and no core has been recovered from them.*" (Ibid).

North of Lake Athabasca, glacial scouring has left numerous fresh outcrops. However, extensive glacial and other surficial deposits do exist in the topographically low ground between outcrops. Near the north shore of Lake Athabasca and south of the lake there is extensive sand plains and glacial material which locally is up to tens of metres or more thick.

Discussion of Resource Potential

The economic potential of the Precambrian rocks of northeastern Alberta has been discussed by several workers, including (Godfrey 1958b, 1960; Edwards *et al.* 1991). The mineral occurrences shown on the various 1:63,360 scale maps which have been published by the AGS, and from unpublished data on file, were compiled and presented at 1:250,000 scale for NTS 74M and 74L/N½ by Godfrey (1986b). These data were supplemented by the inclusion of drill holes for core that is on file at the Mineral Core Research Facility (MCRF) maintained in Edmonton by the AGS (Figure 7 in Edwards *et al.* 1991). In 1992 the AGS examined 88 mineral occurrences in the Andrew Lake-Charles Lake area and compiled information from the available sources for 39 other occurrences; these 127 occurrences are documented in the report by Langenberg *et al.* (1993).

Based on the geologic and tectonic setting, and on comparison with other metallogenic provinces, the potential ore deposit types that may exist in the Precambrian rocks of northeastern Alberta include: **uranium deposits**, such as (1) unconformity-related uranium-polymetallic deposits similar to those associated with the Athabasca Basin in Saskatchewan (Marmont 1988), (2) vein-type uranium deposits similar to those which exist at the Beaverlodge camp at Uranium City, Saskatchewan (Beck 1969, 1986), (3) pegmatite-related uranium deposits similar to those which exist at Charlebois Lake, Saskatchewan (Mawdsley 1957, 1970); **gold deposits**, such as (4) the Archean lode gold deposits associated with shear zones similar to those at Hemlo, Kirkland Lake and Red Lake in Ontario (Bursnall 1989, Roberts 1988), (5) intrusion-associated gold deposits such as those at Lamaque and Belmoral, Quebec (Eckstrand 1984); and (6) **volcanogenic massive sulphide base metal deposits** in Archean rocks similar to those in the Abitibi belt of Ontario and the Slave Province in the N.W.T. or in Proterozoic rocks in Manitoba and Saskatchewan (Franklin *et al.* 1981; Franklin and Thorpe 1982). The above deposits are believed to have the greatest potential, but there are a few other deposit types that may exist in the Precambrian of northeastern Alberta, including: (7) **magmatic nickel, copper, platinum group element (PGE) deposits** associated with basic or ultramafic rocks such as at Langmuir, Ontario or Thompson, Manitoba (Naldrett 1981a,b, Eckstrand 1984, Macdonald 1988), (8) **granophile mineral deposits** of such metals as tin, tungsten, uranium, molybdenum, beryllium, boron, lithium, fluorine and rare earth elements (REE) (Maurice 1980, Ishihara 1981, Strong 1988, Whitney and Naldrett 1989), (9) **Olympic Dam type Cu-U-Au-Ag-REE deposits** associated with hematite-cemented breccia similar to those at Roxby Downs, Australia (Roberts and Hudson 1983, Oreskes and Einaudi 1990), and (10) **diamondiferous kimberlite or lamproite diatreme pipes** similar to those that exist at Lac de Gras, Northwest Territories, in central Saskatchewan and elsewhere in the world (Mitchell 1993, Gent 1992, Helmstaedt 1992, Lehnert-Thiel 1992).

Uranium Deposits

During the uranium exploration boom of the 1960's and 1970's, and following the release of the detailed geological mapping done by the AGS (geological reports and maps by Godfrey and others summarized in Edwards *et al.* 1991), both the Precambrian Shield basement rocks and the overlying Athabasca Group in Alberta were extensively explored for uranium. This exploration was mainly directed towards vein-type uranium deposits of the Beaverlodge type and towards unconformity-related uranium deposits of the Athabasca type, and it resulted in the discovery of numerous minor uranium occurrences (Maps 3 to 5).

Unconformity-related Uranium-Polymetallic Deposits

The greatest potential for uranium deposits in the Precambrian of northeast Alberta is unconformity-related deposits similar to those found associated with the Athabasca Group in Saskatchewan. Sediments of the Middle Proterozoic Athabasca Group were deposited between about 1,635 Ma and 1,310 Ma (Armstrong and Ramaekers 1985; Wilson 1987). "*Major late Hudsonian northeasterly-trending faults divide the Athabasca region into a series of subparallel basins. ... The pattern and types of faulting, the presence of intrusives, and the nature of the clastics suggest that the basins of the Athabasca region ... formed as a series of pull-part structures in an episode of transcurrent faulting during and following a Hudsonian plate suture in eastern Saskatchewan. ... These basins coalesced at an early stage when infilled by sediments of the Athabasca Group, a molasse wedge shed from the region of the Hudsonian suture zone. The deposits are fluvial in the east, but predominantly lacustrine or marine in the western half of the area.*" (Ramaekers 1981, 1990). "*Beneath the Athabasca Group, the basement rocks are altered in the form of a weathered soil profile, the regolith* [or saprolite]. *Over most of the basin the regolith is 20 m to 40 m thick. Areas where the basin floor had strong relief may have little or no regolith on high parts, whereas areas where faulting has broken the basement rocks, may have 100 m or more of regolith*" (Langford 1986). Characteristically, the regolith or saprolitic zone comprises an upper red division consisting of hematite capped by a layer of bleached material a few centimetres thick, underlain by a green chloritic zone that is gradational into the overlying red profile and the underlying fresh bedrock. Macdonald (1980, 1985) concluded that this saprolite or regolith formed during a period of lateritic weathering under tropical to subtropical climatic conditions, but Ramaekers (1983) noted that the regolith beneath the Athabasca Group may, in places, be a result of or has been affected by diagenesis after the basinal sedimentation. That is, the Athabasca Group sediments and post-Athabasca diabase dykes have undergone hematitization, illitization and kaolinitization during a period of post-sedimentation alteration. Within Alberta, Wilson (1986) stated that "*a zoned saprolite is present regionally on the basement immediately beneath the unconformity. It represents a period of Helikian surficial weathering preserved by deposition of the Athabasca Group. The saprolite is crosscut by two types of widespread hydrothermal alteration, a thin bleached zone at the unconformity and a more widespread alteration associated with fracturing. ... Locally, a fourth type of alteration, which may be associated with mylonitic rocks, shows enrichment in several potentially economic minerals (including uranium, nickel, zinc, lead and gold), and has a geochemical signature similar to the halos around some uranium deposits in Saskatchewan.*" In Saskatchewan, the alteration directly associated with the unconformity-related uranium-polymetallic deposits includes one or more of "*chloritization, argillitization, carbonatization (commonly dolomitization), silicification, sulphidation and tourmalinization. The intensity of the alteration increases with proximity to better mineralized sections*" (Marmont 1988). The intense zone of saprolitization beneath the Athabasca Group and the later alteration of Athabasca Group are important to exploration for uranium for two reasons: (1) the alteration of the basement rocks and Athabasca Group sediments is believed to have transformed trace uranium into the more readily mobile hexavalent state, U^{6+}, and (2) alteration types which are associated with uranium deposits have been used as a guide to ore because typically the alteration haloes extend for a few hundred metres or more away from the uranium deposits.

Characteristics of unconformity-related uranium-polymetallic deposits in Saskatchewan and Australia in the world have been tabulated by a number of workers, including Marmont (1988), Hoeve and Sibbald (1978a,b), Sibbald and Quirt (1987), and Sibbald *et al.* (1990). In general, the Saskatchewan unconformity-related uranium deposits typically are characterized by: (a) being spatially restricted to within a few tens of metres immediately above and below the unconformity between Athabasca Group and the underlying basement, (b) being spatially associated with steep reverse or normal faults that locally offset the unconformity, (c) hosted in or associated with carbonaceous or calc-silicate metasedimentary rocks in the underlying basement, (d) associated with an alteration halo that has affected both the basement rocks and overlying Athabasca Group, (e) the ore minerals comprise uranium, with or without one or more of Ni, Co, Ag, Mo, Cu, Pb, Zn, Bi, Se, As and, in places, Au, and (f) an association with solid or gaseous hydrocarbons. Cumming and Krstic (1992) stated that the existing age data indicate that "*almost all the deposits formed in a restricted time interval between about 1,330 and 1,380 Ma. ... Periods of reworking and-redeposition occurred at ~1,280, ~1,000, ~575, and ~225.*" They (Ibid) noted, however, that the McArthur River uranium deposit is the one major exception in that it has given a well determined age of 1,514 ± 18 Ma.

In Saskatchewan, the majority of the important uranium deposits occur near the eastern to southern part of the Athabasca Basin (MacDougall *et al.* 1990). Elsewhere in the basin, small uranium deposits exist along the northern margin of the Athabasca Group at Middle Lake and at Nisto near Black Lake (Homeniuk and Clark 1986), at Fond-du-Lac (Anonymous 1981a), at Stewart Island south of the Crackingstone Peninsula (Anonymous 1981b), and at Maurice Bay near the Alberta-Saskatchewan Border (Ibid, Lehnert-Thiel *et al.* 1981, Mellinger 1985, Harper *et al.* 1986). Near the western part of the basin, but still in Saskatchewan, several economically important uranium deposits exist at Cluff Lake within the Carswell Circular Structure (Lainé *et at.* 1985).

In Alberta, there are more than 280 uranium or radioactive occurrences in the region underlain by Precambrian rocks northeast of Lake Athabasca. Many of the occurrences in bedrock comprise radioactive minerals in pegmatites or associated with narrow fractures cutting various rock types. In several places there are rock samples from bedrock that assay between 0.1% and up to 1.76% U_3O_8 (e.g., anomalies 74M-1, -8, -11, -14, -21, -22, -49, -60, -82, -84, -85, -90, -91 and -97, and 74L-1). As well, there are several localities near the northwestern shore of Lake Athabasca where from a few to numerous anomalously radioactive boulders have been discovered. These radioactive boulder localities include: (a) anomalies 7M-59 and 74A-61 to -66 in the Fallingsand Point to Greywillow Point area where at least 387 radioactive boulders were discovered with assays that are up to 0.80% U_3O_8, (b) anomaly 74M-88 about 10 km north-northeasterly of Greywillow Point near Burstall Lake where 30 radioactive boulders with yellow uranium oxides were found, (c) anomaly 74M-25 about 10 km north of Lapworth Point near Belinda-Sebastian Lakes where at least 11 radioactive boulders with assays up to 1.93% U_3O_8 exist, and (d) anomalies 74L-7 and 74L-8 in the Shelter Point to Sand Point area where at least 8 boulders were found with anomalous radioactivity up to 15,000 counts per second (cps, SRAT SPP2N). Many of these radioactive boulders comprise Athabasca Group sandstone or, in places, basement rocks that are mineralized with one or more of pitchblende, coffinite, and secondary yellow and green uranium oxides. South of Lake Athabasca, several small occurrences of anomalous radioactivity or uranium stain are reported to exist in Precambrian basement rocks at the Marguerite River area (Godfrey 1970). Although none of the Marguerite River uranium occurrences are known to be important, they indicate that anomalous amounts of uranium are present at least locally in the basement rocks. Elsewhere south of Lake Athabasca within Alberta, the available assessment records indicate that no important radioactive occurrences have been discovered in bedrock or in boulders in the area underlain by Athabasca Group sedimentary strata or Precambrian basement rocks (Wilson 1985b, 1986). However, Carl et al. (1992) show an "epigenetic uranium deposit" at the Maybelle River area (NTS map-sheets 74E/16 and 74L/1). This may be the same uranium occurrence as that reported in assessment report UAF-144(2) (anomaly 74E-24) which stated "*a deep alteration was encountered in the 1976 drilling at a location just south of the Richardson River (110°, 40' W, 57° 55' N). A small stringer of pitchblende was intersected in this zone. ... The alteration zone has considerable width. This zone lies on a prominent E-W trending magnetic low interpreted to be a fault zone.*" The drilling was done to test a Questor Input-EM anomaly, and was reported to also have intersected a graphite horizon.

Several features favourable for unconformity-related uranium deposits exist in the Precambrian rocks of northeastern Alberta. These favourable features include:

(1) There are numerous minor uranium occurrences and several areally large airborne radiometric anomalies in the Precambrian basement rocks north of Lake Athabasca (Map 4; Godfrey and Plouffe 1978; GSC 1977a,b; Sprenke *et al.* 1986). These data indicate that the Precambrian rocks in many places have a high background or Clarke value of uranium, and that this uranium has at least locally been mobile and formed small zones of anomalous radioactivity or uranium occurrences. In short, the anomalously uraniferous background content that exists indicate the Precambrian of northeast Alberta is a potential "**fertile source area**" for uraniferous deposits.

(2) A weathered saprolitic zone or regolith exists beneath the Athabasca Group in many places in the Alberta portion of the Athabasca Basin south of Lake Athabasca and its thickness locally ranges up to 47 m (Wilson 1986). In some places the altered zone is enriched in U, Ni, Ba, Co, Zn, Pb and Au (Ibid). North of Lake Athabasca, altered basement also is common at many locales. For example, at anomalies 74M-59 and -60 near Fallingsand and Greywillow Points, assessment reports UAF-118(1), UAF-118(3) and UAF-118(4) reported that "*below the unconformity* [with Athabasca Group], *Aphebian basement is moderately to strongly regolithized in depths up to 150 feet* [46 m]". Further, drillhole #5 at anomaly 74M-59 intersected hydrothermally altered and fractured Athabasca Group sandstone overlying altered basement. Interestingly, the detailed geological mapping by Godfrey (1980a,b, 1984)

indicates that the unconformity-related saprolitic zone may extend for several kilometres or more northwesterly from the northern margin of Lake Athabasca. That is, his (Ibid) maps show epidote and chlorite as common alteration minerals in the basement rocks near Lake Athabasca, whereas farther to the north and northwest, he reports garnet is the predominant mineral. It is possible that the chlorite and epidote may not be of metamorphic origin, but instead may be related to the saprolitizing event that occurred prior to deposition of the Athabasca Group. South of Lake Athabasca, altered or saprolitic basement is reported in many drill holes (Wilson 1985a,b, 1986), and at several sites within the Marguerite River area (Godfrey 1970).

(3) There are a large number of diverse basement rock types present in northeast Alberta, including known or inferred graphitic or carbonaceous horizons. Elsewhere in the Athabasca Basin these rock types are favourable hosts for uranium deposits.

(4) At least 8,000 km^2 are underlain by Athabasca Group sedimentary rocks within Alberta south of Lake Athabasca (Wilson 1985b). To the west and southwest, the western termination of the Athabasca Group is uncertain because of extensive drift cover and, in places, overlying Devonian strata. Wilson (1987), for example, based on drilling data from assessment reports, speculated that the western margin of the Athabasca Group may be farther west than is shown on published geological maps. To the north and northwest, Athabasca Group underlies Lake Athabasca and crops out locally along the northern margin of the lake. Furthermore, extensive sand plains and drift covered areas exist along and northerly of Lake Athabasca, hence Athabasca Group sedimentary rocks may exist locally in subcrop for several kilometres or more north of the known outcrops. Farther to the north, between Colin Lake and the Slave River, there is a large westerly trending sand and drift covered area. It is also possible that in parts of this covered area, Athabasca Group may occur in subcrop.

(5) There are numerous faults of several diverse trends and ages, both north and south of Lake Athabasca. These include the southern extension of the Charles Lake shear zone, the southwestern extensions of the Black Bay and Grease River Faults, a northwest-trending fault at Fidler Point and several inferred faults south of Lake Athabasca, including the southeasterly trending Richardson River fault (Maps 3 to 5; Wilson 1986, Ramaekers 1990). In the Saskatchewan portion of the Athabasca Basin, faults are important both to focus the flow of uraniferous ore fluids and to provide sites that are favourable for uranium deposition. Of particular exploration interest are those localities where faults coincide with or are near to graphitic or sulphidic zones. Possible examples of such geological settings exist at several places in Alberta. For example, graphitic or sulphidic zones in basement rocks are reported at anomalies 74L-38, 74L-39 and 74E-24 south of Lake Athabasca, and at anomalies 74L-6, 74L-10 and 74L-11 near Point Basse on the northern shore of Lake Athabasca.

(6) In places in northeast Alberta the basement rocks or overlying Athabasca Group sandstone adjacent to the unconformity are reported to contain uranium minerals. For example, at anomaly 74M–A41 near Whitesand Point, assessment report UAF-062(2) stated that drilling done in 1954 intersected pitchblende-bearing zones in basement rocks and that surface rock samples assay up to 0.086% U_3O_8. At anomaly 74M-60 near Greywillow Point, assessment report UAF-118(2) stated that Athabasca Group quartzitic sandstone adjacent to the unconformity contains minor amounts of pitchblende and coffinite, and surface rock samples assay up to 0.62% U_3O_8. South of Lake Athabasca at anomaly 74L-78, drilling intersected altered basement a few metres below the unconformity with overlying Athabasca Group, and the altered basement contains up to 292 parts per million (ppm) U, 2.7 grams gold per tonne (g Au/t) and is also enriched in Ni, Co, Zn, Ag and As (Wilson 1987; assessment report UAF-150). This indicates that uranium and other metals have been mobile along or adjacent to

the basement-Athabasca Group unconformity and, in places, have been deposited in quantities sufficient to form 'anomalous' concentrations.

(7) Lastly, the compilation has identified numerous sites within and adjacent to the Alberta-portion of the Athabasca Basin where highly anomalous concentrations of uranium exist in bedrock, in glacially transported boulders, or in surficial lake sediment, lake water, soil or bog samples (Tables 2 and 5). At this time, the most prospective area may be along the northern margin of the Athabasca Basin north of Lake Athabasca where numerous minor uranium occurrences exist in outcrop and hundreds of anomalously radioactive uraniferous boulders have been discovered. Many of the boulders have uranium contents ranging from 0.1% to 1.93% U_3O_8 (anomalies 74M-25, 74M-59 to 74M-65, 74M-88, 74L-7 and 74L-8; Map 4).

The two most prospective areas for uranium north of Lake Athabasca may be (a) in the Fidler Point to Greywillow Point region, and (b) in the Pointe Basse to Sand Point region. Although some parts of the Fidler Point to Greywillow Point region (e.g., anomalies 74M-59 and 74M-60) have been extensively drilled searching for the source of the uraniferous boulder trains, no important uranium deposits have been discovered in Alberta to explain the numerous boulders and boulder trains that exist in this area. It is possible that the uraniferous boulders have been derived from a source that has been completely eroded or is small, or their source exists further to the east from deposits such as Maurice Bay in Saskatchewan. It is also possible, however, that the source of at least some of the boulders is in Alberta, but has yet to be discovered. In total, more than 400 anomalously radioactive boulders have been discovered and in assessment report UAF-118(6) the authors believed that most of these boulders originated within Alberta, perhaps from a source beneath the waters of Lake Athabasca. The existence of the Maurice Bay uranium deposit just east of this area within Saskatchewan indicates that Alberta's comparable geology should be equally favourable for a uranium deposit.

In the Point Basse to Sand Point region (anomalies 74L-1 to 74L-11), several radioactive boulders were discovered, although not as many as at the Fidler Point to Greywillow Point region. The boulders have assayed up to 1.72% U_3O_8. With the exception of a small amount of drilling at anomaly 74L-1 near Point Basse and on the north shore of Burntwood Island, there has been no drill testing for uranium at the Point Basse to Sand Point region. Of interest in this regard are untested geophysical anomalies at anomaly 74L-10. Assessment reports UAF-164(1) to UAF-164(4) stated that this anomaly comprises three airborne electromagnetic (AEM) conductors which in part are coincident with a weak gravity anomaly and a very low frequency electromagnetic (VLF-EM) conductor. The authors of the assessment reports speculated that anomaly 74L-10 may represent a "*mineralized fault*". Nearby, there are pyritic metasedimentary rocks (anomaly 74L-11) and minor amounts of yellow and green uranium oxides in bedrock (anomaly 74L-1). Anomaly 74-10 was not drill tested because the bedrock source of the geophysical anomalies is overlain by the waters of Lake Athabasca and the thickness of the Athabasca Group strata overlying the basement-Athabasca Group unconformity is estimated to be about 270 m.

South of Lake Athabasca, the area underlain by or near to the Athabasca Group is also highly prospective for uranium because of its geological similarities to the uraniferous parts of the Athabasca Basin that occur in Saskatchewan. The unconformity between basement rocks and the Athabasca Group lies at a depth of 600 m or less in over 75%, or about 6,000 km^2, of the Athabasca Basin in Alberta (Wilson 1987). In Saskatchewan, important uranium deposits such as Cigar Lake and P2 North have been found at depths of several hundred metres below surface. Although much of the Alberta portion of the Athabasca Basin has been staked and explored for uranium in the past, most of this work occurred prior to about 1981. The available assessment records indicate that many geochemical and airborne geophysical anomalies were not satisfactorily explained. For example, northerly of Bowen Lake within NTS 74L/8 there are several anomalies (74L-22, -23, -24, -25, -53, -54, -55, -57, -59 and -60) that have one or more of high contents of U, Mo, Cu or helium in lake sediment or water. As well, a few airborne radiometric or aeromagnetic anomalies (74L-19, -53, -64 and -75) exist in the vicinity of these anomalous lakes. Assessment report UAF-136(1) shows that a hole (anomaly 74L-30) was drilled at this locale to test a lake sediment anomaly of 18.8 ppm U_3O_8. This hole penetrated 47.6 m of overburden and 136.6 m of Athabasca Group strata, but it did not penetrate the underlying basement, nor did it satisfactorily explain the lake sediment anomaly. Northwesterly of Bowen Lake there are several other geochemically anomalous locales that are unexplained. For example, (a) in the vicinity of anomalies 74L-12 and 74L-13, there are lakes that have sediment with up to 30 ppm U and 95.5 ppm U, respectively, and water containing up to 0.5 ppb U [assessment reports UAF-115(1), UAF-116(3) and UAF-117(1)]. Interestingly, anomalies 74L-12 and 74L-13 also are coincident with an inferred basement fault identified by Wilson (1986, his Figure 7). (b) At anomaly 74L-53, 11.2 ppm U, 132 Mo and 28 ppm Cu exist in lake sediment and 0.48 ppb U exists in lake water [UAF-129(1)]. (c) At anomaly 74L-54, 13.7 ppm U and 180 ppm Zn exist in lake sediment, and 0.46 ppb U exist in lake water [UAF-129(1)]. Lastly, (d) at anomaly 74L-59, 195 ppm Zn exists in lake sediment [UAF-129(1)]. In general, results greater than about 2.0 ppm U and 10 ppm Cu, Zn or Mo in lake sediment, or greater than 0.1 ppb U in lake water, are considered anomalous and warrant follow-up exploration.

With respect to uranium or radioactive zones in bedrock, there is the pitchblende occurrence intersected by drilling at Maybelle River area and a narrow zone of anomalous radioactivity in Athabasca Group sandstone in a drill hole at anomaly 74L-50, which is southwest of Richardson Lake near the inferred western margin of the Athabasca Basin and near the intersection of two inferred faults (Map 5). At this occurrence, Saskatchewan Mining Development Corporation reported anomalous radioactivity, which comprised a small gamma kick of 30 80 cps above background, across a 2 m interval of Athabasca Group sandstone about 4.5 m above the basement-Athabasca Group unconformity [drill hole WB-1 in assessment report UAF-162]. The stratigraphy in this hole comprised about 93.9 m of overburden, 60.6 m of Athabasca Group and 36.6 m of altered basement.

The existence of several such inadequately evaluated geochemical and radioactive anomalies within and adjacent to the Athabasca Basin in Alberta, coupled with the other favourable geological conditions and numerous uranium occurrences which are present, indicate that the potential for discovery of an unconformity-related uranium-polymetallic deposit in Alberta is good. Exploration should concentrate on those areas underlain by or adjacent to Athabasca Group sandstone south of and near the northern margin of Lake Athabasca. As well, selected sand and drift covered areas that may be underlain by a thin veneer of Athabasca Group north of Lake Athabasca may also be geologically favourable for unconformity-type uranium deposits.

Vein-type Uranium Deposits

Prior to the discovery of the large, often high-grade unconformity-related uranium-polymetallic deposits in Saskatchewan, the 'classical vein-type' uranium deposits at the Beaverlodge District near Uranium City, Saskatchewan were economically important. During the 1950's, 16 uranium deposits had been brought into production in this camp (Beck 1969, 1986; Tremblay 1978). As well, there exist several hundred epigenetic pitchblende occurrences and a few syngenetic occurrences of uraninite in pegmatite in the district. Only the former is of economic significance and the pitchblende deposits can be divided into two groups on the basis of mineralogy. "*A large group of simple mineralogy comprising over 90* *per cent of the known occurrences, and a smaller group of more complex mineralogy. The deposits of simple mineralogy consist of pitchblende accompanied by quartz, carbonates, chlorite and hematite often with minor amounts of pyrite, chalcopyrite and galena. Nolanite is present in a few deposits. Occasionally brannerite and/or coffinite occurs in small amounts in the ore zones. In contrast, the deposits of complex mineralogy consist of pitchblende accompanied by one or more of the following: Co-Ni arsenides and sulphides; Co-Ni-Pb-Cu selenides; and native elements (Pt, Ag, Au, Cu). Typical gangue minerals are carbonates, quartz, chlorite and hematite. The deposits of simple mineralogy are distributed widely but those of complex mineralogy are* [areally more restricted and most occur near the margin of Lake Athabasca south of Beaverlodge Lake]. *... Most of the deposits occur in minor faults and breccia zones subsidiary to the major faults of the region. The three dominant fault sets trending east, northeast, and northwest appear to be equally favourable for ore emplacement. The major faults are not mineralized but probably acted as channelways for mineralizing solutions. Deposits occur in a wide variety of rock types including granite, migmatite, paragneiss, amphibolite, metavolcanics and dolomite of the Tazin* [Group] *and in sediments and volcanics of the Martin Formation. Apart from the Gunnar deposit and Eldorado's Dubyna deposit, which are in granitoid rocks, the most important deposits ... are closely associated with mafic rocks particularly amphibolite, meta--argillite, chlorite-epidote rock and chlorite schist. In detail, however, individual veins are a result of open space filling and structural control is more important than lithological control.*" (Beck 1986) The initial pitchblende mineralizing event that formed the Beaverlodge deposits occurred about 1,780 ± 20 Ma (Koeppel 1968), which is about 400 Ma older than the age of most of the unconformity-type uranium deposits in the Athabasca Basin. It is believed that the simple mineralogy pitchblende veins at the Beaverlodge District are of Hudsonian metamorphic-hydrothermal origin, with "*the liberation of uranium and other metals from country rocks during granitization, their transportation by metamorphically-derived fluids along structural channelways and eventual precipitation in suitable physico-chemical traps*" (Beck 1986). However, the complex veins are believed to have been emplaced about 1,110 Ma ago during a period of remobilization equivalent to that found associated with the unconformity-type uranium deposits in the Athabasca Basin.

In northeast Alberta north of Lake Athabasca, there exist several geological features that are similar to the setting of the Beaverlodge vein-type deposits. These include: (a) several major fault systems, as well as numerous subsidiary faults. The faults trend east, north, northeast and northwest, similar to the fault trends at the Beaverlodge district. (b) There exist a wide variety of rock types, including several large and small belts of metasedimentary, metavolcanic and mafic lithologies similar to those which are host to uranium deposits at the Beaverlodge district. (c) There are numerous uranium occurrences in both pegmatite and vein-type settings. Many of the vein-type occurrences comprise pitchblende and secondary uranium oxides associated with one or more of silicification, hematitization and sulphides. (d) Lastly, most of the uraniferous veins are fracture-controlled or are spatially related to nearby faults or topographic lineaments that probably reflect faults. In northeast Alberta, most of the vein-type or fracture-controlled uranium occurrences exist south and west of Andrew Lake and in the vicinity of Colin Lake (Map 4). A descriptive overview of many of these radioactive occurrences is given in Godfrey (1958b) and, more recently, by Langenberg *et al.* (1993).

The most prospective locale for vein-type uranium deposits in the Precambrian of northeast Alberta, based on the existing geological and mineral occurrence data, is along or spatially associated with the Bonny Lake fault zone west and south of Andrew Lake. Associated with this major fault structure are several occurrences of anomalous radioactivity, sulphide occurrences, breccia zones, quartz stockworks, hematitization, chloritization, feldspathization and marginal shears (Godfrey 1961, 1963, 1966). As well, this fault cuts several diverse rock types, including several bands of metasedimentary and mafic rocks. In places, the assessment data indicate uranium grades are of exploration interest. For example, at anomalies 74M-5 and 74M-14 near Holmes Lake, grab samples that assay up to 0.14% U_3O_8 were collected from hematitized fractures associated with the Bonny Lake fault zone; several trenches and one hole exist at this locale (Langenberg *et al.* 1993). South of Andrew Lake at anomaly 74M-8, which is near a small lake informally named "Carrot Lake", a chip sample assays 0.16% U_3O_8 across 1.0 m and a grab sample which was collected in 1992 from a gouge zone assays 1.79% U (Ibid). Pitchblende, thucholite and secondary uranium oxides exist at this locale and occur in a northwesterly trending zone that ranges up to about 150 m wide. To the south, nearer to Cherry Lake, there are numerous other uranium or radioactive occurrences (e.g., at anomalies 74M-1, 74M-11 and 74M-12) which are associated with hematitized and silicified fractures and shears. Interestingly, although these uraniferous zones are spatially associated with southeasterly trending splays of the Bonny Lake fault zone, many of the radioactive zones trend northerly to northeasterly (Ibid). Assays from chip samples at anomaly 74M-1 assay up to 0.79% U_3O_8 across 1.2 m [assessment report UAF-001(1)]. In the vicinity of anomaly 74M-1, black A horizon soil samples from a swampy area have assays up to 1.76% U_3O_8. A hole was drilled by McIntyre Porcupine Mines Ltd. under this swamp, but failed to intersect important uraniferous zones or explain the anomaly. At anomaly 74M-12 a chip sample from a trench assays 0.5% U_3O_8 across 1.5 m. As well, a trench in the vicinity assays 0.19% U_3O_8 and 0.28% MoS_2 across 0.6 m [assessment report UAF-001(1)]. Pyrite, pyrrhotite, molybdenite, chalcopyrite and pervasive silicification exist at this locale, but gold assays are low because two samples which were collected during 1992 assay only 12 parts per billion (ppb) Au or less (Langenberg *et al.* 1993). A northeasterly trending uraniferous zone which is spatially associated with splays of the northwesterly trending Bonny Lake fault, also exists at Spider Lake area (anomalies 74M-2 and 74M-13). Spider Lake is a few kilometres west-northwesterly of Cherry Lake (Godfrey 1963). At the northern end of Spider Lake there are several radioactive occurrences associated with a northeasterly trending fault zone that cuts a belt of metasedimentary rocks which is several hundred metres wide. Uranium is present as yellow and green secondary oxides, and rock sample assays range locally up to 0.17% U_3O_8. Molybdenite, limonitic weathered iron sulphides, hematitization and silicification are associated with the radioactive zones. Trenching and drilling, however, did not intersect any important uraniferous zones [assessment report UAF-001(3)].

There are a number of other potential vein type uranium occurrences west and southwest of Andrew Lake, including anomalies 74M-37, -84, -85 and -97. Rock samples from several of these anomalies are reported to assay from 0.1% to greater than 1.0% U_3O_8. At anomaly 74M-97 which is south of the big bend in the west arm of Andrew Lake, for example, Godfrey (1958b) collected three samples that assay up to 3.93% U_3O_8 and 1.4% Mo. A hole which was drilled at this locale in 1968 intersected a uraniferous zone in a silicified, brecciated band of biotite schist that assays 0.22% U_3O_8 across 1 m [assessment report UAF-112(6)]. Much further to the southwest, near Disappointment Lake (anomaly 74M-49), rock sample assays up to 0.365% U_3O_8 exist in a trench and are associated with hematite, magnetite and pyrite. In places the bedrock is extensively weathered, and anomaly 74M-49 is spatially associated with a major east trending fault. Assessment report UAF-071(1) indicates that in excess of a hundred radioactive occurrences were discovered near Disappointment Lake in the vicinity of anomalies 74M-49 to 74M-51.

In summary, numerous uranium occurrences, sulphide occurrences, hematitization and silicification are associated with the Bonny Lake fault zone or its subsidiary fault and shear splays, with other faults that exist south and west of Andrew Lake, and with the east trending fault zone that exists at Disappointment Lake. In places, the surface uraniferous zones have been explored by one or more of geological mapping, radiometric surveys, trenching or drilling, but this work did not result in the discovery of important uraniferous zones. However, drift cover is extensive, particularly along known faults and topographic lineaments which indicate faults. Therefore, there is good potential for undiscovered Beaverlodge Lake vein-type uranium deposits to be present in northeastern Alberta, both north and south of Lake Athabasca.

Other Types of Uranium Deposits

Other types of uranium deposits that may exist in northeast Alberta include: (a) pegmatite hosted uranium deposits, (b) unconformity-type or sediment hosted-type uranium deposits related to the Phanerozoic-Precambrian unconformity, and (c) granite related uranium deposits.

Langenberg *et al.* (1993) stated that the uranium occurrences they examined during 1992 in northeastern Alberta "*are overwhelmingly hosted in pegmatite and pegmatitic phases of granitoids or granite gneisses.*" They (Ibid) also noted that "*in many instances, uranium is reconcentrated along sheared zones and fractures.*" Geologically similar pegmatite hosted uranium deposits also exist at Charlebois Lake, which is northeast of Black Lake in Saskatchewan. At Charlebois Lake there are numerous occurrences of uraninite disseminated in lit-par-lit pegmatites that exist in migmatitic zones along the contact between metasedimentary rocks and granite/granite gneiss (Mawdsley 1957, 1958, 1970). The individual radioactive pegmatite bodies can reach a few tens of metres in width, by several hundreds of metres in length. Although the Charlebois uranium occurrences exist in migmatitic pegmatite, Thomas (1981) speculated that there was an original sedimentary control. In general, evaluation of these pegmatite hosted deposits is difficult due to the erratic nature of the uraninite, and none of the uraniferous occurrences at Charlebois Lake area are considered important (Beck 1969). Therefore, although radioactive and uraniferous pegmatites are common in northeastern Alberta, it is probable that they will not host an economically important uranium deposit.

With respect to the possibility for unconformity-type uranium or sediment hosted-type uranium deposits to be associated with the unconformity between Precambrian Shield rocks and overlying Phanerozoic strata, the available assessment data indicate that little exploration has been performed in northeastern Alberta to assess the potential for these types of uranium targets. In the Northwest Territories, there are a large number of uranium occurrences between Great Slave Lake and Great Bear Lake that are spatially associated with the Phanerozoic-Precambrian Shield unconformity, and exploration has been performed in that area for unconformity-related uranium deposits (Olson 1981). With respect to northeast Alberta, Olson (1984) concluded that "*unconformity-related vein-type uranium deposits may exist at or below both the Precambrian/Paleozoic unconformity and the Precambrian/ Cretaceous unconformity because (a) a regolith and zone of saprolitic alteration is reported to exist at least locally beneath each unconformity, (b) porous clastic rocks exist locally above the unconformity, (c) regional zones of uranium enrichment which may have acted as fertile source areas exist in the Precambrian basement at or near the unconformity, (d) numerous fault structures exist in the basement, some of which may also cut Paleozoic and, possibly, locally, Cretaceous rocks, and (e) favourable reductant lithologies exist locally in both the basement rocks and in the overlying Phanerozoic strata.*" However, he (Ibid) also noted that the evaluation for such uranium deposits rests solely on geological comparisons with other regions known to contain these types of deposits because only a few minor uranium occurrences are spatially related to the Precambrian-Phanerozoic unconformity in northeastern Alberta (Tables 2, 4 and 5; Maps 4 and 5).

The copper occurrences that exist on the Stony Islands along the Slave River are of interest with respect to the potential for uranium occurrences to be spatially related with the Precambrian-Phanerozoic unconformity. This is because of the common association of uranium with copper at many sediment hosted uranium deposits. At the Stony Islands, saprolitized Precambrian granitic and metasedimentary rocks are overlain by granite wash, rubbly bedded to thin bedded dolomite, and thin bedded interlayered dolomite, shale and flaggy limestone (Godfrey 1973, Godfrey and Langenberg 1987). Chalcopyrite, secondary copper carbonate minerals and marcasite are present in a 0.3 m thick rubbly dolomitic bed and in the overlying upper flaggy limestone unit. Copper minerals were also found locally in the granite wash. Godfrey and Langenberg (1987) stated that the copper minerals are disseminated in small quantities in at least three spatially separate occurrences over an area of about 300 m near the south end of the westernmost island at Stony Islands. A selected grab sample assays 1.08% Cu, but Godfrey and Langenberg (Ibid) noted that the copper content probably averages less than 0.3% over a selected bed thickness of 0.1 m. In 1984, Dr. R.A. Olson (*personal field notes*) visited this occurrence and reported that the radioactivity of the granitic basement was typically about 300 cps (SRAT SPP2N), and locally reached 500 to 750 cps along some minor fractures and shears. These radioactive results, although not outstanding, are nonetheless radiometrically anomalous and indicate that there may be potential for more important uraniferous zones to exist along or near the Precambrian-Phanerozoic unconformity in Alberta.

Granite-related Uranium Deposits

The potential for granite or granophile-related uranium deposits is discussed in a subsequent section entitled Granophile Mineral Deposits.

Gold Deposits

The assessment records indicate that little attention has been paid to the exploration for gold in the Precambrian rocks of northeastern Alberta. Godfrey (1986b), in his compilation of mineral showings in northeastern Alberta, does not show any gold occurrences, although he does show several arsenopyrite occurrences. Arsenopyrite occurrences are of interest because of the common association of this mineral, as well as some other sulphides, with gold. In total, there are at least eight arsenopyrite occurrences at five separate locales in northeastern Alberta north of Lake Athabasca: (a) three occurrences at and near Pythagoras Lake, (b) one occurrence at Hutton Lake along the Bonny Lake fault zone, (c) two occurrences near Waugh Lake, (d) one occurrence west of the south end of Potts Lake, and (e) one occurrence south of the south end of Charles Lake. South of Lake Athabasca, there are at least two reported gold occurrences: (f) at anomaly 74L-78 which is near the southern margin of Lake Athabasca east of Point Brule, and (g) at anomaly 74E-26 near Fort MacKay on the Athabasca River (Maps 4 and 5).

During 1992, Langenberg *et al.* (1993) examined the eight occurrences north of Lake Athabasca where arsenopyrite had been reported. At Pythagoras Lake, arsenopyrite, pyrite, pyrrhotite, smaltite and one other white arsenide occur in rusty zones in a north-northeasterly trending belt of metasedimentary rocks. Up to 25 volume per cent sulphides exist locally, and Godfrey (1958b) reported a grab sample which contains 0.39% Ni and 0.3 ounces silver per ton (oz Ag/T, or 10.3 g Ag/t). Langenberg *et al.* (1993) reported a grab sample from the sulphide occurrence west of Pythagoras Lake that assays 603 ppb Au (0.6 g Au/t), and two other samples that assay 116 and 131 ppb Au. The latter sample was collected from a sulphide occurrence near Lindgren Lake, which is a few hundred metres northerly of the gold-bearing sulphide occurrence near Pythagoras Lake. At the Hutton Lake occurrence, Godfrey (1961) reported arsenopyrite exists in a metasedimentary band near the north margin of the northwestern arm of Hutton Lake, but he provided no detailed description of this occurrence. During 1992, Langenberg *et al.* (1993) searched for this arsenopyrite occurrence, but were unable to locate it. At the Waugh Lake area, Godfrey (1986b) reported two arsenopyrite occurrences, one north of and one south of Waugh Lake, whereas map 61-2A in Godfrey (1963) shows only the arsenopyrite occurrence north of Waugh Lake. Godfrey (1958b) also shows two sites near the east side of Waugh Lake at which he reported "*small amounts of pyrrhotite(?), pyrite and arsenopyrite are found in quartzite*". The arsenopyrite occurrence north of Waugh Lake was examined by Langenberg *et al.* (1993) during 1992, who obtained a sample that assays 416 ppb Au (0.42 g Au/t) from a northerly trending zone of "*massive pyrite, pyrrhotite and arsenopyrite stringers a few millimetres thick*" which occurs in quartz biotite and quartz sericite schist. Prior workers also reported that a chip sample from a trench at this locale assays 0.1% Ni, 20.6 g Ag/t and 0.34 g Au/t [assessment reports UAF-003(1) and UAF-003(2)]. At Potts Lake, Godfrey (1966) reported that "*concentrations of massive arsenopyrite were present in a 3-foot* (0.9 m) *zone within a siliceous, chloritic metasedimentary band ... Minor blue and green* (copper?) *staining is evident. Assays show that gold, silver and nickel are absent.*" Langenberg *et al.* (1993) stated that up to 3 volume per cent combined arsenopyrite, pyrite and marcasite exist along a quartz-chlorite shear within a 0.5 m wide breccia zone at this occurrence. Their (Ibid) four 1992 rock samples from this occurrence only assay up to 81 ppb Au, but a sample on file at the AGS from Godfrey's (1966) work, assays 770 ppb Au (0.77 g Au/t), >10% As, 5,948 ppm W and 205 ppm Bi. Lastly, there is little information about the arsenopyrite occurrence which exists near the south margin of a small lake south of Charles Lake (map 65-6F in Godfrey 1966). Although Langenberg *et al.* (1993) visited this occurrence during 1992 (which they referred to as mineral occurrence 05) and collected three rock samples, they provided no details other than to list the commodities as Ni, Cr and Zn. Presumably their rock samples from this occurrence do not have an anomalous gold content.

South of Lake Athabasca at anomaly 74L-78, 2.7 g Au/t was reported in altered Precambrian basement rocks at a depth of 882.1 m in drill hole 78-LAJV-002. Anomalous concentrations of U, Ni, Co and Zn are associated with this anomalous gold-bearing zone, and the zone occurs about 4.4 m below the Athabasca Group-basement unconformity. At anomaly 74E-26 near Fort MacKay, Allan (1920) reported that a hole, known as Athabasca Oils Ltd. No. 1 well was drilled in 1911 to a depth of 1,130 feet (344.4 m) and terminated in Precambrian basement rocks. The hole intersected the basement unconformity at a depth of 336.8 m, and he (Ibid) reported a zone in the Precambrian granitic basement below the unconformity with overlying Paleozoic strata that assays 0.63 oz Au/T (21.6 g Au/t). The exact location of this hole is uncertain, but was approximately located at LSD 8-2-96-11 W4M. Halferdahl (1986) reviewed the available data and noted that Ells (1926) had stated this same hole intersected the basement-Phanerozoic unconformity at a depth of 291.7 m. He further added, that the driller's log for Athabasca Oils Ltd. No. 1 well reported they had intersected two auriferous quartz veins, which were about 0.9 m and 2.3 m thick and about 1.5 m apart, in limestone at a depth of about 276.5 m to 281.2 m. Halferdahl (1986), therefore, concluded that the gold-bearing zone must be in the Givetian Methy Formation about 15 m above the basement-Phanerozoic unconformity. In 1962, four holes were drilled by Scurry-Rainbow Oil Ltd. near the Athabasca No. 1 well to test for a gold-bearing zone (Ellstone 1963). Three of the holes penetrated into the basement, but apparently no samples were collected and only a few isolated grains of pyrite were discovered (Halferdahl 1986). Other records which are on file at the Alberta Geological Survey, indicate a hole was drilled during 1988 at LSD 11-02-096-11 W4M near the Athabasca No. 1 well. This hole was drilled to a depth of about 280 m, and "*slightly penetrated the Precambrian*", ending in "*Quartz, Lots of Pyrite, Core very slow*" (correspondence from Mr. F.D. Puckett, and anonymous drilling report). The laboratory assay reports indicate that a sample from drill cuttings assays 0.032 oz Au/T (1.1 g Au/t); however, the exact location of this sample in the core is unknown, hence it may be from either the Precambrian rocks or from the overlying Devonian strata. In summary, it is possible that anomalous concentrations of gold may exist in places in the Precambrian basement rocks in northeastern Alberta.

Shear Zone Related Lode Gold Deposits

Gold deposits occur extensively in Precambrian rocks, with the typical epigenetic lode gold deposits comprising auriferous veins and silicified zones related to major structures cutting volcanic rocks or their associated sediments (Boyle 1979). However, "*most of the productive gold deposits in the Canadian Shield are in Archean rocks with only minor deposits in Proterozoic rocks. With respect to the structural provinces of the Canadian Shield ... nearly all of the highly productive gold deposits occur in the Superior and Slave provinces; only a few, relatively small, rich or large low-grade deposits are known in the Churchill* (province). *... The gold deposits related to the Kenoran orogeny are developed mainly in shear zones and faults in the Archean volcanic and sedimentary rocks ..., but some important deposits (e.g. Kirkland Lake) occur in faults in associated intrusive granitic rocks and porphyries. ... The principal gangue is quartz with some carbonate, often ankerite. The main metallic minerals are pyrite, arsenopyrite and pyrrhotite, with minor amounts of galena, sphalerite, chalcopyrite, stibnite, molybdenite, scheelite and various sulphosalts. ... The characteristic elements accompanying gold vary from place to place, but a generalized association includes Cu, Ag, Zn, Cd, B, Pb, As, Sb, Se, Te, Cr, Mo and W. Not all of these are found in any one deposit. Barite is rare as a major gangue mineral. ... Platinum metals are not found except as traces, and then only sporadically. Bismuth is relatively rare in the ores, and uranium and thorium are lacking in more than traces. The rare earths, likewise, occur in the ores only as traces. ... Mercury is generally only a trace constituent of the gold, sulphide minerals and sulphosalts*" (Ibid). With respect to the Archean lode gold deposits, many or most deposits are spatially, and probably genetically, related to linear tectonic zones, regional faults or 'breaks' (Colvine *et al.* 1984, Bursnall 1989, Roberts 1988). "*It is now appreciated that the gold deposits are related to steeply dipping planar shear zones of brittle to ductile deformation, and that the regional faults are a manifestation of brittle deformation within these zones of anomalously high strain. ... The shear zones are regional structures, generally sub-parallel to the volcanic stratigraphy, up to several kilometres wide and may be well over 100 km long. They consist of zones of faulting and intense shearing that may be sub-parallel and relatively continuous or anastomosing with, enclosing islands of relatively unstrained rocks. ... The* (lode gold) *vein systems occur in the central parts of discrete shear zones within the larger regional shear zones where rotational or simple shear strain predominates, but individual veins may extend laterally beyond the sub-vertical shear zone, for a limited distance, into the enclosing less deformed rock where deformation is probably by pure shear strain. Veins may also occur in dilation zones associated with folding. ... Vein systems are tabular, sub-vertical structures. Typically, the thickness of a vein system is measured in metres, its strike and dip directions measured in tens or hundreds of metres. The economically viable part of the vein system may be considerably smaller. ... In some ore zones, veins are not developed. The gold occurs as pervasive disseminations and its location is controlled by the degree of strain in the rocks. ... The formation of veins is part of the deformation process. ... The continuity of vein formation throughout the history of the shear zones implies fluid circulation, or the availability of the fluid, over a long period of time*" (Roberts 1988). In general, the gold deposits are not uniformly distributed along the brittle-ductile shear zones, but instead rather cluster into 'camps'. Commonly these camps exist at dilational jogs formed during late trans-tension, or wrench faulting, along pre-existing faults, or are at the intersection of faults or fault zones of various trends. Further, in detail the gold-bearing zones tend to be associated with second-, third- or higher-order structures along the major first-order shear zone. Colvine *et al.* (1984) stated that "*ductile deformation zones do not necessarily manifest as lineaments and therefore must be defined by careful mapping. Lineaments are produced by brittle, often late, movement and are not necessarily coincident with the principal deformation zones. ... Alteration varies considerably in extent and expression primarily as a function of host* *lithology. Carbonatization is most prominent. Preceding and synchronous with gold deposition, it is best developed in more mafic lithologies where the reactivity of precursor mineral assemblages is high. Silicification, sulphidization and alkali metasomatism are more directly associated with gold deposition and for the most part do not form broad haloes.*" They (Ibid) noted, however, that the alteration directly associated with gold deposition rarely forms a broader halo than gold itself.

In northeast Alberta, there are several major northerly trending shear zones (Figure 1 in Langenberg 1983). From west to east these occur at or near Leland Lakes, Mercredi Lakes, Charles Lake and Bayonet Lake. Recently, McDonough *et al.* (1993) have recognized another shear zone at Andrew Lake, and stated that the Bayonet Lake shear zone is a splay of the Charles Lake shear zone. The shear zones in northeast Alberta cut both Archean and Proterozoic rocks, with Archean metamorphic and granitoid rocks predominating in the vicinity of the Charles Lake shear zone, whereas Proterozoic granitoids predominate to the west and to the east (Langenberg and Nielsen 1983, Godfrey 1986a). In several places, the shear zones transect metavolcanic and metasedimentary rocks, and there are numerous splays and subsidiary structures, including some brittle faults and several topographic lineaments that may reflect such faults (Godfrey 1958a). McDonough *et al.* (1993) stated that "*cataclasis of mylonites in the Charles Lake and Leland Lakes shear zones is accompanied by silicification. Rusty weathering quartz breccias and quartz stockwork related to silicification are locally important in Leland Lakes and Charles Lake shear zones. The occurrences studied to date are devoid of sulphides, however, large volumes of fluid infiltration are probable, suggesting that these zones could bear important sulphide occurrences along strike.*" These silicified zones are of potential interest for shear-hosted gold occurrences, but McDonough *et al.* (1993) do not report they sampled any of the zones for gold or other metals. It seems odd that the silicified occurrences are devoid of sulphides when they are rusty weathering; perhaps the sulphides have been weathered from surface outcrops. Because of the common association of silicification and gold-bearing zones, any quartz breccia, quartz stockwork or silicified zone should be sampled, especially if they are rusty weathering, or the adjacent country rocks are carbonatized, have disseminated sulphides, are chloritized, have undergone alkali metasomatism or are altered to the greenschist assemblage of actinolite-epidote-albite-quartz. However, even supposedly barren veins or silicified zones should be sampled because in some gold deposits, sulphides or alteration can be present only in minor amounts or be overprinted by later metamorphic or metasomatic events.

Occurrences of graphite are of potential exploration interest because gold is notably associated with elemental carbon at many shear-related lode gold deposits (Colvine *et al.* 1984). "*It is common ... to find native gold smeared along graphitic slips in many orebodies. Mention should also be made of the common occurrence of rich shoots of gold where veins and other deposits intersect graphitic beds.*" (Boyle 1979) There are several graphite occurrences in northeastern Alberta, including: (a) eight in the area between the west arm of Andrew Lake and Holmes Lake, (b) one south of Pythagoras Lake, (c) three a few kilometres west of One Week Lake, (d) three west of the south-central end of Leland Lakes, (e) three near the west margin of Loutit Lake, as well as one a few kilometres to the east, and (f) a few other more isolated occurrences (Godfrey 1986b; Map 4).

Intrusion-Associated and Other Types of Lode Gold Deposits

Eckstrand (1984) stated that intrusion-associated gold deposits accounted for about 35% of total Canadian gold production. In many cases the deposits are in or associated with intrusive rocks of alkalic to sub-alkaline composition, which commonly comprise quartz diorite to quartz monzonite stocks, plugs and dykes, but in places the gold lodes are associated with syenite, diorite or even gabbro. Interestingly, although this type of gold deposit occurs in or closely associated with intrusive rocks, "*many deposits are associated with major structural breaks*" (Ibid). That is, the deposit geometry is commonly controlled by individual faults or shear zones, en echelon vein systems or, in places, minor fracture zones. Associated minerals include quartz, carbonates, chlorite, sericite, pyrite, altaite, tourmaline and, less commonly, other sulphides or tellurides.

Maps 4 and 5 show quartz veins, sulphide occurrences, gossans, graphitic and breccia zones, and tourmaline-bearing quartz veins that have been compiled from the detailed maps published by the AGS for northeast Alberta. In general, most of the quartz veins are spatially related to the Wylie Lake granitoids. However, it is not certain whether the documented quartz vein distribution pattern is a reflection of geology or of variation in the emphasis towards quartz veins during geological mapping. Of particular interest with respect to gold is the numerous tourmaline-bearing quartz veins that exist in metasedimentary, metavolcanic and, locally, granitoid rocks near Waugh Lake, both in Alberta and in Saskatchewan (Godfrey 1963, Koster 1961). Tourmaline is a common accessory mineral in gold deposits in the Churchill Structural province and in many Archean-hosted deposits (Boyle 1979, Roberts 1988). During 1992 a few of the quartz-tourmaline veins at Waugh Lake were sampled by Langenberg et al. (1993) who obtained assays up to 157 ppb Au, 455 ppm Mo and 1,119 ppm W. Although the gold assays from the quartz-tourmaline veins are not highly anomalous, further work is required because there are a large number of unsampled veins, as well as numerous faults and a few sulphide and arsenopyrite occurrences, one of which assayed 0.42 g Au/t (Ibid). Another target area of possible interest is a zone of brecciation and brittle faults that is associated with the Charles Lake high-strain zone along the western margin of Charles Lake about 2 km east of Arch Lake (Map 65-6D in Godfrey 1966). Spatially associated with these brittle features are epidote and chlorite alteration, whereas to the west and east Godfrey's (Ibid) map indicates that garnet and hornblende are the common alteration minerals. If silicification or sulphides are associated with this brecciated zone at Charles Lake, then potential exists for lode gold deposits.

In short, there is a possibility that important shear-related or intrusion-related gold deposits exist in the Precambrian rocks in northeastern Alberta. The most favourable host rocks may be the belts of metasedimentary, metavolcanic and amphibolitic rocks because these frequently are important host rocks at many shear-hosted gold deposits. The reasons for this are probably twofold: (1) abrupt variations in rock types provide competency contrasts during deformation and facilitate the formation of dilation openings to permit both the passage of and deposition from gold-bearing fluids; and (2) these rock types commonly act as chemical reductants that affect the gold-bearing ore fluids such that sulphides, alteration minerals and gold are deposited. Although these more mafic rock types may be more favourable for gold, the existence of important shear-related gold deposits in the Archean and Proterozoic granitoid rocks or granitic gneiss is also possible. At Goldfields in the Beaverlodge District on the north shore of Lake Athabasca, for example, there are several gold-bearing quartz veins in silicified and pyritized 'granite' (Coombe 1984). Pyrite, sphalerite, galena, chalcopyrite, arsenopyrite, pyrrhotite, and minor amounts of albite, tourmaline and chlorite are associated with the vein quartz (Ibid). The most important gold-bearing zones occur at the Box and Athona deposits where "*probable reserves ... amount to some 3.5 million tons grading an average 0.07 oz gold per ton* [3.175 million tonnes grading 2.4 g Au/t]. *Some 10 to 15 million tons of lower grade, possible reserves are also reported at the Box* [deposit]" (Sibbald and Jiricka 1985). The gold-bearing zone of silicification and veining at the Box deposit trends northeasterly, but the individual quartz veins trend mainly northerly (Coombe 1984). At the Athona deposit the two gold-bearing zones trend northerly to north-northwesterly, but the individual quartz veins trend north-

northeasterly (Ibid). Other examples in Saskatchewan, south of the Athabasca Basin, exist in both the La Ronge and Glennie Domains where numerous gold showings and deposits have been discovered since the early 1980's (Ibid, Delaney 1992). In the La Ronge Domain the majority of these gold-bearing zones "*comprise quartz-filled, sulphide-bearing fractures within La Ronge Group volcanics and later intrusives. ... A few occurrences are also reported within the flanking greywackes. ... Gold in the Star-Windrum-Waddy Lakes area occurs mainly in late (?) discordant quartz-filled shears and fractures. Mineralization comprises ubiquitous pyrite, accompanied by variable native gold, pyrrhotite, chalcopyrite, galena, sphalerite and tourmaline. Molybdenite, stibnite, marcasite, hematite, magnetite and arsenopyrite may be present locally. Adjacent wall rocks are commonly altered to biotite, especially where the rocks are mafic volcanics, and are variably silicified. Mineralized shear zones are present within ... mafic volcanics, close to the margins of syn-tectonic granitoid plutons and locally within them*" (Coombe 1984). In the Glennie Domain, the gold-bearing zones (a) occur in a variety of lithologies, including plutonic rocks, volcanics and volcaniclastics, sedimentary rocks and migmatites, (b) the rocks have been subjected to upper greenschist to amphibolite facies metamorphism, (c) most gold showings are structurally controlled, (d) quartz vein systems and silicification are important, and (e) one or more of tourmaline, arsenopyrite or other sulphide minerals are common associations (Delaney 1992). Although the gold showings are spatially associated with major high strain zones, they typically occur in the secondary or higher order structures.

Many of the same features which are present in these Saskatchewan lode gold deposits, are present in places in northeastern Alberta. Explorationists should pay particular attention to the major shear zones or their subsidiary splays and faults. Prospecting should be focused along the axes and margins of drift covered lineaments rather than along the axes of resistant outcrops because important gold-bearing zones tend to occur where the rocks are more intensely deformed, sulphidized or altered, hence such zones tend to be recessive weathering. Exceptions to this will be those locales of intense silicification which will tend to be more competent and form zones of positive relief. Also of possible interest are the numerous quartz veins which Godfrey (1980a, 1987) geologically mapped within and adjacent to the Wylie Lake granitoid complex. A large number of these are concentrated along the 'Allan Fault system' which is the southern extension of the Charles Lake shear zone. The available assessment records indicate little, if any, exploration for gold has been performed in the Wylie Lake region. Godfrey (1980a) stated that the "*quartz veins are barren of all other mineralization, and are regarded as late fracture fillings associated with either joints or faults.*" However, his reports do not indicate that any sampling was done to test any of the quartz veins for their gold content. In some places, such as south of a large unnamed lake immediately west of Colin Lake (map sheet No. 8 in Godfrey 1980a), there are a series of relatively closed spaced quartz veins cutting metasedimentary rocks. Also present at this locale are three intersecting faults and a variety of rock types. A second locale with numerous quartz veins is near the north margin of Wylie Lake (map sheet No. 17 in Godfrey 1980a). In addition to the quartz veins at this locale, there are several intersecting faults, a possible fold closure and a variety of rock types, including several small belts of metasedimentary rocks. Both these quartz veined zones, as well as a few other selected zones of quartz veining, should be prospected and sampled for gold and related metals.

Base Metal Deposits

In the Precambrian rocks north of Lake Athabasca there are at least 46 sulphide occurrences and 16 gossans which probably reflect weathered sulphide minerals (Map 4). These totals exclude occurrences comprising a small amount of pyrite as disseminations or small patchy zones within the metasedimentary, metamorphic or intrusive rocks. The 46 sulphide occurrences include: (a) 21 occurrences with molybdenite, (b) 13 occurrences with chalcopyrite or copper carbonates, including

3 copper occurrences with associated molybdenite, 1 copper occurrence with associated galena, and 1 copper occurrence with associated arsenopyrite and nickel, (c) 11 occurrences with arsenopyrite, and (d) 3 occurrences with galena. The sulphide occurrences exist in a variety of rock types, although the majority tend to be hosted by metasedimentary or metavolcanic rocks. South of Lake Athabasca there are no sulphide occurrences, although two gossans are reported in mylonite in the southern part of the Marguerite River map area (Godfrey 1970). Most of the sulphide occurrences in northeast Alberta are of a minor nature, but in a few places the available records indicate that "*considerable sulphides*" are present (e.g., at anomalies 74M-6 near Waugh Lake, 74M-20 near Selwyn Lake and 74M-47 near Myers Lake). In general, the abundant sulphides are pyrite, pyrrhotite or both. Typically the sulphide minerals are associated with quartz veins or silicified zones.

Although the assays for base metals which have been reported in assessment records tend to be low, prior exploration has not been sufficient to rule out the possibility for an important base metal deposit to exist in northeast Alberta. Geologically, potential exists for volcanogenic massive sulphide base metal deposits and magmatic nickel-copper deposits with associated precious metals such as gold and the platinum group elements.

Volcanogenic Massive Sulphide Deposits

The characteristics of volcanogenic massive sulphide (VMS) deposits are now well known (Sangster 1972, 1980a,b, Franklin *et al.* 1981, Hutchinson *et al.* 1982, Wood and Wallace 1986, Eckstrand 1984, Lydon 1988a,b). Typically, VMS deposits range up to a few million tonnes and the main ore metals are Cu, Zn and lesser amounts of Pb, Ag and Au. Lydon (1988a) broadly classified VMS deposits into two main types based on their major ore metal content: Cu-Zn deposits and Zn-Pb-Cu deposits. There is much overlap between these two broad classes, but the Cu-Zn type tends to be more common in mafic volcanic rocks or their sedimentary derivatives or correlatives with lesser amounts of felsic volcanic rocks, whereas the Zn-Pb-Cu type tends to occur where the regional footwall succession is dominantly felsic volcanic rocks or mica/clay-bearing sedimentary rocks. VMS deposits are synvolcanic and broadly concordant within the stratigraphy that host them, and generally comprise a stratabound massive sulphide lens or lenses that is underlain by or sources from a discordant crosscutting feeder stockwork. Many deposits exist at a mafic to more felsic volcanic transition, and are interlayered with fine grained sediments and tuffs that reflect a period of volcanic extrusive quiescence, but active fumarolic activity. Associated rock types include one or more of rhyolite domes, phreatic explosion breccias, and volcanic derived sedimentary rocks, including sulphidic chert, iron and manganese oxide units, and carbonaceous argillites. VMS deposits are found in rocks of all ages, but in Canada they are most common in Archean (2.75 Ga), Proterozoic (1.9-1.7 Ga) and Cambro-Ordovician age rocks.

The sulphide lenses are typically massive, rubbly or brecciated, but they grade laterally into either layered sulphides, interlayered sulphide and sedimentary bands or 'layered' clastic massive sulphide. The predominant sulphide minerals comprise pyrite, pyrrhotite, chalcopyrite, sphalerite and galena. These minerals tend to be characteristically zoned outwards from the core of the stringer zone: chalcopyrite, pyrite and pyrrhotite are more common near the core, grading outwards to pyrite and sphalerite with some galena, to sphalerite, galena, pyrite and, in some cases, barite. The stratigraphic footwall and, particularly, the stockwork feeder zone are hydrothermally altered, and are characterized by varied amounts of Mg, Si, K, Ca and Na metasomatism. The stratigraphic hangingwall, in contrast, typically is unaltered to little altered in comparison to the footwall stratigraphy. Hydrothermal silicate alteration products comprise quartz and chlorite in the stringer zone core, surrounded by a halo of sericite. In places, Fe, Ca and Mg carbonates, smectite, talc, actinolite and some other Fe- or Mg-bearing minerals comprise part of the alteration assemblage. In general, Fe and Mg are enriched in the central stringer zones, whereas Ca, Na, Si and K are depleted. In highly metamorphosed deposits, however, alteration assemblages are represented by cordierite, anthophyllite, biotite, talc, kyanite, sericite, gamet, staurolite and gahnite. Characteristically, the individual VMS deposits tend to occur in clusters around volcanic or fumarolic centres. In a typical VMS camp, "*Sangster (1980b) calculated that the average area occupied by a typical cluster was about 850 square kilometres, equivalent to a circular area of about 32 km in diameter, and that it contained an average of 12 deposits and 94 million tonnes of ore.*" (Lydon 1988a). Important exploration guides to VMS ore deposits include: (1) synvolcanic fractures in submarine volcanic rocks which permitted fumarolic fluids to discharge at the seafloor-sediment interface; (2) mafic to felsic volcanic transitions, (3) phreatic felsic volcanic centres; (4) altered stringer zones with disseminated sulphides; (5) associated pyroclastic rocks in the immediate stratigraphic footwall; and (6) an overlying thin to, locally, thick sulphidic and siliceous exhalative horizon, black carbonaceous shale or baritic layer.

Although the characteristics of the 'typical' VMS deposit have been well summarized by various workers, in detail there is much variation between geographically or geologically separate VMS camps, and often between deposits within the same camp. Further, where the host rocks have been strongly deformed or metamorphosed or both, it is often difficult to clearly recognize those characteristics that are considered 'typical' for VMS deposits. At the Geco mine and related massive sulphide deposits in the Manitouwadge area of Ontario, for example, the deposits occur in highly deformed gneiss and schist that are at almandine--amphibolite facies metamorphic grade (Friesen *et al.* 1982, Bakker *et al.* 1985). Many of the deposits are associated with folds, hence they originally were believed to be epigenetic structurally-related replacement sulphide deposits, whereas subsequent work has shown them to have been deposited synvolcanically and genetically to be both pre-deformation and pre-metamorphism. Therefore, with respect to northeast Alberta, because most of the Precambrian rocks are both regionally deformed and highly metamorphosed, any pre-existing VMS deposits, if such exist, may now be difficult to recognize.

The most prospective rock units for discovery of VMS deposits in the Precambrian Shield of northeast Alberta are the Archean high grade metasedimentary and amphibolite rocks, and the Aphebian low-grade Waugh Lake Group. The high grade metasedimentary rocks comprise "*dark greenish gray quartzite interlayered with subordinate biotite-chlorite-sericite schist and has ferruginous, garnetiferous and graphitic zones, locally scattered pyrite, gossans and milky quartz pods. Cordierite, sillimanite and andalusite are present locally. Common variations are: (1) metamorphic quartzo-feldspathic phases; (2) retrograde phyllite and schist (biotite, chlorite, sericite, and uncommonly hornblende) and phyllonite;* [and] *(3) minor amphibolite*" (Godfrey 1986b). Amphibolite units are common locally in northeast Alberta, and two somewhat more extensive belts exist east of Cherry Lake and south of Peters Lake (Godfrey 1963, 1980a; Godfrey and Piekert 1963).

The Archean metasedimentary and amphibolite rocks in northeast Alberta are a southern continuation of a belt of metasedimentary and metavolcanic rocks that exists in the N.W.T. (Henderson 1939, Wilson 1941). In places in the N.W.T., this belt of rocks hosts concordant massive sulphide deposits that may be of VMS origin. For example, at Thubun Lakes, which is within NTS map areas 75E/5,12 about 190 km northerly of the Alberta-N.W.T. border, there is a belt of metasedimentary and metavolcanic rocks that contain a number of Cu-Zn-Pb showings. Some of these base metal showings, for example those within the old DIK or Bun claims, may be metamorphosed but concordant VMS deposits (Irwin and Prusti 1955, Baragar and Hornbrook 1963, Thorpe 1966, Reinhardt 1969). At the Bun occurrence, chalcopyrite, sphalerite, galena and bornite exist in a zone of calcareous metasedimentary gneiss and schist, and up to a few per cent Cu and Zn across a thickness of about 4.5 m are present in a zone that is exposed at surface for at least 60 m.

In northeast Alberta, an interesting massive sulphide occurrence exists in a belt of high grade metasedimentary rocks of probable Archean age that crops out a few hundred metres west of the north end of Selwyn Lake (anomaly 74M-20). A chip sample from this occurrence assays 0.12% Cu across 3.05 m and the sample was collected from a sulphide pod in biotite granite gneiss that contains pyrrhotite, pyrite and chalcopyrite [assessment report UAF-077(2)]. During 1992, Langenberg et al. (1993) visited this massive sulphide occurrence and stated "*the mineralized zone is located within one band of high grade metasedimentary rocks which consist of grey biotite quartzite, sericite sillimanite schist and chlorite rich silicified amphibolite. The enclosing country rock is pink to red biotite granite gneiss which grades into a banded mylonite near the shore.*" Locally, between 20 and 50% sulphides are present, and they "*occur in massive layers with a breccia-like texture and in anastomosing streaks within regular alternation of green and dark grey-green laminae of cherty looking chloritized quartzite. ... The laminae are arranged in 3 to 5 cm wide sequences. Sulfidic horizons are also found in whitish grey biotite quartzite interlayered with layers of quartz sericite schist and chlorite rich silicified amphibolite. ... They contain 15 to 40% sulfides* [pyrite, pyrrhotite and minor chalcopyrite] *which are well laminated, and have a breccia-like texture. The sulfide rich horizons have a true thickness of 3 m exposed at the site of the trench. ... Two types of alteration seem to affect the different horizons. The main alteration is the pervasive silicification of the high grade metasediments and metavolcanics. Secondary chloritic alteration is observed in green quartzite and amphibolite layers. ... The amount and distribution of sulfides appear related to the stratification.*" In short, this occurrence has several characteristics that are similar to those of VMS deposits, including: the sulphide mineralogy, laminated sulphides, a transition from mafic to more felsic host rocks, and the silica and chlorite alteration. It is also possible, however, that the deposit may be epigenetic shear-related rather than of VMS origin.

Further to the south, the belt of high grade metasedimentary rocks that extends from just north of Fletcher Lake, southwestward to Grouroches Chère which is southwest of Fort Chipewyan, is also a prospective target for VMS deposits. In this belt there are several gossans and at least five Cu occurrences (Map 4). Although there is little information available about these occurrences, Godfrey (1980b, 1984) summarily described them as minor occurrences of chalcopyrite in gossanous zones within the high grade metasedimentary rocks. As well, assessment report UAF-088(2) indicates that at anomaly 74L-M5, pyrite, graphite and chalcopyrite exist in a small band of high grade metasedimentary and amphibolitic rocks. Also present in this belt is the Fishing Creek Quartz Diorite which Godfrey (1980b) stated is "*found in association with the metasedimentary group of rocks. It is characteristically found in the principal zone of metasedimentary rocks peripheral to the Slave Granitoid pluton and in other metasedimentary rock patches within the granite gneiss belt bordering Lake Athabasca.*" This rock unit is of interest because its rather restrictive spatial association is inconsistent with the fact that the unit is generally considered to be of deep-seated intrusive origin. Lithologically, the modal composition of the Fishing Creek Quartz Diorite essentially comprises quartz, K-feldspar, plagioclase, biotite, and minor amounts of epidote, muscovite and accessory minerals (Godfrey 1980a,b, 1984). Therefore, the rock unit is of potential exploration interest because it may be a highly metamorphosed felsic hypabyssal intrusive or extrusive or both, rather than a more deep-seated intrusive plutonic rock. Sangster (1972) noted, for example, that "*during metamorphism the textures and structures of the host rocks* [for VMS deposits] *are often destroyed and their mineralogy radically altered making it difficult for the exploration geologist to recognize, and to trace, favourable host rocks.*" Therefore, it is possible that some of the 'high grade metasedimentary' and 'igneous' rocks in northeastern Alberta are the metamorphic equivalents of one or more of the VMS-related rock types listed in Table 8. Hence, just because the metasedimentary and associated rocks in northeastern Alberta are described as "*quartzite*", "*amphibolite*" or even as "*quartz diorite*" it does not necessarily mean they are unlikely to be prospective host rocks for VMS deposits. For example, it is possible that the Fishing Creek Quartz Diorite and the associated belt of high grade metamorphic rocks may represent, in whole or in part, a felsic volcanic assemblage within an intermixed package of clastic sedimentary and volcanic rocks with local more basaltic (i.e., amphibolitic) horizons.

TABLE 8

COMPARATIVE METAMORPHOSED ROCK TYPES IN VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS[1]

Primary or Low Grade Metamorphic Rock	Medium Grade Metamorphism	High Grade Metamorphism
Chert	Siliceous schist	Quartzite
Pyritic, cherty iron formation	Pyrite-pyrrhotite-magnetite mica schist	Pyrrhotite-magnetite mica quartzite
Rhyolite flows, tuff, breccia and agglomerate	Quartz-feldspar-sericite gneiss	Quartz-feldspar gneiss
Andesitic tuff and flows(chlorite-schist)	Biotite-chlorite-quartz schist and epidote-plagioclase amphibolite	Biotite-quartz gneiss and hornblende-plagioclase--amphibolite gneiss
Basalt	Epidote amphibolite	Amphibolite

[1]After Sangster (1972)

Another prospective target for VMS deposits in northeast Alberta is in the Aphebian Waugh Lake Group, which straddles the Alberta-Saskatchewan border east of Andrew Lake (Watanabe 1961, Koster 1961, Godfrey 1963). This group of rocks comprises greenstone and amphibolite derived from basalt, gabbro and possibly tuff, as well as quartzite with subordinate biotite-chlorite schist, phyllite and phyllonite, with local ferruginous, garnetiferous and graphitic horizons (Godfrey 1986a). There are, as well, some other interesting lithologies present, including "*siliceous conglomerate*", "*sericitic, porhyroblastic phyllonite*" with "*sheared, crush conglomerate*" and schists that locally are "*ferruginous, chloritic, and highly sheared with development of crush conglomerate*" (Watanabe 1961). The sericitic porphyroblastic phyllonite crops out in proximity to a large basic body that probably originally was mafic volcanics. It is possible that the basic to phyllonitic rocks represent a mafic to more felsic transition, or vice versa. Further, some or all of the siliceous and sheared conglomerate may be highly deformed volcaniclastic or fragmental rocks associated with volcanic venting processes. Watanabe (Ibid) reported that the deformed conglomerates contain clasts up to 0.25 m in diameter and the clasts comprise a variety of lithologies, including quartz, granite, argillite, schist and quartzite. The clasts exist in "*a sheared, sericitic matrix rich in felsic minerals*" (Ibid). Sangster (1972) noted that "*the close spatial association between acid agglomerates (or coarse pyroclastics) and massive sulphide ores* *is a characteristic feature of many established mining camps in the Precambrian*". He (Ibid) termed these commonly heterogeneous volcanic fragmentals "*mill rock*" because the coarsest of such rocks were invariably within hearing of a nearby mine mill. Godfrey (1963) and Watanabe (1961) favoured a clastic sedimentary to dynamic origin for the sheared conglomerate and sericitic porhyroblastic phyllonite in the Waugh Lake Group, but Koster (1961) was less certain of this and stated "*if the conglomerate is of sedimentary origin, special conditions must have existed to account for the large, and often angular character of the fragments.*" At present, no important base metal occurrences have been discovered in the Waugh Lake Group. Godfrey (1963), however, stated that "*small amounts of arsenopyrite, pyrrhotite, galena, molybdenite, and chalcopyrite have been noted*". As well, several minor occurrences of chalcopyrite and galena have been reported in the equivalent rock units in Saskatchewan east of Waugh Lake (Koster 1961, Coombe 1991). Also present in Saskatchewan, are a number of VMS deposits that exist in rocks that are age equivalent and, in some cases, lithologically similar to the Waugh Lake Group (Coombe 1991). These include important VMS deposits in the Aphebian Wollaston, La Ronge and Kisseynew Domains. Interestingly, the host rocks for the Saskatchewan VMS deposits include clastic sediments such as quartzites, feldspathic quartzites and arkoses in the Wollaston Domain, and various intermixed volcanic-sedimentary rocks in the La Ronge and Kisseynew Domains. In some cases, the VMS deposits "*exhibit some volcanogenic characteristics, but deformation and/or metamorphism have obscured diagnostic deposit-type classification*" (Ibid).

In summary, further exploration for VMS deposits is warranted in selected parts of northeastern Alberta. The belts of Archean high grade metasedimentary rocks that exist west of Andrew Lake and between Fletcher Lake and Fort Chipewyan, and the Aphebian Waugh Lake Group volcanic-sedimentary package are of particular interest. In each of these belts, the known gossans and sulphide occurrences should be examined to assess whether they are stratigraphically related to more important stratabound or stockwork VMS deposits. As well, consideration should be given to flying all or selected parts of each of these belts of rocks with detailed airborne geophysical surveys, particularly multi-coil, multi-frequency electromagnetics, to search for conductive, blind VMS deposits. Prospective targets identified by these surveys will need to be followed up by one or more of detailed prospecting, geological mapping, ground and drill hole geophysical surveys, and diamond drilling. As well, lithogeochemical surveys to identify VMS associated alteration can prove useful as a guide to ore (Wood and Wallace 1986, Lydon 1988a).

Magmatic Nickel-Copper Deposits With Associated Precious Metals

Magmatic Ni-Cu deposits with, in places, associated platinum group elements (PGE) or Au or both, are important base and precious producers at several places in Canada and elsewhere in the world (Naldrett 1981a,b; Eckstrand 1984; Macdonald 1988; Whitney and Naldrett 1989). In general, this deposit type can be broadly classified as (1) those hosted in large ultrabasic intrusive complexes, such as Sudbury, Ontario, Stillwater, Montana, and the Bushveld Complex in South Africa, (2) those hosted in tholeitic or komatiitic extrusive rocks, such as at Langmuir, Ontario and the Kambalda District, Australia, and (3) those associated with ultrabasic and ultramafic sills and dykes intruded into metasedimentary-metavolcanic packages, such as those at Thompson, Manitoba. There are no large ultrabasic intrusive complexes in northeast Alberta, hence the first type of magmatic Ni-Cu deposit is not considered further. There is, however, a possibility that the other two types of magmatic Ni-Cu deposits could exist because minor Ni, Cu or both occurrences are reported. For example, copper has been reported at 13 occurrences (Table 5, Map 4). Nickel is reported at anomaly 74M-6 near Waugh Lake and at anomaly 74M-7 at Lindgren Lake. At anomaly 74M-6, pyrite and pyrrhotite with minor amounts of chalcopyrite and arsenopyrite exist in a schist, and rock samples assay up to 0.01% Cu and 0.017% Ni [assessment report UAF-006(1)]. At anomaly 74M-7, arsenopyrite, pyrite, pyrrhotite, smaltite and another white arsenide exist in a gossanous zone in a band of feldspathic quartzite and biotite schist. Rock samples at 74M-7 assay up to 0.39% Ni and 10.3 g Ag/t (Godfrey 1958b).

Although the probability may be low that a magmatic Ni-Cu deposit is present in northeast Alberta, it cannot be ruled out because Ni-Cu occurrences with anomalous PGE and Au do exist in rocks of equivalent age and lithological composition to the north at Rutledge Lake, Stern Lake and Thekulthili Lake in the N.W.T. Rutledge Lake is about 170 km, Stern Lake is about 115 km and Thekulthili Lake is about 105 km northerly of the Alberta-N.W.T. border. At Rutledge Lake, numerous gossans exist in mafic and ultramafic pods in a belt of paragneiss, charnockitic gneiss, metabasite and granite gneiss (Culshaw 1984a,b; Burlet and Trigg 1987; Buhlmann 1989). Interestingly, the Rutledge Lake area had originally been regionally geologically mapped as only being underlain by granitiod rocks, and the belt of metasedimentary, metavolcanic and associated intrusive rocks had been missed (Henderson 1939). The sulphide occurrences at Rutledge Lake comprise one or more of pyrrhotite, chalcopyrite and pyrite with minor amounts of pentlandite, molybdenite and bornite. Sulphide content ranges from less than 1 up to about 55 volume per cent in places, and the sulphidic zones are up to 30.8 m wide in drill core, although surface exposures tend to be much narrower (Burlet and Trigg 1987). Rock samples contain locally up to 1.25% Cu, 0.53% Ni, 55.2 g Ag/t, 0.32 g Au/t, 1.25 g Pt/t, 0.23 g Pd/t, 0.66% Cr, 0.3% W, plus anomalous contents of Co, Mo and Zn (Ibid, Buhlmann 1989. Burlet and Trigg (1987) suggested that the Rutledge Lake nickel-copper occurrences are similar to the magmatic intrusive Cu-Ni deposits in the Thompson Nickel belt in Manitoba, whereas Buhlmann (1989) proposed that the Rutledge Lake occurrences are more similar to the distal sulphide facies of Outokumpu type exhalative volcanic centres which exist in eastern Finland. With respect to the Stern Lake showing, little information exists about this occurrence. Copper, nickel and cobalt are reported to occur in magmatic mafic rocks (Chamberlain and Johnston 1970). At Thekulthili Lake, again little information exists, but Gibbins (1986) suggested that ultramafic rocks at this locale might have potential for Cu-Ni-PGE deposits. There are also a number of Cu-Ni occurrences in northern Saskatchewan north of Lake Athabasca, including the Dinty Lake deposit northeast of Uranium City and several occurrences north of Fond du Lac (Coombe 1991). These are reported to be magmatogenic deposits related to Archean-Kenoran metallogeny (Ibid).

In summary, there exist in places in northeast Alberta, rock types and Cu-Ni mineral occurrences that are geologically similar to those present in adjacent parts of the N.W.T. and northern Saskatchewan. Therefore, there is a possibility that important magmatic Cu-Ni occurrences, with or without associated PGE's or Au, could be present in Alberta. The most prospective rocks will be the amphibolitic to ultramafic units that exist in the Archean high grade metasedimentary terranes or, possibly, in the Waugh Lake Group. At Rutledge Lake and elsewhere, many of the better sulphidic zones are poorly exposed and exist beneath lakes or overburden covered areas, hence such zones are difficult to discover. Detailed airborne geophysical surveys, especially a combination of magnetic and electromagnetic results, have been found to be an effective way to initially explore for such blind sulphidic zones. Selected airborne geophysical anomalies can then be followed up by detailed prospecting, ground geophysical surveys (magnetics and horizontal loop electromagnetic methods) and drill testing. Such an exploration methodology may prove effective for Cu-Ni sulphide deposits in northeast Alberta.

Other Types of Mineral Deposits

Other types of 'metallic' mineral deposits that may exist in northern Alberta include: (a) **granophile-related mineral deposits**, (b) **Olympic Dam type Cu-U-Au-Ag-REE deposits** and (c) **diamondiferous kimberlite or lamproite diatremes**. Although the probability of these types of deposits being present in northeast Alberta may be low, nonetheless, some potential does exist.

Granophile-related Mineral Deposits

The geology of various types of granophile-related mineral deposits has been summarized by Ishihara (1981), Taylor and Strong (1985), Strong (1988), and Whitney and Naldrett (1989). References pertinent to the Canadian situation for selected granophile elements include those for: (1) **tin** (Mulligan 1975), (2) **tungsten** (Little 1959, Mulligan 1984), (3) **niobium** and **tantalum** (Rowe 1958, Dawson 1974), (4) **lithium** (Mulligan 1965), (5) **beryllium** (1968), (6) **mica** (Hoadley 1960), and (7) **barium**, **strontium** and **fluorine** (Dawson 1985).

Typically, granophile mineral deposits are associated with various granitoid rocks that texturally range from aphanitic to granite-textured, and compositionally range from true granite to rocks of more intermediate composition, such as diorite. Strong (1988) grouped mineral deposits associated with granitoid rocks into two broad types: (1) "*porphyry type*", which are characterized by Cu and Mo in granitoid rocks of mainly intermediate composition that were emplaced at shallow depths of a few kilometres or less, and (2) "*granophile*" deposits, which are typically hosted by quartz-rich leucocratic granitoids enriched in such elements as Sn, W, U, Mo, Be, B, Li, P, Cl, Fl and CO_3^{2-}. Porphyry Cu-Mo deposits are rare in Precambrian terranes and are not considered further here. Granophile-related mineral deposits have several sub-types, such as: (a) **skarns**, which typically comprise one or more of Fe, W, Cu, Pb, Zn, Mo, Ag, Au, U, REE, F, B and Sn as replacement deposits found most commonly in carbonate rocks; (b) **greisens**, which typically comprise one or more of Be, B, Li and P with associated Na, Rb, Cs, REE and F in pneumatolitically altered intrusions or adjacent country rocks, (c) **rare-element pegmatites**, which typically comprise one or more of Li, Rb, Cs, Be, Ga, Sc, Y, REE, Sn, Nb, Ta, U, Th, Zr and Hf, and (d) anomalously **uraniferous granitoids** (Meinert 1993, Strong 1988, Černý 1993a,b, Maurice 1982).

Skarn Deposits

Skarn deposits occur in rocks ranging in age from Precambrian to Tertiary, but the majority are in rocks of Mesozoic or younger age (Einaudi *et al.* 1981). Skarns are most commonly found in limestone, but can also occur in other types of carbonates, in various other sedimentary rocks, in volcanic rocks and even in some igneous plutonic rocks. Typically, there is a strongly pronounced alteration assemblage associated with the ore-bearing zones, but the alteration assemblage is to a certain extent dependent on the host lithology. In general, the alteration assemblage includes various combinations of marbilization of the host limestone, and deposition of one or more of garnet, pyroxene (diopside and hedenbergite are common), olivine, pyroxenoids (wollastonite is common), various amphiboles (tremolite-actinolite and hornblende are common), epidote, anorthite, scapolite, axinite and a few other minerals (Meinert 1993). The major ore metals in skarns comprise Fe, Au, W, Cu, Zn-Pb, Mo and Sn, whereas more locally enriched elements include REE, Co, Ni, Ba, U, PGE, F, B, Cr and C. Most major skarn deposits are directly related to igneous activity, and broad correlations between igneous composition and skarn type have been made (Ibid). Ishihara (1981), for example, classified skarns as either a magnetite-bearing series or as a magnetite-free ilmenite series. He (Ibid) suggested (a) the *magnetite series skarns* are associated with chalcophile sulphides (Cu, Zn), Au, Ag, W in scheelite and to a lesser extent Mo, whereas (b) the *ilmenite series skarns* are associated with Sn in cassiterite, W in wolframite and other more lithophile elements (e.g., F, Li, Be, B, REE, etc.). Meinert (1993) noted that the iron skarns are more typically associated with low-Si, Fe-rich, relatively primitive plutons, whereas the Sn and Mo skarns are typically associated with high-silica, strongly differentiated plutons. Einaudi *et al.* (1981) stated that W and base metal (Cu, Zn-Pb and Mo) sulfide skarns are most characteristic of continental margin orogenic belts and are associated with subduction-related I-type granites. In contrast, Sn and ilmenite series skarns are more typically associated with anorogenic S-type intrusions that formed in stable cratons in which partial melting of crustal material occurred (Meinert 1993). In summary, skarn systems are characterized by disequilibrium and strong changes in chemical variables over very short distances. As a result, the magmatic fluids change dramatically in their chemistry and carrying capacity for a variety of elements (Whitney 1989).

In northeast Alberta, the majority of the metasedimentary rocks have been mapped as quartzite with subordinate biotite-chlorite-sericite schist (Godfrey 1986a). Limestone and limy rocks are rare to absent, hence the potential for important skarns associated with this type of lithology is low. The existence of skarn deposits cannot, however, be ruled out because skarns do occur in various other sedimentary, volcanic and some igneous lithologies, at least some of which are present in northeast Alberta. Prospective targets in northeast Alberta would be along the margins of intrusions in contact with belts of metasedimentary rocks. One area of possible interest for magnetite-series skarns may be a few kilometres northeast of Reef Lake (sheet no. 22 in Godfrey 1984). At this locale there are at least five magnetite occurrences and one Cu occurrence in either metasedimentary rocks or biotite granite gneiss. Also present in the vicinity are a few small stocks of Chipewyan red granite, which contain minor pegmatites and quartz veins. Godfrey (Ibid) stated that "*dispersed magnetite is locally present in small percentages within the granite gneisses, but is sufficiently abundant to cause problems with the normal use of a magnetic compass.*" The magnetite occurrences are coincident with a positive aeromagnetic anomaly that ranges up to about 63,000 nanoteslas (nT) which is a few hundred nanoteslas or more higher than most of the surrounding aeromagnetic anomalies (GSC 1964). The aeromagnetic anomaly trends northeasterly for a few kilometres, which indicates that the magnetite-bearing zone may be more extensive than shown by Godfrey (1984). These magnetite occurrences are anomalous in that the detailed mapping done by the AGS from the 1950's to the 1970's did not report other such magnetite-bearing locales in northeast Alberta (Map 4).

Greisen Deposits

Greisen deposits are of a variety of ages, although most tend to be Mesozoic or younger, and they can form in a variety of rock types. In greisens, alteration assemblages include varied combinations of white mica (which commonly is Li-rich), quartz, topaz, tourmaline and fluorite. Typically, mica, quartz and topaz occur in the contact zone of the intruding granitoid, whereas (a) quartz, plagioclase, phlogopite, biotite, talc, chlorite and amphiboles form in the adjacent mafic to ultramafic country rocks, (b) topaz, fluorite, mica, tourmaline and marmoritization of limy rocks occur in carbonate country rocks, and (c) quartz, mica, tourmaline, sericite, adularia, sulphides and hornfelsization occur in aluminosilicate country rocks (Strong 1988). As well, feldspathization, sericitization and kaolinitization of the country rocks can either precede, accompany or follow greisenization. In general, the "*granophile elements tend to concentrate towards the contact zones of related granitoids, and occur as disseminations or pegmatites in the pluton (endocontact) and as veins and stockworks developed upward or outward from it (exocontact). There is typically a zonation of elements, with Sn, W, As and U passing outward through (U, Ni, Co) to Cu to Pb-Zn-Ag to Fe and Sb sulphides. ... Such element zonation is known to occur on a very broad scale* *and can serve as a useful exploration guide in distinguishing between plutons of high and low mineralization potential*" (Ibid). Greisens can be associated with skarns, but the effects of greisenization often extend farther, both in the intrusion and in the surrounding country rocks. In summary, greisens tend to be associated with water-rich, silicic magmas and form at intermediate depths (about 5 to 12 km below surface), whereas at shallower depths hydrothermal fluids are lost into adjacent fractures and can form metalliferous quartz veins, and at deeper depths the fractionating intrusive fluids tend to form simple to complex pegmatites. A notable Canadian example of a greisen deposit is the East Kemptville, Nova Scotia tin deposit which is in the Carboniferous or younger Davis Lake intrusive complex (Richardson 1985). This deposit is currently the largest tin deposit in North America, containing about 58 million tonnes of 0.165% Sn with minor economic values in Cu and Zn, and was not discovered until the early 1980's.

In northeast Alberta, there are no reported important Sn or W occurrences, although there are at least 17 Mo occurrences, 9 Cu occurrences and 3 Cu-Mo occurrences, many of which are spatially associated with granitoid intrusions. During 1992, Langenberg *et al.* (1993) sampled a number of potential Au showings and several of their samples returned anomalous W results. For example, a rock sample from west of the south end of Potts Lake contains 0.62% W, and near the southwest end of Waugh Lake a rock sample contains 0.11% W (Ibid).

Maps in Mulligan (1975, 1984) show two acidic intrusions in northeast Alberta that may have potential for Sn or W or both. One prospective intrusion is adjacent to the west side of the Charles Lake Shear Zone west of Colin Lake, and the other is near the junction of the Slave and Peace Rivers north of Fort Chipewyan. However, because of the scale of the maps, the specific intrusions being referred to by Mulligan (Ibid) are uncertain, and do not obviously correspond to specific granitoid bodies which are shown on Godfrey's (1986a) compiled geology map. Perhaps the greatest potential for greisen deposits in northeast Alberta is associated with the Colin Lake Granitoids which are in the Andrew Lake-Cherry Lake-Waugh Lake area (Godfrey 1961, 1963; Godfrey and Piekert 1963, 1964). The Colin Lake Granitoids comprise a diverse assemblage of various 'granitic' phases. "*Lithologies in this group range from granite to quartz diorite and are gradational in character. Feldspar megacrysts (ranging from 3 to 10 to 15 to 40 mm long) are in a biotite-rich, well-foliated matrix. ... Subordinate aplo-pegmatite patches and dykes are characteristic.*" (Godfrey 1986a). Goff *et al.* (1986) stated that both the Colin Lake and Wylie Lake Granitoids are heterogeneous, peraluminous hornblende-biotite granodiorites to quartz monzonites, which in some phases have higher contents of Nb, Zr and Y. As well, the leucocratic pods which are present appear to have formed by the fractional crystallization of highly differentiated melts. At and south of Andrew Lake, Godfrey (1961, 1963) geologically mapped a plutonic phase of the Colin Lake Granitoids that contains abundant muscovite, coarse red or white feldspars, and feldspar- and muscovite-pegmatite. Spatially associated with this pluton are numerous radioactive occurrences, several Mo occurrences, as well as a few base metal and arsenopyrite occurrences and, near Waugh Lake, a large number of tourmaline-bearing quartz veins (Map 4). Feldspar, muscovite, tourmaline, Mo, Cu and As are minerals and elements that commonly are associated with greisenization processes. The muscovite is of particular interest because it is stable only at depths greater than about 3 km, which indicates the Colin Lake plutons were emplaced at depths where greisens tend to occur.

Other potential target areas in northeast Alberta for greisen deposits include: (1) a small body of Colin Lake Granitoids that is east of Cornwall Lake and south of Potts Lake, (2) a locale with numerous uranium occurrences near Colin Lake that is underlain by both Colin Lake and Wylie Lake Granitoids, and (3) associated with the Wylie Lake Granitoids south of Colin Lake. The Wylie Lake Granitoids are dominated by granodiorite and quartz diorite which locally has megacrystic feldspars (5 to 10 mm long). Spatially associated with the Wylie Lake Granitoid igneous body are several uranium occurrences, a few sulphide occurrences and numerous quartz veins (Map 4). In places, the Slave Granitoids may also be prospective for greisen-type mineral occurrences because it locally contains Mo, U and base metal occurrences, and aplo-pegmatite dykes and quartz veins.

Other than the reconnaissance sampling by Langenberg *et al.* (1993), there is no evidence that the Colin Lake, Wylie Lake or Slave Granitoids and adjacent country rocks have been systematically explored for Sn, W or other greisen-related metalliferous deposits. Further exploration is warranted for greisens, particularly in the Andrew-Cherry Lake-Waugh Lake area. This future exploration should include systematic sampling for selected elements such as Sn, W and other pathfinder elements where the main ore minerals (cassiterite, stannite, scheelite, wolframite) are often difficult to recognize in hand specimen, especially if they are fine grained. As well, the study of mineral occurrence and alteration zoning patterns, use of an ultraviolet lamp for identification of scheelite and other such fluorescent minerals, and radiometric surveys for associated U-bearing minerals, will assist in the exploration for greisen-related mineral deposits.

Rare Element Pegmatites and Other Rare Earth Occurrences

Rare element pegmatites commonly contain a suite of exotic elements, including Li, Rb, Cs, Be, Ga, Sc, Y, REE, Sn, Nb, Ta, U, Th, Zr and Hf. As well, some industrial minerals can also be economically important. These include: ceramic and dental feldspar, optical quartz and fluorite, petalite and refractory spodumene, sheet and crushed micas, and ceramic amblygonite (Černý 1993a). The high concentrations of rare metals and high purity of most of the industrial minerals, combined with their coarse grain size, are the main factors favouring exploitable rare-element pegmatites. Although many of these elements are referred to as 'exotic', they nonetheless have several important uses for current and future industrial and high technology applications. Lithium, for example, is used in the production of primary aluminum, ceramics, glass and lubricants, and in future is expected to be in demand for lithium batteries and aluminum-lithium alloys (Ferrell 1985). Cesium is used in medical and chemical applications, and in future will have expanded usage in electronic applications (Jensen 1985). Beryllium and gallium have important applications in the electronics industry (Petkof 1985a,b). Beryllium metal also has important applications in the aerospace and defence industries because of its high strength, light weight and high thermal conductivity (Petkof 1985a). Yttrium and the rare earth elements have a wide variety of uses in catalysts, metallurgical processes, phosphors, optics and electronics, and in future may play an important role in semi-conductors (Hedrick 1985). Lastly, Sn, Nb, Ta, Zr and Hf are important in many industrial applications (Carlin 1985, Cunningham 1985, Adams 1985, Pell and Hora 1990). Rare earths and the potential for rare earth deposits in Canada has recently been summarized by Sinclair *et al.* (1992).

In Canada there are a number of important rare-element pegmatites, with the most well known probably being the Tanco pegmatite (Ta, Li, Cs, Be, Rb) in southeastern Manitoba (Thomas and Spooner 1985). Other notable Canadian examples include the Bancroft area (U_3O_8) in Ontario, the Thor deposit (Be, Y, REE, Nb-Ta, Zr, Ga, Li) at Thor Lake, N.W.T. and the Preissac-Lacorne property (Li) in Quebec (Robertson 1978, Griffith, 1986, Trueman *et al.* 1985, Mulligan 1965, Černý 1993a,b). All of these examples are in Precambrian rocks that range from Archean to Proterozoic in age. With respect to their geology, "*the forms of rare-element granitic pegmatites are greatly variable, and are controlled mainly by the competency of the enclosing rocks, the depth of emplacement, and tectonic and metamorphic regime at the time of emplacement. ... The shapes ... are controlled by the ductility of their host rocks. They range from lenticular, ellipsoidal, turnip-*

or mushroom-shaped forms in plastic-behaving lithologies to fracture-filling dykes and stocks in brittle host rocks. ... Most of the economically interesting bodies average hundreds of metres in length and a few tens of metres across. ... Rare-element pegmatites commonly exhibit heterogeneous, complex internal structure. In the broad spectrum of structural patterns, three principal types can be distinguished, typical components of which can be recognized even in the most complicated cases: homogenous, zoned and layered structures. ... (a) *Homogeneous course-grained pegmatites with more or less uniform distribution of most components are exceptional. ... The only variety which consistently exhibits a quasi-homogeneous structure is the albite-spodumene type.* (b) *Zoned pegmatites are the most common ones, and the most diversified. They consist of up to nine units with variable textural characteristics and mineral modes. ... We may distinguish: (1) zones of primary crystallization, more or less concentric shells, ... (2) replacement bodies formed at the expense of pre-existing units under lithologic or structural control; and (3) fracture fillings in dilated dislocations. ...* [Lastly,] (c) *Layered pegmatites may be considered extreme cases of the geometric and compositional assymetry of zoned intrusions*" (Černý 1993a). In summary, rare-element pegmatites are magmatic phenomena formed as a result of fractionation of a volatile-rich magma, which is enriched to varying degrees in lithophile rare elements, followed by deposition at relatively high temperatures and pressures in brittle to ductile-brittle openings in the vicinity of the invading pluton (Černý 1993a,b). They tend to form at depths ranging from 10 to 20 km, and are associated with 'fertile' granitoid intrusions that are heterogeneous, leucocratic, silicic, peraluminous, poor in Fe, Mg and Ca, and with the K_2O/Na_2O ratio varying among the different intrusive facies (Černý and Meintzer 1985, Strong 1988). Worldwide, rare-element pegmatites have formed in most tectono-magmatic cycles of geological history, except the oldest (>3,000 Ma). These productive orogenies include the Kenoran and Churchill orogens of the Canadian Shield (Černý 1993b).

In northeast Alberta, there are a large number of quartz-feldspar pegmatites, many of which are radioactive from U- or Th-bearing minerals, or they contain molybdenite (Langenberg *et al.* 1993). There are, however, no reported occurrences of Be, Nb/Ta or Li pegmatites in the Precambrian Shield of northeast Alberta, northwest Saskatchewan or the adjacent part of the Northwest Territories (Mulligan 1965, 1968; Dawson 1974). Rowe (1958) did report that Nb/Ta minerals (euxenite-polycrase? and pyrochlore-microlite?) exist in a chloritic shear zone in coarse-grained granite near Hazelton Lake, Saskatchewan which is a few kilometres east of Waugh Lake in northeast Alberta. In general, the target areas and granitoid rocks that may be favourable for rare-element pegmatites in northeast Alberta are the same as those which are favourable for greisen deposits. These include the Colin Lake and Wylie Lake Granitoids. Of particular interest is a REE occurrence discovered during 1992 by Langenberg *et al.* (1993) near the west shore at the south end of Potts Lake. A rock grab sample from this occurrence contains 1.06% total REE and 0.27% Th, with individual rare earth elements assaying up to 0.22% La, 0.56% Ce, 0.25% Nd and 0.02% Sm (Ibid). The sample was collected from a leucocratic pink pegmatite interlayered in biotite gneiss. Langenberg *et al.* (1993) also sampled several other anomalously radioactive pegmatites near Charles, Potts and Andrew Lakes and reported that "*several of these mineral occurrences have been found anomalous in both Th and La from ICP* (induction coupled plasma spectrometry) *analysis*". Rock grab samples from these occurrences assay up to 0.045% Th and 0.075% La.

Also of potential interest for rare earth elements in northeast Alberta is a belt of allanite occurrences and quartz veins which exist east and southeast of Cornwall Lake (Map 4; Godfrey 1980a, Godfrey and Langenberg 1987). Allanite is a member of the epidote group of sorosilicates in which one or more of Ce, other REE, Be and Th replace Ca in amounts up to a few weight per cent. Allanite occurs as an accessory mineral in many granitoid rocks, and in larger amounts in some limestone skarns and pegmatites (Deer *et al.* 1966). Godfrey and Langenberg (1987) said little about the allanite occurrences near Cornwall Lake except "*an unusual amount of allanite was noted in both Biotite and Hornblende Granite Gneisses in this part of the Granite Gneiss belt.*" Worldwide, the main source of REE is from monazite beach sands, but a REE-bearing bastnaesite, allanite and thorgummite deposit does exist at Morro do Ferro in Brazil (Hedrick 1985). Therefore, further exploration is required to determine if the allanite occurrences in northeast Alberta contain anomalous concentrations of REE. Because allanite typically contains some Th, radiometric prospecting can be used to explore for allanite occurrences.

Uraniferous Granitoid Rocks

Anomalously uraniferous granitoid rocks are not common worldwide, but a small proportion of granitic and syenitic rocks do contain above normal radioelement concentrations in a few places (Darnley 1982). In western Canada, a linear negative gravity anomaly which extends about 1,600 km from Edmonton, Alberta to Baker Lake, N.W.T., is coincident with a zone of high uranium in Precambrian rocks. This anomalous uraniferous zone exists mostly in granitoid rocks that exist both in the exposed Shield northeast of the Athabasca Basin and at depth in the Precambrian basement which underlies the Prairie region (Ibid). In general, uraniferous granitoid rocks are not important producers of uranium, but important resources do exist at the Rössing deposit in South West Africa, the Illimaussaq intrusion in southern Greenland, at Johan Beetz in Quebec and at the Gunnar deposit in northern Saskatchewan (Ruzicka 1975, Bohse *et al.* 1974, Hauseux 1977, Beck 1969). Although such uraniferous granitoids do not tend to be economically important, Ruzicka (1982) noted that a major portion of the known global uranium resources occur in deposits that are spatially related to such anomalously uraniferous granitic rocks. At the Rössing deposit, which is a large uranium resource of about 136,000 t U_3O_8 in ore grading 0.035% U_3O_8 per tonne, the host rock is mainly a pegmatitic alaskite with xenoliths of metasediments in which there are a large number of narrow uraniferous zones (Rich *et al.* 1977). At the Illimaussaq intrusion, which comprises peralkaline rocks with up to 0.15% U_3O_8 and, in places, associated anomalous Th, the U is concentrated in refractory minerals that presently make recoveries uneconomic. At Johan Beetz, uraninite and phosphuranylite occur in plagioclase-rich granite characterized by brick-red feldspar, smoky quartz, magnetite and a coarse to pegmatitic grain size. At the now-closed Gunnar mine, a pipe-like ore body comprised of stockworks and breccia zones exists in carbonatized syenitic rocks near the intersection of two major faults. "*The syenite appears to have been derived from granitic gneiss through albitization, carbonatization, and desilicification alteration processes, with carbonate replacing quartz*" (Rich *et al.* 1977). Pitchblende and minor amounts of uranophane are finely disseminated or form small stringers in the syenite at Gunnar. Associated minerals include chlorite, hematite, calcite, dolomite, quartz, pyrite, chalcopyrite and galena. Total production from Gunnar was about 5 million tonnes grading 0.175% U_3O_8 per tonne (Beck 1969).

In northeast Alberta, regional airborne radiometric surveys by the GSC show a belt of uranium equivalent (eU ppm) anomalies that trend from the Taltson Lake map-area (NTS 75E) in the N.W.T., south into Alberta (Darnley *et al.* 1975; GSC 1977a,b). Charbonneau (1982) referred to this anomalously radioactive belt as the "*Fort Smith*" belt and stated "*it is a north-trending belt, approximately 50 km wide and 200 km long intruded diapirically by an early Hudsonian megacrystic granitic to quartz monzonitic batholith. These rocks are generally pink, coarsely porphyritic and foliated, and consist of microcline or microcline-perthite phenocrysts, calcic oligoclase, quartz, biotite and accessary garnet, muscovite, ilmenite, anatase, rutile, hematite, fluorite, pyrite, and radioactive minerals.*" The main radioactive mineral is thoriferous monazite, with minor amounts of zircon and uraninite. However, he (Ibid) also stated that uranium "*is concentrated in the less thoriferous evolved* *portions of the granite. In the Fort Smith belt, some uranium was expelled outwards to the edge of the intrusion and into the wall rocks creating a flanking uranium/thorium anomaly. This marginal anomaly may relate to the escape of volatiles (plus uranium) with pressure related to upward movement of the diapir (Bostock 1981). Uraninite associated with fluorite has been located along the margins of the intrusion and discrete radioactive sources, tentatively identified as uraninite, have been found in the older charnockitic wall rocks (Charbonneau 1980).*" These features indicate that potential for a granophile uranium deposit exists in northeast Alberta.

Both Godfrey and Plouffe (1978) and Sprenke *et al.* (1986) used the GSC's (1977a,b) airborne radiometric eU and eU/eTh data to identify large radiometric anomalies in the Precambrian Shield area of northeast Alberta. Godfrey and Plouffe (Ibid) identified 11 anomalous areas: three large areas south of Lake Athabasca and eight areas north of the lake. Sprenke *et al.* (Ibid) identified "*six domains of potential, economic uranium mineralization*" in the Alberta Shield north of Lake Athabasca. He refers to these as the Tulip Lake, Cherry-Spider Lakes, Colin Lake, Cockscomb Lake, Ryan Lake South and North, and the Fidler Point domains. "*The Ryan Lake Domain is the largest uraniferous domain of the Alberta Shield. This domain, roughly centered on Ryan Lake, is composed mainly of Slave Granitoids, with minor amounts of Arch Lake Granitoids and metasedimentary rock bands. The domain can be subdivided into northern and southern parts, which are distinguished on the basis of eU values*" (Ibid). Map 4, however, shows that the two areas with the greatest number of minor uranium or radioactive occurrences are: (a) near the contact zone between the Wylie Lake and Colin Lake Granitoids, and (b) south of Andrew Lake within the Cherry-Spider Lakes Uraniferous Domain. In both these locales, uraniferous granite pegmatites are common.

In summary, it is possible that some of the anomalously radioactive granitoid rocks that exist in northeast Alberta may contain uranium concentrations of exploration interest. However, the probability is low that an economically important uraniferous granitoid deposit will be found. It is more probable that the large areas of anomalously uraniferous granitoids may have acted as a 'fertile source' for uranium, or may be associated with some other type of granophile deposit (e.g., Sn, W).

Olympic Dam type Cu-U-Au-Ag-REE Deposits

The Olympic Dam Cu-U-Au-Ag-REE deposit at Roxby Downs, South Australia contains over 2,000 million tonnes of hematite breccias grading 1.6% Cu, 0.06% U_3O_8, 0.6 g Au/t and 3.5 g Ag/t (Oreskes and Einaudi 1990). In addition to these metals, the breccias are enriched in F and Ba, and also contain about 0.5% REE. The "*hematite breccias, the host rocks to Cu-U-Au-Ag ore at the Olympic Dam deposit, occur as steeply dipping, northwest-striking, dike-like bodies within fractured granite. The breccia complex has a strike length of over 5 km and extends to depths greater than 1 km. Both the deposit as a whole and the individual breccia bodies are zoned from weakly brecciated, sericitized and hematitized granite on the margins, through heterolithic breccias to hematite-quartz microbreccia at the center. ... Relict magnetite is rare and most iron oxide was deposited as hematite*" (Ibid). The localizing structure for the deposit is a graben that has associated strike-slip and dip-slip faults which strike both parallel to, and at a high angle to, the long axis of the graben. The predominant alteration comprises hematite, sericite and chlorite, which are widespread in the deposit, but silica and carbonate alteration do occur locally. The most common ore and waste minerals at the Olympic Dam deposit include the Cu and Fe sulphides: bornite, chalcopyrite, chalcocite, digenite and pyrite; the U minerals: uraninite, coffinite and brannerite; free Au; the rare earth minerals: bastnaesite, florencite, monazite, xenotime and britholite; and the gangue minerals: hematite, quartz, sericite, tourmaline, chlorite, fluorite, barite, siderite and dolomite. The rare earth minerals are enriched in both light and heavy REE (mainly La and Ce, plus some Nd, Sm, Eu, Gd, Tb, Dy, Yb and Lu). The sulphide minerals are zoned both on the scale of the deposit and on the scale of individual breccia bodies. "*The central hematitic core of the deposit largely is barren of sulfides, containing only minor amounts of chalcocite-bornite. Sulfides are zoned outwards from this barren core through the chalcocite-bornite and bornite-chalcopyrite to distal chalcopyrite-pyrite assemblages; boundaries between zones are generally steep and parallel to the trend of the breccia bodies. Many individual breccia bodies reflect this zonation from barren or poorly mineralized hematitic cores, through bornite-rich assemblages, to high sulfide assemblages on the margins. ... The distribution of copper grade generally follows both the lithological and sulfide zonal pattern. ... Copper grades are low in weakly brecciated granite and tend to display a positive correlation with the degree of fragmentation and hematitization of the granite*" (Ibid). In general, Cu, U, Fe, La, Ce and F are concentrated in matrix-rich polymict breccia units; Cu and U are low where siderite is more abundant; in places, U and L can occur in relatively high concentrations without associated Cu, but the reverse is rarely true; Co is elevated where pyrite is more common; Ba tends to be low where Cu, U, La and Ce are high; Ag is erratic, but tends to be higher where bornite is more abundant; and Pb and Zn are low in the copper mineralized area (Roberts and Hudson 1983).

Originally, the Olympic Dam deposit was believed to have formed by low temperature syngenetic or diagenetic processes (Roberts and Hudson 1983). Recent work, however, indicates the Olympic Dam breccias are of hydrothermal origin, and were formed by a combination of explosive brecciation, and hydrothermal alteration and replacement (Oreskes and Einaudi 1990). The Olympic Dam deposit occurs in Middle Proterozoic (about 1,590 Ma) granitic rocks, but the exact age of the mineralizing event is poorly constrained. The deposit is believed to have formed about 200 million years younger than the host granite.

Although the probability may be low for the discovery of an Olympic Dam type Cu-U-Au-Ag-REE deposit in northeast Alberta, there is at least one locale which has several features that are similar to those which exist at Olympic Dam. This locale is along the Bonny Fault, which has been discussed previously as having potential for gold and uranium deposits. Godfrey (1958b) stated "*on the west shore of Andrew Lake this fault is a brecciated zone, 500 feet* (about 150 m) *in width, filled with quartz and hematite. The breccia is bounded by parallel shears. In general, these features characterize the fault over at least 7 miles* (11.3 km) *northwest from Andrew Lake. ... Radioactivity has been noted at intervals along the fault zone. ... Significant radioactivity was found in the marginal shears and locally in the hematized (sic) breccia.*" Common alteration minerals within the breccia and along the marginal shears of the Bonny Fault include hematite, silicification, feldspathization and chloritization (Godfrey 1963, Langenberg *et al.* 1993). Between Andrew Lake and Hutton Lake, there are several converging fault splays, extensive breccias, several U or radioactive occurrences, and an arsenopyrite occurrence (Map 4). To the southeast there are a few Cu sulphide occurrences as well as numerous other radioactive occurrences that are spatially related to either the main Bonny Fault or to splays off this fault. As well, pyrite, pyrrhotite and arsenopyrite occur in a few places along or near the Bonny Fault zone. Interestingly, during 1992 Langenberg *et al.* (1993) collected a sample from a "*red cataclasite*" that exists along the Bonny Fault near the west shore of Andrew Lake. This sample assays 751 ppm La. In summary, the Bonny Fault zone should be systematically prospected for Olympic Dam type Cu-U-Au-Ag-REE deposits. Most or all prior exploration was focused on finding a vein-type U deposit of the Beaverlodge type, hence other metals such as Au and the REE may have been overlooked.

Diamondiferous Kimberlite or Lamproite Diatremes

As a result of the successful discovery of diamondiferous diatremes in the N.W.T., and the belief that such deposits also might exist in Alberta, several claims were staked in the Precambrian of northeast Alberta during late 1992 and in 1993. This indicates that at least some explorationists believe there is potential for diamondiferous diatremes in northeast Alberta. Langenberg *et al.* (1993) stated that "*ultrabasic intrusions have (not yet) been mapped in the* (northeastern Alberta) *area, but some of the circular magnetic anomalies might be underlain by such bodies.*"

The potential for diamondiferous diatremes in Alberta is discussed in somewhat greater detail under the "Foothills and Mountains" and "Plains" sections of this report. As well, during 1993 to March 31, 1994, the AGS, in conjunction with R.A. Olson Consulting Ltd. and Dr. D.R. Schmitt of the University of Alberta, are conducting a regional synthesis of the structural and stratigraphic setting of Alberta, and compiling other pertinent data, to assist industry in their search for diamondiferous deposits in Alberta (Dufresne et al. In preparation). This report will provide a more comprehensive treatment of the potential for diamondiferous diatremes in Alberta, including the Precambrian Shield of northeast Alberta.

RESOURCE POTENTIAL OF THE PRECAMBRIAN AND PHANEROZOIC STRATA IN THE FOOTHILLS AND ROCKY MOUNTAINS OF ALBERTA

Prior Work and Known Mineral Resources

The first geological map of the southern Canadian Rocky Mountains was published by Dawson (1886). Other pioneer work was done by McConnell (1887) and Daly (1912). The discovery of gas in 1924, followed by crude oil in 1936, at Turner Valley (Hume 1938) was the impetus for large mapping programs in the Foothills and Front Ranges of Alberta in order to assist in the search for additional hydrocarbon accumulations. Excellent summaries of the state of the geological knowledge at that time are given by Clark (1954), North and Henderson (1954), Hume (1957), Fox (1959) and Shaw (1963). Much of the Canadian Rockies was mapped during a second period of increased mapping activity during the 1950's and 1960's. The geologists from the GSC that were most notably involved during this period are Price, Mountjoy and Ollerenshaw. Their work is well summarized by Bally *et al.* (1966), Dahlstrom (1970), Douglas *et al.* (1970) and Price (1981). Much of the work during this period was focused on unravelling the complex Precambrian and Paleozoic stratigraphy, and the structural history of these rocks, but the geological mapping was not focused toward searching for features indicative of metallic mineral occurrences or processes. The Alberta Rocky Mountains and Foothills are encompassed by about 81 NTS map areas at a scale of 1:50,000 and 11 map areas at a scale of 1:250,000. At present, only about 47 of the 1:50,000 scale NTS map areas are described by published geology maps at a scale of 1:63,360 or larger, and most of the geological mapping for these published map sheets was completed prior to 1970.

Exploration by private industry in the Rocky Mountains and Foothills of Alberta has occurred periodically from the late nineteenth century to the present. In the late 1800's, mineral exploration and mining occurred in the Banff - Field corridor as a result of the greater access provided by the railway that was pushed through from Calgary to British Columbia. In the late 1950's and through the 1960's, base metals were explored for in the area from Canmore to Waterton Lakes National Park. Metallic mineral exploration in southwest Alberta peaked in the late 1960's to early 1970's, when extensive exploration for copper and other metals was conducted in the Clark Range. Based on the available assessment records, there has been minimal exploration for metallic minerals in the Rocky Mountains of Alberta since the Government of Alberta implemented the Eastern Slopes Policy in 1977. In the late 1980's, a reported gold discovery in the Crowsnest Pass area fuelled a staking rush and kindled renewed interest in exploration for the rumoured 'Lost Lemon Gold Mine' in southwest Alberta (Stewart 1989).

The Monarch Pb-Zn-Ag deposit was discovered in 1884 on Mount Stephen near Field, British Columbia (Hedley 1954). Production commenced from the Monarch deposit in 1888. Ore was mined periodically between 1888 and 1952 from the Monarch deposit and from the nearby Kicking Horse deposit, which was discovered in 1917. East of Field, on the Alberta side of the border, Dawson (1886) reported the discovery of Cu in limestones at Castle Mountain (also known as Mount Eisenhower and Protection Mountain; anomaly 82O-1), and Cu, Pb and Ag in the Copper Mountain area (anomalies 82O-2, -3 and -4) at about the same time that the Monarch deposit was discovered (Map 6). Little information exists about the mineral prospects within the former Baker Creek claims on the northwest flank of Castle Mountain (anomaly 82N-3) or about the Eldon Cu-Pb-Zn deposit on the east flank of Panorama Ridge west of Castle Mountain (anomaly 82N-4). Evans (1965) suggested that these prospects were explored and partially developed during the 1890's and early 1900's. This is confirmed in National Mineral Inventory (NMI) sheet 115097, which briefly summarizes development work on the Eldon property. Most of the base metal deposits, prospects and occurrences in this region are reported to be hosted in limestone or argillaceous limestone of the Middle Cambrian Cathedral Formation. Little scientific work has been done on the metallic mineral occurrences within the Alberta portion of the Banff-Field corridor because they now are encompassed within Banff National Park.

During the early 1900's, small-scale mining was performed on two Cu-bearing diorite dykes at Coppermine Creek (Map 1, anomaly 82H-4) in the Clark Range of southwest Alberta, within what is now Waterton Lakes National Park (Goble 1970; Morton *et al.* 1974; Goble 1976). However, there are no records that indicate much regional exploration accompanied this mining activity. During the early 1960's, the Goble family rediscovered Cu-Zn mineralized zones in the Middle Proterozoic rocks of the Clark Range (Map 6). Considerable staking and exploration followed, with important concentrations of stratabound Cu and Ag being discovered at the Spionkop (anomaly 82G-7), Yarrow (anomaly 82H-1), Grizzly (anomaly 82G-10) and Whistler (anomaly 82G-9) prospects (Bradshaw 1967, 1968; Duncan 1970; Halferdahl 1971; Van Dyck 1971; Gyr 1971; Goble 1971, 1972; Goble 1973a; Allan 1973; Collins and Smith 1977), and stratabound Pb-Zn-Ag and Cu-Ag mineral occurrences being discovered in the North Kootenay Pass area (Carter 1971; Goble 1973a, 1973b, and 1975). In total, over 70 Cu-Ag and Pb-Zn-Ag showings have been found in the Clark Range (Map 6).

The Oldman (formerly called Bearspaw) Pb-Zn-Ag prospect was discovered on the east flank of Mount Gass (Map 6, anomaly 82J-42) near the headwaters of the Oldman River by hunters in 1912 (Hedley 1954; Holter 1973, 1977). West Canadian Collieries acquired the prospect and performed exploration during the early 1950's. Holter (1973, 1977) stated that galena and sphalerite are associated with intersecting faults in dolomitic limestone of the Upper Devonian Palliser Formation. However, Salat (1988) provided evidence that the Oldman prospect is spatially related to a dolomitization front and is hosted in a paleokarst system that developed at the top of the Palliser Formation. He (Ibid) also suggested that the deposit has potential for about 2.0 to 2.5 million tons with an average grade of 6% Zn, 1 oz Ag/T (34.3 g Ag/t), 1% Pb and 1 pound per ton Cd (lb/T). Assessment data indicate that other poorly documented base metal occurrences exist in the vicinity of the Oldman prospect. These include a Pb occurrence (anomaly 82J-1) on the northeast slope of Beehive Mountain and a Cu occurrence (anomaly 82J-2) at Mount Livingstone (Gillis 1970). Assay certificates that accompany the assessment report by Gillis (1970) indicate that the Cu occurrence is hosted in the uppermost Devonian Big Valley Formation. The Big Valley Formation is predominantly limestone and is time equivalent to the Costigan Member of the Upper Palliser Formation. A joint lithogeochemical project between the GSC and Esso Minerals Canada resulted in the systematic sampling of the Palliser Formation and the overlying shale of the Lower Exshaw Formation (Geldsetzer *et al.* 1987). Four stratigraphic sections were sampled between Jasper and the Smoky River southwest of Grand Cache. Samples from two of the sections yielded anomalous concentrations of metals in the Palliser Formation with up to 1,160 ppm Zn, 74 ppm Cu, 44 ppm Pb, 53 ppm As and 293 ppm Cr_2O_3 (Map 2, anomalies 83E-4 and -5). The Exshaw Formation was not sampled in any of the four sections. Fifteen sections were sampled between Canmore and the Clark Range. Samples from seven of the sections yielded anomalous concentrations of metals in the Palliser Formation carbonates, with up to 540 ppm Zn, 44 ppm Cu, 200 ppm Ni, 2,000 ppm V, 47 ppm As and 3.6 ppm Ag (anomalies 82G-121, -122, 82J-54, -55, 82O-35 and -36). Samples from twelve sections yielded anomalous concentrations of metals in the Lower Exshaw Formation shale, with up to 775 ppm Zn, 68 ppm Cu, 155 ppm Ni, 4,000 ppm V, 23 ppm As, 33 ppm Sb, 1,240 Ba, 230 ppm Cr_2O_3 and 4.0 ppm Ag (anomalies 82G-119, -120, -121, -122, -123, 82J-54, -55, -56, -57, -58, 82O-35 and -36).

The geology of the magnetite deposits (Map 6; anomalies 82G-83, -84 and -89) that are hosted in Upper Cretaceous rocks near Burmis in the Crowsnest Pass region was first described by Leach (1912). Allan (1931) published a more detailed account of the stratigraphy and structure of the magnetite deposits north of Burmis, and he also prepared a brief unpublished report in 1941 on the Dungarvan magnetite deposit (Map 1, anomaly 82H-6), which is in Upper Cretaceous rocks south of Pincher Creek. During the 1950's, extensive exploration, including trenching, drilling and metallurgical testing, were performed on the Burmis and Dungarvan magnetite deposits. The intent of this work was to determine the potential of the magnetite deposits as feed for a possible iron ore smelter. This work is well-summarized in Bruce (1957), Steiner (1958) and Mellon (1961). During the 1970's and 1980's the magnetite deposits were re-evaluated for the potential use of magnetite in coal beneficiation processes. This work is summarized by Rushton (1972) and Grant and Trigg (1983). In 1993, the Dungarvan magnetite deposit was reported to be under consideration for a production decision (Hamilton, *pers. comm.* 1993).

Many other metallic mineral occurrences have been reported in the Alberta Rocky Mountains and Foothills, but most are either poorly-documented or unsubstantiated. These include base metal occurrences, such as galena associated with vein quartz in the vicinity of Jasper (Map 6, anomalies 83D-4 and -6; Dawson 1901) and sphalerite in the Lower Banff Shale on a spur of Limestone Mountain (Map 6, anomaly 82O-18; Moore 1953). The Limestone Mountain occurrence is about 7.5 km southwest of the Clearwater River and is the northernmost documented base metal occurrence in that portion of the Alberta Rocky Mountains that is outside of the National Parks. Other base metal occurrences that are within Banff National Park include chalcopyrite within the Crowfoot dyke (82N-5; Smith 1963), azurite near the headwaters of Wigmore Creek (anomaly 82O-21; La Casse and Roebuck 1978), sphalerite at the headwaters of Cascade Creek (anomaly 82O-31; Dawson 1899 and NMI sheet 115023) and downstream in the vicinity of the Cascade River (anomaly 82O-32; Dawson 1899 and NMI sheet 115054), sphalerite on the east slope of Storm Mountain (anomaly 82O-28; Dawson 1901 and NMI sheet 115041), bornite at the headwaters of the Panther River (anomaly 82O-30; Dawson 1901 and NMI sheet 115042), and chalcopyrite and chalcocite from the headwaters between Johnston and Cascade Creeks (anomaly 82O-29; Dawson 1901). A few base metal occurrences also exist south of Banff National Park. These include a galena occurrence in the vicinity of Spray River (anomaly 82O-6) about 5 km southwest of Highway 1 between Canmore and Exshaw (Holter 1973, 1977). Geldsetzer *et al.* (1987) described an occurrence of galena in the Palliser Formation that is either the Spray River occurrence or is in the vicinity of the Spray River occurrence reported by Holter (1973, 1977). Geldsetzer *et al.* (1987) gave conflicting evidence as to the exact location of the occurrence. As well, Trigg (1982) described a specimen of galena, sphalerite and anglesite that was brought to him by a client who reportedly collected it from a base metal occurrence at the south end of Mist Mountain (anomaly 82J-47), which is about 18 km southeast of Upper Kananaskis Lake. However, subsequent follow-up field work was unable to locate this occurrence, although a few stream sediment samples that were collected in the vicinity of the occurrence are anomalous in Zn and Ag (Johnston and Olson 1982).

There are several poorly-documented gold occurrences in the Alberta Rocky Mountains and Foothills. Perhaps the most famous and most elusive is the Lost Lemon Gold Mine, which was reportedly discovered in 1870 by two prospectors, Frank Lemon and his partner Blackjack, at the headwaters of a small stream between the Highwood River and Crowsnest Pass (Stewart 1989). Intermittent exploration for the Lost Lemon Gold Mine on the Alberta side of the Rocky Mountains has been ongoing since that time, but little documented information exists on this exploration. A company named Lost Lemon Mines Ltd. performed exploration in the vicinity of Plateau Mountain at the southern boundary of Kananaskis Country in the late 1970's and early 1980's. They drilled a hole in the valley of Dry Creek during 1981 (Map 6, anomaly 82J-45). The drill cuttings were later examined by an employee of Halferdahl & Associates Ltd. The cuttings he examined consisted of limestone, with black shale at the bottom of the hole (Halferdahl, *pers. comm.* 1993). Assay certificates provided to Dr. Halferdahl by his client reported up to 0.013 oz Au/T (0.45 g Au/t) and up to 0.3 oz Ag/T (10.3 g Ag/t) from separate rock samples. The samples are reported to have been from the drill hole, but the interval that contained the anomalous samples was missing from the cuttings provided to Halferdahl & Associates Ltd. Therefore, Dr. Halferdahl could not confirm that the anomalous samples were from the drill hole, from surface in the vicinity of the drill site, or from a completely different source. Elsewhere in southwest Alberta, low amounts of gold have been reported in the Crowsnest volcanics just west of Coleman along Highway 3, where rock grab samples assay up to 0.21 g Au/t, with extracted pyrite concentrates assaying as high as 2.54 g Au/t (Map 6, anomaly 82G-80; Stewart 1989). This announcement precipitated a staking rush and resulted in renewed exploration for gold in southwest Alberta. Assessment data from this exploration are not yet publicly available.

One of the better documented gold occurrences in the Rocky Mountains and Foothills is in the High Divide Ridge area about 15 km southeast of Hinton (Map 2, anomalies 83F-1 and -2; Fox 1991). Reconnaissance stream sediment and rock sampling during 1988 are reported to have returned nine samples with anomalous concentrations of gold. Follow-up geochemical surveys during 1989 and 1990 resulted in concentrations of up to 1,510 ppb Au in stream sediment samples and up to 78 ppb gold in soil samples being reported (Fox 1991). Within Banff National Park, La Casse and Roebuck (1978) reported that gold was mined from a bedrock source until the 1930's at the "Pot Hole" (anomaly 82N-7) which is about 4.8 km northwest of Lake Louise at the south end of Herbert Lake (Map 6). Dawson (1901) reported the presence of gold in amounts up to $8.00 per ton (0.4 oz Au/T or 13.71 g Au/t at $20/oz Au in 1901) in quartz veins in the valley of the Miette River west of Jasper (Map 2, anomaly 83D-5). Dawson (1901) also reported the presence of placer gold in the Miette River. In southwest Alberta, Grant (1981) reported assays up to 1,150 ppb Au in rock samples that were collected from Blairmore Formation sandstone in the Foothills south of the Red Deer River (Map 6, anomaly 82O-26). However, follow-up sampling during 1992 failed to duplicate this result (Grant 1982). Goble (1973a) stated that gold was discovered during the period from 1901 to 1903 in the Clark Range of southwest Alberta, and that a gold occurrence is hosted within Lower Purcell Group quartzites which crop out on the northwest slope of Buchanan Ridge, south of Oil City (Map 1, anomaly 82H-5). However, this occurrence has never been substantiated and is now within Waterton Lakes National Park. Goble (1974b) reported assays of up to 0.04 oz Au/T (1.37 g Au/t) were obtained from dioritic to syenitic intrusions that cut the Siyeh and Sheppard Formations in the Clark Range northwest of Waterton Lakes National Park (Map 6, anomalies 82G-65 to -68). Lastly, a possible gold occurrence was discovered a few kilometres northeast of Blairmore at Transmission-line Structure Site 456 (Map 6, anomaly 82G-82). A non-geological employee of a construction company collected a rock grab sample from a calcareous siltstone at Site 456 that assayed up to 0.76 g Au/t (Olson 1985b). Follow-up rock sampling in the vicinity of Site 456 by a geologist did not duplicate this gold result, but the original site that had been initially sampled by the construction company employee was backfilled and could not be resampled.

Exploration for silver in southwest Alberta has mainly been focused on existing base metal occurrences in the Rocky Mountains and Foothills. Three Ag occurrences of note (Map 6) include:

(a) an assay of 0.729 oz Ag/T (25.0 g Ag/t) from a pyrite-rich limestone that is about 80 km west of Calgary on the Ghost River (anomaly 82O-5; Hoffman 1885), (b) anomalous Ag and P from samples of the Fernie Formation at the headwaters of Westrup Creek near Mount Livingstone (anomaly 82J-44; Hamilton 1978), and (c) up to 0.95 oz Ag/T (32.57 g Ag/t) and 0.021 oz Au/T (0.72 g Au/t) in samples from a series of Late Cretaceous or Early Tertiary syenitic to dioritic intrusions at the headwaters of Jutland Creek near the Alberta and British Columbia border in the Clark Range (anomaly 82G-67; Goble 1974b). The location and description which was given for the sample from the Ghost River occurrence, indicate that the sample may have been collected from Middle Cambrian Cathedral Formation limestone just above a thrust fault that separates it from Cretaceous Brazeau Formation.

Regional geochemical sampling information is sparse for the entire Alberta Rocky Mountains and Foothills. No government-conducted regional geochemical stream sediment or water database exists for the Alberta Rocky Mountains and Foothills, and no documented heavy mineral sampling has been performed by private industry or by government geological surveys. Geochemical stream sediment and rock sampling surveys have been locally performed, including: (a) a recently conducted stream sediment and rock sampling survey in southwest Alberta completed by R.A. Olson Consulting Ltd. (Williamson *et al.* 1993) on behalf of the Canada-Alberta Partnership Agreement on Mineral Development (MDA), (b) a stream sediment survey in the area between Canmore and Vicary Creek completed by Geophoto Services Ltd. for Imperial Oil (O'Donnell and Fuenning 1967), (c) stream sediment and water samples which were collected in the Clark Range southwest of Pincher Creek by various exploration companies during the 1960's and early 1970's (Bradshaw 1967, 1968; Gyr 1971; Halferdahl 1971; Van Dyck 1971; Allan 1973), and (d) systematically mapping and rock sampling in vertical stratigraphic sections of the Devonian Palliser Formation by Esso Minerals and the GSC in the northern and southern portions of the Alberta Rockies (Geldsetzer *et al.* 1987). In general, the conclusions by private industry from the geochemical stream sediment and water surveys which were performed during the 1960's and early 1970's, are that significant geochemical anomalies for follow-up exploration are not present, even in those streams that drain known mineral occurrences. However, a review of the existing publicly available geochemical data which exist in the vicinity of known Cu occurrences in the Clark Range and in the vicinity of the Oldman River Pb-Zn-Ag prospect at Mount Gass, indicates that subtle stream sediment geochemical anomalies are present, but the anomalies tend to be areally restricted in those streams that drain the known occurrences. The existence of anomalous metal contents in some stream sediments has been confirmed by recent stream drainage sampling in southwest Alberta by R.A. Olson Consulting Ltd. (Williamson *et al.* 1993). The lack of a widespread geochemical signature in stream sediments downstream from known mineral occurrences may be explained by one or both of: (a) the high topographic elevations may result in a low subsurface residence time for groundwater, and (b) carbonate buffering of the groundwater by limy country rock. Such buffering would reduce the oxidation of sulphides and hence decrease the resultant release of metals into the groundwater that could then be subsequently captured by the clay and fine fractions of stream sediments.

Other reported geochemical anomalies in the Rocky Mountains and Foothills of Alberta include Cu and Cr in deposits of 'Bog Iron' in the Ghost River area (Map 6, anomalies 82O-11 and -14; Renn 1956), and Fe and P anomalies in the Zephyr Creek area (Map 6, anomaly 82J-49; Norman 1957, Kidd 1958). At the Ghost River area, Renn (1956) stated that Cr is present in a "*yellow section of ore*", and that brown silicate rock was found. The existence of anomalous amounts of Cr and the reference to brown silicate rock may be an indication that mafic intrusions or diatremes exist in the Ghost River area, and hence this area may warrant exploration for diamonds. Such mafic intrusive diatremes have been reported in a few places in the Rocky Mountains and Foothills. For example, Pell (1987a,b) described mafic intrusive diatremes in the Mark diatreme cluster, which is centred on the Alberta-British Columbia border near the Freshfield Icefield, northwest of Banff (Maps 1 and 6). A map presented by Fipke (1990, (Part II) indicates that several diatremes in the Mark diatreme cluster exist on the Alberta side of the border (Map 6, anomaly 82N-

1). Northcote (1983a,b) and Fipke (1990, Part I) reported that a microdiamond was found in the largest diatreme on the Mark claims on the British Columbia side of the border. As well, Takla Star Resources Ltd. (1993a) has reported finding two chromite anomalies in heavy mineral concentrates from creek drainages in the Ram River area near Nordegg, Alberta (Map 2, anomalies 83B-1 and 83C-4). They suggested that the chemistry of the chromites might be indicative of diamondiferous lamproites.

Geological Overview

The regional geology of the Rocky Mountains and Foothills of Alberta is described in (Gabrielse and Yorath 1992; Stott and Aitken 1993; Mossop and Shetsen, *In press*). In summary, the Rocky Mountains and Foothills of Alberta are dominantly comprised of miogeosynclinal sedimentary and volcanic rocks that range in age from Middle Proterozoic to Tertiary. The rocks are largely unmetamorphosed to slightly metamorphosed. The Proterozoic-Phanerozoic sedimentary sequence in southwest Alberta is thought to be underlain by crystalline basement rocks of Archean to early Proterozoic age. In general, the sedimentary sequence comprises:

(a) **Cretaceous and Tertiary**: conglomerate, sandstone, siltstone, shale and coal of marine to continental origin. These rocks include two major clastic wedges derived from uplift in the west. The two clastic wedges are an Upper Jurassic to Lower Cretaceous Kootenay-Blairmore cycle, and an Upper Cretaceous to Oligocene Belly River-Paskapoo cycle.

(b) **Triassic and Jurassic**: generally an incomplete section of continental to marine conglomerate, sandstone, shale, carbonate, evaporite and coal.

(c) **Paleozoic**: mostly carbonate with some shale. Major unconformities below the base of the Cambrian, Middle Devonian and near the top of the Pennsylvanian.

(d) **Middle to Upper Proterozoic**: up to 13,700 m of quartzite, siltstone, argillite and minor amounts of carbonate that thicken to the west.

Intrusive or volcanic extrusive rocks or both, exist in the Proterozoic rocks in the Clark Range and are locally interbedded with Upper Lower Cretaceous sedimentary strata.

Discussion of Resource Potential

Important economically-viable metallic mineral deposits have not, as yet, been discovered in the Rocky Mountains and Foothills of Alberta, although there was minor production early in this century from a few small base metal deposits in southwest Alberta (Goble 1970; Hamilton and Olson, *In press*). In southeastern British Columbia and the adjacent parts of the United States of America., the deposition of some of the important stratiform and vein-type base metal and precious metal deposits, such as those at Sullivan, British Columbia, Spar lake, Montana and Coeur d'Alene, Idaho, may have been genetically linked to periodic activation of the Southern Alberta Rift or to possibly related structures, such as the Lewis and Clark fault system (Kanasewich 1968; Kanasewich *et al.* 1969; McMechan 1981). In Alberta, there a large number of minor base metal and precious metal mineral occurrences in the Rocky Mountains and Foothills (Maps 1, 2 and 6). Although the majority of these exist in southwestern Alberta, within NTS map areas 82G, J, N and O, this may be more a reflection of greater availability of ground for exploration outside National and Provincial Parks and other restricted areas, and of ease of prior access, rather than being due to the greater geological favourability of the southwestern Alberta region. Many of the base and precious metal occurrences in southwest Alberta are hosted in rock types and rock units that are geologically similar or stratigraphically equivalent to those which host economically important metalliferous deposits in British Columbia and the United States of America. Hence, there is reason to believe an economically important metalliferous deposit could be present in the Rocky Mountains and Foothills of Alberta because: (a) there are many diverse types of metallic mineral occurrences, (b) there is a diversity of geologically favourable host rocks with suitable structural complexities and, in places, (c) there are zones of alteration which may be related to mineralizing processes.

Based on the geologic and tectonic setting, and on comparisons with other metallogenic provinces, the potential ore deposit types that may exist in the Rocky Mountains and Foothills of Alberta include: **base metal deposits**, such as (1) carbonate-hosted Mississippi Valley Type (MVT) lead-zinc deposits, (2) stratiform sediment-hosted lead-zinc deposits, (3) stratiform sediment-hosted Kupferschiefer type copper deposits, (4) stratabound sediment-hosted Kipushi type copper deposits, and (5) stratiform shale hosted nickel-zinc deposits; **precious metal deposits**, such as (6) epithermal gold deposits and (7) mesothermal gold deposits; and a few **other types of deposits**, such as (8) magnetite and other heavy mineral placer or paleoplacer deposits, with or without associated precious metals, (9) diamondiferous kimberlite or lamproite deposits, and (10) sediment-hosted U deposits. Following is a discussion of the characteristics of each of these types of deposits, and suggestions for possible exploration targets in the Rocky Mountains and Foothills of Alberta.

Base Metal Deposits

The various types of base metal deposits that may exist in the Rocky Mountains and Foothills of Alberta can be broadly categorized into those that are epigenetic, with mineralization having occurred following deposition of the host rocks, and those that are stratiform and of possible syngenetic origin. Most of the deposit types described above are of epigenetic origin, with the possible exception of the stratiform sediment-hosted Pb-Zn and Ni-Zn deposits, the placer and paleoplacer deposits, and possibly the Kupferschiefer type Cu deposits.

Carbonate-Hosted Mississippi Valley Type Lead-Zinc Deposits

Worldwide, Mississippi Valley Type (MVT) Pb-Zn deposits occur in carbonate rocks of several diverse ages that range from Proterozoic to at least the Mesozoic, although most of the economically important deposits are hosted by Paleozoic strata. In north America, carbonates of either Cambrian-Ordovician or Carboniferous age host the majority of the important MVT deposits (Anderson and Macqueen 1988). However, in the Western Canada Sedimentary Basin the most important MVT lead-zinc deposits are in Devonian strata at Pine Point, N.W.T. and at Robb Lake, British Columbia, and in Middle Cambrian Cathedral Formation in southeastern British Columbia and its stratigraphic equivalents in Washington State.

Much of the Alberta Rocky Mountains and parts of the Foothills are underlain by carbonates of Late Proterozoic to Triassic age. These carbonates contain many geological features that are considered favourable for the presence of MVT Pb-Zn deposits, including dolomitization or silicification fronts; porosity and permeability associated with karstification, faulting or fracturing; the presence of reefal masses; regional transitions from platformal carbonates to basinal shales; several unconformities and disconformities in the stratigraphic sequence, and structural complexities such as folds and faults. These features are considered to be important regional characteristics associated with the formation of MVT deposits (Anderson and Macqueen 1988). Certain structural elements in the Alberta Rocky Mountains and Foothills may also be favourable for the development of MVT Pb-Zn deposits, including the West Alberta Arch, the Southern Alberta Rift and some, possibly long-lived, transverse faults. The existence of a few Pb-Zn prospects and many small Pb, Zn or Pb-Zn occurrences in the Alberta Rocky Mountains (Evans 1965), indicates that potential exists for important MVT deposits in several carbonate-bearing horizons, including those of Middle Proterozoic, Middle Cambrian, Upper Devonian, Carboniferous-Permian and Triassic age.

Within the area of the Southern Alberta Rift, a thick and laterally extensive succession of carbonates occurs in the Sheppard and Kintla Formations in the Clark Range. Sporadic occurrences of MVT type Pb-Zn are reported to exist in dolomite in these two formations near Carbondale River (Map 6, anomalies 82G-11, -46, -50 and -51; Carter 1971; Goble 1973a,b, 1975; Williamson *et al.* 1993).

In the Banff to Field corridor, which straddles the Alberta-British Columbia border, there are three deposits and many occurrences of Pb-Zn-Ag in Middle Cambrian Cathedral Formation limestone (Map 6). Several of these occurrences exhibit characteristics similar to those found associated with MVT deposits. For example, in the vicinity of the Monarch-Kicking Horse Pb-Zn-Ag deposits near Field, the Cathedral Formation limestone is heavily dolomitized and contains solution structures (Ney 1954, 1957; Westervelt 1979). Nesbitt and Muehlenbachs (1993a,b) suggested that there was at least three distinct regional fluid flow events in the Canadian Rockies. Event 1 fluids, which were pre-Laramide thrusting and likely Paleozoic in age, are characterized by high salinities (>20 equivalent weight % NaCl), high concentrations of Mg and Ca, and were likely metalliferous brines with minimum temperatures in the range of 150°C to 200°C. They speculated that this metalliferous brine was derived by fluid migration from the Paleozoic shale basin which existed in the west into the carbonate rocks in the east, and that this metalliferous brine was responsible for the MVT Pb-Zn deposits in the Western Canada Sedimentary Basin, such as the Monarch-Kicking Horse and Pine Point Pb-Zn deposits. Other indications of extensive Mg-metasomatism associated with Event 1 fluid migration in the southern Canadian Rockies include several small brucite occurrences and the Mount Brussilof magnesite deposit in southeast British Columbia (Simandl *et al.* 1991), and a talc occurrence in the Alberta Rockies near Banff (Map 6, anomaly 82O-34; Allan 1921). There are, as well, numerous minor occurrences of base metals in Cambrian rocks in both Alberta and the adjacent parts of British Columbia (Hamilton and Olson, *In press*). Potential for MVT deposits in Cambrian to Silurian carbonates exists east of Banff National Park in the vicinity of the Ghost River Fault (Map 6, anomaly 82O-20; Fitzgerald 1962) where Hoffman (1885) reported a sample of pyritic limestone (anomaly 82O-5) that assayed 0.729 oz Ag/T (25.0 g Ag/t). Other areas with potential for Cambrian to Silurian carbonate-hosted MVT deposits include: (a) the Siffleur River area immediately east and north of Banff National Park in the vicinity of the highly faulted Third Range thrust sheet (Map 6, anomaly 82N-6; Birnie 1961), (b) the area between the southeast end of Jasper National Park and the North Saskatchewan River (Map 2), and (c) northwest of Jasper National Park within the Willmore Wilderness area (Map 2). Little potential exists for Cambrian to Silurian hosted MVT deposits south of Canmore to the Montana border because the Cambrian to Silurian interval of carbonates is either not present or is volumetrically small due to the emergent West Alberta Arch during that time period.

Potential for MVT Pb-Zn deposits is probably most favourable in Upper Devonian strata, such as the Palliser Formation, that are present in the Main Ranges and in some places in the Front Ranges throughout much of the Alberta Rocky Mountains. The Devonian rocks at and near the Oldman prospect in the vicinity of the Oldman River should be considered particularly favourable for exploration for MVT Pb-Zn mineralized zones (Map 6). Paleokarst and dolomitization fronts are reported at the Oldman prospect (anomaly 82J-42; Salat 1988), and the presence of a gypsum deposit accompanied by dolomitic breccias in the Upper Palliser Formation in the vicinity of Mount Head (anomaly 82J-51; Govett 1961) may be evidence that paleokarst is more widespread then previously thought. A stream sediment survey, which was performed by Geophoto Services Ltd., discovered up to 1,200 ppm Zn in a stream draining the Oldman prospect (anomaly 82J-6; O'Donnell and Fuenning

1967). At the headwaters of Lost Creek, which is about 7.5 km north of the Oldman prospect, two stream sediment samples which were collected during the same survey (Ibid), assayed 450 ppm and 580 ppm Zn (anomalies 82J-7 and -8). On a more regional scale, Beales (1953) described widespread dolomitic mottling of the Palliser Formation throughout the Rocky Mountains, and exploration by Esso Minerals during the 1970's and early 1980's found that occurrences of Pb-Zn in the Palliser Formation are common (J.E. MacDonald, *pers. comm.* 1993). Other, somewhat poorly-documented, occurrences of possible MVT type Pb-Zn exist north of the Oldman Prospect at Mist Mountain (anomaly 82J-47; Trigg 1982; Johnston and Olson 1982) and at Beehive Mountain (anomaly 82J-1), which is south of the Oldman prospect (Gillis 1970). The host rocks at these two occurrences are thought to be Devonian in age. A rock sample from Beehive Mountain is reported to contain 47% Pb (Gillis 1970). Another prospective area for MVT mineralized zones in Devonian carbonates is north and east of Kananaskis Lakes within the Elk Range, where six stream sediment samples (anomalies 82J-18, -20, -21, -23, -24 and -35) assayed between 200 ppm Zn and 700 ppm Zn (O'Donnell and Fuenning 1967). These anomalies occur near several prominent transverse faults (Price 1967; McGugan 1987; McMechan 1988). Some of the faults may have been long-lived and formed prior to thrusting (Price 1967). Lithogeochemical sampling of the Palliser Formation carbonates by Esso Minerals Canada and the GSC (Geldsetzer *et al.* 1987) returned assays of: (a) 270 ppm Zn and 3.6 ppm Ag north of the Oldman prospect at the headwaters of Lost Creek (anomaly 82J-56), (b) 350 ppm and 540 ppm Zn from two different sections in the vicinity of Canmore (anomalies 82O-35 and -36), (c) 600 ppm Zn northwest of Jasper near the northern boundary of Jasper National Park (Map 2, anomaly 83E-4) and (d) 1,160 ppm Zn, 74 ppm Cu and 44 ppm Pb southwest of Grand Cache near the Smoky River (anomaly 83E-5).

In the Rocky Mountains of Alberta, the Carboniferous-Permian succession, which includes the Banff, Rundle and Rocky Mountain Groups, comprises thick sequences of carbonates, including dolomite. These platform carbonates are not associated with a regional transition to deeper water shale, but other favourable conditions for MVT Pb-Zn deposits are present. These include, for example, reefal complexes, unconformities and disconformities, vertical to subvertical faults, and several dolomitization fronts. Fieldwork which was conducted during 1992 on behalf of the Canada-Alberta Partnership Agreement on Mineral Development, discovered Carboniferous-Permian limestones with up to 798 ppm Zn, 184 ppm Pb and 0.7 ppm Ag near Blairmore, and up to 197 ppm Zn and 3,105 ppm Ba west of Mount Livingstone (Williamson *et al.* 1993).

In the Triassic Spray River Group, thick limestones and dolomites exist in places within shallow water transgressive cycles. Although such shallow water carbonates are not usually considered suitable hosts for MVT Pb-Zn, the Spray River Group also contains porous and permeable siltstones and sandstones, and evaporitic sequences. The evaporitic sequences may have provided the saline fluids necessary to cause dissolution and create porosity in the carbonates, and also to transport metals in solution. As well, the Spray River Group contains abundant pyrite in dolomites and dolomitic siltstones at several locales in the southern Canadian Rocky Mountains (Gibson 1974). Lastly, the Spray River Group has some geological similarities to the shallow water cycles of the Sheppard and Kintla Formations of the Middle Purcell Group, which do host Pb-Zn occurrences. Therefore, the Triassic carbonates should not be ruled out as exploration targets for MVT deposits, even though to date no Pb-Zn occurrences have been reported within these rocks.

Stratiform Sediment-Hosted Lead-Zinc Deposits

Potential exists in the Alberta Rocky Mountains and Foothills for clastic, sediment-hosted, stratiform Pb-Zn deposits. The types of deposits in this category include: (a) **euxinic**

black shale hosted (Sedex) Pb-Zn deposits, such as those which exist in northeastern British Columbia and the Selwyn Basin, Yukon (Carne and Cathro 1982; Morganti 1988), (b) **turbidite-hosted Pb-Zn deposits,** such as Sullivan at Kimberly, British Columbia (Hamilton *et al.* 1982; Hoy 1982), and (c) **sandstone-hosted Pb-Zn deposits,** such as those at George Lake, Saskatchewan (Bjorlykke and Sangster 1981) or Laisvall, Sweden (Grip 1967). In Alberta, extensive Middle Proterozoic, Jurassic to Lower Cretaceous and Upper Cretaceous to Tertiary shallow-water, sandstone-dominated, clastic wedges are present, but there is little, if any, thick, deep-water flysch deposits consisting of turbidites, shale and chert. As a result, the potential in the Alberta Rocky Mountains and Foothills may be higher for the siltstone- or sandstone-hosted variety of stratiform Pb-Zn deposits, rather than the starved basin, euxinic shale or turbidite varieties.

Many of the clastic wedges in southwest Alberta contain geological features that are considered favourable for sandstone-hosted Pb-Zn mineralized zones, including transgressive basal sandstones or conglomerates, vertical to subvertical faults which may be related to intracratonic rifting, interlayered impermeable cap rocks such as shales or mudstones, and the presence of evaporites in the stratigraphic section. Targets deemed to be structurally favourable for sandstone-hosted stratiform Pb-Zn deposits include those stratigraphic units that were deposited within or adjacent to the Southern Alberta Rift, and those locales with prominent vertical to subvertical, northeasterly-trending transverse, tear or normal faults. In the Carbondale River area, for example, Upper Purcell Group Sheppard and Kintla Formations contain cyclical shallow-water siltstone, shale and dolomite. Carter (1971) reported up to 1.28% Zn and 0.09% Pb across 0.91 m in a surface rock sample from Sheppard Formation siltstone and dolomite which exists near the headwaters of North Lost Creek (Map 6, anomaly 82G-46). Carter (1971) also reported that Sheppard Formation siltstone and dolomite assays up to 0.33% Zn and 0.09% Pb across 4.27 m in a drill hole in the vicinity of anomaly 82G-46. Goble (1973a) reported surface rock samples from black shale and siltstone of the Sheppard Formation that assay up to 2.56% Pb, 1.40% Zn and 2.32 oz Ag/T (79.54 g Ag/t) across 1.8 m at North Kootenay Pass (anomaly 82G-11); 3.40% Pb, 0.20% Zn and 2.75 oz Ag/T (94.3 g Ag/t) across 2.44 m at North Lost Creek (anomaly 82G-46); 3.02% Pb, 1.00% Zn and 3.60 oz Ag/T (123.4 g Ag/t) across 2.74 m at South Lost Creek (anomaly 82G-50), and 1.92% Pb, 1.43% Zn and 4.75 oz Ag/T (162.9 g Ag/t) across 3.35 m at Carbondale River (anomaly 82G-51). Goble (1975) subsequently described a follow-up program of five drill holes at the North Kootenay Pass area. He gave visual estimates of sulphide content, but no assay results were reported.

Other potential clastic host rocks for stratiform Pb-Zn deposits in the Alberta Rocky Mountains include: (a) Triassic Spray River Group siltstone and shale, (b) Jurassic Fernie Group shale, and (c) siltstone and sandstone/siltstone units capped by shale within the Kootenay-Blairmore and the Belly River-Paskapoo clastic wedges. These sequences may have higher potential for Pb-Zn: (a) in the faulted areas that exist in the vicinity of Mount Head (anomaly 82J-53; Douglas 1958), (b) along the Elk, Opal and Misty Ranges east of Kananaskis Lakes (anomalies 82J-46 and -50; Beach 1942; Price 1967; McGugan 1987; McMechan 1988), (c) at Indianhead Creek (anomaly 82N-6; Birnie 1961), (d) near the headwaters of the Clearwater River (anomaly 83C-3; Verrall 1968), and (e) in the vicinity of the Ghost River (anomaly 82O-20; Fitzgerald 1962) and Bighorn Tear Faults (anomaly 83C-2; Verrall 1968; Dahlstrom 1970).

Stratiform Sediment-Hosted Kupferschiefer Type Copper Deposits

Sediment-hosted stratiform copper deposits that occur in shallow marine or epicontinental sedimentary rocks are referred to as Kupferschiefer type deposits (Brown 1992). Numerous occurrences of silver-bearing, disseminated chalcocite, chalcopyrite and bornite exist in Helikian arenites in southwestern Alberta and in southeastern British Columbia (Table 5, Map 6). A geologically similar, but economic deposit named Spar Lake and numerous Cu-Ag occurrences exist in northwestern Montana (Hayes and Balla 1986; Hayes and Einaudi 1986). Thus, potential exists for the discovery of an important Kupferschiefer type stratiform Cu deposit in the Rocky Mountains and Foothills of southwest Alberta.

Regional characteristics that are considered important for Kupferschiefer type Cu deposits include location in a rift basin with extensional faults, a thick sequence of hematitic (red bed) clastic sediments, the presence of evaporites in the stratigraphic section, horizons of chemically reduced sediments that might form a suitable host rock, and rift-generated, mafic volcanic rocks (Gustafson and Williams 1981; Eckstrand 1984; Jowett 1986, 1989, 1991; Jowett *et al.* 1987; Boyle *et al.* 1989; Brown 1992;). All of these characteristics are present at least locally within the Purcell Group rocks of southwest Alberta.

Extensive exploration was conducted in the Clark Range of southwest Alberta during the late 1960's and early 1970's. This led to the discovery of several Cu-Ag occurrences including the Spionkop (anomaly 82G-7), Yarrow (anomaly 82H-1), Grizzly (anomaly 82G-10) and Whistler (anomaly 82G-9) prospects (Bradshaw 1967, 1968; Duncan 1970; Halferdahl 1971; Van Dyck 1971; Gyr 1971; Goble 1972, 1973a; Allan 1973; Collins and Smith 1977). At Whistler Mountain, rock samples from trenches assay up to 6.7% copper and 26 ppm Ag in Upper Grinnell Formation quartz arenites. At least 25 beds are mineralized, but most of them are less than 0.15 m thick (Collins and Smith 1977). The available records indicate that the Whistler prospect was not drill tested. At Grizzly Creek, Cominco Ltd. drilled five holes between 1969 and 1971. The reported initial results are up to 0.95% Cu and 0.10 oz Ag/T (3.43 g Ag/t) across 4 feet (1.22 m), and 1.19% Pb across 5 feet (1.52 m) (Halferdahl 1971). In the mid-1970's, Collins and Smith (1977) resampled the drill core and they reported up to 1.23% Cu, 220 ppm Pb, 130 ppm Co and 25 ppm Ag in quartz arenite beds from the Upper Grinnell Formation. They (Ibid) stated that some of the mineralized beds are up to 7 feet (2.13 m) thick. Halferdahl (1971) reported that the mineralized zones at Grizzly Creek may be fault-related. At the Spar Lake mine in Montana, the initial reserves were 64 million tonnes grading 0.76% Cu and 54 g Ag/t (Hayes and Balla 1986). In southwest Alberta, some of the grades that have been reported for the Whistler and Grizzly prospects approach the grade at Spar Lake, hence an economic deposit could exist if sufficient thickness and volume of mineralized sediments can be found. In the Yarrow Creek to Spionkop Creek area, Goble (1972) reported up to 6.40% Cu in rock grab samples from Grinnell Formation quartzites (Map 6, anomaly 82G-7), and grade across widths of up to 3.38% Cu and 1.20 oz Ag/T across 7 feet (41.15 g Ag/t across 2.13 m; anomaly 82G-79). In this same area (anomaly 82H-1), Goble (1974c) reported proven reserves of 238,500 tons (216,360 tonnes) of 1.97% Cu and 0.62 oz Ag/T (21.26 g Ag/t), probable reserves of 2.4 to 10.5 million tons (2.2 to 9.5 million tonnes) of 1.25% to 2.5% Cu and 0.1 to 0.25 oz Ag/T (3.43 to 8.57 g Ag/t), and possible reserves of 17 to 20 million tons (15.4 to 18.1 million tonnes) of 1.25% to 1.75% Cu and 0.2 to 0.3 oz Ag/T (6.86 to 10.29 g Ag/t). However, the assessment records indicate that Kintla Explorations Ltd. drilled only five holes, and little data are provided to substantiate any of these reserve estimates.

In the late 1960's and early 1970's, several regional to semi-detailed geochemical stream sediment or water sampling programs for base and precious metals were conducted in the Clark Range by various exploration companies (Bradshaw 1967, 1968; Gyr 1971; Halferdahl 1971). Most workers concluded that the results failed to locate known copper mineralized zones, and therefore they believed that stream sediment or stream water surveys were of limited use in the search for undiscovered copper mineralized zones. However, a compilation and review of all the available geochemical data from assessment records indicate that many of the known Cu, Pb or Zn prospects do show up as subtle geochemical anomalies in streams with closely-spaced sampling. As well, there are several other subtle anomalies that are presently unexplained, including anomalies of 150 ppm Cu (anomaly 82G-44) and 125 ppm Cu (anomaly 82G-45) from stream sediment samples collected along Mill Creek or tributaries of Mill Creek (Map 6; Gyr 1971). Neither anomaly exists down-drainage from any known Cu occurrences. It is possible that heavy mineral sampling of drainage sediments in the Clark Range, rather than the standard sampling of stream fines, might better define some of the known mineral occurrences, and thereby be a more useful geochemical exploration method in the search for blind Cu-Ag mineralized zones. In addition, data from the available assessment records indicate that some of the known Cu-Ag prospects which have received little or no diamond drill testing, may warrant further exploration. The Whistler (anomaly 82G-9) and Grizzly Creek (anomaly 82G-10) prospects are two such examples.

Assessment records and work by Morton *et al.* (1974) indicate that the Purcell Lavas and associated dykes are altered and contain anomalous copper. As well, Halferdahl (1971) and Morton *et al.* (1974) suggested that the mineralized zones appear to be locally upgraded in the vicinity of vertical to subvertical tensional faults at the Grizzly, Spionkop and Yarrow Creek prospects or showings. The potential for the Cu-Ag deposits to be enhanced in the vicinity of faults or adjacent to altered Purcell Lavas should not be ignored. Remobilization of Ag, Cu and other metals into vein-type deposits or other such concentrations can form ore from protore. For example, at the prolific silver-producing district of Coeur d'Alene, Idaho, the silver is thought by many to be remobilized from stratiform, Cu-Ag mineralized zones that are widespread in the Purcell Group equivalent Belt Group rocks of northern Montana and Idaho (Hobbs and Fryklund 1968; Venkatakrishnan and Bennett 1988). In summary, the Clark Range of southwest Alberta contains all the regional and local geological characteristics considered important for Kupferschiefer type stratiform, sediment-hosted Cu deposits. As well, selected Phanerozoic, shallow-water clastic sequences should not be ignored as potential hosts for Kupferschiefer type stratiform Cu deposits. For example, favourable porous and permeable clastic host rocks, with cap rocks such as shales, hematitic red beds and evaporites, exist within the Spray River Group, the Kootenay-Blairmore clastic wedge and the Belly River-Paskapoo clastic wedge. Where these clastic packages exist within the confines of the Southern Alberta Rift or other such deep-seated structures, they could have been mineralized by copper leached from either the Middle Proterozoic Purcell Group or the Crowsnest Formation volcanics, both of which contain widespread, elevated concentrations of copper. Regional stream sediment and heavy mineral geochemical surveys, along with trace element lithogeochemical sampling of selected stratigraphic intervals, are needed to better evaluate the potential of these units to host stratiform Cu-Ag deposits in the Alberta Rocky Mountains and Foothills.

Stratabound Sediment-Hosted Kipushi Type Copper Deposits

Kipushi type deposits are essentially stratabound to stockwork Cu-Zn-Pb-Co-Ag deposits in karsted or brecciated dolomites. This deposit type exhibits some similarities to both clastic-hosted stratiform copper deposits of the Kupferschiefer type and carbonate-hosted Pb-Zn deposits of the MVT. Important conditions for Kipushi type mineralization include a rift basin setting with graben faults, permeable carbonates, and a potential source of copper, such as from rift-related basalts, deeply-weathered basement or sediments derived from the erosion of such rocks (Runnells 1969; Cox and Bernstein 1986). North American examples of Kipushi type carbonate-hosted copper deposits include the Cu-Zn-Pb-Ge deposit at Ruby Creek, Alaska (Runnells 1969) and the Acton Vale Cu-Zn-Pb deposits in Quebec (Sassano and Procyshyn 1988; Kumarapeli *et al.* 1990). In the southern Canadian Rocky Mountains of British Columbia and Alberta there are, in a few places, examples of carbonate-hosted stratabound copper deposits and occurrences that have some characteristics similar to those found in a Kipushi type setting. For example, in southeast British Columbia some of the highly-deformed Cu-Zn deposits of the Goldstream area may be of Kipushi type. The Goldstream deposits are hosted in calcareous phyllites, marbles and basalts of probable Lower to Middle Paleozoic age. Hoy *et al.* (1984) proposed that these deposits are of Volcanogenic Massive Sulphide origin, but the deposits also have some similarities to the Ruby Creek and Acton Vale deposits, hence they may be of Kipushi type. In the Rocky Mountains of Alberta, epigenetic copper occurrences exist in Cambrian limestones near Banff (Map 6) at Castle Mountain (anomaly 82O-1), Copper Mountain (anomalies 82O-2 and -3) and Johnston Creek (anomaly 82O-29). A bornite occurrence is reported to exist at the headwaters of the Panther River (anomaly 82O-30; Dawson 1901 and NMI sheet 115042). The described location of the occurrence suggests that it is hosted in either Cambrian or Upper Devonian carbonates. In southwest Alberta, the only reported occurrence of copper in Phanerozoic carbonates is in the vicinity of Mount Livingstone (anomaly 82J-2; Gillis 1970). Assay certificates indicate that the occurrence exists in the "Big Valley Group", which is equivalent to Upper Palliser Formation. Although the geology of these copper occurrences in Phanerozoic carbonate rocks of southwest Alberta is poorly known, some of them may be of Kipushi type.

Exploration potential for Kipushi type base metal deposits exists both in carbonate strata of Proterozoic age in the Clark Range, and in Phanerozoic strata in the Alberta Rocky Mountains and Foothills. In the Clark Range, for example, copper occurrences have been documented in dolomite and dolomitic argillite of the Proterozoic Waterton, Siyeh, Sheppard and Kintla Formations at various localities. In the past, most of the reported exploration in the Clark Range was focused on Lower Purcell Group continental clastic and argillaceous rocks of the Appekunny, Grinnell and Siyeh Formations based on the Kupferschiefer stratiform copper deposit model. However, some exploration for Cu or Pb-Zn in the carbonate rocks of the Sheppard and Kintla Formations has been performed by Alcor Minerals Ltd. (Van Dyck 1971), by Cominco Ltd. (Carter 1971) and by Kintla Explorations Ltd. (Goble 1973a, 1973b, 1975). Van Dyck (1971) described exploration of the carbonate units in Sheppard and Kintla Formations in the main Clark Range southeast of the Carbondale River area, and reported up to 2.3% Cu in Kintla Formation dolomite at Sage Mountain (Map 6, anomaly 82G-38). He concluded, however, that the copper mineralized zones, even though widespread in distribution, were too low-grade or narrow to be of economic interest. Van Dyck (1971) also concluded that the Pb-Zn mineralized zones which occur in the Sheppard Formation at the Carbondale River area, are not economic. Carter (1971) and Goble (1973a, 1973b, 1975), on the other hand, discovered targets of sufficient merit to warrant drill testing at Carbondale River area, and both recommended further exploration, even though their initial drill results indicated the sulphidic intersections were sub-economic.

In a few places, prior geochemical stream sediment results show subtle anomalies are present in creeks draining carbonate rocks in the Clark Range. For example, the data in Gyr (1971) indicate that known copper occurrences in the Grinnell Formation are reflected by subtle geochemical stream sediment 'anomalies' which occur up to several hundred metres downstream in tributaries of Pincher and Whitney Creeks. Further, the data in Bradshaw (1967, 1968) and Gyr (1971) indicate there are at least 14 subtle Cu, Pb or Zn anomalies in stream sediment samples that were collected from sites down-drainage from areas possibly underlain by carbonates in the Sheppard or Kintla Formations (Map 6, Anomalies 82G-3, -44, -45, -51, -99, -100, -103, -106, -107, -109, -114, -116, -117 and -118). Some of the unexplained anomalies that warrant follow up exploration include six anomalous stream sediment samples with assays of up to 150 ppm Cu (anomalies 82G-44 and -45) which were collected from tributaries of Mill Creek (Gyr 1971), and an unexplained anomaly of 250 ppm Zn (anomaly 82G-109) that was collected from a tributary of the West Castle

River which drains Sheppard and Kintla Formations west of Ruby Lake (Bradshaw 1968). These unexplained or inadequately explored Cu and Zn anomalies indicate that there may be potential for carbonate hosted Kipushi type base metal deposits in Sheppard and Kintla Formations of Upper Purcell Group within the Clark Range.

Within the Phanerozoic succession, stratigraphic units that may be potential host rocks for Kipushi type deposits include: (a) Upper Devonian Fairholme Group and Palliser Formation, (b) Carboniferous to Permian Rundle Group and Rocky Mountain Group, and (c) the Triassic Whitehorse Formation of the Spray River Group. The Crowsnest Formation volcanic rocks and the structures associated with the Southern Alberta Rift could conceivably have provided the source and conduit to move and deposit copper in carbonates of these Devonian to Triassic units between the Clark Range and Kananaskis Lakes. The presence of evaporites in the stratigraphic section is sometimes considered as a favourable prerequisite for the transport of copper in solution, prior to its deposition into stratabound deposits. Both the Rundle Group and Whitehorse Formations contain evaporites within the bounds of the Southern Alberta Rift and in the vicinity of the Crowsnest Formation volcanics. The Whitehorse Formation also contains redbeds, which are sometimes considered a possible source of copper.

In summary, many of the regional characteristics considered favourable for Kipushi type deposits exist in the Rocky Mountains and Foothills of Alberta, including: (a) a periodically active rift zone, specifically the Southern Alberta Rift, (b) copper-enriched source rocks, such as the Purcell Lavas, the Lower Purcell Group clastic rocks and, possibly, the volcanic and volcaniclastic rocks of the Crowsnest Formation, (c) carbonate host rocks, such as those that exist in the Proterozoic and Phanerozoic succession, and (d) evidence of vertical and shallow-dipping faults to provide conduits for the migration of fluids. As well, there are numerous minor copper occurrences or copper geochemical anomalies in stream sediments in southwest Alberta between Waterton Lakes National Park and Nordegg (Tables 2 and 5, Maps 1 and 6). The most likely targets for Kipushi type base metal deposits in the Rocky Mountains of Alberta are the Proterozoic carbonate rocks in the Clark Range, and the Paleozoic and Lower Mesozoic carbonate rocks of the Main and Front Ranges.

Stratiform Shale-Hosted Nickel-Zinc Deposits

Volumetrically, shale-hosted Ni-Zn deposits are currently a minor world resource. However, this type of exploration target has received little attention outside of China, and therefore little is known about the geology and potential of this deposit type. Examples of stratiform, shale-hosted Ni-Zn deposits include several deposits in China (Coveney *et al.* 1992), and the Nick deposit in Yukon Territory (Hulbert *et al.* 1992). Shale-hosted Ni-Zn deposits also have the potential to yield significant amounts of Mo, PGE's and Au (Coveney *et al.* 1992). In China, for example, metal enrichment in Cambrian black shale locally reaches up to 7% Mo, 4% Ni, 2% Zn, and 1 g Au/t (Schultz 1991; Coveney *et al.* 1992). In North America, black shales of the midcontinent in Pennsylvania (Middle Pennsylvanian Mecca Quarry Shale) contain up to 5,000 ppm V and 8,500 ppm Zn, and the Upper Devonian-Lower Mississippian New Albany Shale of Indiana contains up to 1,700 ppm Cu, 535 ppm Mo, 837 ppm Ni, 835 ppm Pb and 4,455 ppm V (Schultz 1991).

At the Nick deposit, the first indication of Ni-Zn mineralized zones was provided by a regional stream sediment geochemical survey that was conducted by the Geological Survey of Canada (1977). This regional survey was designed to locate turbidite-hosted Pb, Zn and Ba mineralized zones of the Sedex type (Carne and Cathro 1982). The mineralized zones at the Nick deposit are hosted by black shales at transitions between shelf carbonates and deeper-water clastic rocks, and they are spatially or temporally associated with rift-related graben faults or reactivated basement faults (Hulbert *et al.* 1992).

Potential exists in the Alberta Rocky Mountains and Foothills for shale-hosted, stratiform Ni-Zn deposits similar to those at the Nick. The most prospective units are: (a) black shale in Middle Proterozoic Sheppard Formation of the Clark Range, especially in the Carbondale River area, (b) black shale of the Exshaw Formation, which exists at the transition between Upper Devonian and Mississippian carbonate units, (c) black shale of the Triassic Sulphur Mountain Formation of the Spray River Group, and (d) black shale of the Jurassic Fernie Group.

As previously noted, dolomite, shale and siltstone of the Sheppard Formation in the Carbondale River area have anomalous, but uneconomic concentrations of Pb, Zn, Cu and Ag (Carter 1971; Goble 1973a,b, 1975). Goble (1975) also mentioned the existence of arsenopyrite, up to 0.18% Mo, and anomalous concentrations of U. The presence of elements such as As, Mo and U indicates that potential exists for black shale-hosted Ni-Zn deposits in Proterozoic strata because this suite of elements is anomalous at both the Nick and the Chinese Ni-Zn deposits (Schultz 1991; Hulbert *et al.* 1992; Coveney *et al.* 1992).

With respect to the black shales of the Exshaw Formation, there may be potential for stratiform Ni-Zn deposits based on sparse geochemical and mineralogical data that indicate the Lower Exshaw Formation shales have an anomalously high content of some metals (Table 9). Campbell (1980) reported that elevated concentrations of Ni, Zn and U are most common in the lowermost 1.2 m of the Exshaw shale, and the anomalous concentrations decrease upwards away from the basal contact. In outcrop, even higher concentrations of these metals have been found in the Exshaw Formation. For example, sampling of the Lower Exshaw Formation shale from Canmore to the Clark Range by Esso Minerals Canada and the GSC (Geldsetzer *et al.* 1987) has indicated that concentrations of zinc and other elements are substantially elevated at 12 of the 15 locations that were sampled with up to 775 ppm Zn, 68 ppm Cu, 4.0 ppm Ag, 155 ppm Ni, 4,000 ppm V, 1,240 ppm Ba and 230 ppm Cr_2O_3 (Map 6, anomalies 82G-119, -120, -121, -122, -123, 82J-54, -55, -56, -57, -58). In addition, Richards *et al.* (1993) reported that the GSC has found concentrations of metals in the Lower Exshaw Formation type section at Jura Creek near Exshaw that are up to 21,941 ppm Zn, 4,825 ppm Ni and 560 ppm Mo. They found that the basal shale of the Exshaw Formation contains anomalous concentrations of Ni in the nickel sulphide vaesite and of Zn in sphalerite, in association with pyrite. Interestingly, a sphalerite occurrence is also reported in shale of lower Banff Formation, which is possibly equivalent to the Exshaw Formation, on Limestone Mountain in the Rocky Mountain Front Ranges approximately 7.5 km southwest of the Clearwater River (Map 6, anomaly 82O-18; Moore 1953). This indicates that anomalous metal concentrations in the lower Exshaw Formation and its stratigraphic equivalents may be quite widespread.

Potential for shale-hosted stratiform Ni-Zn deposits may also exist in a black shale member that is near the top of the Triassic Sulphur Mountain Formation. This shale occurs either beneath the uppermost dolomite member of the Sulphur Mountain Formation, or beneath silty dolomite of the Whitehorse Formation. Gibson (1965, 1971) reported that up to 10 volume per cent pyrite exists in this black shale and there are local horizons of massive pyrite. Pyrite is also common in the overlying dolomite of the Whitehorse Formation. Phosphate-enriched sediments are frequently present within the Sulphur Mountain Formation below the upper black shale member. The Nick Ni-Zn deposit exists at the base of a phosphate-enriched chert member within a black shale unit (Hulbert *et al.* 1992). No trace element chemistry has been reported for the Sulphur Mountain Formation, hence its base metal content currently is unknown.

TABLE 9

COMPARISON OF AVERAGE BLACK SHALE TO EXSHAW FORMATION SHALES INTERSECTED IN ALBERTA WELLS

Element	Average Black Shale (ppm)[1]	Exshaw Formation Average Shale (ppm)[2]	Exshaw Formation Maximum Core Results (ppm)[2]
Ni	68	107	391
Zn	95	102	448
Mo	2.6	27.6	167
As	13	21	87.1
Ba	580	325	1,050
U	3.7	15.6	92.2

[1]Average black shale after Mason and Moore (1982, after Turekian and Wedepohl 1961).
[2]Exshaw Formation average black shale based on analyses of 42 core samples from drill holes in the Alberta basin (Duke 1983).

Other black shales, such as those of the Fernie Group, may also have potential to host stratiform Ni-Zn deposits. For example, a rock sample that was collected from a faulted Fernie Group shale northwest of Mount Ptolemy and west of Coleman, Alberta, assays up to 631 ppm Zn, 227 ppm As, 89 ppm Mo and 10 ppm Cd (Williamson *et al.* 1993). Fernie Group shale was actually mined for pyrite at the Thorne Mine located on the east side of Moose Mountain near the head of Bragg Creek, about 9 km north of the Elbow River (Map 6, anomaly 82J-59; NMI sheet 115086). The pyrite is reported to be quite thickly distributed in the shales (Ibid) and warrants sampling for Ni-Zn and other metals at this location. In addition, Williamson *et al.* (1993) reported that many stream sediment samples, which were collected from creeks draining Fernie Group shales or draining shales in the Proterozoic Sheppard and Kintla Formations of southwest Alberta, have elevated concentrations of one or more of Ni, Zn, As, Mo, Ba and U. They concluded that shales in the Sheppard, Kintla, Exshaw and Sulphur Mountain Formations, and Fernie Group, particularly where they are within or near the bounds of the Southern Alberta Rift or other deep-seated structural breaks such as the Bighorn Tear Fault, may be favourable host rocks for Nick type stratiform Ni-Zn deposits.

Precious Metal Deposits

There are few reported precious metal occurrences in the miogeoclinal rocks of the Alberta-British Columbia Rocky Mountains. Nonetheless, potential exists for gold deposits to be present based on analogy to other areas. For example, in the Carlin area of northeastern Nevada there were few gold occurrences and minimal placer gold production prior to the discovery in the 1960's of the Carlin gold deposit. Since that time, many economically important gold deposits and tens of million ounces of gold have been discovered in various sedimentary strata at Carlin area. In some respects the rock units and structural setting at Carlin area are lithologically similar to the faulted strata that exist in the Alberta Rocky Mountains and Front Ranges..

Epithermal Gold-Silver Deposits

Epithermal, disseminated gold-silver deposits are large producers of gold and, in places, silver throughout California, Nevada and Utah. Exploration for this type of deposit in the Canadian Cordillera in British Columbia and the Yukon Territory has resulted in a few discoveries, but none that are of the magnitude of the deposits in the western United States of America. Epithermal Au-Ag deposits exist in a variety of host rocks, but 'dirty' or 'carbonaceous' silty carbonates are a common host, and typically the deposits are low-grade, but large tonnage. Epithermal Au-Ag deposits are also referred to as "No-see-um gold" because of their fine-grained, disseminated nature, or "Carlin type" after the Carlin trend in northeast Nevada. The formation of Carlin type deposits has usually been attributed to epithermal hydrothermal processes associated with the emplacement of high-level felsic intrusions and rhyolitic volcanism (Bagby and Berger 1985; Romberger 1986; Berger and Henley 1989). Because such felsic igneous activity is largely lacking in the Rocky Mountains and Foothills, the potential for Carlin type deposits in Alberta has long been regarded as significantly lower than that for British Columbia or the Yukon Territory. However, recent work on Carlin type deposits has indicated that the assumed genetic relationship to felsic igneous activity may not be universally valid. For example, at the Carlin type Mercur gold district in north-central Utah, the gold deposits are hosted by the Mississippian Great Blue Limestone below the Long Trail Shale. The Mercur deposits are characterized by replacement of carbonate and silty carbonate by silica, phyllosilicates, pyrite, barite, various arsenic, mercury, antimony and thallium minerals, and by disseminated micrometre-sized gold (Jewell and Parry 1987, 1988). At Mercur, there are spatially-associated Tertiary felsic stocks and rhyolites. Recently, however, Wilson and Parry (1990) have dated alteration associated with the gold mineralized zones at between 122 Ma and 193 Ma, hence the Mercur gold deposits are much older than the Tertiary felsic igneous rocks. Wilson and Parry (1990) concluded that the gold-bearing hydrothermal activity is related to Rocky Mountain-style thrust faulting along the Manning Canyon detachment during the Mesozoic, because there are no igneous rocks older than 40 Ma in the Mercur gold district. Therefore, in Alberta it is possible that Rocky Mountain-style thrust faulting of Paleozoic carbonates may have provided the necessary environment for the formation of Carlin type gold deposits. Exploration for Carlin type gold deposits is difficult because (a) gold and silver grades are generally low, (b) the deposits rarely contain visible gold, (c) even where the epithermal Au-Ag deposits are eroded they typically are not geographically associated with placer gold accumulations, and (d) an extensive zone of associated alteration to act as a guide to ore is not always present (Bagby and Berger 1985). In general, most of the Carlin type Au-Ag deposits in Nevada and other parts of the western United States of America which have been discovered since the early 1970's, have been found by systematic geochemical rock or surficial sampling methods, followed by drilling of selected targets. Therefore, perhaps the lack of epithermal Au-Ag discoveries in the Canadian Cordillera is a result of the difficulty in finding such Carlin type deposits, rather than a lack of felsic intrusive activity or other perceived indications of "favourable geology".

A few low-grade gold occurrences have been reported in the Alberta Rocky Mountains and Foothills. These occurrences and other geochemical anomalies might indicate there is some potential for carbonate-hosted, disseminated gold-silver deposits of the Carlin type. For example, these include: (a) up to 1,510 ppb Au in stream sediment samples southeast of Hinton within the foothills (anomalies 83F-1 and 83F-2 in Table 2 and on Map 2; Fox 1991), (b) gold in bedrock that was reportedly recovered from the "Pot Hole" northwest of Lake Louise within Banff National Park (anomaly 82N-7 in Table 5 and on Map 6; La Casse and Roebuck 1978), (c) 1,150 ppb gold in a rock sample from the Blairmore Group sandstone in the Foothills south of the Red Deer River (anomaly 83O-26 in Table 2 and on Map 6; Grant 1981), (d) 0.013 oz Au/T (0.45 g Au/t) from a reported drill cuttings sample of carbonates in the Dry Creek area (anomaly 82J-45 in Table 2 and on Map 6; Dr. L. Halferdahl, *pers. comm.* 1993), and (e) 0.76 g Au/t from a calcareous siltstone northeast of Blairmore (anomaly 82G-82 in Table 2 and on Map 6; Olson 1985b). In addition, Williamson *et al.* (1993) reported that the results of a stream sediment survey conducted during 1992, may indicate that Devonian to Permian carbonates of the Livingstone Range have potential to host Carlin type deposits. Four stream sediment samples that were collected from streams draining the Livingstone Range east of the Oldman prospect and in the vicinity of the Dry Creek gold occurrence (anomaly 82J-45 on Map 6), contain two or more of Au, As, Sb and Hg above the 97.5 percentile for their survey (Ibid). Several other samples, which also were collected during this survey from streams that drain the Livingstone Range in the same area, contain anomalous concentrations of at least one of the above four elements. Gold, arsenic, antimony and mercury are considered by some to be the most useful pathfinder elements in searching for Carlin type gold deposits. In short, although not common, a few gold occurrences and some other geochemical anomalies potentially indicative of Carlin type gold mineralization do exist locally within the Alberta Rocky Mountains and Foothills.

Potential targets for Carlin type Au-Ag deposits in the Alberta Rocky Mountains and Foothills include: (a) places where carbonate rocks are cut by thrust faults or transverse faults, a geological setting that is similar to the Mercur gold district, (b) spatially associated with hydrocarbon pools, and (c) areas where carbonates are intruded by alkalic dykes, sills and stocks. With respect to fault-related epithermal Au-Ag deposits, several economically important examples of Au-Ag deposits associated with detachment faults exist in the southwestern United States of America. These include the Picacho and Mesquite mines in California (Liebler 1988, Willis 1988). At both these mines it is believed that brittle deformation during detachment faulting provided open spaces into which gold and related gangue minerals were deposited in geologically favourable rock types. Therefore, in the Alberta Rocky Mountains and Foothills, it is possible that similar Au-Ag deposits could be associated with Laramide thrust and related fault structures. In some places, such as at the Banff and Miette hot springs in Alberta and at the Radium hot springs in British Columbia, hot fluids are presently migrating and being focused along major structures. It is probable that ancient hot fluids, some of which were possibly gold-bearing, have moved along other fault structures in the Alberta Rocky Mountains and Foothills during or subsequent to the Laramide Orogeny. Recent work by Nesbitt and Muehlenbachs (1993a,b) indicates that ancient hot fluids with minimum temperatures of 120°C to 150°C and low salinities (<10 equivalent weight % NaCl) migrated through the sedimentary column during and subsequent to the Laramide Orogeny. Hamilton (*pers. comm.*, 1994), for example, found anomalous to possibly anomalous Au, As, Sb, Ag and Hg in stream sediment from two drainages spatially related to a high-angle fault in the David Thompson corridor just west of the junction of the North Saskatchewan and Cline Rivers.

With respect to possible hydrocarbon-related Au-Ag deposits, such deposits have been reported elsewhere (e.g., Ballantyne 1993, Green and Hulen 1993, Hulen and Nielson 1993, Pinnell 1993). Ballantyne (Ibid) noted that "*deposition of gold in sufficient quantities to produce an ore deposit requires sustained flow of hydrothermal fluid through a narrow zone that coincides with a stable physico-chemical interface. Hydrocarbon-enriched rocks provide such an interface, at which thermal cracking of hydrocarbons can generate an oxidizing environment by depleting hydrogen. Gold complexes are destabilized, depositing gold on available pyrite and other minerals surfaces*". Hulen and Nielson stated that some of the hydrocarbon fields in Nevada "*share a surprisingly long list of essential attributes with the Carlin-type, low-grade, sediment-hosted gold deposits*". Pinnell (1993) suggested that some hydrothermal systems "*given favourable host rocks, traps, seals, and migratory pathways, might well have formed not only gold deposits, but also rich, spatially coincident* *oil reservoirs*". It is well known that extensive hydrocarbon deposits exist in various Phanerozoic rock units in the Rocky Mountains, Foothills and Plains of Alberta. Further, sulphide minerals, particulary the iron sulphides pyrite and marcasite, are commonly spatially associated with many of the hydrocarbon pools (Aulstead and Spencer 1985; Churcher and Majid 1989; Muir and Dravis 1991, 1992; Packard, *pers. comm.*., 1993). Therefore, it is possible that Carlin-type epithermal Au-Ag deposits could be spatially associated with some of the Alberta hydrocarbon pools or fields.

With respect to possible Au-Ag deposits associated with alkalic intrusions cutting carbonate and other types of sedimentary rocks, Schutz *et al.* (1989) reported that stratiform- to structurally-controlled gold mineralized zones exist within Upper Devonian Jefferson Group dolomites in the Little Belt Mountains (Rocky Mountain Foreland Terrane) southeast of Great Falls, Montana. They (Ibid) stated that the bulk of the gold-bearing zones are spatially and, possibly, genetically related to the intrusion of Tertiary syenite porphyry sills and hornblende-biotite lamprophyres. Other examples of this type are the Geiss, Giltedge and Kendall mines, which are hosted in Mississippian carbonates or Cretaceous clastic rocks east of Great Falls, Montana (Foster and Childs 1993). Geologically similar types of intrusions exist locally in the Rocky Mountains of southwest Alberta. For example, Price (1962) and Goble (1974a,b) described porphyritic trachyte, syenite and diorite dykes and stock-like masses that intrude Siyeh Formation, Purcell Lava and Sheppard Formation in the Clark Range. Goble (1974a) stated that "*excellent gold values associated with diabase, diorite and syenite intrusions in the Siyeh and Sheppard formations*" had been discovered by Kintla Explorations Ltd. on their Commerce Mountain claim block, which is southwest of Sage Mountain in British Columbia, near the Alberta-British Columbia border. Goble (1974b) also reported up to 0.04 oz Au/T (1.37 g Au/t) and 0.9 oz Ag/T (30.86 g Ag/t) from rock samples that were collected on "*traverse seven*" along the continental divide, southeast of Jutland Mountain. In short, because both the Siyeh and Sheppard Formations contain significant amounts of limestone, if these rock units are cut by alkalic intrusions within Alberta then there is the potential for them to host alkalic intrusion-related epithermal type gold deposits. Another potential area for epithermal type gold deposits related to alkalic intrusives is in the vicinity of the Crowsnest Formation volcanics, especially where feeder dykes to the Crowsnest volcanics have intruded other rock units. Such Crowsnest intrusions are reported to exist as dykes cutting Rundle Formation carbonate on Crowsnest Mountain, and cutting Kootenay strata in the vicinity of Coleman (Norris 1955; Price 1962). Therefore, the Devonian to Mississippian carbonate successions in the vicinity of alkalic intrusions related to the emplacement of the Crowsnest volcanics, may be a suitable setting for the existence of epithermal gold deposits.

Successful exploration for epithermal Carlin type Au-Ag deposits in the Rocky Mountains and Foothills of Alberta will require a combination of methods focused towards perceived geologically favourable lithologies, structures or intrusives. For example, it is possible that regional stream heavy mineral geochemical surveys for gold, coupled with analyses for potential pathfinder elements such as Sb, As, Hg and Tl, may assist in the reconnaissance phase of exploration for such gold deposits. As well, systematic rock sampling of favourable lithologies and subtle alteration zones could identify targets of interest. Carlin type epithermal Au-Ag deposits are commonly associated with silicification, particularly the formation of jasperoid (Percival *et al.* 1988, Nelson 1993). Therefore, any zones of silicification or jasperoid that are found should be sampled for gold, even if they appear to be barren of visible gold, sulphide minerals or other such evidence of gold-bearing zones. Sampling of such silicified or jasperoid zones has been an effective reconnaissance prospecting tool for Carlin type gold deposits in the western United States of America.

Mesothermal Gold Deposits

Although the potential for mesothermal gold deposits is regarded as lower than that for epithermal disseminated Carlin type gold deposits, the possibility for mesothermal gold deposits cannot be ruled out in the Alberta Rocky Mountains and Foothills. In general, mesothermal gold deposits (a) can be hosted in a variety of lithologies, (b) they show a strong spatial correlation with major, regional strike-slip faults, and (c) they are often hosted in spatially-related, second- or third-order structures that are sympathetic to the regional faults (Nesbitt and Muehlenbachs 1989). Faults that exhibit evidence of a transition from ductile to brittle-ductile deformation and shear strain are deemed more favourable for the development of mesothermal alteration and associated gold mineralized zones. Lastly, mesothermal gold deposits are often located in rocks metamorphosed to at least greenschist facies and many mesothermal gold districts exist at regional transitions from greenschist to amphibolite metamorphic facies.

Gold-bearing quartz veins were discovered in the 1980's or earlier about 60 km south-southwest of Jasper in the Athabasca Pass area (Map 2), less than 0.5 km east of the Alberta-British Columbia border in British Columbia (Shaw and Morton 1990a,b). The quartz veins are hosted in quartz-dominated clastic rocks of Lower Cambrian McNaughton Formation, which is part of the Lower Cambrian Gog Group. Shaw and Morton (1990a,b) stated that the McNaughton Formation is metamorphosed to pumpellyite or lower greenschist facies, and that the gold-bearing quartz veins were emplaced during compressive tectonism, leading to the formation of the Chatter Creek Thrust Fault. They classify the Athabasca Pass gold mineralized zone as mesothermal in character based on fluid inclusion work (Shaw and Morton 1990b). Dawson (1901) also described gold associated with quartz veins in the Great Cambrian Series rocks in Alberta along the Miette River west of Jasper. Dawson (1901) stated that the most productive veins are those that are reticulated and reach a width of two feet or more. He indicates that grades of up to eight dollars per ton (0.4 oz Au/T or 13.71 g Au/t) were reported from former claims that are now within Jasper National Park (anomaly 83D-5).

In the Rocky Mountains of Alberta, potential exists for gold mineralized zones that are similar to the Athabasca Pass prospect in Proterozoic or, possibly, Lower Paleozoic clastic rocks that have been deeply buried, metamorphosed, and thrust to surface during formation of the Canadian Rockies. In southwest Alberta, the Proterozoic clastic rocks of the Clark Range are the only exposed rocks that display the necessary metamorphic and structural conditions necessary to form mesothermal gold deposits. Other favourable Precambrian to Lower Paleozoic clastic sequences exist locally along the length of the Alberta Rocky Mountains from Kananaskis Lakes to well northwest of Jasper. However, these sequences generally exist within National Parks or Wilderness areas that prohibit metallic mineral exploration.

Other Types of Deposits

There is potential for some other types of 'metallic' mineral deposits in the Alberta Rocky Mountains and Foothills, but the deposit types with a higher probability of existing and being found include: (a) magnetite and other heavy mineral placer or paleoplacer deposits, with or without associated precious metals, (b) diamondiferous kimberlite or lamproite deposits, or diamondiferous alluvial deposits derived from erosion of such diatremes, and (c) sediment-hosted U deposits.

Magnetite and Other Heavy Mineral Placer/Paleoplacer Deposits, With or Without Associated Precious Metals

Magnetite paleoplacer deposits in the Belly River sandstone of southwest Alberta may soon be the first producing metallic mineral mine in Alberta (W. Hamilton, *pers comm.* 1993). The magnetite is to be used for coal beneficiation rather than as iron ore. The Burmis and Dungarvan magnetite deposits also contain significant amounts of titanium (up to 10% TiO_2) in the form of ilmenite, titaniferous magnetite and small amounts of rutile (anomalies 82G-83 on Map 6 and 82H-6 on Map 2). Therefore, potential may exist for mineable paleoplacer concentrations of titanium in the form of ilmenite and rutile. The potential for mineable paleoplacer accumulations of magnetite or titanium is probably highest in the area of the Southern Alberta Rift. This is because the possible source for the magnetite and titanium minerals may be the Crowsnest volcanics, which are centred within the bounds of the Rift.

In addition to the well known paleoplacer deposits of magnetite, ilmenite and rutile, there is also potential in the Rocky Mountains and Foothills of Alberta for placer or paleoplacer accumulations of gold. Fox (1991), for example, reported that a regional stream sediment sampling program resulted in the detection of several gold anomalies in streams of the Rocky Mountains and Foothills. This led to the acquisition of mineral claims southeast of Hinton in the Anderson Creek area. Fox (1991) stated that several stream sediment samples and heavy mineral concentrates had a gold content between 300 ppb and 1,510 ppb (Map 2, anomalies 83F-1 and -2). Concentrations of other elements associated with precious metals, such as arsenic, mercury and antimony, were negligible, perhaps indicating a paleoplacer source for the placer gold. Fox (1991) reported that they prospected and conducted a small soil sampling program looking for the source of the gold in Upper Cretaceous Belly River conglomerates near the headwaters of Anderson Creek. He stated that outcrops of bedrock are rare and their soil sampling results were disappointing. Grant (1981) collected a rock sample of Blairmore Group sandstone in the vicinity of Logan Creek, which is northeast of Canmore, that assays 1,150 ppb Au with elevated concentrations of Zn, Ni, Co and V (anomaly 82O-26). As well, in a recent oral presentation and in a written proposal for exploration, Falconer (1993a,b) reported he had recovered "*about 30 mg.* [micrograms] *of gold from 80 pounds of Paskapoo Formation gravels*" near Hinton, Alberta; the recovered gold included "*many table-salt-size rounded nuggets*". He (1993a) also suggested that paleoplacer accumulations of gold may exist in the Paskapoo Formation clastic wedge that is exposed in the Porcupine Hills of southwest Alberta, but provided no substantiation for this other than an "*old timer*" had told him that "*in the old days gold was found in the Porcupine Hills*". In summary, if gold grades similar to those present in some of the Anderson Creek tributaries and, possibly, in the Logan Creek sandstone exist locally in large enough quantities of gravel or clastic rocks, then the economics may be sufficiently attractive enough for placer mining of unconsolidated sediments or open pit mining of consolidated sediments.

Potential also exists for placer or paleoplacer concentrations of diamonds in bedrock alluvial channels, in more loosely consolidated alluvial Cretaceous or Tertiary strata, or in Recent stream gravels in the Alberta Rocky Mountains and Foothills. However, finding concentrations of diamonds will be dependent upon the presence and partial erosion of diamondiferous source rocks, such as kimberlites or lamproites, in Alberta or British Columbia. The possibility does exist for placer or paleoplacer diamonds because microdiamonds and macrodiamonds are reported to have been found in the Jack and Mark diatremes in southeastern British Columbia near the Alberta border (Northcote 1983a,b; Dummett *et al.* 1985; Fipke 1990).

The highest potential for paleoplacer accumulations of heavy minerals, and perhaps modern placer accumulations derived from the paleoplacers, exists in areas underlain by the Jurassic-Lower Cretaceous Kootenay-Blairmore clastic wedge and the Upper Cretaceous-Tertiary Belly River-Paskapoo clastic wedge. Significant lode gold sources exist in the Cariboo (and Selkirk) Mountains to the west, hence erosion of these gold sources and transport of gold by streams flowing easterly into Alberta in front of the advancing Laramide Orogeny could have formed placer gold deposits. The Cariboo placer gold fields in the Barkerville area, for example, were derived from the erosion of such lode sources. Much of the sediment in the Kootenay-Blairmore and Belly River-Paskapoo clastic wedges was derived from west of the Alberta-British Columbia Rocky Mountains. If sediments in certain formations within the clastic wedges could be traced back to a potential auriferous source, such as the Cariboo Mountains, these sedimentary packages might then be a favourable exploration target for paleoplacer gold. As well, regional heavy mineral sampling could help to better define areas prospective for heavy mineral placer or paleoplacer accumulations.

Diamondiferous Kimberlite and Lamproite Deposits

Much of the Alberta Rocky Mountains and Foothills is underlain by thick Archean or Proterozoic continental crust (Ross and Stephenson 1989; Ross 1991, 1993; Burwash 1993). Thick continental crust in conjunction with deep-seated structures, such as the West Alberta Arch, Southern Alberta Rift and the Snowbird Tectonic Zone, indicate that potential exists for the discovery of kimberlite- or lamproite-hosted diamond deposits in the Alberta Rocky Mountains and Foothills.

Kimberlites and lamproites are complex, alkaline, ultramafic igneous to pyroclastic rocks, that are emplaced along deep-seated structures that have likely tapped the upper mantle, where diamonds are formed (Helmstaedt 1992). Kimberlites are volatile-rich, potassic, ultramafic rocks that occur as small dykes, sills and pipes. The pipes are generally comprised of volcaniclastic and tuffaceous rocks at surface, underlain by a carrot shaped diatreme comprised of volcanic breccia. Lamproites are ultrapotassic, ultramafic rocks, and they contain much less volatiles than kimberlites. Lamproites tend to occur as extrusive volcanic and volcaniclastic rocks, and associated hypabyssal dykes and sills.

World wide, kimberlite and lamproite magmatism has occurred during almost every time period, but certain periods seem to have been more favourable for the emplacement of diamondiferous varieties of these rocks (Table 10). Dawson (1989) suggested that the Middle Jurassic to Late Cretaceous period was the most prolific with respect to diamondiferous kimberlite magmatism.

In North America, there are a number of kimberlite, lamproite or similar mafic intrusive bodies that have been discovered and dated in recent years. These are being tabulated in Dufresne *et al.* (In preparation). There is evidence for at least three, and possibly four, ages of alkaline mafic to ultramafic igneous activity in the Western Canada Sedimentary Basin, some of which may have potential for diamonds. These ages are: Helikian, Paleozoic, Cretaceous and Tertiary.

In the Rocky Mountains and Foothills, the oldest generation of mafic to ultramafic intrusive activity is represented by the Helikian Moyie Sills and Purcell Lavas which are restricted to the Clark Range. The composition of the Helikian dioritic Moyie Sills and the andesitic Purcell Lavas differs significantly from the potassic, mafic to ultramafic compositional fields of kimberlites and lamproites, which are thought to be the necessary igneous host rocks for economic concentrations of diamonds. Therefore, the diamondiferous potential of the Moyie Sills, Purcell Lavas and equivalent intrusive rocks is considered to be low.

TABLE 10

MAIN AGES OF DIAMONDIFEROUS INTRUSIVE EVENTS WORLD WIDE

PERIOD	APPROXIMATE DATES (Ma)	EXAMPLES
Early Tertiary	35 - 60	Mwadui, Tanzania; some pipes in the Lac de Gras region, N.W.T.
Late Cretaceous to Middle Jurassic	80 - 170	Finsch, de Beers and numerous other famous southern Africa diamond producers
Mississippian to Late Devonian	340 - 370	Mir and other diamond producing pipes in Yakutia on the Siberian Platform
Late Middle Helikian	1,100 - 1,200	Premier pipe, South Africa; Argyle lamproite, Western Australia

The second oldest generation of alkaline, mafic to ultramafic igneous activity, consists of Paleozoic diatreme breccias, dykes, sills and stocks that predate compressional deformation in the Canadian Cordillera. These intrusions exist mostly in the Rocky Mountains of British Columbia between Williston Lake and Cranbrook, and they form a complex suite of rocks comprised of carbonatites, nepheline and sodalite syenites, some ijolite series rocks, numerous ultramafic and lamprophyric diatreme breccias, and associated dykes, and one kimberlite diatreme (Pell 1987a,b). Dating of these intrusions by many workers has been summarized by Pell (Ibid), who stated that there are at least three Paleozoic ages of mafic to ultramafic intrusion. These are: Ordovician-Silurian, Late Devonian-Mississippian and Permian-Triassic. North of Golden, British Columbia there are two diatreme clusters, the Jack and the Mark (Northcote 1983a,b; Dummett *et al.* 1985). The Mark diatreme cluster straddles the Alberta-British Columbia border and a few dykes within the Mark cluster exist on the Alberta side of the border (Fipke 1990). The Mark diatremes are believed to be part of the Devonian-Mississippian group of intrusions (Pell 1987a,b). Bulk samples of the Jack and Mark diatremes, and of nearby stream sediments, are reported to contain kimberlitic indicator minerals, including a few microdiamonds and one macrodiamond (Northcote 1983a,b; Dummett *et al.* 1985). Although Pell (1987a,b) and Ijewliw and Schulze (1988) suggested that the diatremes are alkalic, ultramafic lamprophyres and not kimberlites or lamproites, Fipke (1990) suggested that some of the intrusions are lamproitic. The Cross kimberlite, which crops out near the Alberta border about 8 km northwest of Elkford, British Columbia, is the only recognized occurrence of kimberlite in the Canadian Rocky Mountains (Grieve 1982). The Cross kimberlite is of Triassic to possibly Permian age and has not been reported to contain diamonds (Grieve 1982; 1987a,b).

The third generation of alkaline igneous activity in the Alberta Rocky Mountains and Foothills is represented by the Late Early Cretaceous Crowsnest Formation volcanics, which exist north and south of Coleman, Alberta. The volcanics are sodic-rich trachytes to phonolites and do not appear to have a chemistry that is favourable for diamonds. Peterson and Currie (1993) concluded that "*the economic potential of the rocks appears to be generally low*". However, the reported age for the Crowsnest volcanics is 96 Ma (Folinsbee *et al.* 1957), which corresponds closely to the reported age of 94 to 96 Ma for several kimberlites in the Fort a là Corne area of Saskatchewan. The Fort a là Corne diatremes are reported to contain gem-quality microdiamonds and macrodiamonds (Gent 1992; Lehnert-Thiel *et al.* 1992). These dates for the Crowsnest volcanics indicate that alkaline volcanism was occurring in the Alberta Rocky Mountains and Foothills at the same time as diamonds were being transported from the upper mantle to the surface during the Late Early Cretaceous in Saskatchewan. Therefore, it is possible that Upper Lower Cretaceous rocks in the Alberta Rocky Mountains and Foothills are a potential target for kimberlite or lamproite hosted diamond deposits.

A fourth generation of alkaline igneous activity in the Alberta Rocky Mountains and Foothills is represented by the trachytic to syenitic stocks and dykes, which straddle the Alberta-British Columbia border in the Clark Range, in the vicinity of Sage Mountain and Jutland Peak. Price (1962) suggested that these intrusions are Late Cretaceous or Tertiary in age, but their chemistry indicates they may have a closer affiliation with the igneous event responsible for the Crowsnest Formation volcanics. Alkalic minette intrusions of probable Tertiary age do exist in southeast Alberta in the Sweet Grass Hills (Williams and Dyer 1930; Russell and Landes 1940; Irish 1971). These intrusions have been dated at 48 Ma or Eocene (Taylor *et al.* 1964), and they represent the northernmost extension of the 69 to 27 Ma Montana alkaline province. The Sweet Grass intrusives are potassic rocks that crop out as both hypabyssal intrusive dykes and plugs, and as extrusive agglomerates or lahars (Kjarsgaard 1994). In Montana, a few geologically similar Eocene alkaline intrusions are reported to be kimberlitic or lamproitic in composition (Hearn 1989). Cavell and Burwash (1993) have suggested that the Sweet Grass intrusive rocks have geochemical systematics transitional between lamproite and kamafugite. Kjarsgaard (1994), however, suggests that the trace element geochemistry, mineralogy and mineral chemistry indicate that the Sweet Grass intrusives are minettes. He concluded that the economic potential for diamonds, gold and PGE's in the Sweet Grass intrusions is low.

With respect to the Alberta Rocky Mountains and Foothills, at present there is no well documented data to confirm the existence of diamondiferous diatremes. However, there are some reports of mineralogical, geochemical and geophysical anomalies in the Alberta Rocky Mountains and Foothills that indicate potential exists for the discovery of diamondiferous kimberlites or lamproites in bedrock. For example, a corporate press release by Takla Star Resources Ltd. (1993c) shows five spatially separate 'diamond discoveries' and five 'diamond indicator anomalies' in the Foothills between about Ram River and Grand Cache, Alberta. As well, Mr. C. Fipke of Dia Met Minerals Ltd. was quoted as saying that Dia Met has discovered indicator minerals on their Hinton block of mineral claims (Edmonton Journal 1993), and in the Northern Miner (1992) he is reported to have stated he has "*reason to believe that there are diamonds on the ground we have claimed*" in the Alberta Foothills, and "*we hope to outline a new pipe field and duplicate what we have already achieved in the Northwest Territories*". Takla Star (1993c) also stated that their initial exploration surveys have "*confirmed the presence of kimberlite and lamproite diamond indicator minerals on Takla's ground*" in Alberta. In an earlier press release Takla Star (1993a) stated they have found P3 and P4 type chromites in heavy mineral concentrates from two drainage areas centered about 10 km north of Saunders (anomaly 83C-4) and 15 km south of Nordegg (anomaly 83B-1) within their Ram River claim block in the central Foothills region near the North Saskatchewan River. The company suggested that these types of chromites may be indicative of diamond bearing lamproites. Takla's chromite anomalies in drainage sediments are in the vicinity of the Bighorn Tear Fault, which is a suspected deep-rooted structure, and along the projected southern extension of the Snowbird Tectonic Zone, which is a prominent basement structure beneath the Phanerozoic rocks (Ross *et al.* 1991). Takla Star (1993a) suggested that the Snowbird Tectonic Zone is geologically favourable for diamondiferous diatremes because it also underlies the Jack diatreme, which is reported to be lamproitic and contain diamonds (Fipke 1990). In southwest Alberta, Takla Star (Ibid) reported that a number of aeromagnetic anomalies exist on their Pincher Block of claims and that four of these anomalies "*are of a size and profile characteristically associated with diatremes*". Magnetic data which is contained within assessment reports filed for magnetite exploration in the Pincher Creek area, also indicate the presence of subcircular magnetic anomalies that may be characteristic of diatremes (West Canadian Collieries Ltd. 1957). In addition, Ecstall Mining Corporation reported during summer 1993 that "*stream sediments were ... [collected] from the Crowsnest, Oldman, Castle and Highwood rivers within the company's 508,000 hectare permit in southwestern Alberta. The work returned abundant chromite, as well as eclogitic G-5 garnets indicative of a lamproitic source rather than kimberlite*" (Northern Miner 1993d).

In short, the available evidence from company exploration information public releases, albeit unconfirmed by scientific studies, indicates that targets for diamond exploration exist in Alberta's Rocky Mountains and Foothills. One such target may exist in the Ghost River area northeast of Lake Minnewanka in the Paleozoic Front Range. There, Renn (1956) stated that brown iron and magnesium (?) rich silicate rocks (anomaly 82O-9) were found in their exploration of some bog iron deposits in the vicinity of the Ghost River Fault, an east trending vertical fault with evidence of vertical displacement (Fitzgerald 1962). In addition, anomalous chromium is reported from a "*yellow section of ore*" on one of the analytical sheets that accompany the assessment report (anomaly 82O-11; Renn 1956). This is of interest because a yellow-weathering clay-rich zone commonly exists at the top of weathered, preserved diatremes. That is, because chromium is an integral part of the chemistry of kimberlitic or lamproitic diatremes, it may be possible that the chromium- and magnesium-bearing bog iron deposits at the Ghost River area could be spatially associated with a mafic or ultramafic diatreme.

Although the geotectonic controls on kimberlite and lamproite emplacement are not well understood, it is believed that large-scale deep-seated structures must play some role in their ascent from the deep continental crust to the surface (Helmstaedt 1992; Gent 1992). This is because such deep-seated structures are needed to allow magma of kimberlitic or lamproitic affinity to escape the upper mantle and reach surface quickly, prior to reabsorption of any diamond xenocrysts. In the Alberta Rocky Mountains there are two such regional structures: (1) the Southern Alberta Rift and (2) the West Alberta Arch. The Southern Alberta Rift is believed to be a long-lived, deep-seated graben structure, hence marginal structural zones of weakness associated with the Rift may have provided conduit pathways for ascending kimberlite or lamproite diatremes. With respect to the West Alberta Arch, the Paleozoic alkalic igneous intrusions in the Rocky Mountains of British Columbia are distributed west of, but sub-parallel to the Alberta-British Columbia border. The northwest-trending West Alberta Arch was periodically active during the Paleozoic, and its western edge crudely approximates the distribution of these Paleozoic, alkalic intrusions in British Columbia. Bingham *et al.* (1985) suggested that a conductive ridge below the Eastern Rockies may be indicative of high heat flow in the lower crust and it also may be responsible for periodic uplift, extension and igneous activity such as that which occurred during the Paleozoic. Therefore, perhaps the eastern margin of the West Alberta Arch is also a favourable location to search for kimberlites and lamproites, particularly because it is closer to being 'on Archean craton', which is considered important for the existence of diamondiferous kimberlites and, possibly, lamproites.

The above discussion demonstrates that it is important in the exploration for potential kimberlites and lamproites in the Alberta Rocky Mountains to establish the expected intrusive/extrusive age of the alkalic, mafic to ultramafic igneous rocks being sought, and as a consequence, to focus exploration on the associated stratigraphic intervals that may have been intruded, particularly where these intervals are exposed or are near surface. Also important is an understanding of the regional and structural setting for exploration, and once diatremes have been found, the chemistry and mineralogy of the ultramafic host rock, and whether the host rock contains favourable diamond indicator minerals or, possibly, macrodiamonds or microdiamonds. In the Alberta Rocky Mountains and Foothills, important stratigraphic successions to explore for indications of potential kimberlite/lamproite intrusive activity include: (a) the Upper Devonian-Mississippian carbonate and shale succession, (b) Permian-Triassic strata, (c) Upper Lower Cretaceous strata at about the age of the Fish Scale Horizon stratigraphic marker, and (d) Tertiary sequences. The first and third time intervals may be more important for diamond exploration in Alberta because there are diamondiferous diatremes of Devonian-Mississippian age in British Columbia and Late Early Cretaceous age in Saskatchewan. The stratigraphic and paleogeographic setting at the time of intrusive emplacement is also important because many of the kimberlite/lamproite intrusions may have breached the surface subaqueously and be preserved as much wider-spread stratabound volcaniclastic deposits, rather than occurring as the classical carrot-shaped diatreme. Such volcaniclastic deposits are proving to be an important component of the Saskatchewan kimberlite fields (Lehnert-Thiel *et al.* 1992). It is also important to note that most of the Paleozoic successions of the Alberta Rocky Mountains and Front Ranges have been structurally detached, hence any diatremes of Paleozoic age may have structurally detached root zones and be partially eroded due to exposure since the early Tertiary or during the numerous Paleozoic unconformities that represent periods of subaerial exposure.

Sediment-Hosted Uranium Deposits

No important sediment hosted uranium occurrences exist in Alberta, hence an evaluation of the potential for uranium in the Rocky Mountains and Foothills of Alberta rests mainly on geological comparisons with other regions known to contain such uranium deposits. The principal types of sediment-hosted uranium deposits include:

(a) sandstone-hosted deposits, similar to those that exist in the U.S.A. in Wyoming, South Dakota, Colorado, Utah and New Mexico, as well as elsewhere in the world (DeVoto 1978);
(b) uraniferous lignite deposits, similar to those that exist in Europe, the northern U.S.A. and elsewhere (Denson and Gill 1965; Cvancara 1976a,b; Elevatorski 1977);
(c) carbonate-hosted deposits, similar to those present in New Mexico and western Australia (Ruzicka 1975; Langford 1978);
(d) basal conglomerate-hosted deposits, similar to those that exist in south-central British Columbia, Washington state and in Japan (Boyle 1982);
(e) uraniferous phosphorites, such as those that exist in Permian strata in Idaho, Utah, Montana and Wyoming, and in Pliocene strata in Florida (Ruzicka 1975); and
(f) uraniferous black shale, such as the Cambrian Alum Shale of Scandinavia (Bell 1978).

Not included in this sediment-hosted category of uranium are the unconformity-related uranium deposits which exist both in Precambrian basement rocks and overlying Proterozoic sandstone, similar to those that are present in Saskatchewan, northwestern Australia and the Northwest Territories of Canada (Hoeve and Sibbald 1978, 1979; Sibbald and Petruk 1985; Evans 1986). With respect to the above six types of sediment hosted uranium deposits, only the first four are discussed because world-wide, they are economically more important than the latter sediment-hosted types of uranium deposits. Although the last two types of sediment-hosted uranium deposits are not discussed herein, it should be noted that phosphate-bearing strata and black shales exist in several stratigraphic rock units in the Alberta Rocky Mountains and Foothills, hence some potential does exist for these types of uranium deposits to be present.

Following is a brief summary of the characteristics of the first four types of sediment-hosted uranium deposits and the potential for their existence in the Alberta Rocky Mountains and Foothills.

Sandstone-Hosted Uranium Deposits

Sandstone-hosted uranium deposits exist in many places throughout the world, and in the past they have been an economically important source of uranium production. Large uranium deposits of this type occur in sandstones of the western United States of America, in the former East Germany, in the former Czechoslovakia, in Hungary, in the former U.S.S.R. and elsewhere (Ruzicka 1975). Sandstone-hosted uranium deposits can be broadly classified into those that have a stratabound tabular or 'raisin-like' shape, such as those which exist in the Colorado Plateau, and those that are more discordant and are 'roll-front' shaped, such as those which exist in Wyoming and South Dakota (Fischer 1968; Harshman 1968). The tabular deposits can be further subdivided into those that are directly associated with organic matter and those that are vanadiferous with no direct association with organic matter. Examples of the former include the Grants uranium district of New Mexico, and examples of the latter exist in the Monument Valley, Lisbon Valley and Uravan uranium belts in southeast Utah and western Colorado (Wood 1968; Malan 1968; Motica 1968; Kelley *et al.* 1968). Although there are some differences within sandstone-hosted uranium deposits, there also are many commonalities. In general, the important geologically favourable guides for sandstone-hosted uranium deposits include: (a) continental, fluvial, lacustrine or marginal sedimentary sequences as host rocks, (b) abundant tuffaceous material or another source of uranium within the sedimentary sequence or nearby, (c) basin margin uplift during sedimentation, (d) spatial proximity to an oxidizing environment to facilitate the transport of uranium in groundwater, and (e) the presence of carbonaceous or humate matter, pyrite or some other suitable uranium reductant (Harshman 1968; Galloway 1978; Ellis 1979; Galloway *et al.* 1979; Galloway and Kaiser 1979; Adams and Saucier 1981; Adams and Smith 1981; Harshman and Adams 1981; Thamm *et al.* 1981; Crawley 1983). The occurrence of oxidized and reduced alteration fronts in sandstone is also commonly considered a prime exploration guide, but some epigenetic sandstone-hosted uranium deposits, such as those in the southern part of Texas, exist entirely within pyritiferous, reduced sandstone (Galloway *et al.* 1979).

At least some of these geologically favourable features exist in the Proterozoic and Phanerozoic strata in the Alberta Rocky Mountains and Foothills. For example, Bell (1977) reported that Hadrynian Miette Group sandstone, conglomerate and shale which is about 3.2 km east of Geike Creek on the Yellowhead highway west of Jasper, produces anomalously radioactivity up to "7 times background. *In situ* measurements suggests the anomaly is due to U rather than Th". Potential for sandstone-hosted uranium deposits also may exist in some of the Proterozoic arenites in the Clark Range. Goble (1976), for example, reported pitchblende and carnotite, and up to 4.81% U_3O_8 in Helikian Grinnell Formation quartzite at some of the numerous Cu-Ag occurrences that are present in southwest Alberta (e.g., anomaly 82H-1).

In the Phanerozoic strata, fine- to coarse-grained continental clastic rocks which, in places, contain coal or other carbonaceous matter, exist in the Late Jurassic to Cretaceous Kootenay Group, Lower Cretaceous Blairmore Group, Upper Cretaceous Belly River and St. Mary River Formations, Cretaceous to Paleocene Willow Creek Formation, and Paleocene

Porcupine Hills Formation. In many of these Phanerozoic rock units, and particularly the Upper Cretaceous and Lower Tertiary strata, volcanic material comprises a significant portion of the lithic fragments and, in places, tuff beds or other volcaniclastic horizons are abundant. No anomalous radioactivity has been reported in the Phanerozoic strata in the Rocky Mountains and Foothills of Alberta, but anomalous radioactivity has been observed locally in some of their stratigraphic equivalents. For example, Bell *et al.* (1976) discovered anomalously radioactive bone at three localities in southern Alberta. As well, reconnaissance uranium exploration along the Waterton River discovered a site from which a rock sample assays greater than 2,000 ppm U (>0.2% U) in a silty limestone in Willow Creek Formation (anomaly 82H-23; Grant 1982). Lastly, Van Dyke (1981) has provided a comparative uranium resource evaluation of selected rock units in Alberta with geologically equivalent strata in the United States of America.

During 1992, a geochemical stream sediment sampling program was conducted in southwest Alberta under the Canada-Alberta MDA (Williamson *et al.* 1993). Twelve sites produced stream sediment samples with a uranium content that ranges from 4.0 to 5.1 ppm U, including three samples with 5.0 or 5.1 ppm U. These uranium contents exceed the 97.5 percentile for the 1992 uranium results. Other sampling has shown that the uranium content of stream sediments in areas underlain by Phanerozoic rocks in the Plains Region averages about 2.4 ppm U, and values which exceed about 5.0 ppm are 'anomalous' (Southard 1978; Olson 1984, 1985a). The three samples with 5.0 or 5.1 ppm U in southwest Alberta, also contain elevated concentrations of copper (Williamson *et al.* 1993). These three samples are from tributaries to Lynx Creek, Pincher Creek and the West Castle River that drain either Proterozoic or Cretaceous sedimentary rocks. Two other samples with elevated uranium concentrations and associated other metals exist near the headwaters of the Livingstone River, north of Coleman. Williamson *et al.* (1993) stated that the cause of the elevated uranium concentrations and other metals at these sites is unknown. It is possible, therefore, that one or more of these anomalously uraniferous streams are associated with a uranium occurrence in bedrock and therefore are of exploration interest.

Uraniferous Lignite Deposits

Uranium-bearing coals have been mined solely for their uranium content in Europe, the northern United States of America and elsewhere (Ruzicka 1975). Most of the uranium in coals and lignites is of epigenetic origin and was derived from rocks containing abnormal contents of uranium, such as acidic intrusive and extrusive igneous rocks. In general, the important geologically favourable guides for uraniferous lignite deposits include: (a) carbonaceous or lignitic host rocks characterized by high ash contents and high permeabilities, (b) stratigraphic proximity of the carbonaceous host rocks to an unconformity at the base of overlying strata, particularly those of Tertiary age, (c) the existence of thick permeable strata directly overlying and, in places, underlying the carbonaceous unit, (d) shallow structural troughs superimposed on a broad regional structure, and (e) volcanic ash or other volcanic material in the country rocks to provide a readily available source of uranium (Denson and Gill 1965; Pipiringos *et al.* 1965; Noble 1973; Cvancara 1976a,b; Elevatorski 1977; DeVoto 1978). In the northern United States of America, the uraniferous lignite deposits are divisible into two types: "*blanket-type ore bodies which are of relatively uniform mineralization over a large area, and lenticular deposits of higher grade, but generally smaller and irregular in shape. Of the two types, the lenticular type is more prevalent. The lenticular deposits have commonly been found in groups or clusters. ... Most of the deposits have reserves of less than 50,000 tons* [45,360 tonnes]. *Thicknesses range from one to three feet* [0.3 to 0.9 m], *with an average grade of 0.20%* U_3O_8" (Elevatorski 1977). In Canada, uraniferous lignite exists in Tertiary strata in southwestern Saskatchewan and, to a much lesser extent, in southeastern Alberta (Chamberlain 1960; Lang *et al.* 1962;

Cameron and Birmingham 1968, 1970; Cameron *et al.* 1969, 1970). In general, the most anomalous area that has been discovered exists in lignite in Paleocene Ravenscrag Formation near Eastend, Saskatchewan. At this locale, there is anomalous radioactivity up to 40 times background and lithogeochemical samples from outcrop and drill core that assay up to 0.126% U_3O_8.

At least some of the geologically favourable features for uraniferous lignite exist in the Rocky Mountains and Foothills of Alberta. Coal-bearing horizons exist in Jurassic Kootenay Group and Upper Cretaceous Belly River Formation. Although lignite horizons exist in Paleocene Paskapoo Formation in central Alberta and in Paleocene Ravenscrag Formation in southeastern Alberta, lignite or other coaly zones are not reported in the age-equivalent Paleocene Porcupine Hills Formation in southwestern Alberta. To date, important anomalous radioactivity or uranium occurrences have not been discovered associated with the coal-bearing Jurassic and Cretaceous sequences in the Rocky Mountains and Foothills of Alberta. Van Dyke (1981), however, suggested that coal in Upper Cretaceous-Tertiary Scollard Formation in central Alberta may be favourable for uranium concentrations. Hence, it is possible that uraniferous coals may also be present in some strata in southwest Alberta.

Carbonate-Hosted Uranium Deposits

Examples of carbonate-hosted uranium deposits include those present in the Todilto Limestone of New Mexico, and at Yeelirrie, Australia (Langford 1978; Rawson 1980). For the Todilto limestone-hosted uranium deposits, the important geologically favourable criteria include: (a) the margins of carbonate reefs, especially those locales that are organic-rich, (b) an underlying sandstone or other porous rock unit, (c) locales of more intense folding, faulting and/or jointing, (d) recrystallization of the carbonate host, (e) hematitization, (f) existence of certain accessory minerals, including vanadium and manganese oxides, fluorite, barite and pyrite, and, possibly, (g) evaporite conditions during or shortly after deposition of the carbonate host rock to facilitate the circulation of meteoric water (Perry 1963; Rawson 1980). For the Yeelirrie type uranium deposits, the important geologically favourable criteria include: (a) a basement area of moderate to low relief that is being deeply weathered in an arid climate, (b) a large slow-moving volume of reducing or slightly oxidizing water flowing off an extensive granitoid catchment area, (c) a locale where the uranium-bearing waters are constricted, (d) partial evaporation of these waters to promote high concentrations of uranyl ion in the solution, and (e) an upwelling of these waters into an oxidizing environment and/or mixing of these waters with other waters or lithologies that contain a suitable reductant (Mann and Deutscher 1978; Langford 1978).

At least some of the geological features believed favourable for carbonate-hosted uranium deposits are, or were, locally present in some stratigraphic units in the Rocky Mountains and Foothills of Alberta. In the Clark Range, for example, Proterozoic Siyeh, Sheppard and Kintla Formations contain carbonate rocks interbedded with fine- to coarse-grained clastic sedimentary rocks that were deposited in a shallow-water to, at times, hypersaline environment (Aitken and McMechan 1992). Another potentially favourable unit for carbonate-hosted uranium deposits is Triassic Spray River Group which consists of fine- to medium-grained clastic sedimentary rocks, carbonate horizons, intraformational breccia and, in places, evaporites that were deposited marginal to and derived from a craton of low relief (Gordey *et al.* 1992). Also present in the Rocky Mountains of Alberta is a thick succession of Paleozoic carbonate units. However, these carbonates are not considered to be as favourable for carbonate-hosted uranium deposits because they mainly were deposited in a platformal marine environment. Nonetheless, it is possible that some of the Devonian strata in the Rocky Mountains may be potentially favourable host rocks for uranium because during the Devonian, the West Alberta Arch highland existed near the present Alberta-British Columbia border, and carbonate with interbedded clastic sediments and, in places, evaporites were being deposited (Fritz *et al.* 1992; Gordey *et al.* 1992). Lastly, the uranium occurrence that assays 0.2% uranium (anomaly 82H-23) which was discovered by Grant (1982) in silty limestone of Willow Creek Formation, may indicate that limy units in the Upper Cretaceous to Paleocene Willow Creek Formation should be examined for their potential to contain carbonate-hosted uranium deposits.

Basal Conglomerate Hosted Uranium Deposits

Basal conglomerate hosted uranium deposits exist in several places throughout the world, including southern British Columbia, Washington State, France and Portugal (Boyle 1982). Typically, this type of uranium deposit is not large, but in some places economic production has occurred (e.g., Sherwood mine, Washington State). In general, the more important geologically favourable features associated with basal conglomerate hosted uranium deposits include: (a) basement rocks with an above background uranium content, (b) a regolith or saprolitic zone in the basement rocks, (c) fluvial channels filled with relatively permeable conglomerate and related clastic sediments, (d) carbonaceous material or other suitable reductants in the host sediments, (e) faults and fracture zones underlying or proximal to the channel, (f) a cap rock which assists in focusing mineralizing fluid flow, and (g) local intrusive rocks such as dykes or diatremes that may have assisted in the initiation of circulation of the mineralizing fluid (Christopher and Kalnins 1977; Boyle 1982, 1985; Katayama and Kamiyama 1976).

At least a few of these geologically favourable features exist in some of the sedimentary formations in the Rocky Mountains and Foothills of Alberta. In most cases, the formations with the favourable geology are the same continental sequences that were discussed above under "Sandstone-Hosted Uranium Deposits". However, an unfavourable condition in the Rocky Mountain and Foothills of Alberta is that saprolitized basement rocks with an above background uranium content are not present. In summary, the potential for basal conglomerate hosted uranium deposits may be low in the Rocky Mountains and Foothills of Alberta, but their existence at this time cannot be ruled out.

RESOURCE POTENTIAL OF THE PRECAMBRIAN BASEMENT AND OVERLYING PHANEROZOIC STRATA IN THE PLAINS REGION OF ALBERTA

Prior Work and Known Mineral Resources

Exploration for and, in a few places, mining of metallic minerals in the Phanerozoic strata that underlie the Plains Region of Alberta have occurred on a small scale during several time periods. In the late 1800's, placer gold mining peaked in the vicinity of Edmonton along the North Saskatchewan River. In the late 1950's, sedimentary oolitic iron deposits at the Clear Hills district in northwestern Alberta were discovered and extensively explored. During the late 1960's to early 1980's, several companies attempted to evaluate Cretaceous and Tertiary sedimentary rocks of the Phanerozoic basin for a variety of sediment-hosted uranium deposits similar to those present in the United States of America. More recently, exploration has been directed towards diamondiferous kimberlites or lamproite diatremes or diamondiferous alluvial deposits derived by the erosion of such diatremes. In short, although at present there may be few metallic mineral occurrences or indications of diamondiferous deposits in the Plains region of Alberta, this study has documented numerous geological, geochemical and geophysical anomalies that may indicate the presence of such 'metalliferous' deposits (Figure 3, Maps 1 to 3).

Placer gold was discovered in workable quantities along the North Saskatchewan River in 1861 (Allan 1920), and McConnell (1891) reported the discovery of potentially economic concentrations of placer gold along the Peace River in 1890. For the North Saskatchewan River, Allan (Ibid) stated no available records exist that accurately document the amount of gold recovered between 1861 and 1886, but he (Ibid) estimated that between 1887 and 1915 more than 15,000 fine ounces (about 466.5 kg) of gold were recovered, with the peak years being from 1895 to 1897. The available records indicate that the highest concentrations of placer gold in unconsolidated river or preglacial gravels in Alberta have been produced in the vicinity of Edmonton from the North Saskatchewan River or from the associated preglacial upland gravel benches (Halferdahl 1965; Giusti 1983; MacGillivray *et al.* 1984; Edwards 1990). In the upland gravels of the mid-Wisconsinan Empress Formation near Villeneuve, for example, Edwards (1990) reported the gold content ranges from 0.22 to 0.575 g Au/t (Map 2, anomaly 83H-12).

Elsewhere in Alberta, rivers that have yielded concentrations of placer gold greater than 0.01 g Au/t include the Peace, Athabasca, McLeod, Red Deer and Milk Rivers. All occurrences of placer gold in gravel samples that exceed 0.01 g Au/t are compiled on Maps 1, 2 and 3, except those samples that assayed at or near a detection limit that was above 0.01 g Au/t. All of the compiled gold in gravels data are from four sources: Halferdahl (1965), Giusti (1983), MacGillivray *et al.* (1984) and Edwards (1990). Most of the higher grade placer gold occurrences in the above five rivers exist well east or north of the Rocky Mountains and Foothills.

In addition to the 'anomalous' gold in river gravels, any mention of anomalous platinum or other rare metals have been also compiled from these same four references (Ibid). Bi and Morton (1993) have reported that placer platinum group metals, which are associated with many of the placer gold occurrences in Alberta, have an alloy and trace element chemistry that is similar to Alpine-type ultramafic complexes such as those at Tulameen, British Columbia. They (Ibid) suggested that the platinum group metals and gold in Alberta rivers are derived from paleoplacers within Upper Cretaceous or Paleocene clastic rocks, which in turn were derived from the erosion of allochthonous terranes west of the Rocky Mountains prior to uplift during the Cordilleran Orogeny. Supportive evidence for this is the fact that the higher grade placer gold occurrences along the Peace, North Saskatchewan and Red Deer Rivers exist in areas underlain by Lower Upper to Upper Cretaceous rocks and east of Upper Cretaceous and Tertiary strata. Therefore, potential for paleoplacer gold deposits may exist in Upper Cretaceous or Paleocene rocks to the south or west of the Recent auriferous river gravels. More recently, however, Ballantyne and Harris (1994) have suggested that some of the platinum group metals in the rivers in central Alberta may be derived from deep-seated mantle-derived mafic diatremes.

Lode type gold has been reported in the basement rocks of the Fort MacKay area (Map 5, anomaly 74E-26; Allan 1920; Halferdahl 1986) as discussed previously in the Precambrian Shield section of this report. With respect to the Athabasca Oils Ltd. No. 1 well, there is some question as to whether the reported gold-bearing zone was intersected in the Precambrian basement rocks, or in the overlying Devonian sedimentary strata (Halferdahl 1986). In March 1986, Halferdahl (Ibid) supervised two holes that were drilled on the east side of the Athabasca River about 35 km southerly of the Athabasca Oils Ltd. No. 1 well [assessment report UAF-169(1)]. A sample was collected from core from drill hole 86-2R at a depth of 241.4 m in Devonian Methy Formation (Ibid). The sample is reported to have assayed 0.063 oz At/T (2.16 g Au/t), and is from a fractured zone where the drillers had lost circulation, about 2.3 m below a zone with minor amounts of chalcopyrite and malachite (Ibid). Also in March 1986, Tanner Arctic Oil Ltd. drilled a hole about 1.3 km south of the Athabasca No. 1 well; five samples were collected but they all returned "*gold concentrations in the low ppb range*" (Ibid). More recently, Focal Resources Ltd. (1993) is reported to have collected surface samples from Devonian limestone and drilled at least 14 holes at their 'Bradley Property' in northeastern Alberta; most of the holes are vertical and short, being about 15 m to 30 m in length (Northern Miner 1993a; Focal Resources Ltd. 1993). The surface samples are reported to have "*returned values up to two ounces gold per ton, 1.19 oz. platinum, 1.3 oz. rhodium, 4.46 oz. osmium, 3.74 oz. ruthenium, 0.17 oz. palladium and 10.49 oz. iridium. ... Significant* (drill) *intercepts include* *five feet grading 0.4 oz. gold per ton, 2.29 oz. platinum and 0.54 oz. rhodium in Hole 1. ... The mineralized sections also contain appreciable amounts of silver, palladium, osmium, ruthenium and iridium.*" (Ibid). Subsequently, however, it was reported that the above assays were done using "*non-traditional techniques*", but that standard fire assay techniques did give results for five feet intervals of core from Hole 5 where "*one interval returned more than one ounce gold and 50.76 oz. silver while a second returned 0.53 oz gold and no silver.*" (Northern Miner 1993c). Little information is available about the geology of the mineralized intercepts, but apparently the zone is in "*Devonian limestone with high silica and commercial values of gold and platinum group metals in salt form*" (Northern Miner 1993b). During summer 1993, Tintina Mines Ltd. (1993) collected 85 surface rock samples and drilled about 600 m in four vertical holes at their property near Fort MacKay; they reported two drill holes "*were necessarily abandoned in major fault zones at 100 ft and 600 ft ... two of the drill holes encountered severe collapse breccia zones within the upper 500 feet, wherein very finely disseminated microscopic sulfides, sulfide pods, spheroids and sulfide healed fractures are common*". For the 85 surface rock samples, they (Ibid) stated 22 samples were randomly selected and submitted for analysis for gold, silver and PGE's, and that "m*any of the surface samples are characterized by oxidized and ankeritized gossanous material*". The reported fire assay results for these surface rock grab samples include: (a) two samples that assay 10.69 and 15.52 g Au/t, (b) three samples that assay from 5.0 to 10.0 g Au/t, (c) nine samples that assay from 1.0 to 5.0 g Au/t, and (d) five samples that have a low but anomalous gold content ranging from 0.15 to 1.0 g Au/t (Ibid). The reported Atomic Absorption results for silver for these same samples range from 1.0 up to 18.97 g Ag/t. The Devonian rocks that exist at surface in this area are geologically mapped as Upper Devonian Waterways Formation carbonates (Carrigy 1959; Norris 1963). During early 1994, the Geological Survey of Canada (Abercrombie and Feng 1994) reported on the analytical results for some surface rock and drill core samples that they had obtained from Tintina Mines Ltd.'s (1993) work at Fort MacKay area. Abercrombie and Feng (Ibid) stated that "*a number of surface and core samples (carbonates and sandstone) from the* [Fort MacKay] *region were tested by solution and laser ablation inductively coupled plasma-mass spectrometry (ICP-MS)*". Further, that for "*the six samples analyzed, four have Au contents between 0.3-1 ppm, one is 2 ppm, and the highest is 10 ppm* [which equals 10 g Au/t]. *No PGE were detected except for two samples with Pd contents of 30 and 110 ppb. These preliminary results indicate that abnormal amounts of Au and PGE exist is Phanerozoic sedimentary rocks of northeastern Alberta*" (Ibid). In summary, although some questions remain as to the exact geographic location of the surface rock samples which have been collected and some of the holes which have been drilled near anomaly 74E-26, the depth at which core some samples were collected, and the analytical validity of some of the reported precious metal results, it is possible that anomalous concentrations of gold, and possibly silver and selected platinum group elements, do exist locally in either or both the basement rocks or the Phanerozoic strata in the Fort MacKay area of Alberta.

Oolitic iron deposits were discovered in the Peace River region during the 1950's as a result of petroleum exploration activities (Kidd 1959; Bertram and Mellon 1973, 1975). Peace River Mining and Smelting Ltd. defined more than 1.1 billion tons of potential resource grading between 32 and 35 per cent total iron by drilling approximately 245 drillholes between 1959 and 1965 (Edgar 1961, 1962, 1964, 1965; Bertram and Mellon 1973, 1975). The iron deposits exist as four discreet bodies along the southeastern slopes of the Clear Hills, which is about 100 km northwest of the town of Peace River (Map 3, anomalies 84D-3 to -6). The iron formations are hosted in and intercalated with Upper Cretaceous Bad Heart Formation sandstone within Smoky River Group, which is dominantly comprised of dark marine shales. The iron formation comprises a dark brown to black ferruginous oolitic sandstone with interbeds of sideritic ironstone and mudstone. The oolitic iron formation ranges in thickness from 1.5 to 9 m and is dominantly composed of densely packed oolites with the major iron-bearing minerals being goethite and siderite (Bertram and Mellon 1973, 1975). Presently, these deposits are only a resource because they are low grade and mineralogically complex in comparison to other types of iron ore deposits. Many other occurrences of iron exist in the vicinity of and south of the Clear Hills, but most are yet to be evaluated.

Uranium exploration in the Phanerozoic basin of the Alberta Plains has been performed by an assortment of companies from the late 1960's to the early 1980's based upon geological similarities to several types of sedimentary hosted uranium deposits in Phanerozoic basins of the United States of America and other parts of the world. During the late 1960's, detailed fieldwork and drilling were performed in the Cypress Hills area of southeast Alberta (Hage 1968; Newman *et al.* 1970). The target was uranium in Tertiary coals and lignites. Newman *et al.* (1970) reported up to 0.01% U_3O_8 across 2.44 m from drill core of carbonaceous claystone within the Ravenscrag Formation (Map 1, anomaly 72E-2). Subsequent drilling did not extend the intersected zone. Bushell (1970) reported a gamma ray log of 30 times background for a lignite seam within the Ravenscrag Formation in the vicinity of Thelma (anomaly 72E-26). Siddle *et al.* (1979) reported up to 240 ppb U in well waters in the vicinity of a 'faulted zone' at the Eagle Butte Structure in the Bullshead Creek area of the Cypress Hills (anomaly 72E-14). Southwest of the Cypress Hills near Foremost, Siddle *et al.* (1979) also reported up to 144 ppb U in well waters and up to 18 ppm U in rock samples from Upper Cretaceous argillaceous sandstone of the Milk River Formation (anomaly 72E-16). However, Thomas and Trigg (1980) completed follow-up work in the Bullshead Creek and Foremost areas and concluded that the reported anomalous results from Siddle *et al.* (1979) may be attributable to natural variations rather than to indications of important uranium mineralized zones.

During 1980 and 1981, Grant (1981, 1982) conducted uranium exploration at selected locales underlain by Upper Cretaceous and Lower Tertiary rocks in the Plains of southern Alberta. The exploration methodology comprised geochemical stream sediment sampling, car-borne spectrometer surveying, ground radiometric prospecting and geological examinations. The average uranium content for 325 stream sediment samples that were collected during the survey was 0.6 ppm. Anomalous samples that contain from 4 to 6 ppm uranium were collected northeast of Claresholm (Map 1, anomaly 82I-1), along the Little Red Deer River in the vicinity of Sundre (Map 6, anomalies 82O-23 to -25) and along the North Saskatchewan River (Map 2, anomaly 83B-2) in the vicinity of Rocky Mountain House (Grant 1981). Geochemical results for grab rock samples were up to 114 ppm Mo, 120 ppm V and 3.0 ppm U in a coal-rich limonitic zone in the Willow Creek Formation immediately below Porcupine Hills Formation basal conglomerate about 30 km northwest of Fort MacLeod (Map 1, anomaly 82H-19; Ibid). Follow-up fieldwork of the Willow Creek Formation discovered a silty limestone with local anomalous radioactivity along the Waterton River about 30 km south of Fort MacLeod (Grant 1982). At one occurrence, anomalous radioactivity is up to 2,000 cps (SRAT SPP2N), and a rock sample assays greater than 2,000 ppm U, 13 ppm Mo, 78 ppm V and 4 ppm Se (anomaly 82H-23). Upriver about 5 km there is a second occurrence with anomalous radioactivity up to 900 cps and a rock sample that assays 85 ppm U (anomaly 82H-21; Ibid). Follow-up work was recommended for this area, but was never done.

International Mine Services Ltd. conducted a reconnaissance uranium exploration program that involved sampling Upper Cretaceous and Paleocene continental sedimentary sequences from southern Saskatchewan to northwest Alberta (Edmond 1970). Wapiti Group sandstones in the Grande Prairie area were selected for follow-up work which consisted of an airborne radiometric survey, and petrographic and geochemical studies of cuttings from oil and gas wells (Ibid). Samples from the well cuttings yielded assay results of up to 100 ppm U across 3.05 m (Map 2, anomaly 83M-4) and 100 ppm U across 6.10 m (anomaly 83M-6). Other elements that are reported to be anomalous include up to 2,000 ppm Zn and 200 ppm Pb across 3.05 m (anomaly 83M-5), 400 ppm Ni across 9.14 m (anomaly 83M-4) and 400 ppm V across 6.10 m (anomaly 83M-6). Edmond (1970) considered these and other elements, such as As, Cu and Mo, As potential pathfinder elements for sandstone hosted uranium deposits similar to those of the Colorado Plateau. A drilling program was recommended in order to follow-up the results of the 1970 program; however, there is no evidence that any follow-up work was performed.

Only a small amount of exploration for base metals has occurred in the Phanerozoic basin of the Alberta Plains Region. In the past, the only area considered favourable for base metals in the

Plains Region is northeast Alberta because of the proximity of Paleozoic carbonates to surface, and the presence of a few minor base metal occurrences. Carrigy (1959), for example, reported the presence of galena associated with a dolomitized zone in the Methy Formation at Whitemud Falls along the Clearwater River near the Saskatchewan border (anomaly 74D-4; Map 3). La Casse and Roebuck (1978) reported the presence of enargite and malachite at one location and enargite at two other locations along the Clearwater River west of Whitemud Falls and east of Fort McMurray (anomalies 74D-1 to -3). Godfrey (1985) reported that prospectors had found lead-zinc occurrences in Wood Buffalo National Park, but that the finds were never substantiated. Interestingly, at anomalies 74M-92 to 74M-96 (Map 4), which are underlain by Devonian and older strata, water samples contain up to 18.6 ppb U and lake sediment samples contain up to 17.4 ppm U, 340 ppm Zn, and 'anomalous' amounts of Mo, Pb, Ni, Ag and/or Cu (Gleeson 1979). The exact cause of these anomalies is uncertain. To the southwest, along the south slope of the Caribou Mountains, Swinden and Horsley (1971) reported that a rock specimen of quartz containing bornite and a second specimen of chalcocite and bornite in a matrix of dolomite, chlorite and serpentine, were found by trappers (Map 3, anomaly 84J-1). The specimens were brought to Conwest Exploration Company Ltd. who carried out a prospecting and stream sediment sampling program (Ibid). The company was not able to relocate the mineral occurrences, even with the aid of the trappers who discovered the original specimens. Swinden and Horsley (1971) concluded that the specimens were probably collected from abundant glacial drift in the area, much of which is derived from the Precambrian Shield to the northeast. In northeast Alberta, east of the Athabasca River and south of Lake Athabasca, there is only one documented exploration program for Pb-Zn in the assessment records (Groettler 1969). This report describes a small geophysical and geochemical program which was performed northeast of Fort MacKay in the Firebag River area that discovered up to 150 ppm Zn and 22 ppm Hg in soil samples (anomaly 74E-31). However, thick glacial overburden exists in the area sampled, hence the source of the anomalous geochemical results is uncertain.

Zinc with lesser amounts of lead or copper sulphides in subsurface Paleozoic carbonates has been documented in wells at some oil and gas fields in several places in the Plains Region of Alberta (Hitchon 1977, 1993; Dubord 1987, 1988). Hitchon (1993), for example, shows at least 16 reported sphalerite and galena occurrences in the subsurface from hydrocarbon drilling. Those hydrocarbon fields with associated base metal sulphides include: (1) Rainbow (Map 3, anomalies 84L-1 to -4 and 84N-1; Hriskevich 1966; Dubord 1987, 1988; Muir and Dravis 1991), (2) Tangent and other fields associated with the Peace River Arch (Maps 2 and 3, anomalies 83L-1, -2, 83M-1 to -5, 83N-3, 84B-1, 84C-1 and 84D-1; Matheson 1969; Edmond 1970; Hitchon 1977; Dubord 1987, 1988; Packard *et al.* 1991), (3) Wizard Lake (Map 2, anomaly 83H-1; Moore 1953; Haites 1960), (4) Bonnie Glen (Haites 1960), (4) Leduc (Map 2, anomalies 83H-2 to -4; Alberta Research Council no date; Dubord 1987, 1988), (6) Duhamel (Map 2, anomalies 83A-2 and -3; Haites 1960), (7) New Norway (Alberta Research Council 1953; Haites 1960) and (8) Malmo (Haites 1960). It is of interest that formation waters from several of these hydrocarbon fields, such as Duhamel, Bonnie Glen and Malmo, also contain some of the highest values for zinc in Alberta formation waters (Hitchon *et al.* 1971). Table 11 provides details about well names, their township-range location, the types of anomalous base metals present and the host rocks, and Figure 4 shows the approximate location for each base metal-bearing well. In most cases, there are minimal geochemical data available for these well intersections, but a potentially economic grade of 9.9% zinc across 5.58 m, with a higher grade zone of 15.3% zinc across 2.29 m, was reported for Sun-Orr well No. 2-1 from the New Norway oil field (Map 2, anomaly 83A-4, Alberta Research Council 1953). No other metals were analyzed for in this well. The intersection is in Late Devonian reefal carbonates of the Leduc Formation (commonly referred to as the D3 reefal horizon). Another subsurface sulphide occurrence of note in Paleozoic carbonates is a galena occurrence with possible sphalerite that was intersected in a base metal exploration program performed by Gulf Minerals Canada Ltd. in the Steen River area (Map 3, anomaly 84N-4, Germundson and Fischer 1978). Five diamond drill holes were drilled to test Devonian carbonates for copper, lead and zinc mineralized zones in the vicinity of the Steen River structure (anomalies 84N-3 to -6; Table 4). The holes intersected the top of the Devonian section

TABLE 11

WELLS WITH ANOMALOUS PB-ZN IN THE PLAINS REGION

NTS-ID #[1]	WELL NAME	WELL LOCATION Lsd-Sec-Twp-Rg	METALS	HOST UNIT	HOST UNIT AGE	DEPTH TO ZONE (m)[2]
83A-2	Socony-Duhamel #29-14	14-29-45-21 W4	Zn	Woodbend (D3)-Winterburn (D2)	Late Devonian	1,371.0 to 1,467.9
	Socony-Duhamel #29-11	11-29-45-21 W4	Zn	Upper Woodbend (D3)	Late Devonian	1,445.1
83A-3	Socony-Flint #1	13-17-45-21 W4	Zn	Upper Woodbend (D3)	Late Devonian	1,478.3
83A-4	Sun-Orr #2-1 New Norway	2-1-45-21 W4	Zn	Woodbend (D3)	Late Devonian	1,468.8 to 1,490.5
83H-1	Texaco Wizard Lake B-2	5-22-48-27 W4	Zn	Winterburn (D2)	Late Devonian	1,734.0 to 1,734.9
83H-2	Imperial Leduc 253	11-13-50-27 W4	Zn	??		1,792.5 to 1,800.1
83H-3	Imperial Golden Spike #11	11-23-51-27 W4	Cu	Beaverhill Lake	Late Devonian	1,940.4 to 1,955.6
83H-4	Imperial Golden Spike #8	11-26-51-27 W4	Pb	Woodbend (D3)	Late Devonian	1,586.2 to 1,601.4
83J-1	Home KCL Chisholm	10-5-68-2 W5	Pb+Zn	Lower Winterburn	Late Devonian	?
83L-1	?	SE-30-63-4 W6	Zn	Lower Wapiti	Late Cretaceous	?
83L-2	?	SW-8-68-1 W6	Pb+Cu	Lower Wapiti	Late Cretaceous	?
83M-1	B.A. Saddle River	11-23-76-9 W6	Zn	Spray River-Belly R. contact	Triassic - Late Cretaceous	?

83M-2	BP Ethyl Whitburn 7-3	7-30-80-11 W6	Zn	Wabamun-Banff transition	Late Devonian - Early Carboniferous	?
83M-3	Unknown	SW-13-74-11 W6	Zn	Lower Wapiti	Late Cretaceous	?
83M-4	Merrill Calvan Charter Scurry Grande Prairie #4-14	4-14-73-7 W6	Zn+Cu	Lower Wapiti	Late Cretaceous	125.0 to 134.1
83M-5	Imperial Clairmont #1	16-25-72-5 W6	Zn+Pb+Cu	Lower Wapiti	Late Cretaceous	64.0 to 67.1
83N-2	Tangent-Eaglesham Field	several wells	Zn+Cu	Upper Wabamun	Late Devonian	?
84B-1	Calstan et al. Loon River	4-23-89-12 W5	Zn	Muskeg	Middle Devonian	?
84C-1	Lubicon Lubicon EV	2-21-87-13 W5	Cu	Winterburn	Late Devonian	1,109.5
84D-1	PCL Dome Oak	11-8-83-6 W6	Zn	Wabamun	Late Devonian	?
84L-1	Banff Aquitaine Rainbow West 7-32	7-32-109-8 W6	Zn	Muskeg	Middle Devonian	1,766.0
84L-2	B.A. Zama Lake	9-5-114-8 W6	Zn	Keg River.	Middle Devonian	?
84L-3	B.A. Zama Lake A	6-33-113-7 W6	Zn	Keg River	Middle Devonian	?
84L-4	IOE Rainbow	13-20-107-9 W6	Zn	Keg River	Middle Devonian	?
84N-1	Chevron Lutose	16-34-118-21 W5	Zn	Keg River	Middle Devonian	?
84N-4	Gulfmin Anita EV	3-3-121-19 W5	Pb+Zn(?)	Lower Winterburn	Late Devonian	178.0, 181.1

[1]ID # refers to Figure 4. [2]Refers to depth from land surface.

at varying depths ranging from 77 m to 138 m below surface. The entire section that contains the galena occurrence was assayed as one sample and returned a value of 70 ppm Pb across 3.05 m. As well, one sample that is from Late Devonian Winterburn Group carbonate from just above the Calmar Formation shale, assays 220 ppm Zn across 2.6 m (anomaly 84N-5).

A few base metal anomalies have been discovered in Cretaceous rocks within the Alberta Plains. For example, in the drilling program performed by Gulf Minerals Canada Ltd. in the Steen River area, which was primarily designed to test Devonian carbonates, the highest base metal values were obtained from mid Cretaceous Fort St. John Group black shales intercalated with bentonites (Germundson and Fischer 1978). Assays are up to 820 ppm Zn, 310 ppm Cu, 150 ppm Ni and 18 ppm Cd across core intervals up to 3.05 m (Map 3, anomalies 84N-4 to -6). In the Grande Prairie area, Edmond (1970) reported the presence of sphalerite, galena, chalcopyrite and loellingite in oil and gas well cuttings from Late Cretaceous Wapiti Group siltstones and sandstones (Map 2, 83L-1, -2, 83M-3 to -6). He (Ibid) also reported assay results for the well cuttings that are up to 2,000 ppm Zn and 100 ppm Pb across 3.05 m, 400 ppm Ni across 9.14 m, and 100 ppm U and 400 ppm V across 6.10 m. Elsewhere in northwest Alberta, Edmond (Ibid) reported up to 2,000 ppm Zn, 200 ppm Pb, 100 ppm Ni and 100 ppm Co from outcrops of Wapiti Group pyritic sandstone along the Wapiti, Smoky and Simonette Rivers. Lastly, La Casse and Roebuck (1978) reported the presence of bornite and azurite in limey units of the Upper Cretaceous to Tertiary Paskapoo Formation in a coulee along the north bank of the Red Deer River about 9.6 km east of Red Deer (Map 2, anomaly 83A-1).

In some places, base metal anomalies, specifically vanadium and nickel, exist in Cretaceous oil-sand reservoirs such as the McMurray Formation. Oil from McMurray Formation oil-sands typically contains an average of 360 ppm V_2O_5 and 93 ppm NiO (Scott *et al.* 1954). In NMI sheet 115110, the Government of Canada (1984) reported that Suncor Inc. produces approximately 33,000 tons of fly ash per year from its oil-sands operation at Fort McMurray. The fly ash contains 4.5% V_2O_5, and may also contain significant amounts of nickel, copper, gallium, scandium, gold and silver.

The most recent, and perhaps the most active, mineral exploration effort in Alberta is being directed toward the search for diamondiferous kimberlite or lamproite diatremes. A more favourable regulatory environment, the discovery of diamondiferous diatremes in the N.W.T. and Saskatchewan, and the reported existence of diamonds and diamond indicator minerals in surficial drift in Alberta have precipitated a major staking rush in the Plains and Foothills regions of Alberta. At present, however, there are little substantiated data that are publicly available on the results of this diamond exploration. Since 1988, Monopros Ltd. has been exploring a large block of ground in the Plains Region in the vicinity of Peace River, but as yet they have not released any information on their work. However, in an article in the Grande Prairie Daily Herald Tribune (1992), a representative of Ridgeway Petroleum Corp., a company with a large land holding in the Peace River that they are exploring for diamondiferous deposits, has stated "*they* [Monopros] *did quite a bit of drilling and we have reason to believe that they did encounter a lamproite pipe while drilling for trace minerals. ... We think from a reliable source that people have seen the core and identified it as such.*" As well, a corporate press release by Takla Star Resources Ltd. (1993c), shows "*diatremes*" present within the block of mineral claims held by Monopros at Peace River, but the source of this information is unknown. Diamonds have been found locally in Alberta, with probably the most famous being the 'Oppdal diamond'. A prospector, Einar Oppdal, reportedly found one or more diamonds in gravels of the Pembina River west of Edmonton (Map 2, anomaly 83G-1; Edmonton Journal 1992b; Morton *et al.* 1993). Diamonds have also been discovered in gravels of the North Saskatchewan River and associated tributary creeks east of Edmonton (Bryant, *pers comm.* 1993; Morton *et al.* 1993), and in glacial till at Etzikom Coulee near Legend, southern Alberta (Map 1, anomaly 72E-8; Edmonton Journal 1992a; Morton *et al.* 1993; Takla Star Resources Ltd. 1993a). As well, microdiamonds have been reported along the Red Deer River in central Alberta at or near the Cretaceous-Tertiary boundary (Science City News 1992). The bedrock sources for the various reported occurrence diamonds in drift is uncertain at present.

Discussion of Resource Potential

The only important metallic mineral deposits found to date in the Phanerozoic basin of the Alberta Plains are the Clear Hills iron deposits (Hamilton and Olson, *In press*). Presently, these deposits are only considered a resource as they are low grade and mineralogically complex in comparison to other types of iron ore deposits. A few economic to near-economic base metal and precious metal deposits exist in Phanerozoic rocks in the Plains and Cordillera regions adjacent to Alberta. Such deposits include, for example, the Pb-Zn-Ag deposits at Robb Lake, British Columbia, Pine Point, Northwest Territories and George Lake, Saskatchewan, and the gold deposits in the Plains Region southeast and east of Great Falls, Montana. Many of the favourable tectonic and geological features that are present at and near these deposits also exist in lithologically similar or stratigraphically equivalent rocks in the Alberta Plains.

Based on the geologic and tectonic setting, and on comparisons with other metallogenic provinces, the potential ore deposit types that may exist in the Alberta Plains Region include: **base metal deposits**, such as (1) carbonate-hosted Mississippi Valley Type lead-zinc deposits, (2) stratiform sediment-hosted lead-zinc deposits, (3) stratabound sediment-hosted copper deposits, (4) stratiform shale-hosted Ni-Zn deposits, and (5) stratiform sediment-hosted oolitic iron deposits; **precious metal deposits**, such as (6) epithermal gold deposits; (7) **sediment-hosted uranium deposits**; and a few **other types of deposits**, such as (8) gold and other heavy mineral placer/paleoplacer deposits, and (9) diamondiferous kimberlite or lamproite deposits. Following is a discussion of the characteristics of each of these deposits that is relevant to the geology of the Alberta Plains, and suggestions for possible exploration targets.

Base Metal Deposits

There are several base metal occurrences and geochemical anomalies in Phanerozoic strata within the Plains Region of Alberta (Tables 1 and 2, Maps 1 to 3). Most of these occurrences and anomalies are of a minor nature, but they are of several diverse types, hence potential exists for an important base metal deposit to be present.

Carbonate-Hosted Mississippi Valley Type Lead-Zinc Deposits

Much of the Phanerozoic basin of the Alberta Plains is underlain by carbonates of Cambro-Ordovician, Devonian or Carboniferous age. As well, a few carbonate units occur in places in Late Triassic to Early Jurassic strata. Some of these carbonates in the Plains Region contain many of the geological features that are considered favourable for the presence of MVT lead-zinc deposits. However, the most prospective carbonate strata for MVT deposits in Alberta are probably those of Paleozoic age.

Although Cambrian to Carboniferous carbonates underlie much of the Alberta Plains, the only region where these potential host rocks for MVT Pb-Zn deposits exist close enough to surface to explore and develop, other than in the Rocky Mountains and Foothills, is in northern Alberta near and northwest of High Level, and between Fort McMurray and the Alberta-N.W.T. border. In these two regions the primary target for MVT Pb-Zn deposits would be Devonian carbonates and associated sedimentary rocks because there is little if any pre- or post-Devonian carbonate strata (Map 3). Unfortunately for mineral exploration, most of the exposed Devonian rocks in this region are encompassed by Wood Buffalo National Park. Nonetheless, those areas where the Devonian rocks are available for exploration must be considered prospective because stratigraphically and age equivalent rocks at Pine Point in the N.W.T. and at Robb Lake in northeastern B.C. are host to important MVT Pb-Zn deposits (Hamilton and Olson, *In press*). As well, elsewhere in the subsurface of central and northern Alberta, Devonian carbonates are host to many occurrences of one or more of galena, sphalerite and chalcopyrite or other Cu-bearing minerals (Table 11; Figure 4). For example, there are at least 17 hydrocarbon test wells and diamond drillholes in northwestern Alberta that intersected Pb-Zn and/or Cu mineralized zones, and at least 8 wells that intersected Pb-Zn and/or Cu mineralized zones in the vicinity of Edmonton (Table 11, Figure 4). The majority (19 of 25) of these wells with base metal intersections occur in carbonate rocks of Middle or Late Devonian age. The other 6 wells intersected base metal bearing zones in Mesozoic carbonates in the vicinity of Grande Prairie (wells 83L-1, 83L-2, 83M-1, and 83M-3 to 83M-5). The base metal bearing zones in these six wells are mainly hosted in carbonates of Late Cretaceous Lower Wapiti Group (Dubord 1987, 1988; Edmond 1970). The base metal occurrences in these 25 Alberta wells are at depths ranging from about 64 m to 1,956 m below surface. Except for the Cretaceous base metal intersections in some wells at the Grande Prairie area and a carbonate intersection in a well (84N-4) at the Steen River area, most of the 25 base metal intersections exist at depths ranging from 1,100 m to 1,950 m below surface. This is well below what might be currently considered an economically feasible depth to explore for and develop a MVT Pb-Zn deposit. Nonetheless, exploration is possible in northern Alberta where the Devonian strata crop out or exist at a shallow depth below surface. The most favourable target areas for MVT Pb-Zn deposits in the Plains region probably is near the Great Slave Lake Shear Zone in northwestern Alberta, or along the belt of exposed or subcropping Devonian strata in northeastern Alberta.

In northwestern Alberta, particular attention should be given to the Devonian carbonates north of High Level in the vicinity of the Steen River anomaly and along the Great Slave Lake Shear Zone because Germundson and Fischer (1978) have reported an occurrence of galena with possible sphalerite (Map 3, anomaly 84N-4), and up to 220 ppm Zn across 2.6 m in Upper Devonian carbonates in this area (anomaly 84N-5). As well, recent work on Middle Devonian Keg River carbonates at the Rainbow oil field, which is southwest of the Steen River area, indicates that dolomitization, brecciation and the presence of fluorite, sphalerite, galena and chalcopyrite cements are the result of hydrothermal activity along and near the Great Slave Lake Shear Zone (Aulstead and Spencer 1985; Aulstead *et al.* 1988; Muir and Dravis 1991, 1992; Muir, *pers. comm.* 1993). There is also reported mercury and arsenic enrichment of basement rocks in the vicinity of the Great Slave Lake Shear Zone and this provides further evidence that deep-seated hydrothermal fluids have been concentrated along faults that are spatially associated with this major crustal break (Burwash and Culbert 1979). Further to the south, Packard *et al.* (1991) have documented a similar relationship between dolomitization, brecciation and the presence of sulphides in Upper Devonian Wabamun Formation carbonates in the Peace River Arch area. They suggested that the Wabamun carbonates exhibit comparable fabrics and structures to many carbonate hosts of MVT Pb-Zn deposits, such as the Presqu'ile dolomite at Pine Point, N.W.T.

The other area in the Plains Region with favourable geological features for MVT Pb-Zn deposits, is in northeastern Alberta near and south of Wood Buffalo National Park. For example, Dubord (1987) showed several interpreted faults, a large area of interstratal karst and numerous solution collapse features associated with the Devonian strata in northeastern Alberta. In addition, dolomitization and brecciation of Devonian carbonates have been documented in Wood Buffalo National Park (Park and Jones 1987). In general, the dolomitization and brecciation have been attributed to surficial processes and evaporite dissolution rather than to hydrothermal processes (Ibid). Nonetheless, near Fort McMurray several basement structures have been interpreted from aeromagnetic data as possible faults (Garland and Bower 1959), and these may have provided the necessary conduits for metal-rich fluids to dolomitize, brecciate and deposit lead and zinc in the Devonian carbonates. Interestingly, a minor galena occurrence (anomaly 74D-4) and three minor copper occurrences (anomalies 74D-1 to -3) exist in Devonian carbonates along the Clearwater River east of Fort McMurray (Map 3; Carrigy 1959, La Casse and Roebuck 1978).

Lastly, Hitchon (1993) has found that concentrations of Zn and Pb in some of the modern saline formation waters from the Middle Devonian Keg River Formation in northern Alberta are "*high enough for them to be considered as a potential ore source*". However, Hitchon (1993) did not believe these modern saline formation waters were responsible for the MVT Pb-Zn deposits at Pine Point, N.W.T. because of the differences in the Pb to Zn ratios of these modern saline formation waters with that reported from fluid inclusion evidence for the ore fluids responsible for MVT Pb-Zn mineralization, and because the age of the Pine Point deposits, based on Pb isotope and Rb-Sr dating, is probably between Late Devonian (361±13 Ma) to Late Pennsylvanian (~290 Ma; Cumming *et al.* 1990, Nakai *et al.* 1993). Instead, Hitchon (1993) suggested that the Pine Point mineralizing fluid may have been a geothermal brine that rose and migrated in Late Devonian time along then open structural pathways associated with the Great Slave Lake Shear Zone. He also stated that "*the extensive dolomitization found in the Devonian of the Alberta Basin may be relatively rare in a platform-type setting such as is found in western Canada. It might also be more than coincidence that many of the strongly dolomitized trends seem related to underlying basement structures.*" Alternatively, Symons *et al.* (1993) concluded from paleomagnetic data that the "*the MVT ores at Pine Point are Late Cretaceous to Eocene in age, with a mid-Late Cretaceous to Paleocene age (84 - 58 Ma) being most likely*", and that Pine Point MVT deposits were "*formed during the Laramide orogeny (97 - 58 Ma) when tectonic uplift forced Zn - Pb-rich basinal brines out of the Western Canada sedimentary basin into the Presqu'ile barrier reef onto the adjacent foreland shelf*".

In short, the existence of favourable geology, several Pb-Zn occurrences and a mechanism whereby Zn-Pb mineralizing fluids may have been forced to migrate into carbonate strata in the Plains Region, indicate there is potential for the discovery of MVT Pb-Zn mineralized zones in Devonian carbonate strata in northern Alberta. To date, minimal exploration with little success has been performed for MVT Pb-Zn deposits in this region. It is believed this may not be due to a lack of potential, but instead is largely due to: (1) poor exposure of Devonian carbonates and extensive amounts of glacial and other surficial overburden, and (2) a lack of confidence in using indirect methods to find blind MVT Pb-Zn deposits beneath either the glacial overburden or a thin skin of Cretaceous clastic rocks.

Exploration for MVT type deposits in Alberta should be greatly assisted by the public and private databases that can be accessed to provide information on dolomitization and brecciation trends, stratigraphic trends that might indicate favourable deep-seated structures and base metal sulphide intersections, and by the available core for possible relogging or geochemical analyses which is on file at the ERCB and the AGS. For example, a large geological database from tar sands, oil and gas, and coal drilling exists for northern Alberta at the ERCB and at such private consortiums as CANSTRAT. In many instances drill core may not be available in a target area of interest, but downhole geophysical logs are usually available for most oil and gas wells. Although the chances of detecting actual Pb-Zn mineralized zones by downhole methods may be remote, Packard *et al.* (1991) suggested that features such as widespread brecciation do have a recognizable downhole geophysical signature. As well, although the use of regional geochemical surveys and prospecting may not be effective exploration methods for blind MVT deposits due to thick glacial cover or the presence of overlying Cretaceous rocks, airborne and ground geophysical methods should be considered in the search for such blind MVT Pb-Zn deposits in carbonate rocks in northern Alberta. In particular, high frequency electromagnetic surveys to search for subtle conductors, coupled with gravity surveys, could be effective geophysical methods to explore for covered MVT Pb-Zn deposits. The blind Lisheen Pb-Zn-Ag deposit in Ireland, for example, was recently discovered as a result of exploration based on a geological model, coupled with weak geochemical and geophysical anomalies, followed by drilling (Walton 1992, *pers. comm.* 1994).

Stratiform Sediment-Hosted Lead-Zinc

Potential exists in the Alberta Plains for clastic sediment-hosted stratiform Pb-Zn deposits. As previously discussed, deposit types in this category include: (a) euxinic black shale hosted (Sedex) lead-zinc deposits, (b) turbidite-hosted base metal deposits, and (c) sandstone or siltstone hosted lead-zinc deposits. In the Alberta Plains, there are extensive Jurassic to Lower Cretaceous and Upper Cretaceous to Tertiary shallow-water, sandstone-dominated, clastic wedges, but there is little, if any, thick, deep-water flysch deposits consisting of turbidites, shale and chert. As a result, potential in the Alberta Plains may be higher for the sandstone- or siltstone-hosted variety of stratiform Pb-Zn deposits, rather than the starved basin, euxinic shale or turbidite varieties of deposits. Many of the clastic wedges in the Alberta Plains contain geological features that are considered favourable for sandstone-hosted Pb-Zn mineralized zones, including: (a) transgressive basal sandstones or conglomerates, (b) vertical to subvertical faults, possibly related to extensional tectonics, (c) interlayered impermeable cap rocks, such as shales or mudstones, (d) the presence of evaporites in the stratigraphic section, and (e) weathered sialic basement. Areas deemed to be structurally favourable for sandstone-hosted stratiform Pb-Zn deposits in the Alberta Plains include those units that were deposited within or adjacent to the inferred Southern Alberta Rift, and those locales with prominent, deep-seated vertical to subvertical, northeasterly-trending faults such as the Great Slave Lake Shear Zone, the Steen River Anomaly, the Peace River Arch and the Snowbird Tectonic Zone.

Occurrences of sphalerite and galena have been reported in Upper Cretaceous Wapiti Group sandstones and siltstones (anomalies 83L-1, -2, 83M-3, -4 and -5; Edmond 1970), and at the contact between Triassic Spray River and Upper Cretaceous Belly River sediments (anomaly 83M-1; Hitchon 1977, 1993; Dubord 1987, 1988) in the Grande Prairie area (Map 2). These sulphide occurrences, coupled with the presence of favourable lithologies, indicate that the Cretaceous clastic rocks of northern Alberta have the potential to contain sandstone-hosted stratiform Pb-Zn deposits. In several areas, such as near Fort McMurray, Cretaceous clastic rocks exist above Paleozoic carbonate-evaporite successions and are spatially close to paleo-weathered basement. Saline formational waters, due to dissolution of evaporites in these areas, likely are or may have once been metal laden due to the solubility of Pb, Zn and Cu in such chlorine-rich waters (Barnes 1979). Where such waters have been in contact with weathered basement rocks and have moved from Paleozoic carbonate-evaporite successions into Cretaceous clastic rocks due to topographic or other hydrogeologic controls, potential exists for base metals to have been deposited in response to temperature or chemical changes of the waters. Also present in northwestern Alberta is a clean quartzite of Middle Devonian or older age that overlies weathered granitic basement or closely related arkosic sandstone. In the vicinity of the Tathlina Uplift, the quartzite is up to 30 m thick (Belyea 1971). This quartzite should not be ignored for its Pb-Zn potential because Belyea (1971) reported that Pb-Zn sulphide minerals are common in the quartzite above and along the flanks of the Tathlina Uplift. As well, Pb-Zn minerals were encountered in wells east of Kakisa Lake, which is about 95 km north of the Alberta-N.W.T. border (Belyea 1971).

Anomalous concentrations of Zn have also been reported in Lower Cretaceous Fort St. John Group shales (Map 3, anomalies 84N-4, -5 and -6; Germundson and Fischer 1978) and the Exshaw shale (Campbell 1980) in the subsurface of the Alberta Plains. Although these shales are not of the deep basinal euxinic type that commonly hosts the Sedex Pb-Zn deposits in northeastern British Columbia and the Selwyn Basin, Yukon (Carne and Cathro 1982; Morganti 1988), they do have some potential to host Pb-Zn mineralized zones in Alberta. Germundson and Fischer (1978), for example, reported up to 820 ppm Zn across 3.05 m in intercalated shale and bentonite of the Fort St. John Group in the Steen River area (anomaly 84M-5). Bentonites and tuffaceous volcanics are also reported to be present in the lowermost portions of the Exshaw shale (Packard *et al.* 1991; Richards *et al.* 1993), where coincidentally the highest concentrations of Zn are found (Campbell 1980). If the bentonites and tuffaceous horizons are derived from volcanic events that took place well outside of Alberta, the likelihood of economic concentrations of Zn and other base metals being present is low. However, if the bentonites have a more local source, the responsible volcanic and thermal events could have yielded Sedex type Pb-Zn mineralized zones within the volcanics, shales or other associated rocks.

Stratabound Sediment-Hosted Copper

Potential exists in the Alberta Plains for epicontinental clastic- or carbonate-hosted stratabound Cu deposits of either or both the Kupferschiefer and Kipushi type, respectively. As noted previously, regional characteristics deemed important for the formation of Kupferschiefer or Kipushi type Cu deposits include: (a) extensional faults related to a rift basin, (b) the presence of hematitic (red bed) clastic sediments and evaporites within the stratigraphic succession, (c) a source of Cu, such as rift generated mafic volcanic rocks or deeply-weathered granitic basement rocks, and (d) suitable host rocks, such as chemically reduced clastic sediments or shales in the case of Kupferschiefer type deposits or karsted and brecciated carbonates in the case of Kipushi type deposits. At least some of these features exist in the Plains Region of Alberta.

Several occurrences of Cu minerals exist at surface and in the subsurface in a variety of rocks within the Plains region, hence this indicates there is potential for stratabound sediment-hosted Cu deposits. La Casse and Roebuck (1978), for example, reported the presence of bornite and azurite in limey rocks within Upper Cretaceous or Tertiary Paskapoo Formation clastics along the Red Deer River east of Red Deer (Map 2, anomaly 83A-1), and an occurrence of enargite and malachite along with two occurrences of enargite within Paleozoic carbonates along the Clearwater River southeast of Fort McMurray (Map 3, 74D-1 to -3). As well, up to 28 ppm Cu was reported in a soil sample (anomaly 84J-1, Map 3), which was collected in an area underlain by Lower Cretaceous Shaftesbury Formation marine shale, near the southern margin of the Caribou Mountains in northern Alberta (Swinden and Horsley 1971). The soil sampling program was conducted in an attempt to locate the site for samples containing bornite and bornite-chalcocite that were brought to the attention of Conwest Exploration Co. (Map 3, anomaly 84J-1). Edmond (1970) reported the discovery of chalcopyrite in well cuttings of Wapiti Group sandstone, siltstone and shale in the Grand Prairie area (Map 2, anomalies 83L-2, 83M-4 and 83M-5). Chalcopyrite has been also reported in Devonian carbonates in a well in the Golden Spike oil field southwest of Edmonton (Map 2, anomaly 83H-3 in Tables 5 and 11), in several wells in the Tangent oil field in the Peace River area (Churcher and Majid 1989), and in a few wells in the Keg River oil field of northwest Alberta (Muir, *pers. comm.* 1993). Halferdahl (1986) reported the presence of vein associated chalcopyrite and malachite in Methy Formation carbonates in core from a drill hole completed in the vicinity of Fort MacKay (Map 5, anomaly 74E-26). Lastly, native Cu was reportedly recovered from Upper Devonian carbonates in a well in the Lubicon area (Map 3, anomaly 84C-1, Matheson 1969).

Those areas that may have favourable geology for stratabound sediment-hosted Cu deposits include: (1) Cretaceous and Tertiary clastic rocks of the Alberta Plains in the vicinity of major structural features, such as the Southern Alberta Rift, the Snowbird Tectonic Zone, the Peace River Arch, and any other places where extensional faulting may have facilitated the movement of Cu-bearing solutions; (3) Paleozoic carbonates, and Cretaceous and Tertiary clastic rocks in northern Alberta in the vicinity of other anomalous geological features, such as the Steen River anomaly, the Tathlina Uplift and the Grosmont High where extensive hematitic red beds and evaporites have been documented in Middle Devonian carbonates overlying deeply weathered granitic basement (Belyea 1971); and (3) Cretaceous and Tertiary clastic rocks in southern Alberta in the vicinity of the Sweet Grass minette intrusions, which may have provided either a source of Cu or the necessary thermal activity to generate Cu-rich hydrothermal brines. Elsewhere, there is no definitive evidence for igneous activity within the Plains region, but there is some evidence that intrusive activity was associated with the Steen River anomaly, the Tathlina Uplift and possibly even the Great Slave Lake Shear Zone. As well, there is a reasonable probability that kimberlite or lamproite diatremes were emplaced in some parts of Alberta, and the emplacement of these intrusives may have had a thermal affect on geothermal brine movement within the Alberta Plains Region.

Stratiform Shale-Hosted Ni-Zn Deposits

As discussed previously, shale-hosted Ni-Zn deposits are currently a minor world resource, but little is known about the geology and the economic potential of this deposit type. Important regional characteristics include: (a) the presence of black shales at transitions between shelf carbonates and deeper-water clastic rocks, (b) spatially associated phosphate-rich horizons, and (c) rift-related graben faults or reactivated basement faults (Hulbert *et al.* 1992).

Potential exists in the Alberta Plains for finding shale-hosted, stratiform Ni-Zn deposits similar to those in China and at the Nick deposit, Yukon. The most prospective units in the Alberta Plains are: (a) black shale of the Late Devonian Exshaw Formation in northern Alberta, which exists at the transition between Devonian and Mississippian carbonate units, (b) limestone to shale transitions in the underlying Upper Devonian carbonates of north-central to northwest Alberta, (c) black shale of the Triassic Sulphur Mountain Formation of the Spray River Group in northwest Alberta, (d) black shale of the Jurassic Fernie Group in central to northern Alberta, and (e) black shale intercalated with bentonite in Lower to Upper Cretaceous sedimentary strata of central to northern Alberta.

As discussed previously, geochemical and mineralogical data indicate there is potential for stratiform Ni-Zn deposits in the lowermost black shales of the Exshaw Formation. Campbell (1980), for example, stated that elevated concentrations of U, Ni and Zn are most common in the lowermost 1.2 m of the Exshaw shale throughout the Alberta Plains subsurface, and that the concentrations decrease upwards from the base of the contact. As well, there are several zinc occurrences in Upper Devonian carbonates in the Alberta Plains subsurface that exist immediately below the Exshaw Formation (Maps 2 and 3, anomalies 83A-2, -3 and 83N-3; Haites 1960, Dubord 1987, 1988; Packard *et al.* 1991) or, in one case, at the Devonian-Mississippian transition where the occurrence is likely hosted in the Exshaw Formation (anomaly 83M-2; Hitchon 1977, Dubord 1987, 1988). In some cases, it has been suggested that the zinc occurrences in the carbonates have been derived from the Exshaw Formation (Packard *et al.* 1991). Sampling of the lower Exshaw Formation in the Plains region by Duke (1983) indicates that concentrations of zinc and other elements are substantially elevated. The elevated nickel and zinc concentrations in the lowermost portions of the Exshaw shale are coincident with reported occurrences of bentonite or volcanic tuffaceous horizons (Packard *et al.* 1991; Richards *et al.* 1993). In northwest and north-central Alberta, not only is the Exshaw shale reasonably close to surface, but an east to west transition from limestone to basinal shale is present in Upper Devonian carbonates (Majid 1989). This lithological transitional may be a favourable target for stratiform Ni-Zn occurrences, particularly in the vicinity of faults related to the Great Slave Lake Shear Zone or structures associated with the Steen River anomaly.

In northwest Alberta, shale-hosted stratiform Ni-Zn deposits may exist in black shale members of the Triassic Sulphur Mountain Formation (also known as the Daiber Formation). There is little information available to support this hypothesis, but Gibson (1965, 1971) reported that up to 10 volume per cent pyrite is common in the black shale members of the Sulphur Mountain Formation and that there are local horizons of massive pyrite. Pyrite is also common in the overlying dolomite of the Whitehorse Formation. Therefore, it is possible that other metallic sulphides may be associated with the pyritic zones. No trace element chemistry has been reported for the Sulphur Mountain Formation, hence there is no geochemical data currently available to evaluate the potential of the Sulphur Mountain Formation to host stratiform Ni-Zn deposits in the Alberta Plains Region.

Shales of the Fernie Group may also have potential, in places, to host stratiform Ni-Zn deposits. Little information is currently available on the base metal potential of the Fernie Group shales. However, recent work by Williamson *et al.* (1993) indicated that anomalous concentrations of Zn, Ni, As, Mo and Cd exist locally in Fernie Group shales in the Rocky Mountains and Foothills of southwest Alberta. In the Plains Region, Fernie Group shales are present in the subsurface in central and northern Alberta, and are reasonably close to surface in northern Alberta.

Lastly, the shales in Lower to Upper Cretaceous Fort St. John Group are a potential host for stratiform Ni-Zn mineralized zones. For example, Germundson and Fischer (1978) reported up to 150 ppm Ni, 820 ppm Zn, 310 ppm Cu, and 18 ppm Cd in intercalated black shale and bentonites of Lower to Upper Cretaceous Fort St. John Group in the Steen River area (Map 3, anomalies 84N-4 to -6). Edmond (1970) reported up to 400 ppm Ni across 9.14 m of interbedded sandstone and shale of Upper Cretaceous Wapiti Group in the Grande Prairie area (Map 2, anomaly 83M-4). These Lower to Upper Cretaceous shales may have better potential to host stratiform Ni-Zn mineralized zones in the vicinity of the Southern Alberta Rift, the Snowbird Tectonic Zone, reactivated faults associated with the Peace River Arch, and any fault zones associated with reactivation of the Great Slave Lake Shear Zone.

Stratiform Sediment-Hosted Oolitic Iron

The sediment-hosted oolitic iron deposits in the Clear Hills area of the Peace River region are a major resource in Alberta. Peace River Mining and Smelting Ltd. have defined more than 1 billion tonnes of potential resource grading between 32 and 35 per cent total iron by drilling approximately 245 drillholes between 1959 and 1965 (Edgar 1961, 1962, 1964, 1965; Bertram and Mellon 1973, 1975). The iron deposits exist as four discreet bodies along the southeastern slopes of the Clear Hills (Map 3, anomalies 84D-3 to -6). The iron deposits are hosted in and intercalated with Upper Cretaceous Bad Heart Sandstone of the Smoky River Group, which is dominantly comprised of dark marine shales. Many other unevaluated occurrences of iron exist in the vicinity of the Clear Hills area. At present, these deposits are only considered a resource of iron because they are low grade and mineralogically complex in comparison to other types of iron ore deposits. Expensive and perhaps complex beneficiation techniques will be necessary to upgrade the resource to a useable source of iron ore (Bertram and Mellon 1973, 1975; Bertram *et al.* 1973).

Although the Clear Hills deposits may not at present be an economically attractive source of iron, they are of interest because of their uncertain genetic origin. That is, the deposits consist of flat-lying oolitic sandstones ranging from about 1.5 m to 9 m thick. Most of the iron occurs in goethite, but significant amounts of nontronite (iron-rich clay of the montmorillonite group), siderite, chamosite (member of the chlorite group) and ferruginous opal also are present (Hamilton 1980, Bertram and Mellon 1975, Kidd 1959). As well, small amounts of pyrite and glauconite exist in places. Silica is present in amounts ranging from about 20 to 30 volume per cent, and locally in amounts up to about 50 volume per cent SiO_2, and occurs as discrete detrital quartz grains and as an amorphous opaline substance which comprises part of the oolites and of the intergranular matrix (Bertram and Mellon 1975; Samis and Gregory 1962). "*The phosphorous content of the deposits is high* [ranging from about 0.12 to 0.54% P], *although alumina and sulfur contents are relatively low*" (*Ibid*).

It is probable, based on the oolitic nature of the Clear Hills deposits, that the iron, silica and other associated elements were deposited under wave-agitated shallow marine conditions. However, the interesting question is where did the vast amounts of iron and silica originate from. That is, were they concentrated from 'normal' sea water by some anomalous sedimentary process, or is it possible they are from some igneous or volcanic fumarolic event that was occurring during Bad Heart Sandstone time. The Badheart Sandstone is Santonian in age (about 88 to 84 Ma). There are no igneous events in Alberta reported to be of this age, but there was kimberlite/lamproite intrusive activity cutting basement and overlying Phanerozoic rocks about that time at Somerset Island, N.W.T. (105 to 88 Ma; Pell and Atkinson 1993) and in Kansas (91 to 88 Ma; Zartman *et al.* 1967). As well, in Saskatchewan there was kimberlite/lamproite intrusive activity and sedimentation between about 96 to 94 Ma (Lehnert-Thiel *et al.* 1992), and the Crowsnest Volcanics in southwest Alberta were intruded about 96 Ma (Folinsbee *et al.* 1957). It is doubtful that the Clear Hills oolitic iron deposits are related to kimberlite/lamproite igneous activity because these intrusive phenomena typically are emplaced quickly, have minimal thermal anomalies associated with them and tend to be iron-poor rather than iron-rich. However, igneous activity such as the Crowsnest Volcanics may have been associated with more extensive thermal anomalies and hydrothermal activity. Therefore, it is possible that the genesis of the Clear Hills oolitic iron deposits was in some way related to either igneous fumarolic activity or to fumarolic deep-circulating hydrothermal basin fluids. Hence, there could be potential for VMS base metal deposits, epithermal precious metal deposits, or even hydrothermal vein type deposits to be present in the Cretaceous strata in northwestern Alberta.

Precious Metal Deposits

There are only a few precious metal occurrences or related geochemical anomalies in the Plains Region of Alberta (Tables 1 and 2, Maps 1 to 3). Minor amounts of placer gold exist in several rivers and in some upland gravel deposits (Halferdahl 1965; Giusti 1983; MacGillivray *et al.* 1984; Edwards 1990). However, with two exceptions there are currently no reported significant gold occurrences in bedrock in the Plains Region of Alberta. The two exceptions are: (1) at or near anomaly 74E-26 along the east bank of the Athabasca River in the vicinity of Fort MacKay, northeast Alberta where anomalous Au, Ag and PGE analyses have been reported in both the Precambrian basement rocks and the overlying Devonian strata, and (2) in southern Alberta where "*Marum Resources (ASE) reports that a composite sample collected from its JD-2 pipe on the Pinhorn property ... contains anomalous gold values. Fire assays have yielded values of up to 1 gram gold per tonne*" (Northern Miner 1994). At present, the exact location of this second gold occurrence is uncertain.

Both these results are of exploration interest and indicate that a previously unknown precious metal mineralizing event or events may have affected parts of the Phanerozoic succession in the Plains Region of Alberta.

Epithermal Gold Deposits

Epithermal, disseminated Carlin type gold deposits and associated vein type gold deposits are important producers of gold in the plains of Montana, North Dakota and South Dakota (Berger and Henley 1989; Foster and Childs 1993). Little, if any, exploration for these types of deposits has been documented in the Alberta Plains. The formation of Carlin type and associated vein type gold deposits has usually been attributed to epithermal hydrothermal processes associated with the emplacement of high-level felsic intrusions and rhyolitic volcanism (Bagby and Berger 1985; Romberger 1986; Berger and Henley 1989). Because such felsic igneous activity is largely lacking in the Alberta Plains, the potential for Carlin type deposits and associated vein type deposits in Alberta has long been regarded as significantly lower than that for the western United States of America, British Columbia or the Yukon Territory. On the other hand, the common presence of placer or paleoplacer occurrences of fine gold in several river gravels in the Alberta Plains, and the existence of at least a few gold occurrences in the Alberta Rocky Mountains, Foothills and Plains Region, indicate there is some potential, albeit possibly low, for epithermal gold deposits in selected geologically favourable areas in the Alberta Plains.

One potential target area for disseminated Carlin type or associated vein type gold-bearing zones in the Alberta Plains is the Sweet Grass Hills of southern Alberta where Upper Cretaceous to Tertiary limey or carbonaceous clastic sedimentary rocks are intruded by several alkalic minettes and one felsic alkalic dyke (Map 1, anomalies 72E-18 to -23 and -27; Williams and Dyer 1930; Russell and Landes 1940; Irish 1971). In northern Montana, Gavin (1991) has reported the presence of gold deposits at Middle and East Buttes of the Sweet Grass Hills. As well, further to the south in the Little Belt Mountains (Rocky Mountain Foreland Terrane) southeast of Great Falls, Montana, Schutz *et al.* (1989) reported that stratabound- to structurally-controlled gold mineralized zones exist within Upper Devonian Jefferson Group dolomites. They postulated that the bulk of the gold-bearing zones are spatially and, possibly, genetically related to the intrusion of Tertiary age syenite porphyry sills and hornblende-biotite lamprophyres. These intrusions are similar to those that exist locally in the southern Alberta Plains. It is also of interest that up to 1 g Au/t has been reported in a 'pipe' at the Pinhorn property in southern Alberta (Northern Miner 1994). Hence, it is possible that epithermal gold deposits may be spatially associated with the Sweet Grass Intrusions by analogy to the situation in Montana.

Other targets in the Plains Region of Alberta that might have potential for epithermal gold mineralized zones include those areas where Phanerozoic rocks are underlain by the Snowbird Tectonic Zone in central Alberta and by the Great Slave Lake Shear Zone in northwest Alberta. Burwash and Culbert (1979) have reported increased mercury and arsenic in basement rocks near the Great Slave Lake Shear Zone. Mercury and arsenic are often elevated in epithermal gold deposits and, in this case, may provide evidence that deep-seated hydrothermal fluids have been concentrated along faults spatially associated with the Great Slave Lake Shear Zone. As a result, Phanerozoic rocks above these structures may provide a suitable setting for the existence of epithermal gold deposits.

Sediment Hosted Uranium Deposits

The characteristics of the major types of sediment hosted uranium deposits were discussed in a prior section. As well, Maynard (1991) has summarized the characteristics of syngenetic to diagenetic uranium deposits that exist in sedimentary rocks of foreland basins. Of particular exploration interest with respect to the Plains Region of Alberta are the sandstone-hosted uranium deposits. Deposits in this class typically comprise a few hundred to a few million kilograms of U_3O_8, and the uranium has been extracted by open pit and underground mining methods, or by subsurface leaching methods. Such deposits tend to cluster in districts and occur in particular formations within districts. In the United States of America, for example, the most productive lithologic units are continental fluvial sandstones of the Lower to Middle Triassic Chinle Formation, Upper Jurassic Morrison Formation, Lower Cretaceous Dakota Sandstone and Inyan Kara Group, Paleocene Fort Union Formation, and Eocene Wind River and Wasatch Formations (Ridge 1968).

In the Interior Plains of Alberta, Triassic and Jurassic rocks are not exposed. However, Cretaceous and Tertiary continental and marine sedimentary rocks lie at the surface or beneath glacial deposits over greater than two-thirds of Alberta (Green 1972). In the west, these strata represent several major cycles of clastic sedimentary wedges derived from the Cordilleran Orogen (Poulton 1989). As a result, there are several local to regional unconformities and disconformities within the Cretaceous to Lower Tertiary sequence. This complex geological sedimentary setting during the Cretaceous to Early Tertiary time may be a favourable setting for sediment-hosted uranium deposits. Following is a summary of the various clastic wedges, hiatal events and known radioactive occurrences in the Alberta Plains Region.

Early Cretaceous Epoch

During the Early Cretaceous there were several cycles of Cordilleran orogenesis and associated marine transgression-continental regression, followed by widespread marine flooding of the continental interior during the Late Cretaceous. The Early Cretaceous clastic wedge is known throughout the Interior Plains as the Mannville Group. Most of the rocks in the Mannville Group are sandstone and shale, but in places conglomerate and limestone are present (Cant 1989). "*The Lower Mannville infills topography on the sub-Cretaceous unconformity and therefore is extremely variable in thickness. Ridges and valleys on the unconformity reflect the differential erosion of the subcropping Paleozoic rocks. ... The escarpments and channels ... are relatively gentle hills and valleys. In places, these had a topographic relief of up to 100 m and were important in influencing basin infill*" (Cant 1989). Sediment supply during Lower Mannville time was mainly from the south, and the marine-nonmarine transition occurred in north central Alberta. This was followed by marine transgression during Middle Mannville time, then by a another transgression during Upper Mannville time. Some of the basal shales of the Upper Mannville were deposited in relatively shallow water conditions and they "*contain highly radioactive zones caused by uranium enrichment of phosphorites*" (Yorath 1992). As well, there is abundant volcanic debris such as in southwest Alberta towards the top of the laterally equivalent Blairmore Group, where volcanic tuffs are common (Rudkin *et al.* 1964). The Upper Mannville succession is thickest in northwest Alberta, which reflects the anomalous subsidence of the Peace River Arch during the Cretaceous.

Late Cretaceous Epoch

During the Late Cretaceous, there was widespread marine flooding of the continental interior and expansion of the Boreal and Gulfian seas. During this period, the fine clastics of Smoky Group (northwestern Plains and Foothills), Alberta Group (southwestern Foothills), Colorado Group (Plains) and overlying Lea Park and Milk River Formations (Plains) were deposited. The Lower Cretaceous-Upper Cretaceous (Albian-Cenomanian) boundary is marked by the Fish Scale Horizon within Shaftesbury Formation of Colorado Group. During Late Cretaceous to Early Tertiary time, several more clastic wedges were shed easterly into the Interior Plains during cycles of renewed Cordilleran Orogenic activity. "*The extensive and prolonged marine deposition during the Late Cretaceous Epoch was brought to an end as alluvial, coarse grained sandstone and interbedded mudstone, variously assigned to the Belly River, St. Mary River, Willow Creek, Brazeau and Wapiti formations, were deposited. These nonmarine sediments in the west grade eastward into marine shale and are* *conformably to unconformably overlain by nonmarine shale and sandstone of the Tertiary Porcupine Hills and Paskapoo formations. This total succession reaches 1,060 m thick in the western Foothills*" (Yorath 1992). "*Subsidence rates and sediment supply within the foreland basin were extremely high at this time and sediment ... was shed eastwards and northwards as a result of collision of Intermontane Superterrane with North America.*" (Leckie 1989) "*Ash beds such as the Kneehills Tuff attest to volcanic activity late in the* [Cretaceous] *period*" (Williams and Burk 1964).

Paleocene Epoch

Paleocene strata (Upper Willow Creek, Porcupine Hills, Paskapoo and Ravenscrag Formations) were deposited during the last part of the uppermost Cretaceous-lowermost Tertiary clastic wedge. "*Continental sedimentation continued without interruption through uppermost Cretaceous into Paleocene time in most of western Canada. ... The Paleocene Series in the Interior Plains ranges in thickness from more than 5,000 feet* [1,525 m] *in the Porcupine Hills of southwestern Alberta*" (Yorath 1992) to about 70 m for the Ravenscrag Formation in the Cypress Hills of southeastern Alberta. The Ravenscrag Formation conformably overlies Cretaceous Frenchman Formation, whereas in southwestern Alberta, Upper Cretaceous to lower Paleocene Willow Creek Formation is overlain disconformably by Upper Paleocene Porcupine Hills Formation (Stott *et al.* 1993). Towards the north, near Calgary the upper part of the Willow Creek Formation and, possibly, the Porcupine Hills Formation may grade into Paskapoo Formation (Green 1972). However, the exact relationship between the Porcupine Hills Formation and Paskapoo Formation is uncertain (Carrigy 1970). Rahmani and Lerbekmo (1975), for example, have suggested that the Porcupine Hills Formation is of Late Paleocene age and that it disconformably overlies both the Willow Creek and Paskapoo Formations. In central, western and northwestern Alberta, Paskapoo Formation conformably overlies Upper Cretaceous Edmonton Group, Brazeau Formation and Wapiti Group, respectively. The Willow Creek, Paskapoo and Porcupine Hills Formations comprise a series of nonmarine sandstone, bentonitic shales, lignites, and conglomerate that crop out extensively in the area adjacent to the Rocky Mountains and Foothills, and form the surface bedrock over a large area of the western Plains. The total thickness of these formations varies from zero at the erosional edge in the eastern Plains to about 915 m adjacent to the Foothills belt. The upper boundary of the Paskapoo and Porcupine Hills Formations is an erosion surface (Carrigy 1971).

The important genetic factors which control the formation of sediment-hosted uranium deposits in clastic sequences include: (1) a source of readily labile uranium, such as tuffaceous material in the sedimentary sequence; (2) meteoric or other aqueous solutions flowing through permeable sandstones which can both leach uranium and transport it; (3) favourable host rocks, which typically comprise non-marine sandstone interbedded with other clastics, that act to focus fluid flow; and (4) a site which acts as a reductant to cause uranium deposition. Suitable reductants can be one or more of carbonaceous material, pyrite, H_2S, petroleum, humic acids, bitumen or changes in a redox front. Lastly, (5) deposition needs to be followed by a closed hydrodynamic system and other factors that prevent destruction of the sandstone-hosted uranium deposit. The Cretaceous and Tertiary rocks of Alberta have, or may have had, many of these features deemed favourable for uranium deposition. As well, they have many lithologic and paleogeographic similarities to their age equivalent counterparts in the western United States of America that are host to numerous sandstone-hosted uranium deposits. Ruzicka (1977), for example, has suggested that the entire Cretaceous-Tertiary sedimentary package of the Western Canada Sedimentary Basin is favourable for the existence of sediment-hosted uranium deposits. The presence of anomalously radioactive bone (Bell *et al.* 1976), anomalous radioactivity in various drill holes (Maps 1, 2 and 6, anomalies 72E-2, -25, -26, 82H-19, 83M-4, -6 and -7; Bushell 1970; Edmond 1970; Newman *et al.* 1970; Grant 1982), and anomalously uraniferous geochemical stream sediment samples (Maps 1, 2 and 6, anomalies 72E-13, -14, 82O-23 to -25 and 83B-2; Siddle *et al.* 1979; Grant 1981), well water samples (Map 1, anomalies 72E-13 and -14; Siddle *et al.* 1979) and lithogeochemical samples (Maps 1 and 6, anomalies 72E-15, -16, 82H-1, -17 to -24 and 82I-1; Goble 1976; Siddle *et al.* 1979; Grant 1981, 1982), indicate that the Cretaceous and Tertiary rocks in the Plains Region of Alberta have potential to host important uranium deposits.

The most prospective Cretaceous and Tertiary rock units for sandstone-hosted uranium deposits are the Ravenscrag, Paskapoo, Willow Creek, Porcupine Hills and Scollard Formations because: (a) they are predominantly of continental origin, (b) in places they are carbonaceous or contain organic material which could act as a reductant, (c) volcanic rock fragments, tuff and bentonite horizons are locally present to provide a potential source for uranium, (d) in places there exist changes in colour that may reflect oxidation-reduction phenomena, and (e) faults and folds are present in a few places in the Plains region. Bell (1976) and Bell *et al.* (1976), for example, have reported anomalous radioactivity: (a) in flaggy sandstone of Upper Cretaceous Belly River Group near Lundbreck, (b) in Upper Cretaceous Edmonton Formation near Elnora, (c) in Upper Cretaceous St. Mary River Formation near Lethbridge, and (d) in section 11-14-25W near the Little Bow River.

In addition to sandstone-hosted uranium deposits, there also exists potential for uraniferous lignite deposits, basal conglomerate-hosted uranium deposits, carbonate-hosted uranium deposits and, possibly, basinal shale-hosted uranium deposits in Cretaceous and Tertiary rocks in the Plains Region of Alberta. The most prospective rock units for uraniferous lignite deposits are the Ravenscrag, Brazeau and Scollard Formations because: (a) coal beds and carbonaceous lithologies are present, (b) up to at least 0.126% U_3O_8 is known to exist locally in Ravenscrag Formation lignites in Saskatchewan, and (c) uraniferous lignite deposits are known to exist in lithological and age equivalent rocks in adjacent parts of the United States of America.

With respect to basal conglomerate-hosted uranium deposits, the most prospective rock units are at the base of or within some of the conglomeratic horizons in: (a) Cretaceous Kootenay, Blairmore and Edmonton Groups, (b) in Cretaceous-Tertiary Willow Creek Formation, (c) in lower Tertiary Paskapoo, Porcupine Hills or Cypress Hills Formations, or possibly (d) in some of the Miocene-Pliocene upland gravels. However, the probability is low that an important conglomerate-hosted uranium deposit exists in the Plains Region of Alberta.

The existence of limestone, marl and carbonate-cemented conglomerate in a few places in the Cretaceous and Tertiary sequence in the Alberta Plains indicates that there is a possibility a carbonate-hosted uranium deposit may exist. However, because on a world-wide basis carbonate-hosted uranium deposits are uncommon, the probability is low that an important uranium deposit of this type is present in the Alberta Plains. Of particular interest, nonetheless, is the radioactive occurrences along the Waterton River in southwest Alberta (Map 1, anomalies 82H-17 and -20 to -24; Grant 1981, 1982). At anomaly 82H-23, a rock sample was collected that assays 0.2% U (Grant 1982). This occurrence is in silty limestone of the Willow Creek Formation and was never followed up.

The presence of an extensive marine shale basin in parts of the Alberta Plains, and particularly in the northern parts of the province during much of the Cretaceous, may provide a suitable host for deposits of uranium and other metals. In the Cambro-Ordovician Alum Shale in Sweden, for example, the uranium content commonly reaches 400 ppm U in the richest strata (Schultz 1991). Total organic carbon is also very high in the Alum shales; commonly approaching 20 weight per cent. In the Plains region of Alberta, Bell (1976) reported anomalous radioactivity in marine shale of Upper Cretaceous Blackstone Formation of Alberta Group at the Burnt Timber Creek area near Sundre, Alberta. As well, Yorath (1992) reported anomalous radioactivity in basal shales of the Upper Mannville Group. Also of interest is the geochemically anomalous well cuttings reported by Edmond (1970) from Wapiti Formation which assayed up to 100 ppm U, 400 ppm V, 400 ppm Ni, 2,000 ppm Zn and 100 ppm Pb (Map 2, anomalies 83M-4 to -6). Wapiti Formation comprises non-marine grey, carbonaceous feldspathic sandstone, silty shale bentonite and thin coal beds (Green 1972).

Other Types of Mineral Deposits

From a metallogenic viewpoint, the most likely other types of mineral deposits in the Alberta Plains Region are diamondiferous kimberlite or lamproite diatremes, and placer or paleoplacer accumulations of gold or other important heavy minerals, such as alluvial diamonds.

Diamondiferous Kimberlite and Lamproite Deposits

Since 1988, the largest recorded mineral staking rush in Alberta has resulted in much of the Alberta Plains Region being held under permit in order to allow companies to explore for diamonds (Figure 2). Although little data are yet publicly available on diamond exploration in Alberta, much of the Alberta Plains is underlain by thick Archean or Proterozoic continental crust, which is generally considered favourable for the formation and preservation of diamonds in the mantle (Ross and Stephenson 1989; Ross 1991, 1993; Burwash 1993; Helmstaedt 1992). Thick continental crust in conjunction with deep-seated structures, such as the Sweet Grass Arch, the Southern Alberta Rift, the Snowbird Tectonic Zone, the Peace River Arch, the Great Slave Lake Shear Zone, the Steen River Anomaly and several other structural anomalies in the Alberta Plains, indicate that potential exists for the discovery of kimberlite- or lamproite-hosted diamond deposits in Alberta.

As previously discussed, there is evidence for at least three, and possibly four, ages of alkaline mafic to ultramafic igneous activity in the Alberta Rocky Mountains, some of which may have potential for diamonds. These ages are: Helikian, Paleozoic, Cretaceous and Tertiary. Important stratigraphic successions to explore for evidence of potential kimberlite/lamproite intrusive activity in the Phanerozoic basin of the Alberta Plains include: (a) the Upper Devonian-Mississippian carbonate and shale succession, (b) Permian-Triassic strata, (c) Upper Lower Cretaceous strata at about the age of the Fish Scale Horizon stratigraphic marker, and (d) the Tertiary succession. The Devonian-Mississippian and Cretaceous ages may be more important because there are diamondiferous diatremes of Devonian-Mississippian age in British Columbia and of Late Early Cretaceous age in Saskatchewan. The stratigraphic and paleogeographic setting at the time of intrusive emplacement is also important because many of the kimberlite/lamproite intrusions may have breached the surface subaqueously in the Alberta Plains and be preserved as much wider-spread stratabound volcaniclastic deposits, rather than occurring as the classical carrot-shaped diatreme. Such volcaniclastic deposits are proving to be an important component of the Saskatchewan kimberlite fields (Lehnert-Thiel *et al.* 1992; Garnett 1994).

During the initial stages of diamond exploration in Alberta, because of the recessive weathering nature of most kimberlite and lamproite diatremes and the presence of thick sequences of Phanerozoic sedimentary rocks and overlying glacial material, exploration will undoubtedly commonly require or include the search for selected minerals indicative of potentially diamondiferous kimberlite or lamproite bodies. The important indicator minerals include: pyrope garnet, chrome diopside, picroilmenite, chromium-rich chromite, tourmaline, zircon, olivine and phlogopite. In the Peace River region, Edmond (1970) reported the presence of chromite in heavy mineral separates from well cuttings in Wapiti Group sandstones. Monopros has been exploring several large mineral claim blocks near Peace River, but at present they have not released any results. However, a local newspaper article (Grande Prairie Daily Herald Tribune 1992) and a corporate press release (Takla Star Resources Ltd. 1993c) suggested a lamproite pipe or pipes may have been found in bedrock, but this has not been confirmed by Monopros. More recently, Consolidated Carina Resources Corp. (1993) has reported the presence of 44 pyrope garnets and 14 chrome diopsides in 8 till samples from their Carmon Lake property in the Peace River region. Hawkins (1994), on behalf of several clients, reported diamond exploration results for the Peace River area and stated sampling "*has yielded indicator minerals consisting of pyrope garnets and chrome diopsides. Interpretation of grain geochemistry shows that the grains are good kimberlitic indicators. Grain morphology and the presence of partially preserved kelphytic rims on several garnets suggest a nearby kimberlitic source*". He (Ibid) concluded that "*these results appear to confirm the presence of unmapped kimberlitic intrusions in the Peace River area*".

In central Alberta, Takla Star Resources Ltd. have reported the discovery of P1, P3 or P4 type chromites in creek or river gravels northwest of Edmonton in the Westlock-Sturgeon area, and in the vicinity of the North Saskatchewan and Ram Rivers in the Foothills west of Rocky Mountain House (Map 2, anomalies 83B-1, 83C-4 and 83G-2; Takla Star Resources Ltd. 1993a; Westlock Hub 1993; Stewart and Bale 1994). Stewart (Ibid) suggested that the P1, P3 and P4 chromites represent "*significant lamproitic or kimberlitic diamond indicator anomalies*". Also in the foothills of Alberta southwest of Hinton, Dia Met Minerals Ltd. in a joint venture with Cameco Corp. have reported the presence of "*indicator minerals*" on their 3.2 million acre mineral exploration permits (Edmonton Journal 1993). In addition to these indicator minerals, diamonds have been reportedly discovered in gravels of the Pembina River west of Edmonton (anomaly 83G-1; Edmonton Journal 1992b; Morton *et al.* 1993), the North Saskatchewan River and associated tributary creeks east of Edmonton (Bryant, *pers comm.* 1993; Morton *et al.* 1993), and along the Red Deer River in central Alberta at or near the Cretaceous-Tertiary boundary (Science City News 1992). Morton *et al.* (1993) stated that chrome diopsides have also been found along the northeast extension of the Snowbird Tectonic Zone on the Cold Lake Weapons Range east of Edmonton near the Saskatchewan border.

In southern Alberta, a prospector is reported to have discovered two diamonds (0.14 and 0.17 carats) in drift at Etzikom Coulee near Legend (Map 1, anomaly 72E-8; Edmonton Journal 1992a; Morton *et al.* 1993; Takla Star Resources Ltd. 1993a). More recently, Takla Star Resources Ltd. (1993b) indicated that potential kimberlite indicator minerals, including pyrope garnet, chrome diopside and picroilmenite, had been found at Etzikom Coulee and to the northwest of this coulee, which is 'up-ice' or opposite to the direction of former glacial movement. In the vicinity of the southern boundary of the Southern Alberta Rift near Pincher Creek, Takla Star Resources Ltd. (Ibid) also reported that four aeromagnetic anomalies "*are of a size and profile characteristically associated with diatremes*" (Map 1, anomalies 82H-7 to -10). These anomalies are readily apparent as oval to circular weak positive magnetic anomalies on the GSC aeromagnetic maps for NTS areas 82H/3, 4 and 5. Other similar magnetic anomalies are visible on maps developed from privately flown aeromagnetic surveys in the search for magnetite deposits similar to the Burmis and Dungarvan deposits (West Canadian Collieries Ltd. 1957). In the vicinity of the northern boundary of the Southern Alberta Rift, Banerjee (1989) reported the presence of garnet, zircon and tourmaline in petrographic studies of the basal Colorado sandstone from the Cessford oil field. These minerals may or may not be indicative of an igneous source such as kimberlites or lamproites.

In summary, most of the above reported results are from early stage or reconnaissance diamond exploration programs and the significance of the various reported anomalies is yet to be determined. A study in preparation under the Canada-Alberta MDA will provide further additional information about the potential for diamondiferous kimberlites or lamproites in the vicinity of such regional structures as the Sweet Grass Arch, the

Southern Alberta Rift, the Snowbird Tectonic Zone, the Peace River Arch, the Great Slave Lake Shear Zone and the Steen River anomaly (Dufresne *et al., In preparation*). This MDA report is scheduled to be released in mid 1994.

Gold and Other Heavy Mineral Placer/Paleoplacer Deposits

Placer gold has been mined at various places in the Alberta Plains since 1861. Since the early 1900's, however, gold production has been limited to byproduct recovery during gravel mining or from small hand operations along a few rivers or streams. Because of the long history of placer mining and prospecting for placer gold in Alberta, the probability is low that important placer concentrations of gold will be found in or near present day stream watercourses Nonetheless, potential does exist in places for discovery of paleoplacer concentrations of gold in buried, preglacial, unconsolidated, Tertiary channel gravels and in areas underlain by the Jurassic-Lower Cretaceous Kootenay-Blairmore clastic wedge and the Upper Cretaceous-Tertiary Belly River-Paskapoo clastic wedge.

As previously discussed, anomalous amounts of gold of possible paleoplacer origin have been found in the Foothills of Alberta at Anderson Creek (Map 2, anomalies 83F-1 and 83F-2; Fox 1991) and north of Canmore (Map 6, anomaly 82O-26; Grant 1981), with assays of up to 1,510 ppb and 1,150 ppb gold, respectively. The source of this gold is uncertain, but it may be of local origin or, alternatively be derived form more distant sources. Falconer (1993a,b), however, has reported the existence of placer gold in gravels derived from Paskapoo Formation near Hinton. Recent work by Bi and Morton (1993), and previous work by many others, indicates that the original source of gold in the major rivers of the Alberta Plains is likely west of the Alberta Rocky Mountains in such places as the Cariboo or Selkirk Mountains. It is possible that the gold was derived from these remote western areas via the Kootenay-Blairmore clastic wedge and the Belly River-Paskapoo clastic wedge, both of which were formed prior to the Alberta Rocky Mountains. As such, the gold found in present day watercourses may have travelled tremendous distances and could represent a second or third order placer concentration.

Potential also exists for paleoplacer concentrations of magnetite or titaniferous magnetite, ilmenite and rutile in the Belly River sandstones in the vicinity of the Southern Alberta Rift. The source for the magnetite and the titanium minerals is unknown, but may be the Crowsnest volcanics, which are centred within the bounds of the Rift.

Lastly, potential exists for placer or paleoplacer concentrations of diamonds in Tertiary or other upland pre-glacial gravel channels, or in Recent watercourse gravels in the Alberta Plains. However, as discussed previously, the formation of diamondiferous placer deposits will be largely dependant on the presence and partial erosion of diamondiferous source rocks, which have not as yet been confirmed within Alberta.

CONCLUSIONS

Alberta's geology is both complex and diverse. Proterozoic to Tertiary sedimentary and, locally, volcanic rocks overlie Proterozoic and Archean metamorphic and granitoid rocks. In general, the province can be broadly divided into (a) the northeastern Precambrian Shield, (b) the Plains Region, and (c) the Rocky Mountains and Foothills. To the west in the Cordillera, fault and fold structures are common. Although most of this faulting is related to the Laramide Orogeny which produced the Rocky Mountains and Foothills, there are also several other faults and fault zones that are related to older tectonic events. To the east, in the Plains Region, faults are uncommon, but they do exist in a few places. As well, there are a number of other anomalous structural features, such as the Steen River Anomaly, the Eagle Butte Anomaly, and numerous collapse structures related to dissolution of the Phanerozoic evaporites in the Plains Region. Igneous rocks are uncommon in Alberta, but do occur locally in at least Proterozoic, Devonian, Cretaceous and Tertiary strata.

The metallogenic study has identified in excess of 630 mineral occurrences, or geological, geochemical or geophysical anomalies in Alberta (Tables 1 to 5, Figure 3 and Maps 1 to 7). These comprise a diverse suite of metals and minerals, including precious metals, base metals, uranium, iron and even diamond occurrences in surficial sediments or, possibly, bedrock. Although there are more known mineral occurrences in the Precambrian rocks of northeastern Alberta and in the Proterozoic to Tertiary rocks of southwest Alberta than in the Plains Region or in the central to northern Mountains and Foothills Region, this may be a reflection of a greater intensity of past exploration rather than the Plains Region or the northwestern part of the Alberta Cordillera being geologically less favourable.

Potential exists in Alberta for the discovery of a large number of diverse metallic and precious mineral deposits. These include both syngenetic and epigenetic precious metal deposits, base metal deposits, uranium deposits, and bedrock and alluvial diamond deposits. Some of the potential deposit types that may exist in Alberta include: (a) both **bonanza lode and disseminated epithermal gold deposits**; (b) **Mississippi Valley type lead-zinc deposits**; (c) **sediment hosted base metal deposits** with one or more of zinc, lead, copper, nickel, silver and gold; (d) **volcanogenic massive sulphide base metal deposits**; (e) **granitoid-related precious metal and base metal deposits** (e.g., skarns, greisens); (f) **Olympic Dam type copper-uranium-gold-silver deposits**; (g) **magmatic-related nickel-copper deposits**; (h) **sediment-hosted oolitic iron deposits**; (i) **unconformity-related, sandstone-hosted or vein-type uranium deposits, or uraniferous coals or conglomerates**; (j) **diamondiferous diatremes**; and (k) **various types of placer or paleoplacer deposits** with the important placer metals/minerals being gold, magnetite, diamonds or other 'heavy minerals'.

ACKNOWLEDGMENTS

Several individuals assisted with the preparation of this study, including Mr. D. Wynne, Mr. W. Hamilton and Mr. M. Berhane of the Alberta Geological Survey; Mr. D. Rokosh, a student at the University of Alberta who worked under contract to the Alberta Geological Survey; Mr. B. Hudson of Alberta Energy; Mr. H. Selcho of Alberta Environment; Mr. J. Williamson of R.A. Olson Consulting Ltd. and Dr. L. Halferdahl of Halferdahl & Associates Ltd. As well, Mrs.S. Grolway of the Alberta Geological Survey edited the References for the final document. The author's wish to thank each of these individuals for their efforts towards completion of the Metallogenic Study of Alberta.

REFERENCES

Abercrombie, H.J. and Feng, R., 1994. Gold and PGE anomalies in Phanerozoic sedimentary rocks, northeastern Alberta - Potential for new deposits. In The Calgary and Mining Forum, Program and Abstracts, 10 & 11 February, 1994; published by the Calgary Mineral Exploration Group. 51.

Adair, R., 1986. The pyroclastic rocks of the Crowsnest Formation, Alberta, Unpublished, M.Sc. Thesis, University of Alberta, 196 p.

Adams, S.S. and Saucier, A.E., 1981. Geology and recognition criteria for uraniferous humate deposits, Grants uranium region, New Mexico, United States Department of Energy, GJBX-2(81).

Adams, S.S. and Smith, R.B., 1981. Geology and recognition criteria for sandstone uranium deposits in mixed fluvial-shallow marine sedimentary sequences, south Texas, United States Department of Energy, GJBX-4(81).

Adams, W.T., 1985. Zirconium and hafnium. In United States Department of the Interior. Mineral facts and problems, 1985 edition. Bureau of Mines, Bulletin 675. 941-956.

Allan, G.B., 1973. Report on the Spionkop Creek property; unpublished assessment report prepared for Frances Creek Mines Ltd.

Allan, J.A, 1920. Second annual report on the mineral resources of Alberta. Published by the Government of Alberta, Edmonton.

Allan, J.A., 1931. Report on the Geological Survey Division, Research Council of Alberta Report 27, 12th Annual Report. 19-23.

Aitken, J.D. and M.E. McMechan, 1992. Middle Proterozoic Assemblages. In H. Gabrielse and C.J. Yorath (ed's). Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada.

Alberta Chamber of Resources, 1987. Alberta - Opportunities for Metallic Minerals. Document jointly prepared by the Alberta Chamber of Resources (Trigg, Woollett, Olson Consulting Ltd.), Alberta Energy and the Alberta Geological Survey.

Alberta Government, 1984. A Policy for Resource Management of the Eastern Slopes (Revised 1984). Alberta Energy and Natural Resources ENR T/38, ISBN 0-86499-067-7.

Alberta Energy and Natural Resources, 1986b. Metallic Minerals in Alberta. ENR Technical Report No. T/102; ISBN 0-83499-290-4.

Alberta Government. 1984. A Policy for Resource Management of the Eastern Slopes (Revised 1984). Alberta Energy and Natural Resources ENR T/38, ISBN 0-86499-067-7.

Alberta Research Council, 1953. Thirty-third annual report of the Research of Alberta Council of Alberta, 1952; Research Council of Alberta, Report No. 64. 23-24.

Alberta Research Council, No Date. Letter from R.D. Sluzer of Imperial Oil; Research Council of Alberta, Economic Minerals File Report.

Anderson G.M., and Macqueen, R.W., 1988. Mississippi Valley-type lead-zinc deposits; In R.G. Roberta P.A. Sheahan, ed's., Ore Deposit Models, Geoscience Canada, Reprint Series 3. 79-90.

Allan, J.A., 1920. First annual report on the mineral resources of Alberta. Research Council of Alberta Report No. 1.

Anonymous, 1981a. The Fond-du-Lac uranium deposit. In CIM Geology Division Uranium Field Excursion Guidebook, September 8-13, 1981. 76-79.

Anonymous, 1981b. The Stewart Island uranium deposit. In CIM Geology Division Uranium Field Excursion Guidebook, September 8-13, 1981. 82-84.

Armstrong, R.L. and Ramaekers, P., 1985. Sr isotopic study of Helikian sediment and diabase dikes in the Athabasca Basin, northern Saskatchewan. Canadian Journal of Earth Science, vol. 22. 399-407.

Aulstead, K.L., Spencer, R.J. and Krouse, H.R.,1988. Fluid inclusion and isotopic evidence on dolomitization, Devonian of Western Canada; Geochimica et Cosmochimica Acta, vol. 52, no. 5. 1027-1036.

Aulstead, K.L. and Spencer, R.J., 1985. Diagenesis of the Keg River Formation, northwestern Alberta: Fluid inclusion evidence; Bulletin of Canadian Petroleum Geology, vol. 33. 167-183.

Bagby, W.C. and Berger, B.R.,1985. Geologic characteristics of sediment-hosted, disseminated precious-metal deposits in the western United States; In B.R. Berger and P.M. Bethke, ed's., Geology and Geochemistry of Epithermal Systems, Revisions in Economic Geology, vol. 2. 169-202.

Bakker, F., Campbell, J. and Friesen, R.G., 1985. Geology and excursion guide to the Geco Cu-Zn-Ag mine and Manitouwadge area. In R.H. McMillan and D.J. Robinson (ed.) Gold and copper-zinc metallogeny, Hemlo-Manitouwadge-Winston Lake, Ontario, Canada. 16-29.

Ballantyne, J.M., 1993. Hydrocarbon-associated, sediment-hosted gold deposits: A genetic model. The American Association of Petroleum Geologists Bulletin, Association Round Table Abstracts, v. 77, no. 8. 1141.

Ballantyne, S.B. and Harris, D.C., 1994. The exploration significance of Central Alberta Modern an Tertiary Alluvial Platinum Group Minerals, Chromites, Ilmenites and Placer Gold. In The Calgary and Mining Forum, Program and Abstracts, 10 & 11 February, 1994; published by the Calgary Mineral Exploration Group. 50.

Bally, A.W., Gordey, P.L. and Stewart, G.A., 1966. Structure seismic data and orogenic evolution of southern Canadian Rocky Mountains; Canadian Journal of Earth Sciences, vol. 22. 384-398.

Banerjee, I., 1989. Petrography of the Upper Albian basal Colorado sandstone in the Cessford Field, southern Alberta; In Current Research, Part D, Geological Survey of Canada, Paper 89-1D. 9-19.

Baragar, W.R.A. and E.H. Hornbrook, 1963. Mineral industry of District of Mackenzie, 1962. Geological Survey of Canada, Paper 63-9.

Barnes, H.L., ed., 1979. Geochemistry of Hydrothermal Ore Deposits, Second Edition; John Wiley & Sons, 798 p.

Barton, R.H., E.A. Christiansen, W.O. Kupsch, W.H. Mathews, C.P. Gravenor and L.A. Bayrock, 1964. Quaternary. In McGrossan, R.G. and R.P. Glaister (ed's). Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta. 195-200.

Bayrock, L.A., 1971. Surficial geology, Bitumount, Alberta, NTS 74E. Alberta Research Council/Alberta Geological Survey Map 34 at 1:250,000 scale.

Bayrock, L.A., 1972a. Surficial geology, Fort Chipewyan, Alberta, NTS 74L. Alberta Research Council/Alberta Geological Survey map at 1:250,000 scale.

Bayrock, L.A., 1972b. Surficial geology, Peace Point and Fitzgerald, Alberta, NTS 84P, 74M. Alberta Research Council/Alberta Geological Survey map at 1:250,000 scale.

Beach, H.H., 1942. Moose Mountain, Alberta. Geological Survey of Canada Map 688A.

Beales, F.W.,1953. Dolomite mottling in Palliser (Devonian) limestone, Banff and Jasper National Parks, Alberta; Bulletin of the American Association of Petroleum Geologists, vol. 37, no. 10. 2281-2293.

Beck, L.S., 1969. Uranium deposits of the Athabasca region, Saskatchewan. Department of Mineral Resources, Geological Sciences Branch, Precambrian Geology Division, Province of Saskatchewan, Report no. 126.

Beck, L.S., 1986. General geology and uranium deposits of the Beaverlodge District. In E.L. Evans, Uranium Deposits of Canada, CIM Special Volume 33. 85-94.

Bednarski, J.M., 1993. Quaternary geology and till geochemistry of the Precambrian Shield of Alberta. Abstract published In Program and Abstracts, The Calgary Mining Forum, March 3 & 4, 1993. 31.

Bell, J.S. and E.A. Babcock, 1986. The stress regime of the Western Canadian Basin and implications for hydrocarbon production. Bulletin of Canadian Petroleum Geology, vol. 34, no. 3. 364-378.

Bell, R.T.,1976. Geology of uranium in sandstones in Canada. Geological Survey of Canada, Paper 76-1A. 337-338.

Bell, R.T., 1977. Geology of some uranium occurrences in western Canada; Report of Activities, Part A; Geological Survey of Canada Paper 77-1A. 31-32.

Bell, R.T., Steacy, H.R. and Zimmerman, J.R., 1976. Uranium-bearing bone occurrences. Geological Survey of Canada, Paper 76-1A. 339-340.

Bell, R.T., 1978. Uranium in black shales - A review; In M.M. Kimberly, ed., Uranium Deposits: Their Mineralogy and Origin; Mineralogical Association of Canada, Short Course Handbook, vol. 3, October, 1978. 307-329.

Belyea, H.R., 1971. Middle Devonian Tectonic History of the Tathlina Uplift, southern district of Mackenzie and northern Alberta, Canada; Geological Survey of Canada, Paper 70-14, 38 p.

Benvenuto, G. and Price, R.A., 1979. Structural evolution of the Hosmer Thrust sheet, southern British Columbia; Bulletin of the Canadian Society of Petroleum Geologists, vol. 7. 360-394.

Berger, B.R. and Henley, R.W., 1989. Advances in the understanding of epithermal gold-silver deposits, with special reference to the western United States; In R.R. Keays, W.R.H. Ramsay and D.I. Groves, ed's., The Geology of Gold Deposits: The Perspective in 1988, Economic Geology Monograph 6. 405-423.

Bertram, E.F., Hamilton, W.N. and Green, R., 1973. Clear Hills iron deposits information needs; Alberta Research Council Open File Report 1973. 21, 12.

Bertram, E.F. and Mellon, G.B., 1973. Peace River iron deposits; Research Council of Alberta, Open File Report 1973-34.

Bertram, E. F. and Mellon, G.B., 1975. Peace River iron deposits; Research Council of Alberta, Information Series 75.

Bi, D. and Morton, R.D., 1993. Platinum-group metals in Pleistocene sediments of Alberta; in Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Edmonton, Alberta, Program and Abstracts. A-9.

Bingham, D.K., Gough D.I. and Ingham, M.R., 1985. Conductive structures under the Canadian Rocky Mountains; Canadian Journal of Earth Sciences, vol. 22. 384-398.

Birnie, T.A., 1961. Normal faulting in the Indianhead Creek area, Alberta; Alberta Society of Petroleum Geologists, vol. 9. 331-342.

Bjorlykke, A. and Sangster, D.F., 1981. An overview of sandstone lead deposits and their relationship to red-bed copper and carbonate-hosted lead-zinc; *In* B.J. Skinner, ed., Economic Geology 75th Anniversary Volume, 1905-1980. 179-213.

Bohse, H., Rose-Hansen, J, Sorenson, H., Steenfelt, A., Lovborg, L., and Kundzendorf, H., 1974. On the behaviour of uranium during crystallization of magmas - With special emphasis on alkaline magmas. *In* Formation of uranium ore deposits. Proceedings of a symposium on the formation of uranium ore deposits held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency, Vienna.

Bostock, H.H., 1981. A granitic diapir of batholithic dimensions at the west margin of the Churchill Province. *In* Current Research, Part B, Geological Survey of Canada, Paper 81-1B. 73-82.

Bostock, H.S., 1970. Physiographic Subdivisions of Canada. *In* Geology and Economic Minerals of Canada, R.J.W. Douglas (ed.). Geological Survey of Canada, Economic Geology Report No. 1. 9-30.

Boyle, R.W., 1979. The geochemistry of gold and its deposits. Geological Survey of Canada Bulletin 280.

Boyle, D.R., 1982. The formation of sediment hosted uranium deposits in south central British Columbia. Economic Geology, vol. 77. 1176-1209.

Boyle, D.R., 1985. Basal type uranium deposits in south central British Columbia. In E.L. Evans, Uranium Deposits of Canada, CIM Special Volume 33. 309-320.

Boyle, R.W., Brown, A.C., Jefferson, C.W., *et al.*, ed's., 1989. Sediment - hosted stratiform copper deposits; Geological Association of Canada Special Paper 36.

Bradshaw, B.A., 1967. Geological report - Quartz prospecting permit areas (White and Lyons) southwestern Alberta; unpublished assessment report prepared for Kennco Explorations (Western) Ltd.

Bradshaw, B.A., 1968. Geological report - Quartz mineral exploration permit areas no's. 10,11,18 and White and Lyons area, southwestern Alberta; unpublished assessment report prepared for Kennco Explorations (Western) Ltd.

Brown, A.C., 1992. Sediment-hosted stratiform copper deposits; Geoscience Canada, vol. 19, no. 3. 125-141.

Brandley, R.T. and Krause, F.F., 1993. Carbonate and siliciclastic deposition on a wave-swept, cold-water, low-latitude ramp: Lower Carboniferous Mount Head Formation, southwestern Alberta, Canada; CSPG Reservoir, vol. 20, no. 2. 1-2.

Brown, W.L., 1948. Monarch and Kicking Horse Mines. *In* Structural Geology of Canadian Ore Deposits - A Symposium. CIM Jubilee Volume. 231-237.

Bruce, R.W., 1957. Flotation and high-intensity magnetic separation tests on a sample of iron-bearing carbonate rock from the Zep property in southwestern Alberta. Department of Mines and Technical Surveys, Mines Branch Investigation Report IR 58-50.

Buhlmann, E., 1989. The Rutledge Lake property, N.W.T., an Outokumpu type environment for high grade Cu, Zn, Co massive sulfide mineralization, NTS 75 E 7, 10, 15, centering on Lat. 61° 37' N, Long. 110° 45' W. Unpublished report prepared for a client.

Burlet, L.A. and Trigg, C.M., 1987. Rutledge Lake, Research - 1986, LEA 1 to LEA 17, LEA 20, ENEX 3 to ENEX 5, ENEX 7, WWK 1 to WWK 10 and WWK 12 mineral claims, Mackenzie Mining District, N.W.T. Unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. for a client.

Bursnall, J.T. (ed.). ,1989. Mineralization and shear zones. Geological Association of Canada, Short Course Notes, vol. 6, Montreal, Quebec, May 12-14, 1989.

Burwash, R.A., 1993. Geological History of Basement Rocks in Alberta. *In* W.A.D. Edwards et al., Diamonds in Alberta - What's it All About. Abstract from a seminar held on February 2, 1993 at the Alberta Research Council in Edmonton.

Burwash, R.A. and Culbert, R.R., 1979. Abundance and distribution of Hg and As in the polymetamorphic Precambrian basement of western Canada; Canadian Journal of Earth Sciences, vol. 16. 2196-2203.

Bushell, J., 1970. Gamma-ray logging of water wells, southeastern Alberta and southwestern Saskatchewan (62E, 72E and 72F); in Report of Activities, Part A, Geological Survey of Canada Paper, 70-01A. 59-60.

Cameron, A.R., and Birmingham, T.F., 1968. Radioactivity of lignites, southern Saskatchewan; Geological Survey of Canada Paper 68-1A.

Cameron, A.R., and Hacquebard, P.A., Donaldson, J.R. and Birmingham, T.F., 1969. Radioactivity in Tertiary lignites in Saskatchewan, Alberta, British Columbia; Geological Survey of Canada Paper 69-1A. 4.

Cameron, A.R., Hacquebard, P.A. and Birmingham, T.F., 1970. Radioactivity in Tertiary lignites in western Canada; Geological Survey of Canada Paper 70-1A. 18.

Cameron, A.R. and Birmingham, T.F.,1970. Radioactivity in western Canadian coals; Geological Survey of Canada Paper 70-52.

Campbell, F.A., 1980. The uranium content of the Exshaw Formation and Belloy Group in Alberta; *In* Current Research, Part B, Geological Survey of Canada Paper 80-1B. 145-148.

Cant, D.J., 1988. Regional structure and development of the Peace River Arch, Alberta: A Paleozoic failed-rift system?. Bulletin of Canadian Petroleum Geology, vol. 36. 284-295.

Cant, D.J., 1989. Zuni Sequence: The Foreland Basin; Lower Zuni Sequence: Middle Jurassic to Middle Cretaceous. *In* B.D. Ricketts (ed.). Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta. 251-284.

Cant, D.J. and Stockmal, G.S., 1989. The Alberta Foreland Basin: Relationship between Stratigraphy and Cordilleran Terrane-accretion Events. Canadian Journal of Earth Science, v. 26. 1964-1975.

Carl, C., von Pechman, E., Höhndorf, A., and Ruhrmann, G., 1992. Mineralogy and U/Pb, Pb/Pb, and Sm/Nd geochronology of the Key Lake uranium deposit, Ahtabasca Basin, Saskatchewan, Canada. Canadian Journal of Earth Science, v. 29. 879-895.

Carlin, J.F., Jr., 1985. Tin. *In* United States Department of the Interior. Mineral facts and problems, 1985 edition. Bureau of Mines, Bulletin 675. 847-585.

Carne, R.C. and Cathro, R.J., 1982. Sedimentary exhalative (sedex) zinc-lead-silver deposits, northern Canadian cordillera; Canadian Institute of Mining and Metallurgy Bulletin, vol. 75, no. 840. 66-78.

Carrigy, M.A., 1959. Geology of the McMurray Formation. Part III General geology of the McMurray area. Alberta Research Council Memoir 1.

Carrigy, M.A., 1970. Proposed revisions of the boundaries of the Paskapoo Formation in the Alberta plains. Bulletin of the Canadian Society of Petroleum Geologists, v. 18. 156-165.

Carrigy, M.A.,1971. Lithostratigraphy of the uppermost Cretaceous (Lance) and Paleocene strata of the Alberta plains. Alberta Research Council, Bulletin 27.

Carter, K.M., 1971. Final report - North Carbondale project; unpublished assessment report prepared for Cominco Ltd.

Carter, K.M., 1987. Middle Devonian stratigraphy and mineralization, Pine Point area. *In* Second International Symposium on the Devonian System, August 17-20, 1987, Excursion A2, Middle and Upper Devonian of the Hay River region, southern district of Mackenzie, N.W.T., Canadian Society of Petroleum Geologists, Calgary, Alberta.

Cavell, P.A. and Burwash, R.A., 1993. Enriched mantle beneath southern Alberta - Isotopic evidence for a northern extension of the Wyoming Block into Canada: Geological Association of Canada - Mineralogical Association of Canada, Annual General Meeting, May 17 to 19, 1993, Program with Abstracts. A17.

Černý, P., 1993a. Rare-element granitic pegmatites. Part I: Anatomy and internal evolution of pegmatite deposits. *In* P.A. Sheahan and M.E. Cherry. Ore deposit models , Volume II. Geoscience Canada Reprint Series 6. 29-47.

Černý, P., 1993b. Rare-element granitic pegmatites. Regional to global environments and petrogenesis . *In* P.A. Sheahan and M.E. Cherry. Ore deposit models , Volume II. Geoscience Canada Reprint Series 6. 49-62.

Černý. and Meintzer, R.E., 1985. Fertile granites in the Archean and Proterozoic fields of rare-element pegmatites: Crustal environment, geochemistry and petrogenetic relationships. *In* R.P. Taylor and D.F. Strong (ed's). Recent advances in the geology of granite-related mineral deposits. CIM Special Volume 37. 170-207.

Chamberlain, J.A., 1960. On the uranium possibilities of the Southern Interior Plains of Canada; Geological Survey of Canada Paper 59-16.

Chamberlain, J.A. and Johnston, A.G., 1970. Nickel in Canada. Geological Survey of Canada, Map 1258A, 1:5,000,000 scale.

Charbonneau, B.W., 1980. The Fort Smith radioactive belt, Northwest Territories. *In* Current Research, Part C, Geological Survey of Canada, Paper 80-1C. 45-57.

Charbonneau, B.W., 1982. Radiometric study of three radioactive granites in the Canadian Shield: Elliot Lake, Ontario; Fort Smith, and Fury and Hecla, N.W.T. *In* Y.T. Maurice (ed.). Uranium in granites. Geological Survey of Canada, Paper 81-23. 91-99.

Charlesworth, H., 1959. Some suggestions on the structural development of the Rocky Mountains of Canada; Journal of the Alberta Society of Petroleum Geologists, vol. 7, no. 11. 249-256.

Charlesworth, H.A.K., Weiner, J.L., Akehurst, A.J., Bielenstein, H.U., Evans, C.R., et al., 1967. Precambrian geology of the Jasper region, Alberta. Research Council of Alberta Bulletin 23.

Christopher, P.A., and Kalnins, T. 1977. Exploration for basal type uranium deposits in B.C.; Western Miner, April 1977, 75-79.

Churcher, P.L. and Majid, A.H., 1989. Similarities between the Tangent-Wabamun type play of the Alberta basin and the Albion-Scipio type play of the Michigan basin; Bulletin of Canadian Petroleum Geology, vol. 37, no. 2. 241-245.

Clague, J.J.,1989. Quaternary Geology of the Canadian Cordillera. *In* R.J. Fulton (ed.). Quaternary Geology of Canada and Greenland. Geological Survey of Canada, Geology of Canada, no. 1, chapter 1. 15-96.

Clark, L.M., 1954. Cross-section through the Clark Range of the Rocky Mountains of southern Alberta and southern British Columbia; Alberta Society of Petroleum Geologists Guidebook, 4th Annual Field Conference. 105-109.

Collins, J.A. and Smith, L., 1977. Genesis of cupriferous quartz arenite cycles in the Grinnell Formation (Spokane equivalent), Middle Proterozoic (Helikian) Belt-Purcell Supergroup, eastern Rocky Mountains, Canada; Bulletin of Canadian Society of Petroleum Geologists, vol. 25. 713-735.

Consolidated Carina Resources Corp., 1993. Unpublished news release, April 16, 1993.

Colvine, A.C., Andrews, A.J., Cherry, M.E., Durocher, M.E. , Fyon, A.J., et al., 1984. An integrated model for the origin of Archean lode gold deposits. Ontario Geological Survey Open File Report 5524.

Coombe, W., 1984. Gold in Saskatchewan. Saskatchewan Energy and Mines, Saskatchewan Geological Survey, Open File Report 84-1.

Coombe, W., 1991. Base metals in Saskatchewan. Saskatchewan Energy and Mines, Saskatchewan Geological Survey, Open File Report 91-1.

Coveney, R.M., Murowchick, J.B. Jr., Grauch, R.I., *et al.*, 1992. Field relations, origins and resource implications for platiniferous molybdenum-nickel ores in black shales of south China; Exploration and Mining Geology, Journal of the Geological Society of CIM, vol. 1, no. 1. 21-28.

Cox, D.P. and Bernstein, L.R., 1986. Descriptive model of Kipushi Cu-Pb-Zn; *In* D.P. Cox and D.A. Singer, ed's., Mineral Deposit Models, U.S. Geological Survey Bulletin 1963. 227.

Crawley, R.A., 1983. Sandstone uranium deposits in the United States: A review of the history, distribution, genesis, mining areas and outlook; United States Department of Energy, GJBX-15(83).

Culshaw, N.G., 1984a. Rutledge Lake, Northwest Territories: A section across shear belt within the Churchill Province. Geological Survey of Canada, Current Research, Paper 84-1A. 331-338.

Culshaw, N.G., 1984b. Lakeshore geology of Rutledge Lake, N.W.T. Geology Division, Department of Indian and Northern Affairs, Map E.G.S. 1984-3, 1:50,000 scale.

Cumming, G.L. and Krstic,D., 1992. The age of unconformity-related uranium mineralization in the Athabasca Basin, northern Saskatchewan. Canadian Journal of Earth Science, vol. 29. 1623-1639.

Cumming, G.L., Kyle, J.R. and Sangster, D.F., 1990. Pine Point: A case history of lead isotope homogeneity in a Mississippi Valley-type deposit. Econ. Geol., v. 85. 133-144.

Cunningham, L.D.,Tantalum. *In* United States Department of the Interior. Mineral facts and problems, 1985 edition. Bureau of Mines, Bulletin 675. 811-822.

Cvancara, A.M., 1976a. Geology of the Fox Hills Formation (late Cretaceous) in the Williston Basin of North Dakota, with reference to uranium potential; North Dakota Geological Survey Report of Investigation no. 55.

Cvancara, A.M., 1976b. Geology of the Cannonball Formation (Paleocene) in the Williston Basin of North Dakota, with reference to uranium potential; North Dakota Geological Survey Report of Investigation no. 57.

Dahlstrom, C.D.A.,1970. Structural geology in the eastern margin of the Canadian Rocky Mountains; Bulletin of Canadian Petroleum Geology, vol. 18, no. 3. 332-406.

Daly, R.A.,1912. Geology of the North American cordillera at the forty-ninth parallel; Geological Survey of Canada Memoir 38.

Darnley, A.G.,1982. `Hot' granites: Some general remarks. *In* Y.T. Maurice (ed.). Uranium in granites. Geological Survey of Canada, Paper 81-23. 1-10.

Darnley, A.G., Cameron, E.M. and Richardson, K.A., 1975. The federal-provincial uranium reconnaissance program. *In* A.G. Darnley, V. Ruzicka, W. Dyck, E.M. Cameron and K.A. Richardson, Uranium Exploration '75. Geological Survey of Canada, Paper 75-26. 49-71.

Dawson, G.M., 1886. Preliminary report on the physical and geological features of the Rocky Mountains between latitudes 49° and 51°30'. Geological Survey of Canada, Annual Report 1985.169.

Dawson, G.M., 1899. Reports A, H, I, J, M and S. Geological Survey of Canada, Annual Report 1897, Volume X, No. 679.

Dawson, G.M., 1901. Reports A, D, F, G, J, L, M, R and S. Geological Survey of Canada, Annual Report 1898, Volume XI, No. 715.

Dawson, J.B., 1989. Geographic and time distribution of kimberlites and lamproites: Relationships to tectonic processes. *In* Ross, J., ed., *Kimberlites and related rocks, Volume 1: Their composition, occurrence, origin and emplacement*. Geological Society of Australia, Spec. Publ. No. 14. 323-342.

Dawson, K.R.,1974. Niobium (columbium) and tantalum in Canada. Geological Survey of Canada, Economic Geology Report No. 29.

Dawson, K.R.,1985. Geology of barium, strontium and fluorine in Canada. Geological Survey of Canada, Economic Geology Report No. 34.

Dawson, K.M., Panteleyev, A., Sutherland Brown, A., and Woodsworth, G.J., 1992. Regional Metallogeny. *In* Gabrielse, H. and C.J. Yorath. (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 709-768.

Deer, W.A., Howie, R.A. and Zussman, J., 1966. An introduction to the rock-forming minerals. John Wiley and Sons Inc., New York, N.Y.

Delaney, G.D., 1992. Gold in the Glennie Domain. Saskatchewan Energy and Mines, Saskatchewan Geological Survey, Miscellaneous Report 92-5.

Denson, N.M. and Gill, J.R., 1965. Uranium-bearing lignite and carbonaceous shale in the southwestern part of the Williston Basin - a regional study; United States Geological Survey Professional Paper 463.

Devlin, W.J., 1989. Stratigraphy and sedimentology of the Hamill Group in the northern Selkirk Mountains, British Columbia: Evidence for the latest Proterozoic - Early Cambrian extensional tectonism; Canadian Journal of Earth Sciences, vol. 26. 515-533.

Devlin, W.J. and Bond, G.C., 1988. The initiation of the early Paleozoic Cordilleran miogeocline: Evidence from the uppermost Proterozoic - Lower Cambrian Hamill Group of southwestern British Columbia; Canadian Journal of Earth Sciences, vol. 25. 1-19.

DeVoto, R.H., 1978. Uranium in Phanerozoic sandstone and volcanic rocks; In M.M. Kimberley, ed., Uranium Deposits: Their Mineralogy and Origin, Mineralogical Association of Canada, Short Course Handbook, vol. 3, October, 1978. 293-306.

Dingwell, D.B. and Brearly, M.,1985. Mineral chemistry of igneous melanite garnets from analcite-bearing volcanic rocks, Alberta, Canada; Contributions to Mineralogy and Petrology, vol. 90. 29-35.

Douglas, R.J.W., 1950. Callum Creek, Langford Creek, and Gap Map areas, Alberta. Geological Survey of Canada, Memoir 255.

Douglas, R.J.W., 1958. Mount Head map area; Geological Survey of Canada, Memoir 291.

Douglas, R.J.W. (ed.), 1970. Geology and Economic Minerals of Canada. Geological Survey of Canada, Economic Geology Report No. 1.

Douglas, R.J.W., Gabrielse, H., Wheeler, J.O., Stott, D.F. and Belyea, H.R., 1970. Geology of Western Canada. In R.J.W. Douglas (ed.) Geology and Economic Minerals of Canada. Geological Survey of Canada, Economic Geology Report No. 1. 367-488.

Dubord, M.P., 1987. Carbonate hosted Pb-Zn potential of northeastern Alberta and the applicability of Petroleum data for mineral exploration. Alberta Research Council Open File Report 1987-07.

Dubord, M.P., 1988. Lead-zinc potential of northeastern Alberta Phanerozoic rocks. Geoscience Canada, vol. 15. 111-112.

Dufresne, M.B. *et al., In preparation.* The diamond potential of Alberta: A regional synthesis of the structural and stratigraphic setting, and other preliminary indications of diamond potential. In preparation by the Alberta Geological Survey, R.A. Olson Consulting Ltd. and Dr. D.R. Schmitt of the University of Alberta for Alberta Energy as project M93-04-037 under the Canada-Alberta Partnership Agreement on Mineral Development.

Duke, M.J.M., 1983. Geochemistry of the Exshaw shale of Alberta - an application of neutron activation analysis and related techniques; unpublished M.Sc. thesis, University of Alberta, Edmonton.

Dummett, H., Fipke, C. and Blusson, S.L., 1985. Diamondiferous diatremes of eastern British Columbia; Canadian Institute of Mining and Metallurgy Bulletin, Abstract, vol. 78, no. 875. 56-58.

Duncan, N.S., 1970. Report on exploration permits and claims in the Clark Range southwestern Alberta and southeastern British Columbia; unpublished assessment report prepared by L.B. Halferdahl & Associates Ltd. for Canford Engineering Ltd.

Eckstrand, O.R. (ed.), 1984. Canadian Mineral Deposit Types: A geological Synopsis. Geological Survey of Canada, Economic Geology Report 36.

Edgar, N.S., 1961. Iron Prospecting Permit No. 16 (Swift Creek deposit); unpublished assessment report prepared for Peace River Mining and Smelting Ltd.

Edgar, N.S., 1962. Iron Prospecting Permit No. 17 (Clear Hills iron deposit); unpublished assessment report prepared for Peace River Mining and Smelting Ltd.

Edgar, N.S.,1964. Iron Prospecting Permit No, 20; unpublished assessment report prepared for Peace River Mining and Smelting Ltd.

Edgar, N.S.,1965. Iron Prospecting Permit No. 24; unpublished assessment report prepared for Peace River Mining and Smelting Ltd.

Edmond, B.A.,1970. The Grande Prairie permits, Alberta - an exploration venture for sandstone-type uranium mineralization in the Western Alberta Basin; unpublished assessment report prepared by International Mine Services Ltd., 12 p.

Edmonton Journal, October 17, 1992a. Prospector low-key about diamond find.

Edmonton Journal, December 26, 1992b. Loner's find the stuff of lore, PR.

Edmonton Journal, May 18, 1993. Alberta Diamond hunt no waste of time, Dia Met Chief says.

Edwards, W.A.D.,1990. Placer Gold Occurrences in Alberta; Alberta Research Council Open File Report 1990-9.

Edwards, W.A.D., Richardson, R.J.H. and Fildes, B.J., 1991. Geology and Metallic Mineral Potential of Northeastern Alberta. Alberta Research Council/Alberta Geological Survey Open File 1991-6.

Einaudi, M.T., Meinert, L.D. and Newberry, R.J., 1981. Skarn deposits. In B.J. Skinner (ed.). Economic Geology Seventy-fifth Anniversary Volume, 1905-1980. 317-391.

Eisbacher, G.H., Carrigy, M.A. and Campbell, R.B., 1974. Paleodrainage pattern and late orogenic basins of the Canadian cordillera; W.R. Dickenson, ed., Tectonics and Sedimentation, Society of Economic Paleontologists and Mineralogists Special Publication No. 22. 143-166.

Elevatorski, E.A.,1977. Uranium deposits of the northern United States region; published by Minobras.

Ellis, T.R., 1979. Estimation of minimum specifications for economically explorable sandstone-type uranium deposits; Colorado School of Mines Quarterly, vol. 74, no. 1.

Ells, S.C., 1926. Bituminous sands of northern Alberta: Occurrence and economic possibilities; Report on investigations to the end of 1924. Canada Mines Branch Report 362.

Ellstone, E.F., 1963. A memorandum report on the Athabasca gold project of Scurry Rainbow Oil Ltd. Unpublished report prepared for Scurry Rainbow Oil Ltd. 11 pages including 6 figures.

Evans, E.L.,1986. Uranium deposits of Canada; Canadian Institute of Mining and Metallurgy Special Volume 33.

Evans, T.L., 1965. A reconnaissance study of some western Canadian lead-zinc deposits; unpublished M.Sc. thesis, University of Alberta, Edmonton.

Falconer, J.S., 1993a. The Porcupine Hills property, Alberta; Metallic mineral application, 10,240 acres located in township 10, range 1, W5M, for Natalie Ann Harder. Dated "Revised: October 29, 1993". Unpublished exploration proposal.

Falconer, J.S., 1993b. Cemented Tertiary placer gold in the Porcupine Hills, Alberta. Oral paper presented to the Calgary Mineral Exploration Group on December 2,1993.

Fenton, M.M., 1987. Metallic Mineral Exploration on the Interior Platform: Quaternary Contribution. Geoscience Canada, v. 15, no. 2. 85-88.

Fenton, M.M., 1984. Quaternary Stratigraphy of the Canadian Prairies. In R.J. Fulton. (ed.) Quaternary Stratigraphy of Canada -- A Canadian Contribution of IGCP Project 24. Geological Survey of Canada, Paper 84-10. 57-68.

Fermor, P.R. and Price, R.A., 1987. Multiduplex structure along the base of the Lewis Thrust sheet in the southern Canadian Rockies; Bulletin of Canadian Petroleum Geology, vol. 35, no. 2. 159-185.

Ferrel, J.E., 1985. Lithium. In United States Department of the Interior. Mineral facts and problems, 1985 edition. Bureau of Mines, Bulletin 675. 461-470.

Fipke, C.F. 1990. The development of advanced technology to distinguish between diamondiferous and barren diatremes, Part I, II and III; Geological Survey of Canada, Open File 2124.

Fischer, R.P., 1968. The uranium and vanadium deposits of the Colorado Plateau region. In J.D. Ridge (ed.). Ore deposits of the United States, 1933-1967, The Graton-Sales Volume, volume I. 735-746.

Fitzgerald, E.L., 1962. Structure of the McConnell Thrust sheet in the Ghost River area, Alberta; Journal of the Alberta Society of Petroleum Geologists, vol. 10, no. 10. 553-574.

Focal Resources Limited, 1993. Various press releases issued by Focal Resources and provide by the Alberta Stock Exchange. The releases are dated: April 15, 1993; April 21, 1993; May 6, 1993; June 7, 1993; June 28, 1993; and September 15, 1993.

Follinsbee, R.E., Ritchie, W.D. and Stansberry, G.F., 1957. The Crowsnest Volcanics and Cretaceous geochronology; In 7th Annual Field Conference and Guide Book, Alberta Society of Petroleum Geologists. 20-26.

Foster, F. and Childs, J.F., 1993. An overview of significant lode gold systems in Montana, and their regional geological setting. Exploration and Mining Geology, Journal of the Geological Society of CIM, v. 2, no. 3. 217-244.

Fountain,D.M. and McDonough, D., 1984. Crustal structure of northern Montana and southern Alberta and British Columbia based on interpretation of gravity data; *In* J.D. McBane and P.B. Garrison, ed's., Montana Geological Society 1984 Field Conference and Symposium. 253-258.

Fox, F.G., 1959. Structures and accumulation of hydrocarbons in southern Alberta foothills, Alberta, Canada; Bulletin of the American Association of Petroleum Geologists, vol. 43, no. 5. 992-1025.

Fox, P.E., 1991. Assessment report on metallic mineral exploration permits 6889090002 and 6889090003, High Divide Ridge area, Alberta; unpublished assessment report prepared by Fox Geological Consultants Ltd. for Placer Dome Inc.

Franklin, J.M., Lydon, J.W. and Sangster, J.W., 1981. Volcanic-associated massive sulfide deposits. *In* B.J. Skinner (ed.). Economic Geology Seventy-fifth Anniversary Volume, 1905-1980. 485-627.

Franklin, J.M. and Thorpe, R.I., 1982. Comparative Metallogeny of the Superior, Slave and Churchill Provinces. *In* R.W. Hutchinson, C.D. Spence and J.M. Franklin, Precambrian Sulphide Deposits, H.S. Robinson Memorial Volume, Geological Association of Canada, Special Paper 25. 1-90.

Friesen, R.G., Pierce, G.A. and Weeks, R.M., 1982. Geology of the Geco base metal deposit. *In* Hutchinson, R.W., C.D. Spence and J.M. Franklin (ed's). Precambrian sulphide deposits. Geological Association of Canada special Paper 25, H.S. Robinson Memorial Volume. 343-363.

Fritz, W.H., Cecile, M.P., Norford, B.S., Morrow, D. and Geldsetzer, H.H.J., 1992. Cambrian to Middle Devonian Assemblages. *In* Gabrielse, H. and C.J. Yorath. (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 151-218.

Fulton, R.J. (ed.), 1989. Quaternary Geology of Canada and Greenland. Geological Survey of Canada, Geology of Canada, no. 1.

Fulton, R.J., Vincent, J.S., and Klassen, R.W., 1989. Quaternary Geology of the Southern Canadian Interior Plains. *In* R.J. Fulton (ed.). Quaternary Geology of Canada and Greenland. Geological Survey of Canada, Geology of Canada, no. 1, Chapter 2. 97-173.

Gabrielse, H. and Yorath, C.J. (ed's.), 1992. Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada.

Gabrielse, H. and Yorath, C.J., 1992. Tectonic Synthesis. *In* Gabrielse, H. and C.J. Yorath. (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 679-705.

Gabielse, H. and Campbell, R.B., 1992. Upper Proterozoic Assemblages. In H. Gabrielse and C.J. Yorath (ed's). Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 125-150.

Galloway, W.E., 1978. Uranium mineralization in a coastal-plain fluvial aquifer system: Catahoula Formation, Texas; Economic Geology, vol. 73. 1655-1676.

Galloway, W.E. and Kaiser, W.R.,1979. Catahoula Formation of the Texas coastal plain: Origin, geochemical evaluation and characteristics of uranium deposits; United States Department of Energy, GJBX-131(79).

Galloway, W.E., Kreitler, C.W. and McGowan, J.H., 1979. Depositional and ground-water flow systems in the exploration for uranium; Bureau of Economic Geology, The University of Texas at Austin.

Garland, G.D. and Bower, M.E, 1959. Interpretation of aeromagnetic anomalies in northeastern Alberta; in 5th World Petroleum Congress, Section 1, Paper 42. 787-800.

Garnett, R.H.T., 1994. Benefits of uneroded kimberlite at Fort a la Corne, Saskatchewan. In The Calgary and Mining Forum, Program and Abstracts, 10 & 11 February, 1994; published by the Calgary Mineral Exploration Group. 34.

Gavin, B., 1991. Precious-metal mineralization in the Sweet Grass Hills, north-central Montana; In Central Montana Alkalic Province Guidebook, D.W. Baker and R.B. Berg (ed's.), Montana Bureau of Mines and Geology, Special Publication No. 100. 55-62.

Geldsetzer, H.J., de Mille, G., Sangster, D.F., Chung, C.F., McDonald, J.A. and Jonasson, I.R., 1987. Geochemistry and general geology of the Upper Devonian Palliser Formation, Rocky Mountains, British Columbia and Alberta; Geological Survey of Canada, Open File 1021.

Geldsetzer, H.J. and Mountjoy, E.W., 1992. Upper Devonian platform reefs and inter-platform basins, Canmore to Jasper, Alberta; American Association of Petroleum Geologists Annual Convention, Field Trip #23.

Gent, M.R., 1992. Diamonds and precious gems of the Phanerozoic basin, Saskatchewan: Preliminary investigation; Saskatchewan Energy and Mines Open File Report 92-2.

Geological Survey of Canada, 1964. Fitzgerald, 74M, Airborne magnetic survey map no. 7161G, 1:253,440 scale.

Geological Survey of Canada, 1977a. Fitzgerald, 74M, Airborne gamma-ray spectrometric map no. 36374G, 1:250,000 scale.

Geological Survey of Canada, 1977b. Fort Chipewyan, 74L, Airborne gamma-ray spectrometric map no. 36274G, 1:250,000 scale.

Geological Survey of Canada, 1977. Uranium reconnaissance program national stream sediment and water geochemical reconnaissance data, northern Yukon Territory; Geological Survey of Canada Open File Report 418.

Geological Survey of Canada, 1990a. Magnetic anomaly map of Canada, Canadian Geophysical Atlas - Map 11, 1:10,000,000 scale.

Geological Survey of Canada, 1990a. Gravity anomaly maps of Canada, Canadian Geophysical Atlas - Maps 4, 5 and 6, 1:10,000,000 scale.

Germundson, R.K. and Fischer, P.A., 1978. Steen River diamond drill program, Alberta, NTS 84N; unpublished assessment report prepared for Gulf Minerals Canada Ltd., 8 p.

Gibbins, W.A.,1986. Ultramafic rocks and platinum group elements in the Northwest Territories. Open file memorandum prepared by the Geology Division, Department of Indian and Northern Affairs, Yellowknife, N.W.T.

Gibson, D.W., 1965. Triassic stratigraphy near the northern boundary of Jasper National Park, Alberta; Geological Survey of Canada Paper 64-9.

Gibson, D.W., 1971. Triassic petrology of Athabasca - Smoky River region, Alberta; Geological Survey of Canada Bulletin 194.

Gibson, D.W., 1974. Triassic rocks of the southern Rocky Mountains; Geological Survey of Canada Bulletin 230.

Giusti, L., 1983. The distribution, grades and mineralogical composition of gold-bearing placers in Alberta; Unpublished M.Sc. Thesis, University of Alberta, 397 p.

Gillis, N.C., 1970. Geological map - permits 155 and 157; unpublished assessment report.

Gleeson, C.F., 1979. Geochemical report on the Slave project, northwestern Alberta; unpublished assessment report by C.F. Gleeson & Associates Ltd. on behalf of Marline Oil Corp.

Goble, E.O., 1973a. Geological report #V-P-1, June-September 1972, permit areas #171, 172, 173, southwestern Alberta; unpublished assessment report prepared for Kintla Explorations Ltd.

Goble, E.O.,1973b. Supplementary report #W-P-1, May 8 - June 15, 1973, permit area #174, southwestern Alberta; unpublished assessment report prepared for Kintla Explorations Ltd.

Goble, E.O., 1974a. Geological report - Quartz mineral exploration permit #177. Unpublished assessment report prepared for Kintla Explorations Ltd.

Goble, E.O., 1974b. Geological report #S-P-1, permit area 176, southwestern Alberta. Unpublished assessment report prepared for Kintla Explorations Ltd.

Goble, E.O., 1974c. Geological report, 1974 diamond drilling program, Bighorn claims, Yarrow Creek - Spionkop Creek, southwestern Alberta; unpublished assessment report prepared for Kintla Explorations Ltd.

Goble, E.O., 1975. Final report - Quartz mineral exploration permit #174; unpublished report prepared for Kintla Explorations Ltd.

Goble, E.O., 1976. Report on the 1976 prospecting program in southwestern Alberta; unpublished assessment report prepared for Kintla Explorations Ltd.

Goble, R.J., 1970. The Yarrow Creek - Spionkop Creek copper deposit, southwestern Alberta; unpublished M.Sc. thesis, University of Alberta.

Goble, R.J., 1972. Geological report no. B1, spring program 1972, Bighorn claims, Yarrow Creek - Spionkop Creek, southwestern Alberta; unpublished assessment report prepared for Kintla Explorations Ltd.

Godfrey, J., 1985. Lead and zinc - commodity profile: internal report to Alberta Energy and Natural Resources; Alberta Research Council, Internal Report, 22 p.

Godfrey, J.D., 1958a. Aerial Photographic Interpretation of Precambrian Structures North of Lake Athabasca. Alberta Research Council Geological Division, Bulletin I.

Godfrey, J.D., 1958b. Mineralization in the Andrew, Waugh and Johnson Lakes area, northeastern Alberta. Alberta Research Council/Alberta Geological Survey Preliminary Report 58-4.

Godfrey, J.D., 1960. Northeast corner of Alberta and adjacent area: Its development and mineral potential. CIMM Transactions, vol. LXIII. 162-171.

Godfrey, J.D., 1961. Geology of the Andrew Lake, North District. Research Council of Alberta Preliminary Report 58-3.

Godfrey, J.D., 1963. Geology of the Andrew Lake, South District, Alberta. Research Council of Alberta Preliminary Report 61-2.

Godfrey, J.D., 1966. Geology of the Bayonet, Ashton, Potts and Charles Lakes Districts, Alberta. Research Council of Alberta Preliminary Report 65-6.

Godfrey, J.D., 1970. Geology of the Marguerite River District, Alberta. Alberta Research Council geological map at 1:63,360 scale.

Godfrey, J.D., 1973. Stony Islands Copper Showing: Slave River, Alberta. Alberta Research Council Open File Report 1973-36.

Godfrey, J.D., 1980a. Geology of the Alexander-Wylie Lakes District, Alberta. Alberta Research Council Earth Sciences Report 78-1.

Godfrey, J.D., 1980b. Geology of the Fort Chipewyan District, Alberta. Alberta Research Council Earth Sciences Report 78-3.

Godfrey, J.D., 1984. Geology of the Ryan-Fletcher Lakes district, Alberta. Alberta Research Council Earth Sciences Report 84-2.

Godfrey, J.D., 1986a. Geology of the Precambrian Shield in Northeastern Alberta, NTS 74M and 74L N½. Alberta Research Council Map EM 180 at 1:250,000 scale.

Godfrey, J.D., 1986b. Mineral showings of the Precambrian Shield in northeastern Alberta, NTS 74M and 74L/N½. Alberta Research Council/Alberta Geological Survey Map EM 182 at 1:250,000 scale.

Godfrey, J.D., 1987. Geology of the Bocquene-Turtle Lakes district, Alberta. Alberta Research Council Earth Sciences Report 84-5.

Godfrey, J.D. and Langenberg, C.W., 1987. Geology of the Myers-Daly Lakes district, Alberta. Alberta Research Council Earth Sciences Report 84-6.

Godfrey, J.D. and Piekert, E.W., 1963. Geology of the St. Agnes Lake District, Alberta. Research Council of Alberta Preliminary Report 62-1.

Godfrey, J.D. and Piekert, E.W., 1964. Geology of the Colin Lake District, Alberta. Research Council of Alberta Preliminary Report 62-2.

Godfrey, J.D. and Plouffe, R.D., 1978. Synthesis of airborne radiometric surveys for the Canadian Shield in northeastern Alberta. Alberta Research Council/Alberta Geological Survey, Internal report 1978-9.

Goff, S.P., Godfrey, J.D. and Holland, J.G., 1986. Petrology and Geochemistry of the Canadian Shield of northeastern Alberta. Alberta Geological Survey of the Alberta Research Council Bulletin No. 51.

Gordy, P.L. and Edwards, G., 1962. Age of the Howell Creek Intrusions. Alberta Society of Petroleum Geologists Journal, vol. 10, no. 7. 369-372.

Gordey, S.P., Geldsetzer, H.H.J., Morrow, D.W., Bamber, E.W., Henderson, C.M., et al., 1992. Upper Devonian to Middle Jurassic Assemblages. Part A. Ancestral North America. In H. Gabrielse and C.J. Yorath. (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 219-328.

Government of Canada, 1984. Fort McMurray vanadium; Mineral Policy Sector, Department of Energy, Mines and Resources, National Mineral Inventory Sheet No. 115110.

Govett, G.J.S., 1961. Occurrence and stratigraphy of some gypsum and anhydrite deposits in Alberta; Research Council of Alberta Bulletin 7.

Grande Prairie Daily Herald Tribune, 1992. Rumors fuel rush for Peace Diamond claims. Article in Tuesday edition, December 15, 1992. 4.

Grant, A.H., 1981. Exploration for sandstone-hosted uranium deposits within Upper Cretaceous - Lower Tertiary sediments, Alberta (1980); unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. on behalf of a client.

Grant, A.H., 1982. Exploration for sandstone-hosted uranium deposits within Upper Cretaceous - Lower Tertiary sediments, Alberta (1981); unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. on behalf of a client.

Grant, A.H. and Trigg, C.M., 1983. Magnetite sampling and research, 1983, Burmis, Alberta; unpublished assessment report by Trigg, Woollett, Olson Consulting Ltd. on behalf of a client.

Green, D.J. and Hulen, J.B., 1993. Hydrothermal speleogenesis in the Eastern Basin and Range Province - Implications for petroleum and precious metal exploration. The American Association of Petroleum Geologists Bulletin, Association Round Table Abstracts, v. 77, no. 8. 1149.

Green, R., 1972. Geological map of Alberta, 1:2,267,000 scale. Alberta Geological Survey of Alberta Research Council, Map 35.

Green, R., Mellon, G.B., Carrigy, M.A., 1970. Bedrock Geology of Northern Alberta; 1:500,000 scale. Geological map published by the Research Council of Alberta in two sheets (East and West Halfs).

Greenwood, H.J., Woodsworth, G.J., Read, P.B., Ghent, E.D. and Evenchick, C.A., 1992. Metamorphism. In H. Gabrielse and C.J. Yorath. (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 535-570.

Grieve, D.A., 1982. Petrology and chemistry of the Cross Kimberlite (82J/2); British Columbia Ministry of Energy, Mines and Petroleum Resources, Geology in British Columbia, 1977-1981. 34-41.

Griffith, J.W., 1986. Uranium deposits of the Bancroft area, Ontario. *In* E.L. Evans, Uranium Deposits of Canada, CIM Special Volume 33. 57-61.

Grip, E., 1967. On the genesis of the lead ores of the eastern border of the Caledonides in Scandinavia; *In* J.S. Brown, ed., Genesis of Stratiform Lead-Zinc-Fluorite Deposits (Mississippi Valley Type Deposits), A Symposium, Economic Geology Monograph 3. 208-218.

Groettler, G.W., 1969. Government of Alberta quartz mineral permit no.'s 14 and 15 - fieldwork report; unpublished assessment report prepared for C.C Huston and Associates.

Grover, T.W., McDonough, M.R. and McNicoll, V.J., 1993. Preliminary report of the metamorphic geology of the Taltson magmatic zone, Canadian Shield, northeastern Alberta. *In* Current Research, Part C, Geological Survey of Canada, Paper 93-1C. 233-238.

Gustafson, L.B., 1981. Sediment - hosted stratiform deposits of copper, lead and zinc; and Williams, N. *In* B.J. Skinner, ed., Economic Geology 75th Anniversary Volume, 1905-1980. 139-178.

Gyr, T., 1971. Prospecting and stream sediment sampling - Quartz mineral exploration permit area 148, southwestern Alberta; unpublished assessment report for Falconbridge Nickel Mines Ltd.

Hage, C.O., 1968. Report on exploration quartz mineral permits no.'s 32 and 33, Cypress Hills area, Alberta held by Dome Petroleum Ltd.; unpublished assessment report prepared by C.O. Hage on behalf of Dome Petroleum Ltd., 29 p.

Haites, T.B., 1960. Transcurrent faults in Western Canada. Alberta Society of Petroleum Geologists Journal, vol. 8, no. 2. 33-77.

Halferdahl, L.B., 1965. The occurrence of gold in Alberta Rivers; Alberta Research Council Open File Report 1965-11.

Halferdahl, L.B., 1971. 1971 exploration of properties in the Clark Range southwestern Alberta and southeastern British Columbia; unpublished assessment report prepared by L.B. Halferdahl & Associates Ltd. on behalf of Alcor Minerals Ltd.

Halferdahl, L.B., 1986. 1986 late winter drilling of metallic minerals exploration permit 6886020001 near Fort MacKay, Northeastern Alberta. Unpublished report prepared for Mr. K. Richardson by Halferdahl & Associates Ltd.

Hamilton, J.M., 1982. Geology of the Sullivan orebody, Kimberly, British Columbia, Bishop, D.T., Canada; *In* R.W. Hutchinson, C.D. Spence and J.M. Franklin, Morris, H.C. and ed's., Precambrian Sulphide Deposits, Geological Association Owens, O.E. of Canada Special Paper 25. 597-666.

Hamilton, W.N., 1978. Unpublished internal report; Alberta Research Council Economic Minerals File Report.

Hamilton, W.N., 1980. Clear Hills Iron Deposit: Geology, Mineralogy and Ore Reserves. Alberta Geological Survey of Alberta Research Council, Open File Report 1982-13, 43 p.

Hamilton, W.N. and Olson, R.A., *In press*. Mineral resources of the Western Canada Sedimentary Basin. *In* G.M. Mossop and I. Shetsen (ed's.). Atlas of the Western Canada Sedimentary Basin. Alberta Geological Survey of the Alberta Research Council, and Canadian Society of Petroleum Geologists.

Harper, C.T., Taylor, R.P. and Fryer, B.J., 1986. Geology and lithogeochemistry of the Maurice Bay uranium deposit, northern Saskatchewan. *In* E.L. Evans (ed.). Uranium deposits of Canada, CIM Special Volume 33. 241-249.

Harshman, E.N. and Adams, S.S, 1981. Geology and recognition criteria for roll-type uranium deposits in continental sandstones; United States Department of Energy, GJBX-1(81).

Harshman, E.N., 1968. Uranium deposits of Wyoming and South Dakota. *In* J.D. Ridge (ed.). Ore deposits of the United States, 1933-1967, The Graton-Sales Volume, volume I. 815-831.

Hauseux, M.A., 1977. Mode of uranium occurrences in a migmatitic granite terrain, Baie Johan Beetz, Quebec. CIM Bulletin, April 1997. 110-115.

Hawkins, P.A., 1994. Indicator mineral geochemistry in the Peace River Diamond Play. In The Calgary Mining Forum, Program and Abstracts, 10 & 11 February, 1994; published by the Calgary Mineral Exploration Group. 37.

Hayes, T.S. and Balla, J.C., 1986. Troy mine; *In* A.C. Brown and R.V. Kirkham, ed's., Proterozoic Sediment-hosted Stratiform Copper Deposits of Upper Michigan and Belt Supergroup of Idaho and Montana, Geological Association of Canada - Mineralogical Association of Canada - Canadian Geophysical Union, Joint Annual Meeting, Ottawa, Ontario, Field Trip 1 Guidebook. 54-64.

Hayes, T.S. and Einaudi, M.T., 1986. Genesis of the Spar Lake strata-bound copper-silver deposit, Montana: Part 1. Controls inherited from sedimentation and preore diagenesis; Economic Geology, vol. 81. 1899-1931.

Hearn, C. Jr., 1989. Alkalic ultramafic magmas in north-central Montana, U.S.A.: Genetic connections of alnoite, kimberlite and carbonatite; *In* Ross, J., ed., *Kimberlites and related rocks, Volume 1: Their composition, occurrence, origin and emplacement.* Geological Society of Australia, Spec. Publ. No. 14. 109-119.

Hedley, M.S., 1954. Mineral deposits in the southern Canadian Rocky Mountains of Canada; Alberta Society of Petroleum Geologists Annual Field Conference, 4th Guide Book. 110-118.

Hedrick, J.B., 1985. Rare earth elements and yttrium. *In* United States Department of the Interior. Mineral facts and problems, 1985 edition. Bureau of Mines, Bulletin 675. 133 -138.

Helmstaedt, H.H., 1992. "Primary" diamond deposits: what controls their size, grade and location; *In* B.H. Whiting, R. Mason and C.J. Hodgson, ed's., Giant Ore Deposits, Proceedings of the Giant Ore Deposits Workshop, Queen's University, Kingston, Ontario, Canada, May 11-13, 1992. 15-108.

Henderson, J.F., 1939. Geology, Taltson Lake, District of Mackenzie, Northwest Territories. Geological Survey of Canada, Map 525A, 1:253,440 scale.

Hitchon, B., Billings, G.K. and Klovan, J.E., 1971. Geochemistry and origin of formation waters in the western Canada sedimentary basin - III. Factors controlling chemical composition; Geochimica et Cosmochimica Acta, vol. 35. 567-598.

Hitchon, B., 1977. Geochemical links between oil fields and ore deposits in sedimentary rocks. In P. Garrrad (ed.) Proceedings of the Forum on Oil and Ore in Sediments, Imperial College, London, England. 1-34.

Hitchon, B., 1993. Geochemistry of formation waters, northern Alberta, Canada: Their relation to the Pine Point ore deposit. Alberta Research Council Open File Report 1993-14.

Hoadley, J.W., 1960. Mica deposits of Canada. Geological Survey of Canada, Economic Geology Series No. 19.

Hobbs, S.W. and Frylund, V.C. Jr., 1968. The Coeur d'Alene district, Idaho; In J.D. Ridge, ed., Ore Deposits in the United States: 1933-1967. 1417-1435.

Hoeve, J. and Sibbald, T.I.I., 1978a. On the genesis of Rabbit Lake and other unconformity-type uranium deposits in northern Saskatchewan, Canada. Economic Geology, vol. 73. 1450-1473.

Hoeve, J. and Sibbald, T.I.I., 1978b. Mineralogy and geological setting of unconformity-type uranium deposits in northern Saskatchewan. In M.M. Kimberley (ed.) Short course on uranium deposits: Their mineralogy and origin, Mineralogical Association of Canada, Toronto, October, 1978. 457-474.

Hoeve, J. and Sibbald, T.I., 1979. Uranium metallogenesis and its significance to exploration in the Athabasca Basin; Saskatchewan Geological Society Special Publication #4. 161-188.

Hoffman, G.C., 1885. Chemical contributions to the geology of Canada: part of the Annual Report, 1884-1885, vol. 1, part M, Geological and Natural History Survey of Canada.

Hoffman, P.F., 1987. Continental transform tectonics: Great Slave Lake shear zone (1.9 Ga), northwest Canada. Geology, v. 15. 785-788.

Holter, M.E., 1973. The Oldman River Pb-Zn occurrence, southwestern Alberta; Alberta Research Council Open File Report no. 1973-25.

Holter, M.E., 1977. The Oldman River lead-zinc occurrence, southwestern Alberta. Canadian Society of Petroleum Geologists Bulletin, vol. 25. 92-109.

Homeniuk, L.A. and Clark, R.J., 1986. North rim deposits, Athabasca Basin. *In* E.L. Evans (ed.). Uranium deposits of Canada, CIM Special Volume 33. 230-240.

Hopkins, J.C., 1987. Contemporaneous subsidence and fluvial channel sedimentation: Upper Mannville C Pool, Berry Field, Lower Cretaceous of Alberta; American Association of Petroleum Geologists Bulletin, vol. 71, no. 3. 334-345.

Hopkins, J.C., 1988. Syn- and post-depositional salt-dissolution structure traps in Lower Cretaceous sandstones, Cessford Field, Alberta, Canada; Canadian Society of Petroleum Geologists Reservoir, vol. 15, no. 10.

Hoy, T., 1982. The age, chemistry and tectonic setting of the Middle Proterozoic Moyie Sills, Purcell Supergroup, southeastern British Columbia. Canadian Journal of Earth Sciences, vol. 26. 2305-2317.

Hoy, T., 1989. The age, chemistry and tectonic setting of the Middle Proterozoic Moyie Sills, Purcell Supergroup, southeastern British Columbia; Canadian Journal of Earth Sciences, vol. 26. 2305-2317.

Hoy, T., Gibson, G. and Berg, N., 1984. Copper - zinc deposits associated with basic volcanism, Goldstream area, southeastern British Columbia; Economic Geology, vol. 79. 789-814.

Hriskevich, M.E., 1966. Stratigraphy of Middle Devonian and older rocks of the Banff Aquitaine Rainbow West 7-32 discovery well, Alberta; Bulletin of Canadian Petroleum Geology, vol. 14, no. 2. 241-265.

Hulbert, L.J., Carne, R.C., Gregoire, D.C. and Paktunc, D., 1992. Sedimentary nickel, zinc and platinum-group element mineralization in Devonian black shales at the Nick property, Yukon, Canada: A new deposit type; Exploration and Mining Geology, Journal of the Geological Society of CIM, vol. 1, no. 1. 39-62.

Hulen, J.B. and Nielson, D.I., 1993. Hydrothermal systematics, alteration and mineralization in the Grant Canyon, Bacon Flat, and Blackburn oil fields, Nevada - Intriguing parallels with Carlin-type gold deposits. The American Association of Petroleum Geologists Bulletin, Association Round Table Abstracts, v. 77, no. 8. 1152.

Hume, G.S., 1938. Preliminary report, Turner Valley, Alberta; Department of Mines and Resources Paper 38-7.

Hume, G.S., 1957. Fault structures in the Foothills and eastern Rocky Mountains of southern Alberta; Geological Society of America Bulletin, vol. 68, no. 4. 395-412.

Hunt, G., 1962. Time of Purcell eruption in southeastern British Columbia and southwestern Alberta; Journal of the Alberta Society of Petroleum Geologists, vol. 10. 438-442.

Hutchinson, R.W., Spence, C.D and Franklin, J.M. (ed's). Precambrian sulphide deposits. Geological Association of Canada special Paper 25, H.S. Robinson Memorial Volume.

Ijewliw, O.J., 1987. Comparative mineralogy of three ultramafic breccia diatremes in southeastern British Columbia, Cross, Blackfoot and HP (82J, 82G, 82N). In Geological Fieldwork 1986, British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987-1. 273-282.

Ijewliw, O.J. and Schulze, D.J., 1988. The Golden Cluster of diatremes and dykes; British Columbia Ministry of Energy, Mines and Petroleum Resources, Exploration in British Columbia. B39-B46.

Irish, E.J.W., 1968. Foremost, Alberta; Geological Survey of Canada Map 22-1967.

Irish, E.J.W., 1971. Geology, southern plains of Alberta, west of fourth meridian; Geological Survey of Canada, Map 1286A.

Irwin, A.B. and Prusti, D.B., 1955. O'Connor Lake (west half), District of Mackenzie, Northwest Territories. Geological Survey of Canada, Paper 55-9.

Ishihara, S., 1981. The granitoid series and mineralization. In B.J. Skinner (ed.). Economic Geology Seventy-fifth Aniversary Volume, 1905-1980. 458-484.

Jensen, N.L., 1985. Cesium. *In* United States Department of the Interior. Mineral facts and problems, 1985 edition. Bureau of Mines, Bulletin 675. 133-138.

Jewell, P.W. and Parry, W.T., 1987. Geology and hydrothermal alteration of the Mercur gold deposits, Utah; Economic Geology, vol. 82. 1958-1977.

Jewell, P.W. and Parry, W.T., 1988. Geochemistry of the Mercur gold deposit, Utah; Chemical Geology, vol. 69. 245-265.

Johnston, R.K. and Olson, R.A., 1982. Exploration 1982, Mist Mountain, Alberta; unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. on behalf of a client.

Jones, P.B., 1971. Folded faults and sequence of thrusting in Alberta foothills; The American Association of Petroleum Geologists Bulletin, vol. 55, no. 2. 292-306.

Jowett, E.C., 1986. Genesis of Kupferschiefer Cu-Ag deposits by convective flow of Rotliegendes brines during Triassic rifting; Economic Geology, vol. 81. 1823-1837.

Jowett, E.C., 1989. Effects of continental rifting on location and genesis of stratiform copper-silver deposits; *In* R.W. Boyle, A.C. Brown, C.W. Jefferson, E.C. Jowett and R.V. Kirkham, ed's., Sediment - Hosted Stratiform Copper Deposits, Geological Association of Canada Special Paper 36. 53-66.

Jowett, E.C., 1991. The evolution of ideas about the genesis of stratiform copper-silver deposits; *In* R.W. Hutchinson and R.I. Gauch, ed's., Historical Perspective of Genetic Concepts and Case Histories of Famous Discoveries, Society of Economic Geologists, Economic Geology Monograph 8. 117-132.

Jowett, E.C., Rydzewski, A. and Jowett, R.J., 1987. The Kupferschiefer Cu-Ag ore deposits in Poland: A reappraisal of the evidence of their origin and presentation of a new genetic model; Canadian Journal of Earth Sciences, vol. 24. 2016-2037.

Kanasewich, E.R., 1968. Precambrian rift: Genesis of strata-bound ore deposits. Science, vol. 161. 1002-1005.

Kanasewich, E.R., Clowes, R.M. and McCloughan, C.H., 1969. A buried Precambrian rift in western Canada. Tectonophysics, vol. 8. 513-527.

Katayama, N., and Kamiyama, T., 1976. Favourable conditions for the formation of basal type uranium deposits; paper presented to 25th International Geological Congress, Sydney, Australia, August, 1976.

Kelley, V.C., Kittel, D.F. and Melancon, P.A., 1968. Uranium deposits of the Grants region. *In* J.D. Ridge (ed.). Ore deposits of the United States, 1933-1967, The Graton-Sales Volume, volume I. 747-769.

Kidd, D.J., 1959. Iron occurrences in the Peace River region, Alberta. Alberta Research Council, Preliminary Report 59-3.

Kjarsgaard, B.A., 1994. Potassic magmatism in the Milk River area; southern Alberta: Petrology and economic potential. *In* Current Research 1994-B; Geological Survey of Canada.

Koeppel, V., 1968. Age and history of the uranium mineralization of the Beaverlodge area, Saskatchewan. Geological Survey of Canada Paper 67-31.

Koster, F., 1961. The geology of the Thainka Lake area (west half), Saskatchewan. Province of Saskatchewan, Department of Mineral Resources, Mines Branch, Geology Division, Report No. 61.

Kidd, D.J., 1958. Lower Mesozoic phosphorous siderites in the Highwood area, Iron prospecting permit no. 15; unpublished assessment report prepared for G.C. McCartney & Associates.

Kumarapeli, P.S., Kheang, L., Hoy, L. and Pintson, H., 1990. Chalcopyrite-bornite and chalcopyrite-bornite-barite in the Acton Vale limestone, southeastern Quebec: Mineralized shelf-margin slivers in a Taconian nappe; Canadian Journal of Earth Sciences, vol. 27. 27-39.

La Casse, L.J. and Roebuck, J., 1978. Minerals of Alberta; Hallamshire Publishers, Edmonton.

Lainé, R., Alonso, D. and Svab M.(ed's.), 1985. The Carswell structure uranium deposits, Saskatchewan. Geological Association of Canada Special Paper 29.

Lang, A.H., Griffith, J.W. and Steacy, H.R., 1962. Canadian deposits of uranium and thorium; Geological Survey of Canada Economic Geology Series no. 16.

Langenberg, C.W., 1983. Polyphase Deformation in the Canadian Shield of Northeastern Alberta. Alberta Geological Survey of the Alberta Research Council Bulletin No. 45.

Langenberg, C.W. and Nielsen, P.A, 1982. Polyphase Metamorphism in the Canadian Shield of Northeastern Alberta. Alberta Geological Survey of the Alberta Research Council Bulletin No. 42.

Langenberg, W., Salat, H., Turner. A and Eccles ,R., 1993. Evaluation of the economic mineral potential in the Andrew Lake-Charles Lake area of northest Alberta. Alberta Research Council/Alberta Geological Survey, Open File Report 1993-08.

Langford, F.F., 1978. Mobility and concentration of uranium in arid surficial environments; *In* M.M. Kimberly, ed., Uranium Deposits, Their Mineralogy and Origin, Mineralogical Association of Canada, Short Course Handbook, vol. 3, October, 1978. 383-394.

Langford, F.F., 1986. Geology of the Athabasca Basin. *In* E.L. Evans (ed.). Uranium deposits of Canada. CIM Special Volume 33. 123-133.

Leach, W.W., 1912. Geology of the Blairmore map area, Alberta; Geological Survey of Canada Summary Report 1911. 192-200.

Leckie, D.A., 1989. Upper Zuni SequenceL Upper Cretaceous to Lower Tertiary. *In* B.D. Ricketts (ed.). Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta. 269-284.

Leech, G.B., 1962. Metamorphism and granitic intrusions of Precambrian age in southeastern British Columbia; Geological Survey of Canada Paper 62-13.

Lehnert-Thiel, K., Loewer, R., Orr, R.G. and Robertshaw, P, 1992. Diamond-bearing kimberlites in Saskatchewan, Canada: The Fort à la Corne case history. Exploration and Mining Geology, Journal of the Geological Society of CIM, vol. 1, no. 4. 391-403.

Lehnert-Thiel, K., Kretschmar, W. and Petura, J., 1981. The Maurice Bay Deposits - Uranerz Exploration and Mining Limited. *In* CIM Geology Division Uranium Field Excursion Guidebook, September 8-13, 1981. 104-108.

Liebler, G.S., 1988. Geology and gold mineralization at the Picacho Mine, Imperial County, California. *In* R.W. Schafer, J.J. Cooper and P.G. Vikre (Ed's.) Bulk mineable precious metal deposits of the Western United States, Symposium Proceedings. Geological Society of Nevada, Reno, Nevada. 453-472.

Lis, M.G. and Price, R.A., 1976. Large-scale block faulting during deposition of the Windermere Supergroup (Hadrynian) in southeastern British Columbia; Geological Survey of Canada Paper 76-1A. 135-136.

Little, H.W., 1959. Tungsten deposits of Canada. Geological Survey of Canada, Economic Geology Series No. 17.

Lorenz, J.C., 1982. Lithospheric flexure and the history of the Sweetgrass Arch in northwestern Montana. *In* R.B. Powers (ed.) Geological Studies of the Cordilleran Thrust Belt: Rocky Mountain Association of Association of Geologists - 1982 Symposium, Denver, Colorado. 77-89.

Lorenz, J.C., 1984. The function of the Lewis and Clark Fault system during the Laramide Orogeny; In J.D. McBane and P.B. Garrison, ed's., Montana Geological Society 1984 Field Conference and Symposium. 221-230.

Lydon, J.W., 1988a. Volcanogenic massive sulphide deposits, Part 1: A descriptive model. *In* R.G. Roberts and P.A. Sheahan (ed's). Ore deposit models. Geoscience Canada Reprint Series 3.

Lydon, J.W., 1988b. Volcanogenic massive sulphide deposits, Part 2: Genetic models. *In* R.G. Roberts and P.A. Sheahan (ed's). Ore deposit models. Geoscience Canada Reprint Series 3.

Macdonald, A.J., 1988. Platinum group elements: Genesis and classification. *In* R.G. Roberts and P.A. Sheahan. Ore Deposit Models. Geoscience Canada, Reprint Series 3. 117-131.

Macdonald, C.C., 1980. Mineralogy and geochemistry of a Precambrian regolith in the Athabasca Basin. Unpublished Univ. of Sask. M.Sc. thesis. 151.

Macdonald, C.C., 1985. Mineralogy and geochemistry of the sub-Athabasca regolith near Wollaston Lake. *In* T.I.I. Sibbald and W. Petruk. Geology of uranium deposits, Proceedings of the CIM-SEG uranium symposium, September 1981. CIM Special Volume 32. 155-158.

MacDougall, D.G., Guliov. and Harper, C.T., 1990. Mineral resource map of Saskatchewan. Saskatchewan Energy and Mines, 1990 edition.

MacGillivray, J.R., Sham, P.C. and Boisvet, D.R., 1984. Alluvial gold project, North Saskatchewan River, Alberta; Alberta Research Council Open File Report 1984-29.

Majid, A.H., 1989. Regional geology and hydrocarbon occurrences in the Wabamun Group, west-central Alberta; in Current Research, Part D, Geological Survey of Canada, Paper 89-1D. 25-33.

Malan, R.C., 1968. The uranium mining industry and geology of the Monument Valley and White Canyon districts, Arizona and Utah. *In* J.D. Ridge (ed.). Ore deposits of the United States, 1933-1967, The Graton-Sales Volume, volume I. 790-804.

Mann, A.W. and Deutscher, R.L., 1978. Genesis principles for the precipitation of carnotite in calcrete drainages in Western Australia; Economic Geology, vol. 73. 1724-1737.

Marmont, S., 1988. Unconformity-type uranium deposits. *In* R.G. Roberts and P.A. Sheahan. Ore Deposit Models. Geoscience Canada, Reprint Series 3. 103-115.

Mason, B. and Moore, C.B., 1982. Principles of Geochemistry, 4th edition, John Wiley & Sons, publishers.

Matheson, K.A., 1969. Geological report on Lubicon EV 2-21-87-13, W5M; unpublished assessment report prepared for Oilfield Consultants Ltd., 17 p.

Maurice, Y.T. (ed.), 1982. Uranium in granites. Proceedings of a workshop held in Ottawa, Ontario, 25-26 November, 1980, Geological Survey of Canada, Paper 81-23.

Mawdsley, J.B., 1957. The Geology of the Charlebois Lake area, northern Saskatchewan (Map with marginal notes). Department of Mineral Resources, Geological Sciences Branch, Precambrian Geology Division, Province of Saskatchewan, Report no. 24.

Mawdsley, J.B., 1958. The radioactive pegmatites of Saskatchewan. International (Second) Conference on the Peaceful Uses of Atomic Energy Proceedings, vol. 2. 484-490.

Mawdsley, J.B., 1970 (reprinted). The Geology of the Charlebois Lake area, Athabasca Mining Division, northeastern Saskatchewan. Department of Mineral Resources, Geological Sciences Branch, Precambrian Geology Division, Province of Saskatchewan, Report no. 5 (originally issued 1950).

Maynard, J.B., 1991. Uranium: Syngenetic to diagenetic deposits in foreland basins. *In* E.R. Force, J.J. Eidel and J.B. Maynard (ed's). Sedimentary and diagenetic mineral deposits: A basin analysis approach to exploration. 187-197.

McConnell, R.G., (1891). Summary report on the Athabasca region, Alberta. Geological Survey of Canada, Summary Report 1890 in Annual Report No. 5, Part D.

McConnell, R.G., 1887. Report on the geological structure of a portion of the Rocky Mountains; Geological Survey of Canada, Summary Report, vol. 2.

McDonough, M.R., Grover, T.W., McNicoll, V.J. and Lindsay. D.D., 1993. Preliminary report of the geology of the southern Taltson magmatic zone, northeastern Alberta. *In* Current Research, Part C, Geological Survey of Canada, Paper 93-1C. 221-232.

McGrossan, R.G. and Glaister, R.P., 1964. Geological History of Western Canada. Alberta Society of Petrolem Geologists, Calgary, Alberta.

McGugan, A., 1987. "Horses" and transverse faults in the Lewis thrust sheet, Elk Range, Kananaskis Valley, Rocky Mountain front ranges, southwest Alberta; Bulletin of Canadian Society of Petroleum Geology, vol. 35, no. 3. 358-361.

McMechan, M.E. and Thompson, R.I., 1989. Structural Style and History of the Rocky Mountain Fold and Thrust Belt. *In* B.D. Ricketts (ed.) Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta. 47-71.

McMechan, M.E., Thompson, R.I., Cook, D.G., Gabrielse, H. and Yorath, C., 1992. Structural Styles , Part E. Foreland Belt. *In* Gabrielse, H. and C.J. Yorath. (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 634-650.

McMechan, M.E., 1981. The Middle Proterozoic Purcell Supergroup in the southeastern Purcell Mountains, British Columbia and the initiation of the Cordilleran miogeocline, southern Canada and adjacent United States; Bulletin of Canadian Society of Petroleum Geology, vol. 29. 583-621.

McMechan, M.E., 1988. Geology of Peter Lougheed Provincial Park, Rocky Mountain Front Ranges, Alberta; Geological Survey of Canada Open File 2057.

Meinert, L.D., 1993. Skarns and skarn deposits. *In* P.A. Sheahand and M.E. Cherry (ed's). Ore deposit models, Volume II. Geoscience Canada Reprint Series 6. 117-134.

Mellinger, M., 1985. The Maurice Bay uranium deposit (Saskatchewan): Geology, host rock alteration and genesis. *In* T.I.I. Sibbald and W. Petruk. Geology of uranium deposits, Proceedings of the CIM-SEG uranium symposium, September 1981. CIM Special Volume 32. 140-150.

Mellon, G.B., 1961. Sedimentary magnetite deposits of the Crowsnest Pass region, southwestern Alberta. Alberta Research Council, Bulletin 9. 98.

Mitchell, R.H., 1993. Kimberlites and Lamproites: Primary sources of diamond. *In* P.A. Sheahan and M.E. Cherry. Ore Deposit Models, Volume II. Geoscience Canada Reprint Series 6. 13-28.

Moffat, I.W. and Gardner, D.A.C., 1981. Basinal isotatic adjustment faults and their petroleum significance: Discussion. Bulletin of Canadian Petroleum Geology, vol. 30, no. 1. 43-44.

Moffat, I.W. and Spang, J.H., 1984. Origin of transverse faulting, Rocky Mountain front ranges, Canmore, Alberta; Bulletin of Canadian Society of Petroleum Geologists vol. 32, no. 2. 147-161.

Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T. et al., 1992. Upper Devonian to Middle Jurassic Assemblages. Part B. Cordilleran Terranes. *In* Gabrielse, H. and C.J. Yorath. (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 281-328.

Morganti, J., 1988. Sedimentary - type stratiform ore deposits: Some models and a new classification; *In* R.G. Roberts and P.A. Sheahan, ed's., Ore Deposit Models, Geoscience Canada Reprint Series 3. 67-78.

Morton, R.D., Goble, R.J. and Fritz, P., 1974. The mineralogy, sulphur-isotope composition and origin of some copper deposits in the Belt Supergroup, southwest Alberta, Canada; Mineralium Deposita, vol. 9. 223-241.

Morton, R.D., Stewart, J.P., Bale, W.C. and Day, R.C., 1993. A review of diamond occurrences and potentials in Alberta, Canada; *In* Dunne, K.P.E. and Grant, B. (ed's..), *Mid-Continent Diamonds*. GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993. 101-104.

Mossop, G.D. and Shetsen, I. In press. Geological History of the Western Canada Sedimentary Basin. Alberta Geological Survey of the Alberta Research Council and Canadian Society of Petroleum Geologist.

Motica, J.E., 1968. Geology and uranium-vanadium deposits in the Uravan mineral belt, southwestern Colorado. *In* J.D. Ridge (ed.). Ore deposits of the United States, 1933-1967, The Graton-Sales Volume, volume I. 805-813.

Muir, I.D. and Dravis, J.J., 1991. Burial porosity development in Middle Devonian Keg River Reservoirs; Canadian Society of Petroleum Geologists, CSPG Reservoir, vol. 18, no. 10. 2-3.

Muir, I.D. and Dravis, J.J., 1992. Burial porosity development in Middle Devonian Keg River Reservoirs; in G.M. Ross, ed., Alberta Basement Transects Workshop (March 4-5), Workshop Report #28, LITHOPROBE Secretariat, University of British Columbia. 102-103.

Mulligan, R., 1965. Geology of Canadian lithium deposits. Geological Survey of Canada, Economic Geology Report No. 21.

Mulligan, R., 1968. Geology of Canadian beryllium deposits. Geological Survey of Canada, Economic Geology Report No. 23.

Mulligan, R., 1975. Geology of Canadian tin occurrences. Geological Survey of Canada, Economic Geology Report No. 28.

Mulligan, R., 1984. Geology of Canadian tungsten occurrences. Geological Survey of Canada, Economic Geology Report No. 32.

Nakai, S., Halliday, A.N., Kesler, S.E., Jones, H.D., Kyle, J.R. and Lane, T.E., 1993. Rb-Sr dating of sphalerites from Mississippi Valley-type (MVT) ore deposits. Geochim et Cosmochimica Acta, v. 57. 417-427.

Naldrett, A.J., 1981a. Nickel sulfide deposits: Classification, composition and genesis. *In* B.J. Skinner (ed.). Economic Geology Seventy-fifth Anniversary Volume, 1905-1980. 628-685.

Naldrett, A.J., 1981b. Platinum-group element deposits. *In* L.J. Cabri (ed.). Platinum-group elements: Mineralogy, Geology, Recovery. CIM Special Volume 23. 197-231.

Nelson, C.E., 1993. Comparative geochemistry of jasperoids from Carlin-type gold deposits of the western United States. The American Association of Petroleum Geologists Bulletin, Association Round Table Abstracts, v. 77, no. 8. 1157.

Nesbitt, B.E. and Muehlenbachs, K., 1989. Geology, geochemistry and genesis of mesothermal lode gold deposits of the Canadian cordillera: Evidence for ore formation from evolved meteoric water; In The Geology of Gold Deposits: The Perspective in 1988, Economic Geology Monograph 6. 553-563.

Nesbitt, B.E. and Muehlenbachs, K., 1993a. Synorogenic fluids of the Rockies and their impact on paleohydrogeology and resources of the Western Canadian Sedimentary Basin. *In* G.M. Ross (ed.), Alberta Basement Transects Workshop (March 1-2), LITHOPROBE Report #31. 60-62.

Nesbitt, B.E. and Muehlenbachs, K., 1993b. Crustal hydrogeology of the Rockies: Implications to the origins of brines and Pb-Zn mineralization in the Western Canadian Sedimentary Basin. *In* Geological Association of Canada Annual Meeting, May 17-19, 1993, Edmonton, Alberta, Program with Abstracts. A76.

Newman, E., Jarre, G.A. and Cornish, E.C., 1970. 1969 field exploration Alberta uraniferous lignites; unpublished assessment report prepared by Intercontinental Resources, Inc. on behalf of Scotaire Exploration Ltd.

Ney, C.S., 1957. Monarch and Kicking Horse Mines. In Structural Geology of Canadian Ore Deposits - Volume II. CIM Congress Volume. 143-152.

Ney, C.S., 1954. Monarch and Kicking Horse Mines, Field, British Columbia; Guidebook, Fourth Annual Field Conference, Alberta Society of Petroleum Geologists. 119-136.

Noble, E.A., 1973. Uranium in coal; *In* United States Geological Survey and other agencies, Mineral and Water Resources of North Dakota, North Dakota Geological Survey Bulletin 63. 80-85.

Norman, H.C., 1957. Report on the Zep iron deposit Highwood River, Alberta; unpublished assessment report prepared for G.C. McCartney & Associates.

Norris, D.K., 1955. Blairmore, west of fifth meridian, Alberta; Geological Survey of Canada, Map 55-18.

Norris, D.K., 1963. Devonian stratigraphy of northeastern Alberta and northwestern Saskatchewan; Geological Survey of Canada Memoir 313.

North, F.K. and Henderson, G.L., 1954. Summary of the geology of the southern Rocky Mountains of Canada; *In* 4th Annual Field Conference Guide Book, Alberta Society of Petroleum Geologists. 15-81.

Northcote, K.E., 1983a. Report on Mark property, Pangman Peak (82N/15W); British Columbia Ministry of Energy, Mines and Petroleum Resources Assessment Report 13596.

Northcote, K.E., 1983b. Report on Jack claims, Lens Mountain (82N/14E); British Columbia Ministry of Energy, Mines and Petroleum Resources Assessment Report 13597.

Northern Miner, 1992. DiaMet ponders Lac de Gras ramp, calls latest sample values 'best ever'. The Northern Miner newspaper, August 3 issue. 1.

Northern Miner, 1993a. Focal drills Alberta prospect. The Northern Miner newspaper, April 26 issue. 3.

Northern Miner, 1993b. ASE requests fire assays of Focal drill samples. The Northern Miner newspaper, May 3 issue. 1, 2.

Northern Miner, 1993c. ASE requests new assays. The Northern Miner newspaper, May 24 issue. 2.

Northern Miner, 1993d. Ecstall Mining. The Northern Miner newspaper, August 30 issue. 11.

Northern Miner, 1994. The Northern Miner newspaper, January 31 issue. 6.

O'Connell, S.C. and Bell, J.S., 1990. Geology of the Peace River Arch. Canadian Society of Petroleum Geologists Bulletin, v. 38A. 250-269.

O'Donnell, J.R. and Fuenning, P., 1967. Minerals investigation of the Rocky Mountains area, Alberta and British Columbia; unpublished assessment report prepared by Geophoto Services Ltd. for Imperial Oil Enterprises Ltd.

Ollerenshaw, N.C., 1975. Kananaskis Lakes, British Columbia - Alberta; Geological Survey of Canada Open File 263.

Olson, R.A., 1981. Review of 1976, 1977, 1978, 1979 and 1980 exploration, Marian River Project (519), Mackenzie Mining District, Northwest Territories. Unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. for a client.

Olson, R.A., 1984. Compilation of exploration performed and evaluation of uranium potential in Phanerozoic rocks, Fort Smith, Northwest Territories to La Ronge, Saskatchewan. Unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. for a client.

Olson, R.A., 1985a. Compilation of exploration performed and evaluation of uranium potential: Tertiary of Alberta, Saskatchewan and Manitoba. Unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. for a client.

Olson, R.A.,1985b. Results from field examination of transmission line structure sites 454 and 456 near Blairmore Alberta; unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. on behalf of a client

O'Neill, J.M. and Lopez, D.A., 1985. Character and regional significance of Great Falls tectonic zone, east-central Idaho and west-central Montana; The American Association of Petroleum Geologists Bulletin, vol. 69. 437-447.

Oreskes, N. and Einaudi, M.T., 1990. Origin of the rare earth element-enriched hematite breccias at the Olympic Dam Cu-U-Au-Ag deposit, Roxby Downs, South Australia, Economic Geology, vol. 85, no. 1. 1-28.

Osadetz, K.G., 1989. Basin Analysis Applied to Petroleum Geology in Western Canada. In B.D. Ricketts (ed.). Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta. 287-306.

Osadetz, K.G. and Haid, F.M., 1989. Tippecanoe Sequence: Middle Ordovician to Lowest Devonian Vestiges of a Great Epeiric Sea. *In* B.D. Ricketts (ed.). Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta. 121-137.

Packard, J.J., Pellegrin, G.J., Al-Aasm, I.S., Samson, I., and Gagnon, J., 1991. Diagenesis and dolomitization associated with hydrothermal karst in Famennian Upper Wabamun ramp sediments, northwestern Alberta; in G.R. Bloy and M.G. Hadley, ed's., The Development of Porosity in Carbonate Reservoirs, Canadian Society of Petroleum Petrologists, Continuing Education Short Course. 9-1 to 9-19.

Park, D.G. and Jones, B., 1987. Brecciation in the Devonian Keg River Formation of northern Wood Buffalo National Park, northeast Alberta; Bulletin of Canadian Petroleum Geology, vol. 35, no. 4. 416-429.

Pearce, T.H., 1970. The analcite-bearing volcanic rocks of the Crowsnest Formations, Alberta. Canadian Journal of Earth Sciences, vol. 7. 46-66.

Pell, J., 1987a. Alkalic ultrabasic diatremes in British Columbia: Petrology, geochronology and tectonic significance. *In* Geological Fieldwork 1986, Minister of Energy, Mines and Petroleum Resources, Geological Survey Branch, Paper 1987-1. 259-272.

Pell, J. 1987b. Alkaline ultrabasic rocks in British Columbia; British Columbia Geological Survey Branch, Open File 1987-17, 109 p.

Pell, J. and Atkinson, D., 1993. Northwest Territories kimberlites and diamonds: Exploration highlights and implications. *In* Dunne, K.P.E. and Grant, B. (ed's.), *Mid-Continent Diamonds*. GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993. 89-94.

Pell, J. and Hora, Z.D., 1990. High-tech metals in British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Mineral Resources Division, Geological Survey Branch. Information Circular 1990-19.

Percival, T.J., Bagby, W.C. and Radtke, A.S., 1998. Physical and chemical features of precious metal deposits hosted by sedimentary rocks in the western United States. In R.W. Schafer, J.J. Cooper and P.G. Vikre (Ed's.) Bulk mineable precious metal deposits of the Western United States, Symposium Proceedings. Geological Society of Nevada, Reno, Nevada. 11-34.

Perry, B.L., 1963. Limestone reefs as an ore control in the Jurassic Todilto Limestone of the Grants District; In Geology and Technology of the Grants uranium region; New Mexico Bureau of Mines and Mineral Resources, Memoir 15. 150-156.

Peterson, T.D. and Currie, K.L., 1993. Analcite-bearing igneous rocks from the Crowsnest Formation, southwestern Alberta. In Current Research, Part B, Geological Survey of Canada, Paper 93-1B. 51-56.

Petkof, B., 1985a. Beryllium. *In* United States Department of the Interior. Mineral facts and problems, 1985 edition. Bureau of Mines, Bulletin 675. 75-82.

Petkof, B., 1985b. Gallium. *In* United States Department of the Interior. Mineral facts and problems, 1985 edition. Bureau of Mines, Bulletin 675. 291-296.

Pinnell, M.L., 1993. Results of deep exploratory drilling between Long and Newark Valleys, White Pine County, Nevada - Implications for oil migration in the nearby Yankee gold mine paleohydrothermal system. The American Association of Petroleum Geologists Bulletin, Association Round Table Abstracts, v. 77, no. 8. 1158.

Pipiringos, G.N. and Chisholm, W.A., 1965. Geology and uranium deposits in the Cave Hills area, Harding County, South Dakota; United States Geological Survey Professional Paper 476-A.

Podruski, J.A., 1988. Contrasting character of the Peace River and Sweetgrass Arches, Western Canada Sedimentary Basin. Geoscience Canada, v. 15. 94-97.

Pope, A.J. and Thirlwall, M.F. 1992. Tectonic setting, age and regional correlation of ultrabasic-ultrapotassic dykes in the northern Purcell Mountains, southeast British Columbia. Canadian Journal of Earth Sciences, vol. 29. 523-530.

Poulton, T.P., 1989. Upper Absaroka to Lower Zuni: The Transition to the Foreland Basin. *In* B.D. Ricketts (ed.). Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta. 233-247.

Prest, V.K., 1970. Quaternary Geology of Canada, *In* R.J.W. Douglas (ed.). Geology and Economic Minerals of Canada. Geological Survey of Canada, Economic Geology Report 1. 676-764.

Price, R.A., 1962. Fernie map-area, east half, Alberta and British Columbia; Geological Society of Canada Paper 61-24.

Price, R.A., 1967. The tectonic significance of mesoscopic subfabrics in the southern Rocky Mountains of Alberta and British Columbia, Canada; Canadian Journal of Earth Sciences, vol. 4. 39-70.

Price, R.A., 1981. The Cordilleran foreland thrust and fold belt in the southern Canadian Rocky Mountains; *In* K.R. McClay and N.J. Price, ed's., Thrust and Nappe Tectonics, Geological Society of London Special Publication 9. 427-448.

Price R.A. and Lis, M.G., 1975. Recurrent displacements on basement-controlled faults across the Cordilleran miogeocline in southern Canada; Geological Society of America Abstracts with Programs. 1234.

Rahmani, R.A. and Lerbekmo, J.F., 1975. Heavy mineral analysis of upper Cretaceous and Paleocene sandstones in Alberta and adjacent areas of Saskatchewan. *In* W.G.E. Caldwell (ed.). The Cretaceous System in the western interior of North America. Geological Association of Canada, Special Paper No. 13.

Ramaekers, P., 1979. Stratigraphy of the Athabasca Basin. *In* Summary of Investigations 1978. Saskatchewan Geological Survey Miscellaneous Report 79-10. 154-160.

Ramaekers, P., 1981. Hudsonian and Helikian Basins of the Athabasca region, northern Saskatchewan. *In* F.H.A. Campbell (ed.). Proterozoic basins of Canada. Geological Survey of Canada Paper 81-10. 219-233.

Ramaekers, P., 1983. Geology of the Athabasca Group, NEA/IAEA Athabasca Test Area. *In* E.M. Cameron (ed.) Uranium exploration in Athabasca Basin, Saskatchewan, Canada. Geological Survey of Canada Paper 82-11. 15-25.

Ramaekers, P., 1990. Geology of the Athabasca Group (Helikian) in northern Saskatchewan. Saskatchewan Geological Survey Report 195.

Rawson, R.R., 1980. Uranium in Todilto limestone (Jurassic) of New Mexico - example of a sabkha-like deposit; *In* Geology and Mineral Technology of the Grants Uranium Region, 1979, New Mexico Bureau of Mines and Mineral Resources Memoir 38. 304-312.

Reinhardt, E.W., 1969. Geology of the Precambrian rocks of Thubun Lakes map-area in relationship to the McDonald Fault System, District of Mackenzie (75E/12 and parts of 75E/13 and 85H/9). Geological Survey of Canada, Paper 69-21.

Renn, R., 1956. Exploration report - Iron prospecting permit no. 12; unpublished assessment report prepared for Perfection Machine Works Ltd.

Rich, R.A., Holland, H.D., and Petersen, U., 1977. Hydrothermal uranium deposits. Elsevier Scientific Publishing Company, Developments in Economic Geology, 6.

Richards, B.C., Bamber, E.W., Henderson, C.M., Higgins, A.C., Johnston, D.I., Mamet, B. and Meijer-Drees, N.C., 1993. Field Trip #7, Uppermost Devonian (Famennian) and Lower Carboniferous (Tournaisian) at Jura Creek, and Mount Rundle, Southwestern Alberta. Carboniferous to Jurassic Pangea Conference held in Calgary, Alberta, Canada, August 15-19, 1993.

Richardson, J.M., 1985. Field and textural relationships of alteration and greisen-hosted mineralization at the East Kemptville tin deposit, Davis Lake complex, southwest Nova Scotia. In R.P. Taylor and D.F. Strong (ed's). Recent advances in the geology of granite-related mineral deposits. CIM Special Volume 37. 265-279.

Ricketts, B.D. (ed.), 1989. Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta.

Ridge, J.D., 1968. Ore Deposits of the United States, 1933-1967; The Graton-Sales Volume. Published by the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., New York, New York, volumes 1 and 2.

Roberts, D.E. and Hudson, G.R.T., 1983. The Olympic Dam copper-uranium-gold deposit, Roxby Downs, South Australia. Economic Geology, vol. 78, no. 5. 799-822.

Roberts, R.G., 1988. Archean lode gold deposits. *In* R.G. Roberts and P.A. Sheahan. Ore Deposit Models. Geoscience Canada, Reprint Series 3. 1-19.

Robertson, J.A., 1978. Uranium deposits in Ontario. *In* M.M. Kimberley (ed.) Short course on uranium deposits: Their mineralogy and origin, Mineralogical Association of Canada, Toronto, October, 1978. 229-280.

Romberger, S.B., 1986. Disseminated gold deposits; *In* R.G. Roberts and P.A. Sheahan, ed's., Ore Deposit Models, Geoscience Canada, Reprint Series. 21-30.

Ross, G.M., 1991. Precambrian basement in the Canadian Cordillera: an introduction. Canadian Journal of Earth Sciences, v. 28. 1133-1139.

Ross, G.M., 1993. Tectonic Evolution of Crystalline Basement, Western Canada: Implication for Mantle Evolution. *In* D. Sawyer, The Calgary Mining Forum, Program and Abstracts, March 3 and 4, 1993. 12.

Ross, G.M., R.R. Parrish, M.E. Villeneuve and S.A. Bowring, 1991. Geophysics and geochronology of the crystalline basement of the Alberta Basin, western Canada. Canadian Journal of Earth Sciences, v. 28. 512-522.

Ross, G.M. and Stephenson, R.A., 1989. Crystalline Basement: The Foundation of Western Canada Sedimentary Basin. In Ricketts, B.D. (ed.) 1989. Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta. 33-45.

Rowe, R.B., 1958. Niobium (columbium) deposits of Canada. Geological Survey of Canada, Economic Geology Series No. 18.

Rudkin, R.A., 1964. Lower Cretaceous. In McGrossan, R.G. and R.P. Glaister. Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta. 156-168.

Runnells, D.D., 1969. The mineralogy and sulphur isotopes of the Ruby Creek copper prospect, Bornite, Alaska; Economic Geology, vol. 64. 75-90.

Rushton, H.G., 1972. Report on work done - Quartz mineral exploration permit no. 162; unpublished assessment report prepared for CanPac Minerals Ltd.

Russell, L.S. and Landes, R.W., 1940. Geology of the southern Alberta Plains; Geological Survey of Canada, Memoir 221. 128.

Ruzicka, V., 1975. New sources of uranium? Types of uranium deposits presently unknown in Canada. *In* A.G. Darnley, V. Ruzicka, W. Dyck, E.M. Cameron and K.A. Richardson, Uranium Exploration '75. Geological Survey of Canada, Paper 75-26. 13-20.

Ruzicka, V., 1977. Conceptual models for uranium deposits and areas favourable for uranium mineralization in Canada. Geological Survey of Canada, Paper 77-1A. 17-25.

Ruzicka, V., 1982. Some relationships between granitic plutons and the distribution of uranium deposits. *In* Y.T. Maurice (ed.). Uranium in granites. Geological Survey of Canada, Paper 81-23. 167-168.

Ruzicka, V., 1993. Potential for uranium-polymetallic deposits in the Athabasca Basin, NE Alberta. Abstract published *In* Program and Abstracts, The Calgary Mining Forum, March 3 & 4, 1993. 33.

Salat, H.P., 1988. The Oldman River project, southwestern Alberta; unpublished assessment report prepared for Rapparee Resources Ltd.

Sassano, G.P. and Procyshyn, E., 1988. Mineralogy and paragenesis of cupriferous deposits of the Acton Vale-Upton sector, Klippen Belt, Quebec; Mineralium Deposita, vol. 23. 123-131.

Sangster, D.F., 1972. Precambrian volcanogenic massive sulphide deposits in Canada: A review. Geological Survey of Canada, Paper 72-22.

Sangster, D.F., 1980a. Distribution and origin of Precambrian massive sulphide deposits of North America. *In* D.W. Strangway (ed.) The continental crust and its mineral deposits. Geological Association of Canada, Special Paper 20. 723-740.

Sangster, D.F., 1980b. Quantitative characteristics of volcanogenic massive sulphide deposits in volcanic centres. Canadian Institution of Mining and Metallurgy, Bulletin, vol. 73. 74-81.

Samis, C.S. and Gregory, J. 1962. The reduction of Clear Hills iron ore by the R-N process; Research Council of Alberta Information Series 40, 35 p.

Sawatzky, H.B., 1975. Astroblemes in the Williston Basin. American Association of Petroleum Geologists, Bulletin, vol. 59, no. 4. 694-710.

Schultz, R.B., 1991. Metalliferous black shales: Accumulation of carbon and metals in cratonic basins; *In* Sedimentary and Diagenetic Mineral Deposits: A Basin Analysis Approach to Exploration, Reviews in Economic Geology, vol. 5, part 3. 171-176.

Schutz, J.L., Woodward, L.A., Fulp, M.S. and Suchomel, B.J., 1989. Strata-bound gold and silver mineralization in the Jefferson dolomite (Devonian), Little Belt Mountains, Montana; 1989 Montana Geological Society Field Conference, Montana Centennial. 403-409.

Science City News, 1992. Microscopic diamonds may give clue to dinosaurs' doom; v. 2, issue 4, Winter 1992.

Scott, J., Collins, G.A. and Hodgson, G.W., 1954. Trace metals in the McMurray oil sands and other Cretaceous reservoirs of Alberta; Canadian Institute Mining and Metallurgy, Transactions, vol. LVII. 34-40.

Shaw, E.W., 1963. Canadian Rockies - orientation in time and space; *In* Childs, O.E., ed., Backbone of the Americas, American Association of Petroleum Geologists, Memoir 2. 231-242.

Shaw, R.P. and Morton, R.D., 1990a. Gold mineralization in Lower Cambrian McNaughton Formation, Athabasca Pass, Canadian Rocky Mountains: Structural, mineralogical and temporal relationships; Canadian Journal of Earth Sciences, vol. 27. 477-493.

Shaw, R.P. and Morton, R.D., 1990b. A fluid inclusion study of quartzite-hosted lode gold mineralization at Athabasca Pass, Central Rocky Mountains, Canada; Economic Geology, vol. 85. 1881-1893.

Sibbald, T.I.I.. Guliov, D.F. Patterson, F.M. Haidl and P. Reeves, 1991. Mineral Resources of Saskatchewan. Saskatchewan Energy and Mines, Saskatchewan Geological Survey Miscellaneous Report 91-5.

Sibbald, T.I.I. and Jirick, D.E., 1985. Geology of the gold deposits, Goldfields, Saskatchewan. In L.A. Clark and D.R. Francis (ed's). Gold in the Western Shield. CIM Special Volume 38. 412-414.

Sibbald, T.I.I. and Petruk, W., ed's., 1985. Geology of uranium deposits; Canadian Institute of Mining and Metallurgy Special Volume 32.

Sibbald, T.I.I. and Quirt, D.H., 1987. Uranium deposits of the Athabasca Basin. Saskatchewan Research Council, Publication #R-855-1-G-87.

Sibbald, T.I.I., Quirt, D.H. and Gracie, A.J. 1990. Uranium deposits of the Athabasca Basin, Saskatchewan, 8th IAGOD Symposium Field Trip Guidebook. Geological Survey of Canada Open File 2166.

Siddle, J.E., Olson, R.A. and Trigg, C.M., 1979. Exploration - 1979, Project 537; unpublished report prepared by Trigg, Woollett Consulting Ltd. on behalf of a client. 9.

Simandl, G.J., Hancock, K.D., Hora, D.Z., MacLean, M.E. and Paradis, S., 1991. Regional Geology of the Mount Brussilof Carbonate-hosted Magnesite Deposit, Southeastern British Columbia, Canada. *In* Z.D. Hora, W.N. Hamilton, B. Grant and P.D. Kelly (ed's). Industrial Minerals of Alberta and British Columbia, Proceedings of the 27th Forum on the Geology of Industrial Minerals, May 5 to May 10, 1991, Banff, Alberta. 57-65.

Sinclair, W.D., Jambor, J.L. and Birket, T.C., 1992. Rare Earths and the potential for rare- earth deposits in Canada. CIM Exploration and Mining Geology, Pergamon Press, v. 1, no. 3. 265-282.

Skall, H., 1975. The paleoenvironment of the Pine Point lead-zinc district. Economic Geology, v. 70. 22-47.

Smith, J.Y., 1963. The Crowfoot Dike. In Edmonton Geological Society Guide Book, Sunwapta Pass Area, 5th Annual Field Trip, August 1963. 65-70.

Souther, J.G., 1992. Volcanic Regimes. In H. Gabrielse and C.J. Yorath (ed's). Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 457-490.

Southard, G., 1978. Phanerozoic uranium environments. Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, Report of Field Activities. 89-105.

Sprenke, K.F., Wavra C.S. and Godfrey, J.D., 1986. Geophysical Expression of the Precambrian Shield of Northeastern Alberta. Alberta Geological Survey of the Alberta Research Council Bulletin No. 52.

Stalker, A. MacS., 1983. Quaternary Stratigraphy in southern Alberta; Report III: The Cameron Ranch Section. Geological Survey of Canada, Paper 83-10.

Steiner, R., 1958. Report on the iron ore underlying the area known as "MARASEK'S", Burmis, Alberta. unpublished report prepared on behalf of West Canadian Collieries Ltd.

Stelck, C.R., Burwash, R.A. and Stelck, D.R., 1978. The Vreeland High; A Cordilleran expression of the Peace River Arch; Bulletin of Canadian Petroleum Geology, v. 26, no. 1. 87-104.

Stewart, J., 1972. Initial deposits in Cordilleran geosyncline: Evidence of a Late Precambrian (<850 m.y.) continental separation; Geological Society of America Bulletin, vol. 83. 1345-1360.

Stewart, J.P. and Bale, W.C., 1994. Alberta Diamond Exploration. In The Calgary Mining Forum, Program and Abstracts, 10 & 11 February, 1994; published by the Calgary Mineral Exploration Group. 34.

Stewart, R., 1989. Gold Rush, the search for the Lost Lemon mine. RLM Publishing, Edmonton, Alberta.

Stott, D.F. and J.D. Aitken. (ed's.) 1993. Sedimentary Cover of the Craton in Canada, Geology of Canada, no. 5. Decade of North American Geology (DNAG), vol. D-1, Geological Survey of Canada.

Stott, D.F., Dixon, J., Dietrich, J.R., McNeil, Russell, L.S., and Sweet, A.R., 1993. Tertiary. In Stott, D.F. and J.D. Aitken. (ed's.) 1993. Sedimentary Cover of the Craton in Canada, Geology of Canada, no. 5. Decade of North American Geology (DNAG), vol. D-1, Geological Survey of Canada. 439-465.

Strong, D.F. 1988. A model for granophile mineral deposits. In R.G. Roberts and P.A. Sheahan. Ore Deposit Models. Geoscience Canada, Reprint Series 3. 59-66.

Struik, L.C., 1987. The ancient western North American margin: An alpine rift model for the east-central Canadian cordillera; Geological Survey of Canada Paper 87-15.

Swinden, H.S. and Horsley, T.L., 1971. Summary report on quartz mineral permits 163 to 168; unpublished assessment report prepared for Conwest Exploration Company Ltd.. 7.

Symons, D.T.A., Pan, H., Sangster, D.F. and Jowett, E.C., 1993. Paleomagnetism of the Pine Point Zn - Pb deposits. Canadian Journal of Earth Science, v. 30, no. 5, May, 1993. 1028-1036.

Takla Star Resources Ltd., 1993a. Diamonds in Alberta; unpublished press release, January 20, 1993.

Takla Star Resources Ltd., 1993b. Kimberlite diamond indicator minerals - southern Alberta; unpublished press release, May 10, 1993.

Takla Star Resources Ltd., 1993c. Diamonds & Gold - The shining path! Corporate release dated November 17, 1993.

Taylor, R.P. and Strong, D.F. (ed's), 1985. Recent advances int he geology of granite-related mineral deposits. CIM Special Volume 39.

Taylor, R.S., Mathews, W.H. and Kupsch, W.O., 1964. Tertiary. In R.G. McGrossan and R.P. Glaister (ed's). Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta. 190-194.

Thamm, J.K., Kovschak, A.A. Jr., and Adams, S.S, 1981. Geology and recognition criteria for sandstone uranium deposits of the Salt Wash type, Colorado Plateau Province; United States Department of Energy, GJBX-6(81).

Thomas, M.W. and Trigg, C.M., 1980. Exploration - 1980, Bullshead Creek and Foremost, Alberta, Canada, Project 537; unpublished report prepared by Trigg, Woollett Consulting Ltd. on behalf of a client, 9 p.

Thomas, A.V. and Spooner, E.T.C., 1985. Occurrence, petrology and fluid inclusion characteristics of tantalum mineralization in the Tanco granitic pegmatite, southeastern Manitoba. *In* R.P. Taylor and D.F. Strong (ed's). Recent advances in the geology of granite-related mineral deposits. CIM Special Volume 37. 280-290.

Thomas, D., 1981. Uranium metallogenic studies: Uraniferous pegmatite prospect geology. Saskatchewan Geological Survey Summary of Investigations.

Thorpe, R.I., 1966. Mineral industry of the Northwest Territories, 1965. Geological Survey of Canada, Paper 66-52.

Tintina Mines Limited, 1993. Press release dated October 28, 1993.

Tremblay, L.P., 1978. Geological setting of the Beaverlodge-type of vein-uranium deposit and its comparison to that of the unconformity type. In M.M. Kimberly (ed.) Short course on uranium deposits: Their mineralogy and origin, Mineralogical Association of Canada, Toronto, October, 1978. 431-456.

Trigg, C.M., 1982. Galena-sphalerite specimen; unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. on behalf of a client.

Trueman, D.L., Pedersen, J.C., De St. Jorre, L. and Smith, D.G.W.. The Thor Lake rare-metal deposits, Northwest Territories. *In* R.P. Taylor and D.F. Strong (ed's). Recent advances in the geology of granite-related mineral deposits. CIM Special Volume 37. 280-290.

Turekian, K.K., and Wedepohl, K.H., 1961. Distribution of the elements in some major units of the Earth's crust; Geological Society of America Bulletin, vol. 72.

Van Dyck, G.A., 1971. Exploration of properties in the Clark Range, southwestern Alberta and southeastern British Columbia; unpublished assessment report prepared by L.B. Halferdahl & Associates Ltd. on behalf of Alcor Minerals Ltd.

Van Dyke, C.W., 1981. A uranium resource evaluation of post-Proterozoic sedimentary formations in Alberta; unpublished M.Sc. thesis, Department of Geology, University of Alberta, Edmonton.

van Hees, H. and North, F.K., 1964. Cambrian. *In* R.G. McGrossan and R.P. Glaister (ed's). Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta. 20-33.

Venkatakrishnan, R. and Bennett, E.H., 1988. Structural controls of the Coeur d'Alene ore veins Shoshone County, Idaho; *In* G. Kisvarsanyi and S.K. Grant, ed's., North American Conference on Tectonic Control of Ore Deposits and the Vertical and Horizontal Extension of Ore Systems, Proceedings Volume, University of Missouri at Rolla, Missouri. 125-133.

Verrall, P, 1968. Observations on geological structures between the Bow and North Saskatchewan Rivers. *In* 16th Annual Field Conference Guide Book, Alberta Society of Petroleum Geologists. 107-118.

Wallace, C.A., Lidke, D.J. and Schmidt, R.G., 1990. Faults of the central part of the Lewis and Clarke line and fragmentation of the Late Cretaceous foreland basin in west-central Montana; Geological Society of America Bulletin, vol. 102. 1021-1037.

Walton, G.J., 1992. Discovery and geology of the Lisheen deposit, Rathdowney Trend, Ireland. Oral paper given at the Cordilleran Roundup held in Vancouver, British Columbia, January, 1992.

Watanabe, R.Y., 1961. Geology of the Waugh Lake metasedimentary Complex, northeastern Alberta. Unpublished M.Sc. thesis, University of Alberta at Edmonton. 89 p.

Watanabe, R.Y., 1965. Petrology of cataclastic rocks of northeastern Alberta. Unpublished Ph.D. thesis, University of Alberta at Edmonton. 219 p.

Webb, J.B., 1964. Historical Summary. *In* R.G. McGrossan and R.P. Glaister (ed's). Geological History of Western Canada. Alberta Society of Petrolem Geologists, Calgary, Alberta. 218-232.

West Canadian Collieries Ltd., 1957. Three unpublished aerial magnetometer maps for permits 5, 7, 8 and 9. Magnetometer survey performed by Canadian Aero Service Ltd. on behalf of West Canadian collieries Ltd.

Westervelt, T.N., 1979. Structural superposition in the Lake O'Hara region, Yoho and Kootenay National Parks, British Columbia, Canada. Unpubl. Ph.D. thesis, University of Wyoming, 267 p.

Westlock Hub, January 30, 1993. Diamond traces found in Westlock-Sturgeon area.

Whitney, J.A. and Naldrett, A.J. (ed's.), 1989. Ore deposition associated with magmas. Reviews in Economic Geology, Volume 4. Published by the Society of Economic Geologists.

Whitney, J.A, 1989. Origin and evolution of felsic magmas. *In* J.A. Whitney and A.J. Naldrett (ed's.), 1989. Ore deposition associated with magmas. Reviews in Economic Geology, Volume 4. Published by the Society of Economic Geologists. 183-201.

Williams, G.D. and Burk, C.F., Jr. 1964. Upper Cretaceous. *In* McGrossan, R.G. and R.P. Glaister. Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta. 169-189.

Williams, M.Y. and Dyer, W.S., 1930. Geology of Southern Alberta and Southwestern Saskatchewan; Geological Survey of Canada, Memoir 163.

Williamson, J., Dufresne, M.B. and Olson, R.A., 1993. The Southern Alberta Rift in southwest Alberta, Program to Identify Targets for Metallic Mineral Exploration. Alberta Research Council Open File Report 1993-13A and 13B.

Willis, G.F., 1988. Geology and mineralization of the Mesquite Open Pit Gold Mine. In R.W. Schafer, J.J. Cooper and P.G. Vikre (Ed's.) Bulk mineable precious metal deposits of the Western United States, Symposium Proceedings. Geological Society of Nevada, Reno, Nevada. 473-486.

Wilson, J.A., 1985a. Basement Geology Beneath and Around the Western Edge of the Athabasca Basin, Alberta. Alberta Geological Survey of the Alberta Research Council Map 1985-10.

Wilson, J.A., 1985b. Geology of the Athabasca Group in Alberta. Alberta Geological Survey of the Alberta Research Council Bulletin No. 49.

Wilson, J.A., 1986. Geology of the basement beneath the Athabasca Basin in Alberta. Alberta Geological Survey of the Alberta Research Council Bulletin No. 55.

Wilson, J.A., 1987. The geology and economic potential of the Athabasca Basin in Alberta. CIM Bulletin, February issue. 29-36.

Wilson, J.T., 1941. Geology, Fort Smith, District of Mackenzie, Northwest Territories. Geological Survey of Canada, Map 607A, 1:253,440 scale.

Wilson, P.N. and Parry, W.T., 1990. Mesozoic hydrothermal alteration associated with gold mineralization in Mercur district, Utah; Geology, vol. 18. 866-869.

Winzer, S.R., 1972. The Steen River Astrobleme, Alberta, Canada. 24th International Geological Congress, Section 15. 148-156.

Wood, H.B., 1968. Geology and exploitation of uranium deposits in the Lisbon Valley area, Utah. *In* J.D. Ridge (ed.). Ore deposits of the United States, 1933-1967, The Graton-Sales Volume, volume I. 770-789.

Wood, J. and Wallace, H., 1986 Volcanology and mineral deposits. Ontario Geological Survey Miscellaneous Paper 129.

Yorath, C.J., Gordey, P.L., Williams, G.K., Bustin, R.M., Bell, R.T., et al., 1992. Energy and Groundwater Resources of the Canadian Cordillera. *In* Gabrielse, H. and C.J. Yorath. (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 769-801.

Yorath, C.J., 1992. Upper Jurassic to Paleogene Assemblages. *In* Gabrielse, H. and C.J. Yorath (ed's.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada. 329-371.

Zartman, R.E., Brock, M.R., Heyl, A.V. and Thomas, H.H., 1967. K-Ar and Rb-Sr ages of some alkalic intrusive rocks from central and eastern United States. American Journal of Science, vol. 265. 848-870.

ANOMALY SUMMARY TABLES

TABLE 1: SUMMARY OF METALLIC MINERAL ANOMALIES BY TYPE

TABLE 2: SUMMARY OF GEOCHEMICAL ANOMALIES

TABLE 3: SUMMARY OF GEOPHYSICAL ANOMALIES

TABLE 4: SUMMARY OF DRILLING

TABLE 5: SUMMARY OF MINERAL OCCURRENCES

Table 1: Summary of Metallic Mineral Anomalies by Type

ANOMALY IDENTIFIER	10 DEGREES TM EASTING	10 DEGREES TM NORTHING	GEOCHEMICAL ANOMALY	GEOPHYSICAL ANOMALY	GEOLOGICAL ANOMALY	MINERAL OCCURRENCE	DRILLING ANOMALY
72E-AI01	755056.10	5489146.00					D1
72E-AI02	844379.00	5488795.00	S2				D2
72E-AI03	848904.10	5491378.00					D3
72E-AI04	856374.20	5489989.00					D4
72E-AI05	835192.90	5498506.00					D5
72E-AI06	842860.80	5496945.00					D6
72E-AI07	855047.40	5496780.00					D7
72E-AI08	745045.80	5472110.00				M8	
72E-AI09	832867.90	5502630.00	S9				
72E-AI10	831833.80	5505016.00			G10		
72E-AI11	829553.10	5506934.00			G11		
72E-AI12	826862.10	5504127.00			G12		
72E-AI13	823511.70	5511429.00	S13		G13		
72E-AI14	811567.50	5512624.00	S14				
72E-AI15	839784.10	5508189.00		P15			
72E-AI16	744018.60	5431353.00		P16			
72E-AI17	755507.30	5434480.00	S17				
72E-AI18	758527.60	5434288.00			G18		
72E-AI19	779460.50	5434109.00			G19		
72E-AI20	785876.10	5445878.00			G20		
72E-AI21	787846.10	5439979.00			G21		
72E-AI22	791553.10	5436111.00			G22		
72E-AI23	818128.60	5434588.00			G23		
72E-AI24	820155.20	5479684.00			G24		
72E-AI25	834061.70	5509457.20		P25			
72E-AI26	839459.20	5501396.60		P26			
72E-AI27	788315.50	5448240.70			G27		
72E-AI28	859677.30	5484293.00				M28	
72E-AI29	719678.00	5440363.00	S29			M29	
72L-AI01	791742.80	5645837.00	S1			M1	
72L-AI02	840725.20	5617730.00	S2			M2	
72M-AI01	836723.40	5711295.00			G1		
73E-AI01	713601.80	5977279.00	S1			M1	
73E-AI02	715633.80	5970688.00	S2			M2	
73E-AI03	714935.80	5966345.00	S3			M3	
73E-AI04	717083.10	5962963.00	S4			M4	
73E-AI05	724432.90	5962559.00	S5			M5	
73E-AI06	755246.40	5960379.00	S6			M6	
73E-AI07	771281.60	5972870.00	S7			M7	
73E-AI08	786816.90	5973115.00	S8			M8	
73E-AI09	801026.10	5966889.00				M9	
73E-AI10	809417.10	5962540.00				M10	
73L-AI01	801352.30	6045469.00					D1
73M-AI01	750596.80	6159182.00			G1		
74D-AI01	729967.30	6285380.00				M1	
74D-AI02	735319.20	6285952.00				M2	
74D-AI03	755218.30	6286620.00				M3	
74D-AI04	803056.80	6291835.00				M4	
74D-AI05	805114.50	6218084.00			G5		
74D-AI05	769147.30	6307009.00			G5		
74D-AI06	702279.10	6256370.00			G6		
74E-AI01	793875.83	6436530.89	S1				
74E-AI02	733087.62	6431795.13					D2
74E-AI03	777780.30	6397310.33					D3
74E-AI04	694511.36	6426058.95		P4			
74E-AI05	755439.80	6427395.16					D5

Table 1: Summary of Metallic Mineral Anomalies by Type

ANOMALY IDENTIFIER	10 DEGREES TM EASTING	10 DEGREES TM NORTHING	GEOCHEMICAL ANOMALY	GEOPHYSICAL ANOMALY	GEOLOGICAL ANOMALY	MINERAL OCCURRENCE	DRILLING ANOMALY
74L-AI31	783587.42	6438520.85					D31
74L-AI32	775242.89	6444790.70		P32			
74L-AI33	708139.67	6461111.86					D33
74L-AI34	739566.12	6438148.31					D34
74L-AI35	734842.59	6444593.75					D35
74L-AI36	739696.58	6468973.58					D36
74L-AI37	737150.06	6433518.59		P37			
74L-AI38	739949.10	6438762.73		P38		M38	D38
74L-AI39	742813.48	6438646.52		P39			D39
74L-AI40	729172.03	6460392.61		P40			
74L-AI41	735336.74	6445024.65					D41
74L-AI42	743574.95	6442051.70					D42
74L-AI43	743067.19	6440592.36					D43
74L-AI44	735048.69	6461664.31					D44
74L-AI45	773342.29	6502950.02					D45
74L-AI46	787939.61	6515835.15					D46
74L-AI47	742843.83	6477223.38					D47
74L-AI48	742843.83	6477223.38					D48
74L-AI49	744573.91	6474753.02					D49
74L-AI50	716225.50	6474261.00					D50
74L-AI51	701463.21	6435066.26					D51
74L-AI52	760582.64	6500935.27	S52	P52			D52
74L-AI53	770925.59	6469124.85	S53	P53			
74L-AI54	769071.06	6479024.35	S54	P54			
74L-AI55	775888.93	6475623.02	S55				
74L-AI56	780530.88	6473584.21	S56				
74L-AI57	785437.26	6468218.59	S57				
74L-AI58	786704.84	6465998.47	S58				
74L-AI59	765657.20	6470641.28	S59				
74L-AI60	782991.73	6472364.53	S60				
74L-AI61	763378.06	6476594.76		P61			
74L-AI62	770194.68	6477181.05		P62			
74L-AI63	781187.44	6477372.77		P63			
74L-AI64	781169.99	6473763.93		P64			
74L-AI65	786756.97	6473754.50		P65			
74L-AI66	751666.69	6437880.15					D66
74L-AI67	775755.08	6445250.58	S67				
74L-AI68	741701.14	6449223.31	S68				
74L-AI69	748634.37	6443391.89	S69				
74L-AI70	761804.62	6454854.66	S70				
74L-AI71	772575.77	6528727.93		P71			
74L-AI72	770393.80	6524174.06		P72			
74L-AI73	787282.17	6515294.73		P73			
74L-AI74	774808.26	6487496.41		P74			
74L-AI75	777429.79	6471588.31		P75			
74L-AI76	782593.08	6466293.32		P76			
74L-AI77	759966.40	6487776.41		P77			
74L-AI78	786484.55	6541960.16	S78			M78	D78
74L-AI79	772045.02	6529684.40	S79			M79	D79
74L-AI80	746970.20	6438880.21					D80
74L-AI81	745377.49	6434675.29					D81
74L-AI82	758136.92	6438250.18					D82
74L-AI83	794257.46	6448814.22	S83				D83
74M-AI01	775457.76	6632466.44	S1	P1		M1	D1
74M-AI02	768065.91	6632297.78		P2			
74M-AI03	770341.07	6642082.91		P3			

Table 1: Summary of Metallic Mineral Anomalies by Type

ANOMALY IDENTIFIER	10 DEGREES TM EASTING	10 DEGREES TM NORTHING	GEOCHEMICAL ANOMALY	GEOPHYSICAL ANOMALY	GEOLOGICAL ANOMALY	MINERAL OCCURRENCE	DRILLING ANOMALY
74M-AI60	781278.27	6580851.19	S60			M60	D60
74M-AI61	784092.48	6582272.02				M61	
74M-AI62	776103.14	6574325.68				M62	
74M-AI63	777402.05	6576127.27				M63	
74M-AI64	779029.52	6578201.90				M64	
74M-AI65	781244.01	6579389.95				M65	
74M-AI66	782430.61	6581154.31				M66	
74M-AI67	769361.55	6569652.27	S67				
74M-AI68	765892.50	6571020.95	S68				
74M-AI69	765229.20	6569361.39	S69				
74M-AI70	763601.35	6564843.13	S70				
74M-AI71	760553.64	6567021.53	S71				
74M-AI72	758344.91	6566033.31	S72				
74M-AI73	759688.04	6564542.92	S73				
74M-AI74	757694.74	6563880.10	S74				
74M-AI75	755701.18	6562256.92	S75				
74M-AI76	748797.61	6589646.83		P76			
74M-AI77	749763.19	6594641.68		P77			
74M-AI78	750037.66	6591217.48		P78		M78	
74M-AI79	749194.84	6590820.51		P79			
74M-AI80	776745.48	6592216.16		P80			
74M-AI81	778731.99	6591245.38	S81	P81			
74M-AI82	779178.50	6592271.56	S82	P82			
74M-AI83	774665.80	6592746.64	S83	P83			
74M-AI84	762155.04	6626911.67	S84	P84			
74M-AI85	761810.72	6624901.82	S85	P85			
74M-AI86	780886.24	6587401.64		P86			
74M-AI87	781026.84	6592315.89		P87			
74M-AI88	783346.12	6587989.07				M88	
74M-AI89	779078.50	6596391.86	S89	P89			
74M-AI90	777678.50	6596939.97	S90	P90		M90	
74M-AI91	780558.57	6596470.94	S91				
74M-AI92	669991.43	6649060.74	S92				D92
74M-AI93	675282.35	6647821.79	S93				D93
74M-AI94	684293.20	6636242.64	S94				D94
74M-AI95	672535.27	6635769.60	S95				D95
74M-AI96	676205.91	6651241.57					D96
74M-AI97	763317.79	6637015.40	S97	P97			D97
82G-AI01	565904.53	5445928.89	S1			M1	
82G-AI02	559344.58	5457594.99	S2			M2	
82G-AI03	565395.67	5451294.52	S3			M3	
82G-AI04	567133.57	5456316.75	S4			M4	
82G-AI05	540935.20	5461955.38				M5	
82G-AI06	549793.42	5448507.32	S6		G6	M6	
82G-AI07	571950.10	5451005.82	S7			M7	D7
82G-AI08	568618.09	5455532.40	S8			M8	
82G-AI09	550416.63	5462157.80	S9			M9	
82G-AI10	547224.58	5460277.15	S10			M10	D10
82G-AI11	530688.12	5468834.17	S11			M11	
82G-AI12	569156.85	5452884.11				M12	
82G-AI13	570526.38	5450092.09				M13	
82G-AI14	569539.19	5444954.74				M14	
82G-AI15	571254.75	5453157.86				M15	
82G-AI16	566792.45	5449489.84				M16	
82G-AI17	565240.87	5460955.67				M17	
82G-AI18	566028.12	5457538.25	S18			M18	

Table 1: Summary of Metallic Mineral Anomalies by Type

ANOMALY IDENTIFIER	10 DEGREES TM EASTING	10 DEGREES TM NORTHING	GEOCHEMICAL ANOMALY	GEOPHYSICAL ANOMALY	GEOLOGICAL ANOMALY	MINERAL OCCURRENCE	DRILLING ANOMALY
82G-AI75	565566.71	5453920.68	S75				
82G-AI76	565229.11	5455089.81	S76				
82G-AI77	538674.02	5510221.51	S77				
82G-AI78	541072.12	5515703.68	S78				
82G-AI79	572597.06	5449470.67	S79			M79	
82G-AI80	532946.00	5495357.00	S80			M80	
82G-AI81	568815.00	5453137.00	S81			M81	
82G-AI82	545667.00	5493560.00	S82				
82G-AI83	548374.00	5499315.00	S83			M83	D83
82G-AI84	551655.00	5489605.00	S84			M84	D84
82G-AI85	550809.00	5491212.00					D85
82G-AI86	550406.00	5492607.00					D86
82G-AI87	550058.00	5494317.00					D87
82G-AI88	548859.00	5495959.00					D88
82G-AI89	549786.00	5496325.00				M89	D89
82G-AI90	548850.00	5496917.00					D90
82G-AI91	548846.00	5498213.00					D91
82G-AI92	548388.00	5500927.00					D92
82G-AI93	553514.00	5506205.00				M93	D93
82G-AI94	556055.00	5506475.00				M94	D94
82G-AI95	557069.28	5510040.00				M95	D95
82G-AI96	552140.00	5511213.00				M96	D96
82G-AI97	551916.00	5513627.00				M97	D97
82G-AI98	548669.00	5515375.00				M98	D98
82G-AI99	568130.00	5447314.00	S99				
82G-AI100	566630.00	5452044.00	S100				
82G-AI101	567810.00	5452599.00	S101				
82G-AI102	570011.00	5454060.00	S102				
82G-AI103	564511.00	5454068.00	S103				
82G-AI104	566898.00	5455736.00	S104				
82G-AI105	565016.00	5458742.00	S105				
82G-AI106	562047.00	5460976.00	S106				
82G-AI107	560718.00	5463545.00	S107				
82G-AI108	558041.00	5467427.00	S108				
82G-AI109	547124.00	5451666.00	S109				
82G-AI110	547889.00	5460795.00	S110				
82G-AI111	543223.00	5461862.00	S111				
82G-AI112	540117.00	5461520.00	S112				
82G-AI113	538314.00	5465833.00	S113				
82G-AI114	530873.00	5476428.00	S114				
82G-AI115	561458.00	5466834.00				M115	
82G-AI116	560944.00	5458833.00	S116				
82G-AI117	563300.00	5460026.00	S117				
82G-AI118	561616.00	5461818.00	S118				
82G-AI119	528989.97	5473619.61	S119				
82G-AI120	531329.63	5486457.34	S120				
82G-AI121	525959.84	5494997.55	S121				
82G-AI122	527069.49	5514151.90	S122				
82G-AI123	524032.80	5524028.90	S123				
82H-AI01	573735.50	5447853.80	S1		G1	M1	D1
82H-AI02	573191.41	5445835.55				M2	
82H-AI03	572894.51	5449937.68	S3			M3	
82H-AI04	575769.90	5437444.30				M4	
82H-AI05	573309.70	5432406.10				M5	
82H-AI06	577897.32	5448774.50	S6	P6		M6	D6
82H-AI07	614110.90	5433089.40		P7			D7

Table 1: Summary of Metallic Mineral Anomalies by Type

ANOMALY IDENTIFIER	10 DEGREES TM EASTING	10 DEGREES TM NORTHING	GEOCHEMICAL ANOMALY	GEOPHYSICAL ANOMALY	GEOLOGICAL ANOMALY	MINERAL OCCURRENCE	DRILLING ANOMALY
82J-AI30	486220.28	5616337.37	S30				
82J-AI31	487870.11	5617568.33	S31				
82J-AI32	484227.36	5618380.86	S32				
82J-AI33	483666.29	5620760.08	S33				
32J-AI34	483849.15	5622890.00	S34				
82J-AI35	478443.06	5622075.88	S35				
82J-AI36	479490.34	5629543.90	S36				
82J-AI37	474563.06	5629503.91	S37				
82J-AI38	471837.62	5631710.26	S38				
82J-AI39	475087.21	5636788.48	S39				
82J-AI40	473595.40	5642940.58	S40				
82J-AI41	471372.36	5646565.16	S41				
82J-AI42	519899.00	5550459.00	S42		G42	M42	D42
82J-AI43	521501.00	5597278.00			G43		
82J-AI44	544509.00	5550310.00				M44	
82J-AI45	534730.00	5556324.00	S45			M45	D45
82J-AI46	496585.00	5605491.00			G46		
82J-AI46	494745.00	5617935.00			G46		
82J-AI46	497486.00	5612094.00			G46		
82J-AI47	507395.00	5596005.00	S47			M47	
82J-AI48	487380.00	5612151.00				M48	
82J-AI49	530219.00	5578783.00	S49			M49	
82J-AI50	503947.00	5631639.00			G50		
82J-AI51	523685.00	5588896.00				M51	
82J-AI52	547524.00	5616578.00					
82J-AI53	526066.51	5580666.93	S53				
82J-AI54	522155.73	5547271.70	S54				
82J-AI55	520035.92	5550130.84	S55				
82J-AI56	519729.82	5557531.93	S56				
82J-AI57	519093.55	5559852.55	S57				
82J-AI58	524654.79	5586295.48	S58				
82N-AI01	365763.30	5736651.00			G1		
82N-AI02	424752.40	5700021.00			G2		
82N-AI02	411801.00	5698865.00			G2		
82N-AI02	423077.40	5697806.00			G2		
82N-AI03	429164.30	5689921.00				M3	
82N-AI04	423948.60	5683357.00				M4	
82N-AI05	401667.90	5721587.00			G5	M5	
82N-AI06	427841.10	5744610.00			G6		
82N-AI07	415777.80	5699179.10				M7	
82O-AI01	432415.40	5689539.00				M1	
82O-AI02	436820.10	5671763.00				M2	
82O-AI03	437445.90	5670565.00				M3	
82O-AI04	433474.80	5667847.00				M4	
82O-AI05	489471.20	5679962.00				M5	
82O-AI06	478180.60	5647650.00				M6	
82O-AI07	491018.34	5647914.12	S7				
82O-AI07	491229.70	5648012.00	S7				
82O-AI08	482720.10	5685114.00	S8				
82O-AI09	482172.90	5683531.00	S9				D9
82O-AI10	483785.40	5683454.00					D10
82O-AI11	480237.80	5683264.00	S11				
82O-AI12	479025.30	5683311.00	S12				
82O-AI13	479331.10	5684956.00	S13				
82O-AI14	480733.90	5686929.00	S14				
82O-AI15	481947.00	5694686.00	S15				

Table 1: Summary of Metallic Mineral Anomalies by Type

ANOMALY IDENTIFIER	10 DEGREES TM EASTING	10 DEGREES TM NORTHING	GEOCHEMICAL ANOMALY	GEOPHYSICAL ANOMALY	GEOLOGICAL ANOMALY	MINERAL OCCURRENCE	DRILLING ANOMALY
83H-AI02	579523.00	5905698.00				M2	
83H-AI03	576369.80	5917331.00				M3	
83H-AI04	576096.00	5918916.00				M4	
83H-AI05	583650.10	5910914.00	S5			M5	
83H-AI06	597515.70	5928215.00	S6			M6	
83H-AI07	598984.20	5930351.00				M7	
83H-AI08	621402.10	5955174.00	S8			M8	
83H-AI09	661581.40	5983330.00	S9			M9	
83H-AI10	687698.00	5981806.00	S10			M10	
83H-AI11	579946.20	5945900.00	S11			M11	
83H-AI12	574915.90	5947709.00	S12			M12	
83I-AI01	691005.30	5990581.00				M1	
83I-AI02	641577.60	5982437.00	S2			M2	
83I-AI03	611348.20	6063371.00	S3			M3	
83J-AI01	547755.30	6076359.00				M1	
83J-AI02	452834.20	5985738.00	S2			M2	
83J-AI03	449655.40	6063471.00	S3			M3	
83K-AI01	355160.70	6075508.00				M1	
83L-AI01	267702.20	6039699.00				M1	
83L-AI02	300139.80	6081748.00				M2	
83L-AI03	287704.60	6030349.00	S3			M3	
83M-AI01	230885.50	6166736.00				M1	
83M-AI02	207176.60	6209671.00				M2	
83M-AI03	212197.10	6146348.00				M3	
83M-AI04	249026.00	6134337.00	S4			M4	
83M-AI05	270383.30	6127813.00	S5			M5	
83M-AI06	282089.60	6117382.00	S6			M6	
83M-AI07	291860.90	6100595.00	S7				
83M-AI08	288686.70	6178557.00				M8	
83M-AI09	257905.90	6184916.00				M9	
83M-AI10	271471.70	6201230.00				M10	
83N-AI01	321559.50	6160969.00				M1	
83N-AI02	314703.00	6174563.00				M2	
83N-AI03	319447.50	6181372.00				M3	
83N-AI03	333655.80	6200526.00				M3	
83O-AI01	467157.80	6108550.00				M1	
83P-AI01	657720.40	6117266.00					D1
83P-AI02	657051.10	6165211.00			G2		
83P-AI03	649092.90	6183541.00				M3	
84A-AI01	686115.30	6210437.00			G1		
84A-AI01	662406.10	6280640.00			G1		
84B-AI01	451687.80	6284683.00				M1	
84C-AI01	438455.30	6264764.00				M1	
84C-AI02	338719.90	6262117.00				M2	
84C-AI03	339340.70	6232219.00	S3			M3	
84D-AI01	258019.20	6230959.00				M1	
84D-AI02	196852.00	6269318.00			G2	M2	
84D-AI03	256218.50	6277393.00	S3			M3	D3
84D-AI04	275242.80	6307964.00	S4			M4	D4
84D-AI05	280740.10	6297248.00	S5			M5	D5
84D-AI06	286854.60	6280785.00				M6	D6
84D-AI07	273901.30	6266924.00				M7	
84D-AI08	284011.80	6260363.00				M8	
84D-AI09	300364.50	6259247.00				M9	
84D-AI10	262264.80	6212677.00				M10	
84E-AI01	260787.00	6323179.00				M1	

Table 2: Summary of Geochemical Anomalies

GEOCHEMICAL ANOMALIES	ELEMENT ANALYSED	ANALYTICAL METHOD	UNITS MEASURED	BEST ASSAY (GRAB)	BEST ASSAY (GRADE)	GRADE/WIDTH (m)	NUMBER OF SAMPLES	OVER GRADE
72E-S09	U	Chemical	%U3O8	0.003				10
72E-S13	U		ppm	14.8			1	10
72E-S13	U		ppb	48				
72E-S13	U		ppb	104				
72E-S14	U		ppb	240			1	100
72E-S17	U		ppb	144			1	100
72E-S29	Au		g/t	0.0127				
72L-S01	Au		g/t	0.0022				
72L-S02	Au		g/t	0.0058				
73E-S01	Au		g/t	0.041				
73E-S02	Au		g/t	0.02				
73E-S03	Au		g/t	0.05			3	0.03
73E-S04	Au		g/t	0.05				
73E-S05	Au		g/t	0.167				
73E-S06	Au		g/t	0.135				
73E-S07	Au		g/t	0.036				
73E-S08	Au		g/t	0.0073				
74E-S01	U	Flourometry	ppm	7.2				
74E-S06	U		ppm	123			13	5
74E-S06	U		ppb	0.9	7	0.24		
74E-S07	U		ppm	9.3			6	6
74E-S07	U		ppb	0.53			7	0.24
74E-S11	U		ppm	32.5			2	5
74E-S11	U		ppb	0.54				
74E-S12	U		ppm	30			5	5
74E-S12	U		ppb	0.29				
74E-S13	U		ppm	95.5			3	7.6
74E-S13	U		ppb	0.5			6	0.24
74E-S14	U		ppm	9.1			4	4.7
74E-S15	U		ppb	2.2			24	0.24
74E-S16	U		ppb	0.67				
74E-S17	U		ppb	0.39				
74E-S18	U		ppb	0.88			6	0.33
74E-S19	U		ppb	1.7			8	0.24
74E-S20	U		ppb	1.33			3	0.34
74E-S31	Pb		ppm	10				
74E-S31	Zn		ppm	150				
74E-S31	Hg		ppm	22				
74L-S01	U		%U3O8	0.153			1	0.1
74L-S01	Th		%ThO2	0.06				0.1
74L-S03	U	Radiometric	%U3O8	0.06				0.1
74L-S03	U	Chemical	%U3O8	0.01				0.1
74L-S04	U		%U3O8	0.02				0.1
74L-S04	Th		%ThO2	0.5			1	0.1
74L-S12	U	Fission Track	ppm	8				
74L-S13	U	Fission Track	ppm	5.9			3	5
74L-S20	U	Flourometry	ppm	10.4				
74L-S21	U	Flourometry	ppm	7.4				
74L-S22	U	Flourometry	ppm	18.8			2	5
74L-S23	U	Flourometry	ppm	16.7				
74L-S24	U	Flourometry	ppm	10				
74L-S25	U	Flourometry	ppm	10.5			2	5
74L-S26	U	Flourometry	ppm	6.6				
74L-S27	U	Flourometry	ppm	6.4			3	5
74L-S28	U	Flourometry	ppm	6.2			2	5
74L-S52	U	Flourometry	ppm	12			13	5
74L-S53	U	Atomic absorption spectrophoto	ppm	11.2			2	8
74L-S53	U	Fission Track	ppb	0.48			3	0.4
74L-S53	Mo	Atomic absorption spectrophoto	ppm	132				
74L-S53	Cu	Atomic absorption spectrophoto	ppm	28			2	25
74L-S53A	U	Atomic absorption spectrophoto	ppm	11.2			2	8
74L-S53A	U	Fission Track	ppb	0.48			3	0.4
74L-S53A	Mo	Atomic absorption spectrophoto	ppm	132				
74L-S53A	Cu	Atomic absorption spectrophoto	ppm	28			2	25
74L-S53A	He			22.1			6	9.81
74L-S54	U	Atomic absorption spectrophoto	ppm	13.7				
74L-S54	U	Fission Track	ppb	0.46				
74L-S54	Zn	Atomic absorption spectrophoto	ppm	180				

Table 2: Summary of Geochemical Anomalies

GEOCHEMICAL ANOMALIES	ELEMENT ANALYSED	ANALYTICAL METHOD	UNITS MEASURED	BEST ASSAY (GRAB)	BEST ASSAY (GRADE)	GRADE/WIDTH (m)	NUMBER OF SAMPLES	OVER GRADE
74M-S67	Cu		ppm	8				
74M-S67	Ni		ppm	7				
74M-S67	Zn		ppm	41				
74M-S67	U3O8		ppm	12.6				25
74M-S68	Cu		ppm	12				
74M-S68	Ni		ppm	12				
74M-S68	Zn		ppm	75				
74M-S68	U3O8		ppm	26.7			1	25
74M-S69	Cu		ppm	8				
74M-S69	Ni		ppm	11				
74M-S69	Zn		ppm	62				
74M-S69	U3O8		ppm	41.7			1	25
74M-S70	Cu		ppm	8				
74M-S70	Ni		ppm	16				
74M-S70	Zn		ppm	73				
74M-S70	U3O8		ppm	61.3			3	25
74M-S71	Cu		ppm	12				
74M-S71	Ni		ppm	12				
74M-S71	Zn		ppm	77				
74M-S71	U3O8		ppm	48.6			1	25
74M-S72	Cu		ppm	12				
74M-S72	Ni		ppm	17				
74M-S72	Zn		ppm	111				
74M-S72	U3O8		ppm	31.7			1	25
74M-S73	Cu		ppm	12				
74M-S73	Ni		ppm	10				
74M-S73	Zn		ppm	85				
74M-S73	U3O8		ppm	20.3				25
74M-S74	Cu		ppm	20				
74M-S74	Ni		ppm	14				
74M-S74	Zn		ppm	81				
74M-S74	U3O8		ppm	21.7				25
74M-S75	Cu		ppm	12				
74M-S75	Ni		ppm	12				
74M-S75	Zn		ppm	67				
74M-S75	U3O8		ppm	30			1	25
74M-S81	U	Chemical	%U3O8	0.06				0.1
74M-S82	U	Chemical	%U3O8	0.33			1	0.1
74M-S83	U	Chemical	%U3O8	0.03				0.1
74M-S84	U		%U3O8	0.65			1	0.1
74M-S85	U		%U3O8	0.12			1	0.1
74M-S89	U		ppm	309			6	40
74M-S90	U		%U3O8	0.66			3	0.1
74M-S91	U		%U3O8	0.22			3	0.1
74M-S92	U		ppb	8.3			1	5
74M-S92	U		ppm	3.4				
74M-S92	Mo		ppm	19				
74M-S92	Pb		ppm	14				
74M-S92	Ni		ppm	25				
74M-S92	Ag		ppm	0.7				
74M-S92	Cu		ppm	19				
74M-S92	Zn		ppm	340				
74M-S93	U		ppb	18.6			3	5
74M-S93	U		ppm	6.7				
74M-S93	Mo		ppm	13				
74M-S93	Pb		ppm	16				
74M-S93	Ni		ppm	84				
74M-S93	Ag		ppm	1.6				
74M-S93	Cu		ppm	12				
74M-S93	Zn		ppm	88				
74M-S94	U		ppb	15			1	5
74M-S94	U		ppm	17.4				
74M-S94	Mo		ppm	8				
74M-S94	Pb		ppm	20				
74M-S94	Ni		ppm	38				
74M-S94	Ag		ppm	3				
74M-S94	Cu		ppm	23				
74M-S94	Zn		ppm	167				

Table 2: Summary of Geochemical Anomalies

GEOCHEMICAL ANOMALIES	ELEMENT ANALYSED	ANALYTICAL METHOD	UNITS MEASURED	BEST ASSAY (GRAB)	BEST ASSAY (GRADE)	GRADE/WIDTH (m)	NUMBER OF SAMPLES	OVER GRADE
82G-S32A	Cu		%		0.22	0.25		1
82G-S32B	Cu		ppb	98			5	50
82G-S32B	Pb		ppb	273				
82G-S32B	Zn		ppb	135				
82G-S33	Cu		ppb	24				50
82G-S33	Pb		ppb	306				
82G-S33	Zn		ppb	161				
82G-S34	Cu		ppb	22				50
82G-S34	Pb		ppb	272				
82G-S34	Zn		ppb	155				
82G-S35	Zn		ppb	130			1	120
82G-S36	Zn		ppb	145			3	120
82G-S37	Cu		%		1.55	2.44	1	1
82G-S37	Ag		g/t		10.2857	2.44		
82G-S38	Cu		%		2.3	0.18	2	1
82G-S38	Cu		ppm	1070				
82G-S40	Cu		%		0.15	0.75		1
82G-S41	Cu		ppm	110			5	70
82G-S44	Cu		ppm	150			2	70
82G-S45	Cu		ppm	125			3	70
82G-S46	Zn		%		1.28	0.91	3	1
82G-S46	Pb		%		0.09	0.91		1
82G-S46A	Pb		%		3.4	2.44	2	1
82G-S46A	Zn		%		0.2	2.44		1
82G-S46A	Ag		g/t		104.57138	2.44		
82G-S47	Pb		%		1.26	3.66	2	1
82G-S47	Zn		%		0.4	3.66		1
82G-S47	Cu		%		0.72	3.66		1
82G-S48	Pb		%		2.26	3.05	3	1
82G-S48	Zn		%		0.7	3.05		1
82G-S48	Cu		%		0.23	3.05		1
82G-S49	Pb		%		2.18	7.32	1	1
82G-S49	Zn		%		0.44	7.32		1
82G-S50	Pb		%		3.02	2.74	2	1
82G-S50	Zn		%		1.01	2.74	1	1
82G-S50	Ag		g/t		123.4285	2.74		
82G-S51	Zn		ppm	100				
82G-S51A	Pb		%		1.92	3.35	3	0.1
82G-S51A	Zn		%		1.43	3.35	3	0.1
82G-S51A	Ag		g/t		162.8571	3.35		
82G-S52	Cu		%		0.8	4.27		1
82G-S53	Cu		%		1.68	0.76	2	1
82G-S53	Ag		g/t		12.6857	0.76		
82G-S55	Cu		%		0.78	1.22		1
82G-S56	Cu		%		0.39	1.98		1
82G-S57	Au		g/t	0.342857				
82G-S57	Cu		%	0.1				1
82G-S58	Cu		%	0.25				1
82G-S59	Pb		%		57.35	1.22	4	1
82G-S59	Ag		g/t		148.83	1.22		
82G-S59	Zn		%		0.48	0.3		1
82G-S59	Cu		%	0.24				1
82G-S59A	Pb		%		57.35	1.22	4	1
82G-S59A	Ag		g/t		179.99	1.22		
82G-S59A	Zn		%		0.48	0.3		1
82G-S59B	Pb		%	69.5			3	1
82G-S59B	Ag		g/t	132.6857				
82G-S60	Cu		%		0.76	2.44		1
82G-S60	Ag		g/t		4.253	2.44		
82G-S60A	Cu		%		1.1	1.52	1	1
82G-S61	Zn		%	0.91				1
82G-S65	Au		g/t	0.343				1
82G-S65	Ag		g/t	5.14				
82G-S65	Pb		%	0.002				
82G-S65	Zn		%	0.02				
82G-S67	Au		g/t	0.72				1
82G-S67	Ag		g/t	32.69				
82G-S68	Au		g/t	0.71				1

Table 2: Summary of Geochemical Anomalies

GEOCHEMICAL ANOMALIES	ELEMENT ANALYSED	ANALYTICAL METHOD	UNITS MEASURED	BEST ASSAY (GRAB)	BEST ASSAY (GRADE)	GRADE/WIDTH (m)	NUMBER OF SAMPLES	OVER GRADE
82G-S110	Zn		ppm	130				
82G-S111	Zn		ppm	153				
82G-S112	Pb		ppm	95				
82G-S113	Zn		ppm	100				
82G-S114	Zn		ppm	118				
82G-S119	Cu		ppm	38				
82G-S119	Zn		ppm	280				
82G-S119	Ni		ppm	100				
82G-S119	Ag		ppm	1.8				
82G-S119	Cr2O3		ppm	230				
82G-S120	Cu		ppm	34				
82G-S120	Zn		ppm	172				
82G-S120	Ni		ppm	62				
82G-S120	Ag		ppm	2.3				
82G-S120	Cr2O3		ppm	140				
82G-S121	Ag		ppm	0.8				
82G-S121	Cu		ppm	68				
82G-S121	Zn		ppm	775				
82G-S121	Ni		ppm	65				
82G-S121	V		ppm	380				
82G-S121	Cr2O3		ppm	140				
82G-S121	As		ppm	21				
82G-S121	Sb		ppm	24				
82G-S122	Ag		ppm	0.6				
82G-S122	As		ppm	47				
82G-S122	Cu		ppm	44				
82G-S122	Zn		ppm	380				
82G-S122	Ni		ppm	105				
82G-S122	Ag		ppm	1.5				
82G-S122	V		ppm	4000				
82G-S122	Cr2O3		ppm	180				
82G-S122	Sb		ppm	29				
82G-S123	Cu		ppm	50				
82G-S123	Zn		ppm	625				
82G-S123	Ni		ppm	105				
82G-S123	Ag		ppm	4				
82G-S123	V		ppm	2250				
82G-S123	Ba		ppm	1240				
82G-S123	Cr2O3		ppm	170				
82G-S123	Sb		ppm	33				
82H-S01	Cu		%		1.84	2.13	4	1
82H-S01	Ag		g/t		20.412	2.44		
82H-S01	Cu		%		3.26	2.13	3	1
82H-S01	Ag		%		6.804	2.13		
82H-S01	Cu		%		0.31	3.05		1
82H-S01	Ag		g/t		6.804	1.83		
82H-S01	Cu		%	1.16			2	1
82H-S01	Ag		g/t	57.68				
82H-S01A	U		kgU3O8	2.183			1	0.454
82H-S01A	Cu		%	2.13				
82H-S01A	Ag		g/t	14.742				
82H-S01B	Cu		%		6.7	0.45	13	1
82H-S01B	Ag		g/t		41.14284	2.44		
82H-S01B	Cu		%	3.5				
82H-S01C	Cu		%	2.23			3	1
82H-S01D	Cu		%		0.22	1.98		1
82H-S03	Cu		%		0.17	6.1		1
82H-S06	Au	Atomic absorption spectrophoto	ppb	20				100
82H-S06	Pt	Atomic absorption spectrophoto	ppb	49.99				100
82H-S06	Pd	Atomic absorption spectrophoto	ppb	4.99				100
82H-S19	Mo		ppm	114			1	100
82H-S19	U		ppm	3				
82H-S19	V		ppm	120			3	100
82H-S21	U		ppm	85			1	10
82H-S21	Th		ppm	6				
82H-S23	U		ppm	2000			2	10
82H-S23	Th		ppm	8				
82H-S23	Mo		ppm	13				

Table 2: Summary of Geochemical Anomalies

GEOCHEMICAL ANOMALIES	ELEMENT ANALYSED	ANALYTICAL METHOD	UNITS MEASURED	BEST ASSAY (GRAB)	BEST ASSAY (GRADE)	GRADE/WIDTH (m)	NUMBER OF SAMPLES	OVER GRADE
82J-S18	Cu	Holman Test	ml	1				2
82J-S18	Cu	Hot Extraction	ppm	9.99				25
82J-S18	Zn	Hot Extraction	ppm	200			1	200
82J-S18	Pb	Hot Extraction	ppm	9.99				20
82J-S19	THM	Bloom field test	ml	11			1	10
82J-S19	Cu	Holman Test	ml	1				2
82J-S20	THM	Bloom field test	ml	4				10
82J-S20	Cu	Hot Extraction	ppm	10				25
82J-S20	Zn	Hot Extraction	ppm	220			1	200
82J-S20	Pb	Hot Extraction	ppm	9.99				20
82J-S21	THM	Bloom field test	ml	13			5	10
82J-S21	Cu	Holman Test	ml	1				2
82J-S21	Cu	Hot Extraction	ppm	30			2	25
82J-S21	Zn	Hot Extraction	ppm	300			3	200
82J-S21	Pb	Hot Extraction	ppm	10				20
82J-S22	THM	Bloom field test	ml	4				10
82J-S22	Cu	Hot Extraction	ppm	30			1	25
82J-S22	Zn	Hot Extraction	ppm	140				200
82J-S22	Pb	Hot Extraction	ppm	9.99				20
82J-S23	THM	Bloom field test	ml	25			1	10
82J-S23	Cu	Holman Test	ml					2
82J-S23	Cu	Hot Extraction	ppm	20				25
82J-S23	Zn	Hot Extraction	ppm	400			1	200
82J-S23	Pb	Hot Extraction	ppm	9.99				20
82J-S24	THM	Bloom field test	ml	16			2	10
82J-S24	Cu	Holman Test	ml	1				2
82J-S24	Cu	Hot Extraction	ppm	9.99				25
82J-S24	Zn	Hot Extraction	ppm	260			1	200
82J-S24	Pb	Hot Extraction	ppm	9.99				20
82J-S25	THM	Bloom field test	ml	10			1	10
82J-S25	Cu	Holman Test	ml	1				2
82J-S26	THM	Bloom field test	ml	13			2	10
82J-S26	Cu	Holman Test	ml	1				2
82J-S27	THM	Bloom field test	ml	10			2	10
82J-S27	Cu	Holman Test	ml	1				2
82J-S28	THM	Bloom field test	ml	10			1	10
82J-S28	Cu	Holman Test	ml	1				2
82J-S29	THM	Bloom field test	ml	18			2	10
82J-S29	Cu	Holman Test	ml	1				2
82J-S30	THM	Bloom field test	ml	25			1	10
82J-S30	Cu	Holman Test	ml	1				2
82J-S31	THM	Bloom field test	ml	22			2	10
82J-S31	Cu	Holman Test	ml	1				2
82J-S32	THM	Bloom field test	ml	10			1	10
82J-S32	Cu	Holman Test	ml	1				2
82J-S33	THM	Bloom field test	ml	25			2	10
82J-S33	Cu	Holman Test	ml	1				2
82J-S34	THM	Bloom field test	ml	15			1	10
82J-S34	Cu	Holman Test	ml	1				2
82J-S35	THM	Bloom field test	ml	25			1	10
82J-S35	Cu	Holman Test	ml	1				2
82J-S35	Cu	Hot Extraction	ppm	40			1	25
82J-S35	Zn	Hot Extraction	ppm	700			1	200
82J-S35	Pb	Hot Extraction	ppm	20			1	20
82J-S36	THM	Bloom field test	ml	11			1	10
82J-S36	Cu	Holman Test	ml	1				2
82J-S37	THM	Bloom field test	ml	13			1	10
82J-S37	Cu	Holman Test	ml	1				2
82J-S38	THM	Bloom field test	ml	12			1	10
82J-S38	Cu	Holman Test	ml	1				2
82J-S39	THM	Bloom field test	ml	7				10
82J-S39	Cu	Holman Test	ml	1				2
82J-S39	Cu	Hot Extraction	ppm	30			1	20
82J-S39	Zn	Hot Extraction	ppm	240			1	200
82J-S39	Pb	Hot Extraction	ppm	9.99				20
82J-S40	THM	Bloom field test	ml	12			1	10
82J-S40	Cu	Holman Test	ml	1				2
82J-S41	THM	Bloom field test	ml	11			1	10

Table 2: Summary of Geochemical Anomalies

GEOCHEMICAL ANOMALIES	ELEMENT ANALYSED	ANALYTICAL METHOD	UNITS MEASURED	BEST ASSAY (GRAB)	BEST ASSAY (GRADE)	GRADE/WIDTH (m)	NUMBER OF SAMPLES	OVER GRADE
82O-S14	Fe							
82O-S14	Cr							
82O-S15	Si		%SiO2	88.6			1	1
82O-S15	Fe		%Fe2O3	8.06			1	1
82O-S15	Al		%Al2O3	3.24			1	1
82O-S15	Cr							
82O-S19	Fe							
82O-S19	Ti							
82O-S22	Fe		%Fe2O3	83.9			4	10
82O-S23	U		ppm	4				10
82O-S24	U		ppm	4				10
82O-S25	U		ppm	4				10
82O-S26	Au		ppb	1150			1	100
82O-S26	Zn		ppm	186				
82O-S26	Ni		ppm	109				
82O-S26	Co		ppm	37				
82O-S26	V		ppm	136				
82O-S33	Au		g/t	0.07				
82O-S33	Au		g/t	0.07				
82O-S35	Zn		ppm	350				
82O-S35	Zn		ppm	275				
82O-S35	Ni		ppm	113				
82O-S35	As		ppm	23				
82O-S35	Sb		ppm	30				
82O-S35	V		ppm	1625				
82O-S36	Zn		ppm	540				
82O-S36	Zn		ppm	350				
82O-S36	Ni		ppm	155				
82O-S36	V		ppm	800				
82P-S02	Au		g/t	0.025				
82P-S03	Au		ppb	50				
83B-S02	U		ppm	4				10
83D-S03	U	McPhar.TV-1 3-Threshold Scint.					2	
83E-S02	SiO2		%Wt.	0.05				
83E-S02	CaO		Wt.%	32.79				
83E-S02	MgO		Wt.%	1.77				
83E-S02	Na2O		Wt.%	0.02				
83E-S02	SO3		Wt.%	45.1				
83E-S02	H2O		Wt.%	0.05				
83E-S03	SiO2		Wt.%	0.89				
83E-S03	CaO		Wt.%	32.22				
83E-S03	SO3		Wt.%	46.02				
83E-S04	Cu		ppm	74				
83E-S04	Pb		ppm	44				
83E-S04	Zn		ppm	1160				
83E-S04	Ni		ppm	80				
83E-S04	As		ppm	53				
83E-S04	V		ppm	190				
83E-S04	Ba		ppm	449				
83E-S04	Cr2O3		ppm	293				
83E-S05	Zn		ppm	600				
83F-S01	Au		ppb	1510			5	100
83F-S01	Au		ppb	78				100
83F-S02	Au	HNO3/HCL	ppb	534			4	100
83F-S03	Au		g/t	0.0046				
83F-S04	Au		g/t	0.008				
83F-S04	Pt		g/t	0.012				
83G-S03	Au		g/t	0.0004				
83G-S04	Au		g/t	0.07				
83G-S05	Au		g/t	0.07				
83G-S06	Au		g/t	0.03				
83H-S05	Au		g/t	0.044				
83H-S06	Au		g/t	0.019				
83H-S08	Au		g/t	0.013				
83H-S09	Au		.g/t	0.036				
83H-S10	Au		g/t	0.198				
83H-S11	Au		g/t	0.1				
83H-S12A	Au		g/t	0.07				

Table 3: Summary of Geophysical Anomalies

GEOPHYSICAL ANOMALIES	SURVEY METHOD USED	INSTRUMENT USED	NAME AND MODEL OF INSTRUMENT	SURVEY METHOD NOTES	SURVEY FREQUENCIES	UNITS MEASURED
72E-P-15	Ground Radiometric	Scintillometer	SRAT SPP2			cps
72E-P-16	Ground Radiometric	Scintillometer	SRAT SPP2			cps
72E-P-25	Gamma Ray Logging	Portable borehole	Gearhart-Owen Industries.			gamma
72E-P-26	Gamma Ray Logging	Portable borehole	Gearhart-Owen Industries			Gamma
74E-P-21	Airborne Radiometric	Spectrometer	Scintrex			cps
74E-P-22	Airborne Radiometric	Spectrometer	Scintrex			cps
74E-P-24	Airborne HLEM	Electromagnetic	Apex Max-Min II			
74E-P-30	Ground IP	Induced Polarization	McPhar Frequency Domain	Lines cut every 300m, electrode	3cps and 2.5cps	Metal Factor
				separation at 15m and 60m		
74E-P-31	Ground IP	Induced Polarization	McPhar 660-VHEM	lines cut every 300m, electrode	0.3 cps and 2.5 cps	Metal Factor
				separation at 15m and 60m		
74L-P-01	Ground Radiometric	Scintillometer	Sacker Scientific Model SSL-2			cpm
74L-P-01A	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-1000	7 N-S lines/mile		cps
74L-P-03	Ground Radiometric	Scintillometer				cps
74L-P-09	Airborne Radiometric	Spectrometer	HBOG-AGS Gamma Ray		K40,Bi214,Tl 208	cps
74L-P-10	Airborne EM					
74L-P-10A	Ground VLF-EM	Electromagnetic	McPhar Gen 8	6 grid lines spaced at 200m	Range of 41-5248 Hz (doubling)	
				with 50m stations		
74L-P-10B	Ground Gravity		Lacoste and Romberg #HG-16			Milligals
74L-P-11	Ground VLF-EM	Electromagnetic	Crone Raden EM insrument	switchable to seven VLF		
				transmitting stations		
74L-P-18	Ground Radiometric	Scintillometer	STRATT Model SP-2			cps
74L-P-32	Airborne EM and Magnetic		GSC			gamma
74L-P-37	Airborne EM	Electromagnetic	Questor Mark IV Input Survey	122m above ground		
74L-P-38	Ground HLEM	Electromagnetic	Maxim II Horizontal Loop			Mhos per metre
74L-P-38	Ground VLF-EM	Electromagnetic	McPhar ss-15			
74L-P-38	Ground VLF-EM	Electromagnetic	Geonics EM6			% incline from
						horizontal
74L-P-38	Ground Magnetics	Magnetometer	Geometrics ModelG816			gamma
74L-P-38A	Airborne EM	Electromagnetic	Questor Mark IV Input Survey	122m above ground		
74L-P-39	Ground HLEM	Electromagnetic	Maxim II Horizontal Loop			Mhos per metre
74L-P-39	Ground VLF-EM	Electromagnetic	McPhar ss-15			
74L-P-39	Ground VLF-EM	Electromagnetic	Geonics EM16			% incline form
						horizontal
74L-P-39	Ground Magnetics	Magnetometer	Geometrics ModelG816			gamma
74L-P-39A	Airborne EM	Electromagnetic	Questor Mark IV Input Survey	122m above ground		
74L-P-40	Airborne EM	Electromagnetic	Questor Mark IV Input Survey	122m above ground		
74L-P-52	Ground Radiometric	Scintillometer	SRAT SPP2	305 meter spaced grid		cps
74L-P-52	Ground EM	Electromagnetic	Rhonka EM-16		18.6 Hz and 24.1 Hz stations	
74L-P-52	Ground Magnetics	Magnetometer	Sharp MF-1			
74L-P-53	Airborne Magnetics	Magnetometer	Geoterrex			gamma
74L-P-54	Airborne EM	Electromagnetic	Hudson Bay EM-30		380 Hz and 1225 Hz.	
74L-P-54	Airborne Magnetics	Magnetometer	Geometric Model G-803			
74L-P-61	Airborne Magnetics	Magnetometer	Geoterrex			gamma
74L-P-62	Airborne Magnetics	Magnetometer	Geoterrex			gamma

Table 3: Summary of Geophysical Anomalies

GEOPHYSICAL ANOMALIES	SURVEY METHOD USED	INSTRUMENT USED	NAME AND MODEL OF INSTRUMENT	SURVEY METHOD NOTES	SURVEY FREQUENCIES	UNITS MEASURED
74M-P-14A	Ground Radiometric	Scintillometer				cps
74M-P-15	Ground Radiometric	Scintillometer	SRAT SPP2			cps
74M-P-16	Airborne Radiometric	Spectrometer	Dual Scintrex SC-1			cps
74M-P-17	Airborne Radiometric	Spectrometer	Dual Scintrex SC-1			cps
74M-P-21	Ground Radiometric	Spectrometers	W56 Fisher and IIIB Precision			MR/hr
74M-P-22	Ground Radiometric	Scintillometers	W56 Fisher and IIIB Precision			MR/hr
74M-P-23	Ground Radiometric	Spectrometers	W56 Fisher and IIIB Precision			MR/hr
74M-P-24	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-2000			cps
74M-P-25	Ground Radiometric	Scintillometer	SRAT SPP2			cps
74M-P-25A	Airborne Radiometric	Spectrometer	Imax 287-101	27 lines, 104 line km		cps
				500m spacing		
74M-P-25A	Ground Radiometric	Scintillometer	SRAT SPP2			cps
74M-P-26	Ground Radiometric	Scintillometer	SRAT SPP2			cps
74M-P-27	Ground Radiometric	Scintillometer	SRAT SPP2			cps
74M-P-28	Airborne Radiometric	Spectrometer	Scintrex Model SC-1	lines N-S, 6 lines/mile		cpsU and cpsTh
74M-P-28	Ground Radiometric	Spectrometer	Sharp GIS-2			cpsU and cpsTh
74M-P-29	Airborne Radiometric	Spectrometer	Scintrex Model SC-1	Lines N-S, 6 lines/mile		cpsU and cpsTh
74M-P-29	Ground Radiometric	Spectrometer	Scintrex Model SC-1			cpsU and cpsTh
74M-P-30	Airborne Radiometric	Spectrometer	Scintrex Model SC-1	Lines N-S, 6 lines/mile		cpsU and cpsTh
74M-P-31	Airborne Radiometric	Spectrometer	Scintrex Model SC-1	Lines N-S, 6 lines/mile		cpsU and cpsTh
74M-P-32	Airborne Radiometric	Spectrometer	Scintrex Model SC-1	Lines N-S, 6 lines/mile		cpsU and cpsTh
74M-P-33	Ground Radiometric	Scintillometer				cps
74M-P-34	Ground Radiometric	Scintillometer				cps
74M-P-35	Ground Radiometric`	Scintillometer	McPhar TV-1 Gamma Ray			cpm
74M-P-36	Ground Radiometric	Scintillometer				cps
74M-P-37	Ground Radiometric	Scintillometer				cps
74M-P-38	Ground Radiometric	Scintillometer				cps
74M-P-39	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-1000	lines N-S, 7 lines/mile		cps
74M-P-40	Ground Radiometric	Scintillometer	Sacker Scientific Model SSL-2			cpm
74M-P-40A	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-1000			cps
74M-P-40B	Airborne Radiometric	Spectrometer	INAX model 287-101 GR			cps
74M-P-40B	Ground Radiometric	Scintillometer	SRAT SPP2			cps
74M-P-41	Ground Radiometric	Scintillometer	Sacker Scientific Model SSL-2			cpm
74M-P-41A	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-1000	Lines N-S, 7 lines/mile		cps
74M-P-42	Ground Radiometric	Scintillometer	Sacker Scientific Model SSL-2			cpm
74M-P-42A	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-1000	Lines N-S, 7 lines/mile		
74M-P-43	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-1000	Lines N-S, 7 lines/mile		cps
74M-P-44	Ground Radiometric	Scintillometer	Sacker Scientific Model SSL-2			cpm
74M-P-44A	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-1000	Lines N-S, 7 lines/mile		cps
74M-P-45	Airborne Radiometric	Spectrometer	Expl. H-window DGRS-1000	Lines N-S, 7 lines/mile		cps
74M-P-46	Ground Radiometric	Scintillometer	Sacker Scientific Model SSL-2			cpm
74M-P-47	Ground Radiometric	Scintillometer	Sacker Scientific Model SSL-2			cpm
74M-P-48	Ground Radiometric	Scintillometer	Sacker Scientific Model SSL-2			cpm
74M-P-49	Ground Radiometric	Scintillometer	SRAT SPP2			cps
74M-P-49A	Ground Radiometric	Scintillometer	SRAT SPP2			cps

Table 4: Summary of Drilling

DRILLING ANOMALIES	DRILL HOLE NUMBER	DATE DRILLED	FROM DEPTH (M)	TO DEPTH (M)	CORE LENGTH (M)	TRUE WIDTH (M)	ELEMENT ANALYSED	UNITS MEASURED	ASSAY RESULT
72E-D-01	Foremost 1	69/2/2							
72E-D-02	SX-1221	69/10/13	24.38	26.82	2.44		U	%U3O8	0.01
72E-D-03		00/00/00							
72E-D-04	SX-1252	00/00/00							
72E-D-05		00/00/00							
72E-D-06		00/00/00							
72E-D-07		00/00/00							
73L-D-01	CL 23-1	00/00/00							
74E-D-02	R3	77/8/26							
74E-D-03	16-Jan	00/00/00	38.7	39.6	0.9				
74E-D-05	508-1	76/11/13							
74E-D-06	508-2	76/11/17	257.2	302.9	55.7		U	cpm	4000
74E-D-07	508-5	76/11/24					U		
74E-D-08	508-16	77/2/24					U		
74E-D-09	508-13	77/2/15							
74E-D-10	508-14	77/2/19							
74E-D-23		00/00/00							
74E-D-24	508-37	79/4/8	111.9	119.8	7.9		U	ppm	6.5
74E-D-24	508-41	79/4/24	135.2	144.4	9.2		U	ppm	8.5
74E-D-25	508-38	79/4/11							
74E-D-25	508-40	79/4/17							
74E-D-26	86-1R	86/3/14	318.2	320.3	2.1		Au	ppb	30
74E-D-26	86-2R	86/3/20					Au	g/t	2.16
74E-D-31		67/2/1							
74L-D-01		00/00/00							
74L-D-14	508-8	76/11/30							
74L-D-15	508-9	76/12/4							
74L-D-16	508-10	76/12/7							
74L-D-17	508-12	77/2/12							
74L-D-29	R-5	77/9/10		252.2					
74L-D-30		00/00/00							
74L-D-31	R-8	77/9/26		227.8					
74L-D-33	R1	77/8/20							
74L-D-34		00/00/00							
74L-D-35	R4	77/8/31							
74L-D-36		00/00/00							
74L-D-38	RR-5	79/4/4	106.7	107.9	1.2		U3O8	ppm	3.3
74L-D-38	RR-6	79/4/6	42.7	43.9	1.2		U3O8	ppm	3.1
74L-D-39	RR-2	92/4/27	21.4	22.4	1		U3O8	ppm	1.8
74L-D-41	RR-1	79/3/22	73.4	75.1	1.7		U3O8	ppm	0.8
74L-D-42	RR-3	92/4/29	31.6	32.6	1		U3O8	ppm	11.1
74L-D-43	RR-4	92/4/30							
74L-D-44	RR-10	00/00/00							
74L-D-44	RR-11	00/00/00							
74L-D-44A	RR-10	00/00/00							
74L-D-44A	RR-11	79/6/16							
74L-D-45	OF 78-1	78/10/22	56.69	56.99	0.3		U	%	0.01
74L-D-46	OF 78-2	78/11/28	441.05	441.35	0.3		U	%	0.01
74L-D-47	KDH 78-1	78/10/21							
74L-D-48	KDH 78-2	78/10/29							
74L-D-49	KDH 78-3	78/11/8							
74L-D-50	WB-1	80/8/28	184.8	186.8	2		U	cps	80
74L-D-51	WB-3	80/9/17	210	217	7		U	cps	185
74L-D-51	WB-2	00/00/00							
74L-D-51	WB-4	00/00/00							
74L-D-52	Hole 1	76/3/5							
74L-D-52	Hole 2	76/3/12							
74L-D-66	508-11	00/00/00							
74L-D-78	78LAJV-003	78/7/9	890	890.3	0.3		Au	g/t	
74L-D-78	78LAJV-003	78/7/9	894	894.3	0.3		Ni	ppm	112
74L-D-78	78LAJV-003	78/7/9	897.9	898.2	0.3		As	ppm	420
74L-D-78	78LAJV-003	78/7/9	907.7	908	0.3		Ag	g/t	8.9
74L-D-78	78LAJV-003	78/7/9	915.6	915.9	0.3		Co	ppm	200

Table 4: Summary of Drilling

DRILLING ANOMALIES	DRILL HOLE NUMBER	DATE DRILLED	FROM DEPTH (M)	TO DEPTH (M)	CORE LENGTH (M)	TRUE WIDTH (M)	ELEMENT ANALYSED	UNITS MEASURED	ASSAY RESULT
82G-D-92		00/00/00							
82G-D-93	BN-88	93/1/1	29.57	30.18	0.61		Fe	%Fe2O3	18.09
82G-D-93	BN-88	56/1/1	29.57	30.18	0.61		Ti	%TiO2	3.6
82G-D-94	BN-89	93/1/1	12.13	12.65	0.52		Fe	%Fe2O3	17.36
82G-D-94	BN-89	56/1/1	12.13	12.65	0.52		Ti	%TiO2	2.58
82G-D-95	BN-56	56/1/1	1.22	1.83	0.61		Fe	%Fe2O3	28.77
82G-D-95	BN-56	56/1/1	1.22	1.83	0.61		Ti	%TiO2	4.86
82G-D-96	BN-94	56/1/1	13.41	14.33	0.92		Fe	%Fe2O3	31.01
82G-D-96	BN-94	56/1/1	13.41	14.33	0.92		Ti	%TiO2	5.19
82G-D-97	BN-54	56/1/1	22.86	24.38	1.52		Fe	%Fe2O3	38.93
82G-D-97	BN-54	56/1/1	22.86	24.38	1.52		Ti	%TiO2	7
82G-D-98		00/00/00							
82H-D-01	DDH-5	93/3/1			3.05		Cu	%	2.35
82H-D-01	DDH-5	93/3/1			3.05		Ag	g/t	27.09
82H-D-01A	WB-1	67/7/28	77.66	78.15	0.49		Cu	%	0.7
82H-D-01B	WB-1	67/7/28	77.66	78.15	0.49		Cu	%	0.7
82H-D-06	IF-41	00/00/00	19.81	20.73	0.92		Fe	%	51.29
82H-D-06	IF-41	00/00/00	19.81	20.73	0.92		Ti	%	10.98
82H-D-06	IF-36	00/00/00	9.69	12.5	2.81		Fe	%	47.36
82H-D-06	IF-36	00/00/00	9.69	12.5	0.92		Ti	%	8.8
82H-D-06	IF-36	00/00/00	5.79	13.9	8.11		Fe	%	29.14
82H-D-06	IF-36	00/00/00	5.79	13.9	8.11		Ti	%	5.85
82J-D-42	Hole 2	54/1/1					Pb		
82J-D-45		81/1/1					Au	g/t	0.45
82O-D-09		00/00/00							
82O-D-09		00/00/00							
82O-D-10		00/00/00							
83P-D-01		00/00/00							
84N-D-03	27-Jul	00/00/00							
84N-D-03	27-Jul	77/8/24	76.2	77.42	1.22		Cu	ppm	19
84N-D-03	27-Jul	77/8/24	85.34	88.09	2.75		Pb	ppm	46
84N-D-03	27-Jul	77/8/24	85.34	88.09	2.75		Zn	ppm	42
84N-D-03	27-Jul	77/8/24	70.56	71.78	1.22		Mn	ppm	210
84N-D-03	27-Jul	77/8/24	68.58	70.56	1.98		Fe	ppm	72500
84N-D-03	27-Jul	77/8/24	65.53	68.58	3.05		Ni	ppm	24
84N-D-03	27-Jul	77/8/24	70.56	71.78	1.22		Cu	ppm	25
84N-D-03	27-Jul	00/00/00	70.56	71.78	1.22		Zn	ppm	110
84N-D-03	27-Jul	00/00/00	77	70.56	71.78	1.22	Ba	ppm	500
84N-D-03	27-Jul	77/8/24	70.56	71.78	1.22		Hg	ppb	60
84N-D-04	3-Mar	77/9/2	98.76	100.58	1.82		Cu	ppm	40
84N-D-04	3-Mar	77/9/2	176.78	179.83	3.05		Pb	ppm	70
84N-D-04	3-Mar	77/9/2	100.58	103.63	3.05		Zn	ppm	39
84N-D-04	3-Mar	77/9/2	94.03	96.62	2.59		Mn	ppm	390
84N-D-04	3-Mar	77/9/2	86.87	88.39	1.52		Fe	ppm	83500
84N-D-04	3-Mar	77/9/2	60.96	64.01	3.05		Ni	ppm	150
84N-D-04	3-Mar	77/9/2	60.96	64.01	3.05		Cu	ppm	190
84N-D-04	3-Mar	77/9/2	60.96	64.01	3.05		Zn	ppm	770
84N-D-04	3-Mar	77/9/2	60.96	64.01	3.05		Cd	ppm	18
84N-D-04	3-Mar	77/9/2	86.87	88.39	1.52		Ba	ppm	500
84N-D-04	3-Mar	77/9/2	91.44	94.03	3.05		Hg	ppb	60
84N-D-05	Oct-32	77/9/24	240.79	243.84	3.05		Cu	ppm	29
84N-D-05	Oct-32	77/9/24	124.36	128.02	3.66		Pb	ppm	57
84N-D-05	Oct-32	77/9/24	213.36	215.95	2.59		Zn	ppm	220
84N-D-05	Oct-32	77/9/24	103.63	106.68	3.05		Mn	ppm	280
84N-D-05	Oct-32	77/9/24	115.82	118.87	3.05		Fe	ppm	31400
84N-D-05	Oct-32	77/9/24	97.54	100.59	3.05		Ni	ppm	150
84N-D-05	Oct-32	77/9/24	97.54	100.59	3.05		Cu	ppm	170
84N-D-05	Oct-32	77/9/24	76.2	79.25	3.05		Zn	ppm	820
84N-D-05	Oct-32	77/9/24	97.54	100.593	3.05		Zn	ppm	730
84N-D-05	Oct-32	77/9/24	115.82	118.87	3.05		Ba	ppm	400
84N-D-05	Oct-32	77/9/24	115.82	118.87	3.05		Hg	ppb	20
84N-D-05	Oct-32	77/9/24	97.54	100.59	3.05		Cd	ppm	14
84N-D-06	4-Jan	77/10/11	182.88	185.93	3.05		Cu	ppm	50

REGIONAL METALLOGENIC EVALUATION

OF ALBERTA

APPENDIX I

METALLIC MINERAL DEPOSIT MODELS FOR ALBERTA

METALLIC MINERAL DEPOSIT MODELS FOR ALBERTA

1. PRECIOUS METALS

Gold:
- 1.1 Precambrian Lode Gold
- 1.2 Epithermal Gold-Silver
  - 1.2a Bonanza vein hosted Au-Ag ± base metals
  - 1.2b Disseminated Carlin type Au ± Ag
- 1.3 Phanerozoic Mesothermal Gold
- 1.4 Skarn Gold
- 1.5 Placer Gold

2. BASE METALS

Lead, Zinc:
- 2.1 Mississippi Valley Type Lead-Zinc
- 2.2 Sediment Hosted Stratiform Lead-Zinc
  - 2.2a Shale or turbidite hosted Pb-Zn ± Ag, Ba
  - 2.2b Sandstone hosted Pb-Zn

Copper:
- 2.3 Volcanogenic Massive Sulphides
  - 2.3a Precambrian type Cu-Zn ± Ag, Au
  - 2.3b Kuroko type Zn-Pb-Cu ± Ag, Au, Ba
- 2.4 Sediment Hosted Stratiform Copper
  - 2.4a Kupferschiefer type Cu ± Ag
  - 2.4b Kipushi type Cu ± Pb, Zn, Co, Ge, Ga, Ag
- 2.5 Base Metal Skarns
  - 2.5a W ± Cu, Mo, Bi, Zn
  - 2.5b Cu ± W, Mo, Zn, Bi, Ag, Au
  - 2.5c Mo ± Cu, W, Bi
  - 2.5d Sn ± Mo, W
  - 2.5e Fe ± Cu, Zn, Co, Au
  - 2.5f Zn-Pb ± Ag, Cu
- 2.6 Olympic Dam Type Copper-Uranium-Gold-Silver

Nickel:
- 2.7 Shale Hosted Stratiform Nickel-Zinc
- 2.8 Magmatic Nickel-Copper
  - 2.8a Komatiite Ni-Cu ± Co, Pt, Pd, Rh, Ru,
  - 2.8b Flood basalt Ni-Cu ± Co, Pt, Pd, Rh, Ru, Au
  - 2.8c Layered intrusions Ni-Cu ± Co, Pt, Pd, Rh, Ru, Au

Iron:
- 2.9 Sediment Hosted Oolitic Ironstone
- 2.10 Placer Magnetite

3. URANIUM

- 3.1 Unconformity Associated Uranium
  - 3.1a Precambrian conglomerate hosted U-Au
  - 3.1b Helikian sandstone hosted U
- 3.2 Sandstone Hosted Uranium
  - 3.2a Roll front U
  - 3.2b Tabular or channel type U
- 3.3 Vein Type Uranium
  - 3.3a Classical vein U
  - 3.3b Arsenide vein U-Ag ± Cu, Co, Ni
- 3.4 Uranium Bearing Lignite

4. OTHER

Diamond:
- 4.1 Kimberlite or Lamproite Hosted Diamonds
- 4.2 Placer Diamonds

1.1 Precambrian Lode Gold

Commodity

Au ± Ag

Tectonic Framework

Precambrian lode gold deposits are hosted in a variety of lithological and structural settings. In general, Precambrian lode gold deposits are most common in Archean greenstone belts and are spatially associated with regional structural breaks. This group of deposits is sometimes referred to as Archean shear zone gold deposits.

The deposits exist in almost all rock types contained within Archean greenstone belts including felsic to mafic extrusive and intrusive volcanic rocks, turbiditic sedimentary rocks, and all metamorphic equivalents. On a regional cratonic scale there is little stratigraphic control on Precambrian lode gold deposits. On a district or deposit scale there can be a stratabound control due to a favourable structural and/or chemical environment.

Rocks that host Precambrian lode gold deposits range in age from early Archean to late Proterozoic. The lode gold deposits span the same age interval, but they are epigenetic and are thought to have formed either during or shortly after peak metamorphism of the host rocks. Archean age gold deposits are far more common than the Proterozoic counterparts. Phanerozoic mesothermal gold deposits may be the Phanerozoic equivalents of Precambrian lode gold deposits.

Regional Characteristics

There are many regional characteristics that are recognized as important for Precambrian lode gold deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Archean greenstone belts or metaturbidite basins host the majority of Precambrian lode gold deposits.

2. A spatial relationship with major regional structural breaks, especially second or third order shear zones that either splay off the major structure or are sympathetic to the major structure. The structural geology of the lode gold deposits is, in many respects, a scaled-down version of the structural geology of the greenstone or turbidite belt.

3. Contacts between different lithologies are favourable locations for the development of shear zones and consequently lode gold deposits.

4. Many deposits are hosted in schistose to mylonitic rocks developed as a result of shearing. Gold-bearing lode quartz is often hosted in shears, fractures, dilation zones and other structural features that are congruent with the overall shear zone geometry.

5. Shear zones that exhibit evidence of a transition from ductile to brittle-ductile deformation and shear strain are more favourable for the development of shear hosted lode gold deposits.

6. Folding and fold geometry can be important in the formation of and post-mineralization redistribution of lode gold deposits.

7. Regional metamorphic transitions from greenschist facies to amphibolite facies are regarded as important in some districts.

8. Hypabyssal felsic porphyry intrusions are commonly spatially associated with many lode gold deposits.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Precambrian lode gold deposits are often characterized by the following:

1. The ore zone is generally hosted in subvertical tabular to irregular masses of quartz. Gold within altered wallrock, stockwork zones and replacement zones is common.

2. The ore zone is generally in the form of a subvertical shoot, with the vertical length far greater than the thickness or horizontal length. The ore zone commonly corresponds to a zone of dilation that is related to the shear zone geometry.

3. Native gold and minor amounts of tetrahedrite are the principal ore minerals. Principal gangue minerals are quartz, carbonates, pyrite and arsenopyrite, with lesser amounts of albite, chlorite, muscovite, fuchsite, graphite, tourmaline, pyrrhotite, sphalerite, galena, scheelite and molybdenite. The quartz veins are typically massive to ribboned.

4. On a deposit scale there is little evidence of a vertical mineralogic or elemental zoning. Gold grades vary considerably in the horizontal direction, giving rise to the ore shoot pattern of steeply plunging ore grade zones.

5. The gold/silver ratios of Precambrian lode gold deposits range from 1:1 to values that are orders of magnitude greater than one. Typically, the gold/silver ratio for Precambrian lode gold deposits is greater than 10:1.

6. Hydrothermal alteration varies considerably from deposit to deposit and is often a function of the existing mineralogy, chemistry and metamorphic grade of the host rocks. The most common types of alteration are carbonatization, chloritization and sulphidization, particularly in intermediate to mafic volcanic rocks. Sericitization and silicification are more commonly associated with deposits in felsic volcanic and clastic sedimentary rocks, although silicification can be important in all rock types.

7. Geochemical aureoles that envelope Precambrian lode gold deposits are variable but can be important locally. Typically, the alteration zones around the deposits are enriched in one or more of Si, Ca, K, As, Ba, B, W, Mo, Sb, Ag and Au.

1.2 Epithermal Gold-Silver

Type and Commodity

1.2a Bonanza vein hosted Au-Ag ± base metals
1.2b Disseminated Carlin type Au ± Ag

Tectonic Framework

Epithermal gold-silver deposits are the product of near surface hydrothermal activity. Like the Phanerozoic mesothermal gold deposits, epithermal gold-silver deposits are hosted in a variety of lithological and structural settings. In general, the epithermal deposits are most common in accreted, back-arc volcanic and sedimentary terranes and are spatially associated with felsic volcanism and extensional tectonic settings within these terranes.

The deposits exist in almost all rock types contained within allochthonous terranes, including felsic to mafic extrusive and intrusive volcanic rocks, clastic to chemical sedimentary rocks, and some metamorphic equivalents. On a regional scale there is little stratigraphic control on epithermal gold-silver deposits. On a district or deposit scale there can be a stratabound control due to a favourable structural and/or chemical environment represented by a particular rock unit. The bonanza vein hosted deposits commonly occur in pyroclastic volcanic rocks. Disseminated Carlin type deposits are commonly hosted in impure carbonate rocks.

Rocks that host epithermal gold-silver deposits range from Early Jurassic to at least Late Tertiary. The gold-silver deposits span the same age interval, but they are epigenetic and are thought to have formed either during or shortly after deposition or intrusion of the associated or host volcanic rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for epithermal gold-silver deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics for the bonanza vein hosted gold-silver deposits include:

1. A predominantly extensional tectonic regime superimposed on an allochthonous volcanic-sedimentary terrane with abundant major strike-slip faults.

2. Strong spatial correlation with well developed regions of extensional fracture systems and normal faults. The deposits themselves are often hosted in or are spatially related to second or third order structures that are splays from or are sympathetic to the regional faults.

3. The detailed structural setting of any deposit or district is often a scaled-down version of the regional structural setting.

4. The presence of large scale caldera collapse structures and indications of ancient to present hot spring activity or fumarolic deposits.

5. Permeable subaerial pyroclastic and sedimentary rocks with associated breccia zones.

6. High level plutons or numerous small subvolcanic intrusions that are structurally controlled and either the same age or slightly younger than the subaerial rocks.

Many of the regional characteristics that are important for the bonanza vein hosted gold-silver deposits are also important for the disseminated Carlin type gold ± silver deposits. Some of the regional characteristics that are not important for the bonanza vein hosted deposits, but may be important for disseminated Carlin type deposits include:

1. Carbonaceous host rocks such as limestones, impure limestones, black shales and siltstones.

2. Tendency for these deposits to form along regional linear trends.

3. Overlap of allochthonous terrane over sialic continental crust.

4. Deposits occur predominantly in accreted terranes; however, a select few exist in miogeoclinal sedimentary rocks.

5. Superposition of impermeable cap rocks above permeable host rocks.

6. In some cases, Carlin type deposits have a spatial association with the crests of regional scale antiforms.

7. A few important Carlin type deposits, such as Mercur, have no spatial or temporal association with age equivalent hypabyssal intrusions or subaerial volcanics.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Bonanza vein hosted gold-silver deposits are often characterized by the following:

1. The gold is generally hosted in subvertical tabular to irregular shaped bodies of quartz that branch out into a fan or horsetail shape near the paleosurface. Breccia, stockwork and replacement zones are common. The ore zones are generally formed within 1,000 m of the paleosurface.

2. The ore zone is generally in the form of a subvertical shoot with horizontal length much greater than the thickness or the vertical length. Typically, the vertical length is between 350 m and 600 m.

3. The principal ore mineralogy is native gold and silver with lesser amounts of electrum, acanthite, argentite, tetrahedrite and various other Ag-As-Sb sulphosalts. Other minor ore minerals may include galena, sphalerite, chalcopyrite, enargite, cinnabar, stibnite and telluride minerals. Principal gangue minerals are quartz and carbonates with lesser amounts of fluorite, barite and pyrite. Other gangue minerals may include adularia, sericite/illite, chlorite, hematite, rhodonite and rhodochrosite. The ore and gangue minerals are dominantly deposited as open space filling with banded, crustiform, vuggy, drusy, colloform and cockscomb textures.

4. Most bonanza vein hosted deposits exhibit strong hydrothermal alteration with a pronounced mineralogical and chemical zonation.
   (a) Above the ore zone and near the paleosurface, metallic minerals include

cinnabar, stibnite, realgar and orpiment with occasional native gold. This zone is generally characterized by silica sinters and argillic to acid sulphate alteration. The ore zone occurs generally at about 350 m to 500 m below the paleosurface and is characterized by quartz veins with native gold, silver, electrum and acanthite. The ore zone is spatially associated with silicification and sericitization. With depth the ore zone often passes into a subeconomic, base metal-rich zone characterized by the presence of galena, sphalerite and pyrite with minor amounts of chalcopyrite, enargite, tetrahedrite and argentite.

(b) Gold and silver grades can vary considerably in the horizontal and vertical direction in bonanza vein hosted deposits. Above the ore zone, silver is generally absent and gold is erratic and subeconomic. In the ore zone, the Ag to Au ratio is usually greater than 1:1 (often about 10:1) and it increases downward into the base metal zone.

5. Ore zone alteration is often characterized by silicification and sericitization of the immediate host rock. Widespread propylitic alteration (chlorite, calcite, pyrite, epidote and zeolite) is common in many epithermal districts. Near surface alteration is characterized by clay minerals, alunite and jarosite, with a siliceous cap where hydrothermal fluids reach the surface as hot springs.

6. Geochemical aureoles that envelope bonanza vein hosted gold-silver deposits are variable but can be important. Typically, the near surface siliceous sinter zones above the deposits are enriched in one or more of Au, Ag, Sb, Hg, As, Tl, B, F and Ba. The clay rich alteration zones are commonly enriched in one or more of Au, As and Pb with lesser amounts of Hg, Sb, W, Mo, B and Ag. The ore zones are commonly enriched in Hg, Sb and As with lesser amounts of Pb, Zn, Cu, Tl, Te and Se.

Disseminated Carlin type gold ± silver deposits exhibit many of the same characteristics that bonanza vein hosted deposits exhibit. Some of the differences that disseminated Carlin type deposits exhibit include:

1. The ore zone is often a replacement zone within silty carbonates, or within limy shales and siltstones.

2. The ore zone can vary between deposits or within a deposit from stratabound pods that are near flat-lying, to subvertical shoots that are more structurally controlled.

3. Gold is generally submicroscopic or intergrown with sulphides.

4. The strong mineral and chemical zonation that is present in the Bonanza vein hosted deposits is generally not present in the Carlin type deposits.

5. Alteration is characterized by the removal of carbonate from the host rocks followed by silicification and argillization. Jasperoids, which are hematitic silica replacements of the host rock, are characteristic of Carlin type deposits. Most of the Carlin type deposits contain a near surface oxidized ore zone which is generally bleached, contains iron oxides and sulphates, and may be acid leached.

6. The Carlin type deposits have a similar trace element chemistry to the bonanza vein hosted deposits, except silver and the base metals are usually much less abundant.

1.3 Phanerozoic Mesothermal Gold

Commodity

Au ± Ag

Tectonic Framework

Phanerozoic mesothermal gold deposits are considered by many to be the modern analogues of Archean lode gold deposits. Like the Archean deposits, Phanerozoic mesothermal gold deposits are hosted in a variety of lithological and structural settings. In general, the Phanerozoic deposits are most common in allochthonous terranes and are spatially associated with regional strike slip faults.

The deposits exist in almost all rock types contained within allochthonous terranes including felsic to mafic extrusive and intrusive volcanic rocks, clastic to chemical sedimentary rocks, and all metamorphic equivalents. On a regional scale there is little stratigraphic control on Phanerozoic mesothermal gold deposits. On a district or deposit scale there can be a stratabound control due to a favourable structural and/or chemical environment represented by a particular rock unit.

Rocks that host Phanerozoic mesothermal gold deposits range in age from Precambrian to at least middle Tertiary. The gold deposits span the same age interval, but they are epigenetic and are thought to have formed either during or shortly after peak metamorphism of the host rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for Phanerozoic mesothermal gold deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Strong spatial correlation with major regional strike slip faults. The deposits themselves are often hosted in or are spatially related to second or third order structures that are splays from or are sympathetic to the regional faults.

2. The detailed structural setting of any deposit or district is often a scaled-down version of the regional structural setting.

3. Lithological contacts often are favourable sites for the propagation of major regional faults, and the development of secondary and tertiary structures. As a result, they are favourable sites for the development of mesothermal gold deposits.

4. Fault systems that exhibit evidence of a transition from ductile to brittle-ductile deformation and shear strain are more favourable for the development of mesothermal gold deposits.

5. The gold deposits are often located in rocks metamorphosed to greenschist facies. However, many mesothermal gold districts exist at regional transitions from greenschist to amphibolite metamorphic facies.

6. A regional chemical zonation; that is, mesothermal mercury and antimony deposits may represent distal portions of a mesothermal gold system.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Phanerozoic mesothermal gold deposits are often characterized by the following:

1. The gold is generally hosted in subvertical tabular to irregular shaped bodies of quartz. Stockwork and replacement zones are common.

2. The ore zone is generally in the form of a subvertical shoot with horizontal length and thickness much smaller than the vertical length.

3. Native gold and minor amounts of tetrahedrite are the principal ore minerals. Principal gangue minerals are quartz, carbonates, pyrite and arsenopyrite with lesser amounts of albite, muscovite, fuchsite, graphite, sphalerite, galena, scheelite and pyrrhotite. The quartz veins are typically massive to ribboned.

4. On a deposit scale there is little evidence of a vertical mineralogic or elemental zoning. Gold grades vary considerably in the horizontal direction, giving rise to the ore shoot pattern of steeply plunging ore grade zones. In mesothermal deposits formed nearer to surface, stibnite and cinnabar are present. In some cases, the near surface mesothermal deposits are entirely composed of stibnite and cinnabar with little or no gold.

5. The gold/silver ratios of mesothermal gold deposits range from 1:1 to values that are orders of magnitude greater than 1:1. Typically, the gold/silver ratios of mesothermal gold deposits are greater than one. In comparison, Phanerozoic epithermal gold deposits have gold/silver ratios that are considerably less than 1:1.

6. Hydrothermal alteration varies considerably from deposit to deposit and is often a function of the mineralogy, chemistry and metamorphic grade of the host rocks. The most common type of alteration is carbonatization of intermediate to mafic volcanics, plutonics and serpentinites. Albitization, sericitization and silicification are more commonly associated with deposits in felsic volcanics and clastic sedimentary rocks.

7. Geochemical aureoles that envelope mesothermal gold deposits are variable but can be important. Typically, the alteration zones around the deposits are enriched in one or more of Ca, Si, As, Ba, B, Cu, Pb, Zn, W, Ag and Au.

1.4 Skarn Gold

Commodity

Au ± Cu, Pb, Zn, Ag

Tectonic Framework

Skarn deposits result from the hydrothermal interaction of hot silicate magmas and cooler sedimentary rocks. They are an important source of base and precious metals. Gold-rich skarns are one of seven distinct skarn types. In general, gold skarns are related to the interaction of calcalkaline I-type magmas and accreted or miogeoclinal sedimentary sequences containing carbonates and clastic or volcaniclastic strata. It is not known whether a specific tectonic setting is necessary for the formation of a gold skarn.

The deposits exist in sedimentary sequences with a significant clastic or volcaniclastic component. On a district or deposit scale there can be a stratabound control due to a favourable structural and/or chemical environment represented by a particular rock unit.

Rocks that host skarn gold deposits range in age from Cambrian or older to Miocene. The skarns and associated plutonic rocks span the same age interval.

Regional Characteristics

There are many regional characteristics that are recognized as important for gold skarn deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Carbonate host rocks with a significant clastic or volcaniclastic component.

2. Mafic diorite to granodiorite intrusions that are reduced chemically. The intrusions are usually more equigranular than porphyritic.

3. Extensional tectonic regimes the are favourable for the emplacement of calcalkaline magmatic rocks.

4. Oceanic island arcs are more favourable as they produce more mafic intrusive rocks.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Gold skarn deposits are often characterized by the following:

1. The ore zone is variable in shape and size, and is generally hosted in the distal pyroxene rich portions of the skarn.

2. Arsenopyrite and pyrrhotite are typically the most abundant sulphides with lesser amounts of marcasite and pyrite. In some deposits, abundant native bismuth, and complex bismuth and telluride minerals are associated with gold. In comparison to the other classes of skarns, gold skarns are sulphide and base metal poor.

3. Gold skarns typically exhibit a mineralogical and chemical zonation.

(a) The zone nearest the intrusion (proximal zone) is characterized by abundant garnet, usually grandite, which is intermediate between Fe and Al rich composition. Andradite is the most common garnet in other types of skarns. The distal zone is dominantly comprised of Fe and Al rich diopside or hedenbergite. Other important skarn minerals include potassium feldspar, biotite, idocrase, prehnite, apatite, sphene and scapolite.

(b) The proximal zone is typically Cu enriched, whereas Au, As, Bi and Te are concentrated in the distal pyroxene rich zone. Some deposits exhibit a Pb, Zn, Ag halo beyond the limit of skarnification. In general, Cu, Pb, Zn and Ag are low in gold skarns in comparison to the other types of skarns.

1.5 Placer Gold

Commodity

Au $\pm$ Ag

Tectonic Framework

Historically, placer gold deposits have been a major supplier of world gold. Placer deposits result from the mechanical concentration of moderate to high density minerals. Placer gold deposits form in several distinct geomorphological environments including gulches, creeks, alluvial fans, braided rivers, flood plains, fan deltas and beaches. Placer gold deposits form in a variety of tectonic settings including accreted mobile belts, marginal cratonic basins and intracratonic basins.

Placer gold deposits exist in a variety of complex sedimentary sequences depending upon the geomorphological environment, the local climate, the hydrodynamics of the alluvial system and the distance from the original bedrock source. On a deposit scale, there can be facies control of placer gold due to favourable sedimentological conditions in a specific geomorphological environment. However, facies control can vary unpredictably from one sedimentary environment to another no matter how similar the two environments might be.

Rocks that host placer gold deposits range in age from early Archean to Recent. Placer gold deposits and other associated heavy mineral deposits span the same age interval.

Regional Characteristics

There are many regional characteristics that are recognized as important for placer gold deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Occurrence of gold in the hinterland in either lode deposits or in elevated concentrations in bedrock.

2. A surface of submature to mature topography.

3. Relatively long periods of mechanical and chemical weathering resulting in highly weathered and well dissected terrain.

4. Periodic uplift and/or subsidence.

5. Absence of extensive glaciation.

6. Geomorphological and sedimentological features indicative of ancient or present day gulches, creeks, alluvial fans, braided rivers, flood plains, fan deltas and beaches.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Gold placer deposits are often characterized by the following:

1. Placer deposits that are proximal to a lode gold source generally contain coarse

grained gold in seams, paystreaks or lenses in alluvium at or near bedrock. Examples of this type of environment may include gulches, creeks and immature rivers.

2. In proximal deposits, fractured bedrock and false bottoms, such as clay seams, may play an important role in the concentration of gold.

3. Placer deposits that are distal to a lode gold source generally contain fine grained gold that is finely disseminated to lensoidal throughout the sedimentary column. In the distal deposits, gold can also be concentrated at bedrock. Examples of this type of environment include mature river systems, flood plains, deltas and beaches.

4. Gold in placer deposits is generally finer in value (higher in actual gold content) than the lode source, and exhibits an increase in fineness with distance from the source.

5. The gravel or conglomerate that hosts placer gold is usually relatively clean and quartz rich.

6. Periodic uplift or subsidence can result in terraced paleoplacer deposits, as well as the reworking and further reconcentration of gold into higher grade paystreaks in the present day watercourses.

7. Based on the environment of deposition, a variety of sedimentological conditions are important for the concentration of gold:

   (a) In a gulch or creek setting, gold exists in regular paystreaks that are laterally consistent and are on or near bedrock. The host alluvium is generally thin, with the gravelly sediments being poorly sorted and crudely to distinctly stratified.

   (b) In a mature river or fan delta environment, gold may accumulate in many sedimentological facies but its occurrence is often sporadic and discontinuous. In meandering rivers, gold may concentrate in main channel deposits such as dunes or lag deposits, or in point bar deposits on the inside curve of river meanders. In a braided river, gold may concentrate in a number of areas including channel junctions, channel bends, bank-hugging bars, sluiceways between restricted stable banks and any other areas where stream flow is convergent.

8. The heavy mineral suite that accompanies gold in alluvial placers is dependant upon the stable heavy mineral assemblage in the surrounding country rocks and the heavy minerals associated with gold in the source area. Magnetite and ilmenite are the most common associated heavy minerals, but these may be accompanied by monazite, pyrite, arsenopyrite, cassiterite, wolframite, scheelite, cinnabar, native bismuth, bismuthinite, galena, sulphosalts, platinoids, tourmaline, garnet, chromite, rutile, barite, corundum, zircon, hematite, wad and limonite.

2.1 Mississippi Valley Type Lead-Zinc

Commodity

Pb-Zn ± F, Ba

Tectonic Framework

Mississippi Valley type deposits occur in marine platform carbonate rocks in orogenically inactive tectonic settings. As in the formation of petroleum and natural gas, the formation of Mississippi Valley type deposits is now regarded as being part of the normal evolution of sedimentary basins.

Mississippi Valley type lead-zinc deposits exist in platformal carbonates in relatively undisturbed basins and in foreland fold and thrust belts. Even though this type of deposit forms in a relatively inactive tectonic setting, the deposits are often spatially associated with basin margins or hinge lines of regional arches.

The host rocks for Mississippi Valley type deposits range in age from Proterozoic to Cretaceous, however Cambrian-Ordovician and Carboniferous carbonates are the dominant host rocks world wide. There is little consensus as to the age of the deposits relative to deposition of the host sediments and lithification processes.

Regional Characteristics

There are many regional characteristics that are recognized as important for Mississippi Valley type deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Transition from platform carbonates to basinal shales at the margins of basins.

2. High porosity and permeability in the host rocks created as a result of karstification, fracturing or faulting.

3. The presence of carbonate reef masses or biostromal carbonates.

4. Regional alteration such as dolomitization or silicification.

5. An association with hydrocarbons, especially petroleum.

6. Mississippi Valley type deposits tend to occur in districts which may be distributed over hundreds of square kilometres.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Mississippi Valley type deposits are often characterized by the following:

1. The sulphide zone is generally stratabound on a district scale, but is usually irregular in shape and is discordant with the enclosing host rocks on a deposit scale.

2. Sulphides typically exist as open-space filling of pre-existing cavities in brecciated dolomite and exhibit colloform texture. Massive to disseminated coarsely crystalline aggregates are also common.

3. Pyrite, sphalerite, galena and dolomite are the principal minerals. Lesser amounts of marcasite, calcite, quartz, barite, fluorite and chalcopyrite may be present.

4. Mineral zonation is common, but is variable from deposit to deposit and from district to district.

5. Organic material such as kerogen or bitumen is common in the host rocks and, locally, within some deposits.

6. Sulphide deposition is often accompanied by widespread dolomitization of the carbonate host rocks, and to a lesser degree by silicification. Secondary K-feldspar and K-mica may be present in some deposits.

7. Geochemical aureoles that often envelope Mississippi Valley type deposits include increased Mg, F, Ba and K. Typically, such aureoles are of limited extent beyond the deposit margins.

8. The host carbonates are generally unmetamorphosed.

2.2 Sediment Hosted Stratiform Lead-Zinc

Type and Commodity

2.2a Shale or turbidite hosted Pb-Zn ± Ag, Ba, Cu
2.2b Sandstone hosted Pb-Zn

Tectonic Framework

Sediment hosted stratiform lead-zinc deposits occur in two distinct tectonic settings: deep marine clastic sedimentary rocks (commonly referred to as Sedex deposits), and epicontinental to shallow marine clastic sedimentary rocks. Sediment hosted lead-zinc deposits commonly have a spatial or temporal association with growth faults, reactivated basement faults, marine or continental rifts.

Volumetrically the most important type of sediment hosted stratiform lead-zinc deposits are the Sedex type. These deposits are most commonly hosted in marine shales or turbidites characteristic of deep water marine basins or continental shelves. The sulphide zone in Sedex deposits is commonly overlain by or passes laterally into chemical sediments. In addition, minor amounts of tuffaceous volcanic rocks are sometimes present.

The sandstone hosted lead-zinc deposits are important in some parts of the world, but are minor volumetrically in comparison to the Sedex deposits. The sandstone hosted deposits typically are hosted in clean basal quartzitic or quartzo-feldspathic sandstones characteristic of shallow intracratonic basins or transgressive marine sequences. Sialic basement and evaporites are often spatially associated with this type of deposit.

The host rocks for sediment hosted stratiform lead-zinc deposits range in age from early Proterozoic to Cretaceous. The age of the lead-zinc deposits is generally postulated as the same or slightly younger than the host rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for sediment hosted stratiform lead-zinc deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics for the Sedex deposits include:

1. Cratonic rifts with characteristic syndepositional block faults or growth faults and, in some cases, thin horizons of rift associated volcanics such as tuffs and flows.

2. Second order basins within large sediment- and oxygen-starved marine basins.

3. Within the second order basins anomalously thick sequences of marine sediments that may or may not be fault bounded.

4. Rapid lateral facies changes in clastic rocks that may indicate rift related faulting during sedimentation.

5. Associated conglomerates, debris flows, fault scarp talus, slump and slide breccias deposited during synsedimentary rifting.

6. The presence of chemical sediments such as chert, baritite and sediments enriched in manganese and iron.

7. Sediment hosted stratiform lead-zinc deposits tend to occur in trends in certain favourable stratigraphic horizons.

Some of the important regional characteristics for the sandstone hosted lead-zinc deposits include:

1. Transgressive basal sandstones and conglomerates within an intracratonic rift basin that is tectonically stable over long periods.
2. Vertical to subvertical faults in either the basement below the basal sandstone or cutting across the unconformity into the basal sandstone.
3. Deeply weathered sialic basement formed in low paleolatitudes, sometimes with elevated lead or zinc concentrations.
4. The presence of a suitable host rock and cap rock such as a clean quartzitic sandstone that is capped by an impermeable unit, such as shale or argillite.
5. The presence of evaporites and conglomerates in the stratigraphic section.
6. The presence of local basement lows and highs.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Sediment hosted stratiform Sedex lead-zinc deposits are often characterized by the following:

1. The ore zone is generally stratiform and tabular to lenticular or blanket-shaped. In some cases it may be irregular in shape and crosscut several lithologies. Discordant stringer ore to breccia ore that represents "feeder zones" is present in some deposits. Volumetrically the feeder zones are small relative to the stratiform zones.
2. Typically the mineralized beds that comprise a deposit have a lateral extent that is tens to hundreds of times greater than the thickness.
3. Principal ore minerals include galena and sphalerite, with varying amounts of barite, and minor amounts of chalcopyrite and sulphosalts. Pyrite, marcasite and pyrrhotite are abundant in many deposits. Other gangue minerals that may be present include quartz, carbonates and tourmaline. The sulphides generally are bedded in layers ranging from microns to centimetres in thickness. Individual sulphide beds are often monomineralic.
4. Most sediment hosted stratiform lead-zinc deposits exhibit either lateral or vertical zoning.

    (a) The galena/sphalerite ratio decreases away from the feeder zone. Iron sulphides and oxides generally increase in abundance away form the galena-sphalerite core, but can be abundant within the core. Barite is most abundant peripheral to the sulphide zone. Chalcopyrite and sulphosalts are generally most abundant within the feeder zone or very near to it.

(b) The mineralogical zonation gives rise to a metal zonation with the highest Pb concentrations occurring proximal to the feeder zone. Zn increases in concentration away from the Pb rich core. Fe, Ba and Mn are most abundant at and away from the margins of the ore zone.

5. Major byproducts include Ag and Ba, with minor amounts of Cu, Cd and Sn.

6. Geochemical aureoles of Ba or Mn often envelope the stratiform sulphide ore zone.

7. The most visible alteration associated with stratiform Sedex lead-zinc deposits is often strong silicification in the feeder zone. The feeder zone may also exhibit strong tourmaline-chlorite alteration or carbonatization. Alteration zones peripheral to the main stratiform ore zone are usually restricted in size. Chemically precipitated sediments such as chert, baritite and iron-manganese enriched sediments are often distally associated with the stratiform ore zone and can be quite laterally extensive.

8. Where the sulphide zones are spatially and temporally associated with an extensional fault, they generally exist on the down thrown side of the fault.

The sandstone hosted lead-zinc deposits are often characterized by the following:

1. The ore zone is generally stratabound and lenticular in shape. In some cases it may be irregular in shape and crosscut lithologies. Sulphides are commonly remobilized into faults.

2. Principal ore minerals are usually galena and sphalerite with only minor amounts of chalcopyrite and sulphosalts. Pyrite, marcasite and pyrrhotite are present, but usually occur in minor amounts relative to the abundant iron sulphide content of the Sedex deposits. Other gangue minerals that may be present include quartz and carbonates, with minor amounts of barite and fluorite. The sulphides generally are disseminated homogeneously through the sandstone with some high grade zones concentrated along beds.

4. Most sandstone hosted lead-zinc deposits exhibit a vertical zoning.

(a) The galena/sphalerite ratio decreases upward from the base of the deposit.

(b) The mineralogical zonation gives rise to a metal zonation with the highest Pb concentrations occurring at the base of the deposits and Pb/Zn ratios that decrease upward from the base of the deposits.

5. Major byproducts include Ag and Cu, although in many cases the sandstone hosted deposits are devoid of these byproduct metals.

6. Geochemical and alteration aureoles are limited in their extent and importance in the sandstone hosted lead-zinc deposits.

2.3 Volcanogenic Massive Sulphides

Type and Commodity

2.3a Precambrian type Cu-Zn $\pm$ Ag, Au
2.3b Kuroko type Zn-Pb-Cu $\pm$ Ag, Au, Ba

Tectonic Framework

Volcanogenic massive sulphide deposits occur in marine volcanic rocks or associated marine sedimentary rocks, commonly close to plate margins. These include divergent plate margins, such as oceanic ridges or back-arc basins, or convergent margins including island arcs and continental margins.

The Precambrian copper-zinc type deposits are most commonly associated with tholeiitic or calcalkaline basalts and terrigenous clastic rocks characteristic of divergent plate margins. Kuroko polymetallic zinc-lead-copper type deposits most commonly occur in rocks interpreted to represent island arc related rifts. Island arc volcanism is typically bimodal, calcalkaline, and includes high alumina basalt, andesite, dacite and rhyolite. The massive sulphide lenses in this type of setting often occur at transitions from calcalkaline basalt to the more felsic volcanic rocks.

Volcanogenic massive sulphide deposits range in age from Archean to recent. The copper-zinc type deposits are the most common and volumetrically the most important type of volcanogenic massive sulphides in Archean or early Proterozoic shield rocks. There are some copper-zinc deposits in Phanerozoic rocks, but their distribution and total volume is minor in comparison to Kuroko type zinc-lead-copper deposits, which are more abundant in Phanerozoic rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for volcanogenic massive sulphide deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Major synvolcanic extension faults along which volcanic centres formed. These faults are often reactivated as thrust faults or shear zones during accretion, burial and uplift.

2. Transitions from mafic to felsic volcanic successions.

3. Interfingering of volcanic and sedimentary rocks.

4. Features indicative of volcanic venting, including laterally coarsening volcanic fragmental rocks, volcanic breccias, debris flows within the volcanic and/or sedimentary succession, and abrupt thickening of the volcanic pile.

5. The presence of exhalative horizons rich in iron bearing sulphide, oxide, carbonate or silicate minerals. Other important rock types that may be present include pyritic cherts and shales, carbonaceous or graphitic shales, barite rich horizons and sulphate rich horizons.

6. Discordant sulphide-bearing stringer zones or metasomatic alteration zones characterized by either increased or decreased amounts of one or more of Mg, Si, K, Ca or Na.

7. The presence of hypabyssal intrusions.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Volcanogenic massive sulphide deposits are often characterized by the following:

1. Either a concordant stratabound massive ore or a stringer discordant ore or both may be present.

2. The stratabound sulphide zone may extend laterally for a few hundred metres, or be up to as large as 1 km by 2 km or more. The sulphide zone may be up to 20 m or more thick. The zone may grade laterally and vertically from massive sulphide to disseminated sulphide rich volcanic or sedimentary rocks.

3. The stringer ore zone generally is irregularly cylindrical or funnel-shaped in undeformed deposits. The stratabound massive sulphide ore occurs at the top of the stringer ore zone, at or near the widest part of the stringer zone.

4. Pyrite, pyrrhotite or other iron sulphides or oxides typically are the most abundant metallic minerals in the deposits. Chalcopyrite, sphalerite and galena in varying proportions constitute most of the remaining sulphides. In some deposits, barite and sulphate minerals occur in horizons laterally adjacent to the sulphide deposits.

5. Most volcanogenic massive sulphide deposits show some form of zoning.

   (a) Pyrite, sphalerite and galena are generally more abundant in the upper portions of the massive sulphide lens, with pyrrhotite and chalcopyrite more abundant in the lower portions and in the stringer zone. Sphalerite and galena are also more abundant in the thinner and more laminated distal portions of the massive sulphide lens. These distal, metal rich portions often grade laterally into barite, anhydrite or chert rich beds.

   (b) The mineral zonation gives rise to a metal zonation with Zn to Cu and Pb to Cu ratios increasing stratigraphically upwards and towards the margins of the massive sulphide lens. Precious metal concentrations are variable; enrichment of Au and Ag may occur in the Cu rich stringer zone or in the upper and distal Zn-Pb rich portions of the deposit.

6. Major byproducts are Au, Ag and Cd, with lesser amounts of Se, Bi, Sn and Co.

7. The alteration zones associated with volcanogenic massive sulphide deposits are often larger than the deposits themselves. Chlorite, chlorite-quartz and sericite-quartz are the most common alteration types. Other types of alteration that may be important include carbonate, epidote and magnetite.

8. Geochemical aureoles that often envelope volcanogenic massive sulphide deposits include increased Mg, Ba, As and Sb.

9. The metamorphic and structural setting of the deposits ranges from weakly metamorphosed and deformed, to strongly metamorphosed and deformed.

2.4 Sediment Hosted Stratiform Copper

Commodity

2.4a Kupferschiefer type Cu ± Ag
2.4b Kipushi type Cu ± Pb, Zn, Co, Ge, Ga, Ag

Tectonic Framework

Sediment hosted stratiform copper deposits most commonly occur in shallow marine or epicontinental sedimentary rocks and are referred to as Kupferschiefer type copper deposits. Some sediment hosted stratiform copper deposits are found in continental margin carbonates or intracratonic basin carbonates. These deposits are referred to as Kipushi type copper deposits and are much less common then the Kupferschiefer type copper deposits or other common carbonate hosted deposits, such as Mississippi Valley type lead-zinc deposits. Sediment hosted stratiform copper deposits commonly have a spatial or temporal association with continental or passive margin rifts, grabens or aulocogens.

Kupferschiefer type copper deposits are most commonly hosted in carbonaceous shales, mudstones and siltstones characteristic of shallow intracratonic basins on a continental shelf or within a craton. Typically, hematitic sediments (red beds), evaporites and, to a lesser degree, rift generated mafic volcanics are spatially associated with this type of deposit. Kipushi type copper deposits are most commonly hosted in dolomites formed along continental margin platforms or within deeper portions of intracratonic basins. Mafic volcanic rocks are usually associated with this type of deposit.

The sedimentary host rocks for stratiform copper deposits range in age from early Proterozoic to Tertiary. The age of the copper deposits is generally postulated to be the same or slightly younger than the host rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for sediment hosted stratiform copper deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. A rift basin with characteristic extensional block faults and, in many cases, rift generated mafic volcanics such as basalts.

2. Rapid lateral facies changes in the clastic rocks may indicate ongoing rift-related faulting during sedimentation.

3. The presence of local basement highs.

4. A potential source of copper such as highly weathered granitic basement, copper enriched basalts extruded during rifting or sedimentary rocks derived from these sources.

5. Sediment hosted stratiform copper deposits tend to occur in districts located along rift trends.

Some of the regional characteristics that may not be important for Kipushi type copper deposits but are recognized as important for Kupferschiefer type copper deposits include:

1. Associated sandstones, siltstones, silty limestones and, locally, conglomerates deposited in an arid environment that are coloured red by the presence of hematite.

2. The presence of evaporites in the stratigraphic section.

3. A potential host rock within the clastic sequence that is reducing in nature due to either the presence of organic matter, methane, graphite or sulphides.

Some of the regional characteristics that may not be important for Kupferschiefer type copper deposits but are recognized as important for the Kipushi type copper deposits include:

1. High porosity and permeability in the host rocks due to karsting or brecciation, possibly, associated with rift related or transcurrent faults.

2. Regional transitions from platform carbonates to basinal shales.

3. Stromatolite or reef complexes within carbonates.

4. Dolomitization fronts within limestone.

5. Shale or other types of impermeable units within the carbonate sequence in order to trap or focus fluid flow.

6. An association with hydrocarbons.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Kupferschiefer type copper deposits are often characterized by the following:

1. The ore zone is usually hosted in fine grained clastic rocks and is generally stratiform and tabular or blanket-shaped. In some cases the ore zone may be irregular in shape and crosscut several lithologies.

2. Typically the mineralized beds have a lateral extent of several kilometres, with thicknesses ranging from 0.5 m to 30 m.

3. Principal ore minerals include chalcopyrite, bornite, chalcocite and native copper, with minor amounts of galena, sphalerite and carrollite. Pyrite is often abundant. The sulphides generally exist as fine grained disseminations or in veinlets that range in attitude from bedding parallel to vertical.

4. Most Kupferschiefer type copper deposits exhibit either lateral or vertical zoning, or both.

    (a) Upward and/or outward from the base of the ore zone are hematite, native copper, chalcocite, bornite, chalcopyrite, galena, sphalerite and pyrite.

(b) The mineralogical zonation gives rise to a metal zonation with the highest Cu concentrations occurring proximal to the base of the ore zone. Pb and Zn increase in concentration towards the margins of the ore zone.

5. Major byproducts include Ag, Co, Pb and Zn.

6. The most visible alteration associated with Kupferschiefer type copper deposits is the strong hematitic zone that is usually present at the base of the deposits. This zone is often called "Rote Faule". The highest concentrations of metals generally occur adjacent to the hematitic zone.
Kipushi type copper deposits are often characterized by the following:

1. The ore zone is generally hosted in karsted or brecciated dolomite and is controlled by associated faults. In some cases, the ore zone is comprised of stockwork veins and associated mineralization, or is stratiform, however, the ore zone is usually structurally controlled.

2. Much open space exists in the ore, and sulphides often exhibit colloform textures with rosettes and blades common.

3. Principal ore minerals include bornite, chalcocite, chalcopyrite, carrollite, sphalerite, galena and tennantite, with minor amounts of Co-pyrite, germanite, renierite, gallite, tungstenite, molybdenite and native bismuth. Gangue minerals include pyrite, arsenopyrite, marcasite, dolomite, barite, siderite, quartz and bituminous matter.

4. Surficial supergene caps include malachite, azurite, covellite, digenite, black Co-oxides, pink Co-arsenates, Ge-Ga iron oxides and jarosite.

5. Most Kipushi type copper deposits exhibit a lateral or vertical zoning similar to that of Kupferschiefer type deposits.

   (a) The core of the ore zone is characterized by chalcocite, bornite and chalcopyrite, with increasing galena, sphalerite and pyrite towards the margins.

   (b) The mineralogical zonation gives rise to a metal zonation with the highest Cu concentrations occurring proximal to the core of the ore zone. Pb, Zn and Fe increase in concentration towards the margins of the ore zone.

6. Kipushi type copper deposits exhibit a strong and varied geochemical signature with elements such as Cu, Zn, Pb, As, Co, Ag, Ge, Ga, Ba, Mo, W, Sn, Bi, U and V. Overall these deposit have high Co/Ni, As/Sb and Ag/Au ratios.

7. Alteration accompanying Kipushi type deposits includes dolomitization, siderization and silicification. In some instances, early pyrite or arsenopyrite are recognized as replacement of marcasite.

2.5 Base Metal Skarns

Type and Commodity

2.5a	W ± Cu, Mo, Bi, Zn
2.5b	Cu ± W, Mo, Zn, Bi, Ag, Au
2.5c	Mo ± Cu, W, Bi
2.5d	Sn ± Mo, W
2.5e	Fe ± Cu, Zn, Co, Au
2.5f	Zn-Pb ± Ag, Cu

Tectonic Framework

Skarn deposits result from the hydrothermal interaction of hot silicate magmas and cooler sedimentary rocks. Skarns are monomineralic to polymineralic assemblages of silicates and sulphides that form during contact metamorphism and metasomatism associated with the emplacement of deep-seated to hypabyssal intrusions. They are an important source of base and precious metals. Skarns can be divided into seven distinct types based on the predominant metal: tungsten skarns, polymetallic copper or porphyry copper skarns, molybdenum skarns, tin skarns, iron skarns, zinc-lead skarns and gold skarns (discussed in 1.4). Each of these types of skarns has a unique geological setting, mineralogy and chemical signature.

The majority of base metals deposits in skarns are hosted in limestones or dolomites and are associated with calcic or magnesian skarnification processes. Typically, skarns form in accreted oceanic island arc terranes, accreted volcanic back-arc terranes and continental margin orogenic belts. Based on geological setting the tungsten, copper, molybdenum and tin skarns represent a continuum of deposits that form in continental margin orogenic belts during the evolution of plate collision and subduction. Iron skarns are related to more mafic intrusions in oceanic terranes. Zinc-lead skarns are often distal from their associated intrusions and are commonly structurally controlled.

Rocks that host base metal skarn deposits range in age from Precambrian to Pleistocene. The skarns and associated plutonic rocks span the same age interval, but the majority are Mesozoic or younger. The few important Paleozoic or older examples tend to be tungsten- or tin-rich skarns.

Regional Characteristics

There are many regional characteristics that are recognized as important for skarn deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics for tungsten, copper, molybdenum and tin skarns include:

1. Carbonate host rocks.

2. The intrusions can be mineralized or barren. However the presence of a metal-rich intrusive emplaced into carbonate rocks generally gives rise to a metal enriched skarn.

3. Continental margin orogenic belts. Tungsten and copper deposits are associated with syn-orogenic intrusions, whereas, the molybdenum and tin deposits are often associated with post-orogenic intrusions.

4. Extensional tectonic regimes that are superimposed over the continental orogenic belts are favourable for the emplacement of calcalkaline to felsic magmatic rocks.

5. Tungsten and copper are associated with calcalkaline granodiorite to quartz monzonite intrusions (I-type magmas). Tungsten deposits are associated with deep-seated batholiths, while copper is related to more felsic, porphyry-textured and hypabyssal intrusions.

6. Molybdenum and tin are associated with more evolved leucocratic granodiorite to granite intrusions (S-type magmas).

7. These metal deposits are often proximal to intrusion contacts, especially in the case of copper skarns.

Some of the important regional characteristics for iron skarns include:

1. Carbonate, and in some cases, andesitic volcanic host rocks.

2. Early orogenesis in a dominantly oceanic island arc setting with little interaction of continental crust. In this setting iron skarns are commonly associated with diorite intrusions in basaltic to andesitic volcanics interfingered with back arc marine sedimentary rocks.

3. Later orogenesis in a cordilleran type setting. Iron skarns in this setting are formed as a result of quartz monzonite to granodiorite intrusion into dolomites.

4. Rifted continental margins. Iron skarns in this setting are formed in association with diabase intrusion into carbonates.

Some of the important regional characteristics for zinc-lead skarns include:

1. Carbonate and clastic sedimentary host rocks. In many cases, structural or lithological contacts are the dominant control on formation of the skarn.

2. Continental margin orogenic belts.

3. In comparison to other skarn types, zinc-lead skarns tend to be distal to the associated intrusions. In some instances igneous rocks are not exposed or are several kilometres from the skarns.

4. Associated intrusions, which can form in a variety of geological settings, range in composition from granodiorite to leucogranite, with textures that range from holocrystalline in deep-seated batholiths to porphyritic in hypabyssal stocks and dikes.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Skarn deposits are often characterized by the following:

1. The ore zone is variable in shape and size.

2. The dominant alteration is characterized by metasomatic replacement of carbonate by Ca-Fe-Mg-Mn silicates.

   (a) Tungsten skarns: `Reduced' skarns are comprised of hedenbergite, almandine garnet, biotite and hornblende. `Oxidized' skarns include ferric iron assemblages with andradite garnet and epidote. Other minerals include actinolite and chlorite. Sulphides include scheelite, pyrrhotite, chalcopyrite, pyrite, sphalerite and various Bi and Pb sulphides. The presence of barren, iron-poor, calc-silicates beyond the iron-rich, scheelite-bearing skarn is characteristic of tungsten skarns.

   (b) Copper skarns: predominantly oxidized assemblage with andradite garnet, diopside, magnetite and hematite. High garnet to pyroxene ratios are typical. Sulphides include pyrite, chalcopyrite, bornite, tennantite, sphalerite, scheelite and molybdenite.

   (c) Molybdenum skarns: characterized by hedenbergite, grandite garnet with a pyralspite component and wollastonite. Retrograde epidote, actinolite, hornblende, fluorite and chlorite are locally abundant. Sulphides include molybdenite, scheelite, chalcopyrite and bismuthinite with minor sphalerite and galena.

   (d) Tin skarns: magnesian skarns characterized by early spinel, pyroxene (fassaite), forsterite and calcite, followed by intermediate stage of phlogopite, magnetite and magnesian borates. The latest stage minerals include cassiterite, fluoborate, magnetite and micas. The magnesian skarns are low in sulphides but do contain some pyrite, scheelite, molybdenite, chalcopyrite, sphalerite, galena and bismuthinite. The calcic skarns are comprised of early andradite garnet and wollastonite or an assemblage of idocrase, magnetite and fluorite with minor hedenbergite. The later stages of skarn development are characterized by malayaite, borosilicates, cassiterite, quartz, fluorite and calcite. The later stage is also accompanied by pyrrhotite, arsenopyrite, loellingite, sphalerite and bornite.

   (e) Iron skarns: calcic skarns characterized by an iron-rich calc-silicate gangue of epidote, grandite garnet and ferrosalite with retrograde actinolite and chlorite. The skarns are generally low in sulphide but do contain some pyrrhotite, arsenopyrite, chalcopyrite and sphalerite. Magnesian skarns are characterized by early diopside, spinel, forsterite and calcite, with later humite, borates, magnetite, phlogopite and serpentine. Minor sulphides include pyrrhotite, pyrite, chalcopyrite and sphalerite.

   (f) Zinc-lead skarns: characterized by high pyroxene to garnet ratios, early johannsenitic pyroxene, minor andradite garnet and late Mn-minerals such as bustamite, rhodonite, dannemorite and ilvaite. Abundant sulphide minerals are associated with pyroxene and consist of sphalerite, galena, pyrite and pyrrhotite.

3. Skarn alteration is staged and quite commonly overprinted.

   (a) Initial isochemical contact metamorphism in the surrounding rock units accompanies magma emplacement. Slow-cooling deep-seated magmas tend to have widespread low grade contact metamorphic effects versus high level fast cooling stocks.

(b) Metasomatic skarn formation and initial ore formation accompany cooling and crystallization of the intrusive.

(c) Retrograde alteration and continued ore deposition accompany final cooling of the system.

Mineral zoning patterns of each successive stage commonly crosscut earlier patterns. Metasomatic minerals commonly occur as overgrowths and veinlets in the metamorphic mineral assemblage. The monomineralic metamorphic aureoles breakdown to polymineralic mixtures during retrograde alteration.

4. Broad geochemical correlations exist between the metal contents of skarns and their associated igneous and tectonic setting. Mafic igneous rocks in an oceanic island arc setting produce Fe skarns with significant Cu, Co, Zn and Au. Intermediate to silicic calc-alkaline magmas of early formed continental margins produce W and minor Zn skarns in the mesabyssal environment, and Fe, Cu, Mo and Zn-Pb skarns in the hypabyssal environment. More evolved granitic magmas of late- or post-orogenic continental margin belts produce Sn, W, Mo, Zn, Be, B and F skarns.

2.6 Olympic Dam Type Copper-Uranium-Gold-Silver

Commodity

Cu-U-Au-Ag ± Co, REE's

Tectonic Framework

The Olympic Dam copper-uranium-gold-silver deposit in South Australia exists in a unique geological setting. However, because it is a recent discovery with some controversy as to its origin and it is not exposed at surface, little is known about the tectonic and regional characteristics that were important in its formation.

Originally, it was thought that the Olympic Dam deposit was a sedimentary breccia hosted copper-uranium-gold-silver deposit. Recent work has indicated that the Olympic Dam deposit is hosted in dyke-like bodies of hydrothermal hematite breccias within an early Proterozoic alkalic granite. Researchers have noted similarities between Olympic Dam and the controversial iron deposits of Kiruna, Sweden and southeast Missouri.

The alkalic granite that hosts the Olympic Dam deposit is middle Proterozoic in age and is intruded into early to middle Proterozoic igneous and metamorphic basement rocks. The Olympic Dam deposit is postulated to be slightly younger than the enclosing granitic rocks.

Regional Characteristics

There are several regional characteristics that have been recognized as empirically important for the Olympic Dam copper-uranium-gold-silver deposit. However, the genetic importance of these characteristics is still being assessed. Some of the regional characteristics include:

1. Marginal Proterozoic terranes accreted to Archean cratons. Within the Proterozoic terranes, middle Proterozoic alkalic granitization of either basement rocks, overlying sedimentary rocks or both.

2. Extensional basins with graben faults, collapse structures, volcanism and dyke emplacement.

3. The faults and collapse structures may form regional fault lineaments in the basement rocks or in overlying sedimentary and volcanic rocks.

4. Proterozoic unconformities above hematized alkalic granitic basement rocks.

5. Hematized and baritic sedimentary or volcanic rocks in the vicinity of alkalic granitic basement rocks.

6. Hematite breccias in Proterozoic granites.

Deposit Characteristics

On a deposit scale there are many distinctive features of the Olympic Dam copper-uranium-gold-silver deposit. The deposit is characterized by the following:

1. Ore is in the form of steeply dipping, elongated, pod-like dykes of hematitic breccias

in clusters within a fractured granitic host. The central core of the deposit is a hematite-quartz breccia complex that forms a lensoidal shape about 5 km in strike length and about 2.5 km in width at the widest point. The deposit extends to at least 1 km depth below a middle to late Proterozoic unconformity.

2. Layered hematitic and baritic sedimentary and volcaniclastic rocks are present in the upper portions of the breccia zones.

3. Principal ore minerals are chalcopyrite, bornite, chalcocite and uraninite with lesser amounts of native silver, native gold, coffinite and brannerite. Minor amounts of covellite, digenite, carrollite, cobaltite, native copper and uranium bearing britholite are also present. Gangue minerals include hematite, pyrite, fluorite, quartz, sericite, the rare earth minerals bastnaesite and florencite, and lesser amounts of siderite, barite, chlorite, rutile, monazite and xenotime.

4. Sulphides and metals are zoned on both the scale of the deposit and on the scale of individual breccia bodies.

   (a) The deposit and individual breccia bodies are characterized by a hematite core with minor amounts of chalcocite-bornite. Sulphides are zoned outward from the barren core through zones of chalcocite-bornite, bornite-chalcopyrite and chalcopyrite-pyrite. Immediately below the unconformity is a barren zone that is underlain by a strong chalcocite rich zone that may be the result of supergene enrichment. Uranium and rare earth minerals exist in all sulphide rich zones. Gold and silver exist in all sulphide rich zones, but gold is slightly more enriched in areas of chalcocite-bornite, and silver is slightly more enriched in areas of bornite mineralization.

   (b) The sulphide zonation gives rise to a copper zonation that consists of low copper in the hematitic cores, high copper in the chalcocite-bornite zone and decreasing copper values from the chalcocite-bornite zone through the bornite-chalcopyrite zone, chalcopyrite-pyrite zone, and into fractured and veined granite with sporadic sulphides. The near surface chalcocite rich zone immediately below the barren zone at the unconformity has some of the highest copper grades in the deposit. Uranium and rare earth element (REE) enrichment can occur without associated high copper, but high copper concentrations are almost always accompanied by high uranium and REE's.

5. Major byproducts include Co and REE's.

6. Hematization and sericitization are the dominant alteration types within the ore zone and up to 1 km distant from the deposit in weakly fractured granite. Other important types of alteration include chloritization, silicification and carbonatization.

7. In the deposit the predominant geochemical signature is Fe, Cu, U, Ni, Co, Au, Ag, light REE's, F and Ba. Peripheral to the deposit any number of these elements can be present in fractured to brecciated, veined and altered granite. Weakly altered granite that is distal to the deposit is enriched in Fe and REE's. Within the upper portions of the breccia complex are sedimentary rocks enriched in Fe, Ba, F, Sn, W, Th and Y. This enrichment may have been the result of hydrothermal fluids venting at the paleosurface.

2.7 Shale Hosted Stratiform Nickel-Zinc

Commodity

Ni-Zn ± Mo, PGE's, Au

Tectonic Framework

Shale hosted stratiform nickel-zinc deposits occur in Late Precambrian to Phanerozoic black shales that exist at transitions between platform shelf carbonates and deeper marine clastic sedimentary rocks. The deposits commonly have a spatial or temporal association with growth faults or reactivated basement faults.

Volumetrically, shale hosted nickel-zinc deposits are currently a minor world resource and are being actively mined in China only (Ni-Zn-Mo). The fact that they are a minor world resource may be a function of a lack of knowledge and exploration. These deposits are most commonly hosted in black marine shales at transitions from shelf carbonates to deeper water shale-turbidite successions.

The host rock shales for stratiform nickel-zinc deposits range in age from late Proterozoic to Phanerozoic. The age of the nickel-zinc deposits is generally unknown, but is postulated to be the same or slightly younger than the host rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for shale hosted stratiform nickel-zinc deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Black shales at the transition from platform shelf carbonates to deeper water shale-turbidite sequences.

2. Shelf carbonates beneath black shales with carbonate concretions and phosphorite deposits.

3. Deep basement fractures or faults.

4. Continental margin rifting characterized by normal graben faults.

5. Rapid lateral facies changes in clastic rocks in the vicinity of black shales that may indicate rift related faulting during sedimentation.

6. Associated conglomerates, debris flows, fault scarp talus, slump and slide breccias deposited during synsedimentary rifting.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Shale hosted stratiform nickel-zinc deposits are often characterized by the following:

1. The ore zone is generally stratiform and lenticular to blanket-shaped.

2. Typically the mineralized beds that comprise a deposit have a lateral extent that is hundreds to thousands of times greater than the thickness.

3. The ore zone is typically comprised of massive sulphide with the principal ore minerals being vaesite, sphalerite, wurtzite and jordisite. The gangue minerals are dominantly pyrite, sulpharsenides and a phosphatic-carbonaceous chert. Amorphous silica, bitumen and barite may also be present.

4. Little alteration accompanies the ore zone. However, faults and fractures in the vicinity of the ore zone often contain bitumen veins, and brecciated and silicified shale with a similar chemical signature to the nickel-zinc deposits.

5. Major byproducts include Mo, PGE's and Au.

6. Associated trace elements consist of As, Se, Ba, U, Re and P.

2.8 Magmatic Nickel-Copper

Type and Commodity

2.8a Komatiite Ni-Cu ± Co, Pt, Pd, Rh, Ru,
2.8b Flood basalt Ni-Cu ± Co, Pt, Pd, Rh, Ru, Au
2.8c Layered intrusions Ni-Cu ± Co, Pt, Pd, Rh, Ru, Au

Tectonic Framework

Magmatic nickel-copper deposits occur in mafic to ultramafic extrusive to intrusive volcanic rocks in a variety of tectonic settings. These include intercratonic to marginal cratonic volcanic belts, stable cratons and intracontinental rift zones.

Magmatic nickel-copper deposits are formed when a magma becomes saturated with sulphur and forms an immiscible liquid that is rich in chalcophile elements. The deposits form near the base of komatiitic to tholeiitic flows and hypabyssal intrusions in greenstone belts, near or at the base of large layered intrusions in stable cratonic areas, and in or near feeder zones to large masses of flood plain basalts that are associated with intracontinental rift zones.

Magmatic nickel-copper deposits and their mafic to ultramafic host rocks range in age from Archean to Phanerozoic. However, most of the nickel and copper production has come from Archean to middle Proterozoic mafic to ultramafic rocks. Significant magmatic nickel-copper deposits also exist in late Proterozoic and Triassic rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for magmatic nickel-copper deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics for komatiite nickel-copper deposits include:

1. Archean volcanic belts that exhibit cyclical sequences of ultramafic, mafic, intermediate and felsic volcanics.

2. The deposits are hosted in the basal parts of flows and hypabyssal intrusions generally associated with the lowermost ultramafic rocks in the succession.

3. Major synvolcanic extension faults along which volcanic feeder zones formed. These faults have often been reactivated as thrust faults or shear zones during accretion, burial and uplift.

4. Fault bounded footwall depressions.

5. Linear aeromagnetic or gravity anomalies that may represent major crustal lineaments.

6. Sulphide globules enclosed in silicates, and matrix sulphides molded around cumulate silicates and oxides.

7. Olivine low in nickel may indicate that nickel was partitioned off in a sulphur rich liquid.

8. In the case of Archean komatiitic deposits, those komatiites on the flanks of major

domal structures cored by granite and with MgO > 35 wt% are regarded as most favourable for Ni-Cu. In addition, the presence of spinifex texture and olivine-rich lavas are considered as favourable indicators.

9. Archean komatiitic deposits often exhibit a spatial relationship with iron formations and gold occurrences.

10. Proterozoic komatiitic deposits exist in greenstone volcanic belts, and in thick pelitic sequences deposited near active continental margins.

Many of the regional characteristics that are important for komatiite hosted nickel-copper deposits are also important for flood basalt hosted deposits. Some of the regional characteristics that are not important for komatiite hosted deposits, but may be important for flood basalt hosted deposits include:

1. Deep-rooted continental rift zones.

2. External source of sulphur. For example, anhydrites are often present in the intruded sedimentary package.

Many of the regional characteristics that are important for the komatiite and flood basalt hosted nickel-copper deposits are also important for layered intrusion hosted deposits. Some of the regional characteristics that are not important for either the komatiite or flood basalt hosted deposits, but may be important for layered intrusion hosted deposits include:

1. Large, well differentiated, layered intrusions in a cratonic setting.

2. Intrusions that are mostly mafic rather than ultramafic in composition. However, the mafic intrusions often have ultramafic xenoliths that are thought to represent the parent magma.

3. In some instances these intrusions are associated with flood basalts and intracontinental rift zones.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Magmatic nickel-copper deposits are often characterized by the following:

1. Concordant stratabound ore can occur as massive lenses, as interstitial sulphide matrix (intercumulus) to network, or as disseminated sulphide grains.

2. The sulphidic ore is usually localized in footwall depressions at or near the base of the most mafic or ultramafic portions of the magmatic complex. The footwall depressions are sometimes fault bounded.

3. Higher grade ore often has a morphology of ribbon-like shoots with dimensions such as a few hundreds of metres to 2.5 km in length, 50 to 400 m in width and thicknesses from 1 m to 20 m. Lower grade shoots often have similar length and width dimensions, but can have thicknesses of up to 1 km. Layered intrusions may have much thinner, but much more laterally extensive ore zones.

4. Principal ore minerals are chalcopyrite and pentlandite, with lesser amounts of millerite, cubanite, violarite, bornite and various platinum group element minerals

including sulphides, tellurides, arsenides and alloys. The principal gangue minerals are pyrrhotite, pyrite, magnetite, plagioclase, hypersthene, augite, olivine, chromite and lesser amounts of hornblende, biotite, chlorite, quartz, serpentine, sphalerite and marcasite.

5. Apart from Ni and Cu the major byproducts are Co, Pt, Pd, Rh, Ru and Au, with lesser amounts of Ag, Zn, Ir and Os. Komatiite associated ores are characterized by high Ni/Cu and low Pd/Ir ratios that distinguish them from most other magmatic sulphide ores. Flood basalt associated ore is sometimes characterized by a pronounced zonation with a high Cu/Ni ratio and high total Cu in massive ore at the base of the deposit and in fractures in the underlying bedrock in comparison to the overlying disseminated ore. In general, ore associated with ultramafic rocks has a higher Ni/Cu ratio than ore associated with mafic rocks. In addition, many deposits show a marked decrease in Cu, Ni (to a lesser extent), Pt, Pd and Au upward from the base of the massive ore. The reverse trend is often exhibited by Fe, Co, Rh, Ru, Ir and Os.

6. Alteration does not generally accompany primary sulphide mineralization. However, serpentinization or carbonatization of the ultramafic or mafic host rocks during metamorphism and deformation is common. Subsequent carbonatization, and to a lesser degree serpentinization, can upgrade the nickel and platinum group element content of a deposit.

7. Geochemical aureoles of elements similar to those present in the ore often envelope a deposit, however, the aureoles are usually of limited extent.

2.9 Sediment Hosted Oolitic Ironstone

Commodity

Fe

Tectonic Framework

Sediment hosted oolitic ironstone deposits are hosted in Phanerozoic shallow water clastic sequences. Oolitic ironstones are also known as Clinton-type or Minette-type iron formations and are one of three major classes of iron formations that include Archean Algoma-type iron formations and Proterozoic Lake Superior-type iron formations.

Oolitic ironstones are hosted in shallow water marine to epicontinental clastic rocks formed along passive continental margins or within intracratonic basins. The deposits are initially formed by the deposition of iron-rich sediments in neritic basins, lagoons or estuaries under conditions ranging from oxygenated to euxinic. The ironstones are often modified during diagenesis.

The host rocks for sediment hosted oolitic ironstones range in age from Paleozoic to Cenozoic. The oolitic ironstone deposits are syngenetic to diagenetic and are the same age to slightly younger than the host rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for sediment hosted oolitic ironstone deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Ironstone commonly exists at the top of regressive clastic cycles in shallow shelf to estuarine sedimentary sequences.
2. Standard vertical lithologic succession of basinal shale, followed by prodelta siltstone and sandstone, followed by shallow subtidal siltstone and sandstone, followed by oolitic ironstone.
3. A common association with phosphatic shales and sandstones, and ferruginous siltstones and sandstones.
4. In contrast to the Algoma-type and Lake Superior-type iron formations, the mineralogy of the oolitic ironstones does not seem to be dependant upon the environment of deposition and resultant sedimentary facies type.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Sediment hosted oolitic ironstone deposits are often characterized by the following:

1. Thin horizons that are stratiform, lenticular to blanket shaped and range from 1 m to 10 m thick.
2. The mineralized beds have a lateral extent that is tens to hundreds of times greater than the thickness.

3. Sedimentary features such as oolitic texture and herringbone cross stratification indicate that the ironstones are initially formed in an intertidal environment. Fossil debris in the deposits is common and the ironstones are usually interbedded with shallow marine shales, siltstones and sandstones.

4. The ore zone is typically a massive combination of iron oxides such as hematite and goethite, iron silicates such as berthierine and chamosite, and carbonates such as siderite. Gangue minerals include calcite, ankerite, pyrite and phosphatic clays or apatite.

5. Trace element or alteration aureoles are localized or non-existent.

2.10 Placer Magnetite

Commodity

Magnetite

Tectonic Framework

Historically, iron formations and magnetite skarn deposits have been the major supplier of world magnetite. Magnetite-rich placer deposits are common in many terranes, but rarely have they been mined solely for magnetite. Placer deposits result from the mechanical concentration of moderate to high density minerals. Similar to gold placer deposits, placer magnetite deposits form in several distinct geomorphological environments including gulches, creeks, alluvial fans, braided rivers, flood plains, fan deltas and beaches. Like gold, placer magnetite deposits form in a variety of tectonic settings including accreted mobile belts, marginal cratonic basins and intracratonic basins.

Placer magnetite deposits exist in a variety of complex sedimentary sequences depending upon the geomorphological environment, the local climate, the hydrodynamics of the alluvial system and the distance from the original bedrock source. On a deposit scale, there can be facies control of placer magnetite due to favourable sedimentological conditions in a specific geomorphological environment. However, facies control can vary unpredictably from one sedimentary environment to another no matter how similar the two environments might be.

Rocks that host placer magnetite deposits range in age from Proterozoic to Recent. Placer magnetite deposits and other associated heavy mineral deposits span the same age interval.

Regional Characteristics

There are many regional characteristics that are recognized as important for placer magnetite deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Occurrence of magnetite in the hinterland in either lode deposits or in elevated concentrations in bedrock.
2. A surface of submature to mature topography.
3. Relatively long periods of mechanical and chemical weathering resulting in highly weathered and well dissected terrain.
4. Periodic uplift and/or subsidence.
5. Absence of extensive glaciation.
6. Geomorphological and sedimentological features indicative of ancient or present day gulches, creeks, alluvial fans, braided rivers, flood plains, fan deltas and beaches.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Placer magnetite deposits are often characterized by the following:

1. Placer deposits proximal to a lode magnetite source generally contain coarse grained magnetite in seams, paystreaks or lenses in alluvium at or near bedrock. Examples of this type of environment may include gulches, creeks and immature rivers.

2. In proximal deposits, fractured bedrock and false bottoms, such as clay seams, may play an important role in the concentration of magnetite.

3. Placer deposits distal to a lode magnetite source generally contain fine grained magnetite that is finely disseminated to lensoidal throughout the sedimentary column. In the distal deposits, magnetite can also be concentrated at bedrock. Examples of this type of environment include mature river systems, flood plains, deltas and beaches.

4. The sand, gravel or conglomerate that hosts placer magnetite is usually relatively clean and quartz rich.

5. Periodic uplift or subsidence can result in terraced paleoplacer deposits, as well as cause reworking and further reconcentration of magnetite into higher grade paystreaks in the present day watercourses.

6. Based on the environment of deposition, a variety of sedimentological conditions are important for the concentration of magnetite;

   (a) In a gulch or creek setting, magnetite exists in regular paystreaks that are laterally consistent and are on or near bedrock. The host alluvium is generally thin, with the gravelly sediments being poorly sorted and crudely to distinctly stratified.

   (b) In a mature river or fan delta environment, magnetite may accumulate in many sedimentological facies but its occurrence is often sporadic and discontinuous. In meandering rivers, magnetite may concentrate in main channel deposits such as dunes or lag deposits, or in point bar deposits on the inside curve of river meanders. In a braided river, magnetite may concentrate in a number of areas including channel junctions, channel bends, bank-hugging bars, sluiceways between restricted stable banks and any other areas where stream flow is convergent.

7. The heavy mineral suite accompanying magnetite in alluvial placers is dependant upon the stable heavy mineral assemblage in the surrounding country rocks and the heavy minerals associated with magnetite in the source area. Ilmenite is the most common associated heavy mineral, but it may be accompanied by monazite, gold, pyrite, arsenopyrite, cassiterite, wolframite, scheelite, cinnabar, native bismuth, bismuthinite, galena, sulphosalts, platinoids, tourmaline, garnet, chromite, rutile, barite, corundum, zircon, hematite, wad and limonite.

3.1 Unconformity Associated Uranium

Type and Commodity

3.1a Precambrian conglomerate hosted U-Au
3.1b Helikian sandstone hosted U

Tectonic Framework

Unconformity associated uranium deposits occur in two distinct tectonic and temporal settings. Precambrian conglomerates that host uranium ± gold are part of a fluvial succession in intracratonic basins or in proximal parts of marginal cratonic basins. These deposits were formed during Archean to early Aphebian, prior to evolution of the earth's atmosphere from low oxygen to high oxygen. Helikian sandstones that host uranium exist in intracratonic or marginal cratonic sedimentary successions unconformably above intensely deformed basement rocks. The basement rocks below the Helikian sandstones often host uranium deposits as well.

Precambrian conglomerate hosted uranium ± gold deposits are interpreted to be paleoplacer accumulations prior to the development of a high oxygen atmosphere. These deposits are generally hosted in quartz pebble conglomerates or quartz arenites that rest on Archean basement. The host sedimentary successions lack redbeds and iron formations, except in considerably younger overlying sediments.

Helikian sandstone hosted uranium deposits are interpreted to be epigenetic and are hosted in a variety of rock types at or near the unconformity between undeformed Helikian sedimentary rocks and Archean or Aphebian basement rocks. The deposits are hosted in one or both of overlying altered fluvial or shallow marine quartzose sandstones, or in the underlying basement rocks. In a few instances, uranium accumulations also exist in altered shales.

Regional Characteristics

There are many regional characteristics that are recognized as important for unconformity associated uranium deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics for the Precambrian conglomerate hosted deposits include:

1. Continental basins or proximal marginal continental basins with extensional block faults or faults related to uplift.

2. Favourable sedimentary environment for heavy mineral accumulations. Examples might be facies representing high energy fluvial processes in mature braided stream and deltaic sedimentary environments.

3. Rapid lateral facies changes in the clastic rocks may indicate uplift and faulting during sedimentation.

4. The presence of carbon- or hydrocarbon-rich seams within the sedimentary succession.

5. Basement paleotopographic highs that influence the sedimentology of the fluvial systems deposited in the vicinity.

6. Accumulations of other detrital heavy minerals such as sulphides, certain oxides and, in a few places, diamonds.

7. A potential source of uranium such as highly weathered granitic basement in the hinterland.

Some of the important regional characteristics for the Proterozoic sandstone hosted deposits include:

1. Continental basins with intersecting faults in the basement rocks that may or may not be reactivated after deposition of the sandstones.

2. Episodes of uplift and/or continental rifting may be important.

3. Whether the deposits are hosted in sandstone above the unconformity or in the underlying basement rocks they usually are within 200 m of the unconformity.

4. The deposits are often spatially associated with graphitic schists or dolomitic marbles in the basement rocks or graphitic shales above the unconformity.

5. Hematitic or limonitic sandstones are considered favourable hosts for the deposition of uranium.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Precambrian conglomerate hosted uranium-gold deposits are often characterized by the following:

1. The ore zone is generally stratiform with multiple lenses that are ribbon- or fan-shaped in plan. The distribution is consistent with a placer setting in that grains of uraninite $\pm$ gold exhibit an increase in sorting and roundness, and decrease in size with distance from the source.

2. Continuity, lateral extent and thickness of these deposits are variable.

3. Principal ore minerals include uraninite, brannerite and native gold, with minor amounts of uranothorite and uranoan monazite. Other important minerals that might be present include platinum group minerals and diamonds. Major gangue minerals are quartz pebbles and pyrite, with interstitial minerals such as feldspars, micas, monazite, zircon and rutile.

4. Conglomerate hosted uranium-gold deposits often exhibit a systematic downstream decrease in the U/Th ratio, which is consistent with a fluvial paleoplacer environment.

5. Major byproducts include diamonds and platinum group elements.

6. Little alteration is exhibited by this type of deposit.

7. Metamorphism and deformation are generally minor.

Proterozoic sandstone hosted uranium deposits are often characterized by the following:

1. The ore zone varies from being broadly stratabound within the sandstones to being entirely discordant within the basement rocks. In some cases, the ore zone cuts the unconformity and is present in the basement rocks and the overlying sandstone.

2. Typically the ore zone varies from flattened and blanket-like to cigar shaped. The location and shape of the ore zones are generally structurally controlled in that they are spatially associated with intersecting basement faults, especially normal or reverse faults.

3. Principal ore minerals include pitchblende, coffinite and uraninite, with minor amounts of nickel and cobalt arsenides and sulphides, iron and base metal sulphides, selenium sulphides and native gold. Gangue minerals include kaolinite, illite, chlorite, quartz, graphite and carbonate.

4. Ore in these type of deposits usually consists of a high grade core that is disseminated to near massive and that grades outward into low grade stratiform disseminations with fracture fillings and veinlets. Brecciation of the host rocks and, in some cases, the ore is often prominent.

5. Mineralogical and chemical zonations exist in many of the deposits, however, syn- and post-ore diagenetic, metamorphic and supergene processes have often disturbed the original patterns.

6. Hydrocarbons are common in the ore zone.

7. Major byproducts include Ni and Co with minor amounts of Ag, Mo, Zn, Cu, Pb, Se, Bi and Au.

8. Extensive alteration halos usually envelope this type of deposit. The dominant types of alteration are chloritization and clay alteration comprised of kaolinite and illite. Other important types of alteration include carbonatization, silicification, sulphidization and tourmalinization.

9. These deposits are only weakly metamorphosed, but they often exhibit strong brittle deformation.

3.2 Sandstone Hosted Uranium

Type and Commodity

3.2a Roll front U
3.2b Tabular or Channel type U

Tectonic Framework

Sandstone hosted uranium deposits occur in a distinct tectonic, geological and chemical environment. The deposits are hosted in reduced continental fluvial sequences that are formed in intracratonic basins or proximal parts of marginal cratonic basins.

Sandstone hosted uranium deposits are generally formed in the near surface environment in coarse clastic fluvial sequences. Uranium is transported in oxygenated fluids and deposited closely associated with or during diagenesis. The transporting fluid is generally groundwater; however, in some of the tabular deposits, deeper circulating hydrothermal or diagenetic fluids are interpreted as the main transporting agent. The main differences between roll front uranium deposits and tabular or channel type uranium deposits are the morphology of the deposits and the interpreted origin of the mineralizing fluids.

Most of the economic sandstone hosted uranium deposits and their associated host rocks are Carboniferous or younger. A few deposits of this type exist in late Precambrian sedimentary successions.

Regional Characteristics

There are many regional characteristics that are recognized as important for sandstone hosted uranium deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Intracontinental basins or proximal continental margin basins with coarse fluvial clastic rocks. Stratigraphically or structurally juxtaposed mudstones and coarse fluvial clastic rocks is the favoured environment.

2. A potential source of uranium in uplands, such as highly weathered Archean granitic basement or felsic volcanic successions of continental margin magmatic arcs.

3. Fault bounded basins with normal block faults related to either intracratonic rifting or uplift in the uranium source areas.

4. Rapid lateral facies changes in the clastic rocks may indicate uplift and faulting during sedimentation.

5. Basement paleotopographic highs that influence the sedimentology of the fluvial systems deposited in the vicinity.

6. A permeable and reducing host rock. The presence of organic-rich seams, Fe-Ti oxides, magnetite and sulphides within coarse fluvial sandstones are all considered favourable.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Sandstone hosted uranium deposits are often characterized by the following:

1. (a) Roll front uranium deposits are usually crescent or irregular shaped. The ore zone is generally stratabound but at a high angle to bedding. The ore zone also exhibits a sharp interface between oxidized and leached sandstone with uranium concentrated at that interface.

   (b) Tabular or channel type uranium deposits are generally tabular, near flat-lying and stratiform. The ore zone is generally hosted in a strongly leached sandstone, but does not exhibit any sharp oxidation-reduction fronts as in the roll front deposits.

2. The dominant ore zone mineralogy is comprised of pitchblende, coffinite and uraninite with a gangue of marcasite, vanadium-rich minerals, quartz and calcite.

3. Alteration is generally localized to the ore zone and is characterized by intense leaching of the host rocks, with destruction of organics, pyrite, Fe-Ti oxides and magnetite.

4. Trace elements associated with these deposits consist of V, Mo and Se.

3.3 Vein Type Uranium

Type and Commodity

3.3a Classical vein U
3.3b Arsenide vein U-Ag ± Cu, Co, Ni

Tectonic Framework

Vein type uranium deposits occur in a variety of lithological and structural settings but display many mineralogical and geochemical similarities. Two end members of the vein type uranium deposits, classical vein uranium deposits and arsenide vein uranium-silver deposits, have distinct geological characteristics and tectonic settings.

Classical vein uranium deposits are characterized by simple vein mineralogy and are most common in highly deformed, high grade metamorphic terranes with abundant granitized metasedimentary and metavolcanic rocks. Arsenide vein uranium-silver deposits are characterized by complex vein mineralogy and are most common in much less deformed and metamorphosed volcanic and sedimentary terranes.

The host rocks for vein type uranium deposits range in age from Archean to Proterozoic. The uranium deposits span the same age interval, but they are epigenetic and are thought to have been formed either during or after peak metamorphism of the host rocks.

Regional Characteristics

There are many regional characteristics that are recognized as important for vein type uranium deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics for the classical vein uranium deposits include:

1. Strongly deformed, highly metamorphosed and highly granitized Archean or Proterozoic terrane, often widely retrograded to greenschist metamorphic facies.

2. The deposits are often hosted in second or third order fault structures that are splays or sympathetic faults to the major regional fault structures. Brecciated to strongly mylonitized host rocks are favoured.

3. Superimposed brittle-ductile to brittle faulting.

4. The deposits are often stratabound in nature due to a favourable chemical and/or structural host.

5. Large areas with intense alteration of hematite, chlorite and carbonate. This results in the presence of associated hematitic red coloured rocks.

6. Elevated background concentrations of uranium in metasedimentary, metavolcanic or granitic rocks, which might indicate a potential source rock or the occurrence of a regional mineralizing event.

Many of the regional characteristics that are important for the classical vein uranium deposits are also important for the arsenide vein deposits. Some of the regional characteristics that are not necessarily important for the classical vein uranium deposits, but may be important for arsenide vein deposits include:

1. Tensional faults that may be related to episodes of uplift and/or continental rifting.

2. The presence of mafic magmatism often in the form of diabase dykes and sills in swarms.

3. In contrast to the host rocks for most classical vein uranium deposits, intense deformation and high degrees of metamorphism in the host rocks for the arsenide vein deposits are not as common place.

4. Empirically, an association with unconformities between Archean and Aphebian or Aphebian and Helikian rocks is favourable.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Classical vein uranium deposits are often characterized by the following:

1. The ores zones are generally steeply dipping veins or tabular bodies with a much greater vertical extent than horizontal extent or thickness. Some ore exists as disseminations and fracture filling in altered bedrock adjacent to veins and faults.

2. The ore zone has often undergone significant remobilization, in many cases during more than one period.

3. Principal ore mineralogy of pitchblende, with minor amounts of brannerite, coffinite and nolanite. The dominant gangue minerals are hematite, chlorite, calcite, quartz, feldspar and pyrite with lesser chalcopyrite and galena.

4. There are no significant patterns of mineral or chemical zoning, other than an increase of brannerite with depth in most of the deposits.

5. Alteration is characterized by red hematitic alteration of the wallrocks accompanied by albitization, chloritization and carbonatization.

6. Trace elements associated with the ore include Cu, V, Se and Ti.

Arsenide vein uranium deposits exhibit many of the same characteristics that classical vein uranium deposits exhibit. Some of the differences that arsenide vein uranium deposits exhibit include:

1. A complex mineralogy that is comparable to the mineralogy of the Helikian sandstone hosted uranium deposits of the Athabasca basin.

2. Principal ore minerals include pitchblende, coffinite, native silver, acanthite, silver sulphosalts, nickel and cobalt arsenides, chalcopyrite and native gold. Other metallic minerals include pyrite, arsenopyrite, galena, bismuth, other arsenides and selenium sulphides. Gangue minerals include hematite, chlorite, kaolinite, quartz and carbonate.

3. Major byproducts include Ag, Cu, Ni and Co. Other trace elements include As, Pb, Se, Bi, V and Au.

4. Alteration is similar to that of the classical vein uranium deposits with the addition of sericitization.

3.4 Uranium Bearing Lignite

Type and Commodity

U

Tectonic Framework

Uranium bearing lignite deposits occur in a distinct tectonic, geological and chemical environment. The deposits are hosted in reduced lignitic coal seams that are part of continental fluvial sequences formed in intracratonic basins or proximal parts of marginal cratonic basins.

Uranium bearing lignite deposits are generally formed in the near surface environment in clastic fluvial sequences. Uranium is transported in oxygenated fluids and deposited either during or post lithification. The transporting fluid is generally thought to be groundwater.

Most of the host rocks for economic or near economic uranium bearing lignites or coal deposits are Permian, Carboniferous or Tertiary. The age of the uranium mineralization is thought to be synchronous with lithification to being considerably younger.

Regional Characteristics

There are many regional characteristics that are recognized as important for uranium bearing lignite deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Intracontinental basins or proximal continental margin basins with permeable fluvial clastic rocks. Stratigraphically or structurally juxtaposed lignites, mudstones and coarse fluvial clastic rocks is the favoured environment.

2. Lignites with high ash content and high permeability.

3. Faults, such as those related to local structural troughs, that may juxtapose a sequence of permeable clastic rocks and lignite seams up against impermeable mudstones or shales.

4. Basement paleotopographic highs that influence the sedimentology of the fluvial systems and may cause the juxtaposition of permeable and impermeable units.

5. Active or formerly active sandstone aquifers.

6. A potential source of uranium either in the hinterland to the lignites, above the lignites or below the lignites. These sources might include highly weathered Archean granitic basement, volcanic ash or extrusive rocks, or uraniferous black shales.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Uranium bearing lignite deposits are often characterized by the following:

1. The deposits are generally blanket to lenticular in shape, with the blanket-shaped deposits being relatively uniform and low grade over large areas, and the lenticular deposits being higher grade, thicker but of much less areal extent. In general, the uranium bearing lignites are less than a few metres thick.

2. The Permian and Carboniferous deposits have a dominant ore zone mineralogy comprised of uraninite, uranium humates and secondary uranium minerals. The Tertiary deposits are comprised of uranium-organic compounds with lesser autunite and tyuyamunite.

3. Alteration is generally localized to the ore zone and is generally characterized by leaching of the host rocks with destruction of organics and pyrite.

4. Trace elements associated with these deposits consist of V, Mo, As, Be, Ge and Ti.

4.1 Kimberlite or Lamproite Hosted Diamonds

Commodity

Diamonds

Tectonic Framework

Diamond-bearing kimberlites exist most commonly as volcanic intrusions in sedimentary platform rocks that overlie Archean cratons. Diamond-bearing kimberlites are also known to exist in exposed Archean rocks. Diamond-bearing lamproites are generally found in intracratonic mobile belts or in mobile belts that are adjacent to Archean cratons.

Kimberlite is a volatile-rich, potassic, ultramafic igneous rock which occurs as small volcanic pipes, dykes and sills. Intact kimberlitic volcanic pipes exhibit epiclastic volcanic rocks characterized by tuffs, and a diatreme facies characterized by volcanic breccias. Lamproite is also a potassic ultramafic rock, however relative to kimberlite it is more enriched in silicon, aluminum and potassium, and is less enriched in volatiles, magnesium and calcium. Lamproites tend to occur as extrusive volcanic rocks and hypabyssal dykes and sills. Lamproitic volcanism is similar in style to basaltic volcanism. Diamond-bearing kimberlites are generally restricted to regions of the continental crust underlain by Archean basement. Large, deep-seated regional structures within the Archean basement may act as conduits for kimberlite emplacement. Kimberlites also occur in regions underlain by Proterozoic basement, however they are generally not economic. Diamond-bearing lamproites are most common along the margins of cratons and in adjacent accreted mobile belts that have experienced relatively young and persistent faulting.

Diamonds are usually much older than the kimberlite or lamproite that brought them to surface. Work to date has shown that diamonds range in age from 3.3 Ga to 990 Ma. Further dating may extend this range. Kimberlite and lamproite magmas are the transporting mechanism that brings the diamonds to surface. The oldest known kimberlite or lamproite still preserved is 1.6 Ga and the youngest is 20 Ma. The presence of paleoplacer diamonds in the 2.6 Ga Witwatersrand conglomerate indicates that older kimberlites or lamproites may have existed.

Regional Characteristics

There are many regional characteristics that are recognized as important for kimberlite or lamproite hosted diamond deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics for the kimberlite hosted diamond deposits include:

1. Flat lying Phanerozoic platform or basinal sedimentary rocks that overly Archean cratonic rocks. Diamond-bearing kimberlites, especially the diatreme facies, are much less common in exposed Archean rocks due to erosion.

2. Kimberlites tend to occur in clusters, often the clusters may be spatially associated with regional zones of crustal weakness.

3. Arcuate or linear crustal fracture zones that exist at the flanks of regional cratonic warps, domes, arches or structural basins. The axes of some domes or arches may mirror the axes of thickened Archean crust called keel zones. Keel zones are considered favourable locations for the formation of diamonds in Archean crust.

4. Craton scale drainage divides, which may mirror cratonic domes or arches.

5. Positive regional gravity anomalies, which may indicate anomalous thicknesses of cratonic crust.

6. Arcuate or linear zones characterized by the presence of alkalic intrusive rocks related to hot spot volcanic activity or volcanic activity along transform faults.

7. Crustal extension zones characterized by the presence of diabase dyke swarms or continental flood basalts.

Many of the regional characteristics that are important for kimberlite hosted diamond deposits are also important for lamproite hosted deposits. Some of the regional characteristics that are not important for kimberlite hosted deposits but may be important for lamproite hosted diamond deposits include:

1. Thick crust and lithosphere below or immediately adjacent to accreted mobile belts with multiple episodes of both compressional and extensional tectonic events.

2. Proterozoic mobile belts adjacent to Archean cratons are considered particularly favourable.

3. Continental scale lineaments both parallel to the strike of the mobile belt or crosscutting the strike.

4. Paleorift or subduction zones.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Kimberlite hosted diamond deposits are often characterized by the following:

1. Carrot shaped diatreme or volcanic pipe. Kimberlites also exist as hypabyssal dykes and sills. Commonly, kimberlites are subdivided into 3 facies types; a) crater facies comprised of epiclastic to pyroclastic rocks such as tuffs, b) diatreme facies comprised of volcanic breccias, and c) hypabyssal root zone facies comprised of irregular to regular dykes and sills.

2. Depending upon the level of erosion, diamond producing kimberlite pipes have a surface area between 5 and 30 hectares. The pipes range form oval to lenticular or irregular in shape and they tend to occur in clusters.

3. The majority of kimberlitic diamonds are recovered from diatreme breccias or root zone dykes. Crater facies rocks contain important concentrations of diamonds, but the crater volcanics are volumetrically insignificant due to erosion.

4. Kimberlites are essentially potassic, olivine-rich, ultramafic rocks with a high CO_2 content. The megacryst/macrocryst and groundmass assemblage is characterized by olivine, Mg-ilmenite (picroilmenite), Cr-poor and Ti-rich pyrope garnet, subcalcic diopside to enstatite, Ti-poor phlogopites and a variety of spinels (such as magnesian chromite). Accessory minerals present include monticellite (Ca-rich olivine), perovskite, apatite, calcite and serpentine.

5. Garnets that are high in Mg and Cr, and low in Ca (G10 garnets) are key indicators of diamonds that originate from peridotitic sources. In addition, associated chromites are abnormally rich in Cr. Garnets that contain trace amounts of Na and high Ti are often indicators of diamonds that originate from eclogitic sources.

6. In comparison to the average ultramafic rock kimberlites, are usually enriched in incompatible elements including Li, F, P, K, Ti, Rb, Sr, Zr, Nb, Sn, Ba, Pr, Nd, Sm, Eu, Gd, Hf, Ta, Tl and Pb by a factor of between 10 and 100, and C, Cs, La, Ce, Th and U by a factor of greater than 100. Overlying residual soils may have high concentrations of Ti, Cr, Ni, Mg, Ba and Nb.

Lamproite hosted diamond deposits exhibit many of the same characteristics that kimberlite hosted deposits exhibit. Some of the differences that Lamproite hosted deposits may exhibit include:

1. A champagne-shaped volcanic vent or edifice. Extrusive lamproitic volcanism is characterized by lava flows and pyroclastics similar in style to those of basaltic volcanism. Lamproites do not form diatreme or root zone facies.

2. In contrast to kimberlites, the majority of diamond deposits in lamproites are found in pyroclastic rocks.

3. Lamproites exhibit an extremely wide range in modal mineralogy. Primary phases include Ti-rich and Al-poor phlogopite, Ti-K-rich richterite, forsterite, Al-Na-poor diopside, Fe-rich leucite and Fe-rich sanidine. Minor and accessory phases include priderite, wadeite, apatite, perovskite, Mg-chromite and Mg-ti-magnetite.

4. Lamproites are ultrapotassic ($K_2O/Na_2O>3$), peralkaline ($K_2O+Na_2O/Al_2O_3>1$) and rich in Ba, Zr, Sr, La and F.

4.2 Placer Diamonds

Commodity

Diamond

Tectonic Framework

Historically, diamond-rich placer deposits have been and are a major source of world diamonds. Placer deposits result from the mechanical concentration of moderate to high density minerals. Similar to gold placer deposits, diamond placer deposits form in several distinct geomorphological environments including gulches, creeks, alluvial fans, braided rivers, flood plains, fan deltas and beaches. Unlike gold and magnetite, placer diamond deposits form in a distinct tectonic environment due to the unique setting of diamond-bearing source rocks. Placer diamond deposits form in marginal cratonic basins or intracratonic basins underlain by or in close proximity to stable Archean craton.

Placer diamond deposits exist in a variety of complex sedimentary sequences depending upon the geomorphological environment, the local climate, the hydrodynamics of the alluvial system and the distance from the original bedrock source. On a deposit scale, there can be facies control of placer diamond due to favourable sedimentological conditions in a specific geomorphological environment. However, facies control can vary unpredictably from one sedimentary environment to another no matter how similar the two environments might be.

Rocks that host placer diamond deposits range in age from Archean to Recent. Placer diamond deposits and other associated heavy mineral deposits span the same age interval.

Regional Characteristics

There are many regional characteristics that are recognized as important for placer diamond deposits. However, not all these characteristics are present at every deposit. Some of the important regional characteristics include:

1. Occurrence of diamond-bearing kimberlite or lamproite pipes in the hinterland.
2. A surface of submature to mature topography.
3. Relatively long periods of mechanical and chemical weathering resulting in highly weathered and well dissected terrain.
4. Periodic uplift and/or subsidence.
5. Absence of extensive glaciation.
6. Geomorphological and sedimentological features indicative of ancient or present day gulches, creeks, alluvial fans, braided rivers, flood plains, fan deltas and beaches.
7. Some alluvial placer diamond deposits are up to 1,000 km from their kimberlite or lamproite source.

Deposit Characteristics

On a deposit scale there are many important features that may or may not be present in any particular deposit. Placer diamond deposits are often characterized by the following:

1. Placer deposits proximal to a diamond-bearing kimberlite or lamproite generally contain coarse grained diamonds of varying quality in seams, paystreaks or lenses in alluvium at or near bedrock. Examples of this type of environment may include gulches, creeks and immature rivers.

2. In proximal deposits, fractured bedrock and false bottoms, such as clay seams, may play an important role in the concentration of diamonds.

3. Placer deposits distal to a diamond-bearing kimberlite or lamproite generally contain fine grained diamonds of much higher quality than the proximal deposits. In addition, the diamonds are often finely disseminated to lensoidal throughout the sedimentary column. In the distal deposits, diamonds can also be concentrated at bedrock. Examples of this type of environment include mature river systems, flood plains, deltas and beaches.

4. The sand, gravel or conglomerate that hosts placer diamonds is usually relatively clean and quartz rich.

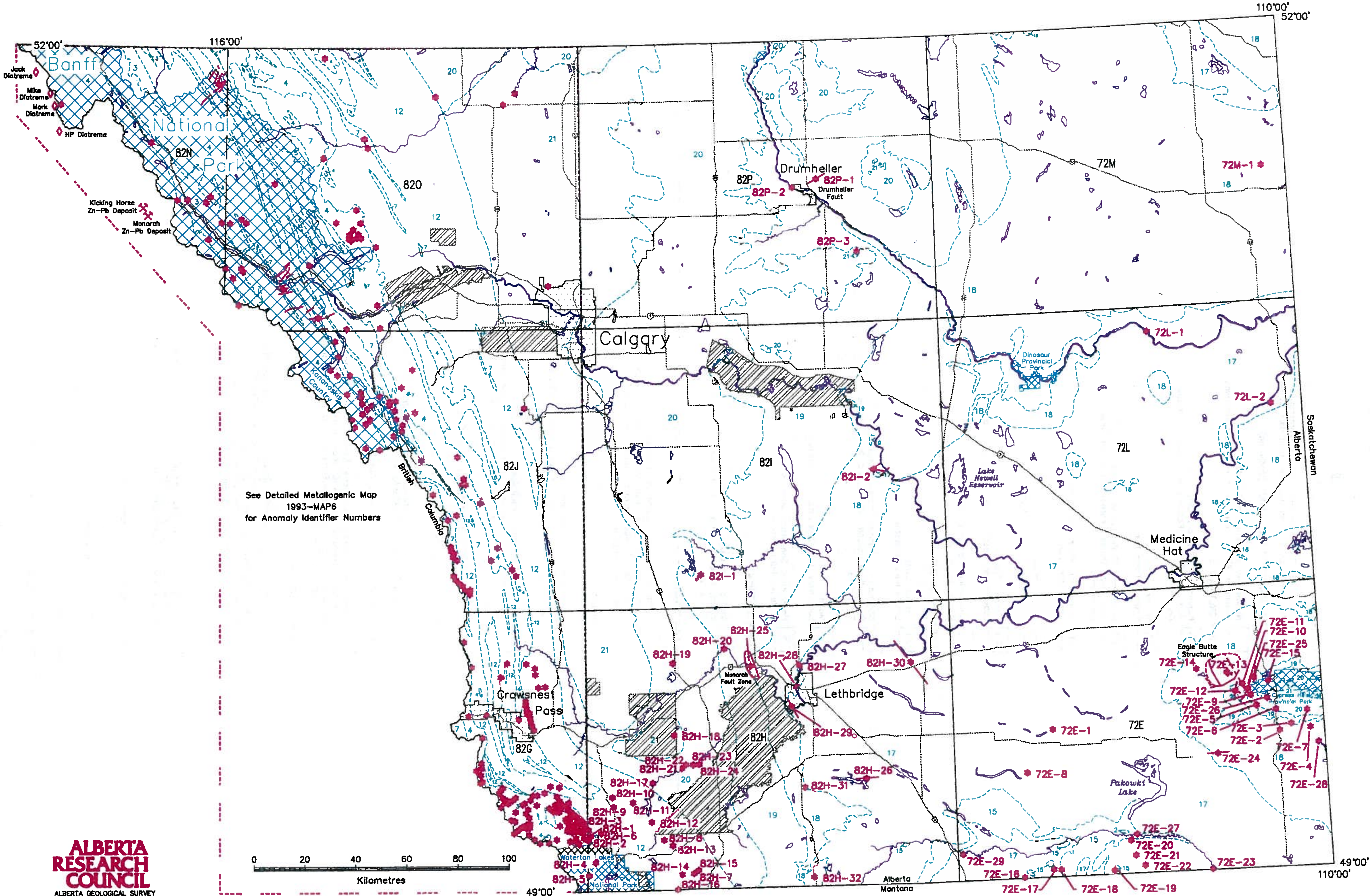
5. Periodic uplift or subsidence can result in terraced paleoplacer deposits, as well as cause reworking and further reconcentration of diamonds into higher grade paystreaks in the present day watercourses.

6. Based on the environment of deposition, a variety of sedimentological conditions are important for the concentration of diamonds;

   (a) In a gulch or creek setting diamonds exist in regular paystreaks that are laterally consistent and are on or near bedrock. The host alluvium is generally thin, with the gravelly sediments being poorly sorted and crudely to distinctly stratified.

   (b) In a mature river or fan delta environment diamonds may accumulate in many sedimentological facies but their occurrence is often sporadic and discontinuous. In meandering rivers diamonds may concentrate in main channel deposits such as dunes or lag deposits, or in point bar deposits on the inside curve of river meanders. In a braided river diamonds may concentrate in a number of areas including channel junctions, channel bends, bank-hugging bars, sluiceways between restricted stable banks and any other areas where stream flow is convergent.

7. The heavy mineral suite accompanying diamonds in alluvial placers is dependant upon the stable heavy mineral assemblage in the surrounding country rocks and the heavy minerals associated with diamonds in the source area. Ilmenite is the most common associated heavy mineral, but it may be accompanied by monazite, rutile, magnetite, pyrope, diopside, chromite, platinoids, uraninite, pyrite, gold, arsenopyrite and zircon.



Southern Alberta Plains and Foothills/Mountains Metallogenic Map: 1994-MAP1.

Metallogenic 1994–MAP1 Legend

PLAINS

TERTIARY

21 Nonmarine: Sandstone and Shale, Conglomerate
Porcupine Hills, Cypress Hills and Hand Hills Formations

TERTIARY AND UPPER CRETACEOUS (Undivided)

20 Nonmarine: Sandstone and Shale
Paskapoo, Willow Creek and Ravenscrag Formations

UPPER CRETACEOUS

19 Nonmarine: Shale and Sandstone
Horseshoe Canyon, Eastend, Whitemud and Battle Formations

18 Marine: Shale
Bearpaw Formation

17 Nonmarine: Shale and Sandstone
Belly River, Oldman, Foremost and Milk River Formations

16 Nonmarine: Shale and Sandstone
Wapiti Formation

15 Marine: Shale
Lea Park and Pakowki Formations

14 Marine: Shale
Labiche Formation, Smoky and Alberta Groups

13 Nonmarine: Sandstone and Shale
Dunvegan Formation

LOWER CRETACEOUS

11 Marine: Shale
Shaftesbury Formation

10 Nonmarine – Marine: Sandstone and Shale
Peace River, Pelican/Joli Fou and Grand Rapids Formations

9 Marine: Shale
Loon River and Clearwater Formations

8 Nonmarine: Sandstone, Minor Shale
McMurray Formation

UPPER DEVONIAN

6 Marine: Limestone and Shale
Ireton, Waterways, Hay River, Mikkwa and Grosmont Formations

MIDDLE DEVONIAN

5 Marine – Evaporitic: Dolomite, Limestone, Gypsum, Anhydrite
Caribou Member, Slave Point, Keg River and Fitzgerald Formations
Marine: Fort Vermilion Member, Slave Point, Muskeg, Nyarling and Chinchaga Formations

PRECAMBRIAN

2 Fluvial – Marine: Sandstone, minor tuffs
Helikian Athabasca Group: Fair Point, Manitou Falls, Wolverine Point, Locker Lake and Otherside Formations

1 Crystalline Basement: Granitoids
Aphebian/Archean: Granite, Granite Gneiss, Metasedimentary Rocks – High Grade and low Grade, Mylonitic Rocks

ROCKY MOUNTAIN AND FOOTHILLS

TERTIARY AND UPPER CRETACEOUS (Undivided)

12 Nonmarine – Marine: Sandstone, Mudstone, Coal and Shale
Brazeau Formation and Alberta Group

LOWER CRETACEOUS, JURASSIC AND TRIASSIC (Undivided)

7 Nonmarine – Marine: Sandstone, Shale, Coal and Siltstone
Mesozoics undivided; includes Cretaceous Blairmore Group, Jurassic Nikanassin–Kootenay Formations and Fernie Group, Triassic Spray River Group

PALEOZOIC (Undivided)

4 Marine: Limestone, Dolomite, Shale, Siltstone and Quartzite
Upper Paleozoic: Devonian and Mississippian Carbonates; minor Pennsylvanian–Permian clastics
Lower Paleozoic: Cambrian carbonates and quartzites; minor Ordovician Quartzite, Silurian Dolomite

PRECAMBRIAN

3 Marine: Argillite, Quartzite, Dolomite, Limestone and Shale
Hadrynian Miette Group: Clastics
Helikian Purcell Supergroup: Clastics, Carbonates, Quartzites

Geology compiled by W.N. Hamilton (1993)

Geological Boundaries

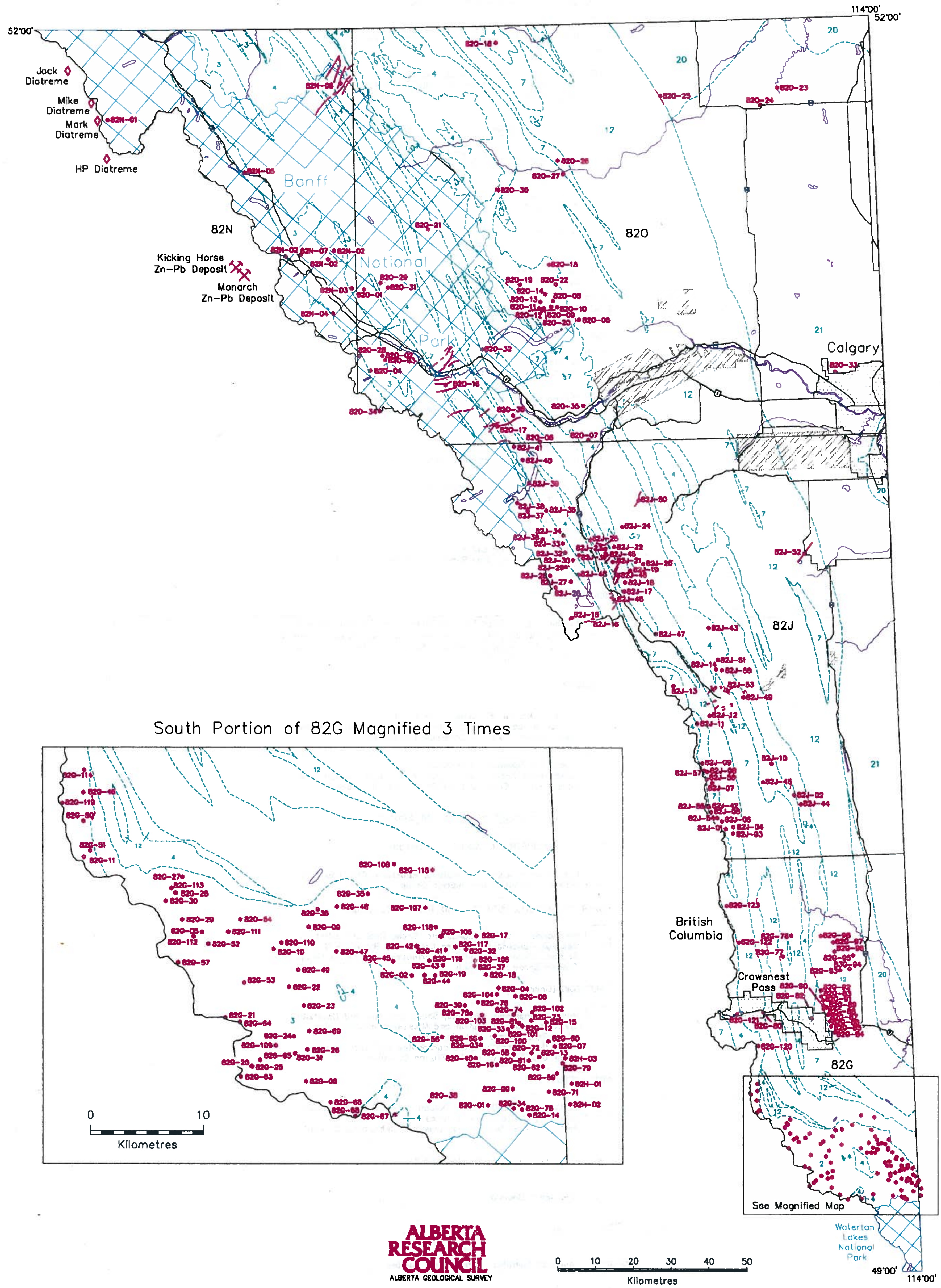
Fault

72E–21 Anomaly Identifier Location and Number

Parks/Restricted Areas

Indian Reservations

Highway



Southwest Alberta (Banff to Waterton Lakes) Metallogenic Map: 1994-MAP6.

Metallogenic 1994–MAP6 Legend

PLAINS

TERTIARY

21 Nonmarine: Sandstone and Shale, Conglomerate
Porcupine Hills, Cypress Hills and Hand Hills Formations

TERTIARY AND UPPER CRETACEOUS (Undivided)

20 Nonmarine: Sandstone and Shale
Paskapoo, Willow Creek and Ravenscrag Formations

UPPER CRETACEOUS

19 Nonmarine: Shale and Sandstone
Horseshoe Canyon, Eastend, Whitemud and Battle Formations

18 Marine: Shale
Bearpaw Formation

17 Nonmarine: Shale and Sandstone
Belly River, Oldman, Foremost and Milk River Formations

16 Nonmarine: Shale and Sandstone
Wapiti Formation

15 Marine: Shale
Lea Park and Pakowki Formations

14 Marine: Shale
Labiche Formation, Smoky and Alberta Groups

13 Nonmarine: Sandstone and Shale
Dunvegan Formation

LOWER CRETACEOUS

11 Marine: Shale
Shaftesbury Formation

10 Nonmarine – Marine: Sandstone and Shale
Peace River, Pelican/Joli Fou and Grand Rapids Formations

9 Marine: Shale
Loon River and Clearwater Formations

8 Nonmarine: Sandstone, Minor Shale
McMurray Formation

UPPER DEVONIAN

6 Marine: Limestone and Shale
Ireton, Waterways, Hay River, Mikkwa and Grosmont Formations

MIDDLE DEVONIAN

5 Marine – Evaporitic: Dolomite, Limestone, Gypsum, Anhydrite
Caribou Member, Slave Point, Keg River and Fitzgerald Formations
Marine: Fort Vermilion Member, Slave Point, Muskeg, Nyarling and Chinchaga Formations

PRECAMBRIAN

2 Fluvial – Marine: Sandstone, minor tuffs
Helikian Athabasca Group: Fair Point, Manitou Falls, Wolverine Point, Locker Lake and Otherside Formations

1 Crystalline Basement: Granitoids
Aphebian/Archean: Granite, Granite Gneiss, Metasedimentary Rocks – High Grade and low Grade, Mylonitic Rocks

ROCKY MOUNTAIN AND FOOTHILLS

TERTIARY AND UPPER CRETACEOUS (Undivided)

12 Nonmarine – Marine: Sandstone, Mudstone, Coal and Shale
Brazeau Formation and Alberta Group

LOWER CRETACEOUS, JURASSIC AND TRIASSIC (Undivided)

7 Nonmarine – Marine: Sandstone, Shale, Coal and Siltstone
Mesozoics undivided; includes Cretaceous Blairmore Group, Jurassic Nikanassin–Kootenay Formations and Fernie Group, Triassic Spray River Group

PALEOZOIC (Undivided)

4 Marine: Limestone, Dolomite, Shale, Siltstone and Quartzite
Upper Paleozoic: Devonian and Mississippian Carbonates; minor Pennsylvanian–Permian clastics
Lower Paleozoic: Cambrian carbonates and quartzites; minor Ordovician Quartzite, Silurian Dolomite

PRECAMBRIAN

3 Marine: Argillite, Quartzite, Dolomite, Limestone and Shale
Hadrynian Miette Group: Clastics
Helikian Purcell Supergroup: Clastics, Carbonates, Quartzites

Geology compiled by W.N. Hamilton (1993)

Geological Boundaries

Fault

82J–02 • Anomaly Identifier Location and Number

Parks/Restricted Areas

Indian Reservations

Highway