NTS 82G, J

In 3 SECTIONS
and in 2 VOLUMES

REGIONAL STRATIGRAPHIC-STRUCTURAL STUDY

ORIENTATION HEAVY MINERAL STREAM SEDIMENT STUDY

SOUTHERN ALBERTA RIFT

SOUTHWEST ALBERTA

(CANADA-ALBERTA MDA PROJECT M93-04-034)

R.A. Olson
R.A. Olson Consulting Ltd.

T.R. Iannelli
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and

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March, 1994

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SECTION I
Volume I of II

OVERVIEW OF THE 1993 PROGRAM

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ACKNOWLEDGMENTS AND DISCLAIMER

The research project (M93-04-034) for which this report is submitted was funded through the Canada-Alberta Partnership Agreement on Mineral Development (1992-1995) by the Alberta Department of Energy.

Project M93-04-034 was performed by Dr. T.R. Iannelli of Tri-Ex Consultants Ltd. (stratigraphic-structural study) of London, Ontario, and by Mr. W.R. Gilmour of Discovery Consultants (orientation heavy mineral stream sediment survey) of Vernon, British Columbia, under the overall project supervision of Dr. R.A. Olson of R.A. Olson Consulting Ltd. of Edmonton, Alberta. Field assistance was provided to Dr. Iannelli by Mr. J. Williamson, a geologist in the employ of R.A. Olson Consulting Ltd., and to Mr. Gilmour by Dr. R.A. Olson and Dr. J. Jianjun, a visiting scientist from the Republic of China who was in residence at the Alberta Geological Survey during 1993. R.A. Olson Consulting Ltd. also wishes to acknowledge the assistance of professional staff of the Alberta Geological Survey who provided advice with respect to the preparation of some figures in digital form, and provided access to scanning equipment and software to facilitate the computerized production of selected figures.

R.A. Olson Consulting Ltd., Tri-Ex Consultants Ltd. and Discovery Consultants assume professional responsibility for the contents of this final report on Canada-Alberta Partnership Agreement on Mineral Development project M93-04-034.

OVERVIEW OF THE 1993 PROGRAM
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OVERVIEW OF THE 1993 PROGRAM

SOUTHERN ALBERTA RIFT

SOUTHWEST ALBERTA

(CANADA-ALBERTA MDA PROJECT M93-04-034)

SUMMARY

Southwest Alberta is underlain mainly by sedimentary and, locally, by volcanic and intrusive igneous rocks that range in age from Middle Proterozoic to Tertiary. The Southern Alberta Rift is an inferred graben-like structure that is deep-seated and long lived, and extends for at least about 450 km from southwestern British Columbia into and across the southwestern and southern part of Alberta to almost the Alberta-Saskatchewan border. It has been suggested that the Southern Alberta Rift began in Middle Proterozoic time, was intermittently active during the Paleozoic and Mesozoic periods, and may have been locally re-activated as late as the early Tertiary. Further, the Southern Alberta Rift has been postulated to have influenced the sedimentary and, possibly, structural evolution of southwest Alberta from the Middle Proterozoic onwards. As well, some workers have suggested that the Southern Alberta Rift may have been responsible for or at least influenced some of the metallic mineralizing events which led to the existence of the numerous metallic mineral occurrences that are present in southwest Alberta.

The intent of the 1993 field program was to follow up the fieldwork that was conducted under Canada-Alberta MDA project M92-04-002 during 1992 (Williamson et al., 1993). The 1993 program consisted of two separate studies. (1) One study comprised the stratigraphic-structural examination and geological mapping of selected stratigraphic sections in rock units ranging from Proterozoic to Cenozoic in age. The intent of this work was to search for changes in sedimentary facies, paleocurrent directions and other such geological features that would indicate the location and duration of the Southern Alberta Rift in southwest Alberta. (2) The second study comprised the orientation heavy mineral sampling of three selected drainages in southwest Alberta. The intent of this work was to determine if selected heavy mineral fractions in stream drainage sediments provide a better 'anomaly' to 'background' contrast as compared to that found by the standard stream silt sampling methodology.

The major contributions from the 1993 stratigraphic-structural study are: (1) definite stratigraphic evidence for rift-related influences on sedimentation patterns in Middle Proterozoic to Cenozoic strata and, less definitively, (2) stratigraphic and structural data that more precisely indicate the inferred margins, particularly the southern margin, of the Southern Alberta Rift. Strata of the Purcell Supergroup contain several notable features that indicate rift-influenced effects on sedimentation patterns. These syndepositional tectonic effects on sedimentation patterns were mainly found in strata of the Appekunny, Grinnell, Siyeh and Sheppard Formations. The effects of rift-related tectonism are not as

obvious in Phanerozoic strata, and an accurate estimation of the rift margins during the Phanerozoic could not be defined by the 1993 field work. However, several features occur within Phanerozoic strata that indicate repeated episodes of syndepositional tectonism that may have been related to reactivation of structures associated with the Southern Alberta Rift. With respect to the location of the margins of the Southern Alberta Rift, it must be kept in mind that the original delineation of the rift boundaries was interpreted from geophysical evidence by Kanasewich (1968) and Kanasewich et al. (1969), hence the inferred margins of the Southern Alberta Rift in southwest Alberta are not accurately known. Nonetheless, the existence of well-defined depocentres and associated facies variations found by the 1993 program comprise hard field evidence that rift-related effects are preserved in the Proterozoic rocks of the Clark Range and have permitted a better understanding of the position of at least the inferred southern margin of the Southern Alberta Rift. This information, coupled with suitable mineral deposits models, will assist in the exploration for various types of metallic mineral deposits in southwest Alberta.

The orientation heavy mineral stream sediment survey has proven successful in detecting known clastic sediment-hosted copper-silver mineralized zones in Proterozoic strata, and carbonate-hosted zinc-lead-silver mineralized zones in Paleozoic strata. The heavy mineral survey results commonly show a contrast between anomalous and background values that is about an order of magnitude greater than that which exists in the standard geochemical stream silt survey results in southwest Alberta. Therefore, the use of heavy mineral concentrates from stream sediments to obtain this better anomaly to background contrast can play a significant role in both identifying specific mineralized zones and in evaluating the mineral potential of drainage basins. Further studies of the regional heavy mineral content of stream drainages are required in southwest Alberta to: (a) confirm the heavy mineral technique's applicability to other areas with differing geological and geomorphological conditions, (b) confirm and refine which of the various heavy mineral fractions provide the best anomaly to background contrast for each element of exploration interest, and (c) more precisely determine the background, threshold and anomalous classifications for each element and heavy mineral fraction.

INTRODUCTION

R.A. Olson Consulting Ltd. (RAOCL) was advised on May 10, 1993 by Ms. K. Cochrane, Director, Minerals Research of the Alberta Department of Energy, that RAOCL's proposed project entitled "Reconnaissance Structural-Stratigraphic Study and Orientation Heavy Mineral Study of the Southern Alberta Rift in Southwest Alberta" had been approved by the Management Committee of the Canada-Alberta Partnership Agreement on Mineral Development (hereafter referred to as the Canada-Alberta 'MDA'). The approved research project (M93-04-034) is governed by the Non-Petroleum Mineral Development Agreement between Her Majesty the Queen in Right of Alberta, and RAOCL that is dated May 10, 1993.

LOCATION, ACCESS, PHYSIOGRAPHY

The Southern Alberta Rift project area is centred on 49°45' N latitude and 114°30' W longitude in southwest Alberta (Figure I-1). The program area comprises all or parts of National Topographic System (NTS) 1:50,000 scale map-sheets 82G/7,8,9,10,15,16 and 82J/1,2,7,8.

Access in the project area is provided by a well-maintained network of primary, hard surface, all-weather roads; secondary, loose surface all-weather roads and numerous tertiary logging roads and trails. Access to elevations of about 1,500 m by loose all-weather roads is common. Access to the higher elevation backwoods areas can be achieved in dry weather by four-wheel drive vehicles and by foot. A helicopter is beneficial for exploration of the steeper mountain ridges, but was not used during the 1993 program.

The Southern Alberta Rift area is comprised of two physiographic regions: the Eastern System of the Western Cordillera and, in the northeast portion of the area, a small wedge of the Interior Plains. The Eastern System of the Western Cordillera is divided into four subprovinces: the Foothills, Front Ranges, Main Ranges and Western Ranges of the Rocky Mountains (North and Henderson 1954). Within the project area, the Eastern System of the Western Cordillera consists of the Foothills and the Front Ranges of the Rocky Mountains in about equal proportions.

The Interior Plains are characterized by a relatively featureless topography of low relief. The flat topography reflects the underlying, near-horizontal to gently west-dipping, easterly-tapering, Phanerozoic sedimentary sequence. Locally, the Plains are cut by rivers that provide moderate relief of up to a few tens of metres. The Interior Plains rise in elevation from east to west across the prairie provinces and reach their maximum elevation of about 1,100 m in the northeastern portion of the Southern Alberta Rift project area.

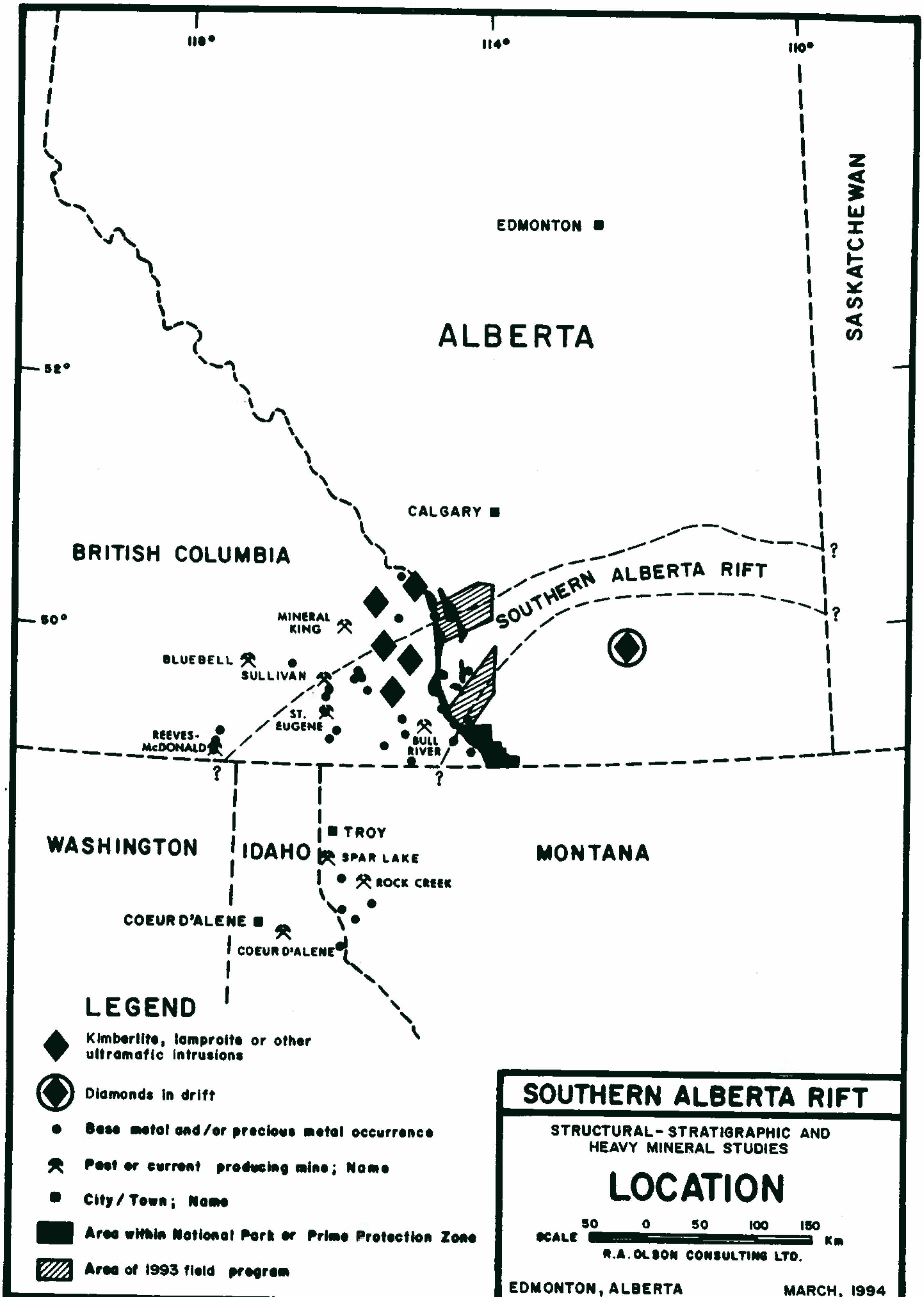
118°
114°
110°
52°
50°
EDMONTON
ALBERTA
SASKATCHEWAN
CALGARY
BRITISH COLUMBIA
SOUTHERN ALBERTA RIFT
MINERAL KING
BLUEBELL
SULLIVAN
ST. EUGENE
REEVES-McDONALD
BULL RIVER
WASHINGTON
IDAHO
TROY
SPAR LAKE
ROCK CREEK
MONTANA
COEUR D'ALENE
COEUR D'ALENE
LEGEND
Kimberlite, lamproite or other ultramafic intrusions
Diamonds in drift
Base metal and/or precious metal occurrence
Past or current producing mine; Name
City/Town; Name
Area within National Park or Prime Protection Zone
Area of 1993 field program
SOUTHERN ALBERTA RIFT
STRUCTURAL-STRATIGRAPHIC AND HEAVY MINERAL STUDIES
LOCATION
SCALE 50 0 50 100 150 Km
R.A. OLSON CONSULTING LTD.
EDMONTON, ALBERTA
MARCH, 1994

Figure I-1

The boundary between the Interior Plains and the Foothills is located at or near the Turner Valley Fault, which is approximately at the unconformable lithological contact between the Cretaceous Belly River Formation and the Tertiary Paskapoo Formation. The Western boundary of the Foothills is located approximately at the McConnell Thrust Fault, where various older sedimentary rocks are thrust over younger sedimentary rocks. The Foothills are characterized by a series of rounded, northerly-trending ridges with elevations up to about 1,800 m.

The Front Ranges occupy the westernmost portion of the project area, from the Foothills, west to the Alberta-British Columbia border and beyond. The Front Ranges are characterized by prominent grey cliffs with elevations at the summits typically reaching about 2,750 m. The characteristic layer-cake appearance of the Front Range cliffs is produced by alternating sequences of resistant Paleozoic carbonates that are thrust-faulted over younger, recessive-weathering, clastic sedimentary rocks.

PRIOR WORK

The prior geological mapping by various government Surveys and prior metallic mineral exploration by various workers, are summarized in Williamson et al. (1993). This work has resulted in the discovery of a large number of metallic mineral occurrences and deposits in southwest Alberta (e.g., see Figure 2 in Williamson et al., Ibid; as well as figures in Hamilton and Olson, In press, and Olson et al., In press).

1993 PROGRAM

The stratigraphic-structural study was performed by Dr. T.R. Iannelli of Tri-Ex Consultants Ltd., who was assisted by Mr. J. Williamson, a geologist employed by R.A. Olson Consulting Ltd. Pre-field office work on the project commenced during May, 1993, and fieldwork was performed between August 21 and September 19. The post-field analysis of data and preparation of the final project report were completed about March 31, 1994. Initally the stratigraphic-structural study was based out of Coleman, Alberta, with fieldwork being concentrated in the Clark Range and in other parts of the southern portion of the Southern Alberta Rift project area. During the latter part of the 1993 field program, Dr. Iannelli worked out of Black Diamond, Alberta and fieldwork was concentrated in the northern portion of the project area. Daily crew deployment was by four-wheel drive vehicle and by foot. In total, Dr. Iannelli performed a total of 27 geological traverses and geologically mapped 32 stratigraphic sections (Figure I-2). Details about the results of the 1993 stratigraphic-structural study are given in Section II, Volume I of II of this report. Section II is a complete report with a text, and includes the following figures: (a) stratigraphic sections in Figures II-1 to II-32, (b) paleocurrent rose diagrams for selected Proterozoic to Tertiary rock units in Figures II-33 to II-65, and (c) various figures and diagrams in the Section II text that are numbered Figures II-66 to II-75. As well, Section II contains 19 tables numbered II-1 to II-19, and three coloured photographic Plates numbered II-1 to II-3.

With respect to the orientation heavy mineral in stream sediment study, this was performed between August 31 and September 5 by Mr. W.R. Gilmour of Discovery Consultants. Gilmour collected a total of 15 heavy mineral stream sediment samples and 15 spatially associated standard stream silt samples at 15 sites at three separate drainages: Grizzly Creek, Pincher Creek and Oldman River (Figure I-2). Mr. Gilmour was assisted during sample collection by Dr. R.A. Olson and by Dr. J. Jianjun, a visiting scientist from the Republic of China who was in residence at the Alberta Geological Survey during 1993. Daily crew deployment was by four-wheel drive vehicle and by foot. The 15 heavy mineral samples were sent to C.F. Mineral Research Ltd., Kelowna, British Columbia for sample preparation, then to both Becquerel Laboratories Inc., Mississauga, Ontario and Bondar-Clegg & Company Ltd., North Vancouver, British Columbia, for analysis for selected elements of exploration interest by various analytical methods. The 15 standard stream silt samples were sent to Bondar-Clegg & Company Ltd. for sample preparation and analysis. Details about the sampling methodology, sample preparation and analysis, and the results of the 1993 orientation heavy mineral study are given in Section III, Volume II of II of this report. Section III is a complete report with a text, and includes the following figures: (a) Geology & Mineral Occurrences, Sample Location, Silt Geochemistry and Heavy Mineral Geochemistry in Figures III-1 to III-12, and (b) histograms for selected heavy mineral fractions in Figures III-13 to III-16. As well, Section III contains five tables numbered III-1 to III-5, and two Appendices numbered III-1 and III-2.

REGIONAL GEOLOGY OF SOUTHWEST ALBERTA

The Rocky Mountains and Foothills of Alberta are dominantly comprised of miogeosynclinal sedimentary and, locally, volcanic rocks that range in age from Middle Proterozoic to Tertiary. The rocks are largely unmetamorphosed to slightly metamorphosed. The Proterozoic to Phanerozoic sedimentary sequence in southwest Alberta is thought to be underlain by crystalline basement rocks of Archean to early Proterozoic age. In general, the various rock units and lithologies comprise:

(a) **Middle to Upper Proterozoic sedimentary rocks**: in southwest Alberta and southeast British Columbia there are up to 13,700 m (45,000 feet) of quartzite, siltstone, argillite and minor amounts of carbonate that thicken to the west.

(b) **Paleozoic sedimentary rocks**: in the Front Ranges of the Alberta Rocky Mountains and Foothill the sedimentary rocks are mostly carbonate with some shale. Major unconformities exist below the base of the Cambrian, Middle Devonian and near the top of the Pennsylvanian sequences.

(c) **Triassic and Jurassic sedimentary rocks**: in the Foothills and Front Ranges there is an incomplete section of continental to marine conglomerate, sandstone, shale, carbonate, evaporite and coal.

(d) **Cretaceous and Tertiary sedimentary rocks**: in the Foothills and Front Ranges there is conglomerate, sandstone, siltstone, shale and coal of marine to continental origin. These rock units include two major clastic wedges derived from uplift in the west. The two clastic wedges are a Late Jurassic to Early Cretaceous Kootenay-Blairmore cycle, and a Late Cretaceous to Oligocene Belly River-Paskapoo cycle.

(e) **Igneous and volcanic rocks**: in the Crowsnest Pass area and in the Clark Range there are and extrusive volcanic rocks and, in places, intrusive dykes and sills that range in age from Middle Proterozoic to late Early Cretaceous.

The Rocky Mountains and Foothills in southwest Alberta are dominated by northwest-trending folds and thrust sheets that developed during accretion of land masses west of the Rocky Mountain Trench. Other enigmatic structures that may have influenced tectonics, sedimentation and metallogenesis in southwest Alberta include the Southern Alberta Rift, West Alberta Arch and various transverse, tear or normal faults.

The regional geology of southwest Alberta is discussed in greater detail in Section II of this report, and in the following selected references: Gabrielse and Yorath (1992), Stott and Aitken (1993), Fulton (1989), Williamson et al. (1993), and Mossop and Shetsen (In press).

SYNOPSIS OF 1993 PROGRAM RESULTS

STRATIGRAPHIC - STRUCTURAL STUDY

The intent of the 1993 field program was to find evidence for rift-related influences on sedimentation patterns in rocks of Middle Proterozoic to Tertiary age associated with the evolution and subsequent periodic reactivation of the Southern Alberta Rift in southwest Alberta. As well, evidence was sought to better delineate the margins of the Southern Alberta Rift and, if possible, to determine the relationship between known mineral occurrences and rifting. The 1993 project was accomplished through geological examination of selected stratigraphic sections and mineralized areas in southwest Alberta.

The major contributions derived from the 1993 stratigraphic-structural study are: (1) definite stratigraphic evidence for rift-related influences on sedimentation patterns in Middle Proterozoic to Cenozoic strata and, less definitively, (2) stratigraphic and structural data that more precisely indicate the inferred margins, particularly the southern margin, of the Southern Alberta Rift. For example, strata of the Purcell Supergroup contain several notable features that indicate rift-influenced effects on sedimentation patterns. These syndepositional tectonic effects on sedimentation patterns were mainly found in strata of the Appekunny, Grinnell, Siyeh and Sheppard Formations, and include: (a) relatively abrupt latero-vertical facies variations in the distribution of carbonate and clastic rocks, (b) the occurrence and nature of cyclic sequences which indicate syndepositional faulting, and (c) changes in thickness trends within some units that indicate possible rift-related depocentres. As well, (d) the existence of the Purcell Lavas indicate a period of syndepositional volcanism that may be due to rift-related differential subsidence. The depocentres typically are parallel or sub-parallel to the strike of and within 15 km of the inferred southern margin of the Southern Alberta Rift. It must be kept in mind that the original delineation of the rift boundaries was interpreted from geophysical evidence by Kanasewich (1968) and Kanasewich et al. (1969), hence the inferred southern margin of the Southern Alberta Rift in southwest Alberta is not accurately known. However, the existence of well-defined depocentres and associated facies variations comprise hard field evidence that rift-related effects are preserved in the Proterozoic rocks of the Clark Range.

The effects of rift-related tectonism are not as obvious in Phanerozoic strata, and an accurate estimation of the rift margins during the Phanerozoic could not be defined by the 1993 field work. However, several features occur within Phanerozoic strata that indicate repeated episodes of syndepositional tectonism that may have been related to reactivation of structures associated with the Southern Alberta Rift. For example, (a) strata of the Mississippian Mount Head and Etherington Formations contain facies and thickness variations that indicate subtle effects of syndepositional faulting and rift reactivation. (b) With respect to the Lower Cretaceous Crowsnest Formation, this formation is thickest in and is mainly areally restricted to the Southern Alberta Rift, which indicates reactivation of intra-rift fault zones. (c) In strata of the Upper Cretaceous Belly River to Willow Creek Formations there is evidence for the presence of major growth faults. These growth faults spatially coincide with the inferred margins of the Southern Alberta Rift and imply a strong genetic link. The facies distribution and cyclic nature of these formations also may have been influenced by reactivation of the ancient faulted rift margins.

The evidence for rifting, fault reactivation and related sedimentary variations having recurred episodically over a long time span indicates that mineral deposits of several types could exist within and near the Southern Alberta Rift. Possible types of rift-related mineral deposits and prospective target rock units include:

(1) **Stratiform sediment-hosted lead-zinc and shale-hosted nickel-zinc deposits of Sedex type.**

Selected basinal successions in the Middle Proterozoic Purcell Supergroup are potential target rock units. In the Phanerozoic succession, the most prospective sequence probably is the thin, but widespread euxinic black shale of the Upper Devonian-Lower Mississippian Exshaw Formation.

(2) **Stratiform sediment-hosted Kupferschiefer-type copper-silver deposits.**

The sandstone-bearing successions of the Appekunny, Grinnell and Siyeh Formations, across the entire Clark Range, are potential host rocks for this mineral deposit type.

(3) **Carbonate-hosted Mississippi Valley Type lead-zinc deposits.**

The dolomitized reef and dolostone clast breccia-bearing successions of the Late Devonian Fairholme Group and Palliser Formation are the most prospective host rock units for this mineral deposit type.

ORIENTATION HEAVY MINERAL STREAM SEDIMENT STUDY

The orientation heavy mineral stream sediment survey has proven successful in detecting known clastic sediment-hosted copper-silver mineralized zones in Proterozoic strata, and carbonate-hosted zinc-lead-silver mineralized zones in Paleozoic strata. That is, the -35HN (-35 mesh, heavy, nonmagnetic) fraction, when analyzed for copper and possibly lead, is best suited to delineate areas of blind or undiscovered copper-bearing mineralized zones hosted by clastic sediments, whereas the -35IP (-35 mesh, intermediate, paramagnetic) fraction, when analyzed for zinc, is best suited for delineating zinc-bearing mineralized zones hosted by carbonate rocks. As well, analysis for silver and mercury in the -35HN fraction and cadmium in the -35IP fraction may augment exploration for the carbonate-hosted zinc-lead-silver mineral occurrences.

The heavy mineral survey results show a contrast between anomalous and background values that is about an order of magnitude greater than that which exists in the standard geochemical stream silt survey results in southwest Alberta. Therefore, the use of heavy mineral concentrates from stream sediments to obtain this better anomaly to background contrast can play a significant role in both identifying specific mineralized zones and in evaluating the mineral potential of drainage basins. Although these preliminary heavy mineral results are encouraging, caution should be used when extrapolating the present results into different geological and geographical areas because of the small size of the comparative data set that was obtained by the 1993 orientation heavy mineral survey.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES

A large number of metallic mineral occurrences and a few small mineral deposits exist in the Southern Alberta Rift area of southwest Alberta. The metallic mineral occurrences and deposits exist in various sedimentary and, locally, volcanic rocks that range in age from Middle Proterozoic to Tertiary.

STRATIGRAPHIC - STRUCTURAL STUDY

The major contributions from the 1993 stratigraphic-structural study are: (1) definite stratigraphic evidence for rift-related influences on sedimentation patterns in Middle Proterozoic to Cenozoic strata and, less definitively, (2) stratigraphic and structural data that more precisely indicate the inferred margins, particularly the southern margin, of the Southern Alberta Rift. Strata of the Purcell Supergroup contain several notable features that indicate rift-influenced effects on sedimentation patterns. The existence of well-defined depocentres and associated facies variations found by the 1993 program comprise hard field evidence that rift-related effects are preserved in the Proterozoic rocks of the Clark Range and have permitted a better understanding of the position of at least the inferred southern margin of the Southern Alberta Rift. This information, coupled with suitable mineral deposits models, will assist in the exploration for various types of metallic mineral deposits in southwest Alberta.

In conclusion, the southwest portion of Alberta is geologically complex and contains numerous different types of metallic mineral showings, hence this area should be considered as a prospective target locale for a variety of other potential precious and base metal deposit types as discussed by Williamson et al. (1993) and by Olson et al. (In press).

ORIENTATION HEAVY MINERAL STREAM SEDIMENT STUDY

The orientation heavy mineral stream sediment survey results show a marked contrast between anomalous and background values than that which exists for standard geochemical stream silt survey results in southwest Alberta. Further regional heavy mineral orientation surveys are required in southwest Alberta to: (a) confirm the heavy mineral technique's applicability to other areas with differing geological and geomorphological conditions, (b) confirm and refine which of the various heavy mineral fractions provide the best anomaly to background contrast for each element of exploration interest, and (c) more precisely determine the background, threshold and anomalous classifications for each element and heavy mineral fraction.

R.A. Olson Consulting Ltd.

PROFESSIONAL GEOLOGIST R.A. OLSON ALBERTA

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

PERMIT TO PRACTICE
R. A. OLSON CONSULTING LTD.
Signature R.A. Olson
Date April 6, 1994
PERMIT NUMBER: P 2374
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

Tri-Ex Consultants Ltd.

T.R. Iannelli

T.R. Iannelli, Ph.D.

Discovery Consultants

RAO for WRG

W.R. Gilmour, B.Sc., P.Geo.

March 31, 1994
Edmonton, Alberta

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CERTIFICATION

I, R. A. OLSON OF 8727 - 181 STREET, EDMONTON, ALBERTA, CERTIFY AND DECLARE THAT I AM A GRADUATE OF THE UNIVERSITY OF BRITISH COLUMBIA WITH A B.SC. DEGREE IN GEOLOGY (1968), A GRADUATE OF THE UNIVERSITY OF WESTERN ONTARIO WITH A M.SC. DEGREE IN GEOLOGY (1971) AND A GRADUATE OF THE UNIVERSITY OF BRITISH COLUMBIA WITH A PH.D. DEGREE IN GEOLOGY (1977). I AM REGISTERED AS A PROFESSIONAL ENGINEER WITH THE ASSOCIATION OF PROFESSIONAL ENGINEERS OF BRITISH COLUMBIA AND AS A PROFESSIONAL GEOLOGIST WITH THE ASSOCIATION OF PROFESSIONAL ENGINEERS, GEOLOGISTS AND GEOPHYSICISTS OF ALBERTA.

MY EXPERIENCE INCLUDES SERVICE AS AN EXPLORATION GEOLOGIST WITH TEXASGULF INC., VANCOUVER, BRITISH COLUMBIA. SINCE 1969 I HAVE CONDUCTED AND DIRECTED PROPERTY EXAMINATIONS, PROPERTY EVALUATIONS AND EXPLORATION PROGRAMS ON BEHALF OF COMPANIES AS A GEOLOGIST IN THE EMPLOY OF TRIGG, WOOLLETT & ASSOCIATES LTD., AND AS A PARTNER IN THE FIRM OF TRIGG, WOOLLETT CONSULTING LTD. AND TRIGG, WOOLLETT, OLSON CONSULTING LTD., EDMONTON, ALBERTA UNTIL THE END OF 1991. FROM JANUARY 1992 UNTIL THE PRESENT I HAVE BEEN THE PRESIDENT AND CHIEF GEOSCIENTIST OF THE FIRMS OF R.A. OLSON CONSULTING LTD. AND, SINCE JANUARY 1994, OF APEX GEOSCIENCE LTD.

I HAVE NO INTEREST, DIRECT OR INDIRECT, IN THE SOUTHERN ALBERTA RIFT AREA OF SOUTHWEST ALBERTA NOR DO I EXPECT TO RECEIVE AN INTEREST IN THE FUTURE.

THE REPORT ENTITLED "STRATIGRAPHIC - STRUCTURAL STUDY, ORIENTATION HEAVY MINERAL STREAM SEDIMENT STUDY, SOUTHERN ALBERTA RIFT IN SOUTHWEST ALBERTA (CANADA-ALBERTA MDA PROJECT M93-04-034)" IS BASED UPON FIELDWORK PERFORMED BY THE PRINCIPALS OF TRI-EX CONSULTANTS LTD. AND DISCOVERY CONSULTANTS, AND UPON STUDY OF PUBLISHED AND UNPUBLISHED DATA. THE FIELDWORK AND OFFICE STUDIES WERE DONE UNDER MY OVERALL SUPERVISION.

PROFESSIONAL GEOLOGIST ALBERTA
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REGIONAL STRATIGRAPHIC-STRUCTURAL STUDY

SOUTHERN ALBERTA RIFT, SOUTHWEST ALBERTA

(CANADA-ALBERTA MDA PROJECT M93-04-034)

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REGIONAL STRATIGRAPHIC-STRUCTURAL STUDY

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SUMMARY

The intent of the 1993 field program was to find evidence for rift-related influences on sedimentation patterns in rocks of Middle Proterozoic to Tertiary age associated with the evolution and subsequent periodic reactivation of the Southern Alberta Rift in southwest Alberta. As well, evidence was sought to better delineate the margins of the Southern Alberta Rift and, if possible, to determine the relationship between known mineral occurrences and rifting. The 1993 project was accomplished through geological examination of selected stratigraphic sections and mineralized areas in southwest Alberta.

The major contributions derived from the 1993 stratigraphic-structural study are: (1) definite stratigraphic evidence for rift-related influences on sedimentation patterns in Middle Proterozoic to Cenozoic strata and, less definitively, (2) stratigraphic and structural data that more precisely indicate the inferred margins, particularly the southern margin, of the Southern Alberta Rift. For example, strata of the Purcell Supergroup contain several notable features that indicate rift-influenced effects on sedimentation patterns. These syndepositional tectonic effects on sedimentation patterns were mainly found in strata of the Appekunny, Grinnell, Siyeh and Sheppard Formations, and include: (a) relatively abrupt latero-vertical facies variations in the distribution of carbonate and clastic rocks, (b) the occurrence and nature of cyclic sequences which indicate syndepositional faulting, and (c) changes in thickness trends within some units that indicate possible rift-related depocentres. As well, (d) the existence of the Purcell Lavas indicate a period of syndepositional volcanism that may be due to rift-related differential subsidence. The depocentres typically are parallel or sub-parallel to the strike of and within 15 km of the inferred southern margin of the Southern Alberta Rift. It must be kept in mind that the original delineation of the rift boundaries was interpreted from geophysical evidence by Kanasewich (1968) and Kanasewich et al. (1969), hence the inferred southern margin of the Southern Alberta Rift in southwest Alberta is not accurately known. However, the existence of well-defined depocentres and associated facies variations comprise hard field evidence that rift-related effects are preserved in the Proterozoic rocks of the Clark Range.

The effects of rift-related tectonism are not as obvious in Phanerozoic strata, and an accurate estimation of the rift margins during the Phanerozoic could not be defined by the 1993 field work. However, several features occur within Phanerozoic strata that indicate repeated episodes of syndepositional tectonism that may have been related to reactivation of structures associated with the Southern Alberta Rift. For example, (a) strata of the Mississippian Mount Head and Etherington Formations contain facies and thickness variations that indicate subtle effects of syndepositional faulting and rift reactivation. (b)

With respect to the Lower Cretaceous Crowsnest Formation, this formation is thickest in and is mainly areally restricted to the Southern Alberta Rift, which indicates reactivation of intra-rift fault zones. (c) In strata of the Upper Cretaceous Belly River to Willow Creek Formations there is evidence for the presence of major growth faults. These growth faults spatially coincide with the inferred margins of the Southern Alberta Rift and imply a strong genetic link. The facies distribution and cyclic nature of these formations also may have been influenced by reactivation of the ancient faulted rift margins.

The evidence for rifting, fault reactivation and related sedimentary variations having recurred episodically over a long time span indicates that mineral deposits of several types could exist within and near the Southern Alberta Rift. Possible types of rift-related mineral deposits and prospective target rock units include:

(1) Stratiform sediment-hosted lead-zinc and shale-hosted nickel-zinc deposits of Sedex type.

Selected basinal successions in the Middle Proterozoic Purcell Supergroup are potential target rock units. In the Phanerozoic succession, the most prospective sequence probably is the thin, but widespread euxinic black shale of the Upper Devonian-Lower Mississippian Exshaw Formation.

(2) Stratiform sediment-hosted Kupferschiefer-type copper-silver deposits.

The sandstone-bearing successions of the Appekunny, Grinnell and Siyeh Formations, across the entire Clark Range, are potential host rocks for this mineral deposit type.

(3) Carbonate-hosted Mississippi Valley Type lead-zinc deposits.

The dolomitized reef and dolostone clast breccia-bearing successions of the Late Devonian Fairholme Group and Palliser Formation are the most prospective host rock units for this mineral deposit type.

In conclusion, the southwest portion of Alberta is geologically complex and contains numerous different types of metallic mineral showings, hence this area should be considered as a prospective target locale for a variety of other potential precious and base metal deposit types as discussed by Williamson et al. (1993) and by Olson et al. (In press).

INTRODUCTION

Fieldwork for the 1993 stratigraphic study occurred during the period from August 21 to September 19 at pre-selected locales within the region underlain by the Southern Alberta Rift in southwest Alberta. During this time 27 geological traverses were completed (see Figure I-2 in Section I), which included 138 stations where geological observations were recorded or stratigraphic sections were measured. The stations were widely distributed across the field area. A total of 32 stratigraphic sections were measured, with a total cumulative thickness of about 9,160 m (Figures I-2, and II-1 to II-32). As well, 447 paleocurrent measurements were collected (Figures II-33 to II-65). The 32 stratigraphic sections in Figures II-1 to II-32 are accompanied by two separate pages that explain the lithologic legend, and the sedimentary and stratigraphic symbols used on each section. With respect to the paleocurrent rose diagrams in Figures II-33 to II-65, these figures are accompanied by a page that explains the plot interval in degrees width, and the number of readings on each plot.

The 1993 project was designed to geologically examine rocks of Middle Proterozoic to Tertiary age to search for evidence concerning:

1. The possible location of the faulted north and south margins of the Southern Alberta Rift in the Foothills and Rocky Mountains of southwest Alberta.

2. The related influences on sedimentation patterns that would be associated with the evolution and subsequent reactivation of the Southern Alberta Rift.

3. The geological setting of any associated mineral showings or alteration zones that were found or known to exist along the locales where traverses were conducted.

In summary, the primary goal of the 1993 field program was to lead to a better understanding of the regional tectono-sedimentary structure and evolution of the Southern Alberta Rift, in order to provide applicable mineralization models to assist industry in their future exploration of southwest Alberta.

REGIONAL GEOLOGY OF SOUTHWEST ALBERTA

The Southern Alberta Rift area is underlain by predominantly Middle Proterozoic to Tertiary age sedimentary rocks.

The Helikian Purcell Supergroup, which includes the Unnamed, Haig Brook, Tombstone Mountain, Waterton, Altyn, Appekunny, Grinnell, Siyeh, Purcell Lava, Sheppard, Gateway, Phillips and Roosville Formations in southwest Alberta, comprises a thick sequence of shallow water marine clastic sediments and near-shore stromatolitic carbonates (McMechan, 1981; Price, 1964; Aitken and McMechan, 1992). The deposition of the Proterozoic sediments ended with uplift during the East Kootenay Orogeny (White

1959; Leech 1962). The Cambrian, which includes the Flathead, Gordon and Elko Formations in southwest Alberta, lies unconformably on the Proterozoic Purcell Supergroup. The Cambrian rocks consist of thick accumulations of carbonate deposited in the Alberta Basin that grade laterally to the west into shallower water shales and conglomerates at the west margin of the Cambrian Purcell Arch (Gabrielse and Yorath, 1992). In southwest Alberta, no Ordovician and Silurian strata are known to exist. Regional uplift occurred during Ordovician to early Devonian time and this caused the erosion or non-deposition, or both, of much of the Ordovician and Silurian strata. In the Early Late Devonian, seas transgressed over the Interior Platform into Alberta, and broad-scale subsidence was common over much of the craton (Stott and Aitken, 1993). Devonian carbonate bank and reef growth that fringed the Interior Platform kept pace with the subsiding craton. The Late Devonian Fairholme Group lies unconformably under the late Late Devonian Alexo and Palliser Formations. A marine regression caused the upper Fairholme Group carbonate reefs to be emergent. The overlying Alexo Formation is comprised of carbonate clastic sediments, possibly related to erosion of the Fairholme Group. Thick accumulations of Palliser Formation carbonates, which conformably overlie the Alexo Formation, are in turn conformably overlain by early Mississippian black shales of the Exshaw Formation. The Mississippian Banff Formation and Rundle Group comprise a thick sequence of shallow-water crinoidal limestone and dolomite, and carbonate clastic sediments. The Pennsylvanian Spray Lakes Group conformably overlies the Mississippian Rundle Group in southwest Alberta, and consists predominantly of quartz arenites. Spray Lakes Group is unconformably overlain by the Permian Ishbel Group. The Ishbel Group comprises shallow-water, cross-bedded sandstones, phosphatic siltstones and cherty dolomite to chert. The Ishbel Group is unconformably overlain by the Triassic Spray River Group. The Spray River Group is comprised of the Sulphur Mountain Formation deltaic sediments, and the Whitehorse Formation, which consists of gypsum, red beds, and collapse breccias that were probably deposited in a restricted basin. The Jurassic in southwest Alberta is represented by the Fernie Group. The retreat of the sea during the Late Jurassic, and an influx of clastic sediments derived from the Columbian Orogen to the west, resulted in the gradational boundary between the Fernie Group and the overlying Jurassic-Cretaceous Kootenay Group. Jansa (1972) suggested that the uppermost sandstones in the Fernie Group may be 'passage beds' and interpreted them as prodelta deposits of an easterly-prograding clastic wedge, which are overlain by the deltaic coal-bearing deposits of the Kootenay Group. The Kootenay Group is unconformably overlain by the Early Cretaceous Blairmore Group. The Kootenay-Blairmore cycle, which is the lower molasse of Eisbacher et al. (1974), comprises deltaic, shallow-marine sediments that are overlain by clastic wedge sediments derived from erosion of the Columbian Orogen to the west. Following the Early Cretaceous Kootenay-Blairmore molasse cycle, the Late Cretaceous-Tertiary marine Alberta Group assemblage and the non-marine Belly River Formation to Paskapoo Group assemblage, comprise the upper molasse of the Columbian Orogen. These molasse cycles are a sequence of continental to near-shore, relatively shallow-water facies that alternate between marine and non-marine clastic sediments. The stratigraphy of southwest Alberta is dominated by these molasse cycles from Late Jurassic to Tertiary time.

In southwest Alberta, major sole thrusts such as the Lewis, McConnell, Turtle Mountain and Livingstone Thrusts carry older sedimentary or volcanic rocks, or both, over younger rocks (Gabrielse and Yorath, 1992). Numerous other thrust faults are present throughout the Foothills and Rocky Mountains of southwest Alberta. The Lewis Thrust sheet forms a large, broad synclinorium which extends from the Akamina Syncline in the Clark Range to several other anticlines and synclines near Mount McCarty, which is south of Blairmore. In addition, steeply-dipping, northeast-trending normal faults of undetermined vertical throw are known to exist within the Southern Alberta Rift area.

Southern Alberta Rift

The Southern Alberta Rift was first described by Kanasewich (1968) and Kanasewich et al. (1969) using deep seismic reflection, magnetic and gravity data. Kanasewich (1968) suggested the trace of the rift is visible for 450 km from just north of Medicine Hat near the Saskatchewan border to the Rocky Mountains southwest of Cranbrook near the 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 Kimberley, 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 Bouguer gravity anomaly maps reveal significant differences in the gravity field on either side of these faults marking the site of a long-lived, crustal scale tectonic feature (Price 1981; Fountain and McDonough, 1984). Rifting during Helikian to early Cambrian time at the edge of the North American continent has been described by a number of authors (Leech, 1962; Stewart 1972; Lis and Price, 1976; Benvenuto and Price, 1979; Struik, 1987; Devlin and Bond, 1988; Devlin, 1989). Evidence for a younger reactivation with, perhaps, lesser magnitude faulting associated with the Southern Alberta Rift 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. Hopkins (1987, 1988) described synsedimentary subsidence of Lower Cretaceous rocks in the Cessford hydrocarbon field associated with a narrow graben that reaches from the Precambrian basement into the Cretaceous section. The Cessford field is 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 Formation volcanics centred within the bounds of the rift (Pearce, 1970; Adai,r 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 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).

PURCELL SUPERGROUP: STRATIGRAPHY

The Purcell Supergroup of southeast British Columbia and southwest Alberta ranges in thickness from approximately 2 km in southwest Alberta to a maximum of more than 11 km in southeast British Columbia (Figures II-66 and II-67). In this area the Purcell Supergroup includes a lower sequence comprised of fine-grained basinal clastic strata in southeast British Columbia, and platformal siliciclastic and carbonate rocks in southwest Alberta. The lower sequence of Purcell Supergroup includes the 'unnamed units' to the Siyeh Formation, and an upper sequence of shallow marine and non-marine rocks that includes the Sheppard to Roosville Formations. The base of the Purcell Supergroup is not exposed.

Facies changes in the Purcell Supergroup are well defined near the northwest part of the Clark Range in southwest Alberta, but are more subtle in southeastern British Columbia (McMechan, 1981). A complex stratigraphy has been erected due, in part, to the presence of regional and local facies changes and also to the usage of different nomenclature between American and Canadian geologists (Table II-1). The proposed origin of the Belt-Purcell basin is also viewed differently:

(i) Canadian geologists, on the basis of thickness variations and southwestward proximal to distal facies changes, have envisioned a continental margin setting and miogeoclinal origin for the Purcell Supergroup (McMechan, 1981; Ross et al., 1989).

(ii) American geologists, however, have interpreted the Belt basin as a miogeocline or an aulacogen (Harrison, 1972; Harrison et al., 1974) and also as an intercratonic basin (Winston et al., 1984).

The Purcell Supergroup has been divided, by Aitken and McMechan (1992), into four broad units on the basis of distinctive lithologies and on the regional correlation of lithostratigraphic units (Table II-2).

Regional and local thickness and facies changes are most pronounced in strata of the Basal Division. The Basal Division encompasses a relatively thin carbonate-dominated platform succession in the Clark Range of southwest Alberta and a thick basinal assemblage in southwest British Columbia (Figures II-66 and II-67). The Basal Division represents a marginal to basinal transition along a divergent continental margin. Variations in the Lower Division reflect the embayed nature of the early passive continental margin. The Middle Carbonate Division comprises a thin platformal facies in southwest Alberta, and a thicker, more basinal facies elsewhere. Facies changes in the Upper Division are more pronounced in southeastern British Columbia (Figure II-67).

FIGURE II-66

COMPOSITE STRATIGRAPHIC SECTION FOR THE PURCELL SUPERGROUP IN SOUTHEAST BRITISH COLUMBIA AND SOUTHWEST ALBERTA
(Modified after Aitken and McMechan, 1992)

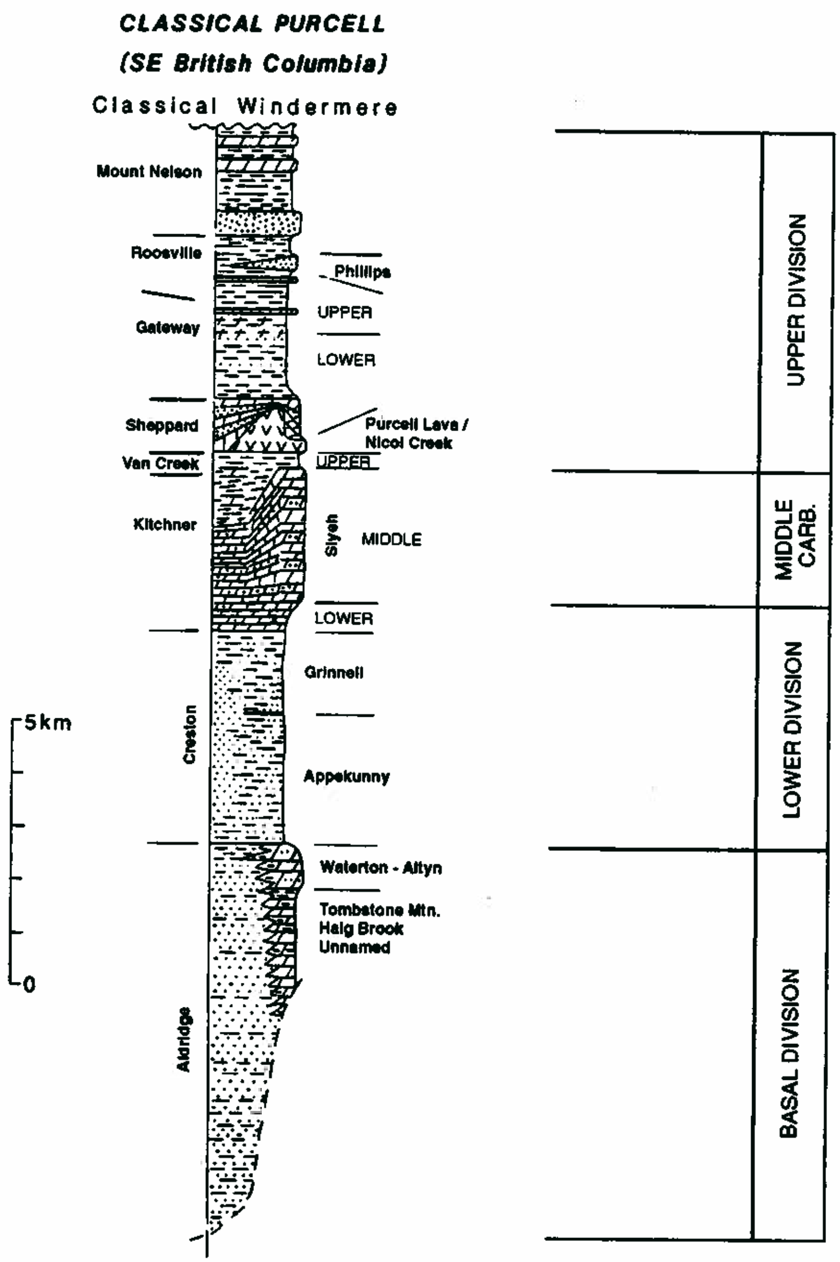


FIGURE II-67

REGIONAL STRATIGRAPHIC CROSS-SECTION FOR THE PURCELL SUPERGROUP FROM SOUTHEAST BRITISH COLUMBIA TO SOUTHWEST ALBERTA (After Ross et al., 1989)

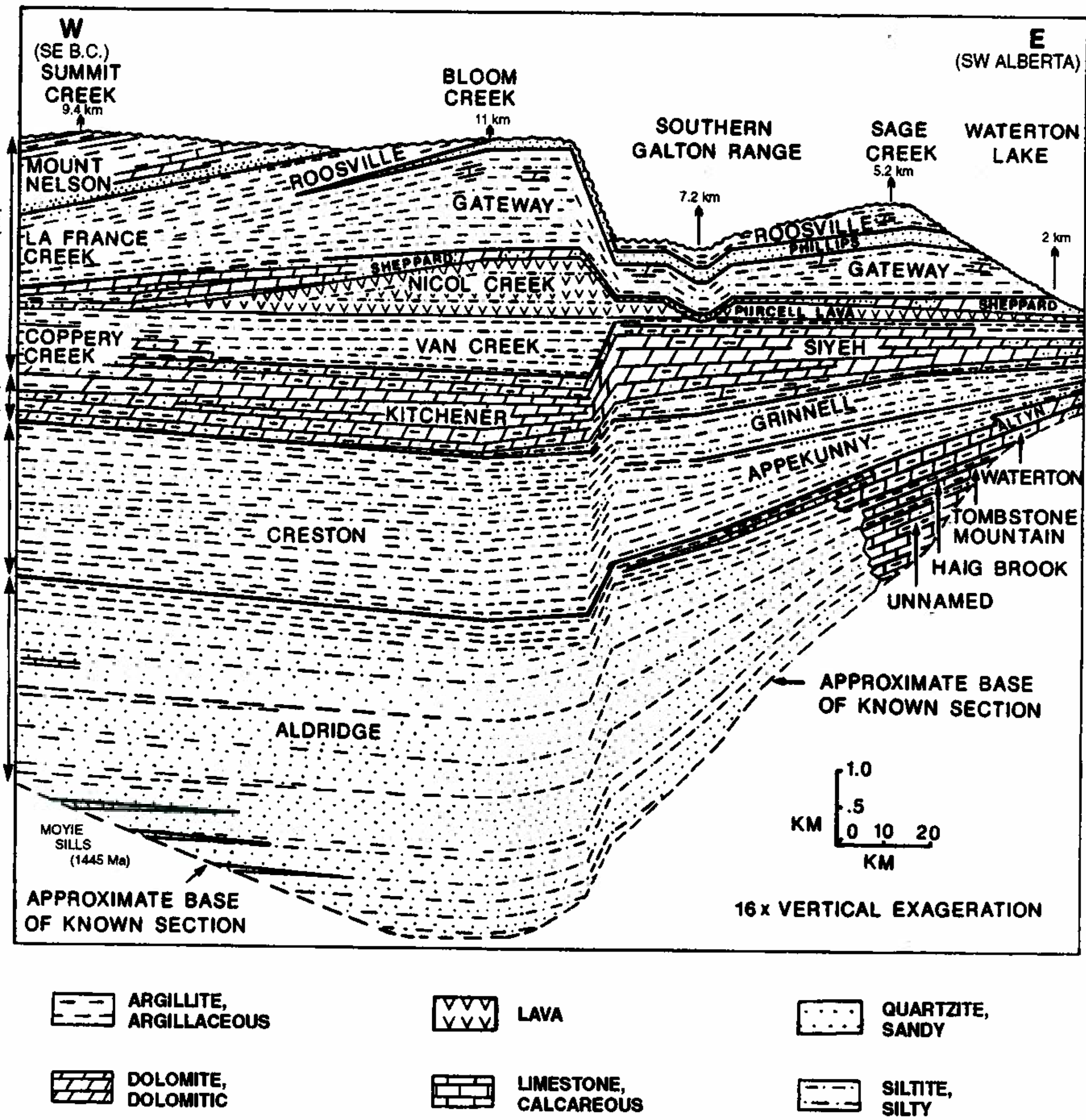


TABLE II-1

NOMENCLATURE FOR THE PURCELL (BELT) SUPERGROUP (After McMechan, 1981; Aitken and McMechan, 1992)

MIDDLE PROTEROZOIC PURCELL (BELT) SUPERGROUP

NORTHERN IDAHO Harrison and Jobin (1963)	WESTERN PURCELL MTNS. Ressor (1984, pers. comm.)	NORTHERN PURCELL MTNS. Ressor (1958, pers. comm.)	HUGHES RANGE Hoy (1979) McMechan et al (1980)	LIZARD RANGE S. PURCELL MTNS. Leech (1958), McMechan (1980)	CLARK RANGE GALTON RANGE Price (1962, 1964), Fermor and Price (1983)	GLACIER PARK MONTANA Earheart et al (1983)
LIBBY FM. (Missoula Group)						
STRIPED PEAK FM. (Missoula Group)	MT. NELSON FM.	MT. NELSON FM.				
		ROOSVILLE FM.	ROOSVILLE FM.	ROOSVILLE FM.	ROOSVILLE FM.	unnamed
WALLACE FM.	'La France Creek' Group	SHEPPARD - GATEWAY FM.	PHILLIPS FM.	PHILLIPS FM.	PHILLIPS FM.	RED PLUME QZ.
			GATEWAY FM.	GATEWAY FM.	GATEWAY FM.	MOUNT SHIELDS FM.
			SHEPPARD FM.	SHEPPARD FM.	SHEPPARD FM.	SHEPPARD FM.
	'Coppery Creek' Group	VAN CREEK FM.	NICOL CREEK FM.	NICOL CREEK FM.	PURCELL LAVA	SNOWSLIP FM.
			VAN CREEK FM.	VAN CREEK FM.	SIYEH FM.	HELENA FM.
		KITCHENER FM.	KITCHENER FM.	KITCHENER FM.		EMPIRE FM.
ST. REGIS FM. (Ravalli Group)	CRESTON FM.	CRESTON FM.	CRESTON FM.	CRESTON FM.	GRINNELL FM.	GRINNELL FM.
REVETT FM. (Ravalli Group)					APPEKUNNY FM.	APPEKUNNY FM.
BURKE FM. (Ravalli Group)						
upper two mbr.	upper unit	upper unit	upper unit	upper unit	ALTYN FM.	ALTYN FM.
					WATERTON FM.	PRICHARD FM.
					TOMBSTONE MTN. FM.	
PRICHARD FM.	ALDRIDGE FM.	ALDRIDGE FM.	ALDRIDGE FM.	ALDRIDGE FM.	HAIG BROOK FM.	
					1	
					2	
					3	
			FORT STEELE FM.		4	
BASE NOT EXPOSED						

Mafic sills and, less commonly, dykes intrude the Purcell Supergroup throughout its area of exposure. Sills occur in all units of the Purcell Supergroup, while lavas occur only in the Upper Division (stratigraphic sections 3I045, 3I055, 3I063; Figures II-10, II-11 and II-12). The intrusions were emplaced during more than one igneous event.

The age of the Purcell Supergroup can be estimated using several different methods: (i) Höy (1989) stated that the Moyie Sills in the basal Aldridge Formation have a minimum age of emplacement of 1,445 million years ago (Ma); (ii) geochronological studies indicate that sedimentation occurred in the Belt-Purcell basin between 1,500 Ma and 850 Ma (Aitken and McMechan, 1992); and (iii) paleomagnetic studies indicate that sedimentation occurred between about 1,500 Ma and 1,200 Ma (Ibid). The paleomagnetic dates seem reasonable and consistent with a rubidium-strontium whole rock date of about 1,300 Ma for the Hellroaring Creek Stock, which cuts folded and metamorphosed Purcell Supergroup strata in southeast British Columbia (McMechan and Price, 1982).

TABLE II-2

TECTONIC AND LITHOSTRATIGRAPHIC UNIT DIVISIONS
OF THE PURCELL SUPERGROUP

TECTONIC DIVISIONS	LITHOSTRATIGRAPHIC UNIT DIVISIONS	
DOWNWARP II	SOUTHEAST BRITISH COLUMBIA	SOUTHWEST ALBERTA
	UPPER DIVISION	
	MOUNT NELSON FORMATION	
RIFT II	ROOSVILLE FORMATION GATEWAY FORMATION SHEPPARD FORMATION NICOL CREEK LAVA	ROOSVILLE FORMATION PHILLIPS FORMATION GATEWAY FORMATION SHEPPARD FORMATION PURCELL LAVA
DOWNWARP I	VAN CREEK FORMATION	UPPER SIYEH FORMATION
	MIDDLE CARBONATE DIVISION	
	KITCHENER FORMATION	MIDDLE SIYEH FORMATION
RIFT I	LOWER DIVISION	
	CRESTON FORMATION	LOWER SIYEH FORMATION GRINNELL FORMATION APPEKUNNY FORMATION
	BASAL DIVISION	
	ALDRIDGE FORMATION	ALTYN FORMATION WATERTON FORMATION TOMBSTONE MOUNTAIN FORMATION HAIG BROOK FORMATION UNNAMED FORMATION (UNITS 1 - 4)

The Moyie Sills of southeastern British Columbia are an extensive suite of basaltic rocks that intrudes into the Aldridge and Fort Steele Formations (Basal Division), where it forms about one-quarter of the sequence (Höy, 1989). The Moyie Sills are the thickest and most abundant sills within the Purcell Supergroup, but there is a decrease in their volume upsection. The minimum age of emplacement for the Moyie Sills is 1,445 Ma, indicating that they are penecontemporaneous with Aldridge Formation sedimentation. Other, younger sills and dykes were also emplaced during Purcell Lava volcanism and in post-Purcell Supergroup times. Many of the post-Purcell sills and dykes may be related to rifting and volcanism associated with the Late Proterozoic Windermere Supergroup (Aitken and McMechan, 1992).

The Moyie Sills provide supportive evidence for deposition of the Purcell Supergroup in a large, subsiding intracratonic basin that formed during Middle Proterozoic rifting. The composition of these sills is subalkalic tholeiitic basalt, with minor alkaline basalt. There are two different chemical trends for these sills, which is typical of volcanism in an incipient rift environment, or in the early stages of continental rifting (Höy, 1989).

Facies and thickness changes in the Aldridge Formation indicate the presence of a structural basin to the south and west of the Boulder Creek Fault and Rocky Mountain Trench in early Purcell Supergroup time. Sedimentation at the edge of this basin was influenced by growth faults (Ibid).

BASAL DIVISION

The northeast limit of exposed Purcell Supergroup occurs along the leading edge of the Lewis Thrust sheet in the Clark Range. The basal strata in this area comprise mainly a platformal sequence, whereas in southeastern British Columbia the equivalent strata are more basinal in nature.

Lowermost Units (beneath the Waterton Formation)

Along the western Clark Range, two new mappable units occur; these are the Tombstone Mountain and Haig Brook Formations (Fermor and Price, 1983). Four additional units, numbered 1 to 4, which were penetrated by the Pacific Atlantic Flathead No. 1 well at Sage Creek in the Clark and Galton Ranges, occur below the Haig Brook Formation (Table II-1). The recently described pre-Waterton Formation successions can be summarized, from top to bottom, as follows (after Fermor and Price, 1983; Figures II-66 and II-67; Table II-1):

Tombstone Mountain Formation (175 m)

Dark grey argillite and argillaceous dolostone and limestone; carbonate content decreases to the south.

Haig Brook Formation (150+ m)

Grey dolostone and limestone; intermixed grey, red and green argillaceous limestone and dolostone.

Unit 1 (107 m)

Dark grey calcareous and dolomitic argillite and black argillite; planar thin laminated.

Unit 2 (314 m)

Light brown-grey to medium grey argillaceous dolostone and black argillite, with red and green dolostone towards the base.

Unit 3 (219 m)

Grey, green, red and white, very finely crystalline dolostone and limestone.

Unit 4 (170+ m)

Medium grey to dark grey argillaceous dolostone; base unknown.

Waterton Formation

The Waterton Formation ranges in thickness from 170 m to 248 m. It forms the base of the Lewis Thrust sheet in the eastern Clark Range, where it consists of (1) very finely crystalline, banded and laminated limestone and dolostone, (2) green argillite and argillaceous, very finely crystalline dolostone, (3) varicoloured brown-red and light green, laminated, very finely crystalline dolostone, (4) dense white limestone and grey stromatolitic dolostone, and (5) cherty dolostone (Price, 1962, 1964). Fermor and Price (1983) identified similar strata in structural windows in the western Clark Range. The strata become more argillaceous southward and, at Sage Creek in southeastern British Columbia, equivalent strata are green-grey, thin-laminated dolomitic and calcareous argillite with minor limestone and argillite interlayers. Similar westward facies changes also occur between Waterton Lake and the southern Galton Range, where a carbonate-dominated platform assemblage passes westwards into argillaceous basinal deposits (Figure II-67).

Altyn Formation

The Altyn Formation ranges from 457 m in thickness in the northwest part of the Clark Range, to 152 m in the northeast and southeast parts of the Clark Range. It comprises dolostone and intermixed minor limestone with variable amounts of argillaceous and arenaceous carbonate and black to grey argillite. Altyn Formation strata conformably overlie those of the Waterton Formation, and pass gradationally upwards into the green argillites of the Appekunny Formation (Table II-1). The Altyn Formation can be divided into lower, middle and upper members in eastern, but not western exposures. The lower member becomes less argillaceous southwards (Fermor and Price, 1983; Hill and Mountjoy, 1984). Altyn Formation strata thicken greatly to the west across Waterton National Park; mainly due to increased thickness of the lower member, which increases from 60 m to 250 m. This thickening trend is accompanied by an increase in the amount of interlayered, thin-laminated argillite.

In the western Clark Range, dolomitic argillite overlies strata that is correlated with the Waterton Formation and underlies green argillite typical of the Appekunny Formation. The dolomitic argillite thickens southwards from 135 m to 210 m. The predominantly planar laminated strata also change from dominantly green to grey. Fermor and Price (1983) proposed that this argillite should be placed in the Appekunny Formation and not the Altyn Formation. Price (1964) interpreted the Altyn Formation and its equivalents as nearshore carbonate platform deposits that graded westward into deeper water, and a more basinal, mud-rich setting.

Strata of the Basal Division of the Purcell Supergroup in the western Clark Range can be correlated with the upper part of the Aldridge Formation (Tables II-1 and II-2; Figures II-66 and II-67). This correlation is supported by a southward increase in argillite content, thin-laminated beds and grey colour in the Altyn, Waterton and Tombstone Mountain Formations. Thickness and facies changes of strata in the Basal Division are consistent with basin margins having been present to the north and east (see Figure 5.7 in Aitken and McMechan, 1992). This figure (Ibid) outlines a northeast-trending trough that may represent a portion of the southeastern end of the Southern Alberta Rift.

LOWER DIVISION

The Lower Division of the Purcell Supergroup comprises largely siliciclastic strata deposited in shallow marine seas or continental settings. The siliciclastic units gradationally overlie carbonate-dominated to carbonate-clastic bearing platformal to basinal strata of the basal unit of the Appekunny Formation, and pass gradationally upwards into strata of the Middle Carbonate Division (Figure II-66).

Appekunny Formation

The Appekunny Formation consists of planar thin- to thick-laminated green, grey and minor red argillite, interlayered with thin-bedded grey-green siltstone and grey-green quartzarenite to quartzitic subarkose. The siltstone and sandstone beds typically contain ripple marks and trough crossbeds (stratigraphic sections 3I015, 3I016 and 3I056; Figures II-1, II-2 and II-3). Appekunny Formation thickens from 300 m to 600 m from east to west across the Clark Range (Figure II-67). This thickness trend is accompanied by a change from green and intermixed red argillite in the east, to mainly green argillite in the west. In the southwestern Clark Range, the argillite-dominated sequences are largely grey. Syneresis cracks and small-scale load structures occur within the strata, and argillite rip-up clasts are common. Additional structures within the Appekunny Formation include small load casts, scour marks and rare hummocky cross-stratified beds.

The Appekunny Formation beds accumulated in a shallow subtidal setting that included sand-dominated beach and channel-fill deposits. Green argillite and minor sandstone interbeds grade upwards into the red argillites and red-pink sandstones of the lower Grinnell Formation (Figure II-67).

Features in the Appekunny Formation that are indicative of rifting are summarized in Table II-3.

TABLE II-3

POSSIBLE RIFT-RELATED FEATURES IN THE APPEKUNNY FORMATION

FORMATION	FEATURE	RIFT RELATION
APPEKUNNY	(a) Strata thicken from 300 m (eastern Clark Range) to 600 m (western Clark Range). This thickness variation is accompanied by a change from green and intermixed red argillite in the east to mainly green argillite in the west and grey argillite in the southwest. These thickness and colour changes probably reflect a transition from proximal (i.e., 'platformal') to more distal (i.e., 'basinal') facies across the continental margin.	Moderate
	(b) The sections measured are characterized by the presence of medium to large scale, coarsening and thickening upward cycles. The cycles range from 3.5 m to 19 m in thickness, and were observed at sections 3I015 and 3I016 (western Clark Range), and 3I056 (eastern Clark Range). The lower portions of the sections are entirely cyclic (see, in particular, section 3I056 where there are several cycles present in the interval from A to K). Cycles also occur in the uppermost part of the formation. Cycles consist of the following three members: (i) Lower member: planar thin-laminated argillite with minor interlayers of lensed to wavy layered, thin-bedded quartzarenite to quartzitic subarkose. The quartzarenite to subarkose have ripple marks, load casts, scour marks and cross-laminations. (ii) Middle member: intermixed, nearly equal amounts of planar thin-laminated argillite and planar to wavy-bedded sandstone, with similar sedimentary structures to the lower member. (iii) Upper member: planar wavy layered to crossbedded quartzarenite to subarkose, with minor partings of argillite. These cycles represent stacked, regressive, shallow-marine-shelf cycles that were deposited in a subtidal regime where successive pulses of sand prograded basinwards (i.e., westwards and southwestwards) across the continental margin. Therefore, these cycles may represent tectonically induced prograding siliciclastic pulses.	Moderate

Grinnell Formation

Grinnell Formation consists of thin-laminated red argillite and intermixed planar layered, cross-laminated to crossbedded, red to pink-white, minor green-grey quartzarenite to subarkose. The quartzarenite and subarkose interbeds are concentrated in the lower one-third and upper one-third of the formation (stratigraphic sections 3I016 and 3I056;

Figures II-2 and II-3; Table II-1; Plate II-1.a). The beds contain syneresis cracks, current ripple marks, trough crossbeds and load structures. Argillite rip-up intraclasts are common and typically occur as intraclast conglomerate layers.

The argillite and sandstone beds of the upper Grinnell Formation pass gradationally upwards into the green to grey argillite and carbonate beds of the lower Siyeh Formation (Figure II-66). The Grinnell Formation increases in thickness from 30 m in the northeastern, to 230 m in the southeastern, and about 520 m in the southwestern parts of the Clark Range (Price, 1962, 1964; Figure II-68). The Grinnell Formation accumulated in a non-marine flood plain over much of the Clark Range area. Subordinate tidal flat deposits may have accumulated in the southwestern part of the Clark Range.

Features in the Grinnell Formation that are indicative of rifting are summarized in Table II-4.

Siyeh Formation - lower member

Strata in the lower member of Siyeh Formation contain the transition from clastic Grinnell Formation up into the carbonate-dominated middle member of the Siyeh Formation (stratigraphic section 31056; Figure II-3). The lower member comprises planar thin-laminated green, grey and grey-brown to black argillite, with minor amounts of variably intermixed thick-laminated to thin-bedded green and green-grey to brown-grey argillaceous dolostone to dolosiltite, and dolomitic quartzarenite to quartzitic sublitharenite. The succession thickens from 9 m in the northwest, to about 30 m in the southwest, and about 150 m in the southeast parts of the Clark Range. The lower member thickens at the expense of the overlying middle member of Siyeh Formation (Figure II-67).

In summary, the thickness changes in the Lower Division of the Purcell Supergroup outline a northeast-trending rectilinear basin or trough in southeastern British Columbia and southwestern Alberta. Platformal to basinal facies changes within the Lower Division also reflect this basinal shape (McMechan, 1981; Figure 5.7b in Aitken and McMechan, 1992). This basin overlies a portion of the proposed northern margin of the Southern Alberta Rift in southeastern British Columbia.

Plate II-1

1.a: **Grinnell Formation**
(stratigraphic section 3I056.OII; Figure II-3)

Maroon thin-laminated argillite and maroon to buff-pink planar layered to cross-laminated sandstone couplets in the lower part of the Grinnell Formation. The beds are exposed along Pincher Ridge in the eastern Clark Range. The sandstone horizon in the upper part of the photograph is 0.2 m thick.

1.b: **Lower to middle Siyeh Formation**

Cliff-forming beds of the lower to middle members of the Siyeh Formation at Rainy Ridge in the western Clark Range. The strata change upsection from thickening-upward cyclic assemblages into more resistant platformal carbonates. The exposed section is about 400 m thick.

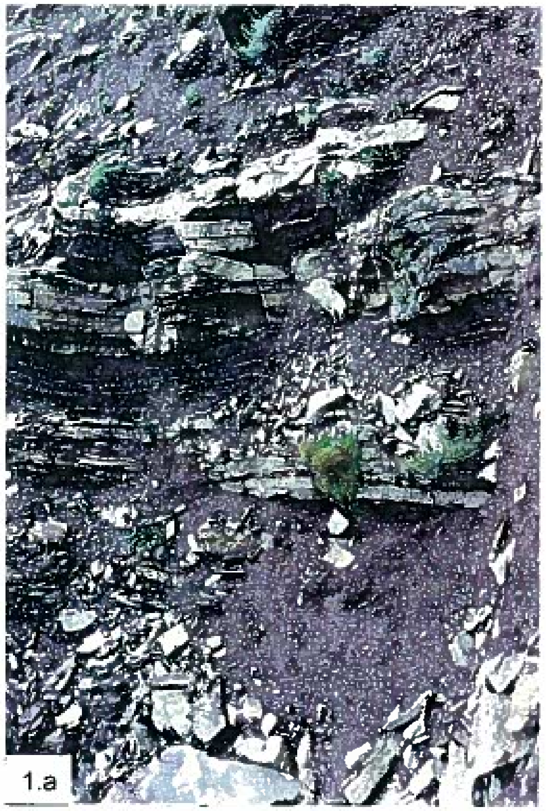
1.c: **Middle Siyeh Formation**
(stratigraphic section 3I016.DD-EE; Figure II-2)

Thickening-upward cycle in strata of the Middle Siyeh Formation at Rainy Ridge. The sequence grades up from thin-laminated dololutite and argillite, through interlayered dolosiltite to dolarenite, with argillite partings, into resistant stromatolitic dolostone at the top of the photograph. Note the sedimentary growth faults at the base of the stromatolitic dolostone layer. The outcrop pictured is about 4 m thick.

1.d: **Upper Siyeh Formation**
(stratigraphic section 3I035; Figure II-8)

General view of strata in the upper member of the Siyeh Formation at Table Mountain in the northeastern Clark Range. Massive-weathering, pillowed andesites of the Purcell Lava (the dark unit at the top of the photograph) are underlain by a 20 m thick horizon comprised of interlayered maroon argillite and sandstone 'redbeds' of Siyeh Formation. The redbeds are underlain by a thick succession of interlayered green and green to buff-grey argillite and sandstone.

PLATE II - 1


1.a


1.b


1.c


1.d

FIGURE II - 68

THICKNESS TRENDS FOR THE GRINNELL FORMATION

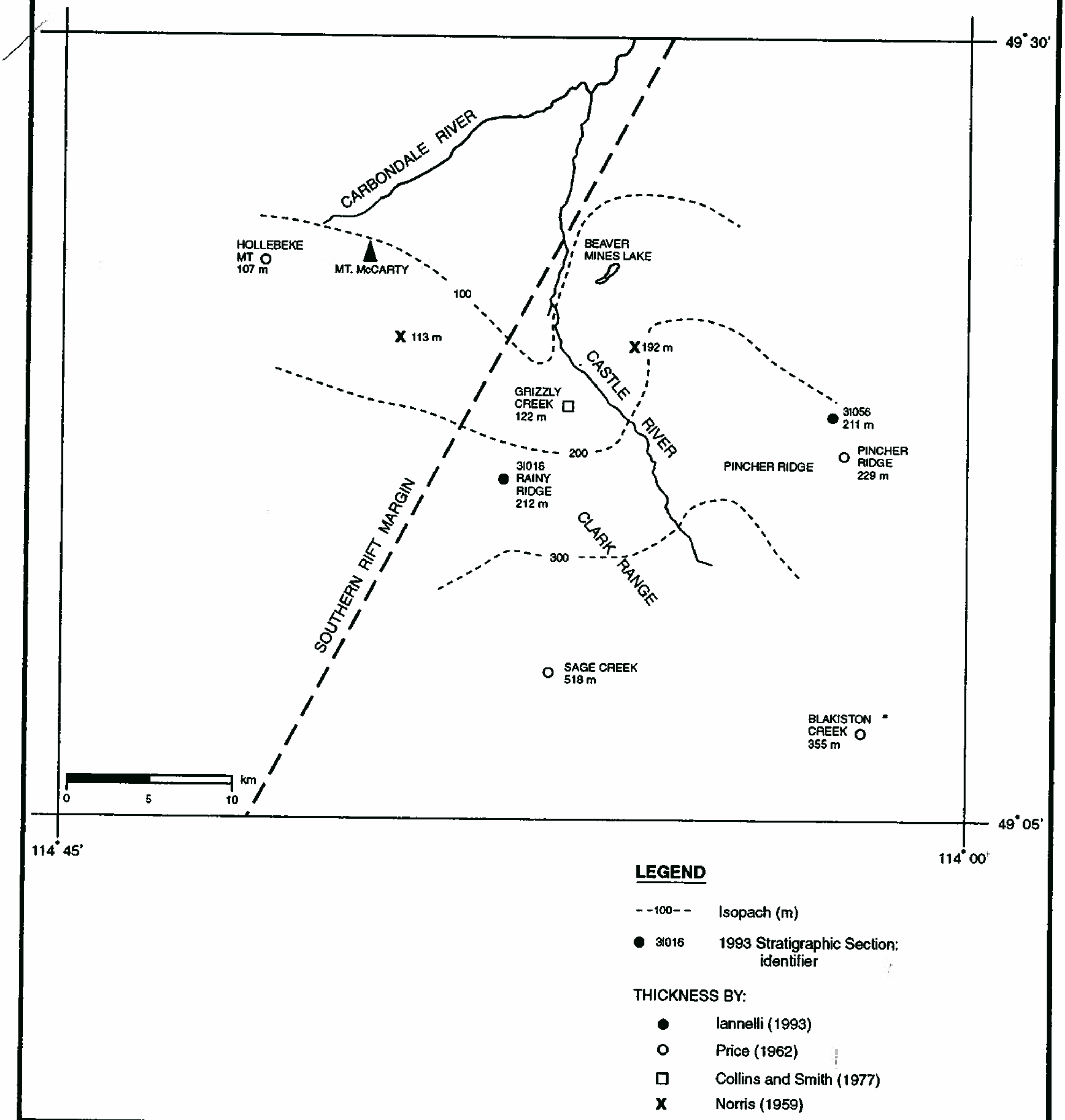


TABLE II-4

POSSIBLE RIFT-RELATED FEATURES IN THE GRINNELL FORMATION

FORMATION	FEATURE	RIFT RELATION
GRINNELL	(a) The formation undergoes a facies change across the Clark Range. Sandstone increases in amount in the upper part of the formation, northwestwards from section 31016 (western Clark Range) to section 31056 (eastern Clark Range), a distance of 20 km. Sandstone content increases at the expense of the argillite-dominated middle member. The upper sandstone-dominated member increases from 37 m at section 31016 to 102 m at section 31056. The middle member thins in the same direction from 153.5 m at section 31016 to 81 m at section 31056.	Moderate
	(b) The formation contains cyclic facies units of at least three styles; these are present in the sandstone-bearing lower and upper members. (i) The most common style consists of couplets, <0.2 m to >2 m thick, of planar, wavy-bedded to cross-laminated or crossbedded sandstone with minor partings of argillite that grade up into planar, thin- to thick-laminated argillite horizons with minor thin beds or lenses of sandstone (Plate II-1.a). These couplets may represent channel infill/migration successions on an alluvial plain. They resemble cycles described by Collins and Smith (1977). (ii) Upper member strata at section 31056 contain three thickening up and coarsening up cycles (thickness is 4 m to 15 m), comprised of three sub-members: (1) the lower sub-member comprises planar thin-laminated argillite with minor thin, planar to wavy sandstone beds; (2) the middle sub-member comprises variably intermixed planar thin-laminated argillite and wavy, cross-laminated to crossbedded sandstone, with the sandstone content increasing upwards; and (3) the upper sub-member comprises crossbedded to cross-laminated, wavy to planar bedded sandstone, with minor thin interbeds and partings of argillite. (iii) The thicker sandstone units, in both the lower and upper members, contain thinning-up successions, with individual unit thicknesses ranging from <0.3 m to >1.5 m. Each unit changes from crossbedded to cross-laminated, wavy bedded sandstone up into sandstone with minor interbeds and partings of argillite. The type (ii) and (iii) successions may represent shallow marine shelf or tidal channel infill sequences. Type (iii) may also represent a channel infill sequence on a sandy braidplain.	Moderate

MIDDLE CARBONATE DIVISION

The Middle Carbonate Division forms a distinctive unit throughout the Purcell Supergroup (Figures II-66 and II-67). The sequence is of platformal character along its northeastern limit of exposure (i.e., the middle member of Siyeh Formation in southwestern Alberta) and of more basinal character elsewhere (i.e., the Kitchener Formation in southeastern British Columbia).

Siyeh Formation - middle member

The middle member of the Siyeh Formation comprises platform facies strata that include thin-laminated to thin-bedded argillaceous dolostone, dolosiltite, stromatolitic dolostone, quartzitic dolostone, dolomitic to calcareous quartzarenite to sublitharenite and graded siltstone-argillite couplets. Intraformational, carbonate flat pebble conglomerates, oolitic limestones and molar tooth-bearing carbonate beds also occur. Syneresis cracks and ripple marks are locally present (stratigraphic sections 3I016, 3I055 and 3I056; Figures II-2, II-11 and II-3, respectively; Plate II-1.b).

In the western Clark Range, the middle member of Siyeh Formation also includes variably intermixed units of silty and argillaceous dolostone, argillaceous limestone, and grey to black, graded dolosiltite-dololutite to siltstone-argillite couplets. Molar tooth structures, load casts and syneresis cracks are common in the in the siltstone-argillite beds. Intermixed quartzarenite, stromatolitic carbonate, flat pebble carbonate conglomerate and rare oolitic beds also are present. The middle member strata were deposited in shallow subtidal to intertidal settings along a carbonate-dominated platform in the northeastern Clark Range, to an intermixed carbonate-siliciclastic platform in the southwestern Clark Range.

A distinctive marker horizon, which is 14 m to 23 m thick, occurs near the upper part of the middle member of Siyeh Formation, and comprises stromatolitic dolostone or limestone (unit EE-FF in Figure II-2, unit A-B in Figure II-4, and unit PP-II in Figure II-3; Plate II-1.c). The horizon contains domal to columnar stromatolites, with the latter including small to large scale *Conophyton* that are arranged into mounds and bioherms.

Strata at the top of the middle member of Siyeh Formation become more argillaceous, and the transition to the argillite-dominated upper member of Siyeh Formation occurs over a few metres. Locally, in the southern Galton Range in southeastern British Columbia, strata of the Sheppard Formation rest disconformably on those of the middle member of Siyeh Formation, and mark a significant intrabasin unconformity (Figure II-67). The middle member of Siyeh Formation within the Clark Range thickens to the south and west. At its northern limits it is about 300 m thick, whereas at its southeastern limits it is about 275 m thick, and it comprises a thin platformal succession. This is in contrast to the southwestern Clark Range where it is about 630 m thick and it comprises a mixed platformal and basinal facies.

In summary, the regional variations in thickness of the Middle Carbonate Division outline a rectilinear basin margin similar to that of the Lower Division (Figure 5.7b in Aitken and McMechan, 1992). Their (Ibid) Figure 5.7b illustrates thickness trends along the north margin of the Southern Alberta Rift. The facies belts within the Middle Carbonate Division follow the isopach thickness trends.

UPPER DIVISION

Siyeh Formation - upper member

The upper member of the Siyeh Formation consists of alternating units of green and green-grey to red, planar thin-laminated argillite, dololutite and minor siltstone to dolosiltite (Figure II-66; stratigraphic sections 3I018, 3I021, 3I024-025, 3I034, 3I035, 3I044, 3I045, 3I055 and 3I056; Figures II-4 to II-11 and II-3, respectively; Plates II-1.d and II-2.a). As well, there are variably intermixed minor units of green and green-grey to buff-grey dolosiltite, dolarenite, and dolomitic quartzarenite to sublitharenite, with variably intermixed lesser amounts of argillite to dololutite.

In general, the Siyeh Formation thickens to the south (Figure II-69). Strata of the upper member of Siyeh Formation, however, increase southeastward in thickness from about 30 m in the northwest, to 104 m in the southwest, 140 m in the southeast and 134 m in the central parts of the Clark Range (Figure II-70). Thickening occurs, in part, at the expense of the middle member of Siyeh Formation. The upper member of Siyeh Formation contains syneresis cracks, cross-laminations, wave and current ripple marks, small trough crossbeds, scour marks, load casts, argillite intraclasts and thin conglomerate layers that contain argillite flat rip-up clasts.

In summary, the upper member of Siyeh Formation accumulated in a depositional environment that alternated between tidal flat-intertidal and non-marine alluvial flood plain settings (Price, 1964; Aitken and McMechan, 1992). The upper member of Siyeh Formation is abruptly overlain by the Purcell Lava. Pillowed andesite of the Purcell Lava sags down into the upper member of Siyeh Formation (Plate II-2.b).

Features in the Siyeh Formation that are indicative of rifting are summarized in Table II-5.

Purcell Lava

The Purcell Lava and its equivalent, the Nicol Creek Formation, form an important chronostratigraphic marker across southeastern British Columbia and southwestern Alberta (Table II-1; Figures II-66 and II-67). The unit consists of dark green, purple- to green-grey, chloritized and pillowed amygdaloidal andesitic flows (stratigraphic sections 3I024-025, 3I035, 3I044, 3I045 and 3I055; Figures II-6, and II-8 to II-11, respectively; Plates II-1.d, II-2.b and II-2.c). Amygdules of quartz, chlorite and calcite are present. in the andesitic flows Layers of porphyritic andesite up to 8 m thick, with tabular plagioclase phenocrysts up to 8 cm long, occur in some places.

Plate II-2

2.a: **Siliciclastic facies in upper Siyeh Formation**
(stratigraphic section 3I035.I; Figure II-8)

Detailed view of the maroon siliciclastic facies assemblage in the upper member of Siyeh Formation at Table Mountain in the northeastern Clark Range. The succession consists of alternating argillite- and sandstone-dominated horizons.

2.b: **Siyeh Formation - Purcell Lava contact**
(stratigraphic section 3I035.L; Figure II-8)

Well exposed contact between green-grey interlayered argillite and sandstone beds of the upper member of Siyeh Formation and overlying pillowed andesite of the Purcell Lava. Note how the pillows have sagged down into the underlying argillite.

2.c: **Purcell Lava - Sheppard Formation contact**
(stratigraphic section 3I035.N; Figure II-8)

Basal contact of the Sheppard Formation with underlying Purcell Lava at Table Mountain. The strata comprise dark green to grey-green volcanic clast sandstone beds that overlie amygdaloidal andesite of the Purcell Lava (at the base of the photograph). The exposure is about 0.5 m thick.

2.d: **Lower member of Gateway Formation**
(stratigraphic section 3I035.Y; Figure II-8)

Strata of the lower member of the Gateway Formation at Table Mountain. Exposure comprises a thinning-upward sequence of buff-red, planar thin-bedded to cross-laminated sandstone that grades up into intermixed thin-laminated maroon argillite and minor thin-bedded sandstone.

2.e: **Halite casts, lower member of Gateway Formation**
(stratigraphic section 3I035.Y; Figure II-8)

Maroon-weathered, thin-bedded sandstone with large halite casts. The sandstone occurs in the lower member of the Gateway Formation at Table Mountain.

PLATE II - 2

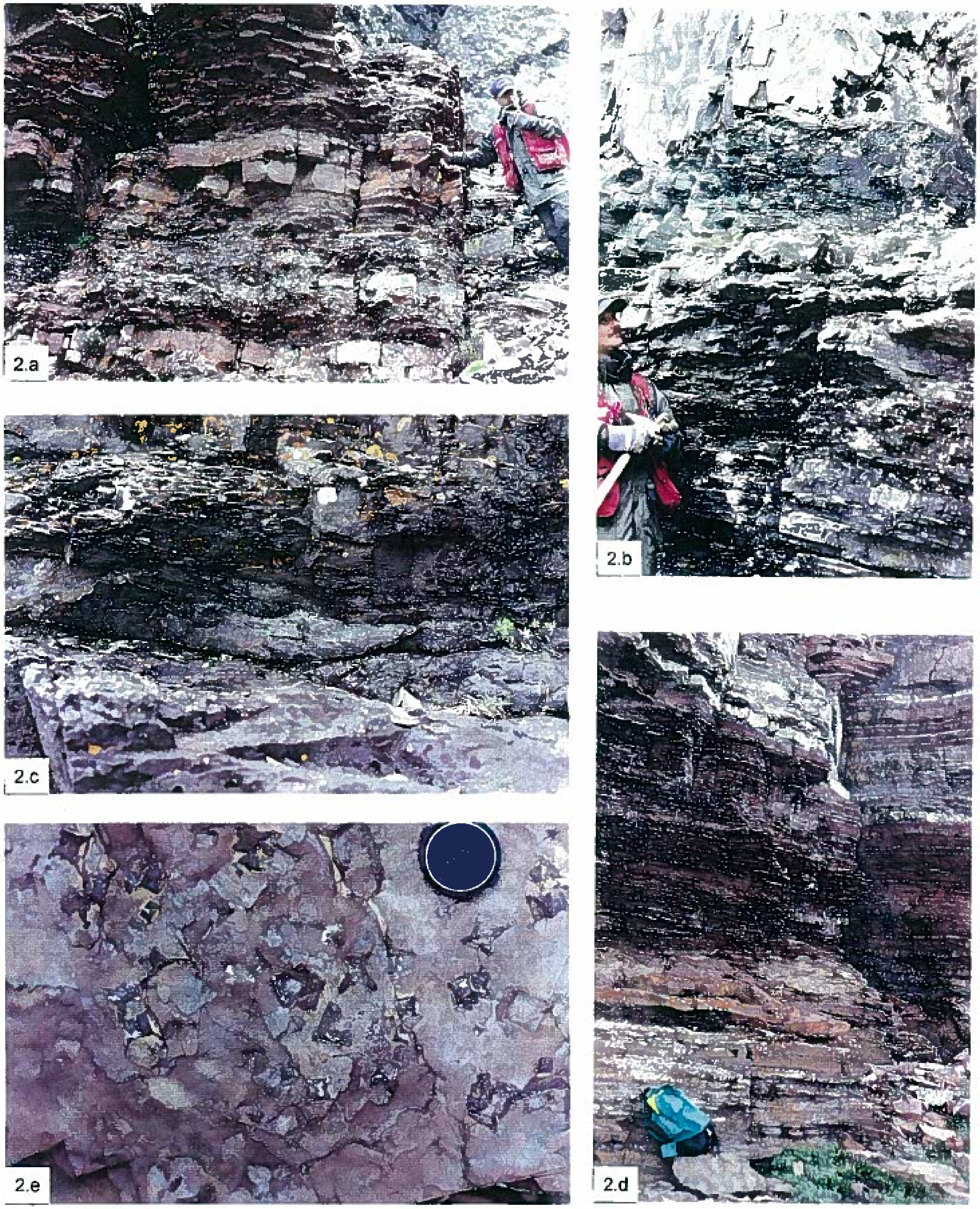
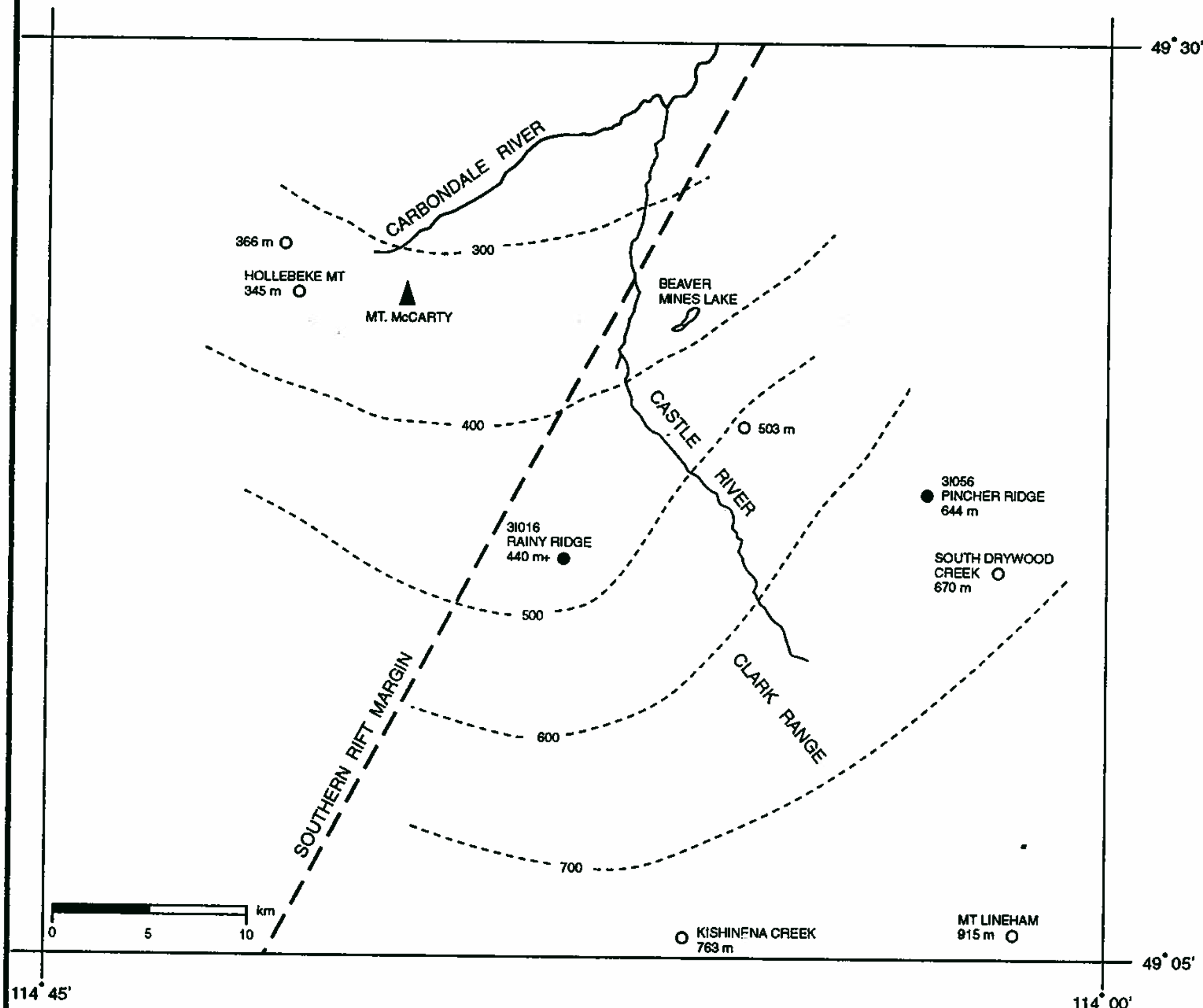


FIGURE II - 69

THICKNESS TRENDS FOR THE SIYEH FORMATION



LEGEND

- - 100 - - Isopach (m)

● 31016 1993 Stratigraphic Section: identifier

THICKNESS BY:

● Iannelli (1993)

○ Price (1962, 1964)

FIGURE II - 70

THICKNESS TRENDS FOR THE UPPER MEMBER OF THE SIYEH FORMATION

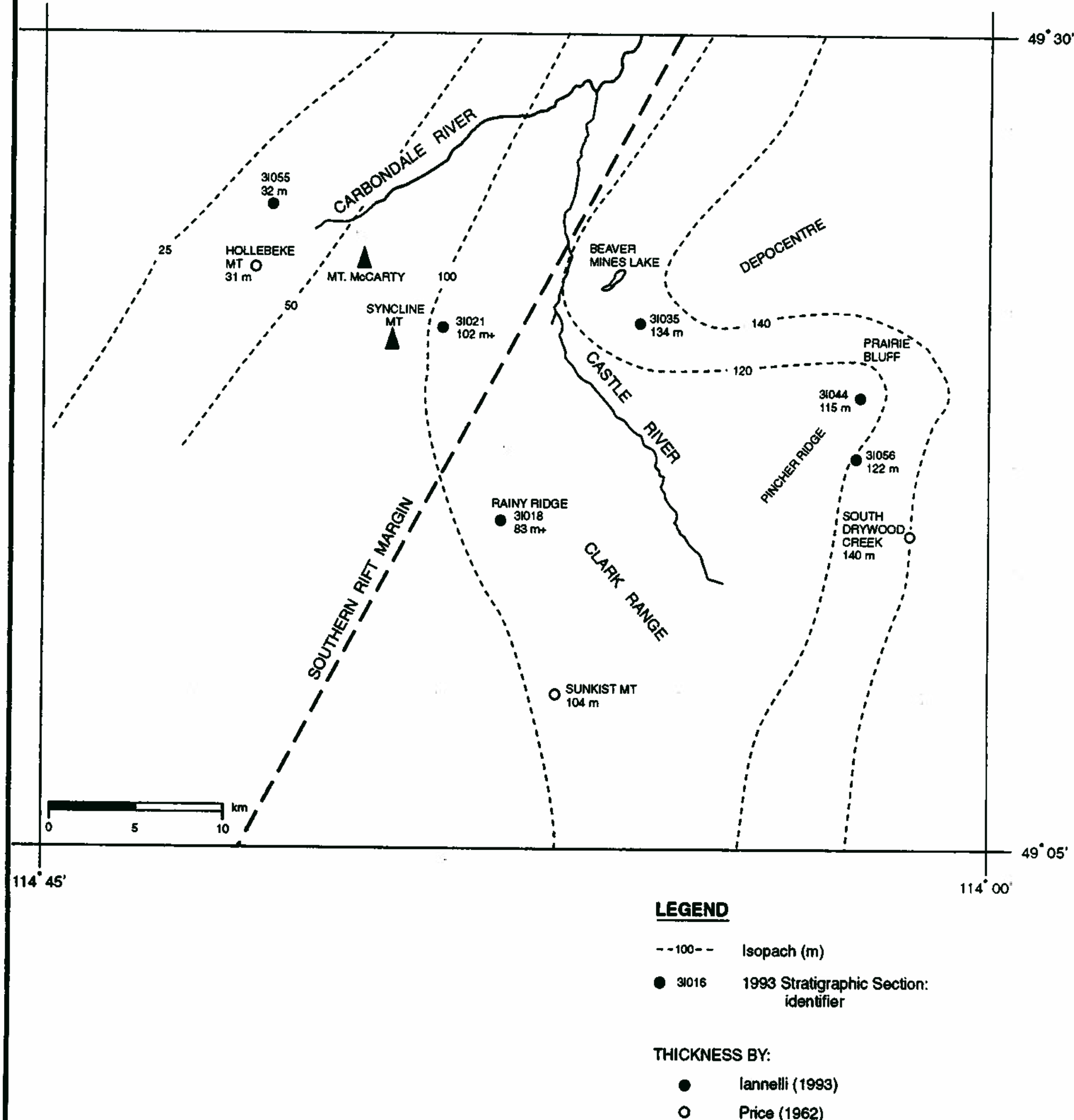


TABLE II-5

POSSIBLE RIFT-RELATED FEATURES IN THE SIYEH FORMATION

FORMATION	FEATURE	RIFT RELATION
SIYEH	(a) Strata of the Siyeh Formation thicken greatly to the south and southeast (Figure II-69). Thickness variations in the upper member of Siyeh Formation are particularly interesting. Strata of the upper member of Siyeh Formation thicken greatly to the east and southeast (Figure II-70). On a local scale, however, significant thickness variations occur across the Clark Range. A thick sequence is preserved in the north-central Clark Range east of Table Mountain. This local thickening may indicate the presence of a depocentre situated in the vicinity of the south margin of the Southern Alberta Rift (Figure II-70).	Strong
	(b) The upper member of Siyeh Formation consists of two contrasting lithofacies assemblages. Strata include carbonate sequences typical of those in the middle member of Siyeh Formation (i.e., intermixed dololutite, dolostone, stromatolitic carbonate, minor dolomitic sandstone), that alternate with thick units of grey-green, green and maroon to red argillite, with subordinate sandstone and carbonate (Plates II-2.a and II-2.b). The siliciclastic content of the upper member of Siyeh Formation has increased at the expense of the carbonate content. The siliciclastic-rich Upper member represents a sedimentation regime quite different from that of the Middle member, and may be a precursor sequence to a second active rift phase where there was carbonate platform destruction due to terrigenous clastic influx.	Strong
	(c) Facies variations are best developed in the upper member of Siyeh Formation (stratigraphic sections 3I018, 3I020-021, 3I035, 3I044, 3I055 and 3I056; Figures II-4, II-5, II-8, II-9, II-11 and II-3). The bulk composition of the upper member changes significantly across the Clark Range. Sequences in the east comprise intermixed argillite and carbonate-dominated lithofacies assemblages (stratigraphic sections 3I044 and 3I056). Argillite-dominated sequences occur in the central Clark Range (stratigraphic sections 3I018 and 3I035). Sandstone- and argillite-dominated sequences are preserved in the northwestern Clark Range (stratigraphic sections 3I020-021 and 3I055). The varied lithologic nature of the upper member, in combination with the thickness trends noted in (a), hint at deposition in a structurally partitioned basin. That is, depocentres were sub-blocks or sub-troughs in a rift complex.	Strong
	(d) The Siyeh Formation conmains cyclic facies sequences of at least three styles, variably distributed within the lower, middle and upper members (stratigraphic sections 3I016, 3I020-021, 3I035, 3I044, 3I055 and 3I056; Figures II-2, II-5, II-8, II-9, II-11 and II-3). (i) Lower and middle members of the Siyeh Formation contain medium to large scale thickening- or shallowing-up cycles that range in thickness from 2 m to at least 20 m, and contain two members (Plates II-1.b and II-1.c). (1) The lowerpart of each cycle comprises intermixed planar thin- to thick-laminated argillite to dololutite and planar to wavy layered, thick-laminated to thin-bedded dolosiltite, dolarenite to dolomitic sandstone. The argillite content decreases upwards while bed thickness increases upwards. (2) The upper part of each cycle comprises variably intermixed, thin-bedded, planar to wavy layered dolosiltite, dolarenite and stromatolitic carbonate, less commonly with thin-bedded to massive layers of molar tooth-bearing limestone, oolitic limestone and dolorudite to sublitharenite. The cycles represent transgressive, shallow carbonate shelf successions, deposited on a deeply subsiding continental margin. The subsidence regime may be an effect of post-rift crustal relaxation or regional downwarp. (ii) Siliciclastic assemblages of the upper member of Siyeh Formation contain alternating sandstone and argillite couplets, similar to those observed in the Grinnell Formation. The couplets consist of alternating planar to cross-laminated or crossbedded sandstone which are 0.1 m to 0.5 m thick, and units of intermixed planar thin-laminated argillite and wavy to cross-laminated siltstone to fine-grained sandstone which are 0.2 m to >1 m thick (Plate II-2.a). (iii) The upper member of Siyeh Formation also contains more clastic-rich, shallowing- or thickening-up versions of the cycles observed in the lower and middle members. The cycles in the upper members range from 1.5 m to 10 m in thickness. (1) The lower part of each cycle comprises planar thin-laminated argillite and intermixed thin-bedded dolarenite and dolomitic sandstone, with argillite decreasing upwards. (2) The upper part of each cycle comprises variably intermixed, planar to wavy bedded to crossbedded dolomitic sandstone to sublitharenite, dolarenite to sandy dolostone. The cyclic origin of the upper member of Siyeh Formation is similar to those in the lower and middle members, but represents a more proximal version.	Moderate

The lava is up to 90 m thick in the northwestern and central Clark Range, and thickens to between 107 m and 148 m in the southeastern Clark Range. The lava is over 120 m thick in the southern Galton Range in southeastern British Columbia, but is absent along nearby Phillips Creek (Figure II-71). There, the Purcell Lava has been removed by erosion, and strata of the Sheppard Formation overlie those of the middle to upper members of the Siyeh Formation (Figure II-67).

Features in the Purcell Lava sequence that are indicative of rifting are summarized in Table II-6.

TABLE II-6

POSSIBLE RIFT-RELATED FEATURES IN THE PURCELL LAVAS

FORMATION	FEATURE	RIFT RELATION
PURCELL LAVA	(a) The presence of pillowed andesite flows in the middle part of the Purcell Supergroup succession lends support for the occurrence of a second phase of extension. That is, the lavas indicate the initiation of a second cycle of continental rifting.	Very Strong
	(b) The Purcell Lava varies in thickness from about 90 m to 148 m within the Clark Range. Regionally, the Purcell Lava thickens to the south and southwest, but the unit is absent along the southern Galton Range in southeastern British Columbia (Figure II-71). There, the andesite flows have been removed during a pre-Sheppard Formation erosional interval. Sheppard Formation strata, with basal volcanic clast sandstone and conglomerate beds, disconformably to unconformably overlie carbonate and carbonate-siliciclastic beds of the middle and upper members of the Siyeh Formation. Up to an estimated 200 m to 250 m of section has been removed. This implies considerable uplift of one or more sub-blocks within a syndepositionally active rift complex, and provides further support for a second phase of active rifting.	Very Strong

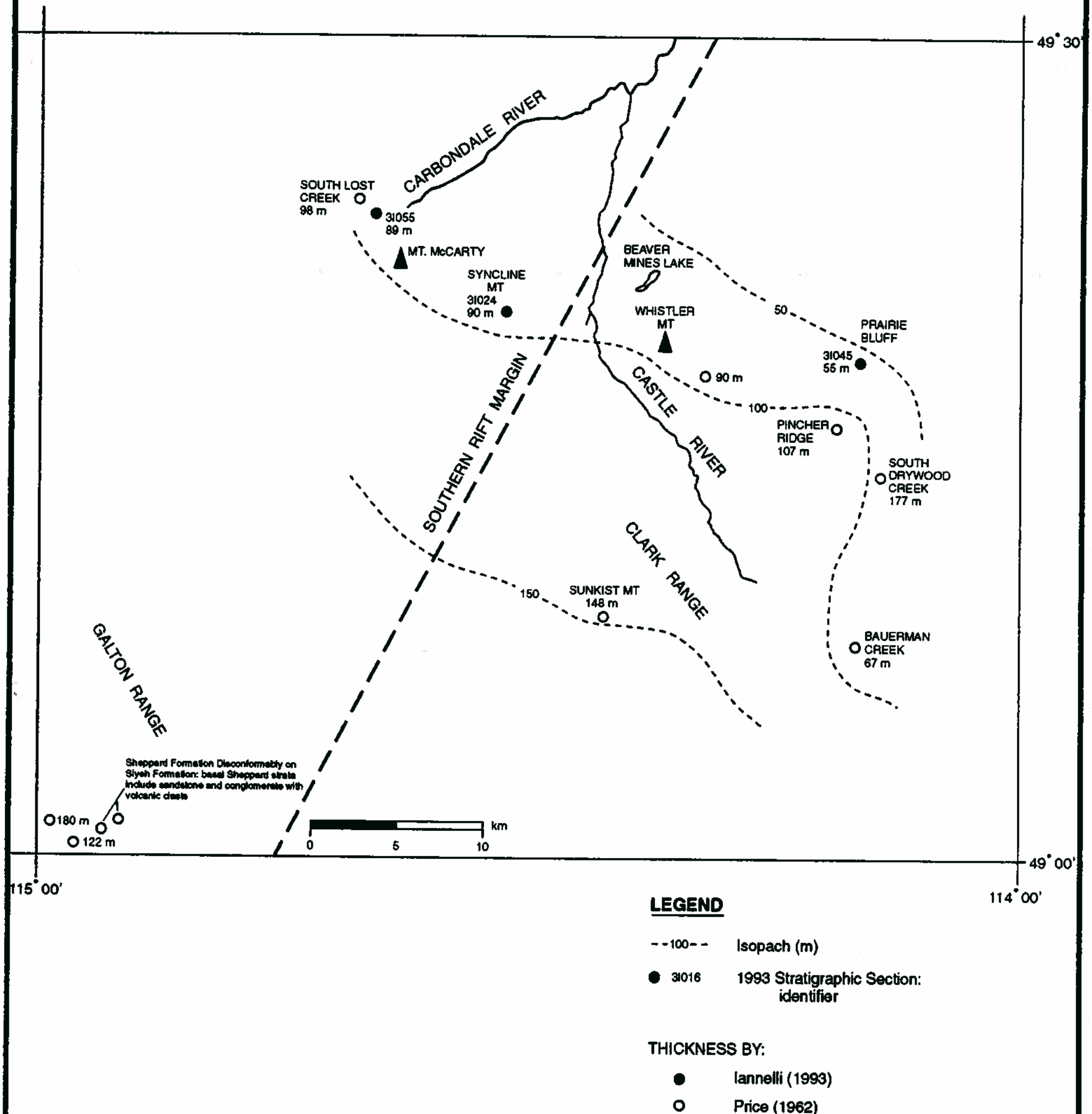
Sheppard Formation

The Sheppard Formation comprises grey and brown-grey to buff stromatolitic dolostone and dolosiltite to dolarenite, grey and pink-grey quartzarenite to dolomitic sublitharenite, green dolomitic siltstone, and minor intermixed green to red, planar thin-laminated argillite (stratigraphic sections 31024-025, 31035 and 31045; Figures II-6, II-8 and II-10, respectively). As well, there are rare interbeds of carbonate flat pebble conglomerate.

Sheppard Formation strata sharply overlie the Purcell Lava, with the contact marked by the occurrence of a dark green to grey-green, volcanic clast-bearing sandstone which essentially is an andesitic litharenite (Plate II-2.c). Intermixed volcanic pebble

FIGURE II - 71

THICKNESS TRENDS FOR THE PURCELL LAVA



conglomerate also occurs in basal sequences of Sheppard Formation along Phillips Creek in the southern Galton Range of southeastern British Columbia. A chloritized lava flow, which is 10 m to 15 m thick, and similar to the Purcell Lava flows, occurs in the lower Sheppard Formation in the southern Clark Range (Price, 1962, 1964). The Clark Range sequences are further characterized by the restriction of red beds to the upper part of the Sheppard Formation, with the red beds becoming more abundant to the east and north. Sheppard Formation strata grade upwards into planar to wavy, thin-laminated to thin-bedded sandstone and siltstone of the Gateway Formation.

Sedimentary structures are common within the Sheppard Formation and include syneresis cracks, small load casts, wave and current ripple marks, cross laminations, and scour marks. Argillite and carbonate flat rip-up intraclasts occur and locally comprise flat pebble conglomerate horizons. Rare domal stromatolites and hummocky cross-stratified layers are locally present. Rare halite casts occur in basal beds of Sheppard Formation at Syncline Mountain (stratigraphic section 3I024-025; Figure II-6).

Sheppard Formation decreases in thickness from up to about 305 m at Victoria Peak in the eastern Clark Range, to less than 150 m in the northern Clark Range, about 125 m in the southwestern Clark Range and to less than 50 m in the southern Flathead Range (Figure II-72). Sheppard Formation strata were deposited in a shallow marine shelf environment that was largely subtidal, with intermittent influxes of terrigenous siliciclastic sediment.

Features in the Sheppard Formation that are indicative of rifting are summarized in Table II-7.

Gateway Formation

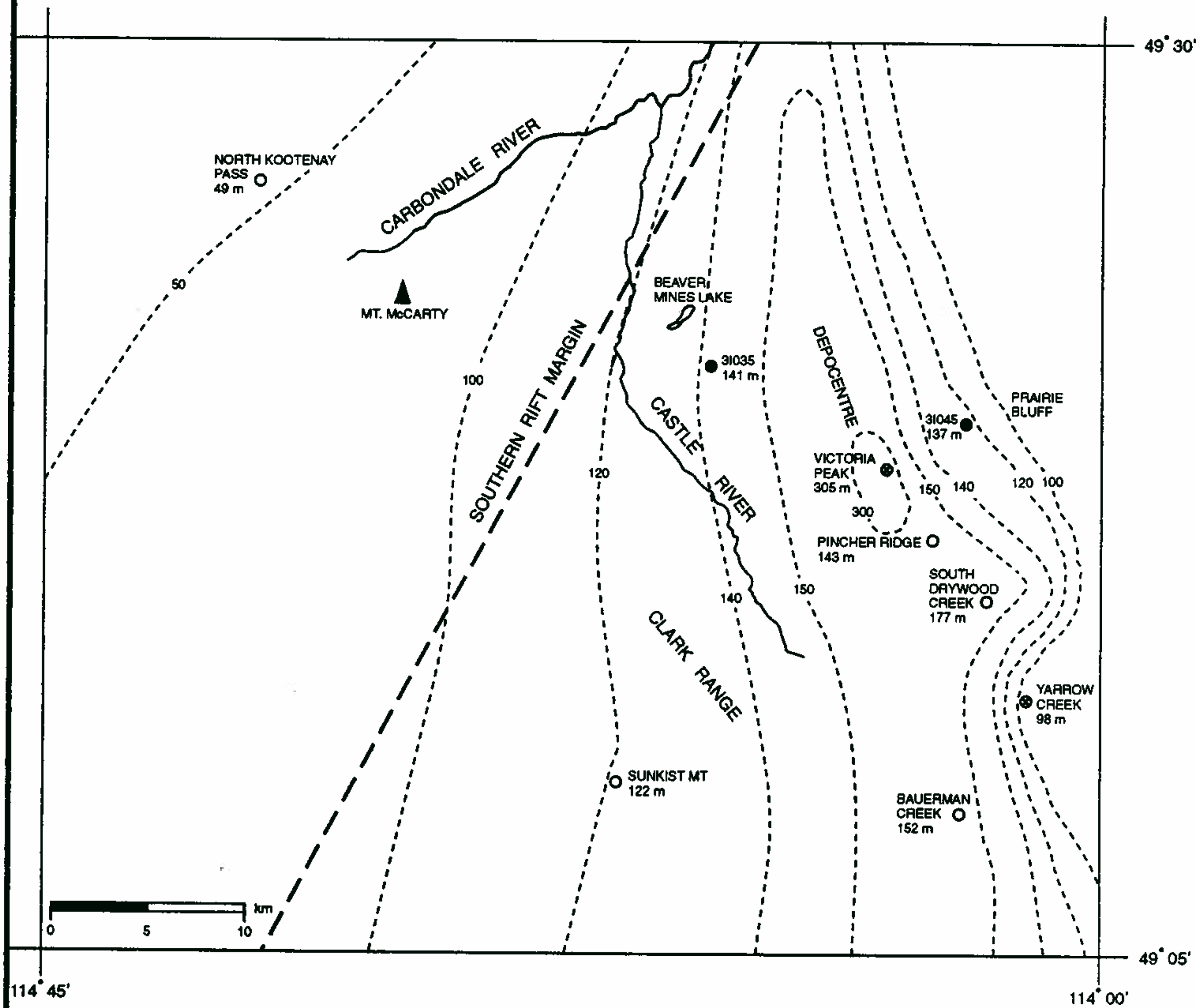
The Gateway Formation can be subdivided into two members.

Lower Member

Strata in the lower member of the Gateway Formation consist mainly of planar to wavy layered, thick-laminated to thin-bedded siltstone, silty argillite to quartzitic subarkose and minor intermixed thin-laminated dolomitic argillite and thin-bedded dolomitic siltstone (stratigraphic sections 3I035 and 3I045; Figures II-8 and II-10; Plate II-2.d). Rare thin layers of planar to wavy-laminated dolostone to stromatolitic dolostone are present. The strata change from mainly dark red and pink- to purple-red in the easternmost Clark Range into beds that are largely green-grey or buff-grey to grey in the rest of the Clark Range. Sedimentary structures are common and include abundant cross-laminations and current ripple marks, syneresis cracks and small load casts. Halite casts are locally common (Plate II-2.e). Rip-up intraclasts and flat pebble conglomerate horizons also occur.

FIGURE II - 72

THICKNESS TRENDS FOR THE SHEPPARD FORMATION



LEGEND

- - 100 - - Isopach (m)

● 31016 1993 Stratigraphic Section: identifier

THICKNESS BY:

● Iannelli (1993)

○ Price (1962)

⊗ Van Dyck (1971)

TABLE II-7

POSSIBLE RIFT-RELATED FEATURES IN THE SHEPPARD FORMATION

FORMATION	FEATURE	RIFT RELATION
SHEPPARD	(a) The formation thickens greatly to the southeast, on a regional scale, across the Clark Range. However, there are considerable local thickness variations within the Clark Range, such that a significant depocentre existed near Victoria Peak in the central Clark Range (Figure II-72). This type of local thickening is characteristic of deposition within a multi-block rift system. The location of the depocentre is not far removed from the location of the south margin of the Southern Alberta Rift.	Strong
	(b) A subtle facies change was noted between stratigraphic sections 3I035 and 3I045 (Figures II-8 and II-10). There is a gradual increase in argillite content northwestwards from section 3I045 to section 3I035, a distance of about 15 km.	Moderate
	(c) Other facies changes and lithological variations were noted within the formation: (i) There is a chloritized andesite flow (10 m to 15 m thick) within lower Sheppard Formation strata in the southern Clark Range (Price, 1962, 1964). This flow provides evidence that the extension-related volcanism, which is indicated by the Purcell Lavas, extended into early Sheppard Formation time. (ii) Red beds are restricted to the upper part of the formation, and are more abundant to the east and north. This may reflect a proximal to distal facies transition along a rifted continental margin. (iii) Basal volcanic clast sandstone and conglomerate beds of variable thickness and extent are present. These reflect pre-Sheppard Formation uplift and erosion of Purcell Lava, and hint at the occurrence of variably subsiding and uplifted sub-blocks in a rift system.	Strong
	(d) Small to medium scale stacked shallowing-up and thickening-up cycles are present in the formation. The thickness of these cycles ranges from 0.5 m to 9 m. The cycles typically alternate with minor, thin layers of stromatolitic dolostone with common domal forms, carbonate flat pebble conglomerate and hummocky cross-stratified to massive sublitharenite to subarkose. The cycles comprise lower members of planar to wavy-bedded intermixed argillite, dololutite to calcilutite and minor dolosiltite, that grade upwards through a decrease in argillite content into intermixed planar to wavy dolosiltite and dolarenite to dolomitic quartzarenite to sublitharenite. The cycles represent shallow marine platform deposits. Siliciclastic material may have been shed basinwards during tectonically active episodes.	Moderate

Upper Member

Strata in the upper member of the Gateway Formation comprise planar thin-laminated, green-grey to green argillite, dololutite, dolomitic argillite and variably intermixed planar to wavy layered, thin-bedded siliceous dolosiltite to dolarenite and dolomitic quartzarenite to siltstone. The carbonate and sandstone beds are grey to buff-grey. Rare thick-laminated stromatolitic dolostone beds occur locally. Sedimentary structures include wave and current ripple marks, cross-laminations, scour marks, small load casts and syneresis cracks. Argillite and carbonate rip-up intraclasts are also present, as are thin flat pebble conglomerate layers.

The uppermost beds of the Gateway Formation grade into sandstone-dominated sequences of the Phillips Formation, through an increase in sandstone content. The Gateway Formation in the Clark Range thickens from 350 m to 380 m in the northwest, to 400 m to greater than 500 m in the northeast and south, and to 700 m to 850 m in the southwest (Price, 1962, 1964; Figure II-73). In southeastern British Columbia, in the Galton Range for example, Gateway Formation successions are at least 762 m thick. Thus the formation thickens greatly to the south and southwest.

The Gateway Formation strata were deposited in shallow subtidal to intertidal settings, with local development of supratidal hypersaline settings.

Features in the Gateway Formation that are indicative of rifting are summarized in Table II-8.

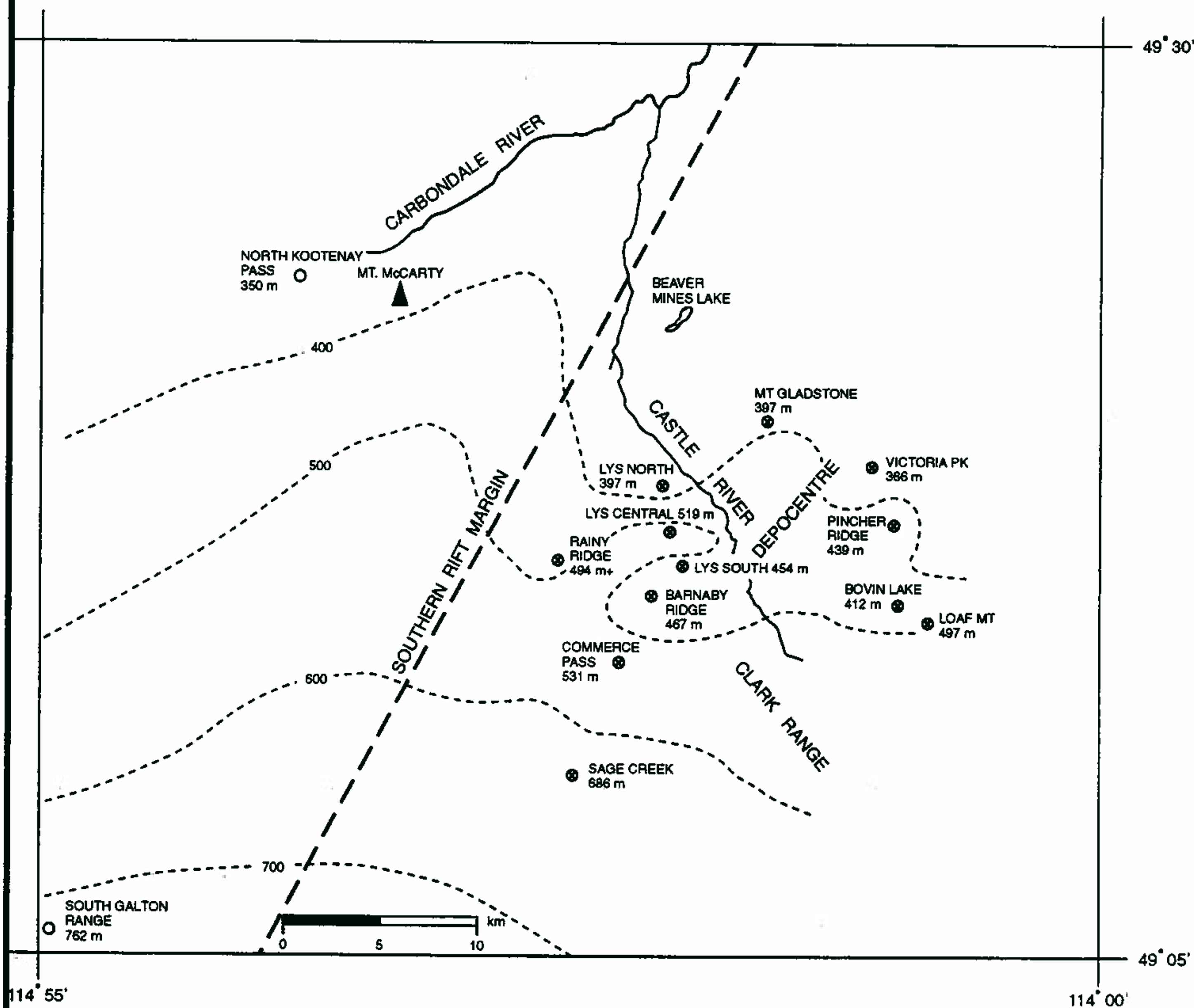
Phillips Formation

The Phillips Formation gradationally overlies the Gateway Formation. Sandstones of the Phillips Formation, in turn, grade upwards into the argillite-dominated strata of the Roosville Formation (Table II-1; Figures II-66 and II-67). The Phillips Formation ranges from 130 m thick in the northwestern, to 200 m in the southwestern Clark Range. Phillips Formation is also about 200 m thick in the Southern Galton Range in southeastern British Columbia.

The Phillips Formation consists of planar to wavy layered, thick-laminated to thin-bedded maroon and red to red-pink quartzarenite to quartzitic subarkose and siltstone. Minor thin interbeds and partings of thin, planar laminated argillite, and argillite flat pebble conglomerate horizons are also present. Sedimentary structures are common and include current ripple marks, cross-laminations, small load casts and syneresis cracks. A shallow water depositional environment, possibly as sheet floods in an alluvial plain setting, has been suggested for the Phillips Formation by McMechan (1981).

FIGURE II - 73

THICKNESS TRENDS FOR THE GATEWAY FORMATION



LEGEND

- - 100- - Isopach (m)

● 3I016 1993 Stratigraphic Section: identifier

THICKNESS BY:

○ Price (1962)

⊗ Van Dyck (1971)

TABLE II-8

POSSIBLE RIFT-RELATED FEATURES IN THE GATEWAY FORMATION

FORMATION	FEATURE	RIFT RELATION
GATEWAY	(a) The lower member consists of generally monotonous successions of thick-laminated to thin-bedded siltstone, argillaceous siltstone and silty argillite, with minor intermixed sandstone and rare silty dolostone. The lower member forms a consistent lithofacies assemblage. However, at Table Mountain (stratigraphic section 31035 area), the basal 30 m are dominated by sandstone, indicating that there may be an increased sandstone component to the northeast within the lower member (Plate II-2.d). However, there are no further data to support this idea.	Weak
	(b) In general, the upper member contains a large siltstone and argillite component. However, in some areas there occurs increased amounts of interlayered silty dolostone, dolomitic siltstone and dolomitic to argillaceous sandstone. Sandstone and dolostone increase upwards in the member. Sandstone and dolostone-bearing successions are most prevalent in the Barnaby Ridge-Lys Ridge area of the central Clark Range.	Weak
	(c) On a regional scale, strata within the Gateway Formation thicken to the south and southwest. However, there are local depocentres superimposed upon this trend, including some where significant local thickness variations occur. The thickest sequences in the Clark Range occur at Lys Ridge area in the vicinity of the south margin of the Southern Alberta Rift (Figure II-73).	Moderate
	(d) Colour variations occur within the lower member. Strata grade from mainly dark red, and pink to purple-red in the easternmost Clark Range, to mainly green-grey and buff-green to grey in the remainder of the Clark Range. This change may reflect proximal (east, northeast) to a distal (west, southwest) transition across the continental margin.	Moderate

Roosville Formation

The Roosville Formation is the uppermost unit in the Purcell Supergroup that is present in southwest Alberta. Strata of the formation are truncated by the sub-Cambrian erosional surface (Figure II-67). The formation is greater than 600 m thick in the southwestern Clark Range, and greater than 1,300 m thick in the Galton Range in southeastern British Columbia (Price, 1962; Aitken and McMechan, 1992). Lithologies consist of planar thin-laminated, green-grey to green argillite-dololutite intermixed with units of grey to green-grey or buff-green dolomitic quartzarenite and siltstone. As well, there are minor amounts of buff-green-grey argillaceous dolostone to stromatolitic dolostone and red, thick-laminated argillite. The carbonate and sandstone beds are planar to wavy layered, and thick-laminated to thin-bedded (stratigraphic section 31063; Figure II-12).

The Roosville Formation contains wave and current ripple marks, cross-laminations and argillite rip-up intraclasts, which in places are also present as argillite flat pebble conglomerate layers. Small-scale load casts, syneresis cracks and scour marks exist in a few places. Rare domal stromatolites occur in thin dolostone horizons. The Roosville Formation was deposited in a marine, siliciclastic shelf environment in a shallow subtidal to intertidal setting.

Features in the Roosville Formation that are indicative of rifting are summarized in Table II-9.

TABLE II-9

POSSIBLE RIFT-RELATED FEATURES IN THE ROOSVILLE FORMATION

FORMATION	FEATURE	RIFT RELATION
ROOSVILLE	(a) The formation forms a monotonous lithofacies assemblage dominated by planar to wavy-laminated to thin-bedded argillite and siltstone to fine-grained sandstone (stratigraphic section 3I063). Subtle facies variations occur across the Clark Range with respect to the concentration of minor lithofacies such as dolostone, dolosiltite and coarser-grained sandstone, but these variations are too indistinct to be of importance in delineating any rift-related effects.	Weak
	(b) Tremendous thicknesses of Roosville Formation are preserved in southwestern Alberta and southeastern British Columbia (i.e., >1,300 m in the Galton Range). This implies significant subsidence along a passive continental margin.	Weak

Overall thickness trends for strata of the Upper Division of Purcell Supergroup, exclusive of the Roosville Formation, resemble the trends established for the Lower Division and the Middle Carbonate Division (McMechan, 1981; Figure 5.7c in Aitken and McMechan, 1992). The most prominent feature continues to be a northeast-trending trough or sub-basin. The isopach trends may reflect an embayed continental margin. The embayments probably are the result of differential subsidence of sub-troughs in the southwesternmost end of the Southern Alberta Rift.

PHANEROZOIC STRATIGRAPHY

Phanerozoic stratigraphy, with the exception of the Cambrian succession, in southwest Alberta is summarized in the "South-central Mtns & Foothills" column of Table II-10. The Cambrian succession, which is described below, is from the "Front Ranges, Foothills, Waterton, Pincher Creek" column in "Figure 1 (sheet 3 of 3)" which accompanies Gabrielse and Yorath (1992).

MIDDLE CAMBRIAN

The Cambrian rock units exist predominantly in the Clark Range of southwestern Alberta and southeastern British Columbia.

Flathead Formation

The Flathead Formation consists of planar thin-bedded to crossbedded, yellow-brown to light grey, coarse grained quartzarenite. The sandstones in the lower part of the formation are interlayered with subordinate pebbly quartzarenite and quartz pebble conglomerate. The basal contact is an erosional unconformity that is developed on argillite-dominated sequences of the Middle Proterozoic Purcell Supergroup.

Sandstone beds of the Flathead Formation overlie progressively older Purcell strata, in a west to east direction, across the Clark Range. The upper contact with the overlying Gordon Formation is gradational. The Flathead Formation thins southwards, from 46 m in the northern part of the Flathead Range in southeastern British Columbia to 26 m in the northern Clark Range and to 15 m in the southern Clark Range. The strata represent shallow marine shelf sand deposits.

Gordon Formation

The Gordon Formation comprises planar thin-laminated, green and green-grey to grey, fissile shale (stratigraphic section 3I064; Figure II-13). The shales are interlayered with minor amounts of thin-bedded, yellow-grey, fine-grained quartzarenite and siltstone in the lower part of the Gordon Formation, and thin lenses and layers of thin-bedded argillaceous limestone in the upper part of the formation. In the southern Clark Range, minor interlayers of thin-laminated dark red shale and argillaceous to glauconitic sandstone and limestone, are present in the basal part of the Gordon Formation.

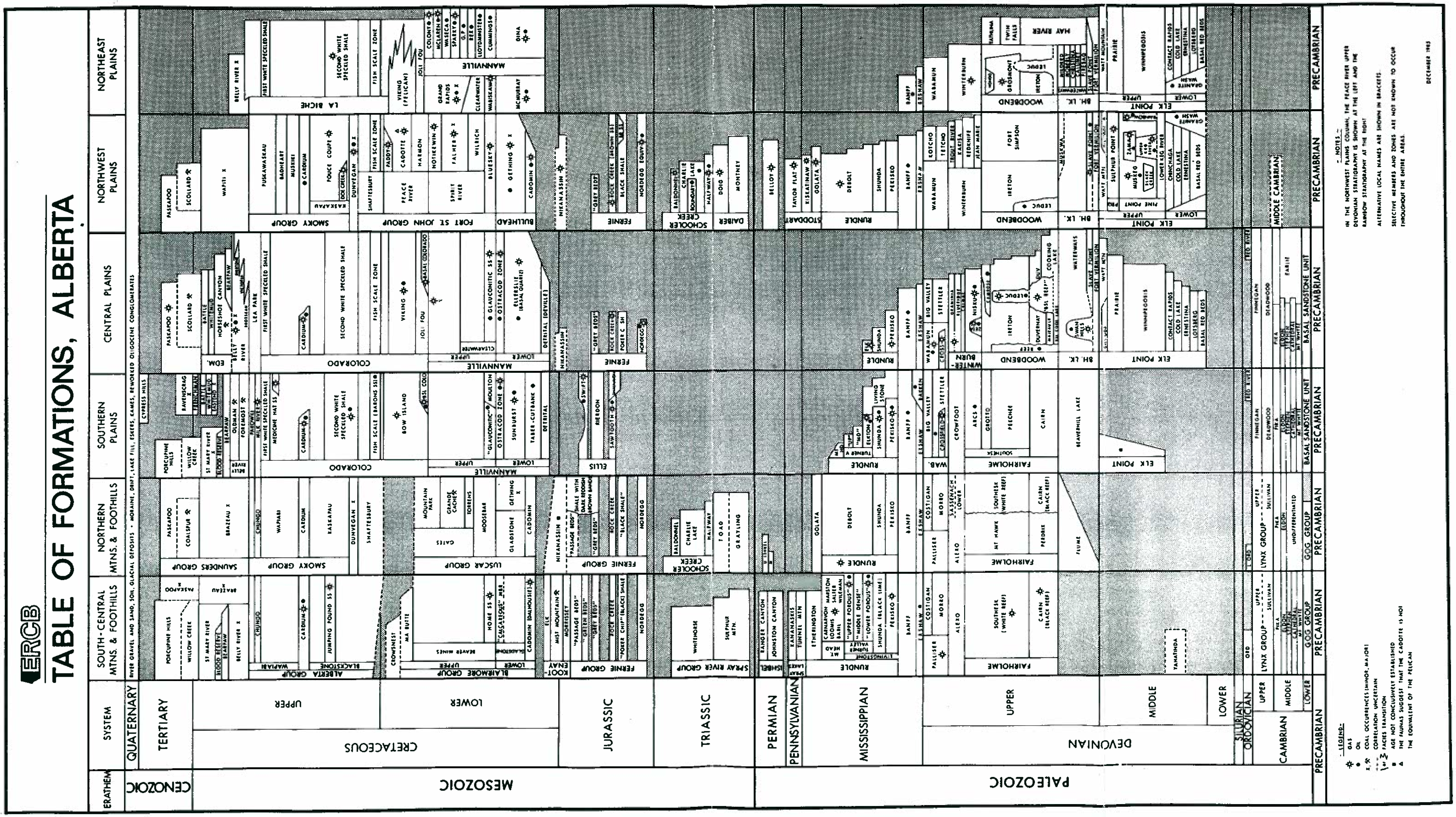
The shale-dominated sequences of Gordon Formation are conformably overlain by carbonates of the Elko Formation (Figure II-13). Strata of the Gordon Formation thicken easterly, from 64 m at Kootenay Pass to 84 m in the northeastern Clark Range. The formation was deposited in a shallow, mud-dominated marine basin.

Elko Formation

The Elko Formation is comprised of massive-weathered, thin- to medium-bedded, dark grey to brown-grey, mottled limestone and dolostone (stratigraphic section 3I064; Figure II-13). The mottled beds consist of fine-crystalline limestone with small lenses and streaks of buff-brown to orange-brown weathered dolostone to dolosiltite. Minor interlayers of less resistant thin- to medium-bedded calcilutite occur in the lower part, and recessive thick-laminated green shale is present in the upper part of the Elko Formation. Rare interlayers and lenses of carbonate flat pebble conglomerate, thin-laminated dolostone and pisolitic dolostone occur locally.

TABLE II-10

TABLE OF FORMATIONS - PHANEROZOIC



The Elko Formation is unconformably overlain by basal dolostone and dolomitic sandstone of the Fairholme Group. The contact is characterized by the occurrence of erosional channels that are downcut into the Elko Formation beds. The Elko Formation thickens to the south and east. Its thickness ranges from 87 m in the central Flathead Range in southeastern British Columbia, to 107 m at North Kootenay Pass along the Alberta-British Columbia border, to 152 m in the northern Clark Range and to 214 m in the southern Clark Range in the vicinity of stratigraphic section 3I064 (Figure I-2; Figure II-13). The carbonate beds of the Elko Formation accumulated as platform shelf deposits.

Features in the Elko Formation that may be related to reactivation of the Southern Alberta Rift are summarized in Table II-11.

TABLE II-11

POSSIBLE RIFT-RELATED FEATURES IN THE ELKO FORMATION

FORMATION	FEATURE	RIFT RELATION
ELKO	Strata of the Cambrian Elko Formation thicken southwards from 87 m in the central Flathead Range, to 214 m in the southern Clark Range. This significant thickness change implies differential subsidence across the Early Paleozoic continental margin. The thickness trend may reflect subsidence following a Late Proterozoic-Early Paleozoic rifting event (Bond and Kominz, 1984; Thompson et al., 1987).	Weak

UPPER DEVONIAN

The Devonian sequence was geologically examined at a few places in southwest Alberta, but a stratigraphic section was geologically measured for only the uppermost Palliser Formation (stratigraphic section 3I043; Figure II-14).

Fairholme Group

The Fairholme Group comprises mainly dark grey and brown to light grey, thick-bedded to massive, fine- to coarse-crystalline limestone and dolostone. The beds thicken to the south and southwest across the Southern Alberta Rift project area, from 290 m to 457 m. The Fairholme Group accumulated on a restricted carbonate shelf that included reef and off-reef deposits. The group includes the Cairn and Southesk Formations (Table II-10).

Cairn Formation

The lower part of the Cairn Formation consists mainly of dark grey, fine-crystalline limestone and argillaceous limestone with minor intermixed units of thin-bedded, light grey to yellow-grey, fine-crystalline dolostone and dolosiltite to calcisiltite. Layers and lenses of carbonate clast breccia, up to 3 m thick, occur variably intermixed throughout the succession. The breccia consists of dolostone and limestone blocks set in a matrix of dolostone to limestone. The basal layers contain dolomitic quartzarenite to sandy dolostone. The lower Cairn Formation succession is 99 m to 122 m thick in the Flathead Range, increasing southeastwards to 153 m in the northern Clark Range.

The upper part of the Cairn Formation consists mainly of thick-bedded to massive, dark grey or brown to black, fine- to coarse-crystalline dolostone, with local vuggy and crossbedded layers. In the southern Flathead Range, the dolostones contain partings and thin interbeds of brown to black shale. The upper Cairn Formation succession is 18 m to 49 m thick in the Flathead Range, and thickens southeastwards to 56 m in the northern Clark Range.

Southesk Formation

The lower part of the Southesk Formation consists mainly of massive, coarse-crystalline, white to light grey dolostone that forms discrete reef structures. The strata are extensively dolomitized, and locally contain lenses of very coarse breccia comprised of dolostone blocks up to several metres in length. The reef margins consist of coarse-crystalline white dolostone interlayered with coarse-crystalline brown dolostone. The reef-bearing unit is up to 30 m thick.

The middle unit of the Southesk Formation comprises dark grey to grey-brown, poorly stratified to massive, fine- to medium-crystalline dolostone. This unit, which typically contain vugs, ranges from 22 m to 35 m in thickness in the Flathead Range. The beds are gradationally overlain by upper Southesk Formation strata that comprise white to light grey, massive to thick-bedded, coarse-crystalline dolostone. The cliff-forming succession of the upper Southesk Formation ranges from 23 m to 47 m in thickness in the vicinity of traverse 7 (Figure I-2). The Southesk Formation is conformably to locally unconformably overlain by carbonates of the Alexo Formation (Gabrielse and Yorath, 1992).

Alexo Formation

The Alexo Formation is comprised of a distinctive recessive, yellow-brown weathering succession of thick-laminated to thin-bedded, fine-crystalline silty limestone and dolostone beds. The strata contain minor intermixed lenses and layers of carbonate flat pebble conglomerate and solution breccia, and rare soft sediment deformed horizons. The Alexo Formation thins northeastwards, from 30 m in southeastern British Columbia to only 8 m in the southern Flathead Range along the Alberta-British Columbia border. The strata were deposited on a restricted shallow marine carbonate shelf.

Palliser Formation

The Palliser Formation consists mainly of dark grey to medium grey, thin- to medium-bedded, fine-crystalline limestone, mottled with brown-grey small lenses to streaks of medium-crystalline dolostone to dolosiltite (stratigraphic section 3I043; Figure II-14). The mottled limestone of the Palliser Formation resembles the carbonate beds of the Elko Formation (Figure II-13). Minor thin interbeds of fossiliferous calcarenite occur locally in the Palliser Formation. The formation maintains a relatively constant thickness in southwestern Alberta, ranging from 198 m to 220 m. The strata accumulated on a restricted shallow marine carbonate shelf.

The Palliser Formation has been divided into lower (Morro) and upper (Costigan) members (Table II-10). The Morro member contains a basal facies assemblage of thin-bedded to massive, brown to grey, medium-crystalline dolostone, with local lenses of dolostone clast breccia. These units are in sharp contact with the underlying carbonates of the Alexo Formation, and they grade upwards into dolostone-mottled limestone beds that comprise the upper part of the Morro member. The Morro member averages 183 m in thickness.

The overlying beds of the Costigan member comprise planar, wavy to nodular layered, thin-bedded, fine-crystalline limestone to argillaceous limestone, that passes upwards into poorly stratified mottled limestone. Minor intermixed lenses and layers of fossiliferous limestone are also present. The Costigan member is 30 m to 45 m thick, and is sharply overlain by black shale beds of the Exshaw Formation (Plate II-3.a).

MISSISSIPPIAN

Exshaw Formation

The Exshaw Formation is comprised of planar thin-laminated black shale with thin interlayers, near the basal contact, of black-brown to rust-brown weathering pyritiferous shale. The shale beds pass up into a 1 m to 3 m thick unit of light grey to buff-grey, thick-laminated to thin-bedded, argillaceous to silty limestone, calcisiltite or glauconitic to calcareous siltstone (stratigraphic section 3I043; Figure II-14; Plate II-3.a). The Exshaw Formation beds are gradationally overlain by argillaceous strata of the Banff Formation. The Exshaw Formation is thin, ranging in thickness from about 1.5 m to 12 m in southwest Alberta. The 12 m thick section exists in a roadcut that is 7 km west of Coleman (Figure I-2). The Exshaw Formation represents a starved basin succession consisting of euxinic shales deposited well below wave base that was succeeded by shallow marine carbonate and siltstone deposits of the Banff Formation (Table II-10).

Banff Formation

The Banff Formation in southwest Alberta ranges in thickness from 244 m in the central Livingstone Range, which is near the central part of the Southern Alberta Rift, to

Plate II-3

3.a: **Exshaw Formation - Banff Formation**
(stratigraphic section 3I043; Figure II-14)

About 12 m of planar thin-laminated pyritic black shales of the Lower Mississippian Exshaw Formation in road cut 7 km west of Coleman. The shales sharply overlie mottled limestone of the Late Devonian Palliser Formation. The shale beds grade upwards into a 2 m thick, buff-grey limestone horizon. Basal calcareous shale beds of the Banff Formation are visible in the upper right corner of the photograph.

3.b: **Mount Head Formation**
(stratigraphic section 3I066; Figure II-15)

General view of interlayered brown- to buff-grey, sandy to argillaceous dolostone and limestone of the Late Mississippian Mount Head Formation. The succession is exposed along the inferred northern margin of the Southern Alberta Rift where it intersects the British Columbia-Alberta border (Figure I-2).

3.c: **Etherington Formation**
(stratigraphic section 3I086.O; Figure II-22)

Detail of a deformed horizon in strata of the uppermost Etherington Formation (Late Mississippian), which is exposed in the northern Livingstone Range. The strata consist of interlayered dolosiltite to siliceous dolostone and minor dolomitic quartzarenite. The deformed layer in the middle of the photograph is bounded by undeformed beds. The disrupted layer may represent a gravity slide horizon.

3.d: **Blairmore Group**
(stratigraphic section 3I036-037; Figure II-24)

Roadcut in the vicinity of Blairmore, Alberta, that exposes alternating horizons of thin-laminated shale, and thin-bedded siltstone and sandstone of the Early Cretaceous Blairmore Group. The strata contain concretions up to 1 m in diameter.

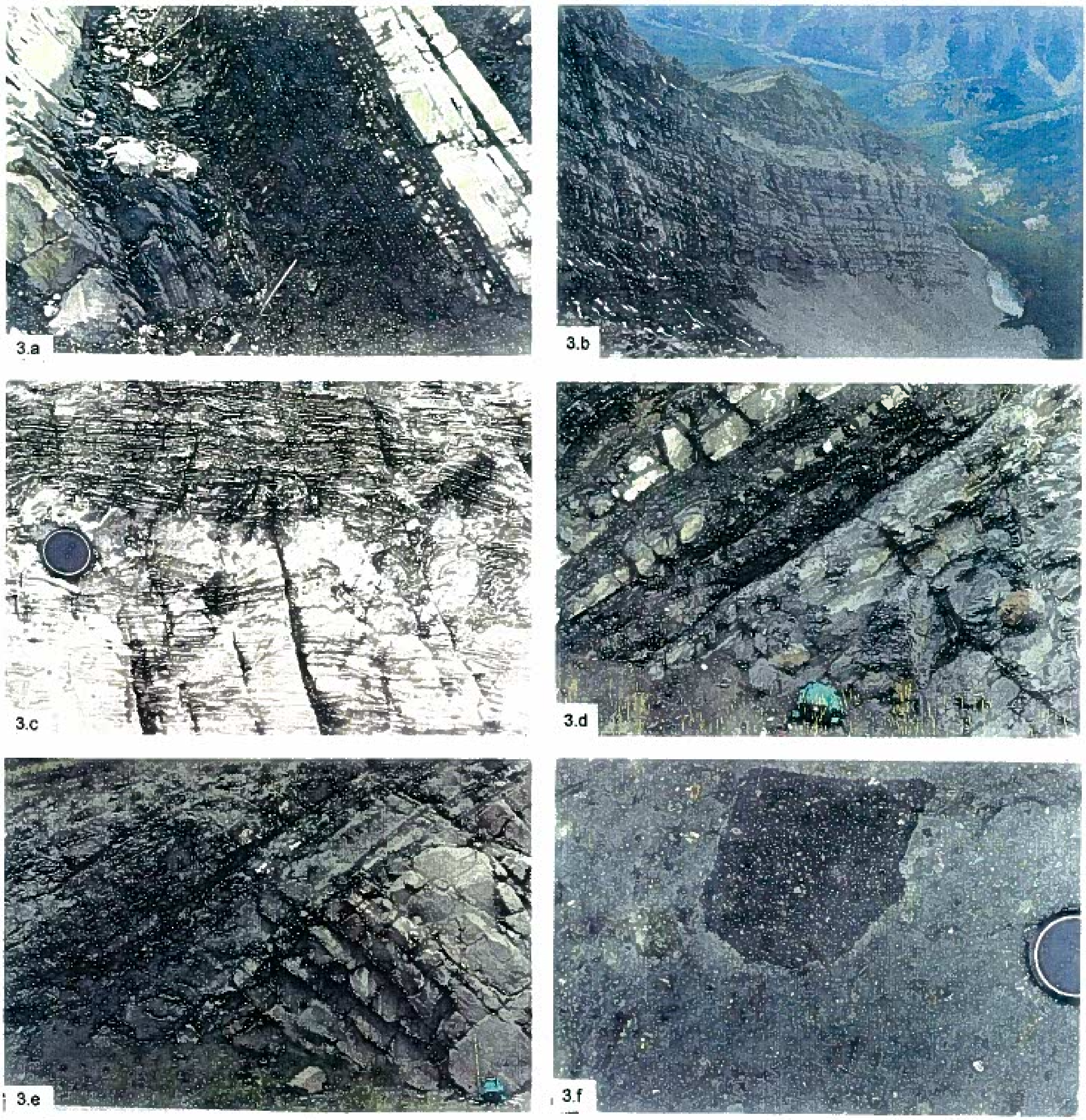
3.e: **Crowsnest Formation**
(stratigraphic section 3I039.E, F; Figure II-28)

Roadcut just west of Coleman, Alberta, that exposes massive to thin-layered volcaniclastic sandstone and conglomerate of the Early Cretaceous Crowsnest Formation.

3.f: **Volcanic agglomerate in Crowsnest Formation**
(stratigraphic section 3I039.J; Figure II-28)

Massive-weathered, dark green to purple-green volcanic agglomerate.

PLATE II - 3



320 m at Tornado Pass in the High Rock Range, and thins southwards to 183 m in the southern Flathead Range. The lower 34 m to 82 m of the Banff Formation is comprised of planar thin- to thick-laminated shale and calcareous shale to calcilutite, variably intermixed with units of thick-laminated to thin-bedded, brown-grey, or dark grey to black, chert banded to lensed limestone and calcisiltite to calcareous siltstone (stratigaphic section 3I043; Figure II-14). The middle 76 m to 137 m of the formation consists of planar to wavy layered, thin- to medium-bedded, dark grey to black-grey to black, chert banded to lensed limestone to argillaceous limestone. The upper 81 m to 122 m of the Banff Formation includes planar to wavy layered, medium grey to dark grey, thin- to medium-bedded limestone to calcisiltite and dolostone to dolosiltite, variably intermixed with dark grey to brown-grey, chert banded to lensed limestone and dolostone (stratigraphic sections 3I066, 3I089, 3I111 and 3I136; Figures II-15 to II-18). The beds within Banff Formation are typically differentially weathered, with chert lenses and streaks weathered out in relief, hence the succession commonly forms prominent ribbed cliffs. The carbonate-dominated successions of Banff Formation were deposited largely in shallow marine shelf to shelf margin settings.

Rundle Group

The Rundle Group comprises several rock units in southwest Alberta, including the Livingstone, Mount Head and Etherington Formations (Table II-10).

Livingstone Formation

The strata of the Livingstone Formation gradationally overlie those of the Banff Formation. Livingstone Formation comprises light grey to buff-grey, thin- to thick-bedded calcisiltite to calcarenite, and fossiliferous calcisiltite and calcarenite to fine-crystalline limestone, variably intermixed with layers of chert banded to lensed limestone to dolostone and minor calcirudite, porous limestone and crossbedded calcisiltite to calcarenite (stratigraphic sections 3I066, 3I089, 3I111, 3I136, 3I124 and 3I137; Figures II-15 to II-20). The beds locally emit a petroliferous odour. Massive-weathering, resistant, thick-bedded units alternate with those that are thin-bedded and semi-resistant, resulting in a ribbed outcrop appearance for the cliff-forming successions of Livingstone Formation.

The thickness trends for Livingstone Formation vary considerably across southwest Alberta. The sequences are 275 m thick in the central Livingstone Range, which is near the central part of the Southern Alberta Rift, 335 m to 418 m thick to the south, and 438 m (Figure II-15) to 498 m (Figure II-16) thick to the north. The carbonate successions of the Livingstone Formation accumulated in shelf margin to restricted shelf settings.

Mount Head Formation

Strata of the Mount Head Formation conformably overlie fossiliferous to cherty limestones of the Livingstone Formation (Table II-10; stratigraphic sections 3I066, 3I089, 3I124, 3I137, 3I049, 3I086 and 3I138; Figures II-15, II-16 and II-19 to II-23; Plate II-3.b). The formation ranges from 214 m to 305 m in thickness in the north, and is 262 m thick in the southern Flathead Range.

The lower part of the Mount Head Formation ranges from 20 m to 55 m thick, and consists of thin- to medium-bedded, planar to wavy layered, brown and brown-grey to dark grey intermixed calcisiltite and calcarenite to limestone. Minor amounts of argillaceous to sandy dolostone, and fossiliferous to chert banded limestone also exist within the lower part of the formation. The beds are resistant to semi-resistant and locally contain small scour marks and load casts.

The middle part of the Mount Head Formation ranges from 30 m to 45 m thick, and consists typically of semi-resistant to semi-recessive brown to brown-grey, thick-laminated to thin-bedded dololutite, dolosiltite to dolostone and intermixed units of calcisiltite to limestone. Thin layers of fossiliferous calcarenite occur in the middle part of the formation in some places.

The upper part of the Mount Head Formation ranges from 75 m to 125 m thick, and is a massive-weathering, cliff-forming succession of buff-grey to dark grey, intermixed fine-crystalline limestone to dolostone, calcisiltite and calcarenite. The thin- to medium-bedded facies are interlayered with minor amounts of fossiliferous calcarenite, green to black shale to dololutite, solution breccia and, in the uppermost part of the succession, chert banded to lensed limestone to calcarenite. The carbonate beds of the Mount Head Formation accumulated in shelf margin to restricted shelf depositional environments.

Etherington Formation

The brown-grey to dark grey weathering carbonates of the Mount Head Formation grade upwards into varicoloured carbonate and intermixed siliciclastic beds of the Etherington Formation (Table II-10; stratigraphic sections 3I049, 3I086 and 3I138; Figures II-21 to II-23). The Etherington Formation thickens from about 70 m between stratigraphic sections 3I086 (Figure II-22) in the Livingstone Range and 3I049 (Figure II-21) near Crowsnest Pass, to 183 m to 305 m to the west at Tornado Creek near stratigraphic section 3I089 (Figure I-2; Price, 1962).

In general, Etherington Formation consists of grey limestone, calcisiltite, dolostone to siliceous carbonate, varicoloured shale and minor thin horizons of solution breccia and anhydrite. At stratigraphic section 3I049 (Figure II-21) near Crowsnest Pass, the sequence consists of alternating units of resistant, light grey to buff-grey, thin-bedded dolosiltite and dolostone to minor dolomitic fine- to coarse-grained quartzarenite, and units of semi-recessive, interlayered purple-grey and green-grey to buff, thick-laminated dolomitic shale to dololutite and grey, purple-grey and maroon dolostone, dolosiltite and dolarenite. These facies alternate in a cyclic fashion of semi-recessive shale-dololutite with more resistant dolosiltite-dolostone horizons. The individual cycles range from 4 m to 8 m in thickness.

At stratigraphic section 3I086 (Figure II-22) in the Livingstone Range, Etherington Formation strata comprise white and grey to brown-grey, planar to wavy layered, thin-bedded calcisiltite, fossiliferous to siliceous calcarenite, dolosiltite, siliceous dolostone to dolarenite, and minor thin-bedded, fine-grained dolomitic quartzarenite, chert banded dolostone to limestone and planar thin-laminated calcilutite. The siliceous carbonate beds locally contain cross-laminations. A deformed layer of dolosiltite to siliceous dolostone, which is about 1 m thick and exists in the uppermost part of the succession, may represent a gravity slide horizon (Plate II-3.c).

The strata of the Etherington Formation accumulated in shelf margin to restricted shelf depositional settings.

Features in the Livingstone, Mount Head and Etherington Formations that may be related to reactivation of the Southern Alberta Rift are summarized in Table II-12.

PENNSYLVANIAN

In southwest Alberta, the Rocky Mountain Supergroup encompasses Pennsylvanian Spray Lake Group and the unconformably overlying Permian Ishbel Group. The Ishbel Group was not examined during the 1993 program and is not discussed below.

Spray Lakes Group ('Rocky Mountain Formation')

The Spray Lakes Group has been geologically mapped as the 'Rocky Mountain Formation' in parts of southwest Alberta (Price, 1962; Norris, 1958a,b). The sandstone beds of Rocky Mountain Formation conformably overlie carbonate successions of the Etherington Formation (Table II-10; stratigraphic sections 3I049 and 3I086; Figures II-21 and II-22). The group thickens westward from 198 m in the southern Flathead Range (Price, 1962), to 305 m at Tornado Pass and 457 m in southeastern British Columbia (Ibid). The carbonate content within the group also increases to the west in a similar manner.

The lower part of the Rocky Mountain Formation between the Livingstone Range and Crowsnest Pass sections (Figures II-21 and II-22), consists largely of brown and buff-grey to grey, planar thin-bedded, fine- to medium-grained quartzarenite to dolomitic quartzarenite, with minor intermixed units of planar to wavy layered, thin-laminated shale, siltstone and quartzarenite. The uppermost part of the succession comprises interbedded grey to brown-grey, fine-crystalline dolostone, dolosiltite and chert-banded dolostone, and minor shale, chert pebble conglomerate and pebbly quartzarenite.

TABLE II-12

POSSIBLE RIFT-RELATED FEATURES IN THE LIVINGSTONE, MOUNT HEAD AND ETHERINGTON FORMATIONS

FORMATION	FEATURE	RIFT RELATION
ETHERINGTON	(a) There are changes in the overall lithology from stratigraphic section 3I049 near Crowsnest Pass (Figure II-21) to stratigraphic section 3I086 (Figure II-22) in the Livingstone Range (Figure I-2). That is, the southern sequence at section 3I049 is comprised of cyclically alternating horizons of varicoloured dolomitic shale, dololutite to dolosiltite, and horizons of interlayered dolosiltite, dolostone and minor dolomitic sandstone. In contrast, the northern sequence at section 3I086 consists of interlayered calcisiltite, calcarenite and siliceous dolosiltite and dolomitic sandstone. The increased sand-sized content at section 3I086 may indicate the effects of limited reactivation of the northern margin of the Southern Alberta Rift, which caused shedding of terrigenous material across the restricted carbonate shelf that existed to the south and west during Etherington Formation time.	Weak
	(b) Significant thickness variations exist in Etherington Formation in southwest Alberta. That is, the succession thickens from about 70 m in the north at section 3I086 (Figure II-22) and to the south near Crowsnest Pass at section 3I049 (Figure II-21), whereas to the west at Tornado Creek near section 3I089 (Figure I-2), Etherington Formation is 305 m thick (Price, 1962). This trend of increasing thickness to the west is, in a general sense, similar to that described for strata of the Mount Head Formation by Brandley et al. (1993), and may be similarly related to reactivation of ancient basement structures.	Weak
	(c) A 1 m to 1.2 m thick horizon of deformed dolosiltite to dolostone occurs in the uppermost part of Etherington Formation at section 3I086 (Figure II-22; Plate II-3.c). This bed may represent a gravity slide horizon and, if so, would indicate that syndepositional tectonism had influenced the depositional patterns of at least some Etherington Formation beds.	Weak
MOUNT HEAD	The Mount Head Formation contains a subtle facies change between the sequence located at stratigraphic section 3I086 (Figure II-22) in the Livingstone Range, and those at stratigraphic sections 3I066 (Figure II-15) and 3I089 (Figure II-16) near the Oldman River (Figure I-22). That is, the successions in Figures II-15 and II-16 contain a dololutite-bearing middle member that is not present in stratigraphic section 3I086 (Figure II-22). This facies change may represent a basinal setting to the southwest, and may reflect the effects of differential subsidence that Brandley et al. (1993) suggested are related to reactivation of ancient basement structures.	Weak
LIVINGSTONE	The formation is characterized by significant thickness variations in southwest Alberta. Strata thicken from 275 m in central Livingstone Range, to 335 m to 418 m near the Clark Range in the south, and to 438 m at stratigraphic section 3I066 (Figure II-15) and 488 m at stratigraphic section 3I089 (Figure II-16) in the Front Ranges near the Oldman River (Figure I-2). These thickness variations may reflect differential subsidence related to incipient reactivation of the Southern Alberta Rift.	Weak

The Spray Lakes Group accumulated in a sand-dominated mixed shoreline to shallow marine shelf setting.

TRIASSIC

Spray River Group

The strata of the Spray River Group in the Livingstone and Blairmore Ranges near the central part of the Southern Alberta Rift, consist of a succession of intermixed planar to wavy layered, thin-laminated to thin-bedded grey siltstone, fine-grained sandstone, and fine-crystalline limestone and dolostone. Thin layers and lenses of black chert pebble conglomerate occur at the base of the succession.

In southeastern British Columbia the Spray River Group is comprised of a lower sequence of planar thick-laminated to thin-bedded grey siltstone, calcareous siltstone and dark grey to brown, planar thin-laminated silty shale, with minor interbeds of dark grey sandstone and chert pebble conglomerate near the base. The upper part consists of light grey to brown, thin-bedded dolomitic to sideritic siltstone and argillaceous siltstone.

The Spray River Group thickens to the north and west. It is about 91 m thick in the Flathead Range, to 198 m thick to the north at Tornado Pass and 457 m thick to the west in southeastern British Columbia (Price, 1962; Gordey et al., 1992). The succession accumulated in a mixed shoreline to shallow marine shelf setting.

JURASSIC

Fernie Group

The strata of the Fernie Group comprise a westward-thickening wedge of variably intermixed shale and sandstone, with lesser amounts of carbonate and conglomerate. The succession thickens in southwestern Alberta from 183 m to the north near traverse 16, to 305 m in the south near traverse 9 (Figure I-2).

The Fernie Group in southwest Alberta consists of three broad subdivisions (Table II-10):

Lower sequence (Nordegg, Poker Chip and Rock Creek units)

The lower sequence comprises a thin basal conglomerate unit, which is succeeded by 15 m to 30 m of variably intermixed thin-laminated dark grey shale, calcareous shale and fine-grained sandstone that, in turn, is overlain by 15 m to 38 m of grey to black, planar laminated shale with concretionary horizons and minor interlayers of argillaceous limestone and calcareous sandstone.

Middle sequence ('Grey Beds')

The middle sequence is comprised of 91 m of grey, planar thin-laminated shale with variably intermixed thin-laminated silty shale, fine-grained calcareous sandstone and sandy limestone.

Upper sequence ('Greenbeds' and 'Passage Beds')

The upper sequence consists of a 20 m thick unit of glauconitic thin-bedded sandstone and glauconitic planar laminated shale, which grades into thin-laminated black shale with limonitic concretions. The uppermost 70 m of the Fernie Group comprises a coarsening-upward succession of planar thin-laminated shale and siltstone that grades up into interlayered thick-laminated shale and thin-bedded sandstone, and an upper unit of brown to grey, thin-bedded, fine- to coarse-grained sandstones. The uppermost beds are conformably overlain by carbonaceous strata of the Kootenay Group (Table II-10).

The Fernie Group succession accumulated in a shallow- to deep-shelf marine setting. The various units represent the final deposits on a passive margin before initiation of foreland basin development in the Late Jurassic.

UPPER JURASSIC - LOWER CRETACEOUS

Kootenay Group

The Kootenay Group comprises an assemblage of intermixed shale, siltstone, sandstone, chert pebble conglomerate and coal. The succession thickens southwestwards from 122 m to 183 m along the Carbondale River south of Coleman, Alberta, to 488 m to 1,068 m in the Fernie Basin in southeastern British Columbia (Price, 1962; Gordey et al., 1992).

The Kootenay Group in southwest Alberta consists of four major intermixed facies (stratigraphic sections 3I036-037, 3I077 and 3I093; Figures II-24 to II-26):

(i) Planar thin-laminated, dark grey to black shale, argillaceous shale and minor thin interlayers and lenses of siltstone.

(ii) Interlayered dark grey to black, thin-laminated shale, and thick-laminated to thin-bedded, planar, wavy layered to cross-laminated siltstone, and fine- to medium-grained quartzitic subarkose. Shale intraclasts occur in the sandstone layers. Coal seams occur throughout this facies.

(iii) Dark grey to brown-grey, planar to wavy layered and crossbedded, thick- to medium-bedded, fine- to coarse-grained quartzitic subarkose and minor sublitharenite. Sedimentary structures are common, and include trough and planar crossbeds, scour marks and current ripple marks.

(iv) Massive to poorly stratified, quartz and chert pebble conglomerate and minor lenses to layers of pebbly subarkose. The beds have scoured and channelled bases that downcut as much as 0.5 m into underlying sandstone beds.

These facies range from 1 m to more than 40 m in thickness, and alternate with each other in a random manner, but in places also occur as cyclic assemblages as follows:

(i) Small- to medium-scale units with thicknesses ranging from 3 m to 12 m and which form coarsening- and thickening-upward cycles of shale into shale-siltstone-sandstone into sandstone facies.

(ii) Fining- and thinning-upward cycles with thicknesses that range from 2 m to 15 m and comprise medium-bedded to crossbedded sandstone grading into planar thick-laminated sandstone, and massive chert pebble conglomerate that grades up into planar thin-bedded sandstone.

(iii) Large-scale coarsening-upward sequences with thicknesses greater than 30 m. An example of this cyclic assemblage is the succession illustrated by units A to E in section 3I077 (Figure II-25).

Strata of the Kootenay Group accumulated mainly in a fluvio-deltaic setting. In this environment, sand- and gravel-dominated fluvial and deltaic distributary channels would migrate across a mud- and silt-dominated floodplain. These sediments represent the initial deposits of the foreland basin that was formed during Kootenay Group time.

Features in the Kootenay Group that may be related to re-activation of the Southern Alberta Rift are summarized in Table II-13.

LOWER CRETACEOUS

The Lower Cretaceous succession in southwest Alberta comprises the Blairmore Group and the conformably overlying, partly interfingered, Crowsnest Formation (Table II-10).

Blairmore Group

The Blairmore Group is a westward-thickening assemblage of largely continental shales, siltstones, sandstones and conglomerates (stratigraphic sections 3I036-037 and 3I054; Figures II-24 and II-27; Plate II-3.d). The succession consists of variably intermixed facies of green, green-grey, dark grey to purple-grey and maroon, planar thin-laminated shale, silty shale to argillaceous siltstone, thick-laminated to thin-bedded, fine- to coarse-grained subarkose to sublitharenite, and layers and lenses of thin- to medium-bedded pebbly subarkose and quartz-chert-sandstone pebble conglomerate. The coarser-grained

TABLE II-13

POSSIBLE RIFT-RELATED FEATURES IN THE KOOTENAY GROUP

FORMATION	FEATURE	RIFT RELATION
KOOTENAY GROUP	(a) Strata of the Kootenay Group thicken greatly to the west and southwest. The succession thickens from between 122 m and 183 m along the Carbondale River, to between 488 m and 1,068 m in the Fernie Basin in southeastern British Columbia (Price, 1962; Gordey et al., 1992). This thickness change is accompanied by an increase in the amount of coarse-grained sandstone and conglomerate in the sequence. These features of Kootenay Group may relate to the deeply subsiding nature of the Fernie Basin and may reflect the influence of reactivation of the Southern Alberta Rift (Yorath, 1992).	Weak
	(b) Large scale coarsening-upward sequences exist in the Kootenay Group (Figure II-25). The cycles, in general, consist of shale units that grade upwards into shale-siltstone-sandstone units and then into sandstone-conglomerate horizons. These coarsening-upward sequences contain smaller-scale fining- and thinning-upward cycles that consist of massive to medium-bedded conglomerate grading up into thick-laminated sandstone. The overall succession represents an assemblage of 'nested cycles'. That is, the strata comprise cyclic sequences of more than one scale. The occurrence of such multiple scale cyclic sequences commonly are interpreted to be, at least to some extent, associated with syndepositional tectonism (Miall, 1990). Such tectonic effects would be more prevalent in an area already weakened by earlier extensional events, such as the Southern Alberta Rift.	Weak

sandstone and conglomerate beds are most abundant in the lower and upper one-third of the Blairmore Group, and these facies also increase in thickness and amount to the west and southwest. Concretions, some more than one metre in diameter, are most common in shale-dominated sequences. The sandstone and conglomerate beds typically contain a shale intraclast-bearing thin basal layer. Sedimentary structures are most common in siltstone and sandstone layers, and comprise scour marks, trough crossbeds and rare hummocky cross-stratification.

The basal contact of Blairmore Group is marked by the presence of intermixed coarse-grained sandstone and layers or lenses of conglomerate that rest unconformably on strata of the Kootenay Group. Strata of the Blairmore Group are overlain near and south of Crowsnest Pass by volcaniclastic siltstone, sandstone and tuff of the Crowsnest Formation, and to the north near traverse 25 (Figure I-2), by thin-laminated black shale beds of the Blackstone Formation. Blairmore Group thickens westward from 365 m in the northern Clark Range to 1,980 m in the Fernie Basin in southeastern British Columbia (Price, 1962; Yorath, 1992).

The Blairmore Group siliciclastic wedge accumulated in sandy braidplain to alluvial plain environments, which resulted in deposition of the sandstone-siltstone-shale dominated assemblages, and in proximal braidplain to alluvial fan conditions, which resulted in deposition of the coarse-grained sandstone to conglomerate assemblages.

Crowsnest Formation

The Crowsnest Formation is comprised of trachyte and phonolite debris that exists as intermixed units of tuff, volcaniclastic siltstone to conglomerate and massive volcanic agglomerate (stratigraphic section 3I039; Figure II-28; Plates II-3.e and II-3.f). The formation is restricted to a belt along the Foothills situated within the central and southern parts of the Southern Alberta Rift, and is absent to the north near the inferred northern margin of the Southern Alberta Rift. The maximum thickness of Crowsnest Formation occurs near Coleman, Alberta, where the formation is 427 m thick (Pearce, 1970; Adair, 1986). The formation thins to 150 m about 5 km west of Coleman, and is absent in the Livingstone Thrust sheet about 30 km north-northeast of Coleman.

The Crowsnest Formation consists of green, green-grey and pink- to purple-grey, planar thin-laminated to thin-bedded volcaniclastic siltstone to sandstone, crystal-lithic tuff, poorly stratified polymictic conglomerate and massive-weathering volcanic agglomerate. The latter unit is comprised of angular trachyte, with quartz, garnet, argillite and sandstone fragments in a fine- to coarse-crystalline mafic matrix (Plate II-3.f). The volcaniclastic sandstone horizons locally contain crossbeds. In areas where the formation is thinner, the succession is dominated by volcaniclastic sandstones and polymictic granule to pebble conglomerates.

The Crowsnest Formation overlies and interfingers with strata of the upper Blairmore Group, and is unconformably overlain by planar thin-laminated shales of the Blackstone Formation (Table II-10). The Crowsnest Formation succession originated as a series of volcanic eruptions from one or more volcanoes built upon the alluvial floodplain deposits represented by Blairmore Group. The original agglomerates, tuffs and flows were largely reworked on the floodplain and were intermixed with Blairmore Group deposits at the outer portions of the volcanic complex (Pearce, 1970; Dingwell and Brearly, 1985).

Features in the Blairmore Group and Crowsnest Formation that may be related to reactivation of the Southern Alberta Rift are summarized in Table II-14

TABLE II-14

POSSIBLE RIFT-RELATED FEATURES IN THE BLAIRMORE GROUP AND CROWSNEST FORMATION

FORMATION	FEATURE	RIFT RELATION
CROWSNEST FORMATION	The thickest sequence of this areally restricted formation occurs at Coleman. The location of the vents forming the volcanic complex may have been controlled by structures associated with the Southern Alberta Rift. Reactivation of a splay off of the southern margin of the Southern Alberta Rift, or reactivation of an intratrough fault system would have provided weakened access routes for the trachytic magma to rise to the paleosurface.	Moderate
BLAIRMORE GROUP	This assemblage of variably intermixed shale, siltstone, sandstone and conglomerate beds forms a westward thickening wedge. The sequence thickens greatly to the west, from 365 m in the northern Clark Range to 1,980 m in the Fernie Basin of southeastern British Columbia (Price, 1962; Yorath, 1992). This thickening trend is accompanied by a westerly increase in the content of sandstone and conglomerate. These features reflect deposition in the deeply subsiding Fernie Basin and, as well, may reflect the influence of the reactivation of the Southern Alberta Rift.	Weak

UPPER CRETACEOUS

In southwest Alberta the Upper Cretaceous is represented by the Alberta Group, and the overlying Belly River, Bearpaw, St. Mary River and Willow Creek Formations (Table II-10).

Alberta Group

Blackstone Formation

The Blackstone Formation is comprised mainly of dark grey to black, planar thin-laminated shale to silty shale with minor interlayers and lenses of planar to wavy layered, thick-laminated to thin-bedded siltstone and quartzitic subarkose. Thin, brown to rust-weathered shale horizons with sideritic concretions are also present. The basal part of the formation contains thin intermixed layers and lenses of chert granule to pebble conglomerate.

The Blackstone Formation thickens northward from 80 m in the Carbondale River area, to about 240 m near traverse 25 (Figure I-2). The shale-dominated sequences are conformably overlain by sandstone-dominated strata of the Cardium Formation (Table II-10). The strata of the Blackstone Formation accumulated in a shallow marine, mud-dominated basin.

Cardium Formation

The Cardium Formation consists of alternating facies of: (a) buff-grey to dark grey, planar thin- to thick-laminated shale and argillaceous siltstone with minor interlayers of wavy to lenticular bedded fine-grained quartzitic subarkose, and (b) brown-grey, thick-laminated to thin-bedded, wavy, cross-laminated to crossbedded, fine- to coarse-grained quartzitic subarkose. Minor thin interlayers of chert pebble conglomerate, pyritic shale and coal occur in the lower part of the formation, and concretions occur locally in the upper part of the formation. These facies locally occur in sandstone-capped coarsening-upward cycles that are 10 m to 18 m thick. Sedimentary structures are common and include scour marks, small load casts, and wave and current ripple marks. Flat shale intraclasts commonly occur at the base of the sandstone and conglomerate layers.

The Cardium Formation is characterized by a pronounced thickening from east to west, and as well by an increased sandstone content. The strata thicken west and northwest from about 30 m near traverse 15, to more than 91 m near traverse 25 (Figure I-2). Cardium Formation is conformably overlain by black thin-laminated shales of the Wapiabi Formation (Table II-10). Cardium Formation sediments accumulated mainly as regressive shoreline and shallow marine siliciclastic shelf deposits.

Wapiabi Formation

Strata of the Wapiabi Formation consist largely of black to dark grey, planar thin-laminated shale intermixed with minor amounts of planar to wavy layered, thick-laminated to thin-bedded grey siltstone, fine-grained quartzarenite and wavy layered to cross-laminated, medium- to coarse-grained subarkose to sublitharenite. Concretions occur throughout the succession. Sedimentary structures are confined mainly to the siltstone and sandstone horizons, and include small scour marks and load casts (stratigraphic sections 3I095 and 3I101; Figures II-29 and II-30).

The Wapiabi Formation thickens significantly between traverse 15 and traverse 25 (Figure I-2), increasing from less than 305 m in the east to 610 m in the west. The formation passes gradationally up into siltstones and sandstones of the Belly River Formation (Table II-10). The fine clastics of Wapiabi Formation were deposited in a shallow marine, mud-dominated basin.

Belly River Formation

Thick successions of Belly River Formation underlie much of the foothills of southwestern Alberta. The formation thickens from east to west, and ranges from about 500 m thick near traverse 5 to over 700 m thick near traverse 7 (Figure I-2). The formation comprises alternating shale- and sandstone-dominated facies (stratigraphic sections 3I095, 3I101 and 3I040; Figures II-29 to II-31), which grade upwards into dark grey, planar laminated shales of the Bearpaw Formation (Table II-10).

A distinctive, resistant, grey- to buff-weathering horizon of fine- to coarse-grained subarkose occurs near the base of the formation (unit L in Figure II-30). The remainder of the formation consists largely of shale, siltstone and sandstone beds arranged into three main facies:

(i) Grey and green-grey to dark grey, planar thin-laminated shale with minor thick-laminated to lensed layers of siltstone and fine-grained quartzitic subarkose.

(ii) Brown-grey to buff-grey, intermixed planar, wavy to lenticular layered, thin-laminated shale and thick laminated to thin-bedded siltstone, and fine- to medium-grained quartzitic subarkose. Sedimentary structures are common and include small scour marks, load casts, current ripple marks and cross-laminations. Shale intraclasts occur within some of the sandstone layers.

(iii) Buff-brown and grey to green-grey, thick-laminated to medium-bedded planar, wavy to crossbedded, fine- to coarse-grained subarkose to sublitharenite. Sedimentary structures are common and include planar and trough crossbeds, large scour marks, cross-laminations and rare hummocky cross-stratification. The sandstone units comprise thinning-up sequences of crossbedded sandstone into cross-laminated and thick-laminated, planar layered sandstone.

The three facies typically are from 2 m to 15 m thick, and occur both randomly arranged and as fining-upward couplets or cycles that average 3 m to 20 m in thickness (Figures II-29 and II-30). Minor thin horizons of carbonaceous shale, planar to nodular bedded limestone and thin coal seams also occur locally in the formation.

The strata of the Belly River Formation accumulated on expansive alluvial to delta plains, where sand-filled fluvial channels migrated across crevasse splay, flood basin and lacustrine mud and silt deposits. Sediment source areas lay to the west and southwest. Features in the Belly River Formation that may be related to reactivation of the Southern Alberta Rift are summarized in Table II-15.

Bearpaw Formation

The Bearpaw Formation is comprised of dark grey, planar thin-laminated shale and concretion-bearing shale, with minor interbeds of brown to grey, planar thick-laminated to thin-bedded, fine- to coarse-grained sandstone. The formation is up to 183 m thick in southwest Alberta, and is conformably overlain by strata of the St. Mary River Formation (Table II-10). The Bearpaw Formation accumulated in a mud-dominated shallow marine shelf setting.

TABLE II-15

POSSIBLE RIFT-RELATED FEATURES IN THE BELLY RIVER FORMATION

FORMATION	FEATURE	RIFT RELATION
BELLY RIVER	The nature of local and regional facies and thickness trends in the Belly River Formation implies that syndepositional tectonism may have influenced sedimentation patterns. Belly River strata are arranged into the following facies: (i) Thinning-upward sequences of crossbedded sandstone that grade up into thick-laminated, planar bedded to ripple marked sandstone. Individual unit thickness ranges from 2 m to 8 m. (ii) Fining- or thinning-upward couplets of crossbedded sandstone with planar bedded sandstone that grade up into intermixed shale, siltstone and sandstone. In general, the shale content in each couplet increases upwards and a couplet thickness ranges from 3 m to 20 m. (iii) An overall thinning-upward trend within the Belly River Formation, in which the thickness and concentration of sandstone facies decrease upsection. The Belly River Formation comprises a succession with cycles of two scales superimposed upon a regional thinning- or fining-upward trend. That is, the succession contains a 'nested' cyclic facies assemblage. As for cyclic sequences in the Kootenay Group, the depositional history of these successions may have been controlled by syndepositional tectonism (Miall, 1990), and hence possibly is related to reactivation of the Southern Alberta Rift. The Belly River Formation is overlain and underlain by the marine shale successions of Bearpaw Formation and Alberta Group. The Belly River Formation forms a siliciclastic wedge that thickens significantly from 760 m in the east to 1,220 m in the west in southwest Alberta. This siliciclastic wedge was deposited in an expansive alluvial plain and delta plain setting which, in the project area, may have been partitioned by northeast-oriented transverse growth faults (Jerzykiewicz and Norris, 1993). The location of the growth faults may have been controlled by reactivation of ancient deep-seated faults in the Precambrian basement associated with the Southern Alberta Rift (Ibid).	Moderate

St. Mary River Formation

The St. Mary River Formation crops out sporadically in southwest Alberta. A well-exposed sequence, which is greater than 975 m thick, crops out along the Oldman River at section 3I119 in the central part of the Southern Alberta Rift (Figures I-2 and II-32). However, this section represents only a portion of the upper part of the sequence. The lower 177 m of the sequence at the Oldman River section consists of horizons of grey and brown-grey, planar to wavy layered, fine- to medium-grained quartzarenite that alternates with planar thin-laminated, grey and green shale with thin coal seams, ironstone beds and oyster coquinas. The overlying 798 m consists of alternating facies of: (a) grey to brown-grey, thin-laminated shale, argillaceous siltstone and minor thin layers to lenses of siltstone and sandstone, and (b) units of grey to brown, thin-bedded, planar, wavy to crossbedded, fine- to coarse-grained quartzitic subarkose to sublitharenite. The subarkose to sublitharenite sandstone units contain scoured bases, trough and planar crossbeds, and cross laminations. They vary laterally in thickness by as much as 1 m because of the undulating scoured bases of the units which are due to the sandstone beds being downcut into the underlying shale-siltstone-sandstone layers. The shale-siltstone-sandstone units are 1 m to 13 m thick, whereas the sandstone units range from 1 m to 5 m in thickness (Figure II-32). The sandstone to finer clastic couplets typically are arranged in thinning-up sequences, similar to those described for sandstone units in the Belly River Formation.

The strata of the lower part of the St. Mary River Formation were deposited in a brackish setting, and represent a transitional succession between the underlying marine muds of the Bearpaw Formation and the alluvial floodplain deposits that comprise the upper part of the St. Mary River Formation. The continental deposits of St. Mary River Formation accumulated from the interaction of meandering fluvial channel sands across floodplain and lacustrine silts and muds.

Willow Creek Formation

The recessive beds of the Cretaceous to early Paleocene Willow Creek Formation conformably overlie the alternating sandstone and shale beds of the St. Mary River Formation (Table II-10). The Willow Creek Formation consists of planar thick-laminated, grey and green to pink shale intermixed with planar to wavy layered, thick-laminated to thin-bedded, fine- to medium-grained sandstone. The Willow Creek Formation has a maximum thickness of 1,250 m in the Southern Alberta Rift project area. The siliciclastic successions of Willow Creek Formation accumulated in a braidplain to delta plain depositional setting.

PALEOCENE

The upper Willow Creek Formation is unconformably to disconformably overlain by Paleocene strata of Porcupine Hills Formation in southernmost southwest Alberta. To the north, the upper Willow Creek Formation is approximately stratigraphically equivalent to the Scollard and Coalspur Formations, which are unconformably to conformably overlain by the Paskapoo Formation (Stott et al., 1993). Although Carrigy (1971) argued that the Paskapoo Formation was overlain by the Porcupine Hills Formation, it is now known that they are approximately age equivalent, both being of mid or late Paleocene age (Stott et al., 1993).

Porcupine Hills and Paskapoo Formations

The facies equivalent strata of the Porcupine Hills and Paskapoo Formations represent the last preserved deposits of the foreland basin in southwest Alberta. These Paleocene strata unconformably overlie the recessive shale and sandstone beds of the Willow Creek Formation (Table II-10). The Paleocene successions are comprised of alternating facies of: (a) brown, yellow-brown and grey, planar thin-laminated to very thin-bedded shale with minor siltstone lenses and layers, and (b) planar layered to crossbedded, fine- to coarse-grained subarkose and sublitharenite. These facies are locally arranged into coarsening-upward cycles that comprise: (1) lower members, which are shale-dominated with thicknesses ranging from 7 m to 10 m, plus minor horizons of siltstone that increase upwards, and (2) an upper sandstone member with thickness ranging from 5 m to 8 m. The sandstone members occur as thinning-upward sequences comprised of: (a) basal units with medium- to large-scale trough crossbeds which reach a maximum height of 1 m, (b) overlying sandstone beds with smaller trough crossbeds which reach a maximum height of less than 0.3 m, and (c) lastly, an uppermost planar and wavy layered, thick-laminated to very thin-bedded sandstone which typically is 0.5 m to 1.0 m thick.

The semi-recessive successions of the Porcupine Hills and Paskapoo Formations are up to 1,220 m thick in the Southern Alberta Rift project area. These formations were deposited in a sandy braidplain setting.

PALEOCURRENT MEASUREMENTS

A total of 447 paleocurrent measurements were collected from Middle Proterozoic to Tertiary strata during the course of field work. The measurements were taken from trough and planar crossbeds, ripple marks and stromatolite mound elongations at 43 field stations (Tables II-16 to II-18).

The Middle Proterozoic Purcell Supergroup accounted for 173, or 39 per cent, of the paleocurrent measurements. Major trends indicate south-southwest to west-northwest directed paleocurrents (Table II-16; Figures II-33 to II-45). Individual paleocurrent trends can be summarized as follows for the Appekunny to Roosville Formations.

1. **Appekunny Formation**: Measurements from trough crossbeds in quartzarenite and quartzitic subarkose indicate predominantly west to southwest directed paleocurrents (Figures II-33 and II-34).

2. **Grinnell Formation**: Measurements from trough crossbeds and ripple marks in quartzitic subarkose indicate predominantly southwest directed paleocurrents (Figures II-35, II-36 and II-37).

3. **Siyeh Formation**: Measurements from trough crossbeds and ripple marks in quartzarenite to sublitharenite, and those from stromatolite mound elongations indicate predominantly southeast to south to southwest directed paleocurrents (Figures II-38 to II-41).

4. **Sheppard Formation**: Measurements from trough crossbeds and ripple marks in quartzarenite to dolarenite indicate predominantly south-southeast and south to southwest directed paleocurrents (Figures II-42 and II-43).

5. **Gateway and Roosville Formations**: Measurements from ripple marks in quartzarenite to quartzitic subarkose indicate predominantly east to south to west directed paleocurrents (Figures II-44 and II-45).

The strata of the Mississippian Livingstone Formation accounted for 27, or 6 per cent, of the paleocurrent measurements (Table II-17). The measurements from trough crossbeds in calcarenite indicate a bimodal trend of predominantly northeast to southwest directed paleocurrents (Figures II-46, II-47 and II-48).

TABLE II-16

PALEOCURRENT TRENDS - MIDDLE PROTEROZOIC

FORMATION (AGE)	SEDIMENTARY STRUCTURES	VECTOR MEAN TREND	RIFT RELATION
ROOSVILLE 31063[1]	ASYM RMK[2]	W to S to E	Weak
GATEWAY 31035	ASYM RMK	W to S to SE	Weak
SHEPPARD 31025 31055	SYM RMK[3] TCB[4]	NNW-SSE SSW to S	Strong Strong
SIYEH 31044 31044 31056 31056	SYM RMK TCB ASYM RMK STROM. MOUNDS[5]	WNW-ESE S to SE S to SW NNW-SSE	Strong Weak Weak Strong
GRINNELL 31016 31056 31056	TCB SYM RMK TCB	SW NE-SW NW to SW	Strong Moderate Strong
APPEKUNNY 31015 31016 31056	TCB TCB TCB	S to W to N S to W to N W to S to E	Moderate Moderate Moderate

TABLE II-17

PALEOCURRENT TRENDS - PALEOZOIC

FORMATION (AGE)	SEDIMENTARY STRUCTURES	VECTOR MEAN TREND	RIFT RELATION
LIVINGSTONE (MISSISSIPPIAN) 31066 31136 31089	TCB[3] TCB TCB	NW to S NE-SW N to W to S	Weak Moderate Weak

Note:
1. Stratigraphic section identifier
2. ASYM RMK is asymmetrical ripple marks
3. SYM RMK is symmetrical ripple marks
4. TCB is trough crossbeds
5. STROM. MOUNDS is stromatolitic mound elongations

TABLE II-18

PALEOCURRENT TRENDS - MESOZOIC AND CENOZOIC

FORMATION (AGE)	SEDIMENTARY STRUCTURES	VECTOR MEAN TREND	RIFT RELATION
PASKAPOO (PALEOCENE)			
31071	TCB[1]	N to NE	Moderate
31073	TCB	NNW to NE to S	Weak
PORCUPINE HILLS (PALEOCENE)			
31105	TCB	N to NE to S	Weak
31106	TCB	NW to NE to SE	Weak
31107	TCB	NW to NE to SE	Weak
ST. MARY RIVER (UPPER CRETACEOUS)			
31108	TCB	W to NW	Moderate
31119	TCB	NW to NE	Moderate
BELLY RIVER (UPPER CRETACEOUS)			
31012	TCB	NNW to NE	Strong
31013	TCB	NNW to NE	Strong
31014	TCB	NNW to NE	Strong
31057	TCB	NE to E to SE	Strong
31058	TCB	NE to E to SE	Strong
31059	TCB	NE to E to SE	Strong
31029	TCB	NW to NE to SSE	Weak
31040	TCB	E	Weak
31068	TCB	NE to E	Strong
31069	TCB	NE to E	Strong
31095	TCB	NNW to NNE	Strong
31096	TCB	NNW to NNE	Strong
BLAIRMORE GROUP (LOWER CRETACEOUS)			
31001	TCB/PCB[2]	NNE to NE	Strong
31002	TCB/PCB	NNE to NE	Strong
31003	TCB/PCB	NNE to NE	Strong
31037	TCB	NW	Strong
31125	TCB	N to NE	Moderate
KOOTENAY (UPPER JURASSIC/ LOWER CRETACEOUS)			
31036	TCB	NW	Strong
31093	TCB	NW to NNE	Strong

Note: 1. TCB is trough crossbeds
2. PCB is planar crossbeds

The successions of Mesozoic to Cenozoic strata accounted for the remaining 247, or 55 per cent, of the paleocurrent measurements (Table II-18). Major trends indicate northeast and north to northwest directed paleocurrents (Figures II-49 to II-65). The individual paleocurrent trends for the various Mesozoic and Cenozoic sequences can be summarized as follows.

1. **Kootenay Group**: Measurements from trough crossbeds in quartzitic subarkose to subarkose indicate predominantly northwest to north-northeast directed paleocurrents (Figures II-49 and II-50).

2. **Blairmore Group**: Measurements from trough and planar crossbeds in quartzitic subarkose to subarkose indicate predominantly northwest through northeast directed paleocurrents (Figures II-51, II-52 and II-53).

3. **Belly River Formation**: Measurements from trough crossbeds in quartzitic subarkose to subarkose indicate predominantly east to north-northwest directed paleocurrents (Figures II-54 to II-59).

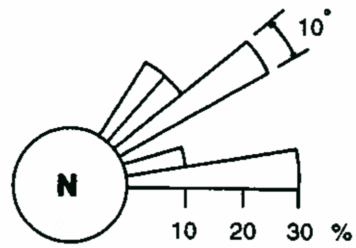
4. **St. Mary River Formation**: Measurements from trough crossbeds in quartzarenite to subarkose indicate predominantly northwest to north-northwest directed paleocurrents (Figures II-60 and II-61).

5. **Porcupine Hills and Paskapoo Formations**: Measurements from trough crossbeds in quartzitic subarkose to subarkose indicate predominantly north-northwest to northeast to southeast directed paleocurrents (Figures II-62 to II-65).

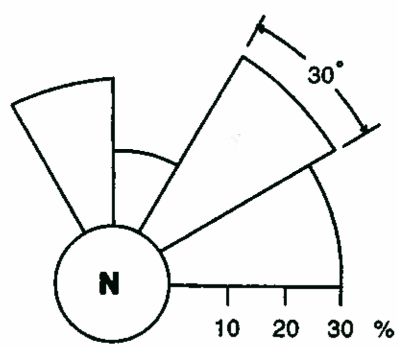
In summary, the regional paleocurrent trends define a change in the major sediment source direction between strata of the Middle Proterozoic to Paleozoic successions and those of the Mesozoic to Cenozoic successions. That is, the predominantly southeast and south to southwest directed paleocurrent trends in the Proterozoic to Paleozoic sequence indicate a major eastern to northern source area for sediments during Proterozoic and Paleozoic time, whereas the predominantly north to northeast directed paleocurrent trends in the Mesozoic to Cenozoic sequence indicate a major western to southern source area during the Mesozoic to Cenozoic time interval.

PALEOCURRENT ROSE DIAGRAM LEGEND

PLOT INTERVAL OF 10° :



PLOT INTERVAL OF 30° :



N = Number of Measurements

PALEOCURRENT ROSE DIAGRAM

APPEKUNNY FORMATION

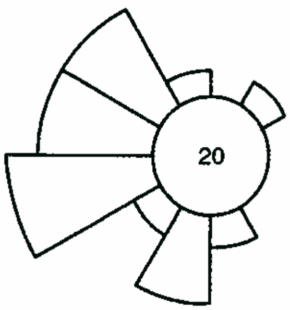


FIGURE: II - 33

LOCATION: Station 31015 UTM E 688100 N 5459900 NTS 82 G/8
Station 31016 UTM E 689670 N 5459120 NTS 82 G/8

LITHOLOGY: Quartzarenite

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Polymodal, Moderate Dispersion

PALEOCURRENT ROSE DIAGRAM

APPEKUNNY FORMATION

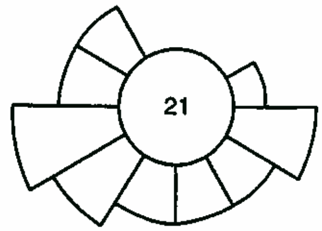


FIGURE: II - 34

LOCATION: Station 31056 UTM E 710740 N 5464290 NTS 82 G/8

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Polymodal, High Dispersion

PALEOCURRENT ROSE DIAGRAM
GRINNELL FORMATION

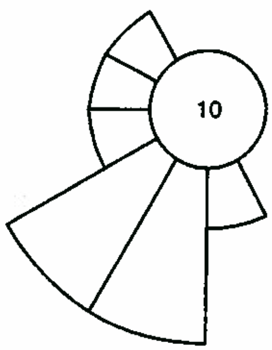


FIGURE: II - 35

LOCATION: Station 3I016 UTM E 688660 N 5459120 NTS 82 G/8

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Unimodal, Moderate Dispersion

PALEOCURRENT ROSE DIAGRAM
GRINNELL FORMATION

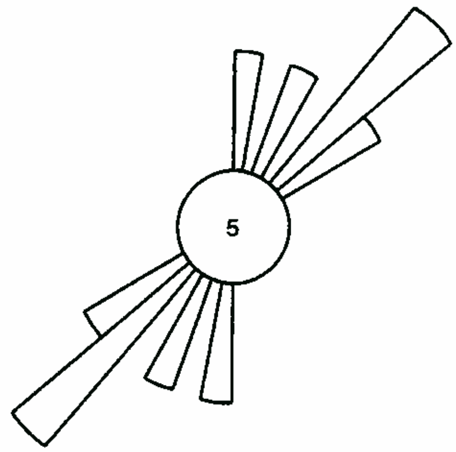


FIGURE: II - 36

LOCATION: Station 3I056 UTM E 710740 N 5464290 NTS 82 G/8

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Symmetrical Ripple Marks

PLOT INTERVAL: 10° **PLOT TYPE:** Bimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
GRINNELL FORMATION

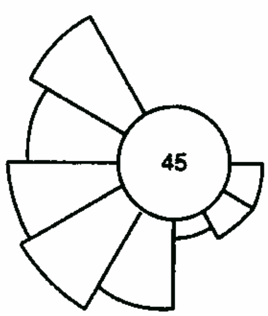


FIGURE: II - 37

LOCATION: Station 3I056 UTM E 710740 N 5464290 NTS 82 G/8

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Polymodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
SIYEH FORMATION

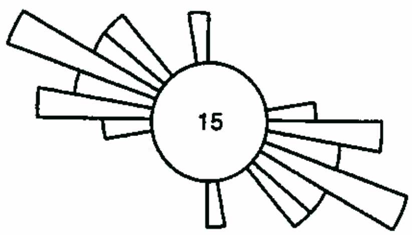


FIGURE: II - 38

LOCATION: Station 31044 UTM E 710190 N 5465225 NTS 82 G/8
LITHOLOGY: Sublitharenite
SEDIMENTARY STRUCTURE: Symmetrical Ripple Marks
PLOT INTERVAL: 10° **PLOT TYPE:** Bimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
SIYEH FORMATION

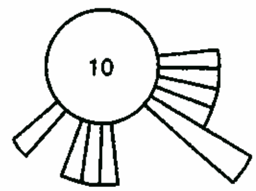


FIGURE: II - 39

LOCATION: Station 31044 UTM E 710190 N 5465225 NTS 82 G/8
LITHOLOGY: Quartzarenite to Sublitharenite
SEDIMENTARY STRUCTURE: Trough Crossbeds
PLOT INTERVAL: 10° **PLOT TYPE:** Polymodal, High Dispersion

PALEOCURRENT ROSE DIAGRAM
SIYEH FORMATION

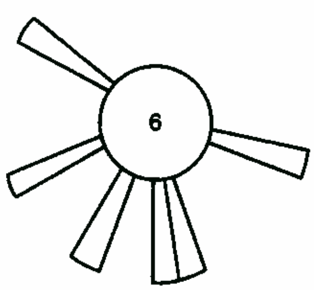


FIGURE: II - 40

LOCATION: Station 31056 UTM E 710740 N 5464290 NTS 82 G/8
LITHOLOGY: Dolosiltite to Sublitharenite
SEDIMENTARY STRUCTURE: Asymmetrical Ripple Marks
PLOT INTERVAL: 10° **PLOT TYPE:** Polymodal, High Dispersion

PALEOCURRENT ROSE DIAGRAM
SIYEH FORMATION

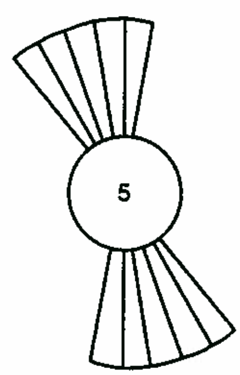


FIGURE: II - 41

LOCATION: Station 31056 UTM E 710740 N 5464290 NTS 82 G/8
LITHOLOGY: Stromatolitic Limestone
SEDIMENTARY STRUCTURE: Stromatolite Mound Elongations
PLOT INTERVAL: 10° **PLOT TYPE:** Bimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
SHEPPARD FORMATION

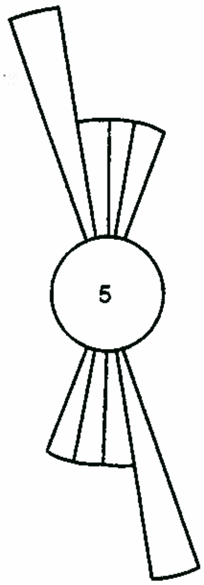


FIGURE: II - 42

LOCATION: Station 31025 UTM E 686110 N 5469700 NTS 82 G/8

LITHOLOGY: Dolosiltite to Dolarenite

SEDIMENTARY STRUCTURE: Symmetrical Ripple Marks

PLOT INTERVAL: 10° **PLOT TYPE:** Bimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
SHEPPARD FORMATION

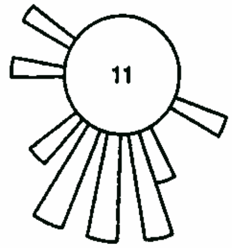


FIGURE: II - 43

LOCATION: Station 31055 UTM E 677250 N 5475370 NTS 82 G/7

LITHOLOGY: Quartzarenite

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 10° **PLOT TYPE:** Polymodal, Moderate Dispersion

PALEOCURRENT ROSE DIAGRAM
GATEWAY FORMATION

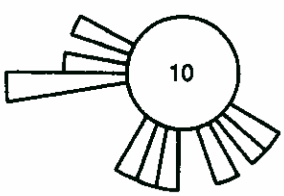


FIGURE: II - 44

LOCATION: Station 31035 UTM E 696930 N 5470700 NTS 82 G/8

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Asymmetrical Ripple Marks

PLOT INTERVAL: 10° **PLOT TYPE:** Polymodal, High Dispersion

PALEOCURRENT ROSE DIAGRAM
ROOSVILLE FORMATION

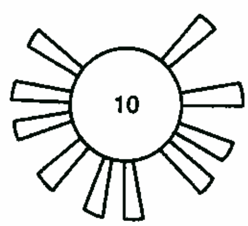


FIGURE: II - 45

LOCATION: Station 31063 UTM E 704400 N 5451600 NTS 82 G/1

LITHOLOGY: Quartzarenite

SEDIMENTARY STRUCTURE: Asymmetrical Ripple Marks

PLOT INTERVAL: 10° **PLOT TYPE:** Polymodal, High Dispersion

PALEOCURRENT ROSE DIAGRAM
LIVINGSTONE FORMATION

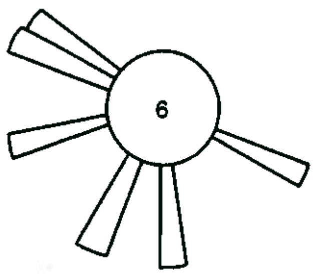


FIGURE: II - 46

LOCATION: Station 31066 UTM E 662830 N 5554280 NTS 82 J/2

LITHOLOGY: Calcisiltite to Calcarenite

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 10° **PLOT TYPE:** Polymodal, High Dispersion

PALEOCURRENT ROSE DIAGRAM
LIVINGSTONE FORMATION

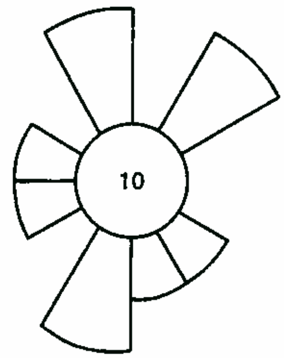


FIGURE: II - 47

LOCATION: Station 31089 UTM E 670240 N 5532050 NTS 82 G/15

LITHOLOGY: Calcisiltite to Calcarenite

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Polymodal, High Dispersion

PALEOCURRENT ROSE DIAGRAM
LIVINGSTONE FORMATION

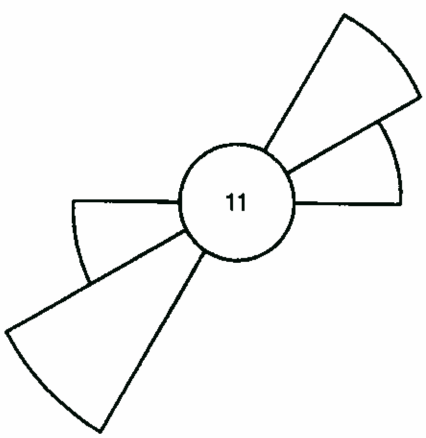


FIGURE: II - 48

LOCATION: Station 31136 UTM E 686070 N 5554980 NTS 82 J/1

LITHOLOGY: Fossiliferous Limestone

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Bimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
KOOTENAY GROUP

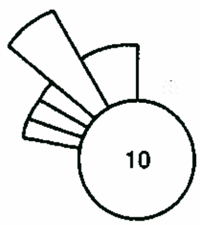


FIGURE: II - 49

LOCATION: Station 31036 UTM E 690680 N 5494530 NTS 82 G/9

LITHOLOGY: Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 10° **PLOT TYPE:** Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
KOOTENAY GROUP

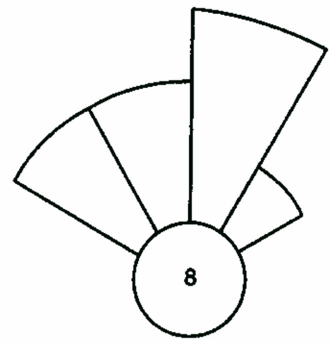


FIGURE: II - 50

LOCATION: Station 31093 UTM E 673270 N 5585480 NTS 82 J/7

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
BLAIRMORE GROUP

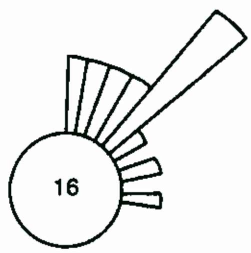


FIGURE: II - 51

LOCATION: Station 31001 UTM E 690310 N 5489640 NTS 82 G/9
Station 31002 UTM E 690870 N 5489920 NTS 82 G/9
Station 31003 UTM E 691330 N 5490270 NTS 82 G/9

LITHOLOGY: Subarkose

SEDIMENTARY STRUCTURE: Trough and Planar Crossbeds

PLOT INTERVAL: 10° PLOT TYPE: Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
BLAIRMORE GROUP

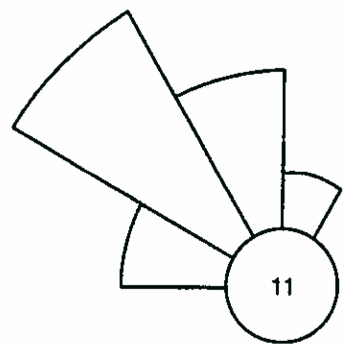


FIGURE: II - 52

LOCATION: Station 31037 UTM E 690310 N 5494880 NTS 82 G/9

LITHOLOGY: Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° PLOT TYPE: Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
BLAIRMORE GROUP

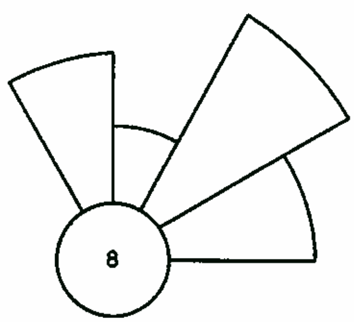


FIGURE: II - 53

LOCATION: Station 31125 UTM E 668220 N 5581160 NTS 82 J/7

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° PLOT TYPE: Bimodal, Moderate Dispersion

PALEOCURRENT ROSE DIAGRAM
BELLY RIVER FORMATION

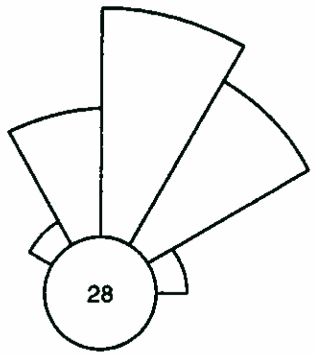


FIGURE: II - 54

LOCATION: Station 31012 UTM E 700320 N 5495180 NTS 82 G/9
Station 31013 UTM E 701390 N 5495390 NTS 82 G/9
Station 31014 UTM E 701920 N 5495780 NTS 82 G/9

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
BELLY RIVER FORMATION

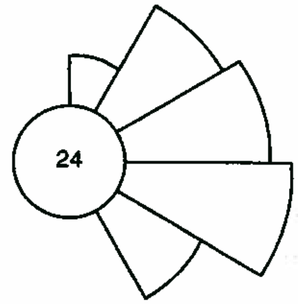


FIGURE: II - 55

LOCATION: Station 31057 UTM E 699660 N 5497630 NTS 82 G/9
Station 31058 UTM E 699570 N 5497920 NTS 82 G/9
Station 31059 UTM E 699470 N 5498340 NTS 82 G/9

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
BELLY RIVER FORMATION

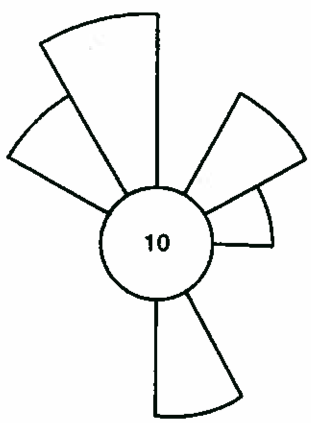


FIGURE: II - 56

LOCATION: Station 31029 UTM E 703050 N 5496450 NTS 82 G/9

LITHOLOGY: Quartzarenite

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° **PLOT TYPE:** Polymodal, High Dispersion

PALEOCURRENT ROSE DIAGRAM
BELLY RIVER FORMATION

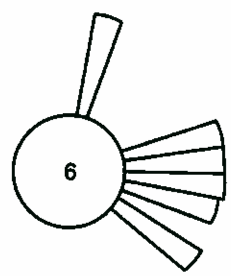


FIGURE: II - 57

LOCATION: Station 31040 UTM E 672100 N 5500090 NTS 82 G/10

LITHOLOGY: Quartzarenite

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 10° **PLOT TYPE:** Polymodal, Moderate Dispersion

PALEOCURRENT ROSE DIAGRAM
BELLY RIVER FORMATION

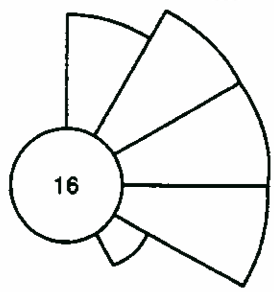


FIGURE: II - 58

LOCATION: Station 31068 UTM E 680950 N 5580210 NTS 82 J/8
Station 31069 UTM E 681020 N 5580290 NTS 82 J/8

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° PLOT TYPE: Unimodal, Moderate Dispersion

PALEOCURRENT ROSE DIAGRAM
BELLY RIVER FORMATION

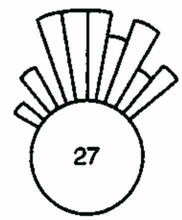


FIGURE: II - 59

LOCATION: Station 31095 UTM E 681530 N 5589840 NTS 82 J/8
Station 31096 UTM E 682170 N 5590670 NTS 82 J/8

LITHOLOGY: Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 10° PLOT TYPE: Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
St. MARY RIVER FORMATION

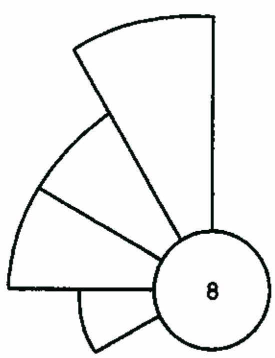


FIGURE: II - 60

LOCATION: Station 31108 UTM E 701150 N 5553740 NTS 82 J/1

LITHOLOGY: Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° PLOT TYPE: Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
St. MARY RIVER FORMATION

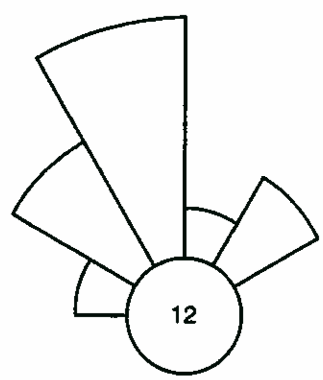


FIGURE: II - 61

LOCATION: Station 31119 UTM E 704780 N 5520510 NTS 82 G/16

LITHOLOGY: Quartzarenite to Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° PLOT TYPE: Bimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
PORCUPINE HILLS FORMATION

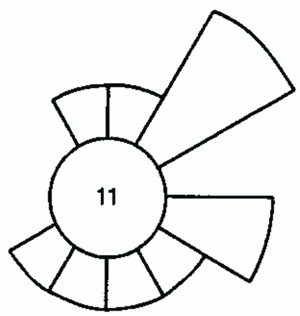


FIGURE: II - 62

LOCATION: Station 31105 UTM E 709030 N 5560790 NTS 82 J/1

LITHOLOGY: Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° PLOT TYPE: Bimodal, Moderate Dispersion

PALEOCURRENT ROSE DIAGRAM
PORCUPINE HILLS FORMATION

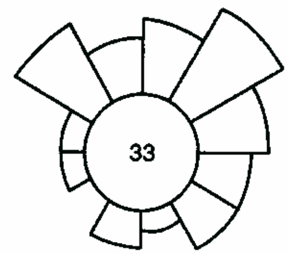


FIGURE: II - 63

LOCATION: Station 31106 UTM E 710190 N 5560460 NTS 82 J/1

Station 31107 UTM E 711110 N 5560530 NTS 82 J/1

LITHOLOGY: Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° PLOT TYPE: Bimodal, Moderate Dispersion

PALEOCURRENT ROSE DIAGRAM
PASKAPOO FORMATION

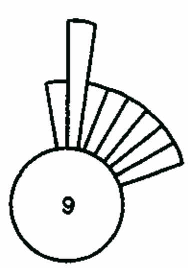


FIGURE: II - 64

LOCATION: Station 31071 UTM E 702310 N 5594250 NTS 82 J/8

LITHOLOGY: Quartzitic Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 10° PLOT TYPE: Unimodal, Low Dispersion

PALEOCURRENT ROSE DIAGRAM
PASKAPOO FORMATION

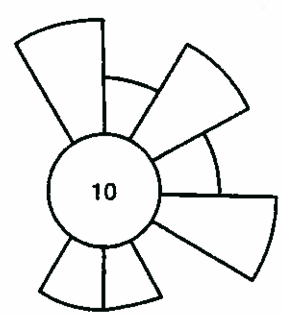


FIGURE: II - 65

LOCATION: Station 31073 UTM E 288800 N 5580600 NTS 82 I/5

LITHOLOGY: Subarkose

SEDIMENTARY STRUCTURE: Trough Crossbeds

PLOT INTERVAL: 30° PLOT TYPE: Polymodal, Moderate Dispersion

DISCUSSION

EVIDENCE TO SUPPORT PROTEROZOIC RIFTING

Evidence from Southeastern British Columbia to Support Proterozoic Rifting

Höy (1982a,b) has discussed the sedimentary and tectonic history of strata in the Purcell Supergroup, and the nature of stratiform lead-zinc deposits and mineral occurrences in southeastern British Columbia. He (Ibid) noted that the Purcell Mountains exhibit a pronounced northeast-trending structural grain, which is delineated in part by transverse faults. As well, Höy (Ibid) suggested that the faults may have been active during deposition of the Purcell Supergroup, influencing sedimentation patterns and partially controlling the location of stratiform lead-zinc deposits.

The evidence for determining syndepositional activity along the faults was based on the examination of Purcell Supergroup strata in the area of the Kootenay King and Sullivan deposits, where several important trends were established. These include: (i) abrupt lateral facies changes and thickness changes across the Boulder Creek Fault in strata of the Aldridge Formation; (ii) the common occurrence of intraformational conglomerates; and (iii) the preferential location of the conglomerates and coarser siliciclastic strata in areas adjacent to major transverse faults. These relatively abrupt variations in thickness and facies support the hypothesis of syndepositional activity along the major northeast-trending faults, such as the St. Mary-Boulder Creek and Moyie-Dibble Creek fault zones.

The northern margin of the Southern Alberta Rift has been interpreted to coincide with the St. Mary-Boulder Creek faults to the north, and the Moyie-Dibble Creek faults to the south (Ibid). The St. Mary-Boulder Creek fault system may have formed the margin of a sub-trough that comprised the southwestward extension of the Southern Alberta Rift into southeastern British Columbia.

The existence of geological features in the Aldridge Formation, such as: (a) the preferential occurrence of stratiform lead-zinc deposits, including for example the Sullivan, Kootenay King, Northstar, Hilo and Stemwinder deposits, adjacent to faults that were active during Purcell Supergroup deposition, (b) the presence of intraformational conglomerates in the footwall of the deposits, and (c) the association of anomalous boron concentrations, indicates that the mineral deposits are genetically linked with syndepositional activity along the fault zones. It is believed by Höy (Ibid) that during Aldridge Formation deposition the northeast-trending fault zones controlled the circulation of metal-rich convective fluids onto the seafloor, which in turn led to the formation of areally restricted sulphide accumulations in fault-bounded sub-basins.

McMechan (1979) studied the geology of the Mount Fisher-Sand Creek area in southeastern British Columbia. In this area, a northwest-trending block of Purcell Supergroup strata is subdivided into three segments or sub-blocks by two right hand transverse faults, named the Bull Canyon and Dibble Creek Faults. The stratigraphy of the Purcell Supergroup varies in each of the sub-blocks. The stratigraphic and lithological variations are interpreted to have resulted from the influence of syndepositional fault activity on Purcell Supergroup sedimentation patterns.

In the Mount Fisher sub-block, the quartzarenite-bearing member of the Aldridge Formation is thicker than normal. This thickness variation represents the infilling of a sub-basin developed before or during Aldridge Formation sedimentation. Subsidence of this sub-basin continued until at least deposition of the Phillips Formation.

The Dibble Creek Fault has been interpreted as lying near the site of an important pre-Middle Devonian transverse structure on which the north side stood low and the south side stood high (Ibid). Her (Ibid) stratigraphic data from the Purcell Supergroup indicate syndepositional activity along this fault zone, with the north side being downdropped.

The relatively thicker section of Purcell Supergroup strata exposed in the Mount Fisher sub-block is interpreted as representing deposition originally within the southwestern part of the Southern Alberta Rift. This succession was subsequently moved southeastward by later fault displacement.

McMechan (1981) studied the stratigraphy and depositional history of Purcell Supergroup strata in southeastern British Columbia. Her (Ibid) detailed sedimentologic study of facies and thickness variations indicate a major northeast-trending re-entrant existed along the north-northwest to north trending Middle Proterozoic passive continental margin. The rectilinear shape was related to the influence of deeply rooted fault blocks that developed during continental rifting. The nature of the thickness and facies changes in the Purcell Supergroup strata and the discordant superposition of a sedimentary prism across the structural grain of the underlying basement, indicates deposition of the Proterozoic succession onto thinned continental crust along a newly rifted continental margin.

The thickness variations in strata of the Basal and Lower Divisions of the Purcell Supergroup indicate there existed a rectilinear north- to northwest-trending continental margin with a westerly deflection of more than 200 km near 49° north latitude. North of this deflection, a prominent northeast-trending re-entrant interrupted the north-trending continental margin. It has been noted that the major transverse faults in southeastern British Columbia, especially the St. Mary-Boulder Creek and the Moyie-Dibble Creek Faults, are aligned with this re-entrant and that the Mount Fisher sub-block is encompassed within it. McMechan's (Ibid) observations indicate that the transverse faults were active during Lower Purcell Supergroup time and had fractured the crust into several tilted sub-blocks. These fault systems are interpreted as an extension of the Southern Alberta Rift and the northeast-trending re-entrant was part of the southwest end of the Rift complex.

Thickness variations in strata of the Proterozoic Middle Carbonate Division also indicate a north-trending continental margin with a major westerly deflection near 49° north latitude and a northeast-trending re-entrant north of this deflection. The facies trends also reflect the existence of this re-entrant.

A more complex basin configuration is indicated by variations in thickness trends in strata of the Proterozoic Upper Division. Isopachs for the Upper Division cut across those in the older Proterozoic strata, and may reflect the presence of newly formed sub-blocks within the rift basin. The occurrence of local unconformities beneath the Sheppard Formation in the Galton Range in southeastern British Columbia and in the Whitefish Range in northwest Montana, imply increased fault activity within this region.

It has also been suggested (Ibid) that the westerly deflection of more than 200 km which is present in the west-trending continental margin of the Purcell Supergroup basin near 49° north latitude, governed the later development of a major structural re-entrant in the Rocky Mountain Fold and Thrust Belt. That is, the formation of this structural re-entrant, which is named the Crowsnest Deflection, is interpreted as an example of inherited structural control from the ancient rifted continental margin.

Evidence From the Northwestern U.S.A. to Support Proterozoic Rifting

White (1984) studied shallow marine carbonate strata of the Altyn Formation in northwest Montana and found that the strata of the lower and upper members of the Altyn Formation contain at least 29 shallowing-upward cycles. These cycles, which range from 1.6 m to 8 m in thickness, are comprised of a basal conglomerate layer, succeeded by dolarenite, which in turn is overlain by dolostone and intermixed stromatolitic dolostone. The depositional setting is interpreted (Ibid) as an Atlantic-type continental margin, along which the Proterozoic Belt Supergroup sediments accumulated in a fault-bounded basin or aulacogen. Sedimentation at the southern margin of the Central Montana Basin or Trough was strongly influenced by syndepositional faulting.

The cycles in the Altyn Formation formed by sediment aggradation and progradation during tectonically quiet periods. The rapid subsidence that preceded development of each cycle is interpreted as being caused by vertical tectonism that affected the entire basin.

The Altyn Formation in southwestern Alberta was not observed during the 1993 field season. If additional stratigraphic work is carried out in the Clark Range, Altyn strata should be examined for the presence of fault-related cyclic carbonate successions similar to those which exist in northwest Montana.

Kidder (1988) also studied facies assemblages in strata of the Upper Belt Supergroup of northwest Montana. He (Ibid) described a basinwide shift in the sedimentation patterns in the transition from lower into upper Libby Formation strata; the Libby Formation is equivalent to the Roosville Formation of southwestern Alberta. This transition is interpreted as evidence for tectonism during Belt Supergroup deposition, and Kidder (Ibid) suggested that a combination of tectonic factors were the cause of the basinwide shift in sedimentation. The effects recorded in strata of the Libby Formation signal the beginning of terminal tectonic activity near the end of Belt Supergroup time. This tectonism may have culminated in the uplift that produced the unconformity between the Libby Formation and the rift-related strata of the overlying Proterozoic Windermere Supergroup.

Peterson (1986) described the general stratigraphy and regional paleotectonics of the Western Montana Overthrust Belt. The major structural framework for western Montana was developed contemporaneously with deposition of the Belt Supergroup. The most prominent structures include the Coeur d'Alene trough, Lemhi Arch, Central Montana Trough, Beartooth Shelf and the Alberta Shelf. The Central Montana Trough is interpreted as an east-west elongate basin that stretches for about 425 km across central Montana, widens from 80 km in the east to 140 km in the west, and is located between the Alberta Shelf and the Beartooth Shelf, only 400 km south of the Southern Alberta Rift. The Central Montana Trough and Southern Alberta Rift are thought to represent re-entrants situated along a rifted continental margin. Peterson (Ibid) also noted that the fault controlled south margin of the Central Montana Trough is characterized by the occurrence of fault-associated conglomerates.

Whipple et al. (1984) studied the stratigraphy of the Belt Supergroup in Glacier National Park and the adjacent Whitefish Range in northwest Montana. The study area was located due south of Purcell Supergroup strata in southeastern British Columbia and southwestern Alberta. His (Ibid) interpretation of preliminary results of the sedimentologic study indicated that the differences between stratigraphic sequences on the east and west sides of Glacier National Park and those in the Whitefish Range were due, in part, to the effects of synsedimentary faulting. The major evidence for this synsedimentary faulting comprises:

1. Unconformities resulting from synsedimentary faulting exist in the Belt Supergroup. For example, an unconformity at the top of the Purcell Lava was noted in the northern Whitefish Range. This unconformity together with the presence of the lava were interpreted as evidence of extensional faulting during deposition of the Lower Missoula Group, which is stratigraphically equivalent to the Upper Siyeh Formation and up into the Sheppard Formation. As well, the unconformity at the base of the Sheppard Formation was suggested (Ibid) as evidence of faulting along a basin margin, and for a second phase of regional extension.

2. The presence of facies changes and the significant thinning of the Appekunny Formation across Glacier National Park were also interpreted as an effect of syndepositional faulting on the sedimentation patterns in this formation.

3. Abrupt lithologic changes in strata of the Grinnell Formation are also present in Glacier National Park. The marked change in grain size and the colour of the strata

across a distance of 16 km suggests that faster subsidence had occurred to the west which resulted in a basinal assemblage, whereas to the east there is a platformal assemblage. These changes reflect the effects of synsedimentary faulting between the basinal and platformal sequences.

4. Facies changes in strata of the Missoula Group, which is equivalent to strata of the Upper Division of the Purcell Supergroup, are present in the northern Whitefish Range. These facies variations are related to the effects of synsedimentary faulting in or near that part of the Central Montana Basin, and are evidence for reactivation of rifting during the deposition of the Upper Division of the Purcell Supergroup.

Winston (1986) studied the sedimentation patterns and tectonic history of the Belt basin in western Montana and northern Idaho. The Belt Supergroup was interpreted as being deposited in an intracratonic basin occupied during much of its depositional history by marginal alluvial fans that graded basinwards into deposits of a restricted sea. The Lower Belt strata, which is equivalent to strata of the Basal Division of the Purcell Supergroup, were deposited during the maximum transgression of the Belt sea and included turbiditic sand and pelagic mud that accumulated across the central part of the basin. Carbonate mud was precipitated on its eastern side, and coarse sandstone and conglomerate accumulated along the fault-bounded southern margin. The strata of the Ravalli Group, which is equivalent to strata of the Lower Division of the Purcell Supergroup, record the progradation of mud flats and alluvial fans from the south and west across the Basin. The Middle Belt carbonate beds, which is equivalent to the Middle Carbonate Division of the Purcell Supergroup, accumulated during a second transgressive phase when siliciclastic and carbonate cycles were deposited along the eastern part of the basin, while turbiditic sand and mud were deposited in the deeper western part of the basin. The Missoula Group, which is equivalent to the Upper Division of the Purcell Supergroup, accumulated as a series of marginal alluvial fans that prograded into the basin, where they intermixed with transgressive mud flat and shallow marine deposits. During the depositional history of the Upper Missoula Group, the basin was dominated by accumulation of siliciclastic sediments in a shallow sea.

The interpreted tectonic history envisions a Belt basin architecture in which the complex is fractured by at least four major syndepositionally active fault zones. The faults include three nearly east-trending structures named the Perry, Garnet and Jocko lines (Ibid). A fourth structure, the Townsend line, exists as a structure trending northwest from the Perry to the Jocko line. The structures delineate the Helena Embayment, a major east-trending re-entrant located across central Montana and situated about 430 km south of the Southern Alberta Rift. The Helena Embayment is interpreted as being comprised of at least four major sub-blocks that underwent differential subsidence during the depositional history of the rift complex. The structure of the rift basin influenced the pattern of Cretaceous to Eocene thrust faulting and folding throughout the area. Thrusts and folds are long and continuous within the rift basin sub-blocks, but dislocated along the Proterozoic fault zones.

EVIDENCE TO SUPPORT PHANEROZOIC RIFTING

Some recent studies indicate reactivation of structures which are associated with the Southern Alberta Rift, affected the carbonate-siliciclastic sequences that were deposited during the Late Devonian to Mississippian evolution of the Cordilleran passive continental margin (Richards, 1989; Brandley and Krause, 1993; Brandley et al., 1993). As well, Jerzykiewicz and Norris (1993, In press), based on their study of the depositional history of the Late Cretaceous siliciclastic assemblages which accumulated during the final stages of the Alberta Foreland Basin, concluded that these strata were affected by northeasterly trending structures associated with the Southern Alberta Rift.

The Prophet Trough, which was active during deposition of the Late Devonian and Mississippian successions, was one of the major structural elements present in the central and southern portion of the Western Canada Sedimentary Basin (Richards, 1989). The Prophet Trough encompassed the downwarped and faulted western margin of the North American craton. The trough formed during Late Devonian and Mississippian rifting of terranes from the western paleo-margin of North America. A broad fault-controlled hinge zone, which marked an area where water depths and sedimentation rates increased rapidly, formed the boundary between the Prophet Trough and the western margin of the North American craton (Ibid). The Prophet Trough included an area in northwest Montana that was periodically positive and developed on the site of the Cambrian landmass known as Montania (Gordey et al., 1992). This local high was covered with a thin Mississippian succession and was bounded on the north by a northeast-trending trough that developed in the same general area as the Southern Alberta Rift (Richards, 1989; Porter et al., 1982). This younger northeast-trending trough was infilled with an anomalously thick Upper Paleozoic succession and was bordered by syndepositional faults. It is probable that the location of these faults was influenced by the structure of the Southern Alberta Rift.

Rift related features have also been identified in the Mississippian carbonate and siliciclastic strata of southwest Alberta and southeast British Columbia by Brandley and Krause (1993) and Brandley et al. (1993). Their work involved study of the depositional history of the Mount Head Formation to determine the influence of basement tectonic controls on sedimentation patterns. The thickness and facies patterns in the Mount Head Formation indicate this unit was deposited in a southwest-thickening wedge that was partitioned into north and south depocenters separated by a central high (Ibid). The thickness trends were illustrated by isopach maps for the total formation and for selected members (Figure 4 in Brandley et al., 1993). The isopach maps show there are two depocenters in southeastern British Columbia, and an arcuate depositional trend. Brandley et al. (Ibid) observed that the depocenters were aligned with previously documented basement features, one of which was the Vulcan Low. The Vulcan Low is an aeromagnetic low located in the Precambrian basement that has been correlated with the Southern Alberta Rift (Ross and Stephenson, 1989; Ross, 1991). The southernmost depocenter, in particular, is aligned with the southwestern part of the Southern Alberta Rift. Brandley et al. (Ibid) suggested reactivation of the structures in the Southern Alberta Rift was associated with tectonic activity during the Late Paleozoic Antler Orogeny.

Jerzykiewicz and Norris (1993) studied the depositional history of Late Cretaceous strata that accumulated during the evolution of the Laramide Foredeep in southwestern Alberta. The Laramide Foredeep formed during the final stages of the evolution of the Alberta Foreland Basin and comprised the exogeocline of the Laramide Orogeny. The basin axis moved progressively eastwards through time in response to cratonward migration of orogenesis. The Crowsnest Deflection, during foredeep infilling, formed a re-entrant which influenced sediment transport and depositional patterns. The position of this re-entrant is believed to have been influenced by the architecture inherited from the Proterozoic rifted continental margin (McMechan, 1981; Aitken and McMechan, 1992).

The Belly River and St. Mary River siliciclastic wedges were deformed by thrusting and partitioned into allochthonous and autochthonous segments that differ significantly in facies and thickness. The Laramide Foredeep was also internally partitioned into discrete drainage domains by growth faults that are transverse to the north-northwesterly regional structural grain (Figures 2 and 6 in Jerzykiewicz and Norris, 1993). The largest growth faults exist in the subsurface beneath the Highwood and Oldman Rivers, in a north-northwest oriented cross section that stretches from Belly River in the south to Black Diamond in the north (Figure II-74). These growth faults are associated with significant thickness changes in the Belly River to Willow Creek Formations (Table II-19).

TABLE II-19

THICKNESS CHANGES IN THE VICINITY OF THE HIGHWOOD RIVER GROWTH FAULT

FORMATION	THICKNESS NORTH OF HIGHWOOD RIVER (m)	THICKNESS IN CENTRAL TROUGH* (m)	INCREASE IN THICKNESS (m)
WILLOW CREEK	420	635	215
ST. MARY RIVER	570	970	400
BEARPAW	0	65	65
BELLY RIVER	450	550	100

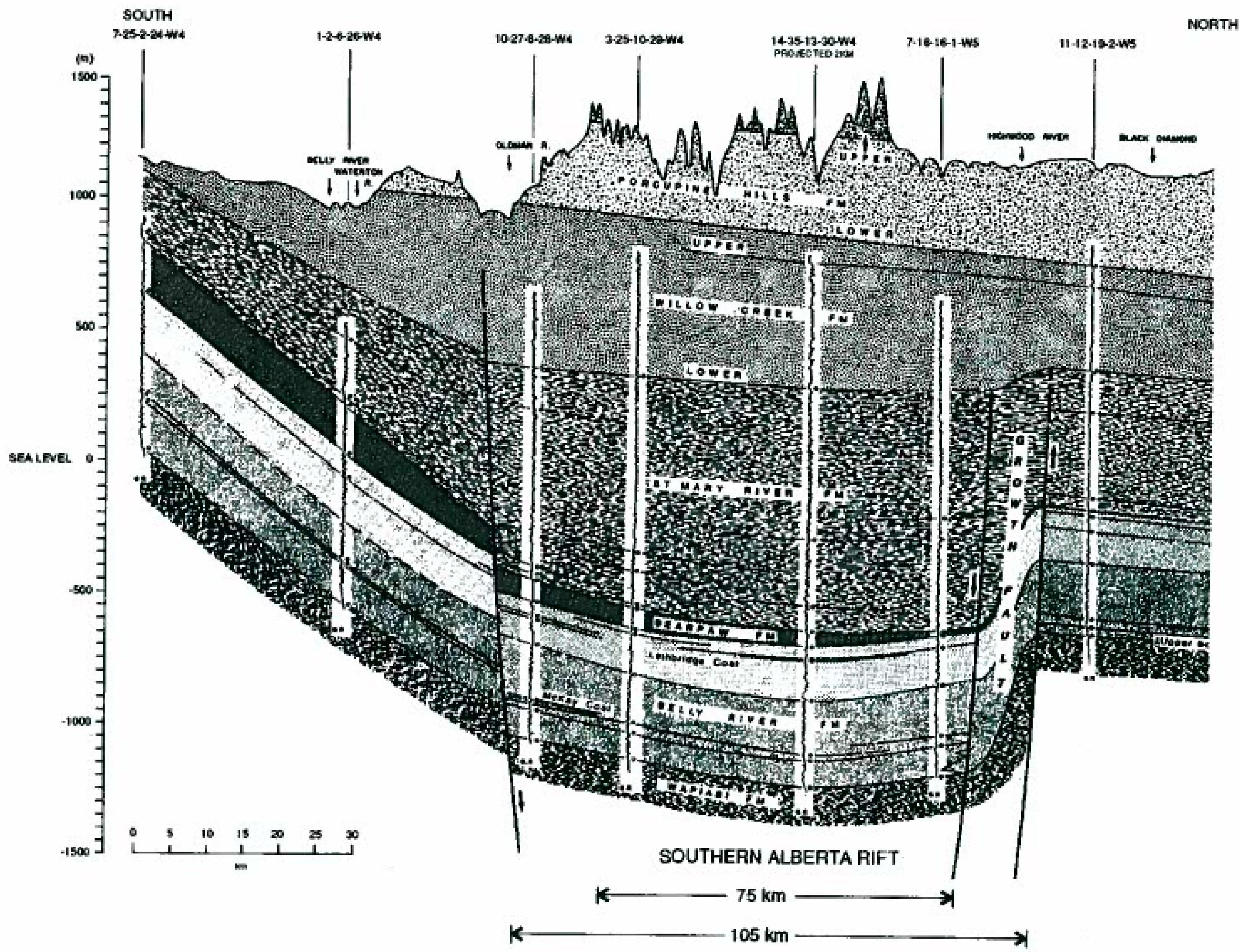
*** Central Trough refers to the trough-like feature bounded by growth faults illustrated in Figure II-74.**

The Highwood River Growth Fault also represents the boundary between two distinctly different facies provinces within the Laramide Foredeep (Jerzykiewicz, 1992).

Jerzykiewicz and Norris (1993) compared these growth faults in southwest Alberta to those present in equivalent strata in the Denver Basin which were described by Wiemer and Land (1975). The growth faults in the Denver Basin strata were responsible for thickness increases of up to 61 m in the Lower Laramie Sandstone. They (Ibid) suggested the location of the growth faults may have been controlled by recurrent movements of deep-seated faults in the Precambrian basement.

FIGURE II-74

CROSS-SECTION OF THE ALBERTA LARAMIDE FOREDEEP BETWEEN BLACK DIAMOND SOUTH-SOUTHEAST TO BELLY RIVER
(Modified after Jerzykiewicz and Norris, 1993)



In summary, it is suggested that the location of growth faults in Late Cretaceous strata of southwestern Alberta, as described by Jerzykiewicz and Norris (1993), may have been controlled by reactivation of marginal fault zones along the Southern Alberta Rift. In support of this conclusion is the fact that the position of the growth faults illustrated in Figure II-74 are nearly spatially coincident with the inferred position of the Southern Alberta Rift margins after Kanasewich (1968). These growth faults delineate a trough-like feature that is approximately 105 km wide. It is further suggested that this syndepositionally active trough influenced the sedimentation patterns of the Belly River, Bearpaw, St. Mary River and Willow Creek Formations, which were deposited in a period about 20 Ma in length.

TECTONO-SEDIMENTARY EVOLUTION OF THE PURCELL SUPERGROUP

A tentative model for the tectono-sedimentary evolution of the Purcell Supergroup in the Southern Alberta Rift can be derived from a synthesis of 1993 field data and relevant literature information. The available facts indicate that deposition of the Purcell Supergroup occurred along a divergent, rifted continental margin that contained major fault-bounded re-entrants such as the Southern Alberta Rift of southwestern Alberta and southeastern British Columbia, and the Helena Embayment or Central Montana Trough of central Montana. The rift regime was characterized by the occurrence of two distinct episodes of regional extension, which were followed by associated stages of regional downwarp that are characterized by the growth and lateral expansion of carbonate-dominated platforms (Figure II-75).

The evidence for Rift Cycle I extension is derived from: (1) the nature of lithofacies and thickness changes in strata of the Basal Division of the Purcell Supergroup, (2) the association of these changes with major fault systems, and (3) the occurrence of syndepositionally intruded mafic sills in the lower Aldridge Formation (Höy, 1982a,b, 1989; McMechan 1979, 1981; McMechan and Price, 1982). Rift Cycle I was characterized by a differentially and deeply subsiding basinal-dominated depositional regime that was gradually succeeded by a phase of regional carbonate platform growth and expansion (Figure II-74). The Cycle I regional downwarp was characterized by the deposition of Middle Carbonate Division strata of the Kitchener and Siyeh Formations. The expansion of the carbonate platform was associated with regional subsidence of the continental margin as the attenuated lithosphere thickened, cooled and sagged.

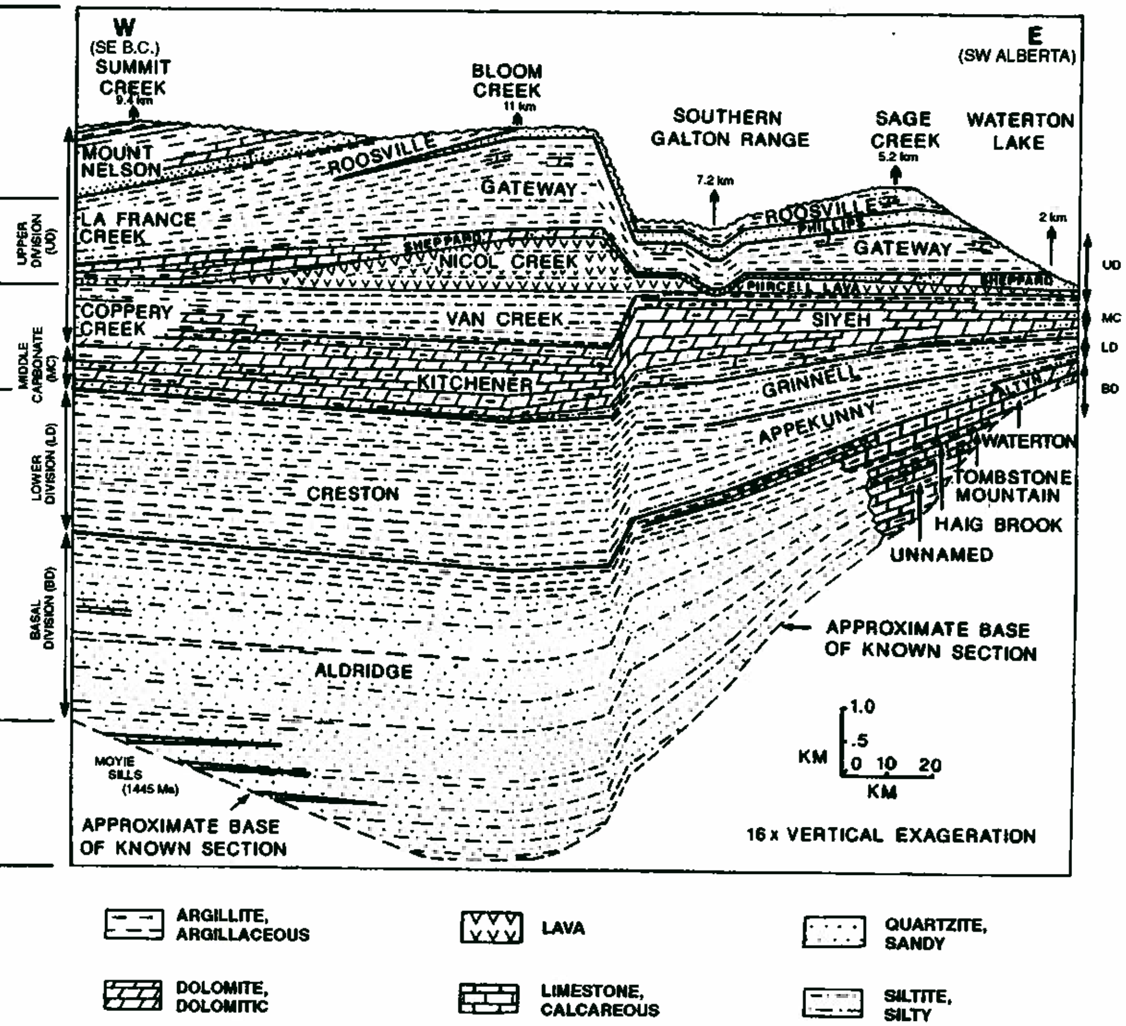
A second phase (Rift Cycle II) of regional extension is supported by several lines of evidence.

1. The siliciclastic facies assemblages, which are intermixed with platformal carbonate assemblages in the upper member of the Siyeh Formation, indicate reactivation of marginal fault zones. The siliciclastics represent terrigenous influxes, which were derived from the craton to the northeast, that would ultimately overwhelm the platform and bring carbonate deposition to an end (Figure II-75).

FIGURE II-75

INTERPRETATION OF THE TECTONIC - DEPOSITIONAL HISTORY OF THE PURCELL SUPERGROUP IN THE SOUTHERN CANADIAN CORDILLERA (Modified after Ross et al., 1989)

RIFT CYCLE	TECTONIC EVENT	DEPOSITIONAL SETTING	REMARKS
II	Downwarp	Platform (slope + basin)	Cessation of 2nd rift extension or transition from extension induced deep subsidence to passive margin conditions with 2nd carbonate platform construction
	CE 5		
	Rift	Deeply Subsiding Basin(s)	Reactivation Event: 2nd period of extension with reactivation imposed on earlier rifted margin
		Initial Extension	
	CE 4		
I	Downwarp	Platform Construction + Expansion (slope + basin)	Cessation of extension related differential rift subsidence and initiation of passive continental margin separation with associated carbonate platform construction
	CE 3		
	Active Rift	Deeply Subsiding Basin(s)	Deposition of Creston Formation and upper Aldridge Formation Transition to deeply subsiding fault basins
	CE 2		
	Passive Rift	Initial Extension	Initial Aldridge Formation sedimentation and intrusion of Moyie Sills
	CE 1		



2. The presence of andesitic pillowed flows of the Purcell Lava at this stage in the evolution of a passive continental margin, implies that fault systems, such as those bounding the Southern Alberta Rift, were reactivated and used as conduits for magma extrusion.

3. Syndepositional tectonism is supported by the presence of significant intrabasin unconformities. For example, the Purcell Lava is absent locally in southeastern British Columbia and northwest Montana. In these areas, strata of the Sheppard Formation disconformably overlie those of the Siyeh Formation (Price 1962, 1964; McMechan, 1979; Whipple et al 1984; Figure II-67).

The second rift stage was also characterized by accumulation of thick siliciclastic successions in deeply subsiding sub-basins such as, for example, deposition of the Gateway, Phillips and Roosville Formations (Figure II-75). As tectonic activity diminished across the Southern Alberta Rift, the continental crust relaxed and thickened. The rift basin was infilled with mixed carbonate and siliciclastic facies assemblages as platform deposits again spread across the passive continental margin.

TECTONO-SEDIMENTARY EVOLUTION OF THE PHANEROZOIC SUCCESSIONS

Cambrian Sequences

Cambrian strata represent the initial Phanerozoic deposits on the rifted continental margin of southwest Alberta. The Cambrian succession comprises a southeasterly thickening prism which began with the deposition of a basal quartzarenite that transgressed across the entire western margin of the craton. The basal sandstones include the Flathead Formation in southwest Alberta. In the oceanward, or western part of the continental sediment prism, the basal Cambrian sandstone succession is (a) more than 2 km thick, (b) contains intermixed arkose, subarkose, conglomerate and units of basic volcanic rocks, and (c) may have been deposited during an Early Paleozoic cycle of rifting (Devlin and Bond, 1988; Devlin, 1989). Bond and Kominz (1984) discussed the stratigraphic evidence for continental extension and separation at about 550 Ma to 600 Ma in the southern Cordillera. The best evidence comes from the subsidence analysis of Middle Cambrian through Lower Ordovician strata. The form of the tectonic subsidence curve approximates that calculated for thermal subsidence of an instantaneously rifted continental margin (McKenzie, 1978). Projecting the tectonic subsidence curve backward to time zero indicates a time of separation between 550 Ma and 600 Ma (Bond and Kominz, 1984; Thompson et al., 1987).

Southwestward thickening carbonate platform deposits accumulated along the subsiding continental margin during Middle Cambrian time and are represented by Elko Formation strata in southwest Alberta. Palinspastic reconstruction of the overthrust belt shows that the carbonate platformal wedge was situated over the rifted Proterozoic continental craton (Price, 1981). This suggests that there may have been intermittent margin-related faulting and differential subsidence along the edge of the craton from Early Cambrian to Middle Devonian time (Struik, 1987; Thompson et al., 1987). In southern British Columbia and Alberta the southeastern edge of the carbonate shelf coincided with the northwest edge of Montania (Gordey et al., 1992), a local high that extended into central Montana.

The northwest margin of Montania was an important northeast-trending hinge zone that was periodically active from early Cambrian to Late Devonian time (Richards, 1989). In southeast British Columbia, within the marginal cratonic wedge, the net stratigraphic separation across this zone is about 8 km along the unconformity at the base of the Upper Devonian. This hinge zone was aligned with northeast-trending structures that had influenced sedimentation patterns in strata of the Middle Proterozoic Purcell Supergroup (McMechan, 1979, 1981), and of the Late Proterozoic Windermere Supergroup (Lis and Price, 1976; Thompson et al., 1987). The magnitude, nature and location of the differential movements across the hinge zone and the carbonate platform indicate that they were influenced by reactivated fault zones beneath the continental terrace wedge. The reactivated structures comprise fault systems within the Southern Alberta Rift.

Devonian to Mississippian Sequences

After an initial period of extensive Middle Devonian erosion, shallow marine settings were re-established within a southward spreading epicontinental sea, and led to the construction and expansion of a broad carbonate platform across southwest Alberta. The carbonates consist of strata in the Fairholme Group. During the earliest part of the Late Devonian, the platform became the foundation for growth of northeasterly-trending linear reefs. The reefs developed as a result of differential rates of deposition and subsidence of the platform, the latter related at least in part to the architecture of the ancient rifted continental crust. A westward prograding apron of shale gradually buried the reefs, and as the siliciclastic supply diminished and the seas regressed, impure carbonates then accumulated over a wide area. These impure carbonates comprise the Cairn Formation in southwest Alberta. This brief stage of regression led to local emergence and influx of silt and sand across a marginal shelf, and may reflect a period when Montania influenced sedimentation patterns. At the beginning of latest Devonian transgression, westerly derived sand was succeeded by the development of a broad carbonate platform, comprising the Alexo and Palliser Formations in southwest Alberta. The platform existed until the latest Devonian to Early Mississippian when black euxinic shales overwhelmed the complex (Gordey et al., 1992).

Deposition of Mississippian strata began with an abrupt transgression marked by a thin, but widespread veneer of dark organic shale of the Exshaw Formation. The shale was followed by a gradual transition from restricted euxinic conditions in the Early Mississippian, to the transgressive stage of open marine, intermixed calcareous shales and limestones of the Banff Formation. These sediments were then overlain by thick successions of crinoidal calcarenites of the Livingstone Formation that accumulated along shallow shelf margins and platformal settings.

Late Mississippian deposits are characterized by accumulation of intermixed limestone, dolostone and argillaceous carbonates of the Mount Head Formation. They are succeeded by variably interlayered carbonate and siliciclastic strata of the Etherington Formation. These Late Mississippian sequences record a period of reactivation of cratonic arches to the east and deepening of the Prophet Trough to the west. They signal a regional regression that preceded deposition of siliciclastic-dominated strata of the Pennsylvanian period. The lateral variations in thickness and facies distribution of the Late Mississippian strata reflect differential subsidence along the western continental margin. These variations have been related, in southwest Alberta to reactivation of faults in the Southern Alberta Rift (Brandley et al., 1993).

Pennsylvanian to Middle Jurassic Sequences

The depositional history of the Pennsylvanian into Middle Jurassic is characterized by a westward shift in the limits of sediment accumulation. This feature is related to the emergence and westward tilt of the craton. This regionally extensive and long term regression is a continuation of a pattern established during deposition of Late Mississippian carbonate and siliciclastic sequences. It is associated with an upward increase in the amount of terrigenous siliciclastic sediment. The abrupt eastward thinning of the Pennsylvanian, Permian and Triassic strata, which are represented in southeast British Columbia and southwest Alberta by the Spray Lakes, Ishbel and Spray River Groups, is a result of depositional attenuation and intermittent episodes of erosion (Porter et al., 1982).

The Pennsylvanian to Middle Jurassic assemblage was separated into two contrasting facies successions by the Early to Middle Jurassic emergence of the northeast-trending Sweetgrass Arch in southeast Alberta. Northwest of the arch the Pennsylvanian to Permian successions were deposited in an extensive shallow marine sea along the continental shelf of the passive margin. The main tectonically active region was the Peace River Arch in northwest Alberta. The Peace River Arch underwent block faulting and significant subsidence. This foundering, which had begun in the Mississippian and continued into the Permian, was related to reactivation of older faults during a period of Late Paleozoic rifting (Cant, 1988). The Triassic deposits, which comprise shale, sandstone, limestone and dolostone of the Spray River Group, appear to have prograded westwards over the continental margin platform as a series of shallow marine shelf deposits.

The final deposits in the Pennsylvanian to Middle Jurassic succession comprise a westward thickening wedge of intermixed shale, sandstone and conglomerate beds of the Fernie Group. The Fernie Group strata accumulated in shallow shelf southwestwards into deeper basinal settings. They comprise the final passive margin deposits before the onset of foreland basin construction.

Late Jurassic to Paleocene Sequences

During the Late Jurassic to Paleocene, a passive continental margin was transformed into a foreland basin. The continental margin comprised a marginal carbonate-siliciclastic shelf and platform that prograded westwards into an adjacent ocean, and the foreland basin consisted of northeasterly thinning wedges of synorogenic siliciclastic sediments that prograded towards the interior of the craton.

The Late Jurassic witnessed a major reversal in the direction of sediment transport and an abrupt influx of siliciclastic debris from the emerging Cordilleran foreland thrust belt. Within the thrust belt the Late Jurassic to Early Cretaceous synorogenic siliciclastic wedge, which is represented in southwest Alberta by non-marine strata of the Kootenay Group, consists of terrigenous material eroded from the rising Cordilleran mountain range. This southwestward expanding assemblage of shale, sandstone, coal and conglomerate thickens to more than 1 km in southeastern British Columbia.

The overlying Early Cretaceous synorogenic siliciclastic succession, which comprises varicoloured mudstone, sandstone and conglomerate of the Blairmore Group, is largely non-marine, contains areally restricted volcanic and volcaniclastic sequences, and thickens westwards to more than 2 km. The northeasterly prograding terrigenous sediments spread across the foreland basin, unconformably overlapping the Paleozoic and older Mesozoic deposits. The expansive, syntectonically influenced continental progradation was succeeded, during deposition of the Late Cretaceous shale-dominated Alberta Group, by an extensive marine transgression. The shallow marine deposits spread across much of the foreland basin during a largely tectonically quiescent period (Cant, 1989).

The marine phase represented by Alberta Group was terminated by accumulation of mainly non-marine, synorogenic sandstone and intermixed sandstone-shale dominated assemblages represented by the Belly River to Willow Creek Formations of Late Cretaceous to Paleocene age (Table II-10). These sequences comprise a major regressive cycle, up to 4 km thick, that records the final stages in the evolution of the foreland basin. During deposition of the Belly River to Willow Creek Formations, there were growth faults that affected the thicknesses of these strata, and these growth faults are geometrically coincident with the south and north margins of the Southern Alberta Rift (Figure II-74).

The Cordilleran Foreland Thrust Belt developed in the zone of compression formed between the North American craton and the tectonic assemblage of displaced continental and oceanic terranes that now comprise the major part of the Cordillera (Price, 1981). The ancestral continental marginal prism had been deposited oceanwards from the Middle Proterozoic rifted edge of the North American craton on a basement of stretched and thinned continental crust. This marginal prism, which was comprised largely of carbonate and siliciclastic sequences, was compressed, thickened and detached from its basement and superimposed over the western margin of the continental craton.

A portion of the supracrustal cover of the platform and foreland basin strata was removed from the craton and incorporated into the overriding mass to form a wedge of imbricate thrust slices (Gabrielse and Yorath, 1992; Price, 1981). The accretionary wedge prograded over the depressed margin of the North American craton. The foreland basin evolved as a cratonward expanding terrigenous siliciclastic fan due to the isostatic flexure of the lithosphere. This flexure was a response to tectonic loads imposed on the crust by the overriding continental terrace wedge and by the growing load of imbricate fault slices (Porter et al., 1982). The largely continental strata that infill the foreland basin consist of material eroded from emerging thrust slices and incorporated into the northeastward thinning sediment prism.

METALLOGENIC COMMENTS

Höy (1982a,b) interpreted the presence of syndepositional sills, abrupt facies and thickness changes, thick turbiditic successions and local occurrences of intraformational conglomerates in strata of the Lower and Middle Aldridge Formation, as evidence of syndepositional faulting and extension in an active rift (Figure II-75). Syndepositional tectonism was associated with northeast-trending fault systems that are present in southeastern British Columbia (Ibid; McMechan 1979, 1981). The occurrence of rich, but areally restricted sulphide deposits and associated tourmaline alteration at the Sullivan, North Star and Kootenay King lead-zinc-silver deposits, indicates that these faults served as conduits for sedimentary exhalative (sedex) mineralization within fault-bounded sub-basins (Höy 1982a,b; Hamilton et al, 1982).

The present restriction of sedimentary exhalative deposits to the thick basinal succession of the Purcell Supergroup in southeastern British Columbia should not be a deterrent to exploration for similar deposits in Basal Division Purcell Supergroup in southwestern Alberta. The equivalent, though thinner, basinal facies assemblages occur in the western Clark Range, and they should be considered as prospective sedex targets. The potentially favourable sequences, in descending stratigraphic order (Figure II-75), for sedex deposits include:

1. **Appekunny Formation**: contains a thickened, deeper water basinal facies assemblage that is dominated by planar thin-laminated grey argillite.

2. **Altyn Formation**: contains an eastern facies assemblage comprised of carbonate strata intermixed with thin-laminated black to grey argillite. The formation thickens westward, grading into a basinal assemblage dominated by thin-laminated grey argillite.

3. **Tombstone Mountain Formation**: contains thin-laminated dark grey argillite and limestone. The argillite increases in amount southwards as the strata grade into a basinal setting.

4. **Unnamed Unit 1**: comprises basinal facies assemblages of dark grey calcareous and dolomitic argillite and intermixed planar thin-laminated black argillite.

5. **Unnamed Unit 2**: contains basinal facies sequences of intermixed grey argillaceous dolostone and thin-laminated black argillite.

In the Clark range in southwestern Alberta, strata of the Purcell Supergroup are host to numerous base-metal occurrences (Williamson et al., 1993). The Appekunny, Grinnell, Siyeh, Sheppard and Gateway Formations contain minor showings of stratabound copper, silver and, less commonly, zinc and lead (Williamson et al., 1993; Collins and Smith, 1977; Van Dyck, 1971; Morton et al., 1974). The most widely mineralized unit, the Grinnell Formation, contains numerous stratabound copper-silver showings. The Grinnell Formation is equivalent to the Revett Formation in Montana (Winston, 1986), which hosts the Spar Lake copper-silver deposit (Harrison, 1972). The Grinnell Formation contains sporadically disseminated chalcocite, bornite and minor copper sulphides. The mineralized zones typically occur in permeable quartzarenite and quartzitic subarkose layers. The mineralized sandstone beds are intermixed with maroon thin-laminated argillite units in cyclic couplets (Plate II-1.a). The copper mineralized zones in the sandstone beds were interpreted by Collins and Smith (1977) to be the product of cyclically controlled redox conditions that developed during episodic depositional processes on an expansive braidplain. Morton et al. (1974), however, associated the source of the metal-bearing fluids to exhalative activity controlled by faults that were active during the evolution of the Southern Alberta Rift. As well, the local enrichment of stratabound copper-silver mineralized zones has been genetically linked by Morton et al. (Ibid) with diabase sills that were emplaced penecontemporaneous with extrusion of the Purcell Lava, and to hydrothermal activity during formation of the Southern Alberta Rift.

If the proposed model for the tectono-sedimentary evolution of the Purcell Supergroup in the Southern Alberta Rift is correct, then there have been two stages of regional rifting and two major phases of syndepositional faulting (Figure II-75). During Rift Cycle I, circulation of mineralized hydrothermal fluids along the active fault zones was responsible for deposition of sedex deposits in southeastern British Columbia, and possibly the stratabound lead-zinc and copper-silver mineralized zones that are widely disseminated in the Basal and Lower Divisions of Purcell Supergroup in southwestern Alberta. The reactivation of the Southern Alberta Rift complex during the deposition of the upper member of Siyeh Formation and of the Sheppard Formation, and extrusion of the Purcell Lava, would provide a mechanism for a second period of regional circulation of mineralized hydrothermal fluids throughout the rift complex. The information gained during the 1993 fieldwork indicates that the inferred southern margin of the Southern Alberta Rift in southwestern Alberta, was active during deposition of the upper Siyeh into Sheppard Formations. This area in the northern Clark Range remains an excellent prospecting target for stratabound rift-related copper-silver mineralized zones of Kupferschiefer type (Jowett, 1989). Such rift-related mineral deposits have already been discovered in rocks of the Belt basin of Montana, and examples include the Spar Lake and Rock Creek copper-silver deposits in the Revett Formation (Harrison, 1972). Similar copper-silver mineral deposits may exist in facies equivalent units in the Purcell Supergroup in the Southern Alberta Rift, with the most geologically favourable being the Grinnell Formation.

CONCLUSIONS

The major contributions derived from the 1993 stratigraphic-structural study are: (1) stratigraphic evidence for rift-related influences on sedimentation patterns in Middle Proterozoic to Cenozoic strata and, less definitively, (2) stratigraphic and structural data that more precisely indicate the inferred margins, particularly the southern margin, of the Southern Alberta Rift.

Purcell Supergroup

Strata of the Purcell Supergroup contain several notable features that indicate rift-influenced effects on sedimentation patterns. These effects are mainly in strata of the Grinnell to Sheppard Formations (Tables II-4 to II-7; Figures II-70 to II-73). Syndepositional tectonic effects on sedimentation patterns are indicated by relatively abrupt latero-vertical facies variations in several units, including:

1. There is an increase in the amount of sandstone in the upper part of the Grinnell Formation to the northwest across the Clark Range (Table II-4, clause 'a').

2. The lower and middle members of Siyeh Formation consist, in part, of medium- to large-scale carbonate-dominated shallowing upward cycles arranged in nested cyclic assemblages. These sequences are indicative of a subsidence regime that may have been related to post-rift downwarp (Table II-5, clause 'd').

3. The upper member of Siyeh Formation consists of two contrasting lithofacies assemblages: one is siliciclastic-dominated and the other is carbonate-dominated. The siliciclastic successions represent a depositional regime quite different from that of the carbonates, and may be the initial deposits which formed during a second cycle of extension related to the Southern Alberta Rift (Table II-5, clause 'b'). Lateral facies variations, comprising differences in the distribution of argillite and sandstone, also occur in the upper member of Siyeh Formation across the Clark Range. That is, argillite-dominated sequences are present in the central Clark range, whereas intermixed argillite and sandstone successions are predominant in the northwestern Clark Range (Table II-5, clause 'c'). These lithologic trends indicate differences in sedimentation patterns in structurally partitioned basins or sub-troughs related to the Southern Alberta Rift.

4. In the Sheppard Formation, facies changes of note include: (a) an increase in argillite content northwestwards across the Clark range, and (b) variations in the thickness of basal volcanic clast sandstones and conglomerates. As well, Sheppard Formation overlies the Purcell Lavas, locally contains an andesitic flow and, in southwestern British Columbia, unconformably overlies Siyeh Formation beds. These features indicate a second cycle of syndepositional tectonism, volcanism and rift-related differential subsidence (Tables II-6 and II-7).

With respect to the stratigraphic evidence for the location of the south margin of the Southern Alberta Rift, it mainly comprises spatially associated depocenters in several formations. For example:

1. In the upper member of Siyeh Formation, a sedimentary depocenter occurs in the area of Beaver Mines Lake in the northern Clark Range (Figure II-70). This depocenter is within 7 km of the inferred south margin of the Southern Alberta Rift.

2. In the Sheppard Formation, a well-defined, north-south oriented depocenter is present in the northeastern Clark Range (Figure II-72). This depocenter is subparallel to the trend of the south margin of the Southern Alberta Rift, and is about 15 km to the east.

3. In the Gateway Formation, an east-northeast trending depocenter exists in the northern Clark Range (Figure II-73). This depocenter is within 10 km of the south margin of the Southern Alberta Rift.

Phanerozoic Successions

Although the effects of extension-related syndepositional tectonism are not as obvious in Phanerozoic strata, several features are present that indicate reactivation of structures associated with the Southern Alberta Rift.

1. In the Mississippian Etherington Formation, facies changes occur from north to south (between section 3I086 and 3I049; Figure I-2). These facies changes comprise variations in the amount of sandstone and argillaceous carbonate, and in the lateral variation and arrangement of lithologies. In addition, a possible gravity slide horizon occurs near the upper part of the Etherington Formation at section 3I086 (Figure I-2; Table II-12, clauses 'a' and 'c').

2. In Early Cretaceous Crowsnest Formation, the thickest sequence of volcanic and volcaniclastic strata occurs in the vicinity of Coleman in the central part of the Southern Alberta Rift. The existence of this volcanic sequence and the anomalously thickened section may have resulted from the reactivation of an intra-rift fault system within the Southern Alberta Rift (Table II-14).

3. During the Late Cretaceous to early Paleocene, growth faults are believed to have affected the thicknesses of the Belly River, Bearpaw, St. Mary River and Willow Creek Formations between Belly River and Black Diamond in southwest Alberta (Figure II-74). These inferred growth faults are geometrically coincident with the inferred southern and northern margins of the Southern Alberta Rift.

RECOMMENDATIONS FOR FURTHER WORK

Additional supportive evidence for the influence of rift-related tectonism on sedimentation patterns in southwest Alberta may be obtained by: (1) geologically mapping one or more units in much greater detail, and/or (2) geologically mapping several units, but in a more restricted target area. For example, some formations that are thought to contain extension-related features and that could be the target of a more detailed stratigraphic-sedimentologic study, include:

(a) **Grinnell, Siyeh (upper member) and Sheppard Formations.** These formations are now known to contain evidence for syndepositional tectonism. Hence, a study of one or two of these formations in closely spaced sections across the Clark Range to geologically examine and map the stratigraphy and sedimentology, would better define the location of the south margin of the Southern Alberta Rift.

(b) **Purcell Lava and Sheppard Formation.** A more detailed study of contact features between these two formations, the defining of the extent of andesitic flows in the Sheppard Formation, and a study of the nature of the basal volcanic clast beds in the Sheppard Formation, would assist in better determining the south margin of the Southern Alberta Rift..

(c) **Mount Head Formation.** A detailed analysis to determine if the thickness and facies trends which were described by Brandley et al. (1993) in southeast British Columbia, also occur in southwest Alberta. This could lead to delineation of one or more rift-associated depocenters.

(d) **Etherington Formation.** A study of the thickness and facies trends, the occurrence of cyclic assemblages, and the differentiation of solution collapse breccias from true syndepositionally deformed beds, would assist in defining depocenters and the margins of the Southern Alberta Rift.

(e) **Belly River Formation or St. Mary River Formation.** A closer examination of thickness and facies changes would provide additional evidence for growth faults and their relation to reactivation of the Southern Alberta Rift.

Although new mineral showings were not encountered during the 1993 field program, the stratigraphic-structural evidence that was found for rifting and fault reactivation, which recurred episodically over a long time span, indicates that mineralizing events of several types could have occurred. Therefore, future mineral exploration projects in southwest Alberta should use the evidence for rifting and fault reactivation, as well as the location and type of known mineral occurrences, in conjunction with selected mineral deposit models, to select and prioritize specific target stratigraphic successions for exploration. Some of the more prospective formations are briefly discussed below. A more detailed analysis of possible mineral deposit types and specific target formations in southwest Alberta, are available in Williamson et al. (1993) and Olson et al. (In press).

Purcell Supergroup

(a) Potential target units for stratiform, sediment-hosted lead-zinc deposits in Purcell Supergroup include: (i) Unnamed unit 1, (ii) Unnamed unit 2, (iii) Tombstone Mountain Formation, (iv) Altyn Formation, and (v) Sheppard Formation (Figures II-66 and II-67). The first four of these formations are part of the Basal Division of Purcell Supergroup, and they are facies equivalent to strata of the Aldridge Formation in southeastern British Columbia. The Aldridge Formation contains the Sullivan deposit at Kimberley. The Basal Division strata represent a basinal setting that is preserved in the western Clark Range, and contains a high concentration of dark grey to black argillite beds.

The Sheppard Formation is characterized by the occurrence of facies and thickness changes, volcanic flows below and within the succession, local horizons of black siltstone and scattered lead-zinc-silver mineral occurrences. The formation was deposited during a time of increased tectonism and heat flow related to a second rift cycle (Figure II-75). Therefore, mineralizing hydrothermal fluid circulation related to the extension event may have circulated along fault systems throughout the basin.

(b) Potential for stratiform, sediment-hosted Kupferschiefer-type rift-related copper deposits is highest in sandstone-bearing successions of the upper Grinnell Formation, but some potential also exists in the underlying Appekunny Formation and overlying Siyeh Formation. The strata of these formations are host to numerous copper-silver showings within the Clark Range, at least some of which are thought to be fault-related (Halferdahl, 1971). Stratigraphically equivalent rocks of the Belt Supergroup in Montana host the Spar Lake copper-silver deposit.

Phanerozoic Successions

(a) Potential for stratiform, shale-hosted nickel-zinc deposits exists in several formations with black shale sequences in southwest Alberta. However, the most prospective sequence probably is the thin, but widespread euxinic black shale of the Upper Devonian to Lower Mississippian Exshaw Formation. This formation contains thin layers of pyritic shale, and geochemical and mineralogical data indicate that there is good potential for stratiform nickel-zinc deposits (Williamson et al., 1993; Olson et al., In press).

(b) Potential for carbonate-hosted Mississippi Valley Type (MVT) lead-zinc deposits is indicated by extensive dolomitization, karst related breccias, faulting or fracturing, presence of reefs and platform to basin facies transitions that exist in some carbonate sequences in southwest Alberta. However, the highest potential for MVT lead-zinc deposits probably is in the Upper Devonian carbonate sequences. More specifically, the following rock units should be explored for MVT deposits.

(i) **Palliser Formation**: contains numerous small lead-zinc showings, and is host to the Oldman lead-zinc-silver prospect, which contains paleokarst features and dolomitization fronts (Salat, 1988).

(ii) **Cairn Formation of Fairholme Group**: contains layers and lenses of carbonate clast breccia up to 3 m thick.

(iii) **Southesk Formation of Fairholme Group**: contains reef structures and lenses of breccia with dolostone blocks up to several metres in length, and the unit is extensively dolomitized.

In summary, in each of these geologically favourable Proterozoic and Phanerozoic Formations, exploration should or could be focused towards those parts of these formations that are proximal to the faulted south or north margins of the Southern Alberta Rift. These locales are more likely to have been the focus of a more complex sedimentological and structural history and, as well, there is a higher possibility that any paleo-hydrothermal fluids would have been focused along these structurally weaker zones.

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STRATIGRAPHIC SECTIONS
(FIGURES II-1 TO II-32)

AND

LITHOLOGICAL LEGEND
STRATIGRAPHIC SYMBOLS

TO ACCOMPANY REPORT ENTITLED

REGIONAL STRATIGRAPHIC-STRUCTURAL STUDY

SOUTHERN ALBERTA RIFT, SOUTHWEST ALBERTA

(CANADA-ALBERTA MDA PROJECT M93-04-034)

LITHOLOGICAL LEGEND

Clastic and Clastic Dominated Lithofacies

Intermixed facies units of thin bedded, planar to wavy layered dolosiltite, dolarenite, subarkose and sublitharenite

Planar, crossbedded to cross laminated fine- to coarse-grained quartzitic subarkose to quartzarenite; minor layers and lenses of coarse-grained to granular subarkose and planar laminated argillite

Intermixed facies units (<1 m to 5 m thick) of planar thick laminated to very thin bedded argillite and wavy- to cross-laminated, thin bedded siltstone and fine- to medium-grained quartzarenite

Planar thick laminated to very thin bedded argillite with minor interbeds of wavy to lenticular layered, very thin bedded, fine-grained quartzarenite to quartzitic sublitharenite; sandstone amount 20% to 25%

Planar to wavy layered, thin laminated to very thin bedded argillite with minor layers and lenses of fine- to coarse-grained quartzarenite, quartzitic subarkose to sublitharenite; sandstone amount <10% to 15%

Planar to wavy layered, thick laminated to thin bedded siltstone

Planar layered, very thin to thick laminated shale

Intermixed facies units of thin to thick laminated, planar layered argillite to dololutite and thick laminated to thin bedded, planar to wavy layered dolosiltite and fine-grained quartzarenite

Intermixed facies units of planar layered, thin laminated argillite to dololutite (amount >70%) and minor planar to wavy layered thin bedded dolosiltite, doloarenite and fine-grained quartzitic subarkose

Conglomerate, Volcaniclastic and Volcanic Lithofacies

Massive to poorly stratified chert and sandstone pebble conglomerate

Dark green, purple- to green-grey, massive to pillowed andesite; amygdaloidal to non-amygdaloidal

Dark green fine-crystalline diabase sill

Massive weathering volcanic agglomerate comprised of trachyte, quartz, garnet, argillite and sandstone fragments in a fine- to coarse-crystalline mafic matrix

Massive to poorly stratified, fine- to coarse-grained volcaniclastic sandstone with intermixed layers of thin to medium bedded, trachyte and sandstone pebble conglomerate

Wavy layered, thin bedded, fine- to very coarse-grained volcaniclastic sandstone; interlayered with planar to wavy layered, thick laminated to very thin bedded crystal-lithic tuff and minor massive to poorly bedded granule to polymictic conglomerate

Planar layered, thin laminated to very thin bedded crystal-lithic tuff to volcaniclastic siltstone with minor lenses and layers of massive to poorly bedded, coarse-grained to granular volcaniclastic sandstone and trachyte-sandstone pebble conglomerate

Carbonate and Carbonate Dominated Lithofacies

Alternating facies units (<1 m to 3 m thick) of thick laminated to thin bedded dolosiltite and stromatolitic dolostone; minor dolostone flat pebble conglomerate and thin to thick laminated dololutite to dolosiltite

Intermixed planar to wavy layered, thick laminated to thin bedded dolostone and dolosiltite; minor thin bedded, fine-grained dolarenite

Interlayered facies units of planar layered, thin to thick laminated dololutite to dolosiltite (amount 30% to 50%) and planar to lensed, thin bedded dolostone, dolosiltite; minor dolarenite and dolorudite

Interlayered facies units of planar layered, thin to thick laminated calcilutite to calcisiltite (amount <15% to 30%) and planar to wavy layered, thin bedded limestone, calcisiltite; minor calcarenite and calcirudite

Planar to wavy layered, thin bedded dolostone and dolosiltite; minor intermixed planar, thin to thick laminated argillite to dololutite (amount <10% to 20%); minor dolarenite, dolorudite, dolomitic subarkose

Planar to wavy layered, thick laminated to thin bedded calcisiltite; minor interbeds of calcareous quartzarenite to sublitharenite

Massive to poorly stratified, mottled fine-crystalline limestone with lenses of relic dolostone and dolosiltite; beds locally emit a petroliferous odour

Planar layered, thick laminated to thin bedded limestone

Thin laminated to thin bedded limestone, stromatolitic limestone and minor calcisiltite; domal to columnar stromatolites typically as mounds and bioherms

Planar to wavy layered, thick laminated to thin bedded dolosiltite; minor interbeds of fine-grained dolarenite and partings of dololutite

Intermixed facies units of planar to wavy layered, thick laminated to thin bedded dolosiltite, dolostone and stromatolitic dolostone

Thin to thick laminated stromatolitic dolostone; domal, columnar to branching stromatolites as mounds and bioherms

Chert banded and lensed, wavy to lenticular layered, thin to medium bedded dolostone to dolarenite; chert amount 30% to +60%

Alternating facies units of planar to wavy layered dolostone, dolosiltite and chert banded to lensed dolostone to dolarenite; chert amount <10% to 30%

Chert banded and lensed, wavy to lenticular layered, thin to medium bedded limestone, calcarenite and minor calcirudite; chert amount 30% to +70%

Alternating facies units (<1 m to +3 m thick) of planar to wavy layered limestone, calcisiltite, minor calcarenite to calcirudite and chert banded to lensed limestone to calcisiltite; chert amount <15% to +25%

Planar to wavy layered, thin bedded calcisiltite, calcarenite; minor calcirudite

Planar to wavy layered, thick laminated to thin bedded intermixed calcisiltite and fine-grained calcarenite

Massive weathering, thin to thick bedded fossiliferous limestone with porous layers and lenses; beds emit a petroliferous odour

Planar, wavy to cross laminated, thin bedded siliceous calcisiltite and minor interlayers of fine-grained calcarenite

STRATIGRAPHIC SYMBOLS

Sedimentary Structures

////	Crossbeds
	Cross Laminations
	Ripple Marks
	Scour Marks
	Load Casts
	Domal Stromatolites
	Columnar Stromatolites
	Shrinkage Cracks
	Molar Tooth Structure
≈	Hummocky Cross Stratification

Minor Lithofacies, Minerals and Non-Sedimentary Structures

	Pillows (Purcell Lava)
• •	Intraclasts; Flat Pebble Conglomerate
□	Halite Casts
o o	Oolites
	Concretions; Ironstone Nodules
Py	Pyrite (Disseminated to Nodular)
c	Coal Seam (Thickness: 10 cm to 50 cm)

SECTION 3I015

APPEKUNNY FORMATION

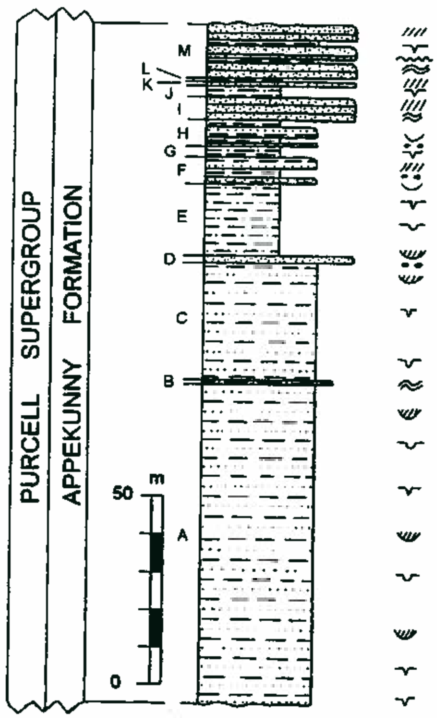
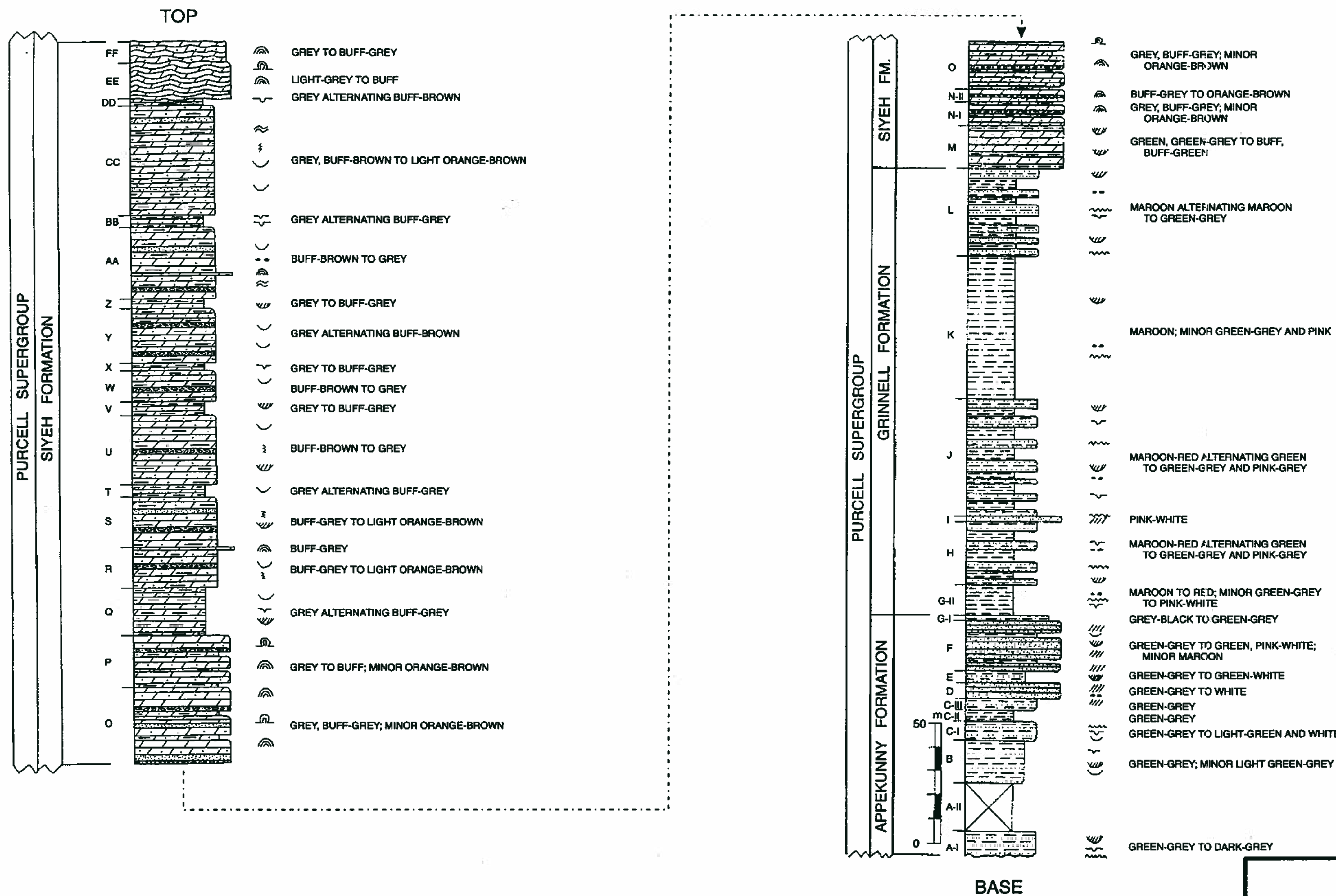


FIGURE: II - 1

LOCATION: UTM E 688100 N 5459900
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 180 m

SCALE: 1 : 2,000



SECTION 3I016

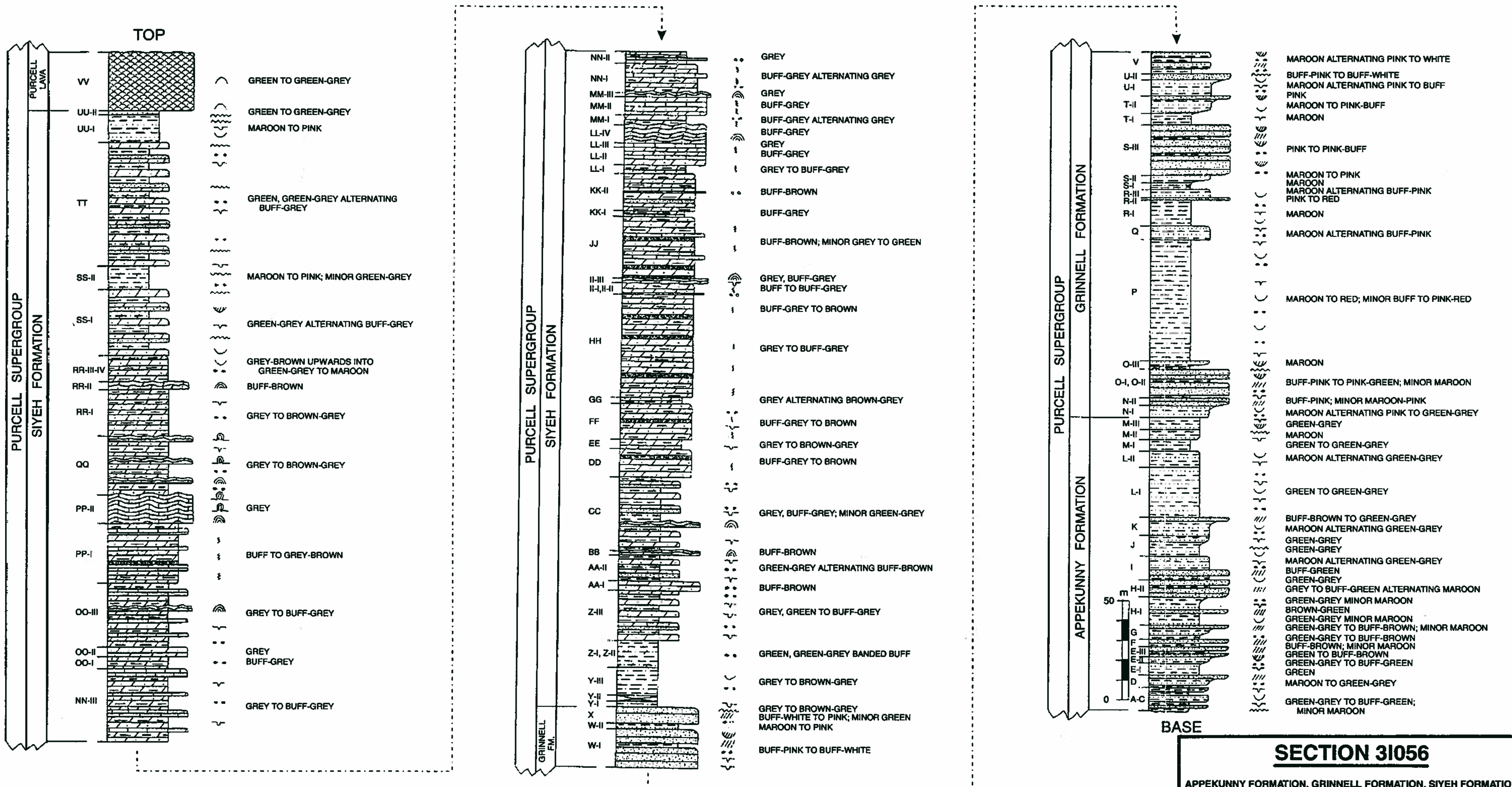
APPEKUNNY FORMATION, GRINNELL FORMATION, SIYEH FORMATION

FIGURE: II - 2

LOCATION: UTM E 688660 N 5459400
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 637 m

SCALE: 1 : 2,000



SECTION 3I056

APPEKUNNY FORMATION, GRINNELL FORMATION, SIYEH FORMATION

FIGURE: II - 3

LOCATION: UTM E 710740 N 5464290
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 1030 m

SCALE: 1 : 2,000

SECTION 3I018

SIYEH FORMATION

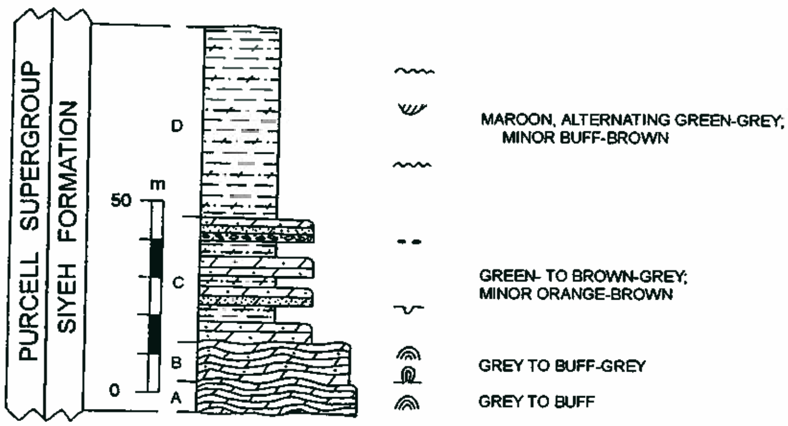


FIGURE: II - 4

LOCATION: UTM E 689750 N 5458790
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 101 m

SCALE: 1 : 2,000

SECTION 3I020 - 021

SIYEH FORMATION

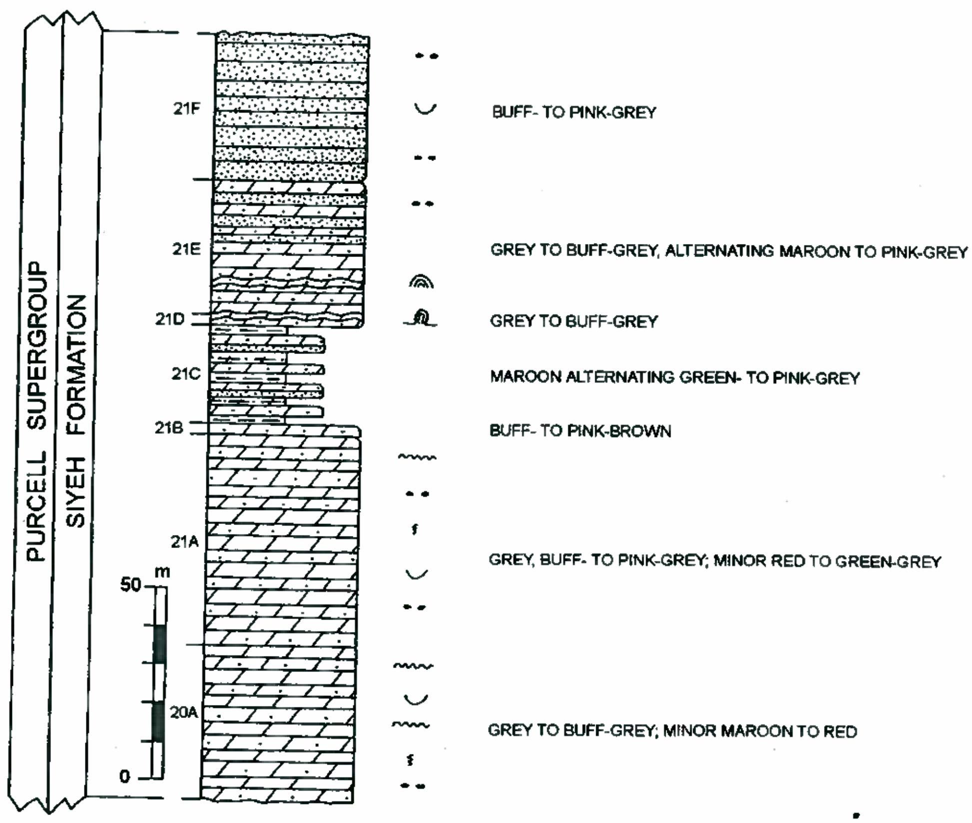


FIGURE: II - 5

LOCATION: UTM E 688450 N 5470610
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 200 m

SCALE: 1 : 2,000

SECTION 3I024 - 025

SIYEH FORMATION, PURCELL LAVA, SHEPPARD FORMATION

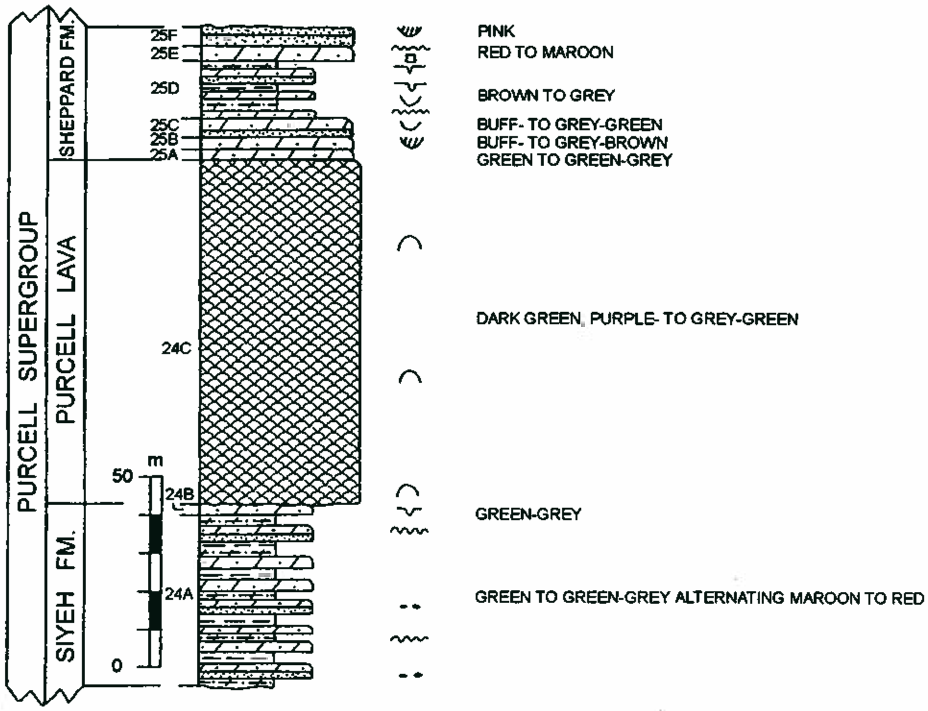
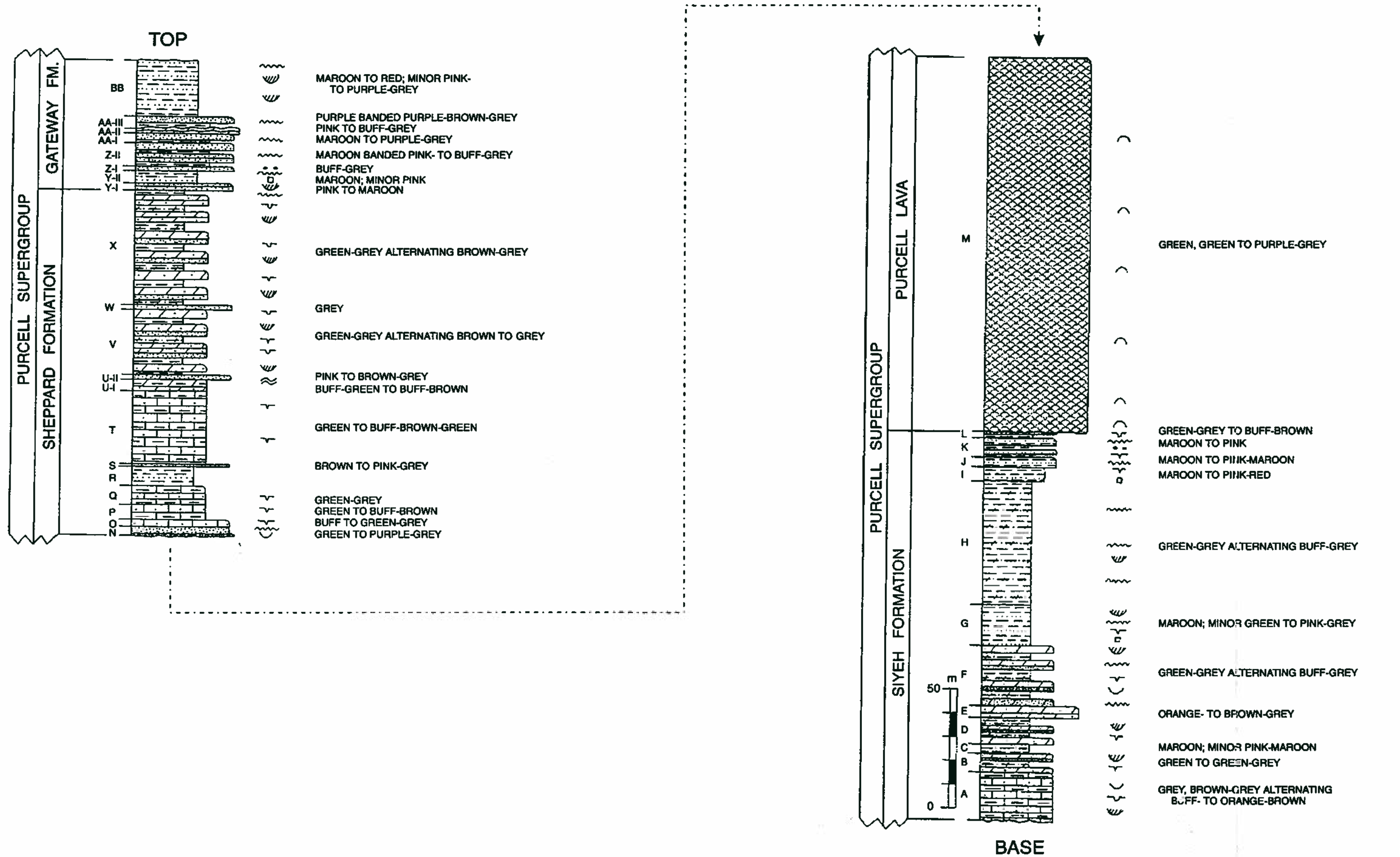


FIGURE: II - 6

LOCATION: UTM E 686190 N 5469930
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 173 m

SCALE: 1 : 2,000



SECTION 3I035

SIYEH FORMATION, PURCELL LAVA, SHEPPARD FORMATION, GATEWAY FORMATION

FIGURE: II - 8

LOCATION: UTM E 696930 N 5470700
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 513 m

SCALE: 1 : 2,000

SECTION 3I034

SIYEH FORMATION

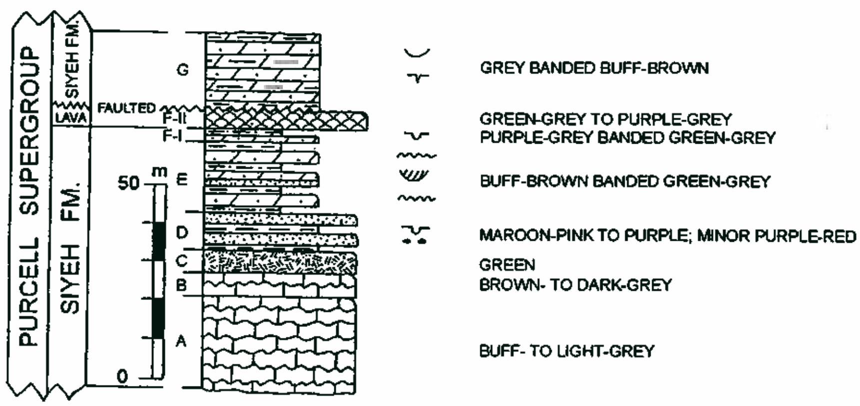


FIGURE: II - 7

LOCATION: UTM E 696870 N 5470810
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 92 m

SCALE: 1 : 2,000

SECTION 3I044

SIYEH FORMATION, PURCELL LAVA

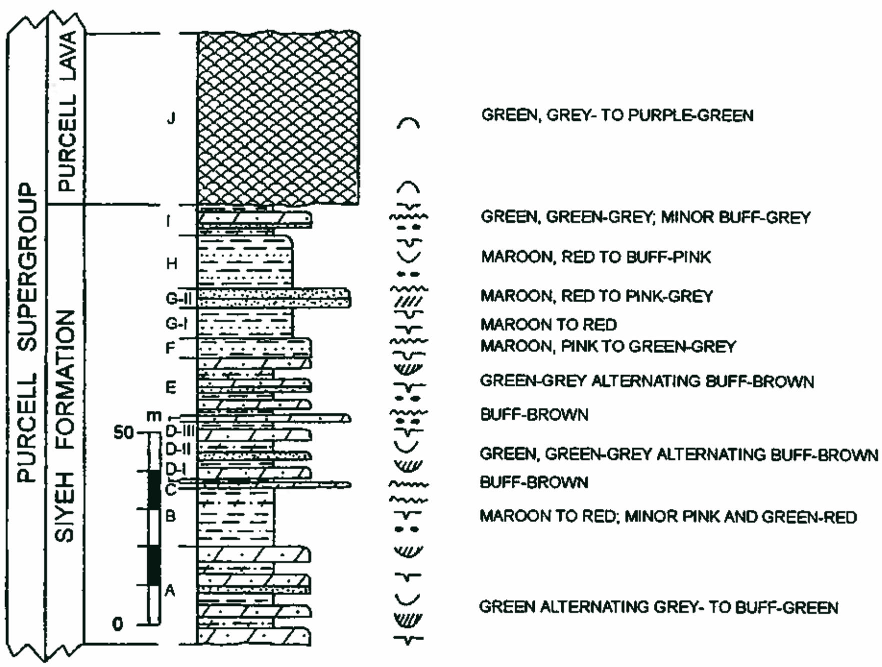


FIGURE: II - 9

LOCATION: UTM E 710190 N 5465225
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 160 m

SCALE: 1 : 2,000

SECTION 3I045

SIYEH FORMATION, PURCELL LAVA, SHEPPARD FORMATION, GATEWAY FORMATION

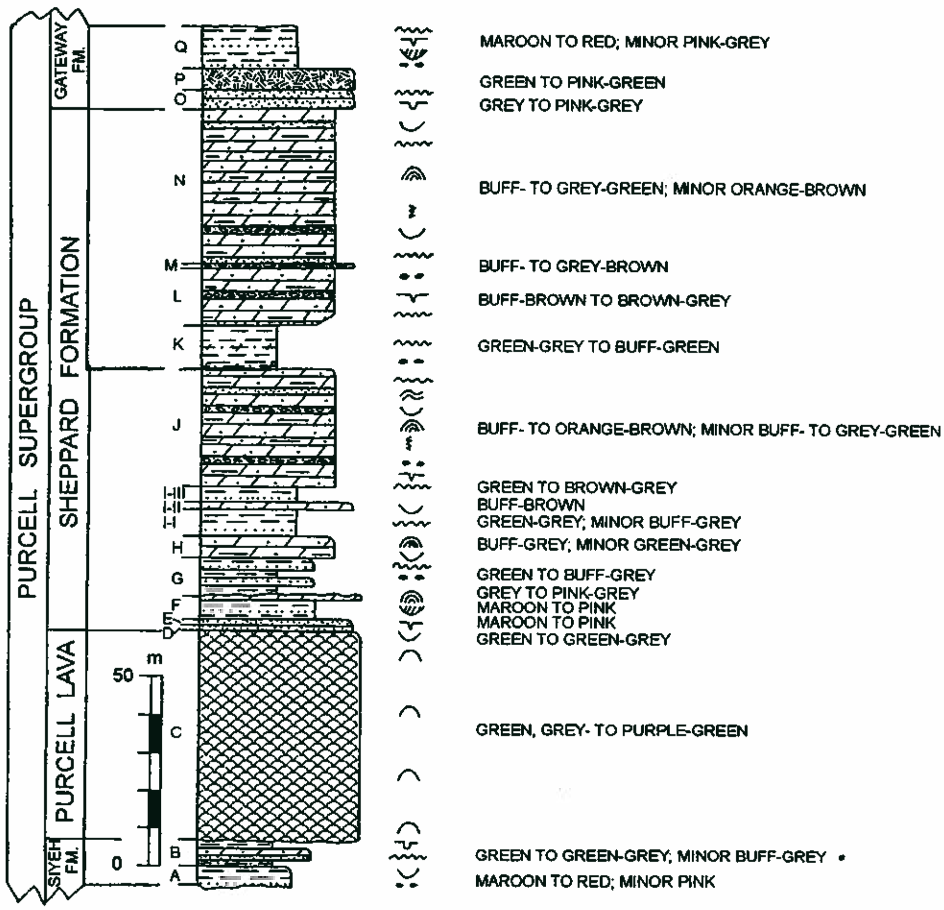


FIGURE: II - 10

LOCATION: UTM E 710390 N 5466210
ZONE 11
NTS 82 G/8

SECTION THICKNESS: 224 m

SCALE: 1 : 2,000

SECTION 3I055

SIYEH FORMATION, PURCELL LAVA, SHEPPARD FORMATION

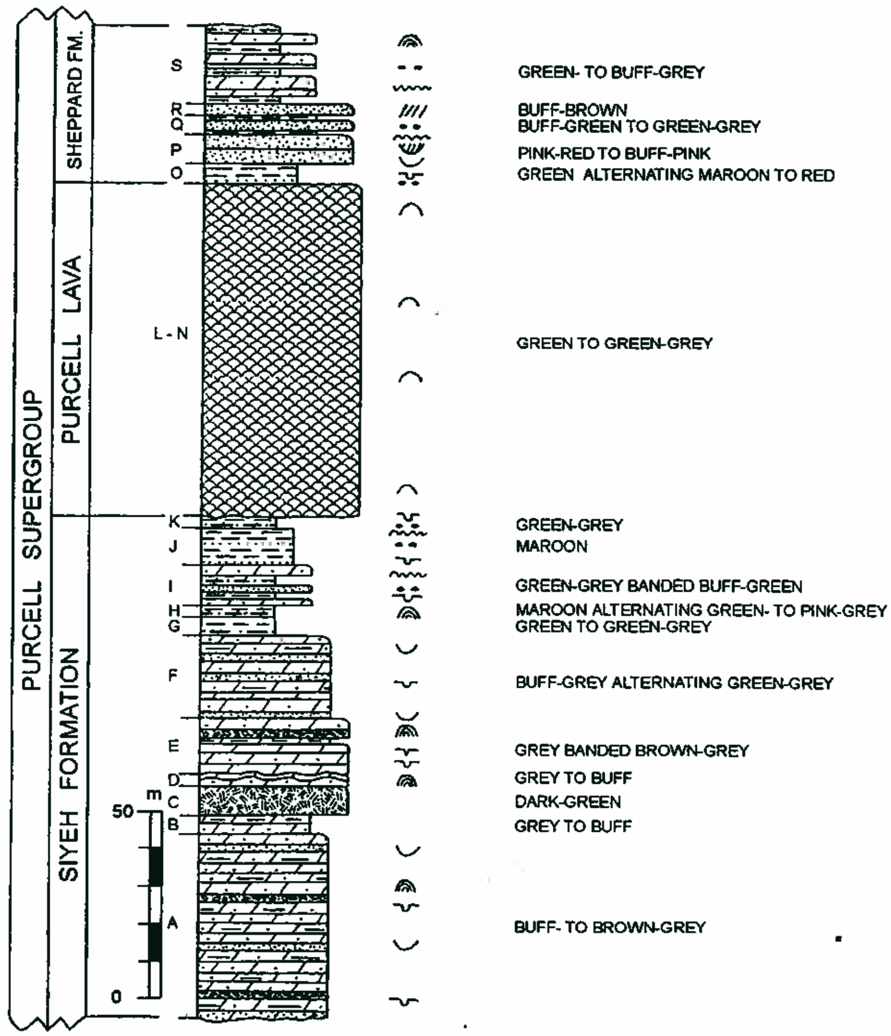
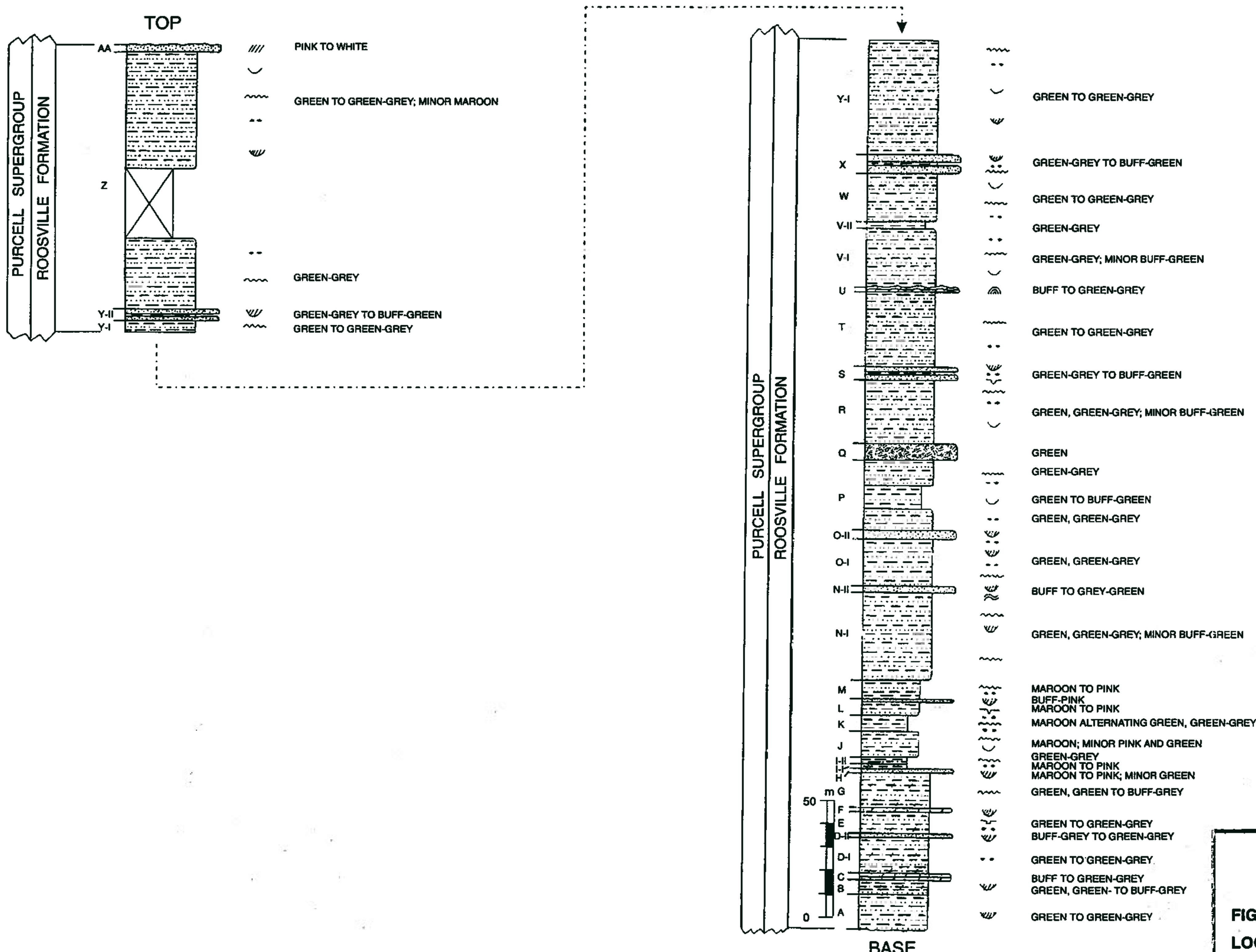


FIGURE: II - 11

LOCATION: UTM E 677250 N 5475370
ZONE 11
NTS 82 G/7

SECTION THICKNESS: 264 m

SCALE: 1 : 2,000



SECTION 3I063

ROOSVILLE FORMATION

FIGURE: II - 12

LOCATION: UTM E 704400 N 5451600
ZONE 11
NTS 82 G/1

SECTION THICKNESS: 504 m

SCALE: 1 : 2,000

SECTION 3I064

GORDON FORMATION, ELKO FORMATION

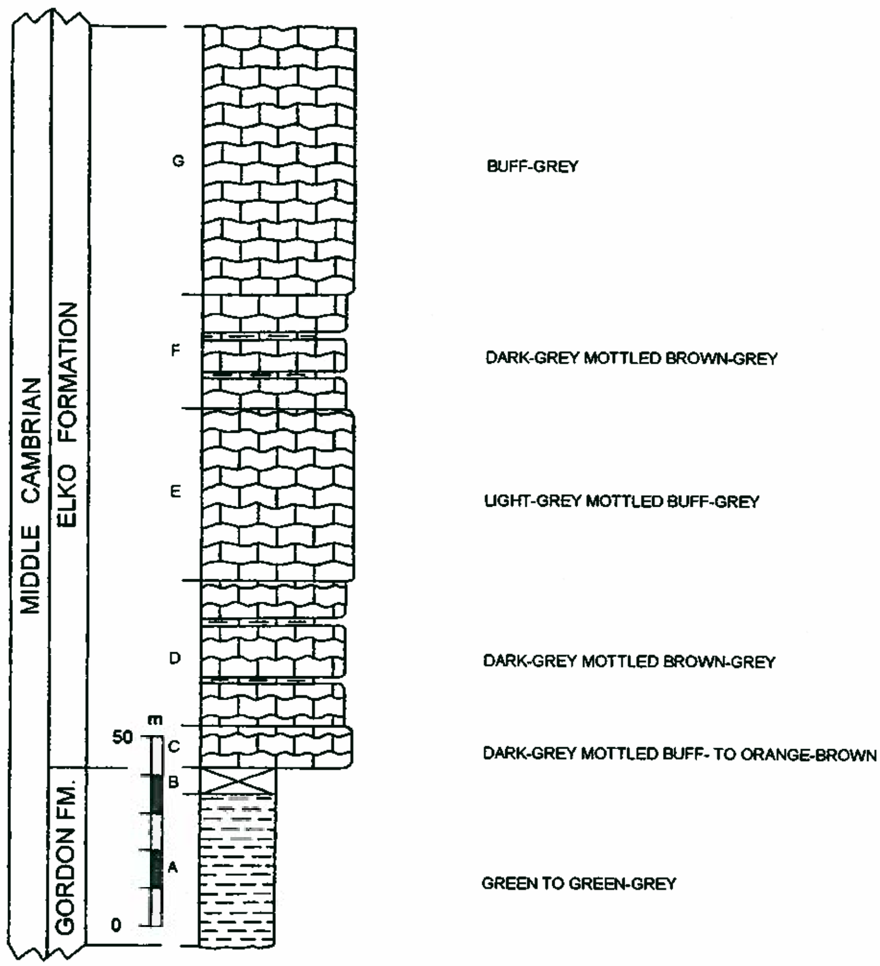


FIGURE: II - 13

LOCATION: UTM E 703700 N 5451050
ZONE 11
NTS 82 G/1

SECTION THICKNESS: 246 m

SCALE: 1 : 2,000

SECTION 3I043

PALLISER FORMATION, EXSHAW FORMATION, BANFF FORMATION

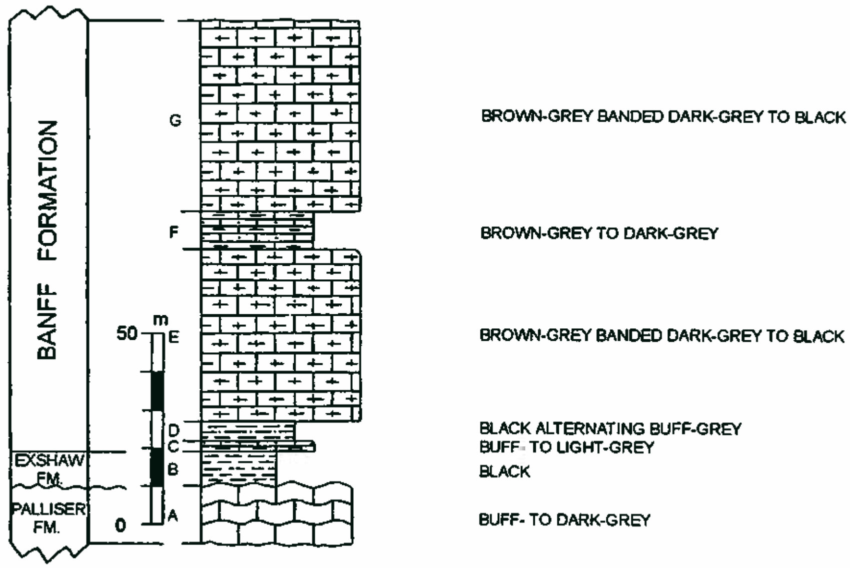
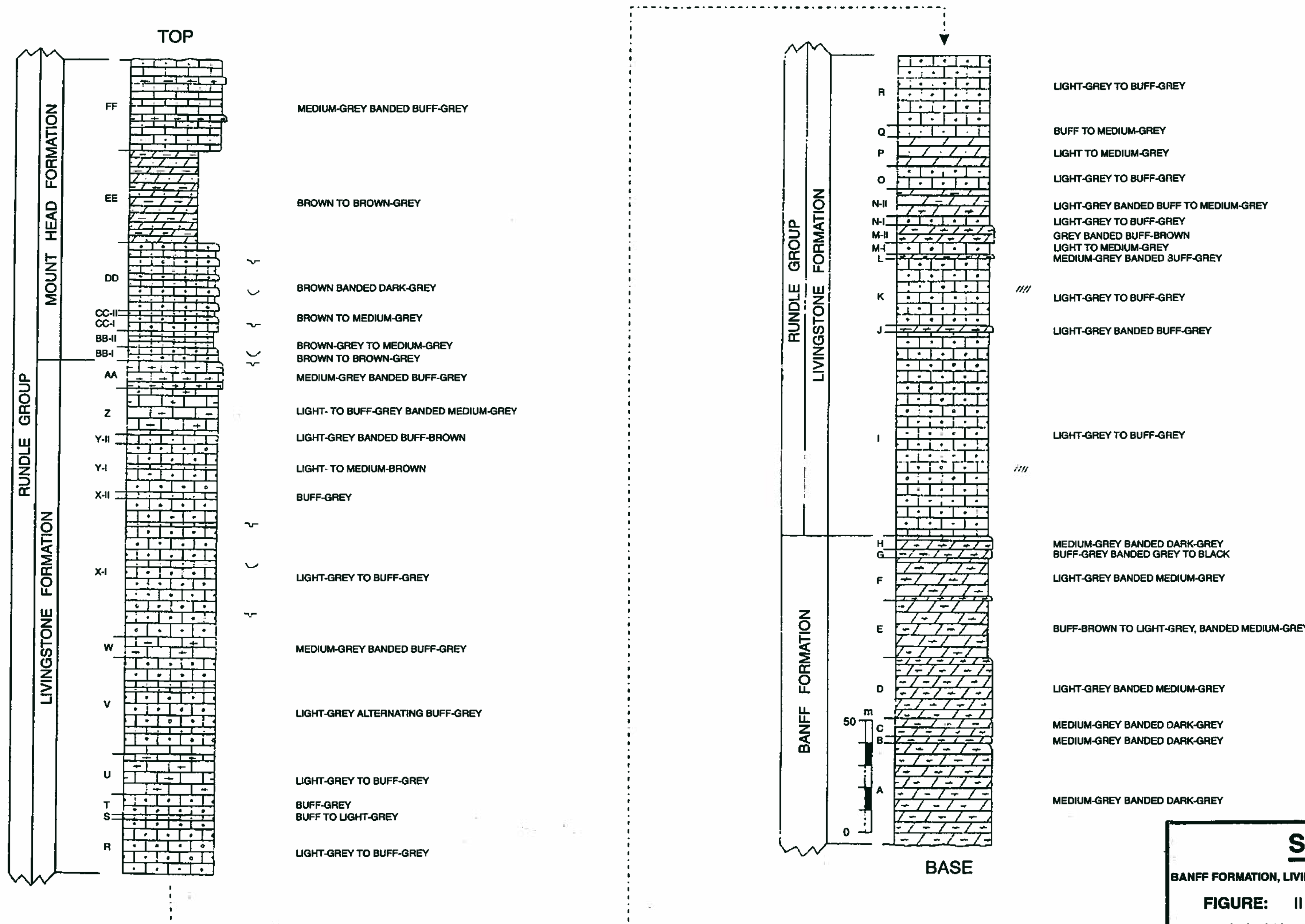


FIGURE: II - 14

LOCATION: UTM E 669910 N 5499470
ZONE 11
NTS 82 G/10

SECTION THICKNESS: 135 m

SCALE: 1 : 2,000



SECTION 3I066

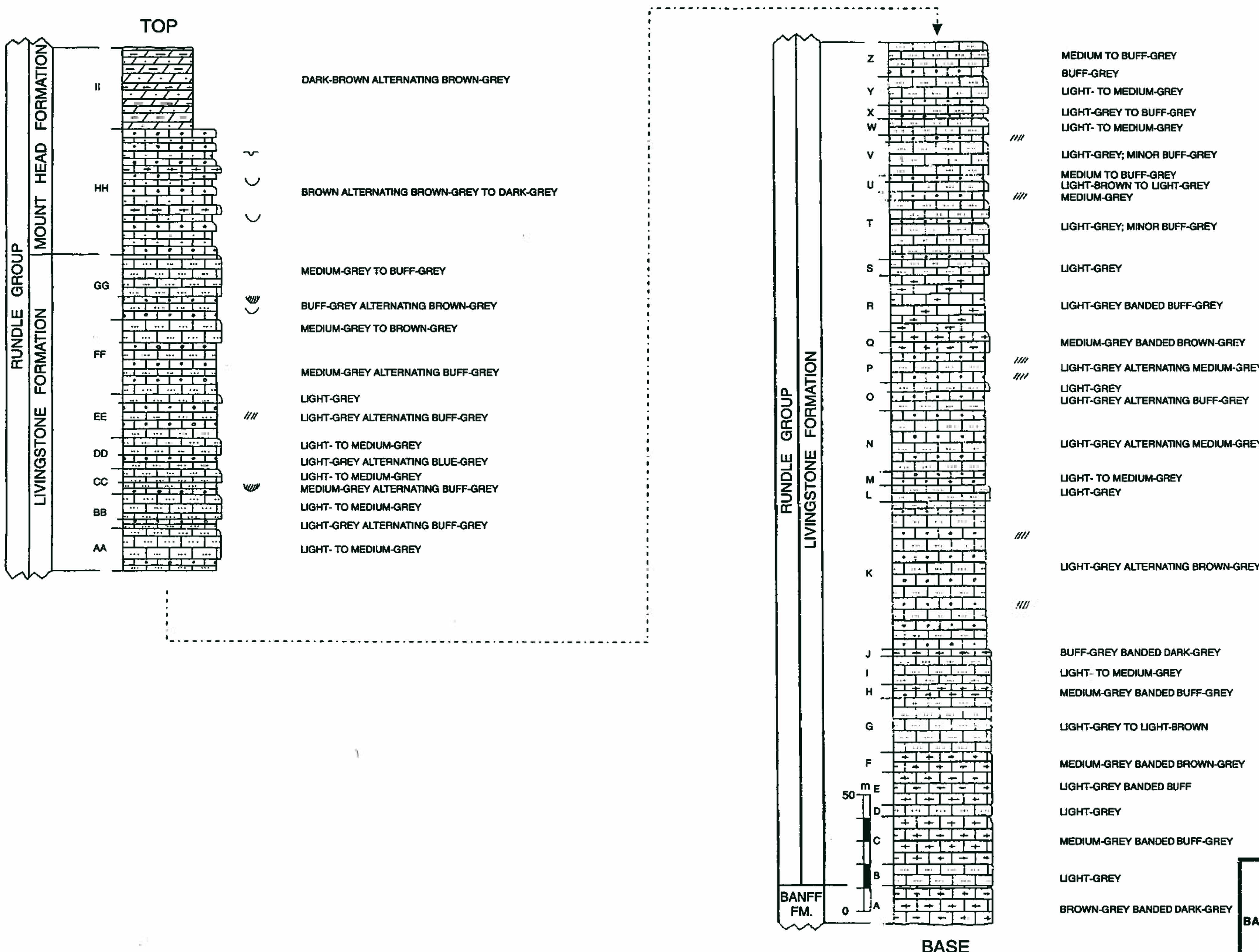
BANFF FORMATION, LIVINGSTONE FORMATION, MOUNT HEAD FORMATION

FIGURE: II - 15

LOCATION: UTM E 662830 N 5554280
ZONE 11
NTS 82 J/2

SECTION THICKNESS: 707 m

SCALE: 1 : 2,000



SECTION 3I089

BANFF FORMATION, LIVINGSTONE FORMATION, MOUNT HEAD FORMATION

FIGURE: II - 16

LOCATION: UTM E 670240 N 5532050
ZONE 11
NTS 82 G/15

SECTION THICKNESS: 604 m

SCALE: 1 : 2,000

SECTION 3I111

BANFF FORMATION, LIVINGSTONE FORMATION

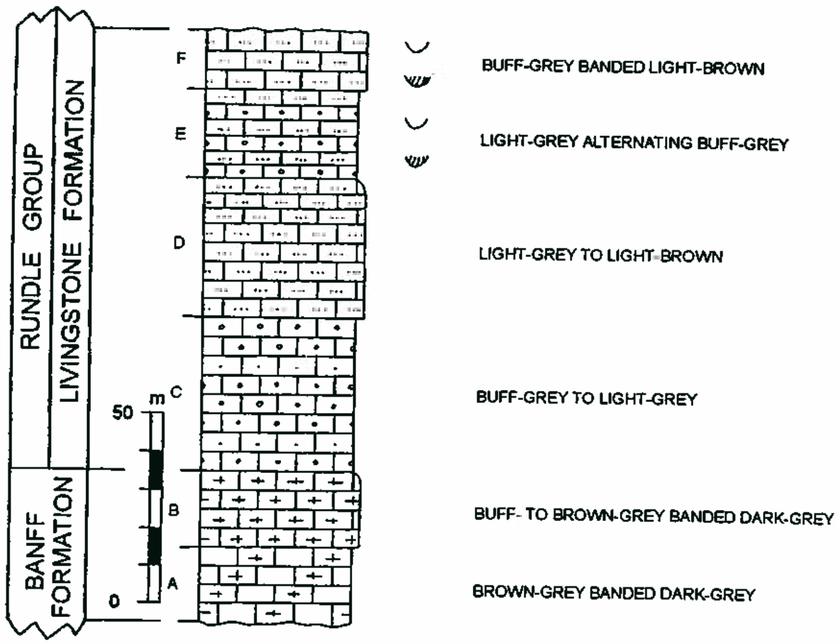


FIGURE: II - 17

LOCATION: UTM E 689280 N 5526660
ZONE 11
NTS 82 G/16

SECTION THICKNESS: 155 m

SCALE: 1 : 2,000

SECTION 3I124

LIVINGSTONE FORMATION, MOUNT HEAD FORMATION

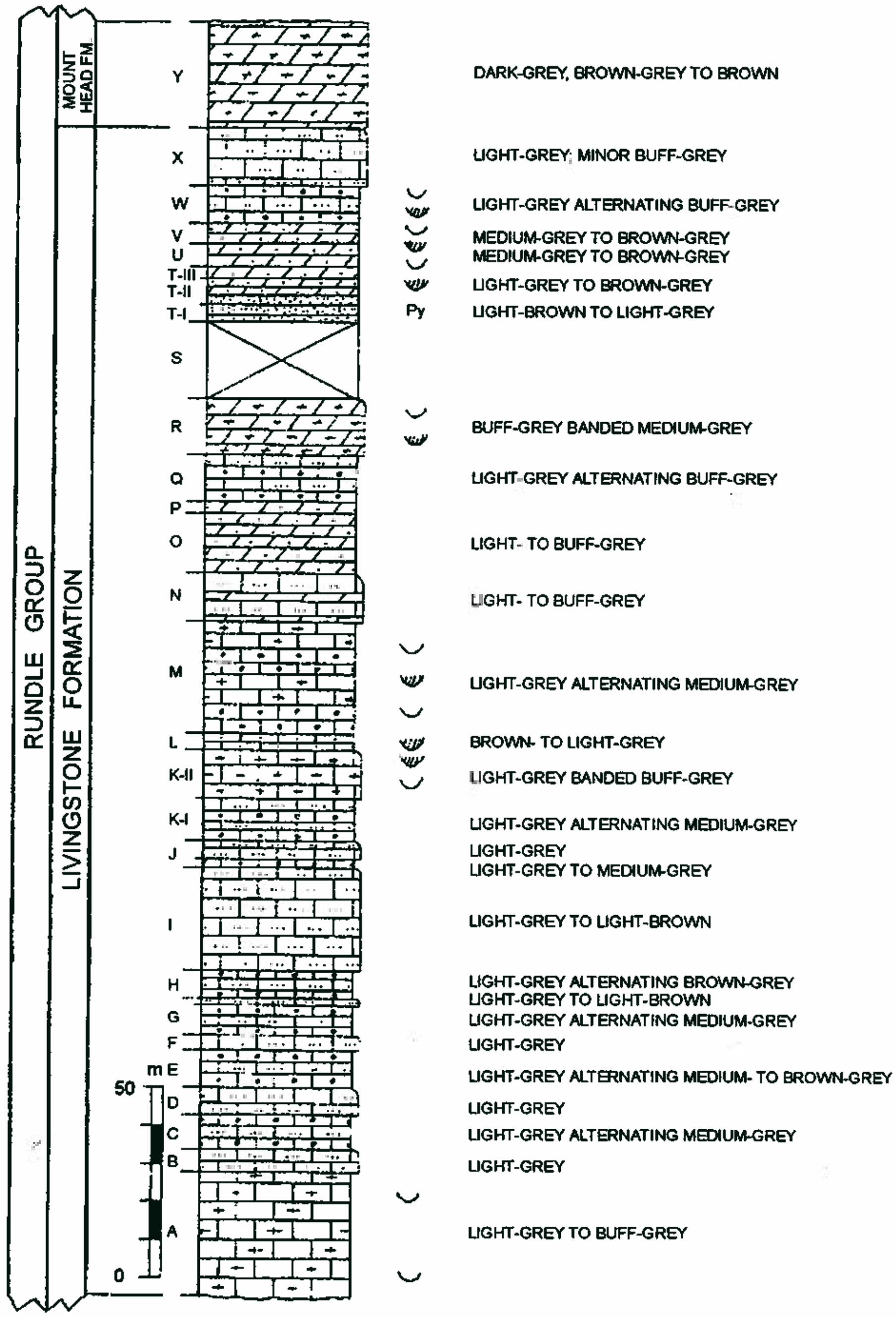
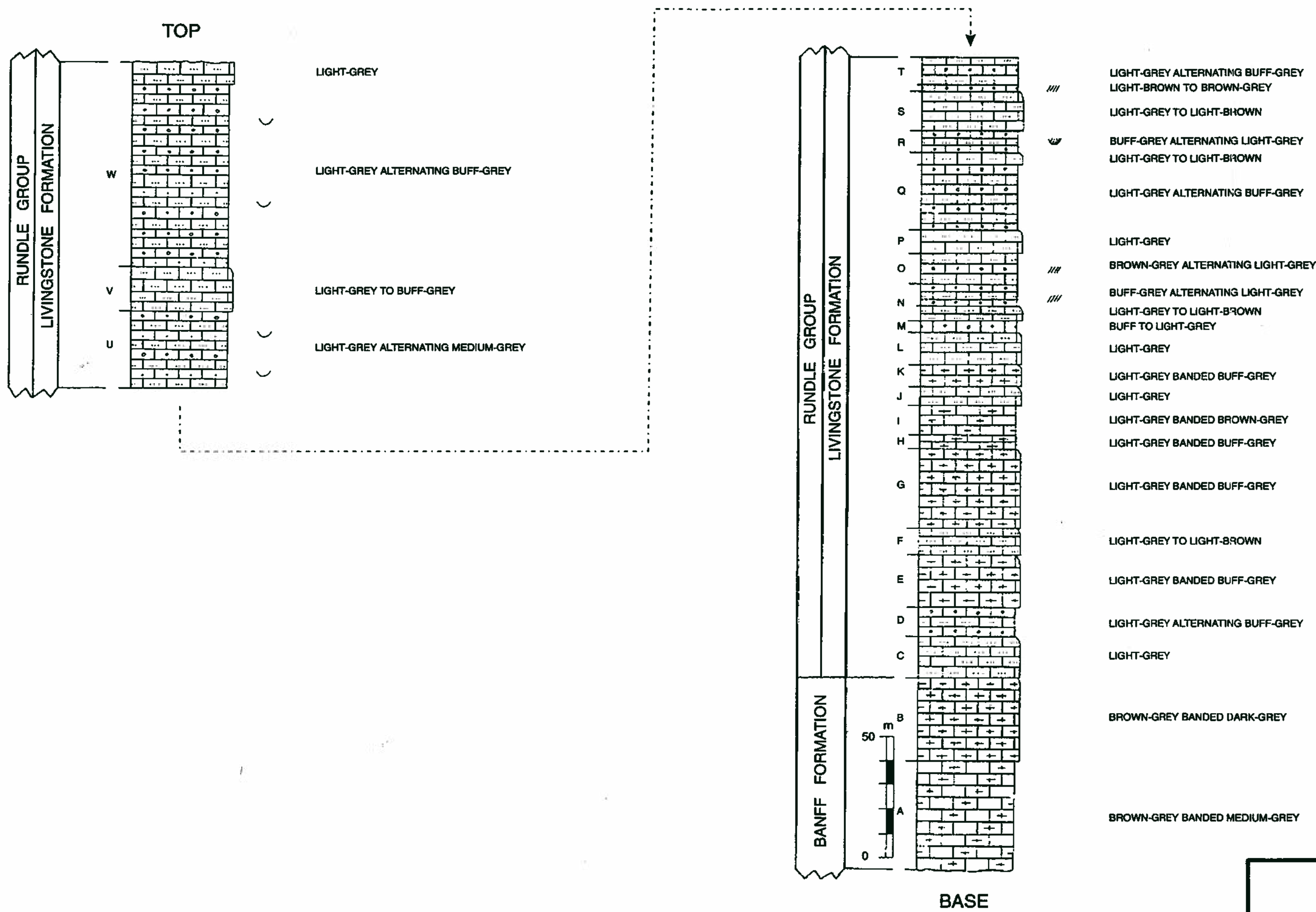


FIGURE: II - 19

LOCATION: UTM E 690330 N 5525790
ZONE 11
NTS 82 G/16

SECTION THICKNESS: 336 m

SCALE: 1 : 2,000



SECTION 3I136

BANFF FORMATION, LIVINGSTONE FORMATION

FIGURE: II - 18

LOCATION: UTM E 686070 N 5554980 ZONE 11
NTS 82 J/1

SECTION THICKNESS: 471 m

SCALE: 1 : 2,000

SECTION 3I137

LIVINGSTONE FORMATION, MOUNT HEAD FORMATION

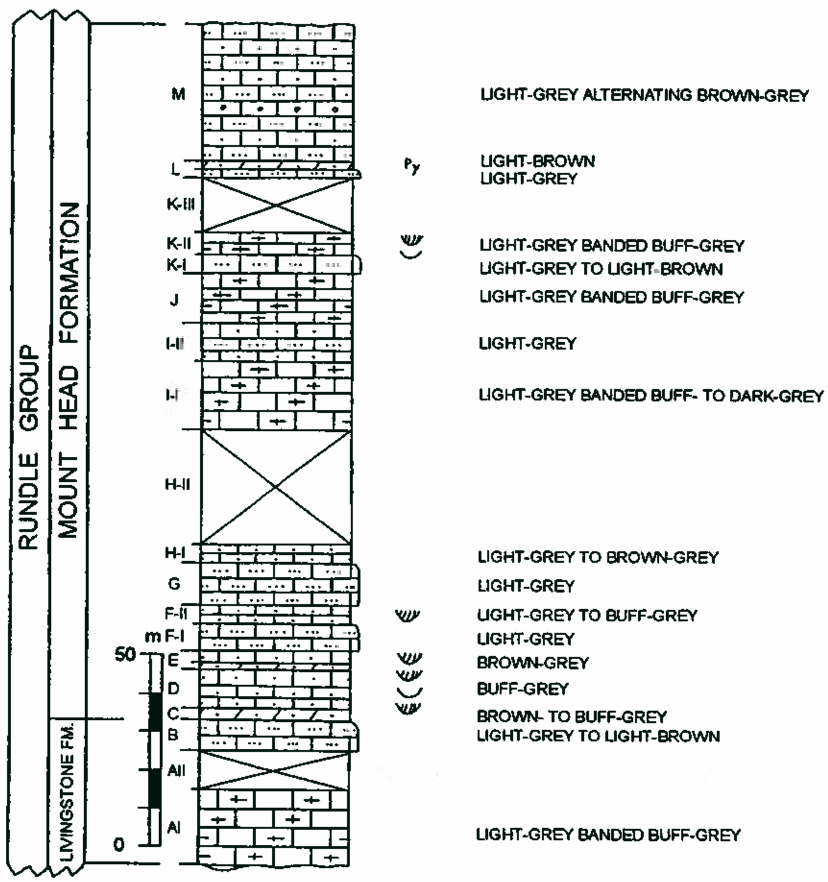


FIGURE: II - 20

LOCATION: UTM E 685520 N 5555260
ZONE 11
NTS 82 J/1

SECTION THICKNESS: 227 m

SCALE: 1 : 2,000

SECTION 3I049

MOUNT HEAD FORMATION, ETHERINGTON FORMATION, ROCKY MOUNTAIN FORMATION

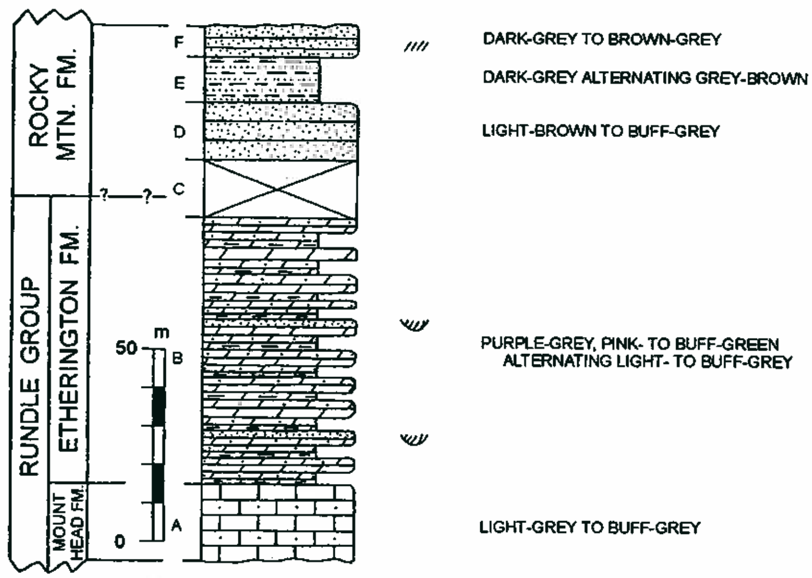


FIGURE: II - 21

LOCATION: UTM E 691410 N 5501220
ZONE 11
NTS 82 G/9

SECTION THICKNESS: 140 m

SCALE: 1 : 2,000

SECTION 3I086

MOUNT HEAD FORMATION, ETHERINGTON FORMATION, ROCKY MOUNTAIN FORMATION

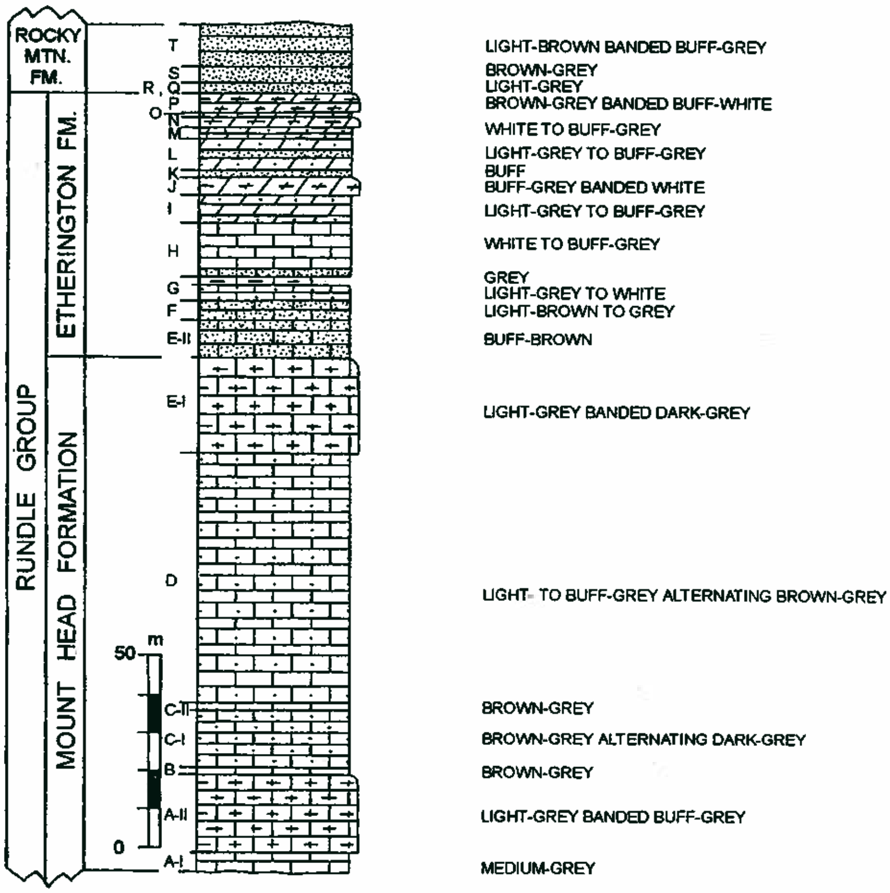


FIGURE: II - 22

LOCATION: UTM E 677260 N 5565180
ZONE 11
NTS 82 J/2

SECTION THICKNESS: 221 m

SCALE: 1 : 2,000

SECTION 3I138

MOUNT HEAD FORMATION, ETHERINGTON FORMATION

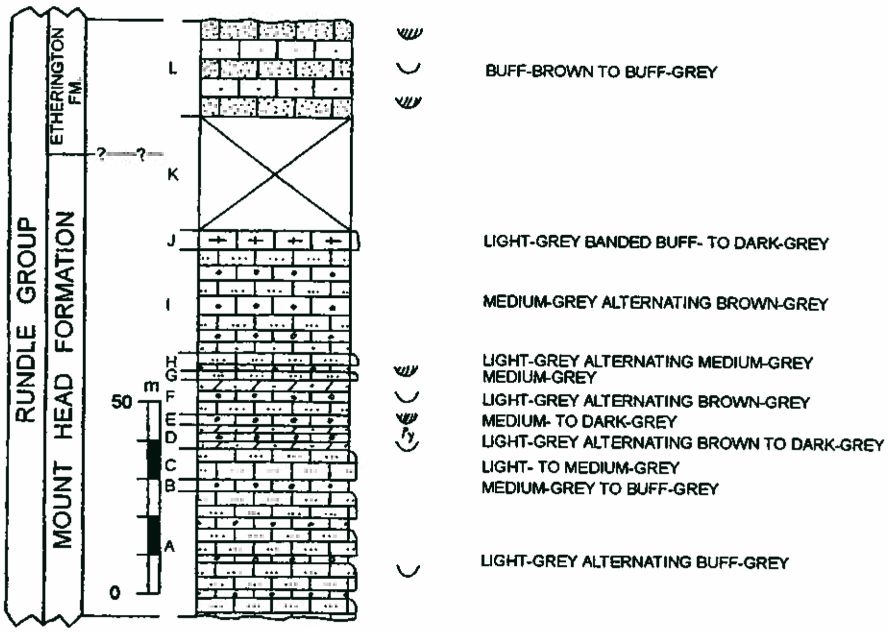


FIGURE: II - 23

LOCATION: UTM E 669910 N 5585060
ZONE 11
NTS 82 J/7

SECTION THICKNESS: 156 m

SCALE: 1 : 2,000

SECTION 3I036 - 037

KOOTENAY GROUP, BLAIMORE GROUP

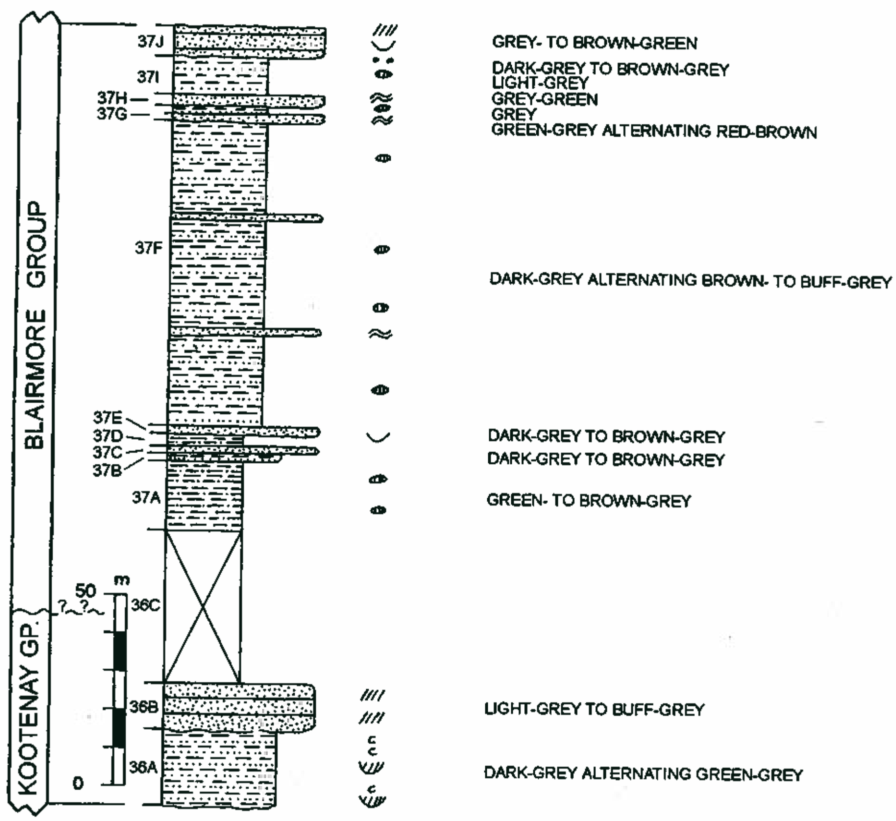


FIGURE: II - 24

LOCATION: UTM E 690680 N 5494530
ZONE 11
NTS 82 G/9

SECTION THICKNESS: 204 m

SCALE: 1 : 2,000

SECTION 3I077

KOOTENAY GROUP

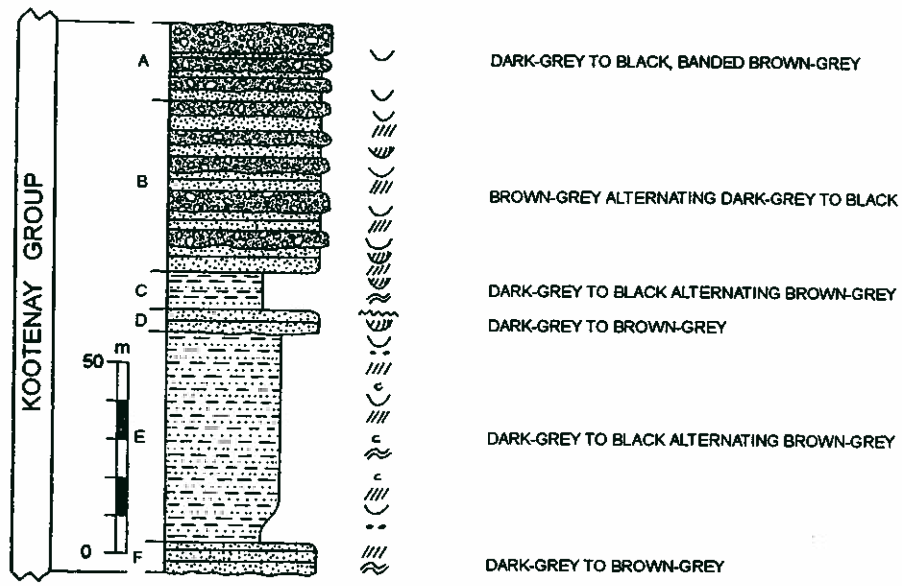


FIGURE: II - 25

LOCATION: UTM E 667680 N 5583850
ZONE 11
NTS 82 J/7

SECTION THICKNESS: 144 m

SCALE: 1 : 2,000

SECTION 3I093

KOOTENAY GROUP

FIGURE: II - 26

LOCATION: UTM E 673270 N 5585480
ZONE 11
NTS 82 J/7

SECTION THICKNESS: 65 m

SCALE: 1 : 2,000

SECTION 3I054

BLAIMORE GROUP

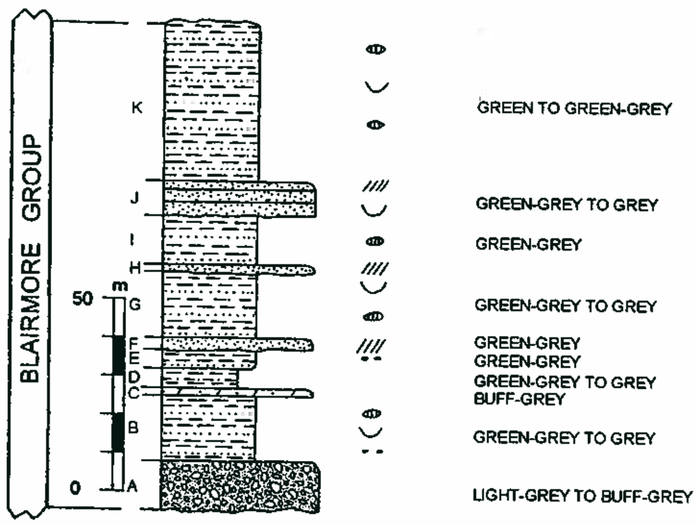


FIGURE: II - 27

LOCATION: UTM E 677420 N 5475210
ZONE 11
NTS 82 G/7

SECTION THICKNESS: 127 m

SCALE: 1 : 2,000

SECTION 3I039

CROWSNEST FORMATION

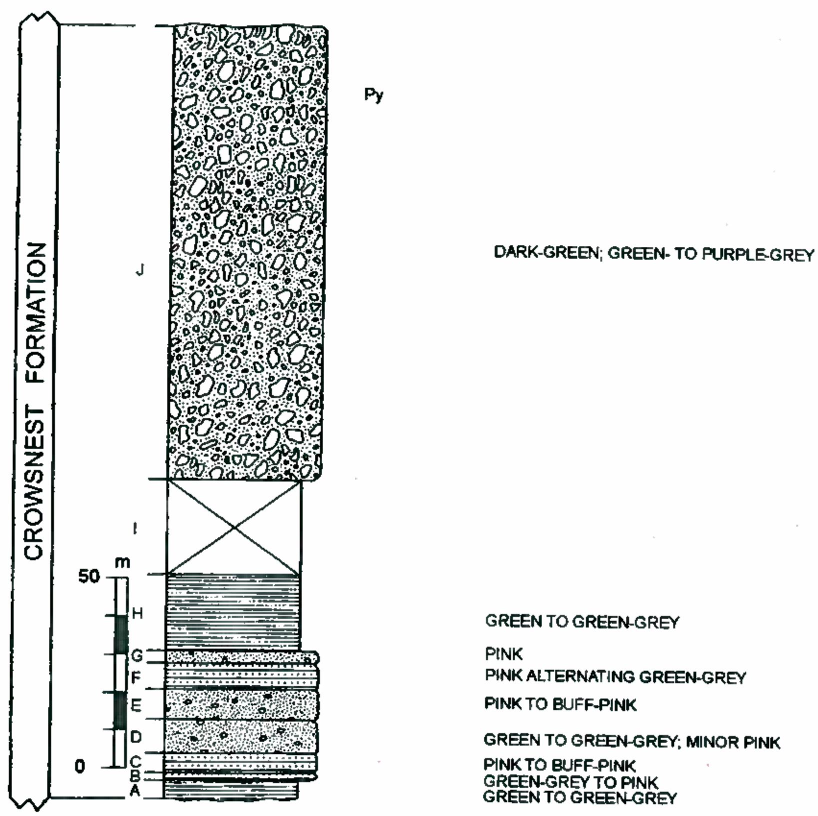


FIGURE: II - 28

LOCATION: UTM E 675830 N 5500670
ZONE 11
NTS 82 G/10

SECTION THICKNESS: 203 m

SCALE: 1 : 2,000

SECTION 3I095

WAPIABI FORMATION, BELLY RIVER FORMATION

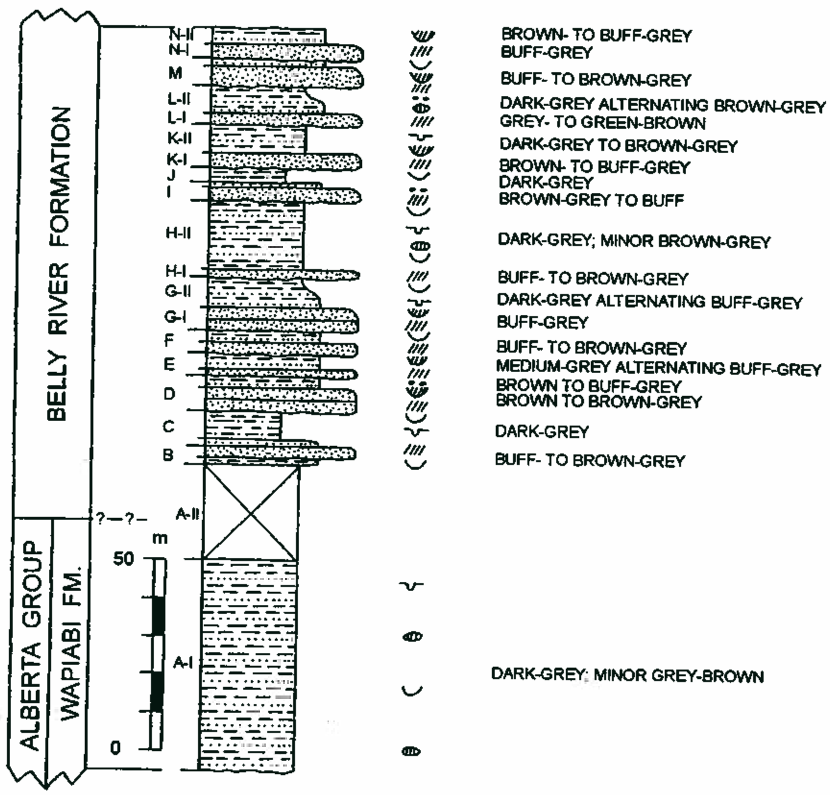


FIGURE: II - 29

LOCATION: UTM E 681530 N 5589840
ZONE 11
NTS 82 J/8

SECTION THICKNESS: 194 m

SCALE: 1 : 2,000

SECTION 3I101

WAPIABI FORMATION, BELLY RIVER FORMATION

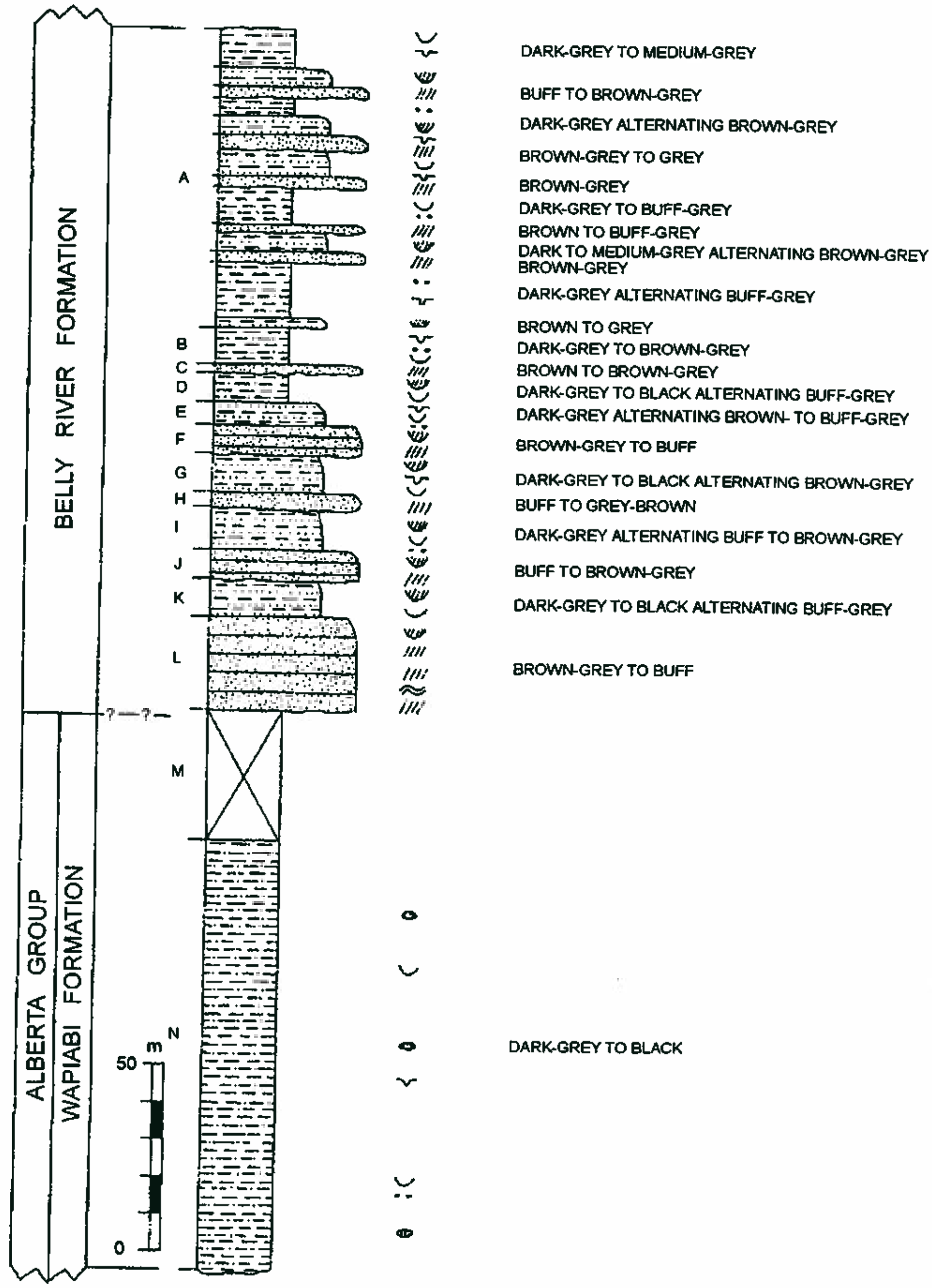


FIGURE: II - 30

LOCATION: UTM E 682930 N 5595630
ZONE 11
NTS 82 J/8

SECTION THICKNESS: 332 m

SCALE: 1 : 2,000

SECTION 3I040

BELLY RIVER FORMATION

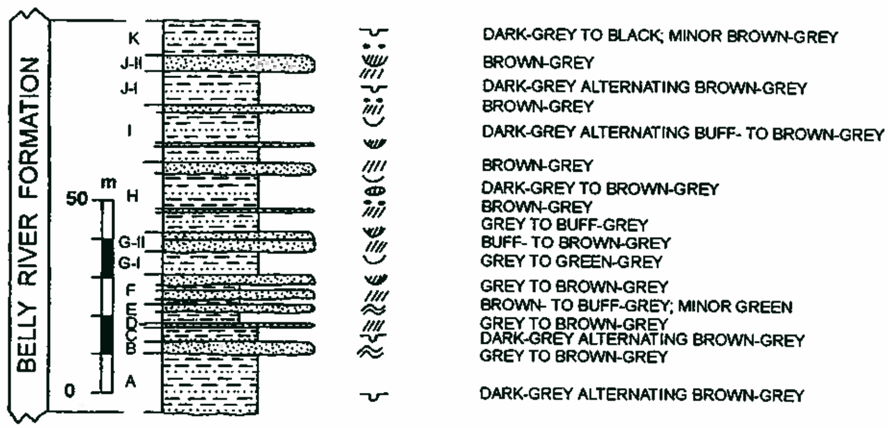


FIGURE: II - 31

LOCATION: UTM E 672100 N 5500090
ZONE 11
NTS 82 G/10

SECTION THICKNESS: 101 m

SCALE: 1 : 2,000

SECTION 3I119

St. MARY RIVER FORMATION

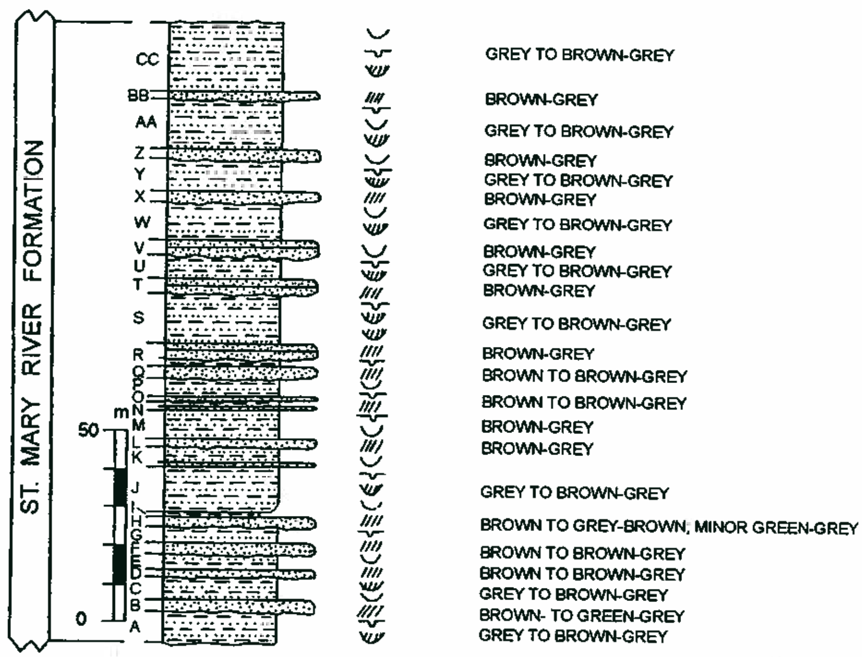


FIGURE: II - 32

LOCATION: UTM E 704780 N 5520510
ZONE 11
NTS 82 G/16

SECTION THICKNESS: 167 m

SCALE: 1 : 2,000