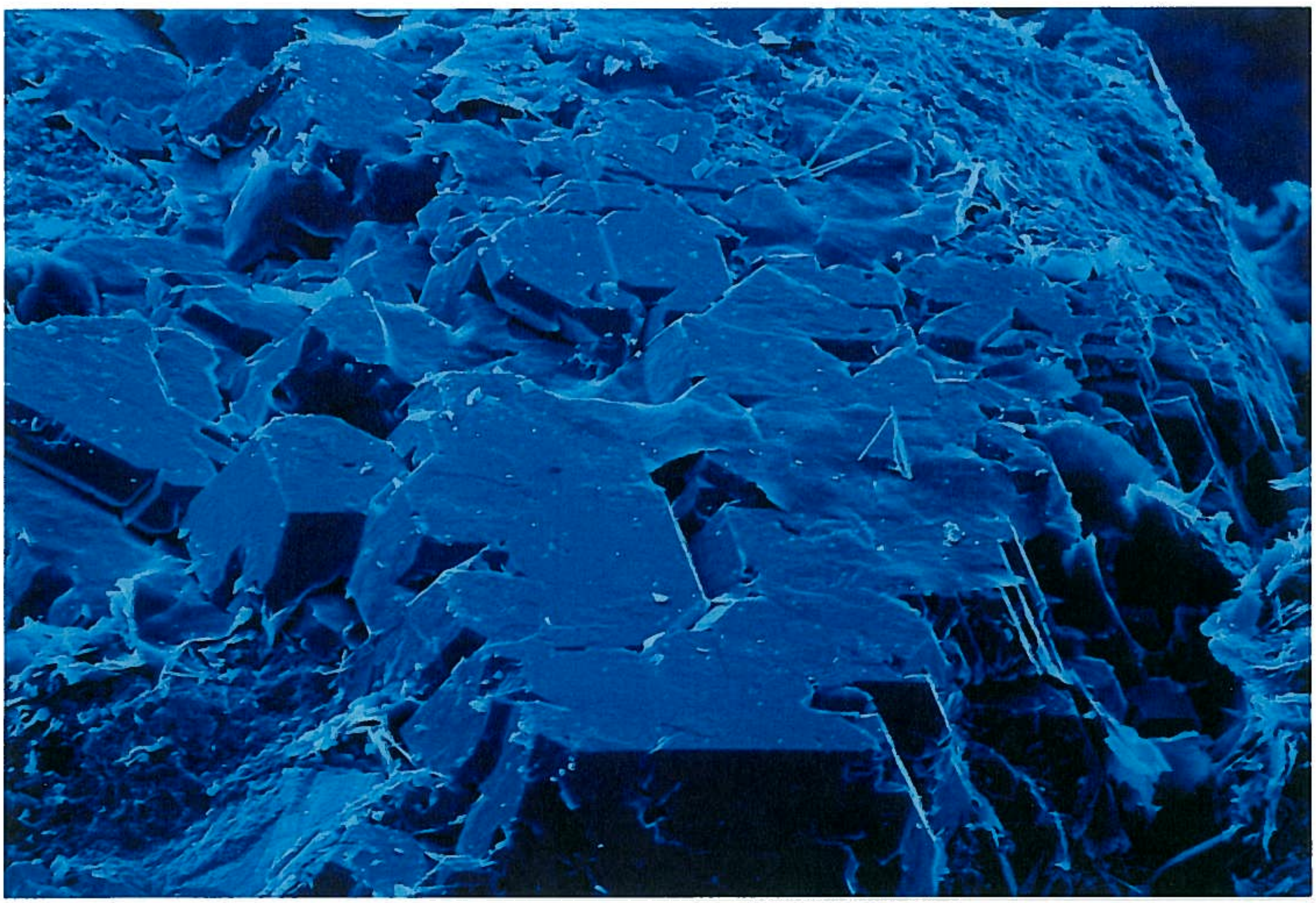
Bulletin No. 49

Geology of the Athabasca Group in Alberta

J.A. Wilson



ALBERTA RESEARCH COUNCIL
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Alberta Geological Survey

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Cover:
Scanning Electron Micrograph of coalesced quartz overgrowths in the Manitou Falls Formation of drill hole FC-009-162-T at a depth of 97.4 m. Width of view is approximately 0.6 mm.

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Thanks are extended to the companies that drilled the core, for their help in collecting the drill core and in producing information on their work.

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Abstract

Four formations of the Helikian Athabasca Group are present in Alberta. They are distinguished by variations in grain size, clay content and sedimentary structures. From the base, they are the Fair Point, the Manitou Falls, the Wolverine Point and the Locker Lake Formations. The Wolverine Point Formation is informally subdivided into an upper and a lower member.

Petrographic studies of the Athabasca Group support the formational divisions and reveal a complex history of diagenesis. The diagenesis affected the porous units within the Athabasca Group and imparted to them a distinctive clay mineral composition that can be broadly related to the lithostratigraphy. Thin section examinations reveal the tuffaceous nature of many siltstones and shales of the upper member of the Wolverine Point Formation. These tuffs are both vitric and ash flow and are derived from a silica-oversaturated volcanicity. The tuffs of the upper member of the Wolverine Point Formation show evidence of having been deposited under nearshore marine conditions; the remainder of the Athabasca Group was deposited in a fluvial setting.

Areas of potential interest for uranium exploration occur where the Athabasca Group is less than 200 m thick and where it is present as outliers. Potential for economic lead-zinc mineralization is also present, associated with zones of fracturing in the sandstone.

Introduction

This study was undertaken in response to uranium exploration activity in Alberta following the discovery of several uranium deposits in the Athabasca Basin of Saskatchewan. The Alberta Energy and Natural Resources Department (the mineral exploration regulatory body for the province) funded the collection and preservation of drill core from the Alberta portion of the Athabasca Basin. The core is stored in the Mineral Exploration Sample Storage (MESS) facility in Edmonton, which is operated by the Alberta Geological Survey.

This bulletin presents the results of research performed on the Athabasca Group rocks between 1980 and 1982. The stratigraphy is established for the Athabasca Group in Alberta and related to the stratigraphy of the Athabasca Basin in Saskatchewan. The sedimentology of the group is also examined. Petrographic study of the stratigraphic succession indicates the sequence of diagenetic events and attempts to relate them to fluid flow and mineral transport within the sandstones.

Location and access

The study area, located in northeastern Alberta between latitudes 57°32′ and 59°26′ north and longitudes 110° and 112° west (figure 1), covers townships 99 to 120 and ranges 1 to 12, west of the 4th meridian. The area encompasses the Fort Chipewyan (NTS 74L) and parts of the Fitzgerald (NTS 74M) and Bitumount (NTS 74E) map sheets. The area borders on Saskatchewan to the east and Wood Buffalo National Park to the west. The Northwest Territories lie close by to the north; to the south are the oil sand deposits of the Fort McMurray area (figure 1).

There are regularly scheduled flights from Edmonton to Fort Chipewyan. From there, boat, helicopter or float plane across Lake Athabasca provide access to the area. Float planes are available in Fort Chipewyan, and the numerous small lakes in the area make this a suitable method of transportation. Access by boat is also possible from Fort McMurray along the Athabasca River and then into the Peace/Athabasca delta. A winter road runs from Fort McMurray to the south end of Old Fort Bay. Seismic cut lines and trails aid foot access and navigation in some areas.

Physiography

Lake Athabasca, the Peace-Athabasca delta and Lake Claire (fig 1) occupy a low-lying trough bisecting the map area from northeast to southwest. Another low-lying area trends north to south along the Athabasca and Slave Rivers. Lake Athabasca, at 212 m above sea level, drains to the north along the Slave River. North of Lake Athabasca, rocks of the Precambrian Shield outcrop as long ridges following the regional trend of the geology. Between these ridges are low-lying areas of trees and sandy or swampy ground. The land rises to the northeast to altitudes of more than 305 m above sea level.

The area south of Lake Athabasca is blanketed by Pleistocene to Recent, glaciofluvial, glaciolacustrine and aeolian deposits (Bayrock, 1972), with only rare isolated bedrock exposures. The land generally rises to the highest point in the region (610 m above sea level) in the extreme southeast corner. Recent alluvial silts, sands and clays in the Peace/Athabasca delta are more than 90 m thick.

Previous work

Until recently, rocks of the Athabasca Group in Alberta had not been extensively studied because outcrops were scarce and the area provided little economic interest prior to the discovery of uranium in Saskatchewan. First mention of the Athabasca Group in Alberta was by McConnell in 1893, when a traverse along the south shore of the lake revealed sandstone at Stone Point. He postulated that the sandstone extended along the entire south shore of the lake and was of Cambrian age. Tyrrell and Dowling (1896) observed many sandstone outcrops and attempted to map their extent. From outcrops on islands and along the north and south shores, they envisaged the sandstone extending under Lake Athabasca and correlated it with other Precambrian sedimentary basins. Alcock (1915, 1920, 1936) distinguished the sandstones south of Lake Athabasca from those in the Beaverlodge area of Saskatchewan, although he grouped both in the "Athabasca Series."

Exploration for Beaverlodge-type uranium deposits in the late 1940s and 1950s produced several papers and reports on the "Athabasca Formation" in Saskatchewan (Christie, 1953; Hale, 1954, 1955; Fraser, 1954; Blake, 1956; Gussow, 1957, 1959; Gravenor, 1959). Fahrig (1961), in the "Geology of the Athabasca Formation," presented the results of the first systematic study of the basin. In 1957, Godfrey began work in Alberta on the Canadian Shield north of Lake Athabasca and referred to the Athabasca Formation (1980a, 1980b). At

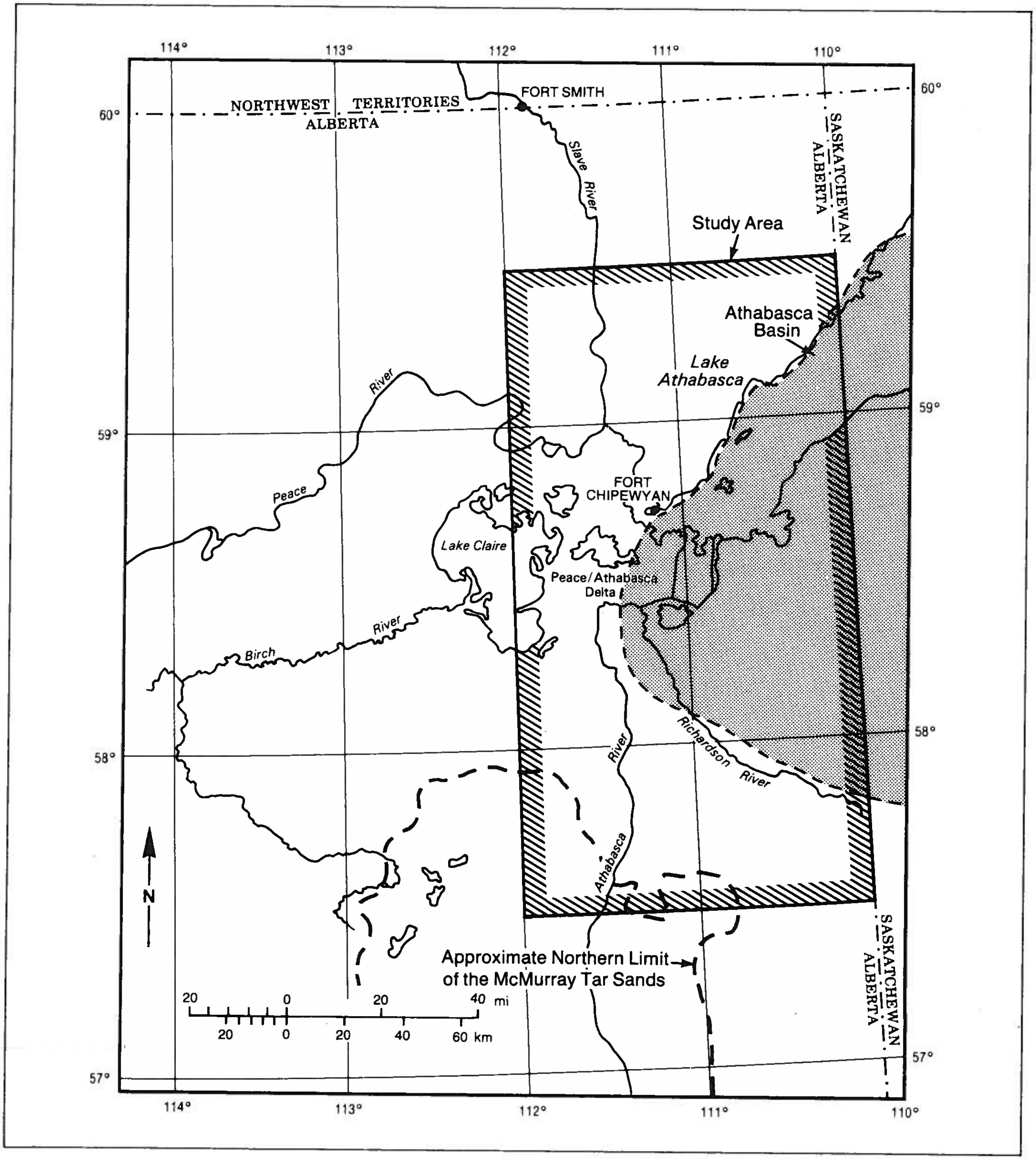

Figure 1. Location map showing the outline of the study area and the Athabasca Basin in Alberta.

that time the "Athabasca Formation" was believed to be a late Precambrian sequence, although Gussow (1957, 1959) had postulated a Palaeozoic, probably Middle Devonian age.

Exploration for uranium deposits within the Athabasca Basin began in the mid-1960s and led to the discovery of ore bodies at Rabbit Lake (1968) and Cluff Lake (1969) in Saskatchewan. These discoveries stimulated activity in Saskatchewan, and led to further discoveries, including the Maurice Bay ore body, 5 km east of the Saskatchewan/Alberta border. Tremblay (1982) provided a good summary of the main deposits.

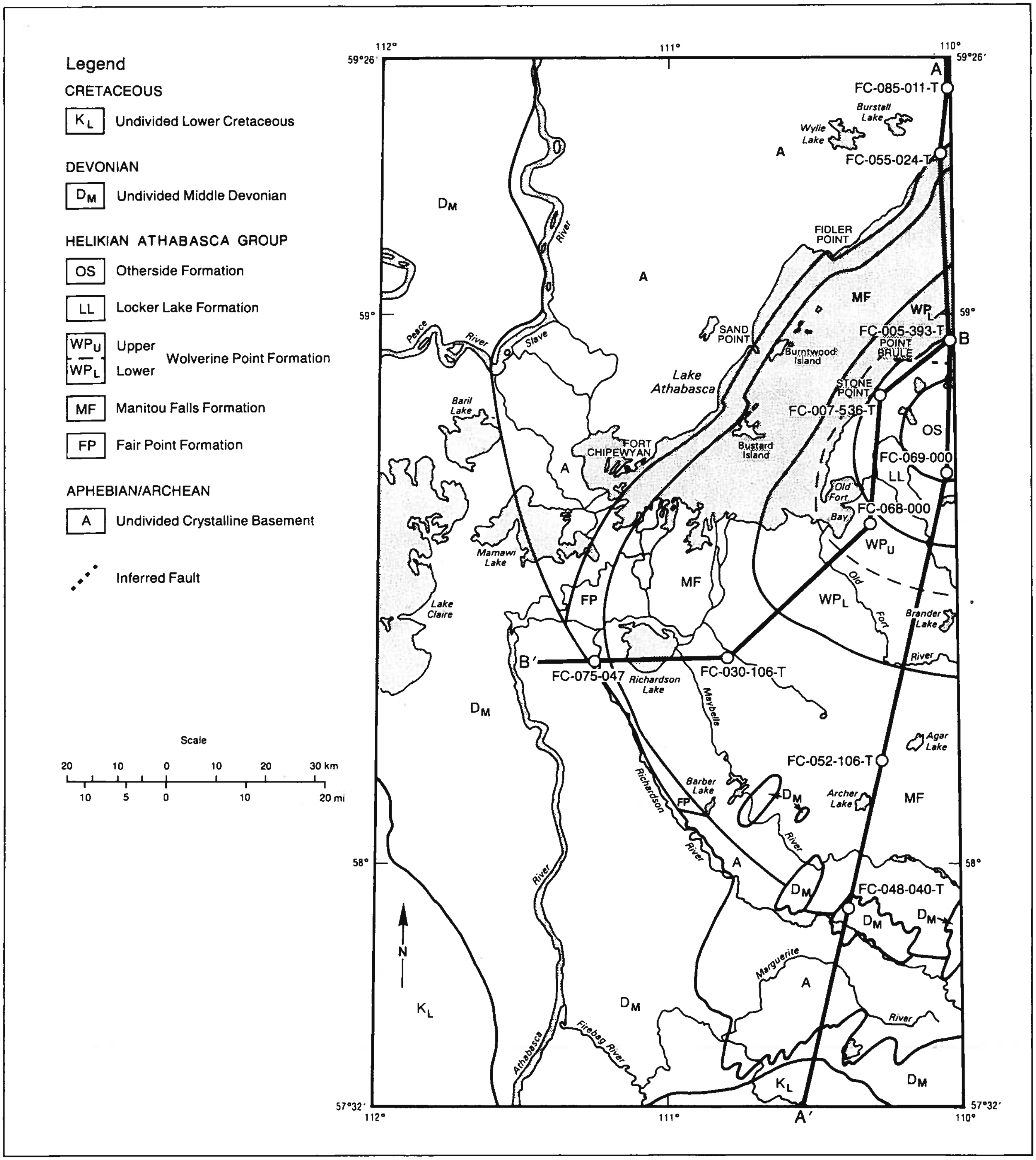

Figure 2. Simplified geological map of the Athabasca Basin in Alberta. For cross sections A-A′ and B-B′ see figure 3.

Activity spilled across the border into Alberta and led to the exploration drilling in the mid- to late 1970s on which this work is based. Hobson and MacAulay (1969) carried out a seismic reconnaissance survey of the basin in the late 1960s.

Interest in exploration of the sandstone led to many geological investigations of the basin in Saskatchewan. The most comprehensive studies were those of Ramaekers (1978, 1979a, I979b, 1980a, 1980b, 1981, 1983), who defined the stratigraphy and established the term Athabasca Group. Cameron (1983) presented detailed work on several exploration methods applied to a small area at the eastern edge of the basin.

The age of the Athabasca Group is established as Helikian. Rb-Sr isochron determinations (Ramaekers, 1979b, 1980a; Bell [in Ramaekers, 1980a]; Fahrig and Loveridge, 1981) on the sandstones and the underlying regolith and paleomagnetic work (Fahrig *et al.*, 1978) suggest a depositional age of 1500-1650 ma.

General geology

The Athabasca Group rocks occupy an oval basin measuring over 400 km east to west and over 200 km north to south with an area of over 80 000 km². Approximately 10 percent, or 8000 km², lie in Alberta south of the north shore of Lake Athabasca (figure 2). In Alberta, strata of the Athabasca Group consist of nearly flat-lying sandstones more than 1255 m thick (figure 3). The succession is underlain, beneath a marked angular unconformity, by predominantly gneissic rocks of the Churchill Structural Province of the Canadian Shield. These basement rocks outcrop extensively to the north and, to a lesser extent, to the south of the basin (Godfrey, 1970). Where the basement is covered by Athabasca rocks, a pre-Athabasca paleosol or regolith is preserved. The regolith consists of a deep red, hematite-stained layer, grading downward to a greenish to white layer, and subsequently down to fresh

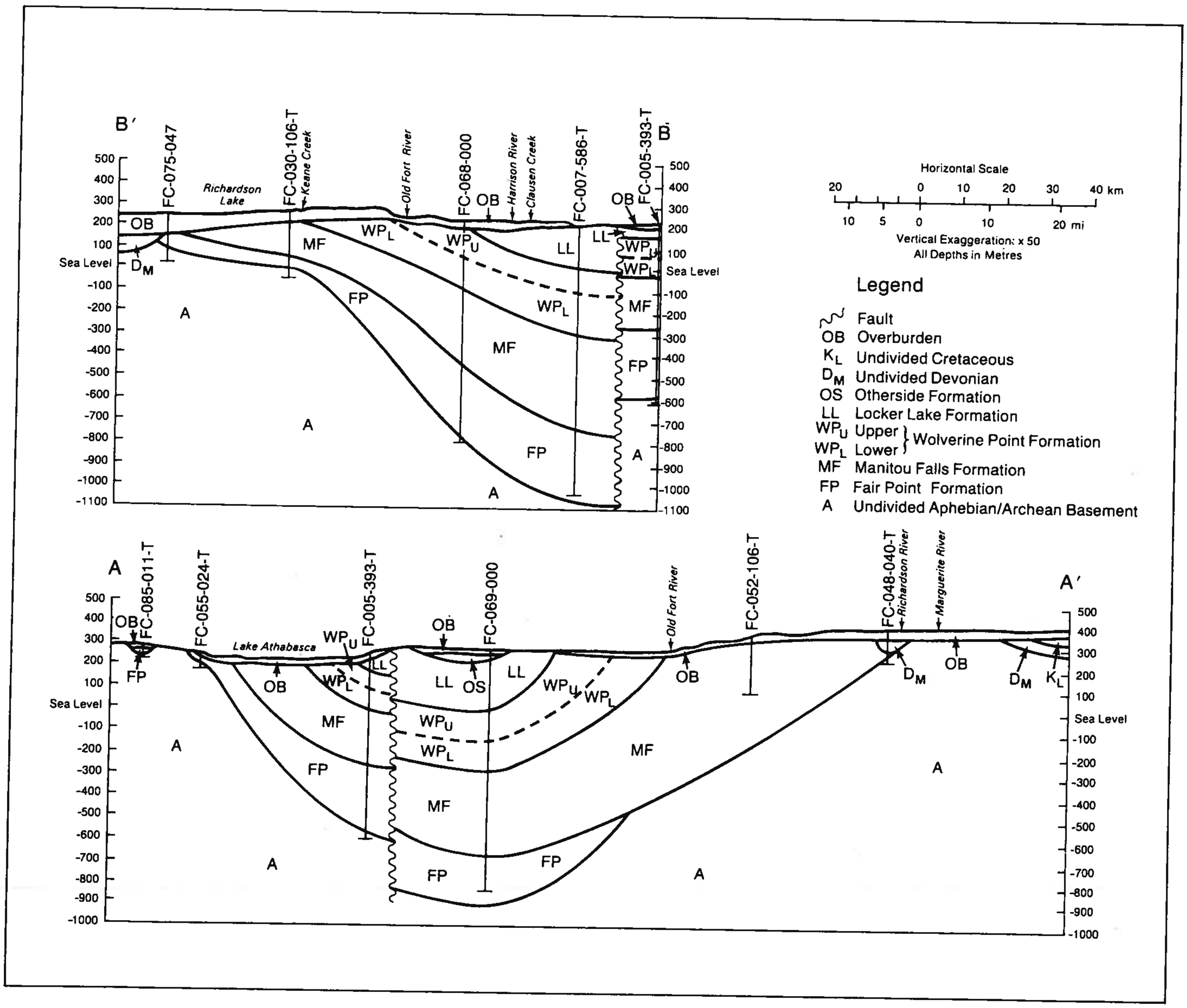

Figure 3. Cross sections through the Athabasca Group. A-A′ and B-B′ are marked on figure 2.

crystalline basement rock. All primary minerals within this weathered zone, with the exception of quartz, are in places replaced by clays, mainly kaolinite or chlorite. The regolith is similar to a present-day lateritic weathering profile (Macdonald, 1980).

Basement topography was a major control on Athabasca sedimentation in Alberta, at least in early Athabasca times. The main sub-Athabasca topographic feature is a broad trough oriented northeast to southwest, with its axis along the south shore of Lake Athabasca (the Jackfish sub-basin of Ramaekers, 1979a). Later in Athabasca times, at least one fault, probably oriented northwest to southeast, affected sedimentation between FC-007-536-T and FC-005-393-T (figures 2 and 3).

A basement high, the remnants of which are exposed in the Marguerite River area (Godfrey,1970; figure 2), may extend under the Athabasca Group to the northeast. This high was a major factor in controlling sedimentation at the southwest margin of the basin. The Marguerite River outcrops may be part of the Patterson high of Ramaekers (1979a).

Devonian carbonates are present west of the Athabasca Basin (figure 4, in pocket). In the southwest these rocks overlap the Athabasca Group with sharp unconformity. Cretaceous rocks are present to the southwest (figure 4), but they do not outcrop and no core has been recovered from them.

Stratigraphy

The stratigraphic nomenclature for the Athabasca Group rocks in Alberta is based on that established in Saskatchewan by Ramaekers (1979a, 1980a). Several cores throughout the Alberta portion of the basin are designated reference sections and are distinguished by the "T" at the end of the number. Appendix D presents lithologs for these cores; the cores are available for inspection at the Edmonton storage facility.

Descriptions of formations in core

The stratigraphy in Alberta is divisible into four formations (table 1), which are mappable in core. From the base, these are the Fair Point (FP), the Manitou Falls (MF), the Wolverine Point (WP), and the Locker Lake (LL). These formations are best seen in a thick, undisturbed sequence in core FC-005-393-T. Formations present in FC-005-393-T are described below from the basal unconformity to the top.

Fair Point Formation

The Fair Point Formation unconformably overlies a regolith-capped crystalline basement, and is overlain by the Manitou Falls Formation (figure 3). The formation, which is 318 m thick, consists predominantly of clay-rich, coarse-grained sandstone (figure 5), with minor medium- to fine-grained portions, scattered pebbles, and rare clast-supported conglomerates. The rare sedimentary structures are limited to low-angle cross-bedding. Bedding is nearly horizontal, on a metre rather than on a centimetre scale, and has gradational contacts.

The bulk of the formation (figure 6) is sandstone, composed of moderately to poorly sorted, subrounded to subangular quartz grains with poorly developed overgrowths, in a clay matrix. Hematite is present in variable amounts throughout the formation, with trace amounts of muscovite, carbonate and heavy minerals. The mean grain size of the sandstone is coarse and is constant throughout the formation (figure 5). Leisegang rings[1] are not well developed. The muscovite is found on bedding planes and increases in quantity with depth. Solution seams and stylolites are common in some sections, appearing in core as irregular clay seams containing concentrations of the heavy minerals. The quartz is intensely corroded in these seams, which may represent considerable thinning in places.

The interbedded medium- and fine-grained sections are rarely more than 1 m thick. Their contacts with the coarse sandstones are gradational over a few centimetres. These sections are not intensely hematite stained, are well sorted, and do not contain the pebbles typical of the rest of the formation. The mineralogy of the sandstones does not vary with the grain size.

Isolated pebbles are scattered throughout the formation, although they are more abundant towards its base. Pebbles are characteristically well rounded, and commonly exceed the drill core diameter (35 mm) in size. Most pebbles are quartz, although a small proportion of angular, regolithic fragments are present, especially toward the base of the formation. Recognizable fragments of fresh crystalline basement are rare. Pebble content increases close to the unconformity and conglomerates are formed locally.

Distinguishing features of the Fair Point Formation are the presence of scattered pebbles, the high clay content and the coarse mean grain size. The contact with the Manitou Falls Formation is marked by a sharp decrease of the mean grain size from coarse to medium (figure 5). Other characteristics of this contact are the disappearance of the large isolated pebbles, decrease in the clay content over a few metres and, in core FC-005-393-T, the presence of thin (up to 5 cm) hematite rich beds, which may represent paleosols.

Manitou Falls Formation

The Manitou Falls Formation, which is 250 m thick in hole FC-005-393-T, consists of medium- to fine-grained sandstone (figure 5) with scattered pebbles and locally, small-pebble conglomerates, interbedded with thin siltstones and shales. Sedimentary structures are much more pronounced than in the underlying Fair

[1]Bands of alternating bleached and hematite-stained rock related to oxidation-reduction fronts moving through the rock. They can be on a very fine scale and are unrelated to bedding.

Table 1. Generalized stratigraphy of the Athabasca Group in Alberta

Formation	Maximum Thickness (m)	Lithology
Otherside*	?	Not seen in outcrop or core in Alberta. In Saskatchewan is a well-sorted, fine-grained, cross-bedded sandstone with minor siltstone.
Locker Lake	>205	Pebbly sandstone, commonly massively bedded, cross-bedded, cemented by quartz overgrowths and clay. Pebbles rarely exceed 10 mm across. Variable proportions of kaolinite and illite.
		unconformity
upper member	117	Altered vitric and ash-flow tuffs interbedded and intermixed with medium-grained, clay-rich, friable sandstones. Common small (<5 mm) ovoid tuff intraclasts, patchy interstitial fluorapatite cement. Predominantly illitic with a significant chlorite content.
Wolverine Point		
lower member	178	Medium-grained sandstone, cross-bedded, cemented by quartz overgrowths and clay. Interbedded minor siltstone <1 m thick. Possible minor tuffaceous component. Predominantly illitic with minor chlorite and kaolinite.
Manitou Falls	457	Medium-grained, pebbly sandstone, cross-bedded, abundant irregular clay intraclasts (<10 mm) especially near the top. Pebbles rarely exceed 15 mm and are more common towards the base, cemented by quartz overgrowths. Kaolinite with minor illite at base but illite increases towards the top. To the south of the basin pebbles increase in both size and number and the clay becomes predominantly illite with only a trace of kaolinite.
		possible depositional hiatus
Fair Point	360	Coarse-grained sandstone, clay rich, pebbly, conglomeratic at base, minor cross-bedding. Pebbles commonly in excess of 35 mm and composed of quartz, basement and regolith. Kaolinitic with a trace illite.
		unconformity

Both the Fair Point Formation and parts of the Manitou Falls Formation lie directly upon a pre-Athabasca soil formed on the Archean and Aphebian crystalline basement.

*From Ramaekers (1979a, 1980a).

Point Formation. Centimetre-scale bedding and graded bedding are common, with the base of the graded bed commonly cutting into the top of the underlying bed. Small-scale trough and planar cross-bedding are common. Large (up to 5 cm) irregular clay intraclasts are common.

The sandstone forming the bulk of this unit (figure 7) consists of moderate to well sorted, subrounded quartz grains cemented by quartz overgrowths, with minor interstitial clay. Minor to trace amounts of hematite, muscovite, carbonate and heavy minerals are present.

The mean grain size of the sandstone is commonly medium-grained, although it varies throughout the formation (figure 5). Upward fining sequences 2 to 3 m thick grade from very coarse-grained to siltstone. The quartz grains commonly show well-developed overgrowths, which impart an induration to some sections of this unit that is uncommon elsewhere. Hematite staining varies throughout this formation, and leisegang rings are common (figure 8). Muscovite is common only in the solution seams, which are abundant in places and crisscross the core at low angles to the bedding. Solution seams reach a thickness of 1 cm and can be mistaken for bedding. Clay intraclasts are scattered throughout the formation, but are more common toward the top.

The small-pebble conglomerates are present in beds a few centimetres thick, or as single pebble horizons. These conglomerates are more prevalent toward the base of the formation, but are not areally extensive. Pebbles, isolated or in conglomerates, rarely exceed 10 to 15 mm in diameter and are composed of quartz.

Clay and siltstone beds are rarely thicker than a few centimetres and may exhibit gradational contacts with the surrounding sandstones. The beds show no internal structure.

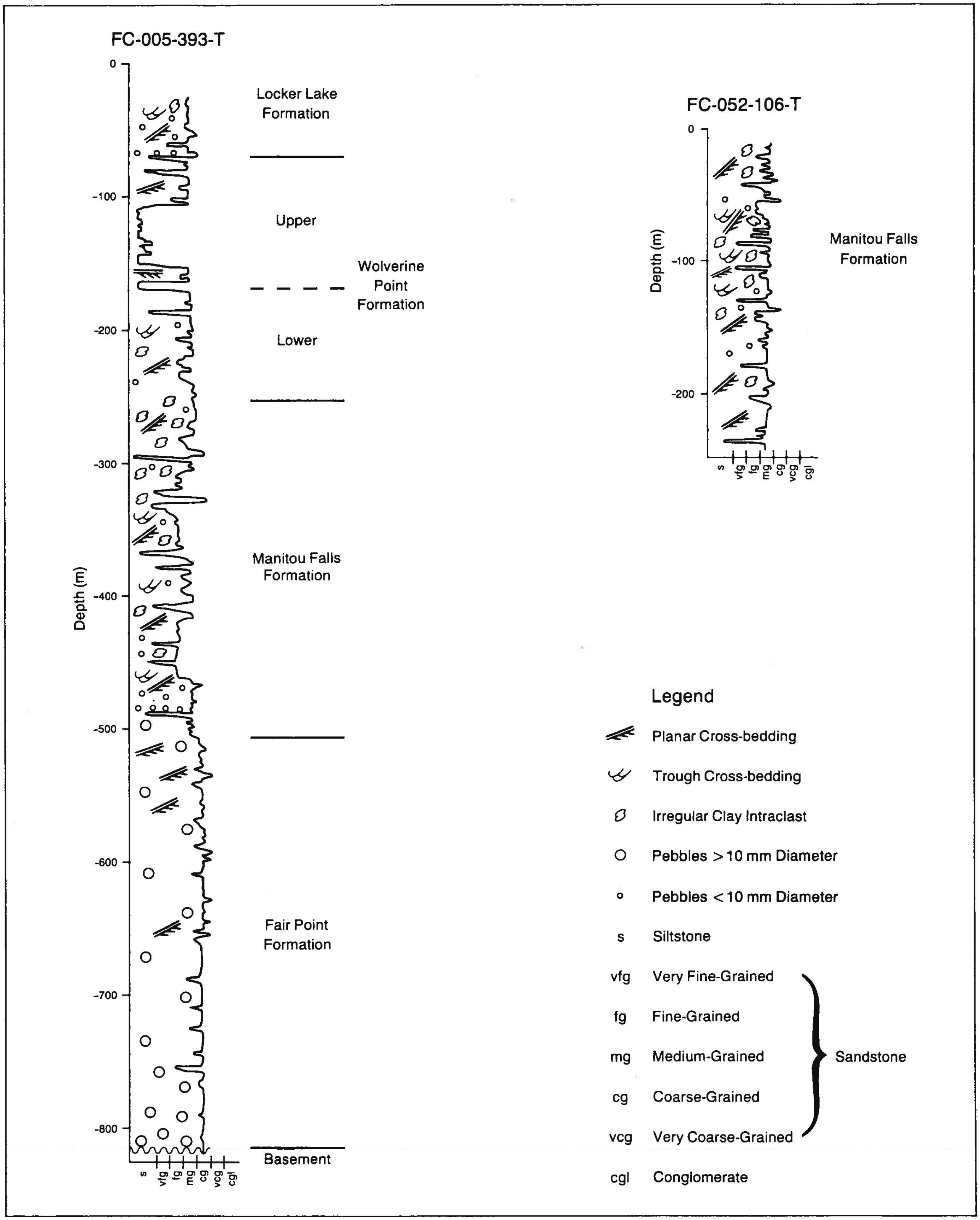

Figure 5. Schematic plot of the mean grain size for cores FC-005-393-T and FC-052-106-T. Measurements were taken at 1 m intervals.

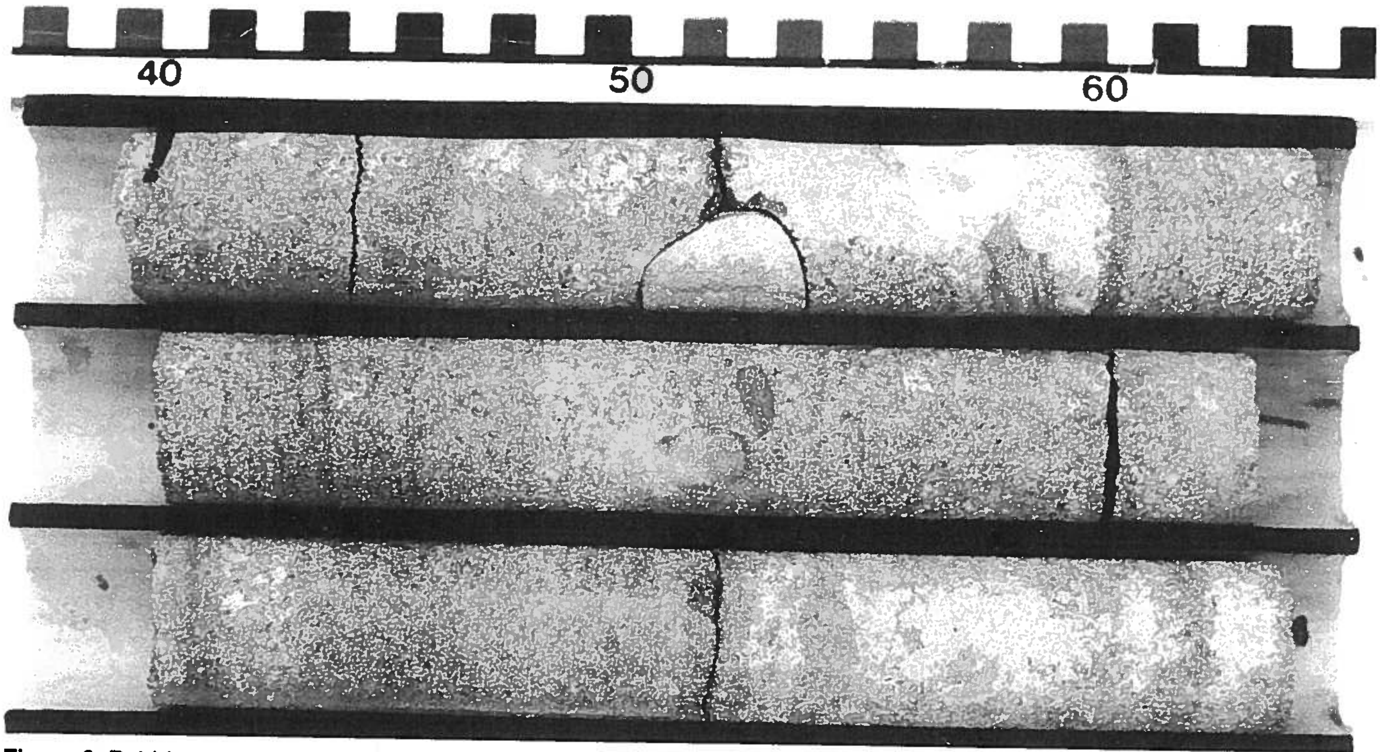

Figure 6. Pebbly sandstone, typical of the Fair Point Formation. The scale is in centimetres. The top of the core is to the right.

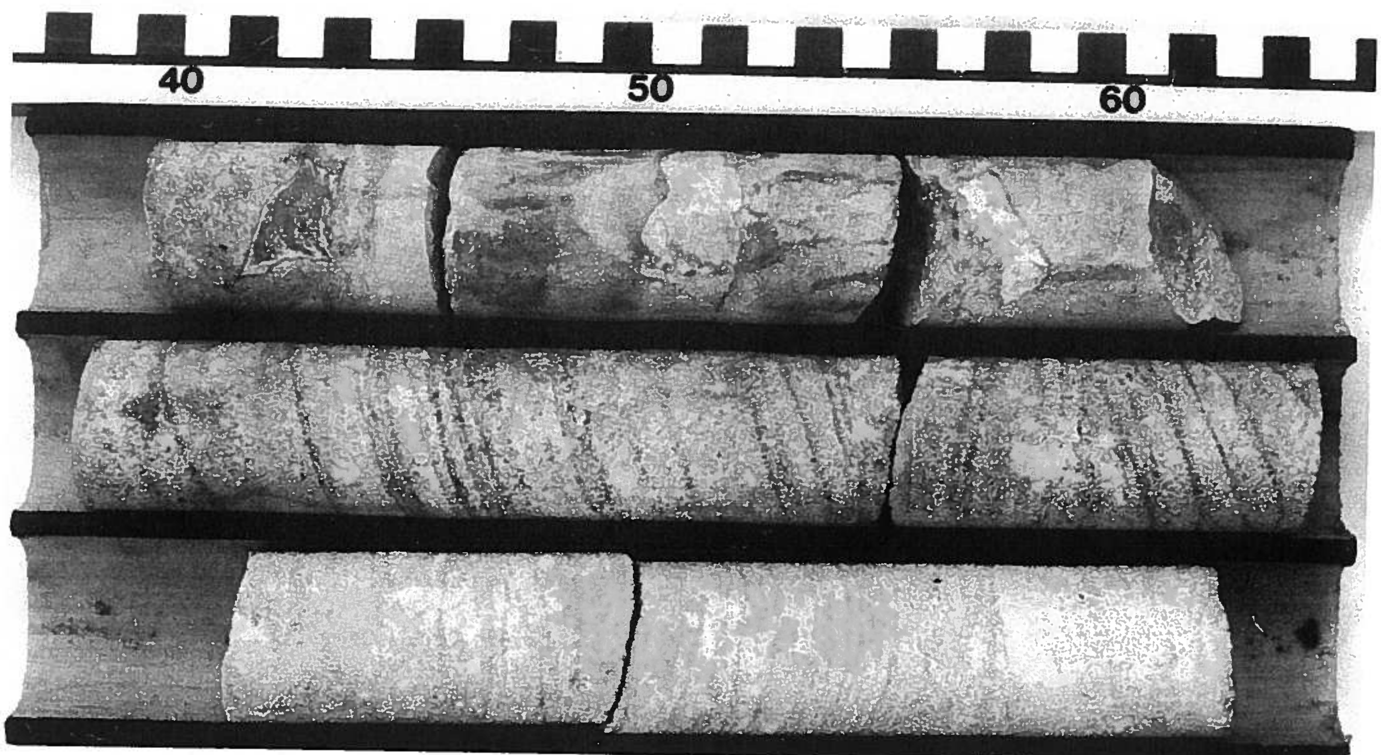

Figure 7. Medium-grained, cross-bedded, intraclast-rich sandstone, typical of the Manitou Falls Formation. The scale is in centimetres. The top of the core is to the right.

The Manitou Falls Formation has a smaller mean grain size, smaller pebbles and less interstitial clay than the Fair Point Formation; it also lacks the thick siltstones of the upper member of the Wolverine Point Formation. The contact with the Wolverine Point is taken where the siltstone and shale beds of the lower member appear; specifically, it is taken at the top of the clay intraclast rich zone.

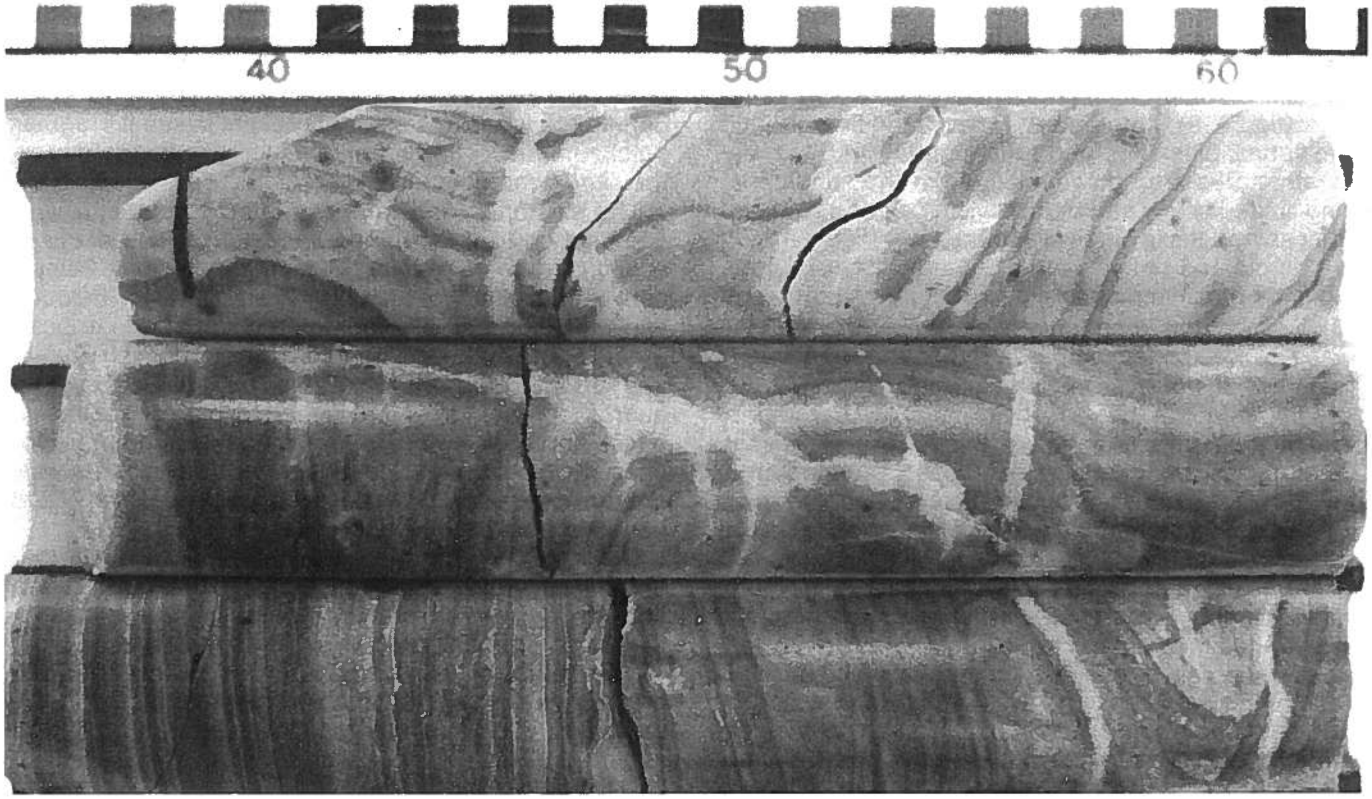

Figure 8. Leisegang rings in the Manitou Falls Formation. Note later bleaching along fractures. The scale is in centimetres. The top of the core is to the right.

South of FC-005-393-T, the character of the Manitou Falls Formation changes. Pebbly sandstones and conglomerates are more common rock types within the formation and the pebbles increase in size to a maximum of 20 mm. Interbedded with the sandstone are deep red, pebbly, laterally restricted siltstones and shales. These distinctive rock types are present only toward the southern edge of the basin, near the base of the Manitou Falls and Fair Point Formations.

Wolverine Point Formation

The Wolverine Point Formation, 184 m thick,is divided informally into a lower and an upper member, equivalent respectively to the Wolverine Point A and B of Ramaekers (1980a). Both units are characterized by a higher proportion of fine-grained beds than the surrounding formations; the upper member more so than the lower member. The units are described separately.

Lower member

The lower member of the Wolverine Point Formation is 84 m thick. Contacts with the Manitou Falls Formation are gradational (figure 3). The lower member consists of medium- to fine-grained sandstone, with interbeds of siltstone and shale less than 1 m thick (figure 5). Sedimentary structures are not well-developed, although some trough and planar cross-bedding is present in the sandstones and micro-slump and flame structures are present in the siltstones and shales.

The sandstone forming most of this unit comprises moderately to well sorted, subrounded to rounded quartz grains, cemented by quartz overgrowths and clay. Minor to trace amounts of hematite, muscovite, biotite, chlorite and heavy minerals are present.

The sandstones are similar to those of the underlying Manitou Falls Formation, grading from very fine-grained to coarse-grained, with rare pebbles up to 5 mm in diameter. The chlorite content, although low, distinguishes the clays of this unit from those below. Well-developed leisegang rings or a strongly mottled or speckled effect is the result of hematite staining. Muscovite is present on bedding planes, associated with shale beds and with solution seams. Biotite is rarely present in the siltstones or very fine-grained sandstones.

The siltstones and shales form less than five percent of the unit and are present as discrete beds, commonly highlighted by a deep red or purple stain. Contacts with the surrounding sandstones are either sharp, or gradational over a short distance. Small (up to 5 mm) cigar-shaped intraclasts are present, although not in the quantities observed in the upper member. The fine-grained beds decrease in thickness and frequency downward as the Manitou Falls Formation contact is approached. The top of the lower member is a marked change in the character of the formation. Within the upper member, fine-grained beds increase dramatically in thickness and number, and the clay content of the sandstone increases, giving the rock a very friable texture.

Upper member

The upper member of the Wolverine Point Formation, 100 m thick, is overlain unconformably by the Locker Lake Formation (figure 3). This member consists of clay-rich, medium- to fine-grained, pebble-free sandstone (figure 9), with interbedded very fine-grained sandstones, siltstones and tuffs (figure 10). Sedimentary structures are not well-defined in the sandstone, being limited to low and high angle cross-beds defined in places by lines of small clay intraclasts (figure 10). In the fine-grained units, beds of rip-up-clasts are common and both slump and flame structures are present.

The sandstone is commonly extremely friable, consisting of well-sorted, subrounded to rounded quartz grains with minor overgrowths, in a matrix of clay. Accessory amounts of muscovite, biotite, carbonate, hematite, chlorite and heavy minerals are present. Generally, as the grain size decreases, the amount of clay decreases and quartz overgrowths become more significant as a cementing agent, making the rock less friable.

The mean grain size of the sandstone is medium-grained or finer (figure 5), with a gradation from the medium- to fine-grained sandstone down through very fine-grained sandstone to siltstones and shales. This gradation, however, occurs over such a short distance, and the finer-grained units exhibit such a different character, that they are considered separately. No pebbles occur in this unit. The friable sandstone is commonly creamy white with very irregular patches of hematite staining, giving the core a mottled or speckled appearance (figure 9). The clay intraclasts in the upper member are unlike those of the Manitou Falls Formation. Upper member intraclasts are mostly smaller, ovoid, and occur in clusters or on bedding planes. A few large, irregular intraclasts are also present. The carbonate is a late stage cement present in small irregular patches. Muscovite and biotite increase in quantity as the sandstone becomes finer.

The siltstones and tuffs are interbedded with very fine-grained to fine-grained sandstones, and occur in sections up to 46 m thick. Tuffs comprise over 20 percent of the volume of the upper member. The siltstones and tuffs are generally mottled reddish purple to pale green (figure 10), depending on the amount of hematite and chlorite present. Mineralogically, they consist of quartz, clay, chlorite and minor to trace amounts of biotite, muscovite, apatite, carbonate, hematite and, possibly, glauconite. The tuffaceous nature of the fine-grained beds can only be seen in thin section, and hence will be discussed later.

Distinguishing characteristics of the upper member of the Wolverine Point Formation are the high proportion of fine-grained beds, the mottled hematite staining, the common presence of ovoid intraclasts, and the friable nature of the sandstone. The top of the upper member is defined by the erosional contact with the pebble-rich Locker Lake Formation (figure 11).

Locker Lake Formation

The Locker Lake Formation forms the top of the succession in FC-005-393-T where it is 41.5 m thick (figure 3); it consists of medium-grained sandstone (figure 11), with

Figure 9. Hematite stained, friable sandstone of the upper member of the Wolverine Point Formation. The scale is in centimetres. The top of the core is to the right.

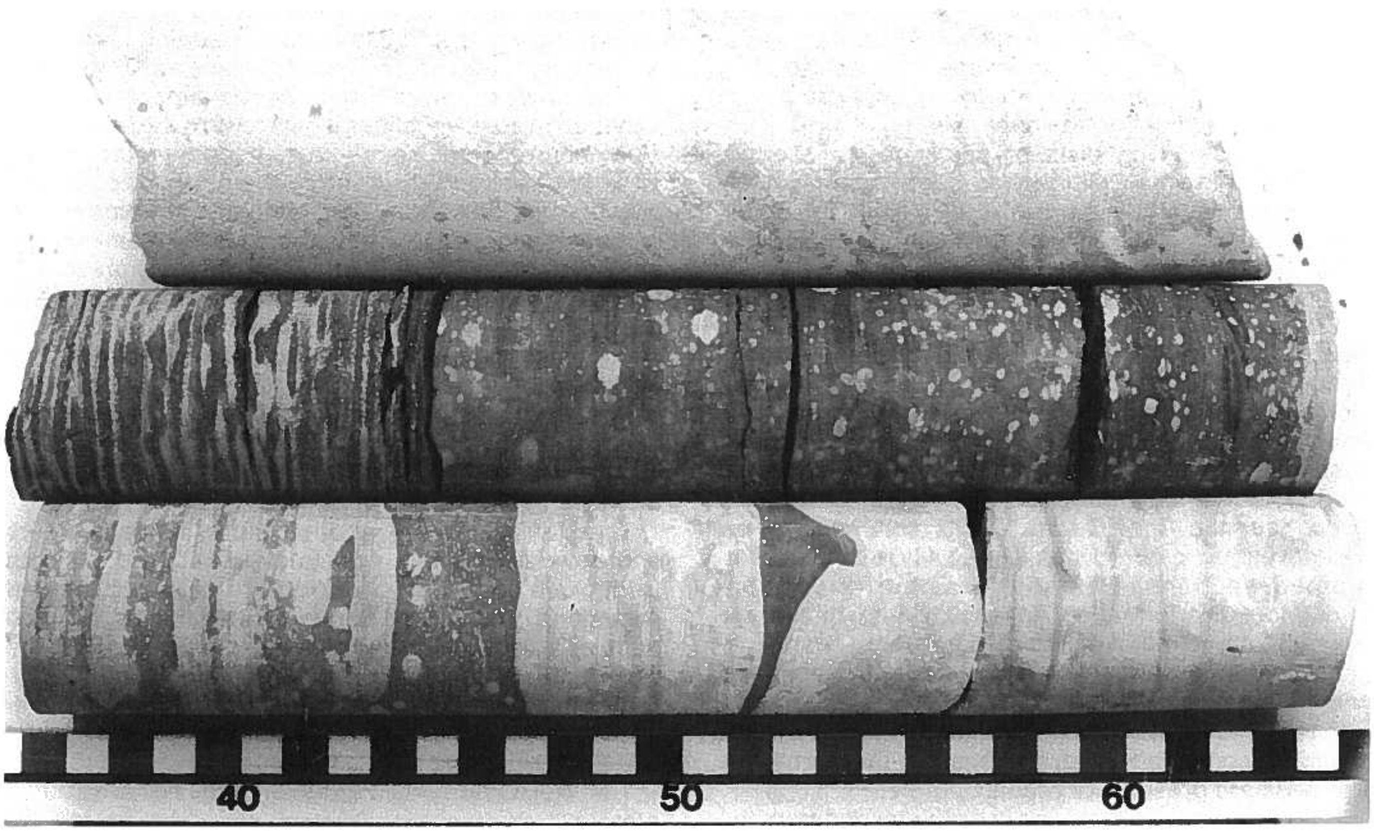

Figure 10. Hematite stained tuffs, and cross-bedding outlined by ovoid intraclasts in the upper member of the Wolverine Point Formation. The scale is in centimetres. The top of the core is to the right.

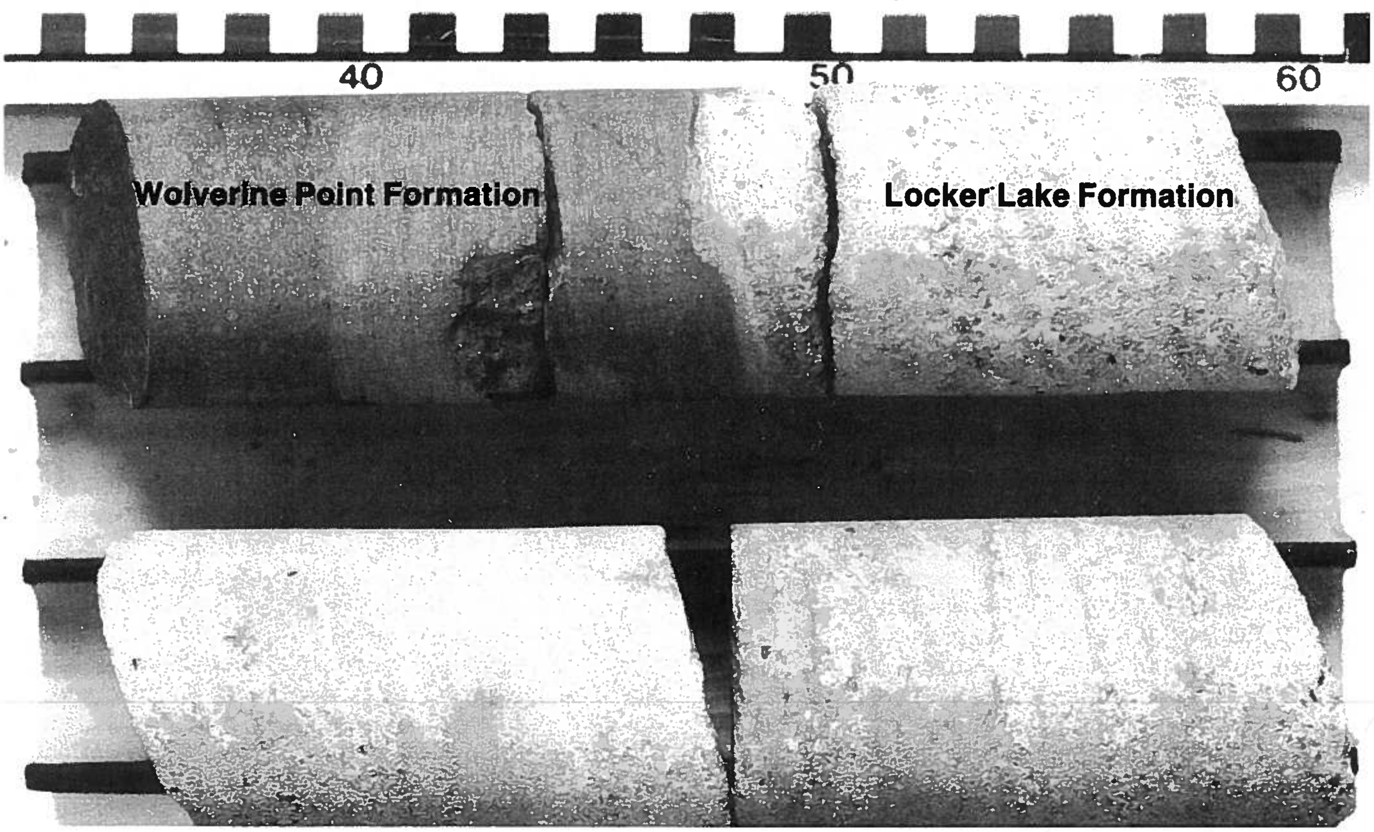

Figure 11. Erosional contact between the Wolverine Point Formation and the Locker Lake Formation. The scale is in centimetres. The top of the core is to the right.

scattered pebbles and local conglomerates, interbedded with thin siltstones and shales. Sedimentary structures are confined to well-developed graded bedding and some trough and planar cross-bedding. Bedding is nearly perpendicular to the core axis.

The sandstone consists of poorly to well sorted, subrounded to very well rounded quartz grains locally cemented by quartz overgrowths, with some interstitial clay. Accessory minerals include hematite, muscovite, chlorite, biotite and heavy minerals.

The sandstone is dominantly medium-grained (figure 5). Only rarely is it fine-grained, or very coarse-grained. Pebbles up to 10 mm in diameter are scattered throughout the formation. Locally, pebbles form conglomerate beds that grade upward into sandstones. Pebbles are commonly quartz, although regolith and basement as well as sandstone clasts are present, and irregular, large clay intraclasts are scattered sparsely throughout the unit. Quartz grains commonly show well-developed overgrowths, especially in the coarser-grained sections. Hematite staining is variable throughout the formation. Muscovite and biotite are common only in the fine-grained sandstones. Pyrite occurs in patches, sometimes associated with fracturing, and bitumen staining is present.

Siltstone and shale beds, rarely more than 5 cm thick, are more common toward the base of the formation. The beds are greenish or reddish purple.

The Locker Lake Formation is distinguished from the Wolverine Point Formation by the presence of pebble beds and the absence of fine-grained units. Distinguishing the Locker Lake from the Manitou Falls Formation is difficult.

Outcrops of the Athabasca Group in Alberta

Outcrops of the Athabasca Group in Alberta are scarce and found only north of township 110 (figure 4). The remainder of the basin is covered by overburden, locally more than 90 m thick. Three formations described in the Stratigraphy section are present in several localities north and south of Lake Athabasca (figure 4).

The Fair Point Formation crops out only on the north shore of Lake Athabasca (figure 4). At several points between Fort Chipewyan and Sand Point the shoreline consists of large blocks of Athabasca Group, predominantly the Fair Point Formation. Although the sandstone is not in situ at any of these locations, the Fair Point Formation lies near the surface. The small island between Shelter Point and Point Basse is also composed mainly of Fair Point Formation boulders. Many Fair Point Formation boulders and a few outcrops are found near Grey Willow and Fallingsand Points.

At Fidler Point, an area of approximately 1.5 km by 200 m is underlain by Fair Point Formation and contains numerous outcrops (figure 4). The outcrop area runs northwest to southeast on the sheltered southwest side of the point and disappears under the lake to the southwest. The Fair Point Formation outcrop is very similar to its core, a coarse-grained, pebbly to conglomeratic sandstone with a clay matrix. Exposure at the surface has, in some cases, altered the color of the rock and given it a friable texture. Bedding at the outcrop is very irregular, and generally dips at 30° to 50° to the southwest, away from the basement outcrop, although at some localities it dips toward the basement. One occurrence of trough cross-bedding indicated an apparent transport direction to the north. The contact between the Fair Point Formation and the underlying regolith is exposed to the southeast of the main outcrop of sandstone at Fidler Point. The contact is present at lake level on a continuation of the presumed contact at the main outcrop. The contact is not faulted (figure 12) and dips at 55° to the southwest. The sandstone contains scattered pebbles, but has no basal conglomerate. The regolith is an intensely weathered zone extending from the unconformity downward for 10 m into the basement. The weathered zone is present in all the basement rock types.

The Manitou Falls Formation is present as boulders and several flat-lying, frost-heaved outcrops on both Burntwood and Bustard Islands. The medium-grained sandstone is cemented by quartz overgrowths. Isolated pebbles up to 7 mm across are scattered through the sandstone, and minor pebble beds are found locally. Ripple marks, cross-bedding on a scale of approximately 30 cm, sole markings, and slumped and disturbed bedding are present.

The Wolverine Point Formation does not crop out in Alberta.

The Locker Lake Formation crops out more extensively than any other of the Athabasca Group formations. Most notably it is exposed in an arc north of Stone Point that runs north and then northeast to the north end of Lillabo Lake on the Alberta-Saskatchewan border (figure 4). Outcrops within this area typically occur as low glaciated whalebacks covered with lichen. The exception is a low terraced ridge running parallel to the lake shore from northeast of Stone Point to just east of Point Brule. The ridge has a relief of almost 30 m in places and exposes bedrock for much of its length. The outcrop consists of medium- to fine-grained pebbly sandstone, with scattered small pebbles (up to 10 mm in diameter) and small-pebble conglomerates, and is generally coarsest at the base. Bedding in both the ridge and the whaleback outcrops is nearly flat-lying with the impression of a slight dip to the southeast. Sedimentary structures consist of graded bedding, ripple marks, megaripples (figure 13) and rare trough cross-bedding. Overturned cross-bedding (figure 14) and a small cut-and-fill channel (figure 15) were also noted. The sandstone is predominantly quartz-overgrowth cemented, and in places has clay intraclasts.

The other area of Locker Lake Formation outcrop is north of an unnamed lake on the Alberta-Saskatchewan border due east of Old Fort Bay (figure 4). The outcrop is made up of several isolated whalebacks, some reaching a height of 6 metres. The sandstone, which is reddish, except at ground level where it is bleached, consists of medium- to fine-grained, quartz overgrowth-cemented, pebbly sandstone, with minor thin, small-pebble (up to 10 mm) conglomerates. Bedding is in-

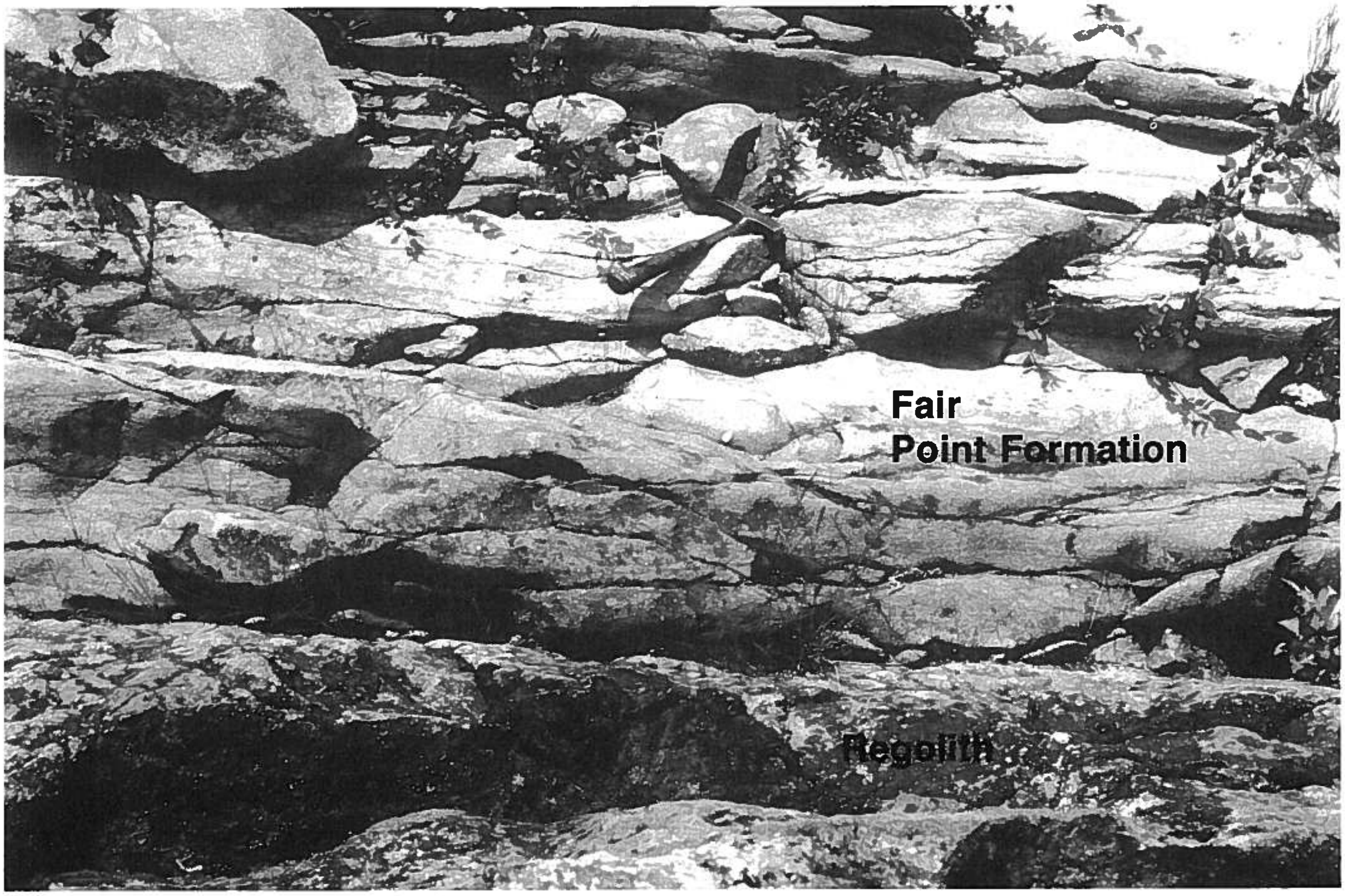

Figure 12. Contact between the Fair Point Formation and the underlying regolith at Fidler Point.

distinct, and dipping 5° to 10° to the northeast. Ripple cross-lamination and trough cross-bedding are more common here than in the outcrop area to the north. The few measurable cross-beds found indicate sediment transport to the west. Three joint planes strike at 035°/ dip 75° northwest; 100°/dip 70° southwest; and 085°/ dip 90°. Most outcrops and erratics at this location have marked wind-polished surfaces, indicating sand-laden winds blowing predominantly from the southeast. This wind polish probably occurred soon after deglaciation, before plant cover became extensive (Tremblay, 1961).

Bedrock geology interpretation

General drill hole data are given in appendix A. Elevations and formation tops are given in appendix B. The subcrop of the Athabasca Group formations beneath the Quaternary in Alberta is shown in figure 2.

The Fair Point Formation subcrops in a belt parallel to the north shore of Lake Athabasca, and near drill holes FC-072-040-T, FC-071-071-T, FC-027-101-T and FC-033-068-T (figure 4). Southeast of FC-039-092-T, the Fair Point is absent and the Manitou Falls Formation lies directly on the regolith. The Fair Point Formation also pinches out in Saskatchewan, just south of the Crackingstone Peninsula. A line can thus be drawn from the Crackingstone Peninsula through a point between FC-033-068-T and FC-039-092-T, and probably with a distinct curve to the east or southeast, that would define the extent of the Fair Point Formation. This early basin may have been fault controlled. Outliers are present to the northwest of the Fair Point sub-basin and may occur beneath the Manitou Falls Formation to the southeast. The local presence of paleosols at the Fair Point/Manitou Falls contact suggests a hiatus between the deposition of the two formations.

The Manitou Falls Formation subcrops over large areas in the southern part of the Athabasca Basin (figure 2), and underlies Lake Athabasca to the north. The formation cannot be subdivided into a, b, c and d units as Ramaekers (1980a) has done in Saskatchewan. As outlined in the Stratigraphy section, the lithologic character of the Manitou Falls Formation changes between FC-005-393-T and FC-052-106-T. In the southern part of the basin, the Manitou Falls Formation lies directly on the weathered crystalline basement and is close to a source area to the south. To the north, the formation lies on the Fair Point Formation and probably incorporates some reworked material from that formation. The Lazenby Lake Formation, a pebbly sandstone mapped in the south of the basin in Saskatchewan (Ramaekers, 1980a) between the Manitou Falls and Wolverine Point Formations (figure 16), is not present in Alberta. This formation may be a lateral facies variation of the Manitou Falls.

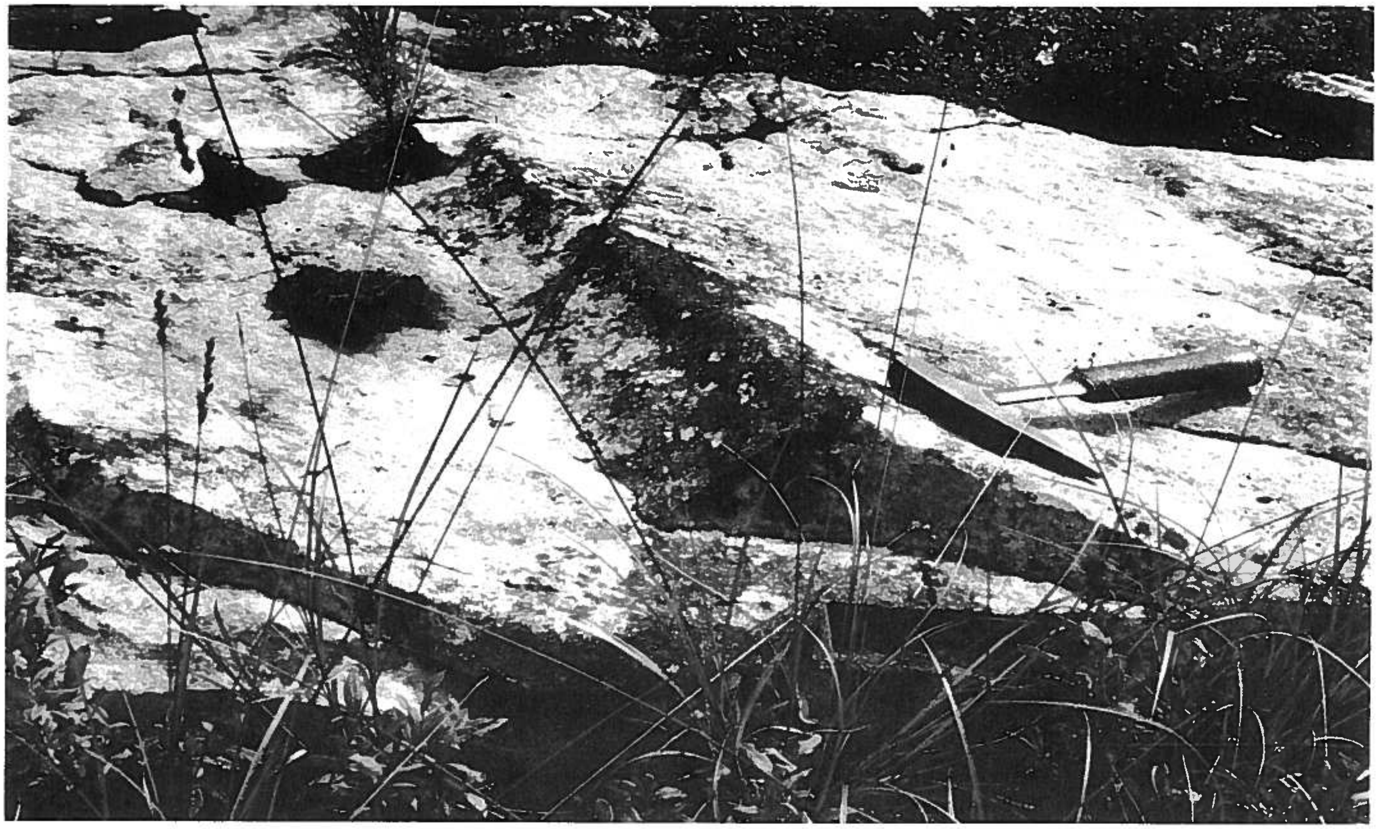

Figure 13. Megaripples in the Locker Lake Formation.Current direction from right to left.

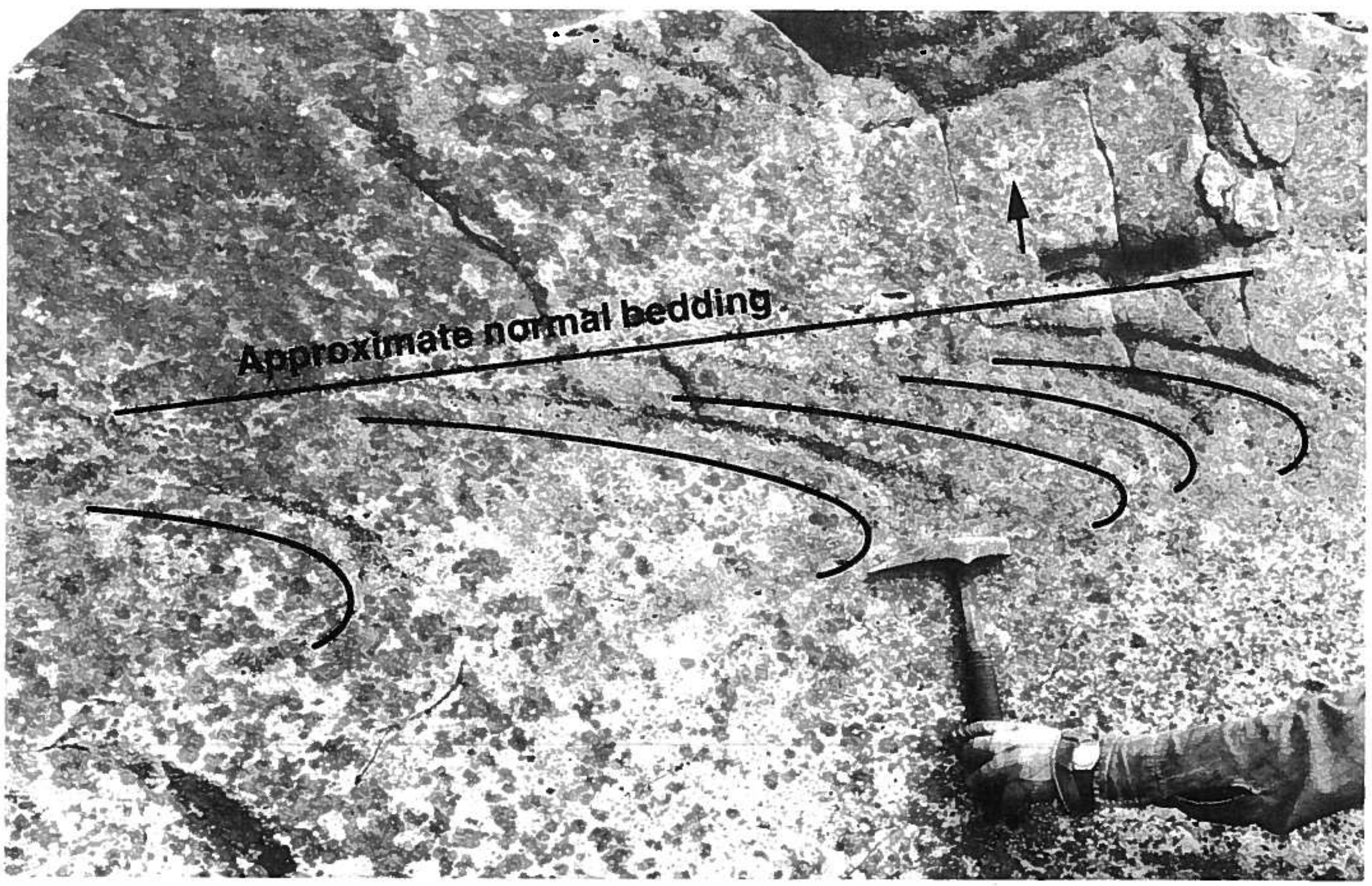

Figure 14. Overturned cross-bedding in the Locker Lake Formation.

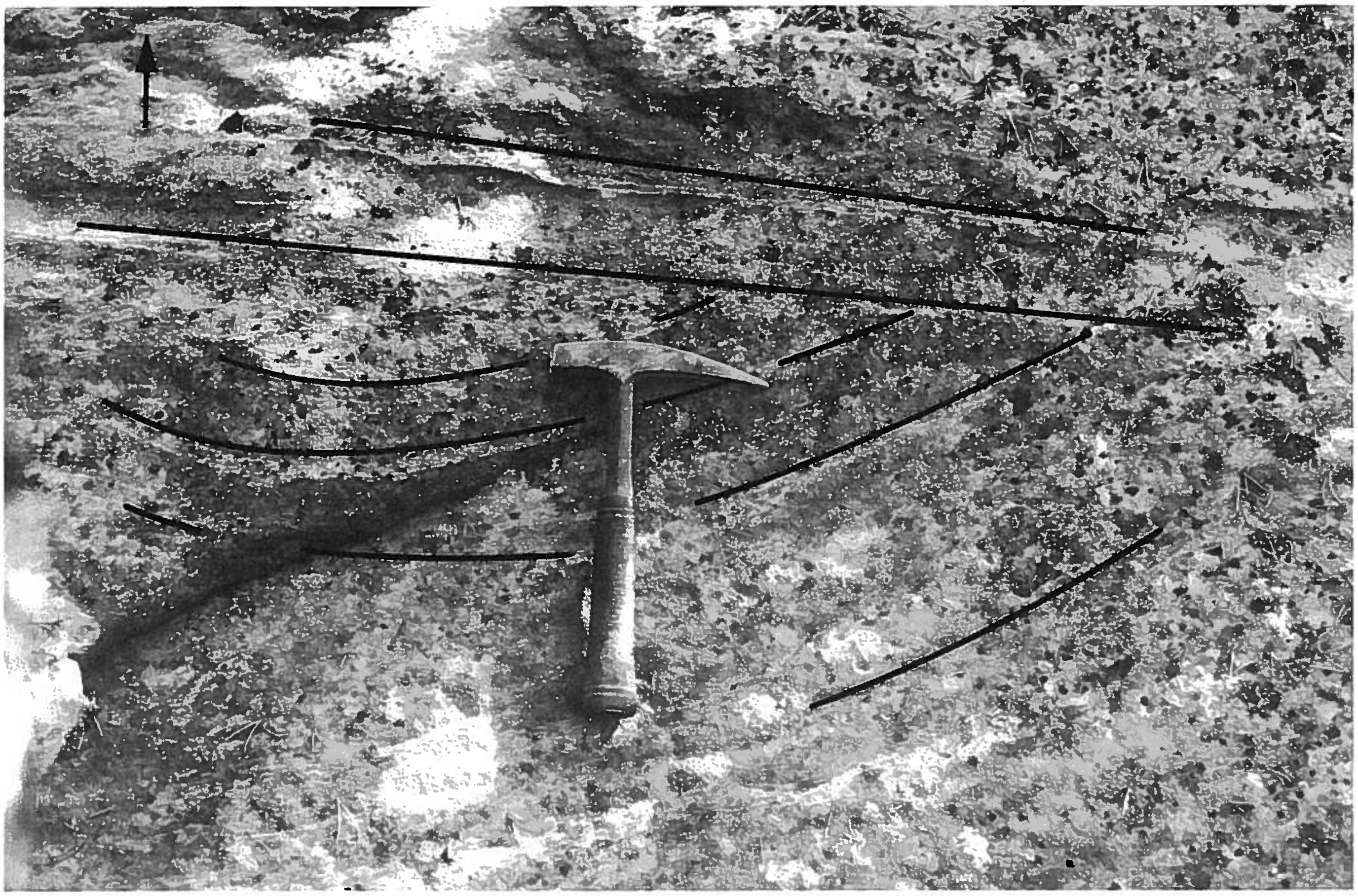

Figure 15. Small cut-and-fill channel in the Locker Lake Formation.

The Wolverine Point Formation does not crop out in Alberta and is present only in cores from FC-005-393-T, FC-007-586-T and surrounding holes. The presence of this formation is inferred from company logs of FC-068-000 and FC-069-000 (although the actual core from these holes was lost in a brush fire). This inferred subcrop forms an arc below the southern part of Lake Athabasca (figure 4) and swings around beneath Old Fort Bay and back into Saskatchewan at townships 109 and 110. The interpreted fault affecting the Manitou Falls Formation between FC-005-393-T and FC-007-586-T (figure 4) may still have been active during the deposition of the Wolverine Point Formation.

The Locker Lake Formation is present in FC-005-393-T and FC-007-586-T and is inferred in FC-069-000. This formation, which is present in outcrop and subcrop along the southern shore of Lake Athabasca, swings around north of Old Fort Bay and into Saskatchewan at township 111 (figure 4). The pattern of Locker Lake Formation subcrop and the thickness of the Wolverine Point Formation suggests that, by Locker Lake times, the axis of the basin had swung to a much more easterly direction than that of the Fair Point subbasin.

Overlying the Locker Lake Formation, and inferred at the top of FC-069-000, is the Otherside Formation. In Saskatchewan the formation is composed of well-sorted, medium- to fine-grained sandstone with minor interbedded siltstones (Ramaekers, 1979a). Since the Otherside Formation is not seen in core or outcrop in Alberta, its presence can only be inferred (figure 4).

Faulting of Athabasca and post-Athabasca age may be much more extensive than is shown on figure 4. One fault, active during deposition of the Manitou Falls Formation, occurs between FC-005-393-T and FC-007-586-T (figure 4). This fault is the cause of thickening of the Manitou Falls and later formations from FC-005-393-T to FC-007-586-T (figure 3). The trend of the fault is probably west-northwest/east-southeast.

The extensive fracturing found in the Manitou Falls Formation in FC-007-586-T may relate to other faulting. The fracturing dips steeply, has sulfide mineralization associated with it and shows little evidence of movement. Fracturing in some holes to the south may also indicate proximity to faulting. Mineral assessment reports for exploration permits on the southern edge of the basin (McWilliams and Cool, 1979; Fortuna, 1979) illustrate the problems involved in attempting to detect bedrock faults through a thick overburden. Geophysical work carried out as part of uranium exploration (Fortuna, 1979), however, suggests the presence of pre-Athabasca Group faults in the basement along Richardson River and possibly Maybelle River.

Interpretation of the Athabasca Group stratigraphy in Alberta correlates moderately well with the published information for Saskatchewan. As mentioned above, the Lazenby Lake Formation is not a mappable unit in

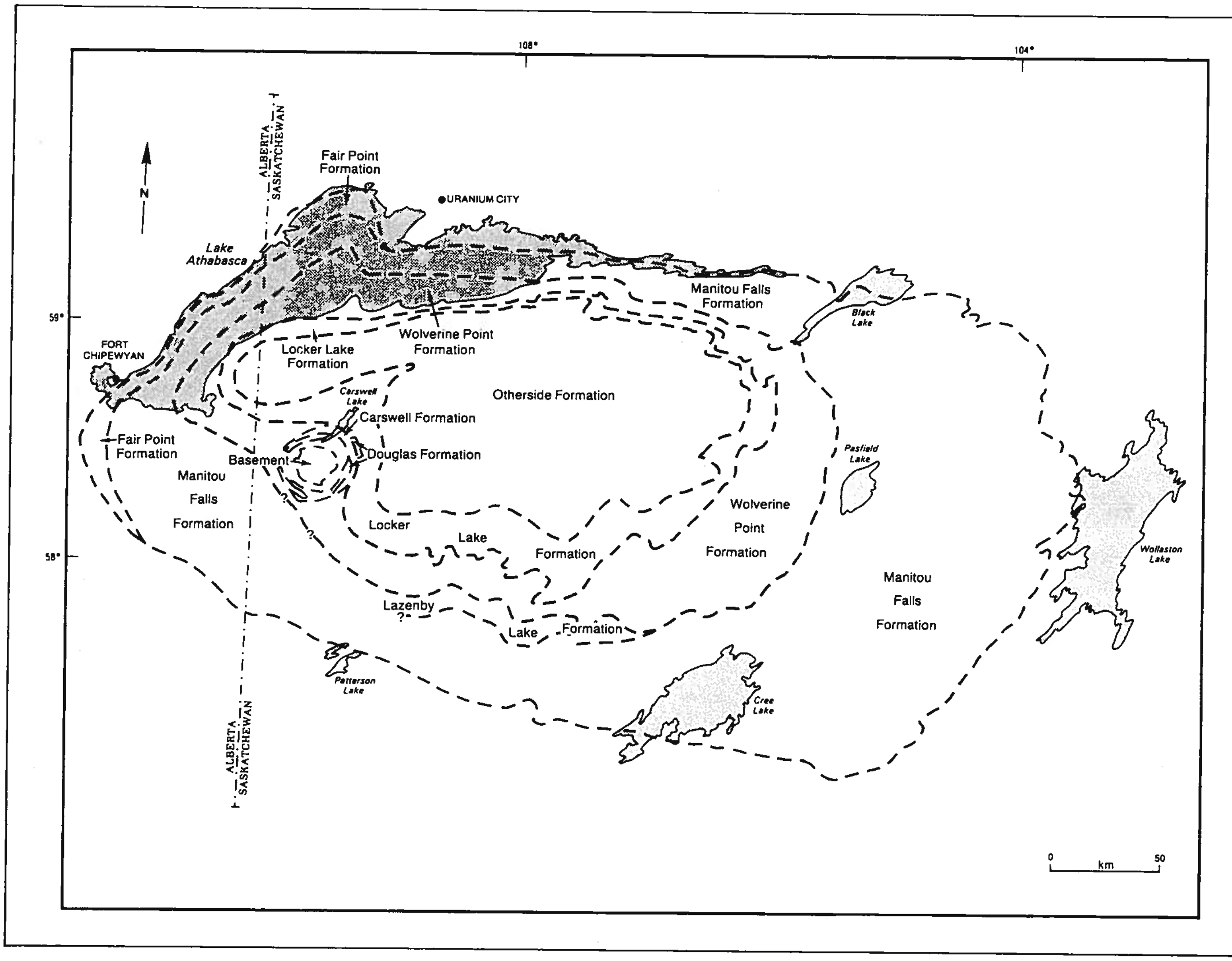

Figure 16. Geological map of the Athabasca Group in Saskatchewan (after Ramaekers 1979a, 1980a, modified from this work).

Alberta. The extension of the Manitou Falls Formation into the southwestern part of the Saskatchewan basin is also problematical. Because the formation extends as far north as Brander Lake in Alberta, the area south of the Carswell structure is probably also underlain by Manitou Falls Formation (figure 16).

In Alberta the outcrop due east of the north end of Old Fort Bay is ascribed to the Locker Lake Formation; in Saskatchewan it is considered the Tuma Lake Formation (Ramaekers, 1980a). The Tuma Lake Formation is a poorly exposed, pebble-rich sandstone, very similar in appearance to the Locker Lake Formation and overlying the Otherside Formation in Saskatchewan (Ramaekers, 1979a, 1980a). The formation is found around and to the north and northeast of the Carswell circular structure (Ramaekers, 1980a). Company logs from FC-068-000 indicate that the top of the succession in this hole is high in the Wolverine Point Formation, which makes the presence of the Tuma Lake Formation in Alberta unlikely. The top of the succession in FC-069-000 appears to be either high in the Locker Lake Formation or low in the Otherside Formation (figures 3 and 4), which, combined with the apparent shallow northeasterly dip of the bedding in the outcrops east of Old Fort Bay, strongly suggests that the outcrop is Locker Lake Formation.

If this interpretation is correct, the Locker Lake Formation probably swings around to the north and east of the Carswell structure (figure 16), making the Tuma Lake Formation much less extensive than previously thought.

Petrography

Sampling and procedures

For this study, 351 thin sections of samples from the Athabasca Group (appendix C) were examined microscopically. This work was augmented by x-ray diffraction (XRD), x-ray fluorescence (XRF) and scanning electron microscope (SEM) study. The thin sections, which are stored in the Edmonton core storage facility, are available on request.[2] The classification of the sandstones in each formation is based on point counts presented in appendix E. The classification scheme is taken from Pettijohn *et al.* (1972).

The petrography of each formation of the Athabasca Group is described below. Table 2 contains a summary of the main petrographic characteristics of each formation.

Fair Point Formation

Of the 87 thin sections from this formation examined, 74 were of sandstone, pebbly sandstone, or conglomerate; the remainder were entirely or predominately of siltstone or shale.

Sandstone

The sandstone in this formation is classified as lithic greywacke (appendix E). Sorting is poor although, where the mean grain size decreases to fine- or very fine-grained, the rock is well-sorted. Quartz grains in the sand size range are subangular to subrounded. Silt-sized grains are angular and pebbles rounded. The high clay content characterizes the sandstone of this formation as immature.[3]

Quartz - Quartz grains comprise an average of 45 percent by volume of the sandstone in this formation. The grains commonly show boehm lamellae[4] and strain extinction, and contain inclusions. Inclusions are small and composed of vacuoles, needles or minute flecks of mica. Some inclusions, however, may reach 0.5 mm across; these are predominately of muscovite or biotite or, rarely, feldspar. Authigenic overgrowths on the quartz grains are rarely well developed and account for less than 10 percent of the rock by volume (appendix E). Where quartz grains are in contact with recognizable clay intraclasts or shale beds, the side in contact with the clay has no overgrowth, whereas the other may have well-developed overgrowths (figure 17). Overgrowths also form where quartz grains come into close contact with each other to form a meniscus fabric (Scholle, 1979).

Evidence of quartz solution is present as stylolites, microstylolites and solution seams.[5] Microstylolites predominate and, in some cases, form a complex network throughout the rock so that they surround each quartz grain. Well-developed solution seams are not as common as in some overlying formations. Where they are present, however, they contain a concentration of muscovite, highly birefringent clay and heavy minerals.

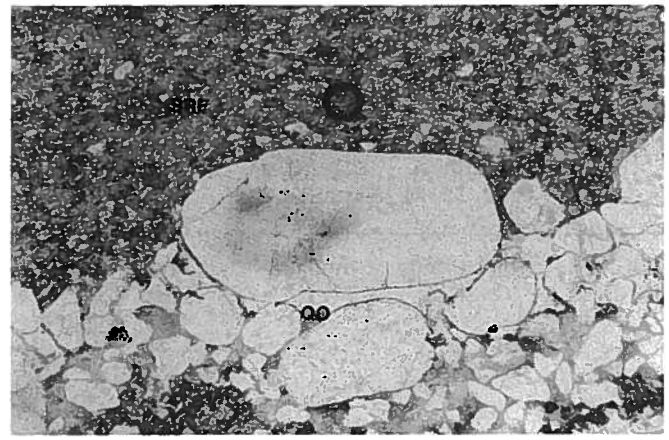

Figure 17. Sedimentary rock fragment (SRF) inhibiting quartz overgrowth (QO) formation on one side of a quartz grain. JAW81-009-9.9. Manitou Falls Formation. Plane polarized light (24.5x).

Quartz grain contacts are complexly intergrown (especially where microstylolites are present), curved or, where overgrowths have formed, straight.

Extensive fracturing of the quartz grains is locally present. Although some fracturing is due to the thin section grinding process, some appears to be due to original factors, perhaps indicating proximity to fracturing or faulting. Fracturing due to causes other than thin section preparation can only be definitely recognized where the fractures are healed with some later mineral, or where it forms a definite zone through the rock (figure 18).

Rock fragments - Rock fragments form 20 percent by volume of the rock in this formation (appendix E). They tend to be dominant in the fraction above 1 mm, but are present down to fine-grain. The fragments consist mainly of high grade metamorphic fragments composed of composite, equant, polycrystalline to elongated crenulate quartz or semicomposite quartz (figure 19). The presence of hematite within a fragment indicates a regolithic origin. Patches of clay suggest the presence of original

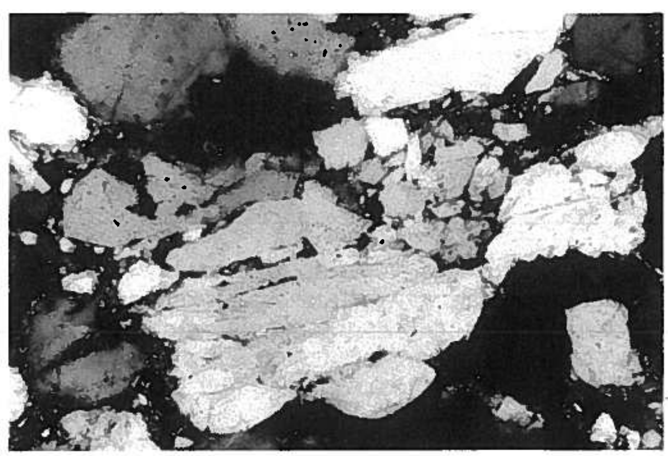

Figure 18. Zone of shattered quartz. JAW81-052-194.3. Manitou Falls Formation. Crossed nicols (62x).

[2] The numbering system used is as follows: JAW81-005-112 where JAW81 is the identification code with the year the thin section was made, 005 is the hole number, and 112 is the depth in metres at which the sample was taken.
[3] The maturity of the sandstones is classified according to Folk (1974).
[4] Subparallel lines of very small bubbles...the product of intense strain deformation of quartz grains (Scholle, 1979).
[5] These are essentially different degrees of the same process. Microstylolites are only seen under the microscope. Stylolites are seen in hand specimen, are high irregular and occur as clay-rich partings. Solution seams have a measurable thickness and occur at low angles to the bedding.

Table 2. Summary of the main petrographic characteristics of the various formations of the Athabasca Group in Alberta.

Formation	Sandstone Type (Pettijohn et al, 1972)	Mean Sandstone Clast Size (Wentworth)	Maximum Clast Size	Clay Mineral Percentages Tr=trace	Accessory Minerals trace amounts	Cementing	Intraclasts	Percentage of Beds With Mean Grain Size Finer Than Sandstone
LOCKER LAKE	sublitharenite	medium	<10mm	illite 60% kaolinite 30% chlorite 10%	zircon tourmaline anatase carbonate muscovite crandallites	clay and quartz overgrowths	rare irregular	<1%
WOLVERINE UPPER	lithic greywacke	medium	<1mm	chlorite 50% illite 40% kaolinite 10%	zircon tourmaline anatase carbonate fluorapatite muscovite feldspar biotite glauconite? crandallites	clay	common ovoid	<25%
POINT LOWER	sublitharenite	medium	<5mm	kaolinite 50% illite 30% chlorite 20%	zircon tourmaline anatase muscovite carbonate cristobalite crandallites	clay and quartz overgrowths	rare ovoid and rare irregular	<10% <5%
MANITOU FALLS	sublitharenite	medium	<15mm	illite 60% kaolinite 40% chlorite tr	zircon tourmaline anatase carbonate bitumen muscovite cristobalite fluorapatite sulphides crandallites	quartz overgrowths	common irregular	<5%
FAIR POINT	lithic greywacke	coarse	>35mm	kaolinite 90% illite 10% montmoril-lonite tr chlorite -	zircon tourmaline anatase carbonate muscovite cristobalite fluorapatite pyrite feldspar crandallites	clay	rare irregular	<1%

feldspar. Chert grains, although rare, are present throughout, as are siltstone or shale fragments. Clay-rich sedimentary rock fragments were originally more common than at present, but compaction has distorted them so they are commonly indistinguishable from the detrital or authigenic matrix. "Clayballs" of kaolinite are present and show evidence of shrinkage cracks within them, probably the result of dewatering. Fragments of illite and kaolinite are present, but probably represent diagenetic alteration of feldspar and not rock fragments.

Accessory minerals - Carbonates are widespread throughout the formation, but are present only in small amounts. Siderite is commonly associated with concentrations of heavy minerals (JAW81-027-244) and with hematite. Dolomite rhombs (figure 44, page 34) are scattered throughout the matrix in some areas where

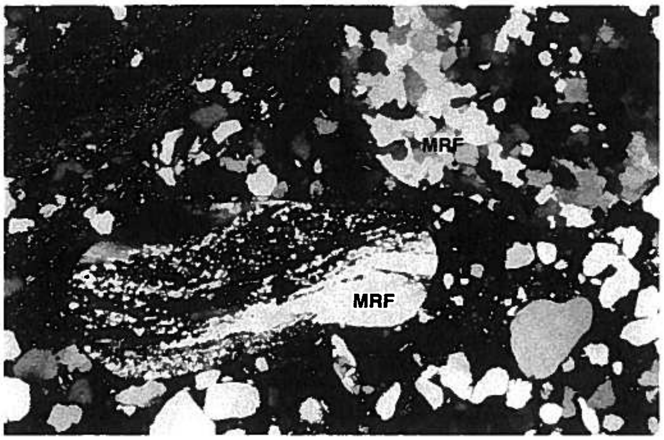

Figure 19. Rounded metamorphic rock fragments (MRF) in a finer matrix. Possible bimodal distribution. JAW81-035-116.9. Manitou Falls Formation crossed nicols (24.5x).

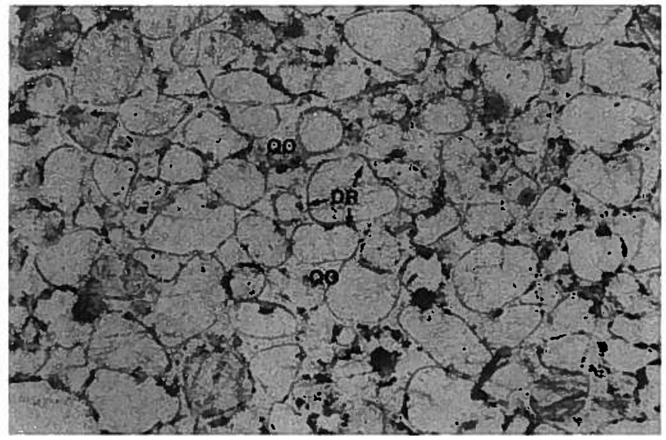

Figure 20. Well-developed quartz overgrowths (QO) with the original, rounded grains outlined by dust rims (DR). JAW81-030-89.8. Manitou Falls Formation. Plane polarized light (24.5x).

the porosity is high and calcite forms a patchy late cement locally.

Muscovite laths are present in the sandstones and are commonly replaced by kaolinite. Larger books of muscovite (1 mm across) show exfoliation, frayed edges and crushing between quartz grains. Hematite may be present along the exfoliation partings, which can result in the form of the muscovite crystal being retained, even after it is completely replaced by kaolinite (figure 4, page 33). Where the clay content is high and the grain size is fine, small authigenic laths of muscovite are present, generally aligned subparallel to any bedding. Muscovite is also present in the stylolites and solution seams.

Hematite is ubiquituous and may vary considerably in form and quantity. It is commonly present as a fine dust, which may form rings around detrital quartz grains beneath the overgrowth (figure 20) or may be scattered through the matrix. Hematite may be intimately associated with the authigenic kaolinite, or may be present as small, hexagonal, authigenic, blood-red flakes up to 10 μm across. Authigenic specular hematite, which is present locally (figure 39, page 33), is commonly associated with heavy mineral concentrations (JAW81-027-244) and may be partly oxidized to red hematite. Detrital metallic hematite (figure 39, page 33) is also present and may be partly or entirely oxidized. Pyrite is seen in small amounts as scattered authigenic grains (JAW81-029-171).

Cristobalite, identified by XRF and XRD, is authigenic and occurs as scattered fibers anchored in a notch on a quartz overgrowth face (figure 21), or as a mass of fibers filling porosity (figure 22). A veinlet of apatite oriented 12° to the core axis is present in thin section JAW81-009-113.5. XRD analysis indicates that the mineral is either fluorapatite or hydroxyapatite, not carbonate-fluorapatite. In thin section, the apatite appears very similar to the phosphate minerals seen in the upper member of the Wolverine Point Formation. The apatite forms a colorless, high-relief cement in which quartz grains float. The cement occurs in a zone about 1 cm wide, which grades rapidly into quartz-overgrowth cemented sandstone with interstitial kaolinite. The sandstone is much more noticeably compacted than is the apatite-cemented zone. The apatite contains minor amounts of hematite dust and has corroded the quartz grains, leaving them with finely scalloped surfaces.

Feldspar is extremely rare in this formation. Microcline and orthoclase are seen as inclusions within quartz grains, and patches of illite suggest replacement of feldspars. In addition, a small detrital grain of feldspar, probably plagioclase, can be seen in JAW81-009-113.5 at the edge of the apatite-cemented zone. The feldspar has probably been preserved by the non-porous apatite cement.

Trace amounts of members of the crandallite group of aluminous phosphate minerals are found throughout the Fair Point and other formations (Wilson, 1985). Crandallite ($CaAl_3(PO_4)OH_5$), goyazite ($SrAl_3(PO_4)OH_5$) and gorceixite ($BaAl_3(PO_4)OH_5$) (Ross, 1983) are present interstitially in the sandstones, commonly associated with kaolinite. These minerals are present as scattered cubes around 7 μm across.

Tourmaline is ubiquitous, although only present in trace amounts. It exhibits brown to green pleochroism, rounding, and is commonly surrounded by frayed authigenic overgrowths or "suns." Detrital grains can

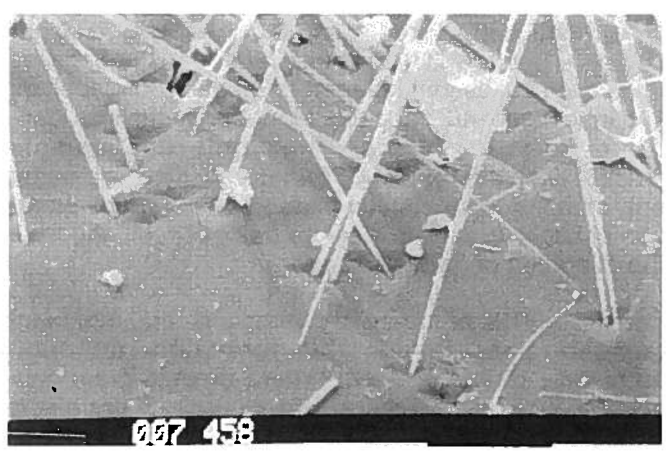

Figure 21. Fibrous cristobalite on a quartz overgrowth face. JAW81-007-458. Lower member, Wolverine Point Formation. Scale bar is 20 μm long.

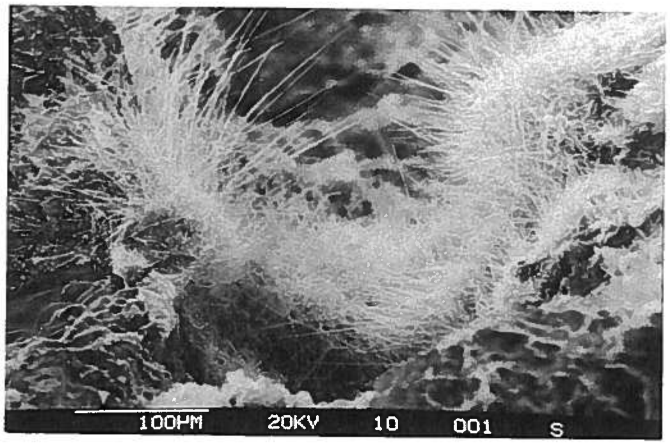

Figure 22. Mass of fibrous cristobalite forming in pore space. JAW81-028-186.6. Fair Point Formation.

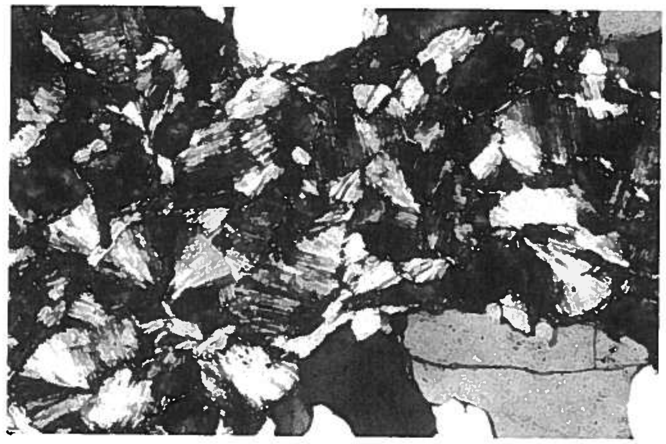

Figure 23. Authigenic kaolinite filling oversized pore spaces. JAW81-015-197. Crossed nicols. Fair Point Formation (62x).

reach a relatively large size (0.5 mm) and in some cases show fracturing as a result of compaction (JAW81-005-566).

Zircon, the most common heavy mineral, occurs throughout as well-rounded to euhedral detrital grains up to 0.7 mm in size. Zircon is also found as well-rounded inclusions in quartz.

Anatase, a low temperature polymorph of rutile, is the third member of the heavy mineral suite. Although usually detrital, anatase may in some cases be authigenic. Leucoxene is found as an alteration product of the anatase.

Matrix - Kaolinite, illite and montmorillonite are present in sandstones of the Fair Point Formation. Kaolinite is the dominant clay mineral in this formation (figure 36, page 28) and can be found in many forms, both original and authigenic (figure 23). A tight groundmass of structureless kaolinite, which may exhibit a pale yellowish or greenish tinge, represents original clay. Quartz grains or rock fragments floating in clay (figures 24 and 25) also suggest original matrix. Authigenic kaolinite is most common as areas with distinctly vermicular texture (figure 26) or as rectangular patches with a noticeable undulose extinction. The rectangular grains of kaolinite suggest replacement, possibly of feldspar (figure 41, page 33) or muscovite. In some cases muscovite flakes can be seen to be partly replaced by kaolinite (figure 40, page 33). Montmorillonite was identified in XRD patterns from only one sample (JAW81-028-186.6), out of 34 analyzed. Illite, is present only in minor amounts. It occurs as an apparent alteration of kaolinite and as discrete patches resulting from the alteration of detrital grains.

Cement - The primary clay matrix is the dominant cementing medium in this formation, although authigenic clay is present. Where grain-to-grain contacts occur, quartz overgrowths or grain intergrowths contribute to the cementing. Overgrowth cement is present as meniscus fabrics between quartz grains or as interference of regular overgrowths on adjacent grains. Grain intergrowth contacts range from concavo-convex, to straight, to irregular. Hematite, fluorapatite and carbonate cement are present locally.

Siltstone and shale

The siltstone and shale units interbedded with the sandstones of the Fair Point Formation are, with minor exceptions, only a few centimetres thick. These beds consist of a groundmass of primary kaolinite in which angular, silt-sized grains of detrital minerals are floating. The presence of more than 50 percent by volume of silt-sized grains classifies the rock as a siltstone (Picard, 1971). Within the groundmass of original kaolinite, ovoid "eyes" and grains of authigenic kaolinite up to 0.2 mm across are common. These grains are commonly elongated subparallel to bedding and probably represent replacement of a previous mineral. Micro-laths of muscovite are present throughout and define the bedding. Quartz is the dominant detrital mineral, with the grains showing no internal features and lacking overgrowths. Hematite dust is scattered through the groundmass. Where the shale beds are in contact with the porous sandstone beds,

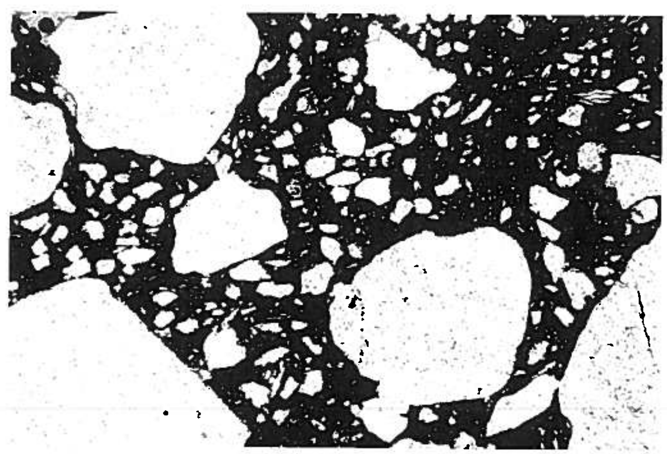

Figure 24. Quartz grains floating in a heavily hematite stained clay matrix. Note the lack of quartz overgrowths and the fact that the grains are floating, indicating that the matrix is original. JAW81-027-266.5. Fair Point Formation. Plane polarized light (24.5x).

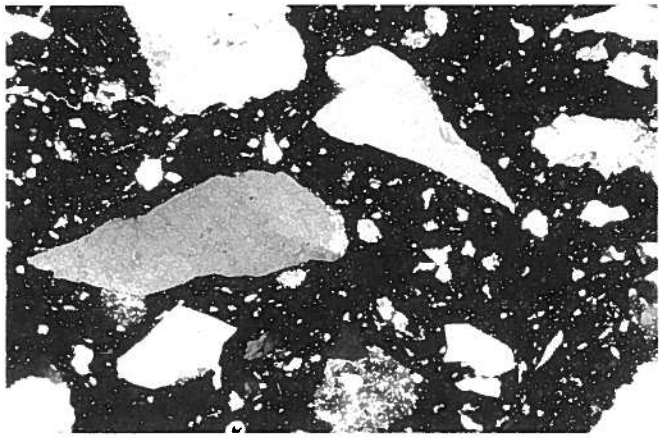

Figure 25. Very angular fragments of quartz floating in a hematite stained clay matrix. JAW81-039-171.1. Manitou Falls Formation. Crossed nicols (24.5x).

some quartz solution and incipient illitization is commonly noted, extending a few millimetres into the shale.

In core FC-027-101-T, the siltstones and shales are heavily hematite-stained and reach 2 m in thickness. Quartz grains, sand-sized and pebble-sized, are present floating in the shale groundmass. Locally these beds become conglomeratic. Thin beds of siltstone and very fine-grained to fine-grained sandstone occur within the shales. Where these thin beds are present, the bedding is generally disrupted, possibly as the result of dewatering during compaction. Illite is rarely the dominant groundmass mineral (JAW81-027-260.4); in these cases biotite, rather than muscovite, is the mica present.

Manitou Falls Formation

Of the 158 thin sections examined from this formation 143 were sandstone, pebbly sandstone or conglomerate. The remainder were entirely or predominantly of siltstone or shale.

Sandstone

The sandstone in this formation is classified as

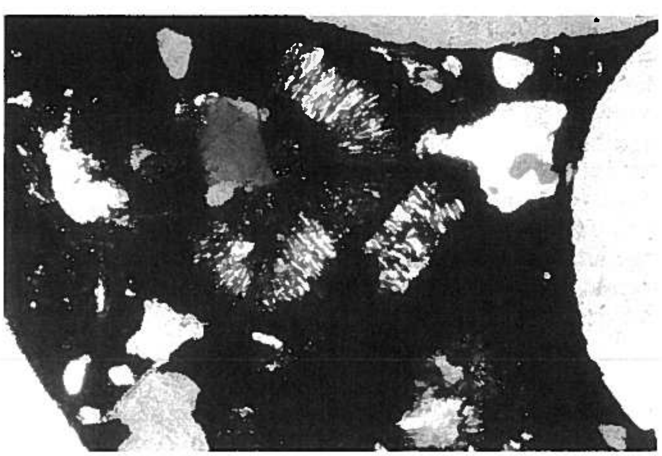

Figure 26. Vermicular kaolinite surrounded by and intimately intermixed with hematite. JAW81-043-143.6. Manitou Falls Formation. Crossed nicols (98x).

sublitharenite (appendix E). In the north (FC-005-393-T), the sandstone is moderately to well sorted; toward the southern margin of the basin it is moderately to poorly sorted. Sand-sized quartz grains are subrounded to subangular. Pebbles are well rounded or angular and silt-sized grains are angular. The sandstone is commonly submature or, rarely, supermature in the north; locally immature to the south. In the southern basin areas, supermature sandstones are present (figure 20).

A well-developed basal conglomerate (figures 19 and 25) is present in four holes, FC-035-037-T, FC-039-092-T, FC-041-031 and FC-043-038. The conglomerates are a mix of round and angular fragments of altered gneissic basement, regolith, siltstone and conglomerate, in a more-or-less hematite-rich illitic groundmass, which shows evidence of alteration from kaolinite.

Quartz - Quartz grains comprise an average of 67 percent of the sandstone. The quartz grains exhibit the same features as those described for the Fair Point Formation. North of the basin, authigenic quartz overgrowths are well developed (figure 20) and form 19 percent by volume of the rock (appendix E). Toward the southern edge of the basin, quartz overgrowths are less well developed and account for only 4 percent of the rock (appendix E). The presence of interstitial clay or deformed sedimentary rock fragments inhibits the formation of quartz overgrowths. Heavy hematite staining also inhibits the development of overgrowths, although a thin single, or rarely double, dust rim of hematite is commonly present beneath the overgrowths (figure 20). Overgrowths are most pronounced on clean, strain-free quartz and are least well developed on rock fragments composed of polycrystalline quartz.

Stylolites, microstylolites and solution seams are common in this formation. Quartz solution is commonly associated with siltstone or shale rock fragments (figure 39, page 33) or with the contact between siltstone or shale beds and sandstone. Where well-developed, the solution seams show considerable quartz solution (figure 41, page 33) and a concentration of illite, muscovite and heavy minerals.

Microscopic fracturing of quartz grains is common in some sections of core. In FC-007-586-T, an extensive fracture zone within the Manitou Falls Formation is seen microscopically as a pervasive microfracture system through the quartz grains. There is little pulling apart or fracture filling on a microscopic scale, although every quartz grain in a thin section may show the fractures. In JAW81-030-89.8, a system of very fine fractures runs across the thin section. These fractures are partially filled with carbonate or pyrite. In FC-014-090, FC-027-101-T and FC-030-106-T, fracturing is present at grain contacts or around open pores. The fractures may be open. Some fractures may simply be flaking at the edges of quartz grains from the thin section preparation, or they may be filled with tar, pyrite or carbonate.

Rock fragments - Rock fragments comprise an average of 7 percent of the sandstones in the Manitou Falls For-

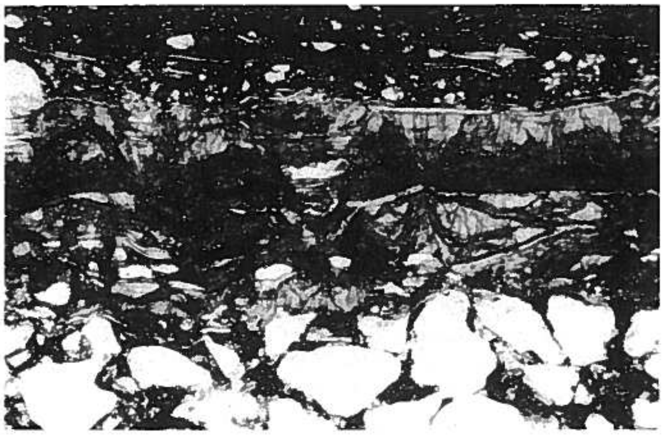

Figure 27. Cone-in-cone structures formed in a carbonate filled fracture. JAW81-035-116.9. Manitou Falls Formation. Plane polarized light (62x).

Figure 28. Hematite rich horizons close to the Fair Point/Manitou Falls Formation contact. JAW81-005-503.5. Reflected light (24.5x).

mation. Where the formation becomes conglomeratic, rock fragments form 50 percent of the detrital component of the rock. Composition of the rock fragments is the same as that of the Fair Point Formation.

Accessory minerals - Siderite, dolomite and calcite are commonly present, but in small amounts. The carbonates are more common in the south of the basin than in the north, and occur as patchy poikilitic cement or as a fracture filling (figure 27). Muscovite is present, associated with stylolites and solution seams, and as detrital 'books.'

Hematite is very common and is present in varying quantities and forms. Some beds close to the contact with the Fair Point Formation are composed almost entirely of hematite (figure 28). These beds are deep red and dense and, in reflected light, are seen to consist of red hematite and minor amounts of metallic gray hematite. Angular silt to very fine-grained quartz grains (without overgrowths), muscovite laths and patches of kaolinite float in this hematite.

Pyrite and marcasite are present in small amounts as fracture fillings and pore fillings around FC-027-101-T. The fractured core in FC-007-586-T, at approximately 544 m depth, contains sulfide mineralization - mainly pyrite, marcasite, galena and sphalerite. Fibrous cristobalite is also present in some samples in the same form as that described for the Fair Point Formation. Fluorapatite or hydroxyapatite was discerned by XRD of sample JAW81-027-114.8. The expected suite of heavy minerals (zircon, tourmaline and anatase) is present.

Matrix - Kaolinite, illite and chlorite occur as matrix minerals in the Manitou Falls Formation. The chlorite was identified only by XRD of samples from close to the top of the formation. Kaolinite occurs as both a primary and authigenic matrix and is the predominant matrix mineral in the northern half of the basin in Alberta. Illite is authigenic (figure 43, page 34), commonly as a replacement of kaolinite, and is the dominant clay mineral to the south of the basin. Intraclasts, which are very common in some sections of the formation, are composed predominantly of kaolinite.

Cement - Quartz overgrowths are the dominant cementing agent. Clay cement is also present, especially locally in the southern area. Minor amounts of hematite and carbonate form the cement locally.

Siltstone and shale

The siltstones and shales of the Manitou Falls Formation are generally only a few centimetres thick. Although more common than those of the Fair Point Formation, these siltstones and shales are petrographically the same. Close to the southern edge of the basin, red, pebbly siltstones and shales occur close to the basal unconformity. These red siltstones vary in thickness, but are the same as the beds described for the Fair Point Formation from core FC-027-101-T.

Wolverine Point Formation, lower member

From the lower member of the Wolverine Point Formation, 14 thin sections were examined; 10 were of sandstone and the remainder of siltstone or shale.

Sandstone

The sandstone of the lower member is a sublitharenite (appendix E) and is essentially the same as the sandstone of the Manitou Falls Formation, varying only in the following respects. Pebbles are rare in the lower member and do not exceed 5 mm in diameter, the detrital grains are generally better sorted and better rounded than those of the underlying formation, and rock fragments are less common. The matrix clays are the same as in the Manitou Falls Formation, but the proportion of chlorite is increased. Cementing is by quartz overgrowths and clay.

Siltstone and shale

The siltstones and shales of the lower member of the Wolverine Point Formation are more common and thicker than those of the Manitou Falls Formation. Mineralogically, however, they are the same, consisting of kaolinite with minor illite and a trace of chlorite.

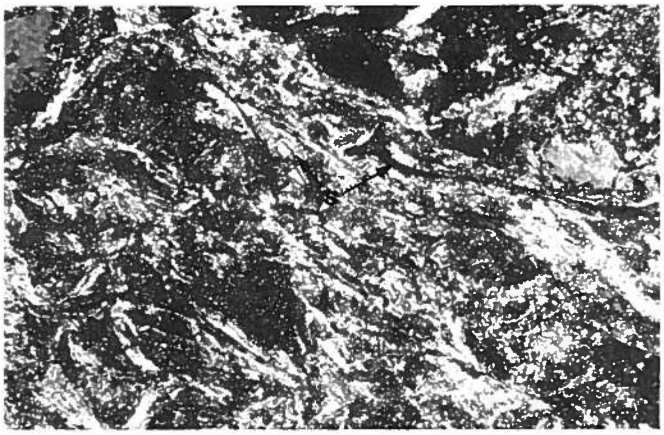

Figure 29. Welded tuff. Note shards (S) stretched out by flow. JAW81-005-168.6. Upper member Wolverine Point Formation. Crossed nicols (246x).

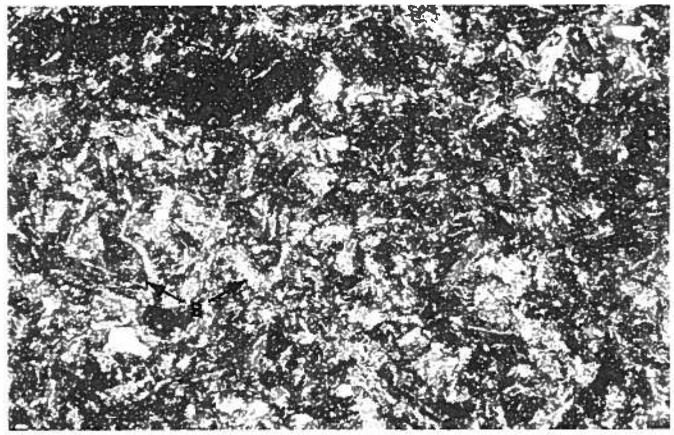

Figure 30. Vitric tuff. Devitrified shards (S) are replaced by high birefringent illite. JAW81-005-149.9. Upper member Wolverine Point Formation. Crossed nicols (98x).

Authigenic kaolinite "eyes" are common, either consisting of a mass of radiating patches of kaolinite or of uniformly oriented kaolinite.

Wolverine Point Formation, upper member

From this unit, 75 thin sections were examined; 20 were of sandstone, 5 of which had a recognizable volcanic component. The remainder, on the basis of grain size, would be considered siltstones and shales. However, 48 display features associated with a pyroclastic origin, so are classified as tuffs.

Tuff

The tuffaceous nature of the upper member of the Wolverine Point Formation is determined texturally and mineralogically. The presence of nonvolcanic detrital material and the effects of compaction and diagenesis have destroyed much of the pyroclastic character of these rocks. Thus, a complete gradation exists between well-preserved tuffs and the sandstone or siltstones and shales described below.

Shards - The main feature distinguishing the tuffs from the rest of the Athabasca Group is the presence of devitrified glass shards. These shards are now composed of illite, but retain, to some degree, their original shape (figure 29). The shards vary in size from 50 to 400 μm across. A high proportion of the shards are Y-shaped or have at least one curved side (figure 30), because they are fragments of gas-filled vesicles. An entire vesicle is rarely preserved (figure 31). A smaller proportion of the relict shards have no distinct shape and simply occur as irregular patches of illite (figure 31). The shards may have been stretched out by flow while still fluid, giving them an elongated shape (figure 29). Commonly, only ghosts of the original shard texture are present in an illitic groundmass between quartz grains.

Quartz - The quartz grains in the tuffs commonly exhibit a volcanic origin, most obviously recognized where the grain is part of a devitrified shard (figure 31). Other criteria can, however, be used. The volcanic quartz is unstrained, lacks overgrowths, contains vacuoles, is angular or has a euhedral shape. Well-developed embayments are present and sometimes are filled with illitic remnants of devitrified glass. The presence of inclusion-rich overgrowths on an inclusion-free quartz grain also indicates a volcanic origin. Many quartz grains, however, are indistinguishable from those observed in other formations.

Accessory minerals - Muscovite is present as small authigenic laths and, rarely, as rounded detrital grains (figure 31). Where detrital, the muscovite may be partly altered to kaolinite or may show crushing from compaction. Biotite is common in some thin sections and is sometimes partly or completely altered to chlorite. Alkali feldspar, rarely present, occurs as silt-sized grains that, unless twinned, are indistinguishable from the silt-sized quartz grains without staining. Hematite is present as a fine dust scattered through the groundmass. Zoned fluorapatite occurs locally as a high-relief cement (figure 32). Kaolinite is present as authigenic

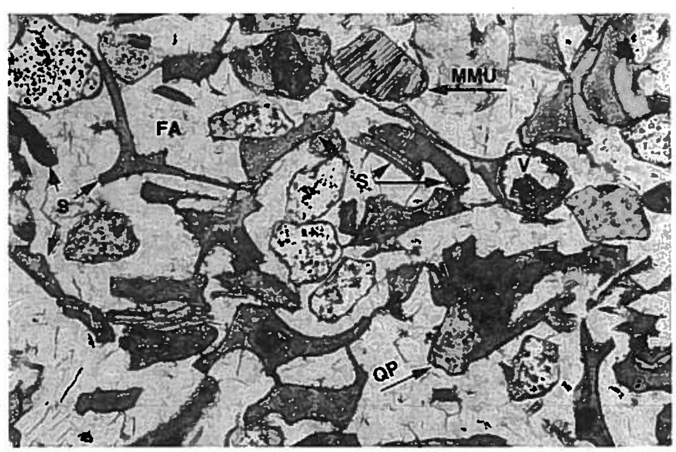

Figure 31. Shard (S) texture preserved in a fluorapatite cement (FA). Note muscovite (MMU), complete vesicle (V), and quartz phenocryst (QP) as part of a shard. JAW81-008-265. Upper member Wolverine Point Formation. Plane polarized light (62x).

"eyes" up to 500 μm across, and as structureless ovoid intraclasts.

Matrix - The dominant matrix in the tuffs is illite, with minor amounts of chlorite, and is also the primary cement. The illite is present as a groundmass, which is commonly structureless, but sometimes shows ghost shard textures (figure 30). Fluorapatite, present locally as a matrix (figure 31), occurs as a high-relief, colorless cement composed of zoned crystals (figure 32) of almost pure fluorapatite (appendix H). Where present, the fluorapatite completely encloses shards, quartz and accessory minerals. In some cases, the fluorapatite is associated with intraclasts that are themselves composed of shards in a fluorapatite cement (figure 46, page 37). Toward the edges of the fluorapatite-cemented areas, the grain size of the fluorapatite decreases and the quartz grains become more densely packed. The interstitital illitic shards become progressively distorted until, where no fluorapatite is present, they form a structureless groundmass, indistinguishable from a non-volcanic clay matrix.

Ovoid intraclasts of reworked tuff or structureless kaolinite or illite are common locally. These intraclasts do not show signs of compaction and may be aligned along bedding planes. Some of these features may be altered accretionary lapilli (Bohor and Triplehorn, 1984; Moore and Peck, 1962).

Sandstone

The sandstone in the upper member of the Wolverine Point Formation is classified as a lithic greywacke (appendix E). The pyroclastic origin of at least some of the interstitial clay would characterize it as tuffaceous. The detrital grains are well-sorted and subangular. The rock is immature.

Quartz - Quartz grains comprise 50 percent by volume of this sandstone. Two distinct types of quartz grains are present. For one type, composite texture, strain extinction, rounded shape and inclusions indicate an origin from erosion of the metamorphic basement. For the other, uniform extinction, broken inclusion-rich overgrowths, good crystal shape and well-developed embayments indicate a volcanic origin. The bulk of the quartz grains, however, lie between these two extremes. Authigenic overgrowths on the quartz grains are rarely well developed and commonly account for less than 5 percent by volume of the rocks (appendix E). Microstylolites are common in some thin sections, but solution seams are not present.

Rock fragments - Rock fragments form only 4 percent by volume of the rock (appendix E). The fragments commonly consist of equant, polycrystalline quartz similar to those seen in other formations. Locally, concentrations of ovoid intraclasts are present. These intraclasts may be of tuff or siltstone, or of structureless kaolinite or illite.

Accessory minerals - Many accessory minerals are present in the same form as in other formations. Carbonate is locally important (JAW81-005-II3.I) as a poikilitic cement. Zircon, tourmaline and anatase make up the heavy mineral suite and sphene is present as inclusions in quartz grains. Cubes of pyrite are scattered through the sandstone. Muscovite is more common in the sandstone of this unit than the others, but exhibits the same form. Biotite occurs locally within the sandstones (figure 33), although commonly partially altered to clay minerals. Apatite occurs associated with tuffaceous intraclasts (figure 46, page 37). Clay balls composed of illite (figures 34, 47, page 37) are present in the many thin sections commonly associated with biotite.

Matrix - Illite and chlorite are the dominant matrix minerals. Minor amounts of kaolinite occur at the top and bottom of this unit. The clay matrix accounts for an average of 39 percent by volume of the sandstone (appendix E). Much of the illite and chlorite are primary, although authigenic illite and chlorite replacing micas are present. Kaolinite occurs as an authigenic rim around quartz grains, where the porosity is high, and is the main consituent of many ovoid intraclasts.

Cement - The primary clay matrix is also the dominant

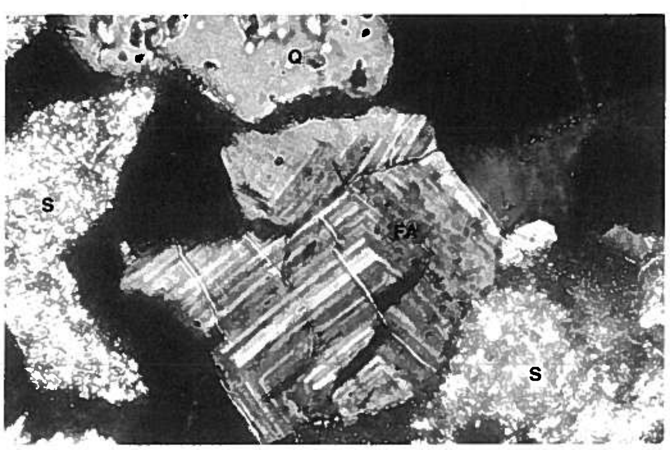

Figure 32. Zoned, authigenic fluorapatite (FA). Note shards (S) and quartz grains (Q). JAW81-008-265. Upper member Wolverine Point Formation. Plane polarized light (393x).

Figure 33. Exfoliated, partly altered biotite (B) surrounded by volcanic quartz (Q). JAW81-006-136.4. Upper member Wolverine Point Formation. Plane polarized light (98x).

Figure 34. Shrinkage halo around former glauconite grain (G) (?). Note rim of authigenic clay (C) around quartz grains (Q). JAW81-007-230.2. Upper member Wolverine Point Formation. Plane polarized light (246x).

cementing medium in the sandstones of the upper member of the Wolverine Point Formation. Where grain to grain contacts occur, miniscus overgrowths contribute to the cementing. Locally, carbonate and fluorapatite are present.

Siltstone and shale

Siltstones and shales showing no evidence of a volcanic origin rarely occur in the upper member of the Wolverine Point Formation. Mineralogically these rocks consist of illite with minor chlorite and a trace of kaolinite. The illite forms a structurelss groundmass in which silt-sized quartz grains, muscovite, biotite, feldspar and hematite dust float. Much of the chlorite is primary, although it is also present as an alteration of mica. Kaolinite occurs as authigenic "eyes."

Locker Lake Formation

Seventeen thin sections of the Locker Lake Formation were examined; 13 were of sandstone and 4 of siltstone or shale.

Sandstone

The sandstones in this formation are classified as sublitharenite (appendix E). Sorting is moderate to poor, although locally the sandstone may be well sorted. Detrital grains in the sand-size range are subrounded. Silt-sized grains are angular and pebbles rounded. The clay content of 9 percent (appendix E) characterizes the bulk of the sandstones in this formation as immature, however, supermature sandstones are present locally.

Quartz - Quartz grains comprise 64 percent by volume of the sandstone in this formation. The quartz grains are identical to the detrital quartz grains observed elsewhere in the Athabasca Group. Authigenic quartz overgrowths are very well developed in some sections of this formation, and may comprise up to 20 percent by volume of the rock. Hematite commonly forms lines of dust inclusions between the original grains and the authigenic overgrowths. Where well-developed, the overgrowths have good crystal terminations and frequently have straight line contacts with each other. Microstylolites, stylolites and solution seams are common.

Rock fragments - Rock fragments, comprising 11 percent by volume of sandstone of the Locker Lake Formation, are more common in the grain-size fraction above 1 mm and consist of the same rock types seen elsewhere. Quartz overgrowths are less well developed on the quartzitic rock fragments than on the common quartz grains.

Accessory minerals - Carbonate, which is common, but only in small amounts, has formed authigenically in pore spaces and may replace the edges of quartz overgrowths and grains. Dolomite rhombs, patchy calcite and reddish brown siderite are all present.

Muscovite laths, present in the fine-grained sandstone, are commonly partly altered to kaolinite. Some patches of authigenic kaolinite suggest total replacement of mica. The laths are often bent around or crushed between, quartz grains, indicating they were present before compaction and are detrital.

As mentioned above, the hematite is present in many cases as a dust rim around detrital quartz grains. In some cases (JAW81-005-58.5), patchy interstitial hematite is so heavy that it prevents the formation of quartz overgrowths and now forms the matrix between the quartz grains. The expected suite of heavy minerals (zircon, tourmaline and anatase) is present.

Matrix - The matrix of this formation is composed largely of kaolinite and illite with minor amounts of chlorite. The kaolinite occurs both as a structureless, primary groundmass and as authigenic pore filling. Illite occurs as a structureless groundmass, as a replacement of kaolinite and as a fringe around some quartz grains (JAW81-007-69.7). Chlorite, most common in the finer-grained beds, is authigenic.

Cement - Where a primary clay matrix is present, it forms the dominant cementing medium. Quartz overgrowths are also present where quartz grains come into contact. Where there is little or no primary clay matrix, quartz overgrowths are the dominant cement and may completely fill the porosity to give the rock an extremely well indurated texture. Locally, carbonate or hematite cements are present.

Siltstone and shale

The siltstone and shale beds within the Locker Lake Formation are rarely in excess of a few centimetres thick. Siltstones are more common, grading up to very fine-grained sandstone, and commonly thinly interbedded with sandstones. The siltstones consist of angular quartz grains in a matrix of clay minerals and muscovite laths. Within the siltstone are clusters of sand-sized quartz grains and floating quartz grains up to 1 mm. in size. These larger grains are rounded to subrounded and show no quartz overgrowths.

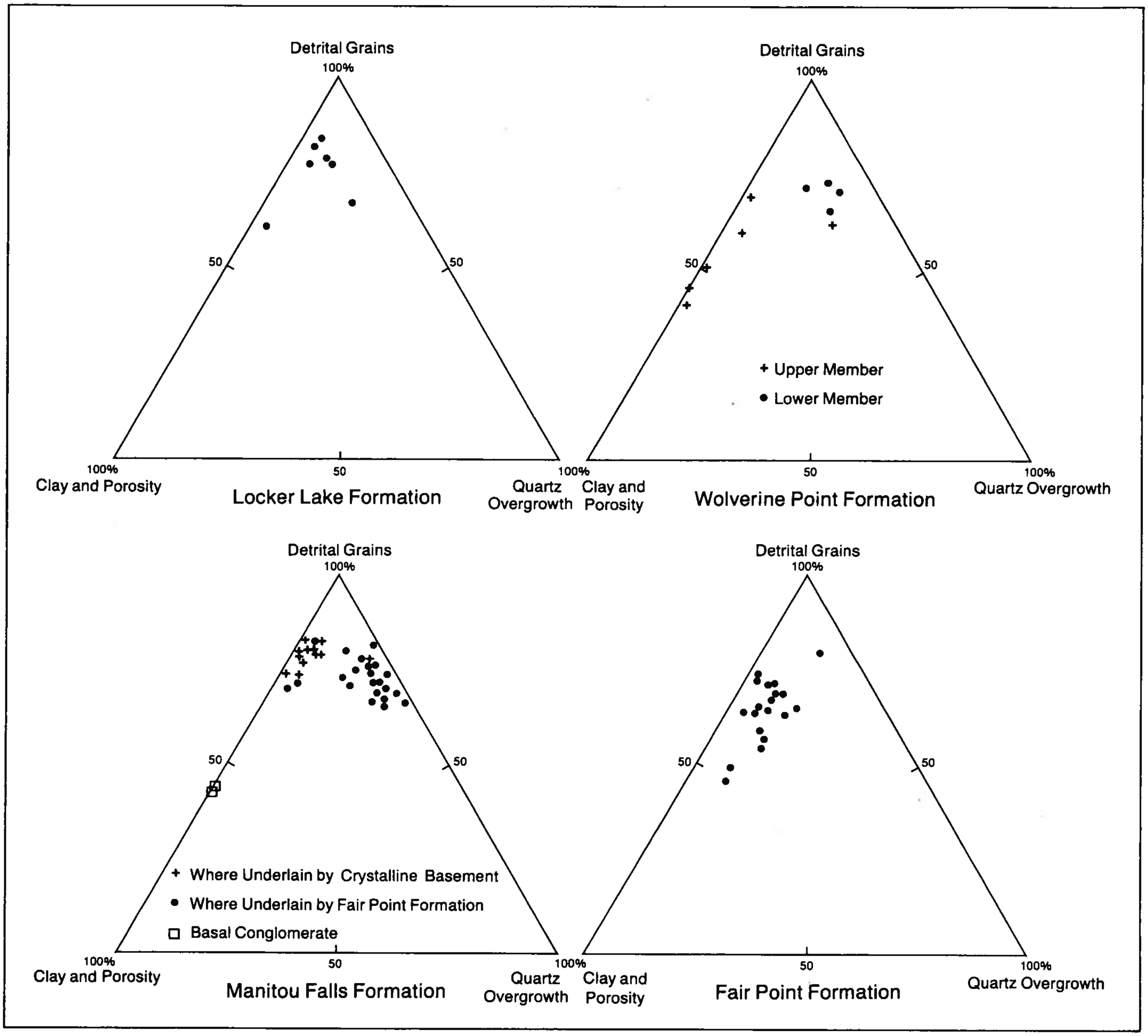

Figure 35. Summary of the point count data for the formations of the Athabasca Group.

Authigenic kaolinite is common in the siltstones in two distinct forms. The most common is the vermicular form, which occurs in masses or eyes up to 1 mm across, and is composed of closely packed kaolinite "worms" and radial aggregates. Kaolinite also occurs in rectangular masses up to 1 mm across with no vermicular or radial textures. This form appears to be a direct replacement of a pre-existing mineral.

Kaolinite, the dominant clay mineral in the shales of the Locker Lake Formation, is present in many cases as a fine groundmass that shows no structure. In this form, the kaolinite may be intimately mixed with minor amounts of illite.

Discussion

The petrographic characteristics of the formations within the Athabasca Group are summarized in table 2 and figure 35, which highlight several features. The Fair Point Formation differs from the Manitou Falls in the mean grain size, maximum grain size, clay composition and clay content. These changes happen over a short section of core (figure 5). The Manitou Falls and Wolverine Point Formations show several trends in petrographic characteristics. Upward in both formations, the maximum grain size decreases, the clay content of the sandstones increases and the percentage of fine-grained beds increases. In addition, the kaolinite content broadly decreases upward with the exception of the lower member of the Wolverine Point Formation. The Locker Lake Formation marks a return to larger maximum grain size, higher kaolinite content, lower overall clay content and fewer siltstone and shale beds.

The tuffs of the upper member of the Wolverine Point

Formation form a distinct petrographic unit. In some cases the tuffs are welded or bedded and, hence, some at least have been deposited in place with no reworking. The shape of the shards and the presence of quartz phenocrysts within the shards indicate rhyolitic or dacitic volcanism (Heiken, 1972). The instantaneous nature of deposition of a bedded tuff allows no chance for the incorporation of a detritral component, except where there has been reworking. Where the shard textures are preserved, the tuffs are easily recognizable; however, where no shards have survived, the mineralogy must be relied on to outline the tuffaceous beds. The presence of a high illite content, biotite, chlorite, illitic clay balls with shrinkage cracks, feldspar, ovoid intraclasts or volcanic quartz can all be taken as indicators of at least a partly volcanic origin.

The heavy mineral suite of zircon, tourmaline and anatase is very consistent throughout the Athabasca Group. The good rounding of the zircons and tourmalines was taken by Fahrig (1961) to indicate reworking of the sediments. The presence of rounded heavy minerals as inclusions within quartz grains indicate, however, that they were already well-rounded in the source rock. Double hematite dust rims beneath quartz overgrowths indicate either two phases of overgrowth in place or, if both are rounded, multiple cycle grains. Heavy minerals are concentrated along solution seams; however, sedimentary concentration of heavy minerals also occurs in several thin sections (JAW81-007-428.7, JAW81-027-157.6 and JAW81-027-244).

In summary, the petrography of the Athabasca Group in Alberta provides a basis for several generalizations. The Fair Point Formation is distinct from the overlying formations. The Manitou Falls Formation and the lower member of the Wolverine Point Formation form a distinct unit, with the influx of pyroclastic material distinguishing the upper member of the Wolverine Point Formation. The Locker Lake Formation marks a return to the conditions prevalent during deposition of the Manitou Falls Formation.

Clay mineralogy

Methods

The quantitative XRD work on which this section is based was performed by J. Hoeve, K. Rawsthorn and D. Quirt of the Saskatchewan Research Council. Samples from 23 cores penetrating the Athabasca Group in Alberta were submitted for analysis (appendix F). Two holes (FC-003-043 and FC-004-090) were sampled by P. Ramaekers before this study began and 4 drill cores (FC-081-005, FC-082-007, FC-084-010 and FC-085-011-T) were submitted independently by Norcen Energy Resources Ltd.

The methodology for the analysis is outlined in Hoeve *et al.* (1981a). In summary, the process involves taking a sample of the clay component from the rock (a sandstone or conglomerate, a bedded clay horizon or an intraclast) and determining the proportions of kaolinite, illite and chlorite present. The proportions of these three clays can then be plotted against depth and compared to the lithostratigraphy (figures 36, 37). In addition to the clay proportions, the Kübler Index of illite crystallinity is also obtained and plotted against depth (figure 36).

Clay mineral stratigraphy for sandstone

The clay analyses for sandstone samples from core FC-003-043 are given in figure 36. The pattern from this hole shows a good correlation with the lithostratigraphy. The Fair Point Formation is characterized by high kaolinite percentage with only minor illite. The Manitou Falls Formation has variable kaolinite percentages, although the values decrease upward as the illite percentage increases. The lower member of the Wolverine Point Formation shows a greater kaolinite concentration than the top of the Manitou Falls Formation combined with increasing chlorite. The upper member of the Wolverine Point Formation is distinguished by high illite and chlorite concentrations and very little kaolinite. Although only the base was sampled, the Locker Lake Formation shows a return to higher kaolinite values.

Clay mineral logs for the holes sampled are given in appendix F. Core FC-004-090 gives results very similar to FC-003-043. Cores FC-055-024-T, FC-081-005, FC-082-007, FC-084-010 and FC-85-011-T, although based on few samples, show the high kaolinite percentage characteristic of the Fair Point Formation. FC-027-101-T, FC-030-106-T and FC-072-042-T show agreement between the clay stratigraphy and the lithostratigraphy established in the cores to the northeast; FC-030-106-T shows greater variations than expected within the Manitou Falls Formation. FC-014-090, although only a few kilometres from FC-030-106-T, shows a distinctly anomalous clay signature for the Manitou Falls Formation. Except for the basal 40 m, which is Fair Point Formation, the illite percentage is unusually high, with the kaolinite only rarely approaching 10 percent.

In the cores where the Manitou Falls Formation lies directly on the crystalline basement (FC-016-015, FC-017-027, FC-035-037-T, FC-037-062, FC-039-092-T, FC-050-005, FC-051-006, FC-052-106-T), a very high illite percentage becomes the norm. Only locally within a core does the kaolinite percentage increase above 10 percent and these areas bear no relationship to the lithostratigraphy. FC-033-068-T and FC-034-037 both lie close to the edge of the Fair Point Formaton and both show very variable results. In the northern and western portions of the basin in Alberta, the clay mineral logs define a stratigraphy close to the lithostratigraphy established in FC-005-393-T. The Manitou Falls Formation, however, which has a variable clay signature, is kaolinite-rich in the north and west of the study area, (where it is underlain by the Fair Point Formation) and

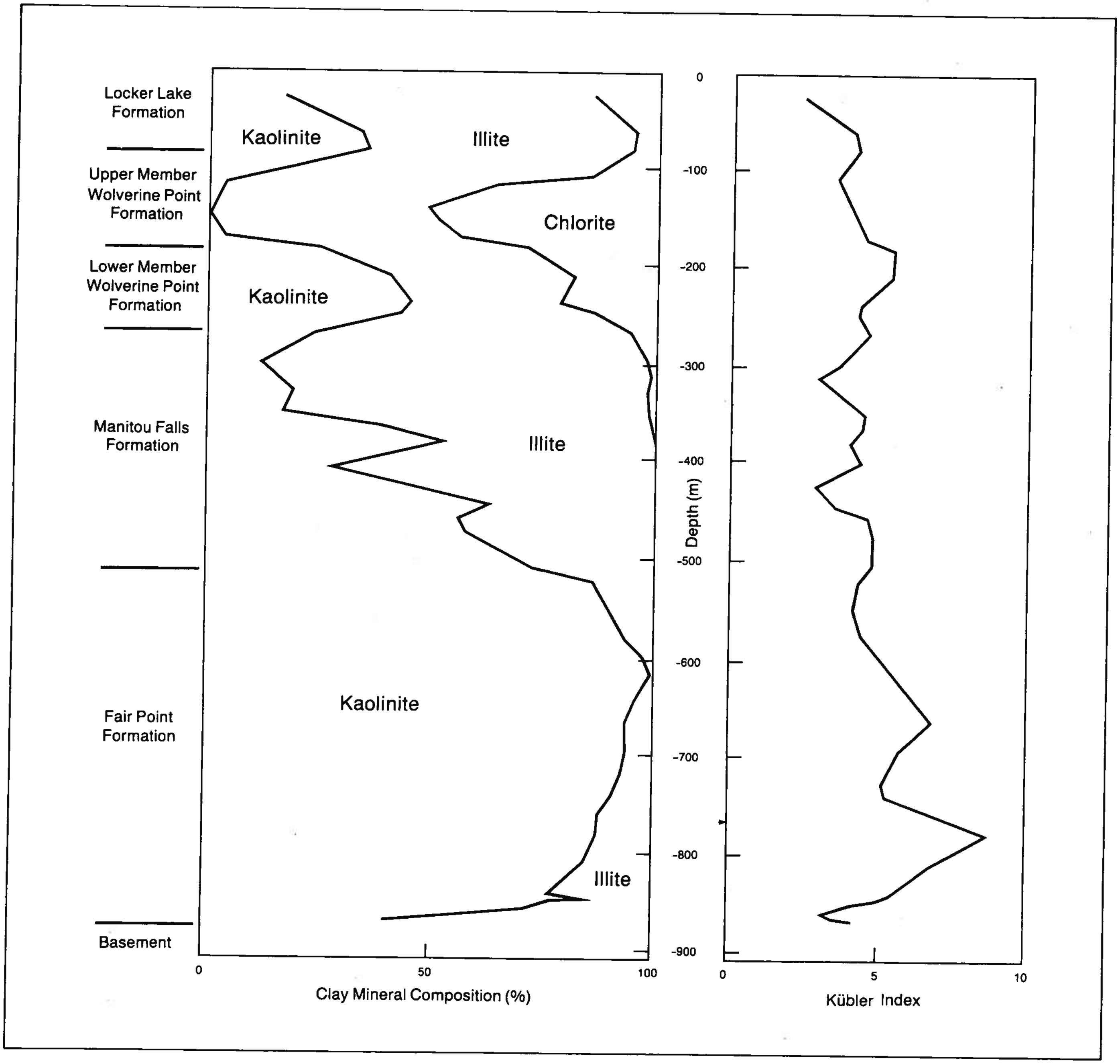

Figure 36. Clay mineral composition and Kübler indices for sandstone samples from drill hole FC-003-043. Samples were taken every 10 m.

illite-rich in the south (where it lies directly on crystalline basement).

In all cores where the Fair Point Formation overlies the basement, the clay mineral logs show a sharp decline in the kaolinite percentages immediately above the unconformity. This feature is widespread, suggesting a basin-wide event. The cause could be the interaction of basement and sandstone fluids at their contact. Specifically it would have involved the rise of potassium-rich alkaline water from the basement, which would lead to the illitization of the kaolinite in the basal Fair Point Formation. The sandstones of the Fair Point Formation have a high primary clay content (appendix E), so they would not have been very permeable. Thus, the basement fluids could not penetrate more than a few metres into the sandstone. The Manitou Falls Formation, which has a low clay content (appendix E), is more permeable than the Fair Point Formation. If the basement fluids rose into the sandstone where no Fair Point Formation was present, the resultant illitization would extend much further from the unconformity. This could explain the high illite and low kaolinite percentages in the Manitou Falls Formation where no Fair Point Formation is present.

Clay mineral stratigraphy for shale

The clay proportions for bedded shale and clay in-

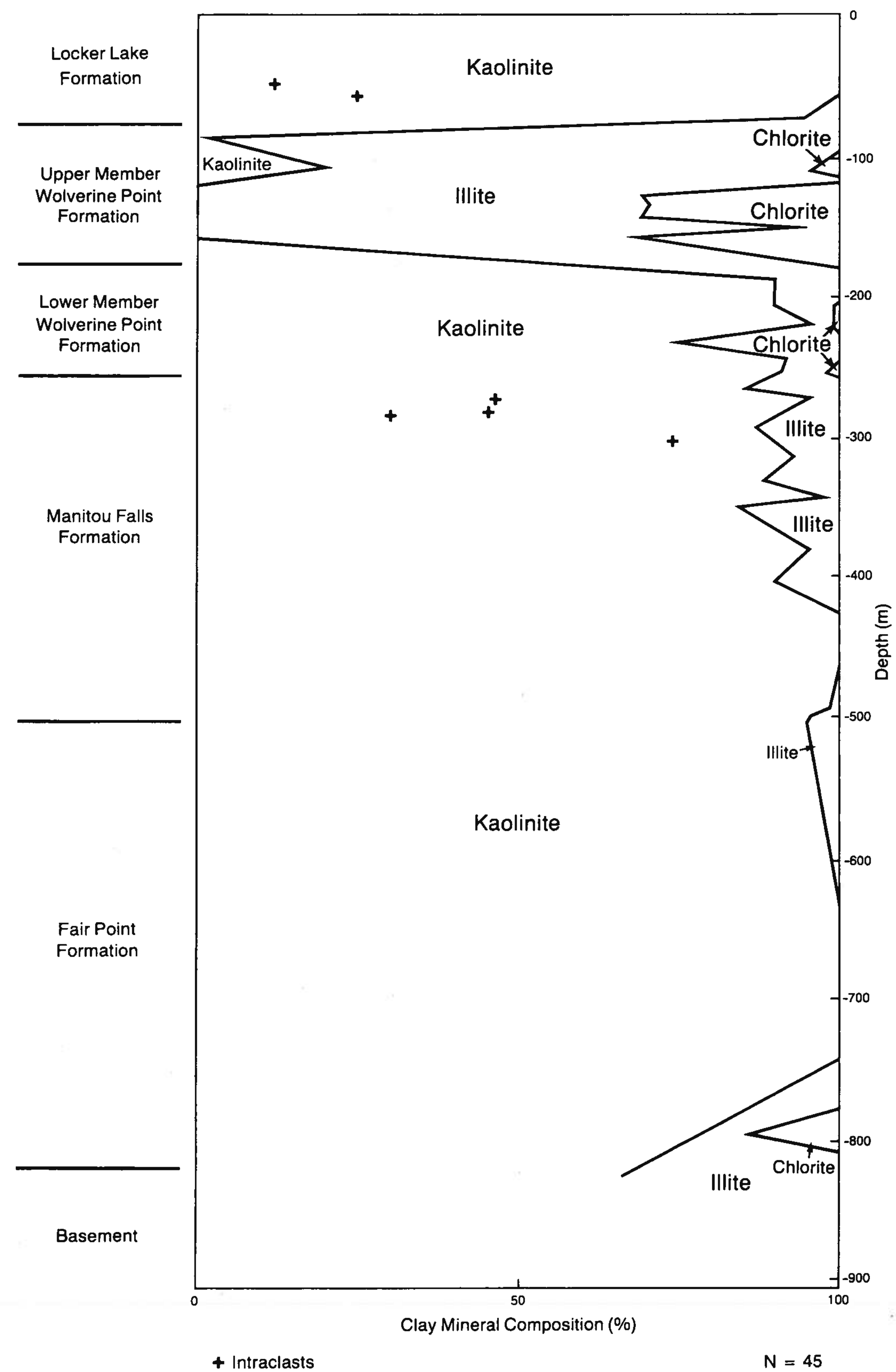

Figure 37. Clay mineral composition for bedded clay and clay intraclast samples for drill hole FC-005-393-T. N = 45.

traclast samples for core FC-005-393-T are presented in figure 37. The shale samples, with the exception of the upper member of the Wolverine Point Formation, have a very high concentration of kaolinite with only minor amounts of illite. The upper member of the Wolverine Point Formation has a high concentration of illite with minor amounts of chlorite. The shale clay log for FC-005-393-T (figure 37) can be compared to the sandstone clay log for FC-003-093 (figure 36) since the two holes were drilled less than a kilometre apart. This comparison shows that for the Fair Point Formation and the upper member of the Wolverine Point Formation the clay mineral logs for both sandstone and shale are similar. For the remainder of the succession, the bedded-shale clay logs show a much higher concentration of kaolinite than the sandstone clay logs. The clay intraclasts have values closer to those for the sandstone clay logs than the bedded-shale clay logs.

The bedded shales are much less permeable than the bulk of the surrounding sandstone. As a result, they are less susceptible to diagenesis from migrating fluids and preserve a composition closer to that of the original rock than the sandstone (J. Hoeve, pers. comm.). The sandstones of the Fair Point Formation and upper member of the Wolverine Point Formation have a high interstitial clay content (appendix E), so they are impermeable and retain the clay signature of the bedded shales. One might, therefore, conclude that the illite outside the upper member of the Wolverine Point Formation is authigenic. Petrographic study supports this conclusion.

The illitization of the clays in the permeable sandstones could result from post-depositional degradation of potash feldspar, muscovite and biotite. These processes would have released potassium into the formation waters that would in turn have illitized a portion of the kaolinite. Outside the Fair Point Formation and the upper member of the Wolverine Point Formation, the clay content of the sandstone is small, and would not have required much feldspar breakdown to have altered a significant portion of the kaolinite to illite (J. Hoeve, pers. comm.). Alternatively, the illitization could be due to an influx into the Athabasca Group of potassium-rich waters from the basement. This latter possibility is supported by the illitization of the Manitou Falls Formation, where it directly overlies the basement.

A late, fault-controlled kaolinitization event is also recognized in the Athabasca Basin in Saskatchewan (Hoeve *et al.*, 1981a). This event is probably the result of acidic waters percolating down fault zones during a period of uplift (Hoeve *et al.*, 1981b). Hoeve *et al.* (1981b) tentatively correlated the event with the 250 Ma uranium mobilization event.

Kübler Index

The Kübler Index is an index of the crystallinity of illite (Kübler, 1968). The crystallinity of illite increases with depth of burial (Weaver 1956, 1960; Kübler, 1964, 1969) and thus can be used to indicate the degree of diagenesis. Values for the Kübler Index range from zero to 15. Lower values of the Kübler Index indicate increasing illite crystallinity with higher-grades of diagenesis and greater depth of burial. Kübler indices for clay samples from the sandstones of FC-003-043 are plotted against depth in figure 36. The values have a limited range, lying between 4 and 7. These values are typical for high-grade diagenesis (Hoeve *et al.*, 1981a).

From the work of Esquevin (1969) and Dunoyer de Segonzac (1969, 1970), Hoeve *et al.* (1981a) characterized the Kübler indices of the illite in the sandstone of the Athabasca Group in Saskatchewan as having been subjected to deep burial and temperatures of the order of 150 °C to 200 °C. This suggests the removal of a considerable thickness of sediments from the top of the basin, but is in keeping with fluid inclusion studies carried out by Pagel (1975 a,b).

Summary

The clay signature of the sandstones of the Athabasca Group can be plotted against depth and matched against the lithostratigraphy (figure 36). With the exception of the Manitou Falls Formation, each formation has a distinct clay signature which is constant throughout the Alberta portion of the basin. The clays of the Manitou Falls Formation vary depending on whether the formation is underlain by the Fair Point Formation or the crystalline basement. This variation is probably due to the interaction of formation clays with basement fluids.

The bedded shales are impermeable and have been protected from interaction with migrating fluids. The clay signatures of the bedded shales give results similar to the signatures obtained for the clays from the sandstones for the Fair Point Formation and for the upper member of the Wolverine Point Formation, because both of these formations have a high clay content and low permeability which protected them from diagenesis. The bedded shales of the more permeable formations show a much higher kaolinite proportion than for the sandstones, indicating that the illite present in the sandstone is diagenetic.

The conclusion drawn is that the clay mineralogy was determined by the permeability of the rock at the time of migration of the illitizing fluids. Thus, the clay mineral stratigraphy only matches the lithostratigraphy where the lithostratigraphy defines permeability units, or where a permeable unit is protected from fluid flow by impermeable units. It is not possible, therefore, to determine which formation is present in an area of unknown stratigraphy on the basis of clay mineralogy alone.

The Kübler indices indicate deep burial diagenesis for the sandstones, which implies the removal of a thick layer of sediment from the top of the Athabasca Group.

Diagenesis

The rocks of the Athabasca Group have been subjected to a long and complex history of post-depositional alteration. Some original textural and mineralogical features, and even some early diagenetic events, have probably been obliterated by later changes. Thus the rock currently under study may be significantly different from the original sediment.

As noted above, the diagenesis of the Athabasca Group is high-grade (Hoeve *et al.*, 1981a). The sandstones that form the bulk of the Athabasca Group have undergone similar diagenesis, so are considered together. The siltstones and shales, being impermeable, have been protected from some of the diagenetic changes and are considered separately. The different mineralogy of the pyroclastic units within the upper member of the Wolverine Point Formation also warrant its consideration as a separate unit.

Diagenesis of the sandstones

The diagenetic history of the sandstones of the Athabasca Group is schematically portrayed in figure 38. This diagram takes no account of the length of time required for the deposition of individual formations or of depositional hiatuses within the sequence. Thus, while one formation was being deposited, diagenesis could have been well-advanced in an earlier formation. Locally, variations in the permeability and the chemistry of the pore fluids also produce diagenetic variations within the sandstones.

The most widespread and easily recognizable feature is the quartz overgrowths. Accordingly, other less-widespread features are initially categorized as pre-overgrowth or post-overgrowth, and then — where possible — related to each other. The formation of quartz overgrowths, however, does not represent a distinct time-line for all sandstones. The overgrowths probably occurred at different times in different formations and may not have been one event; thus, the sequence of diagenetic events is a relative one.

Diagenesis prior to silica precipitation

Many detrital quartz grains have dust rims of hematite beneath the silica overgrowths (figure 20). Where the hematite coating of the original grain is well-developed, it completely or partially inhibits the formation of the overgrowths. Detrital grains of hematite are commonly associated with lath-like, authigenic hematite (figure 39), but it is not clear whether this authigenic hematite formed before or after the quartz overgrowths.

During the early phase of iron mobilization, hematite was precipitated along the exfoliation partings of detrital micas (figure 40), indicating that the micas had already begun to alter. Early hematite is also present intimately associated with vermicular kaolinite (figure 26) and siderite (figure 40) indicating early phases of kaolinite and carbonate formation (figure 38).

Members of the crandallite group of hydrous aluminous phosphates (Ross, 1983) are present beneath quartz overgrowths in sample JAW84-007-206 (Wilson, 1985). The phosphates must either be detrital or an early diagenetic phase.

Silica precipitation

Quartz overgrowths are inhibited by deformed clay clasts (figure 17) indicating formation after initial burial and compaction of the sediment. These overgrowths are formed over detrital quartz grains in optical continuity with the grain. They have grown where porosity has allowed silica-saturated waters to permeate around the quartz grains (Siever, 1962) and commonly exhibit good crystal terminations. Experimental studies have shown that silica overgrowths form preferentially on strain-free quartz grains, less readily on strained quartz, and least readily on polycrystalline quartz grains (Ernst and Blatt, 1964). Quantitatively, the quartz overgrowths are an important cementing agent (figure 20) and locally can comprise up to 30 percent of the rock by volume (appendix E).

The literature suggests many sources for the silica of quartz overgrowths. In a marine environment, the role of silica-secreting microorganisms is stressed by Siever (1962). A terrestrial environment may produce siliceous dust through aeolian abrasion and the dust may be taken into solution by alkaline, desert groundwater (Waugh, 1970). The alteration of siliceous clays or the devitrification of volcanic glass also releases silica to groundwaters (Pettijohn *et al.*, 1972). Stylolites and the pressure solution of quartz grains is often cited as a source for dissolved silica (Heald, 1955, 1959; Siever, 1962).

Microorganisms are indicated within the Athabasca Group (see below, fluorapatite formation). The permeable Athabasca Group sediments were deposited in a vegetationless terrestrial environment, so the presence of at least a reworked aeolian contribution is probable. The devitrification of the tuffs of the upper member of the Wolverine Point Formation would have been a good source for dissolved silica, at least locally. The presence of microstylolites, stylolites and solution seams throughout the sandstone suggest this as a source for dissolved silica. The major source for the dissolved silica was probably the solution seams with minor contributions from devitrification of the tuffs and dissolution of siliceous aeolian dust.

An absolute time cannot be assigned to the formation of quartz overgrowths. Many authors (Heald, 1955; Dapples, 1967; Siever, 1962; Ernst and Blatt, 1964; Waugh, 1970) suggest that the cementing overgrowths formed soon after deposition. In the case of the Athabasca Group, however, the quartz overgrowths formed after compaction and some diagenetic alteration of the rock. The overgrowths also probably formed over a long period since, locally, double or even triple dust rims of hematite are present.

Silica solution

Microstylolites, stylolites, solution seams and contacts between clay beds and sandstones represent areas of quartz solution. Clay minerals appear to play an impor-

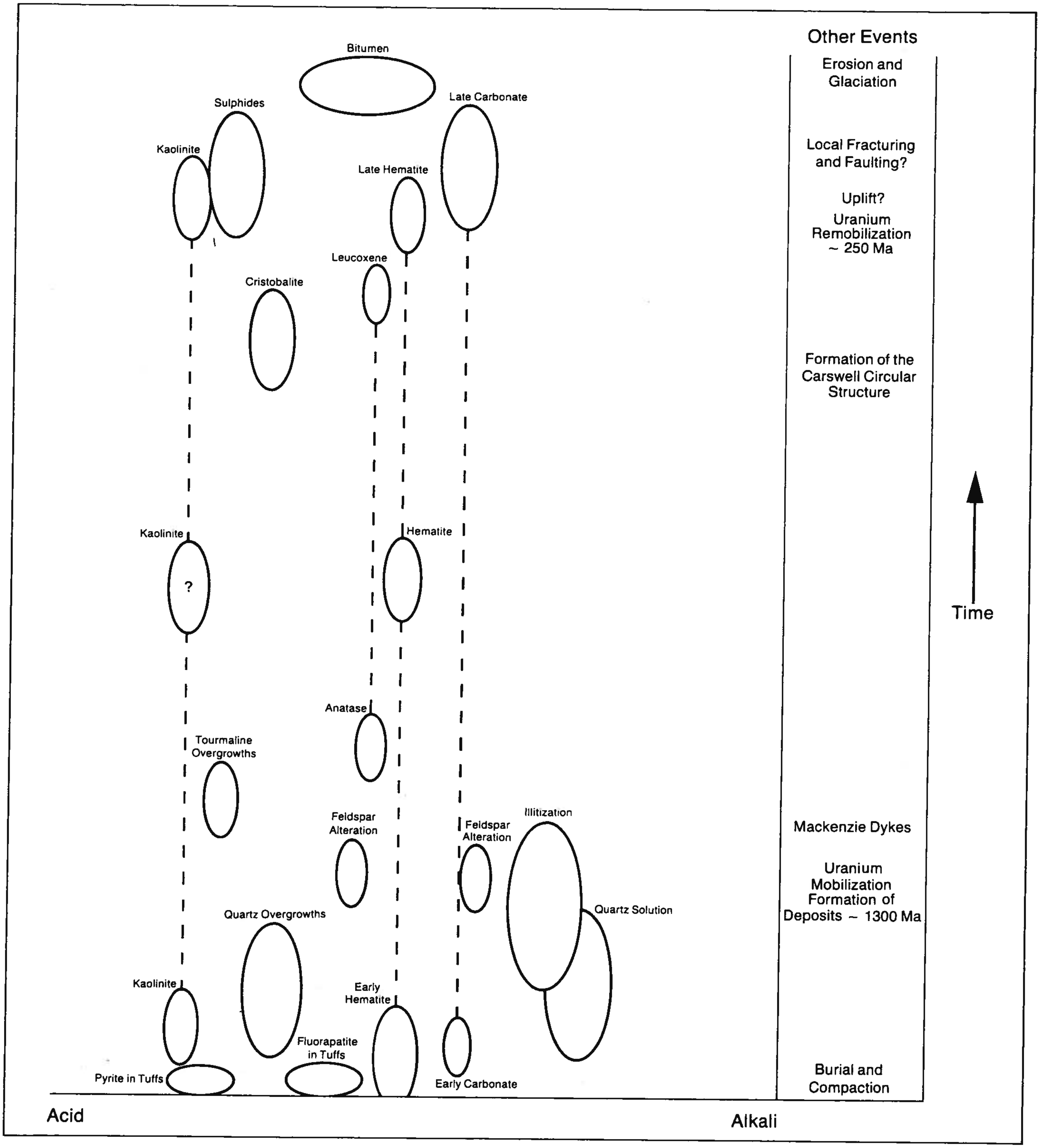

Figure 38. Diagenetic events postulated for the sandstones of the Athabasca Group. Both the time axis and the pH axis represent only relative scales.

tant role in the dissolution of silica. Stylolites have a clay parting and locally terminate in a distorted clay intraclast (figure 39). Where silica solution has occurred at a clay-sandstone contact, the kaolinite is often illitized for a few millimetres into the clay bed. Since a high pH is necessary for quartz dissolution (Fairbridge, 1967) and also for illitization (Grim, 1968) this is consistent. These observations suggest, however, that the quartz solution is due to chemical reaction rather than to simple pressure solution.

If the quartz solution was a source for the silica precipitation as quartz overgrowths, both precipitation

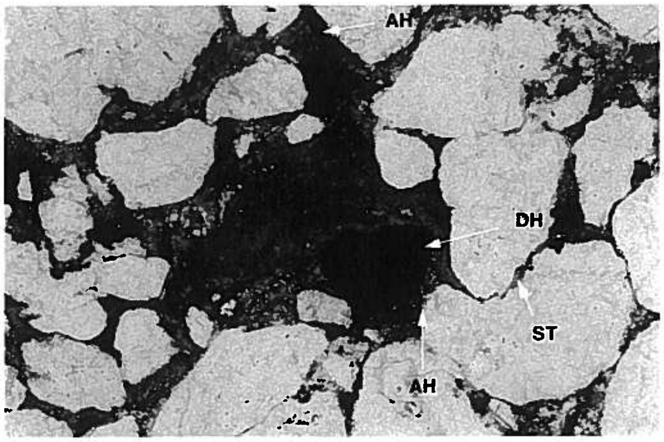

Figure 39. Sedimentary rock fragment (SRF) distorted by compaction. Note that the ends tail off into stylolites (ST). The large isotropic mineral below the SRF is detrital hematite (DH) and has scattered, authigenic laths of hematite (AH) around it. JAW81-028-292.6. Fair Point Formation. Plane polarized light (24.5x).

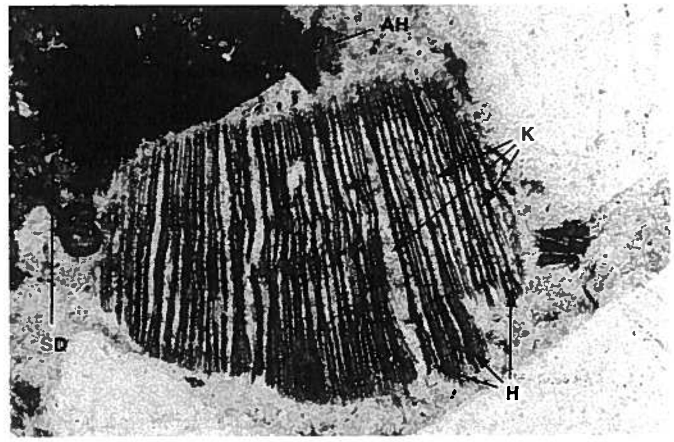

Figure 40. Detrital mica replaced by hematite (H) and kaolinite (K). At top left siderite (SD) is intimately associated with authigenic hematite (AH). JAW81-039-168.6. Manitou Falls Formation. Plane polarized light (98x).

and solution must have occurred largely contemporaneously (figure 38). Locally, however, some solution seams cut both quartz grains and well-developed quartz overgrowths. This suggests a more complex relationship.

Clay alteration

As outlined in the clay mineralogy section, kaolinite is the major original clay in the sandstones. This detrital kaolinite is recognized by its densely packed nature, by its pale greenish color and by the fact that it inhibits quartz overgrowths. Authigenic kaolinite, present in several forms, commonly occurs as a loosely packed, coarse-pore filling, which may exhibit vermicular textures (figure 26) or radiating textures (figure 23). As outlined above, some authigenic kaolinite of the vermicular type formed before the quartz overgrowths; however, the bulk of the authigenic kaolinite formed in pore space after the silica was precipitated (figure 38). Kaolinite is also present replacing detrital muscovite. Most commonly this is a partial replacement; however, in some cases, the muscovite is entirely replaced (figure 40). Some kaolinite completely replaces unknown precursor minerals. Figure 41 shows an example where kaolinite replaces what may have been an original feldspar. The kaolinite replacement in figure 42 shows evidence of having replaced a twinned mineral, probably plagioclase.

The presence of authigenic kaolinite implies a low pH, a high Al:Si ratio, and absence of Na, Ca, K, Mg and Fe (Bucke and Markin, 1971; Grim, 1968). A low pH dissociates the formation of kaolinite from the quartz dissolution event, which required a high pH (figure 38). The presence of dissolved silica is well-established and the aluminum could have come from degradation of plagioclase feldspar or muscovite. Na, Ca, K, Mg, and Fe either were not present, were locked with other minerals and were therefore, unavailable.

The largely authigenic illite within the sandstones of the Athabasca Group is seen as a fine-grained groundmass, or as a fringe on quartz grains (figure 43), or as a direct alteration of kaolinite. Illite is commonly present as partings in kaolinite and may be altered to muscovite. A close correlation exists between illitization and quartz dissolution (figure 38). The clays within stylolites and solution seams are illite, and kaolinite is illitized close to areas of quartz solution.

Illitization requires a high pH and the presence of potassium (Grim, 1968). A high pH would be present during the silica dissolution. The potassium could arise from the degradation of feldspars (Grim, 1968) or, as is suggested by the distribution of illite related to the permeability (clay mineralogy section), could have come from the underlying basement. After the formation of quartz overgrowths in the sandstone, at least two phases of authigenic clay formation occurred: a low pH phase that produced kaolinite and a high pH phase commonly associated with quartz solution that produced illite.

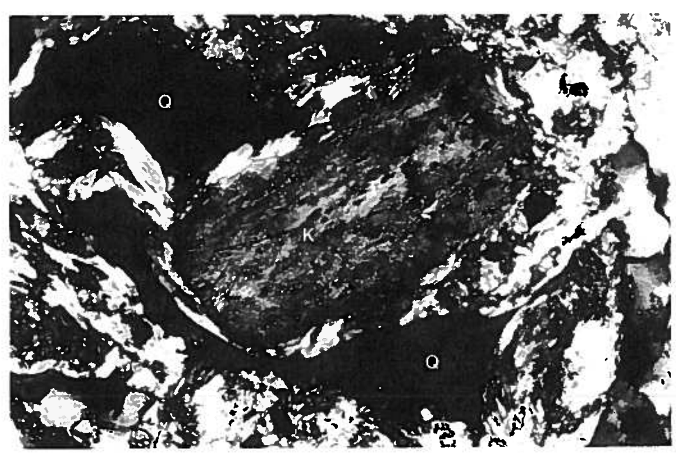

Figure 41. Kaolinite (K) replacing an original mineral, possibly feldspar. Note extensive solution of quartz grains (Q) around the replaced grain. JAW81-031-79. Manitou Falls Formation. Crossed nicols (246x).

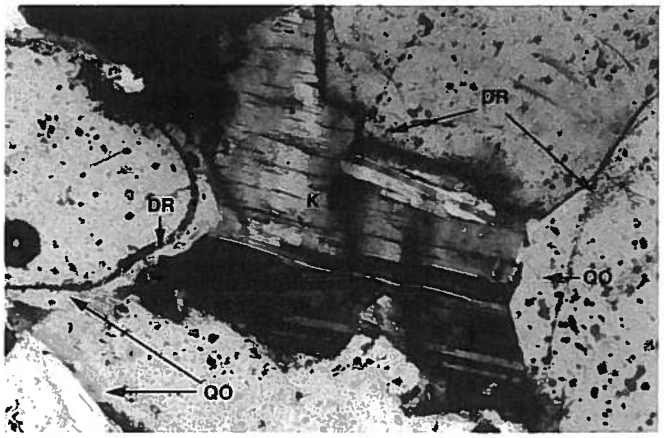

Figure 42. Kaolinite (K) replacing a twinned mineral, possibly plagioclase feldspar. Note well-developed quartz overgrowths (QO) and dust rims (DR) around well-rounded quartz grains. JAW81-007-374.1. Lower member Wolverine Point Formation. Crossed nicols (98x).

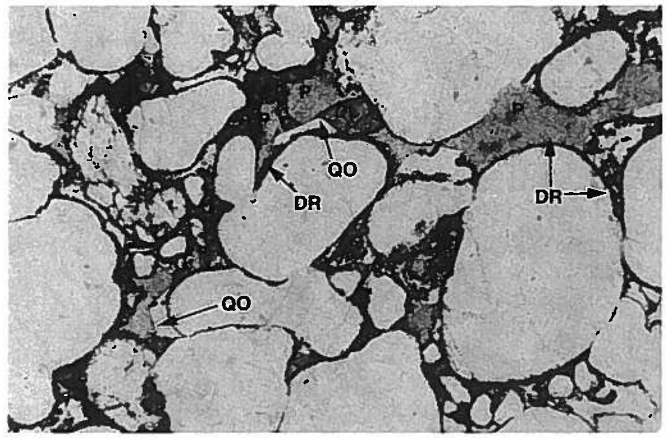

Figure 44. Pre-quartz overgrowth hematitic dust rims (DR) and post-overgrowth dolomite rhombs (DL) in a porous sandstone. Pores (P), quartz overgrowth (QO). JAW81-030-179.8. Manitou Falls Formation. Plane polarized light (24.5x).

Diagenesis after silica precipitation
Prominent among the post-quartz overgrowth effects are at least two phases of hematite mobilization (figure 38). These phases show up as the small, zoned, red platelets described in the petrography of the Fair Point Formation and are commonly densely packed and opaque, or intimately associated with kaolinite. These phases of iron mobilization produced the leisegang rings. Two cross-cutting phases of leisegang rings are present in core. An even later stage of hematite bleaching is associated with minor fractures (figure 8) and intraclasts.

Calcite and dolomite are present in patches throughout the sandstones. In some cases the dolomite may be an alteration of pre-existing calcite. The calcite is present as a replacement of the groundmass and, rarely, of quartz grains. The calcite commonly occurs as poikolitic cement encompassing the detrital minerals. The other occurrence of calcite is as fracture fills (figure 27). The dolomite occurs in the same form as the calcite and also as isolated rhombs (figure 44).

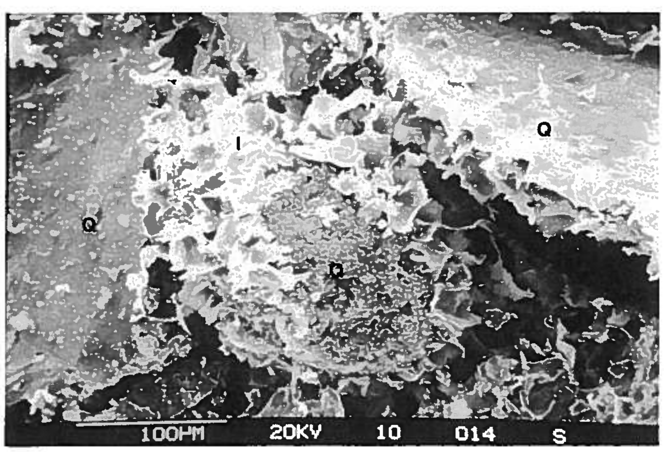

Figure 43. Authigenic illite (I) formed on the surfaces of quartz grains (Q). JAW81-005-165.2. Upper member Wolverine Point Formation. Scanning electron micrograph.

Sulfide minerals are present in fractures associated with the carbonates. The most common is pyrite, which is also in evidence as disseminated blebs through some sections of core and as a porosity filling. Pyrite, marcasite, galena and sphalerite occur locally (FC-007-586-T) in a fracture system. Sulfide formation associated with ore deposits at Midwest Lake has been dated at 265 $\pm$ 50 Ma and within the past 50 Ma (Cumming et al., 1984).

The fluorapatite present in the sandstones of the Fair Point Formation (JAW81-009-113.5) has etched quartz overgrowths and is, thus, a late mineral. Fibrous cristobalite (figures 21, 22), tourmaline overgrowths, anatase, leucoxene and bitumen formed, or were introduced late in the diagenetic history of the sandstone (figure 38). Insufficient data exist to relate the formation of these minerals to each other.

Many post-quartz overgrowth events cannot be definitely related to one another. If it is assumed that most of the fracturing occurred at one time, this can be used as a marker to which some diagenetic events can be related. The minerals that fill the fractures — sulfides, carbonates and cristobalite — are obviously post-fracturing. Hematite is common throughout the sandstone and yet only rarely seen in fractures; thus, the bulk of the hematite mobilization occurred before the fracturing.

Diagenesis of the siltstone and shale

The low permeability of the siltstones and shales of the Athabasca Group has protected them from many diagenetic events. Quartz overgrowths are not present, so a relative time scale is difficult to establish. Hematite is present in most of the shales, as a fine dust mixed with the matrix clay. This may be an early diagenetic event, or may correspond to one of the late phases of hematite mobilization. The hematite may not have moved far, but may have simply been reprecipitated within each unit. Later bleaching around intraclasts and fractures indicates later removal of hematite from some zones.

The clays in the fine-grained units are composed of kaolinite, except near the contacts with the sandstone, where they have been illitized. This illitization is related to the quartz dissolution in the sandstones.

Diagenesis of the tuffs

Tuffaceous beds are recognized only in the upper member of the Wolverine Point Formation. The original mineralogy of the tuffs combined with the low permeability of the member imparts a distinctive character to this unit. Most diagenetic events seen in the tuffs probably occurred before or during their devitrification. Since then, they have acted as a closed unit, protected from further diagenetic change. One cannot establish a sequence for diagenetic events in the tuffs, nor is it possible to relate events within them to events within the surrounding sandstones, other than to say that devitrification of the tuffs occurred early in the diagenetic history of the Athabasca Group.

Fluorapatite formation

Patchy fluorapatite cement occurs throughout the upper member of the Wolverine Point Formation (figure 45). The fluorapatite is zoned (figure 32), has a very low carbonate content (appendix H) and is not uraniferous. Where present, the fluorapatite invariably preserves shards (figure 31) indicating an early pre-compaction origin. This is born out by the fact that the fluorapatite sometimes occurs as a cement within intraclasts that are the result of penecontemporaneous erosion (figure 46). A relationship between the fluorapatite and the crandallites such as that observed in the Thelon Formation (Miller, 1983) is not indicated.

Figure 45 shows the relationship of the fluorapatite to the grain size of the tuffaceous units. The most highly tuffaceous beds are the finest-grained. The fluorapatite cement is concentrated not in these fine-grained beds but in the coarser beds on either side of them. This relationship suggests that the fluorapatite was released from the tuffs during devitrification and reprecipitated in more permeable beds as it came in contact with the surrounding groundwater. This is supported by the evidence of the phosphate-rich intraclasts. The intraclasts have a fluorapatite matrix and are commonly surrounded by a halo of fluorapatite cement (figure 46). This halo is the result of expulsion of phosphate from the intraclast and its reprecipitation in the surrounding sediment. Thus, the phosphate has been remobilised soon after deposition, on both a coarse scale (figure 45) and fine scale (figure 46).

The original precipitation of the fluorapatite occurred very soon after deposition, and, in the upper member of the Wolverine Point Formation, exhibits a close association with the volcanicity. Lowe (1972) provides a model for the formation of the phosphates within the Wolverine Point Formation. The model involves the introduction of silicic pyroclastics into a restricted marine environment. The phosphate is supplied by decaying microorganisms, the fluorine by the volcanicity. Reducing bottom conditions in a quiet water restricted marine environment allows the process to proceed. Post-depositional alteration of the silicic glass removes magnesium from the seawater, thus allowing phosphate crystallization (Martens and Harriss, 1970). The devitrification also induces alkaline bottom conditions that would promote the precipitation of phosphate just below the sediment-water interface. This model does not explain why fluorapatite, rather than carbonate fluorapatite, is present in the Athabasca Group.

Fluorapatite, which is petrographically very similar to the occurrences within the Athabasca Group, has been described from the Thelon Formation of the Northwest Territories (Miller, 1983). The fluorapatite occurs as zoned crystals within fluvial clastics and resembles the occurrence in the Fair Point Formation (JAW82-009-113.5). The occurrence of fluorapatites within the Thelon Formation is related to ephemeral saline lakes and the migration of phosphatic brines soon after deposition (Miller, 1983). This mechanism explains the fluorapatite within the fluvial clastics of the Fair Point Formation, but is not adequate to explain those of the Wolverine Point Formation.

Stratigraphically, an interval of several hundred metres separates the two occurrences of fluorapatite within the Athabasca Group, and the environment of deposition of the sediments surrounding the occurrences differed. Unless there is unrecognized volcanicity within the Fair Point Formation, two distinct mechanisms for the occurrences may be postulated.

Diagenesis of the non-phosphate beds

Several diagenetic effects, other than fluorapatite formation, have occurred within the upper member of the Wolverine Point Formation. The events probably occurred as a result of devitrification and, thus, very early in the post-depositional history of the sediments.

The presence of illite, the dominant clay mineral associated with the tuffs, is the result of devitrification, or the alteration of smectites, which were themselves the result of devitrification. The shards preserved within fluorapatite cement are composed of illite. As the fluorapatite cement decreases, the shards become distorted, until they form an illitic groundmass that shows little or no evidence of a pyroclastic origin. Thus, the shards were illitized before, or simultaneously with, the formation of fluorapatite. Illitization probably occurred before compaction.

Illite also occurs as clay balls (figures 34, 47). Shrinkage textures in these clay balls suggest an original glauconitic composition.

Kaolinite is present in minor amounts as the replacement of a pre-existing mineral (probably feldspar) and as a rim of radiating fibres around quartz grains (figure 34). Chlorite is present throughout the tuffs, but its fine-grained nature makes characterization difficult. Most of the chlorite is probably the result of the degradation of biotite. Fresh and partially altered biotite is present in many horizons (figure 33).

Scattered pyrite cubes are present within the tuffs. The condition of the model for fluorapatite formation (that is, reducing bottom conditions in a restricted

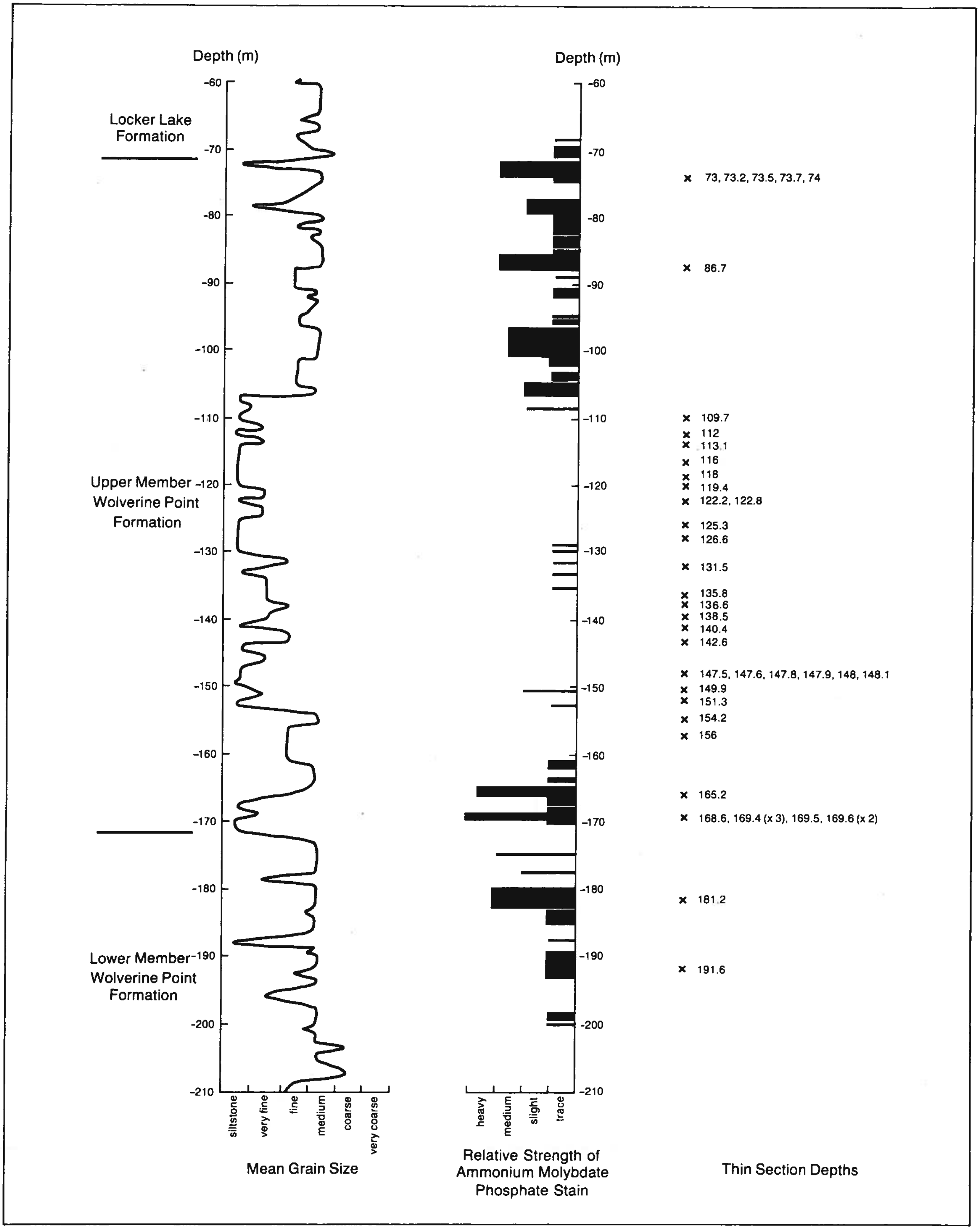

Figure 45. Mean grain size plot for the upper member of the Wolverine Point Formation from core hole FC-005-393-T, compared to the relative concentration of phosphate. The core was stained with ammonium molybdate in nitric acid.

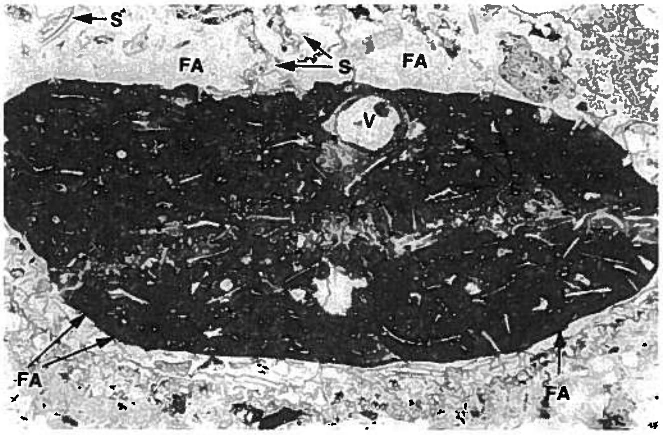

Figure 46. Tuffaceous intraclast surrounded by fluorapatite (FA) cemented tuff. Note vesicle (V) within the intraclast and the generally finer nature of the shards (S) within the intraclast. JAW81-005-169.6. Upper member Wolverine Point Formation. Plane polarized light (24.5x).

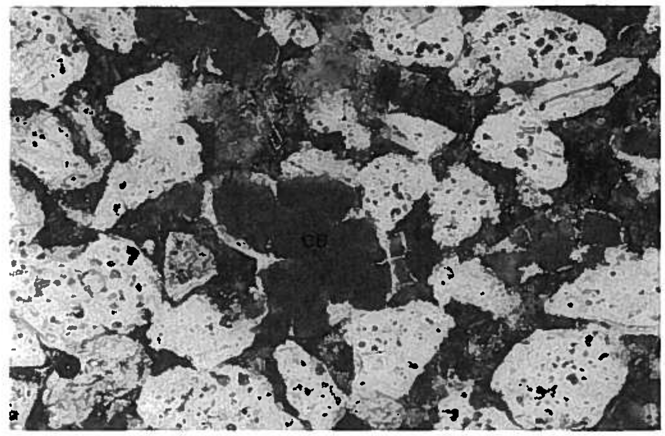

Figure 47. Shrinkage cracks in an illitic clay ball (CB), possibly originally glauconite. JAW81-007-253. Upper member Wolverine Point Formation. Plane polarized light (98x).

marine environment) would also promote pyrite formation.

Carbonates are present in the coarser, more permeable beds of the upper member of the Wolverine Point Formation. These carbonates are similar to those seen elsewhere and probably formed within permeable units during the last carbonate event (figure 38).

Although hematite staining is present in the same manner as that seen within the siltstones and tuffs, it was probably not introduced into the tuffaceous units, but rather represents remobilization of pre-existing iron.

Summary

Diagenetic events within the Athabasca Group can be organized into a relative time sequence (figure 38). The diagenesis was controlled by variations in original mineralogy, permeability and depth of burial. The mineralogy and permability variations have led to differences between the impermeable tuffaceous rocks of the upper member of the Wolverine Point Formation and the more permeable clastics of the other formations. Kübler Index values (figure 36) do not indicate any variation of illite crystallinity as a result of depth of burial of the Athabasca Group sediments.

The overall effect of the diagenesis of the permeable beds has been to simplify the mineralogy and reduce the porosity. The clay mineralogy has been altered to one less-dominated by kaolinite. The feldspar content, although never high, has been lowered, as has the proportion of biotite in the rock. The growth of secondary quartz, authigenic clays, and locally, carbonates, sulfides and cristobalite have reduced the porosity. Hematite has been remobilized at least twice during the post-depositional history of the basin, and phosphates have been introduced into the tuffs and the sandstones. At a late stage in the history of the rock, bitumen was introduced into the porous horizons of the group.

The diagenetic events outlined above cast some light on the history of fluid flow and mineral transport through the Athabasca Group. Reactions that occurred at similar pHs (for example, silica solution and illitization) may be genetically related and represent widespread fluid movement through the sediments. Reactions that occurred at different pHs (for example, kaolinitization and illitization) represent distinct events in the history of fluid flow.

The distinct phases of hematite mobilization may represent periods of uplift and erosion, which allowed oxidizing surface waters to percolate down through the sandstones. A date of 450 Ma has been tentatively assigned to one phase of kaolinitization (Hoeve *et al.*, 1981b). Diagenesis within the tuffaceous beds probably occurred soon after deposition and was related to devitrification. Evidence that the illitization was the result of fluid flow from the basement to the sandstones could have implications for the history of mineralization in the basin.

Environment of deposition

The rocks of the Athabasca Group contain no hard-bodied or trace fossils to aid in the interpretation of the environment of deposition. Outcrops of Athabasca Group rocks are extremely rare in Alberta and do not present good, clean faces where sedimentary structures may be observed and measured. Many sedimentary structures cannot be positively identified in small-diameter drill core. Thus, only gross features can be described. In addition, Long (1978) points out many of the problems involved in interpreting Precambrian sedimentary sequences when the style of deposition may have been radically different from the present day. Nevertheless, some deductions can be made. As in the diagenesis section, the clastic and pyroclastic sediments are considered separately.

Origin of the clastics

Largely on the basis of hummocky cross-bedding and herringbone cross-bedding, Ramaekers (1980a, 1981) characterizes the bulk of the Athabasca Group as near-shore marine, commonly with a tidal influence. The exception is the Manitou Falls Formation, where low paleocurrent variance at the outcrop level, and abundant clay intraclasts in some horizons, are taken to indicate interbedded fluvial units. The evidence is not as clear in Alberta.

The source of the clastics of the Athabasca Group in Alberta is important in determining the character of the rock. Most sandy units of the Athabasca Group were derived from subaerial erosion of a lateritic type of soil formed on the crystalline basement (McDonald, 1980). Very little transportation and alteration of this weathering product could produce the sandstone. Within the regolith, feldspars and mafic minerals are heavily altered to clays. A relatively short transport distance would, therefore, remove large amounts of the clay and could round the quartz fragments to produce a submature or mature arenite or wacke.

To postulate a marine environment of deposition for the basal Fair Point Formation, and the basal Manitou Falls Formation where it lies on the crystalline basement, presents problems. It requires an assumption that the clay-rich, easily eroded paleosol that formed subaerially was not subject to erosion until inundated by a large, marine body. Rates of formation of the paleosol likely varied and were locally subject to erosion. This erosion may have been sheet-like, since the soil lacked a protective vegetation cover. The products would be carried by sediment-laden rivers until deposited in areas of low energy. Thus, as the basin subsided, it would gradually fill with locally derived fluvial sediments. A change from this fluvial deposition to a marine deposition is not observed anywhere within the formations that lie on the basement. The entire formations are assumed to be fluvial.

The dominance of planar and trough cross-bedding in the sandstone suggests a fluvial origin (Long, 1978), as does the presence of overturned (figure 14) and deformed cross-bedding (Allen and Banks, 1972). Further evidence exists in the presence of irregular clay intraclasts, most commonly in the Manitou Falls Formation, but also present in other formations. Rain prints and dessication cracks (Fahrig, 1961) indicating periodic subaerial exposure, and the presence of possible paleosols between the Fair Point and Manitou Falls Formations, are in keeping with a fluvial model (Long, 1978). The small-scale cut-and-fill channels in the Locker Lake Formation (figure 15) are also more likely in a fluvial than in a marine setting (Fahrig, 1961). The presence of hematite dust rims around detrital quartz grains, even in bleached sections of core, suggests that the sandstones were part of an original red bed sequence (Miller, 1983). Although none of these features alone is conclusive evidence of a fluvial origin for the sediment, when taken together they strongly suggest a fluvial, rather than a marine environment of deposition.

The clay mineralogy can also be used to help ascertain the environment of deposition. As discussed in the clay mineralogy section, the original clay in the sandstones of the Athabasca Group was kaolinite. Kaolinite does not form under marine conditions (Grim, 1968, p.537). In addition, kaolinite-quartz is a common assemblage in nonmarine quartzose sandstones (Carrigy and Mellon, 1964). The preponderance of kaolinite in the original clay mineral assemblage argues against its introduction into a marine setting as a detrital mineral.

The facies change within the Manitou Falls Formation between FC-005-393-T and the southern edge of the basin requires explaining. Some features such as the decrease in sorting and the increase in pebble concentration and size toward the south can be explained by increased proximity to a source. Other features in the south, however, such as the presence locally of very rounded, well-sorted sand grains (figure 20), the presence of possibly bimodal sorting (figure 19) and the extremely clean nature of much of the sand suggest a different explanation. These latter features are more pronounced over large areas of the basin in Saskatchewan, south and east of the Carswell structure (D. Quirt, pers. comm.). These features suggest the possibility of an aeolian influence in this area, possibly aeolian working of the sand grains between streams followed by the eventual reworking and deposition of the aeolian deposits by the fluvial system.

Fahrig *et al.* (1978) identified the paleolatitude of deposition of the Athabasca Group as 39°, which is in keeping with the lateritic-type of weathering observed in the pre-Athabasca Group regolith (MacDonald, 1980). A latitude of 39° is also close to the most favorable latitudes for phosphate formation (Christie, 1980).

Although no marine units were identified within the clastics of the Athabasca Group in Alberta, their presence is not ruled out. A marine influence has been identified in Saskatchewan (Ramaekers, 1980a, 1981) and marine tongues may be present in Alberta. The evidence presented above, however, suggests that most of the clastics were deposited in a fluvial setting. Specifically, this setting was probably similar to the braided stream environment outlined by Walker and Cant (1979).

Origin of the tuffs

The tuffaceous beds of the upper member of the Wolverine Point Formation suggest a different environment of deposition from that of the clastics. The pyroclastics were introduced suddenly into a sedimentary environment. As the volcanicity waned, the detritial component of the sediment became relatively more abundant.

The model proposed for the formation of the fluorapatite requires a restricted marine environment with little or no influx of detrital material (Lowe, 1972). Marine conditions are also indicated by the presence of scattered pyrite cubes and the possible presence of glauconite (Odin and Letolle, 1980). The dominance of illite as opposed to kaolinite is also in keeping with a marine environment.

The waters into which the tuff was deposited were generally quiet, because many of the tuffs are not reworked and are finely laminated. Nevertheless, periods of more active conditions are suggested by the abundance locally of ovoid intraclasts and by the current marks present in outcrop in Saskatchewan (Fahrig, 1961). Thus, the upper member of the Wolverine Point Formation represents a tuff introduced into the predominantly quiet water of a restricted marine environment, either in sufficient quantity to overwhelm the clastic contribution or at at time of little clastic input.

Summary

The Fair Point Formation is the result of subaerial erosion of deeply weathered, crystalline basement. Transport and deposition of the sediment was by fluvial means and the formation is capped by a paleosol. The Manitou Falls Formation is also a fluvial unit with a source to the south. A marine influence may have existed in the lower member of the Wolverine Point Formation, but by upper Wolverine Point time, when a large amount of volcanic debris was introduced, marine conditions prevailed. Following the volcanic events, a regression led to a return to fluvial conditions in the Locker Lake Formation.

Economic geology

With the discoveries of uranium deposits in northern Saskatchewan in recent years, the Athabasca Basin has become the center of much economic interest. Published figures for reserves in unconformity-type uranium deposits (Tremblay, 1982) are in the order of 18 000 000 ore tonnes. With an average grade of 1.04 percent, these reserves yield around 180 000 tonnes of uranium. The deposits (figure 48) are scattered along the northern and eastern edges of the basin and at the Carswell structure. No economic deposits have yet been found in Alberta, so it is necessary to examine the Saskatchewan deposits in order to assess the potential in Alberta.

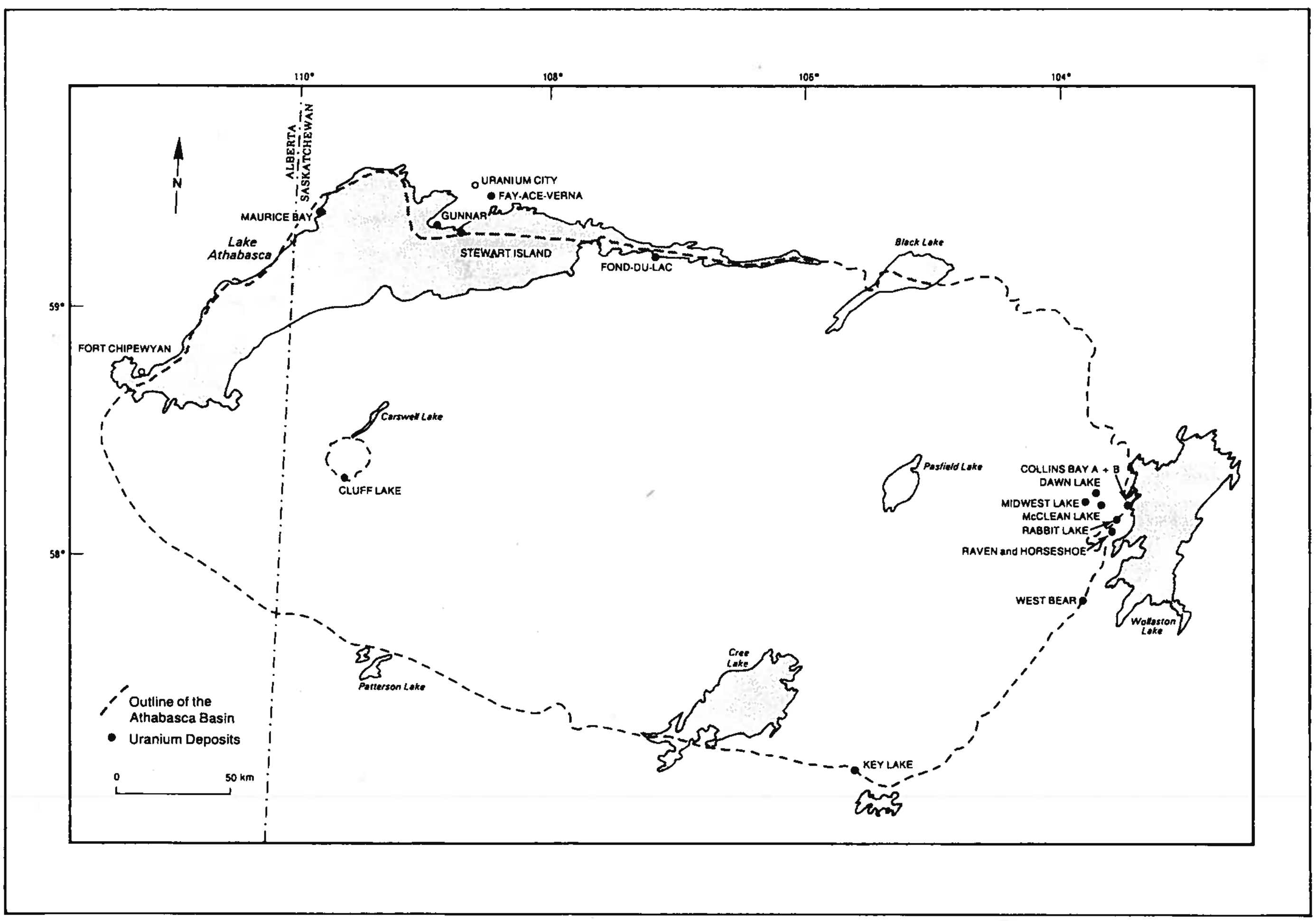

Figure 48. Location of the major uranium deposits in the Athabasca Basin of Saskatchewan (after Tremblay, 1982).

Outline of the Saskatchewan uranium deposits

Data in this section, unless otherwise credited, come from Tremblay (1982). Twelve of the 14 deposits in figure 48 are related to the sub-Athabasca unconformity. The exceptions are the deposits around Uranium City to the north of the basin, and even these may have an origin closely related to the other deposits. The unconformity-type deposits have several aspects in common:

1. All are deposited within a range of 40 m above to 100 m below the unconformity.
2. Many are associated with distinct relief at the unconformity, either as a result of pre-Athabasca weathering or of post-Athabasca faulting.
3. Faulting is an important factor, the faults generally being reactivated basement faults trending between north and east.
4. Graphitic basement rocks are associated with the deposits and are present even beneath deposits that occur entirely within the sandstone.
5. Sericite and chlorite, the result of hydrothermal alteration, are invariably present in a halo around the ore bodies.
6. The deposits are most commonly linear or ovoid, with the long axis following faulting in the basement or bedding in the sandstone.
7. All the main phases of mineralization occurred about 1281 ± 11 Ma (Cumming and Rimsaite, 1979), and all show evidence of later uranium remobilization.
8. The temperature of the main phase of mineralization is considered to be less than 300°C (Dahlkamp, 1978; Pagel, 1975a) and the overburden thickness at the time was less than 5 km (Pagel, 1975b).

Differences between deposits depend on many factors. The eastern deposits occur in Aphebian metasediments of the Wollaston Fold Belt, whereas those to the west and north of the basin are in or underlain by Archean basement. If the basement is the source for the uranium, this explains certain differences. The Aphebian rocks generally have a higher uranium content and, consequently, are a better source rock than the Archean rocks. This results in the eastern deposits being more numerous, being more closely spaced and containing a much higher tonnage of uranium than the western and northern deposits. The mineralogy of the ore deposits is also determined, to an extent, by the source rocks. The ore deposits in Aphebian rocks tend to be richer in nickel, cobalt and silver than those in the Archean rocks. The mineralogy is also affected by position of the ore deposit relative to the unconformity. Ore deposits at the unconformity tend to be richer in uranium and have a more complex mineralogy than those found away from the unconformity. The clay minerals also vary with deposit. Rich deposits have extensive phyllosilicate development, whereas deposits with little clay development, notably along the northern rim of the basin, tend to be low grade with a simpler mineralogy.

Numerous models have been put forward to explain the unconformity-type deposits below the Athabasca Group (Langford, 1977, 1978; Knipping, 1974; Little, 1974; Morton, 1977; Munday, 1979; Hoeve and Sibbald, 1978; Hoeve *et al.*, 1980; Tremblay, 1982). Tremblay (1982) supports a model showing that the uranium was concentrated sedimentologically and anatectically in the basement before Athabasca Group sedimentation. Further concentration during the formation of the regolith was preserved by the overlying sandstone. After deposition of the Athabasca Group, groundwater remobilized the uranium and deposited it near the unconformity. This sequence produced the present ore bodies that were only slightly altered by later remobilization. The main phase of mineralization occurred around 1260 Ma ago (Tremblay, 1982).

The unconformity-type uranium deposits in Saskatchewan have been compared to uranium mineralization in other Proterozoic Basins in Canada (Clark *et al.*, 1982). Many similarities have also been noted between the ore deposits of northern Saskatchewan and those of northern Australia (Langford, 1974; Clark and Burrill, 1981).

Exploration in Alberta

The information above makes it possible to determine broadly what type of uranium ore deposit would most likely be found in Alberta. Unless Aphebian metasediments are present in quantity beneath the Athabasca Group, any deposit in Alberta will have characteristics similar to those present in the Archean rocks. Accordingly, Alberta deposits will be relatively low-grade, although small high-grade pods may be present. These pods will occur at, or close to, the unconformity, with greater probability of being found within the sandstone than in deposits at the eastern edge of the basin. The ore deposits will be associated with basement faults, which were reactivated after the deposition of the Athabasca sandstone, hence contribute to relief on the unconformity. The basement rocks will contain a graphitic component, and there may be a sericitic and chloritic halo around the deposit. All these factors are used to aid exploration.

Exploration for uranium in the Athabasca Basin in Alberta has been intermittent and beset by difficulties. The announcement of the discovery of the Rabbit Lake orebody in 1968 sparked interest in Alberta, and most land thought to be underlain by Athabasca sandstone was optioned within the following year. Work on individual permits, however, was minor and limited to airborne reconnaissance with little or no ground follow-up. In 1974, Eldorado Nuclear Limited took out permits along what was then thought to be the edge of the sandstone. This led to a new phase of exploration that lasted until 1981.

Eldorado Nuclear Limited (Laanela, 1977; Fortuna, 1979), Norcen Energy Resources Limited (McWilliams and Cool, 1979) and British Petroleum Minerals Ltd. (Bradley, 1978) extended the mapped southwestern limit of the Athabasca Group considerably farther west than previously thought. The results obtained by these three companies, however, were disappointing. The anomalies discovered by airborne reconnaissance were found on ground follow-up to be surficial features in the Devonian cover, or features within the basement with no overlying sandstone. Graphitic horizons in the basement subcrop could not be traced beneath the sandstone. In all cases, thorium values were higher than uranium and assays of basement rocks produced no values higher than 10 ppm uranium. Inferred faults in the area that may offset the sandstone edge do not show on airborne input EM or magnetometer surveys and, therefore, are not graphitic and probably are completely healed.

To the north, Uranerz Exploration and Mining Ltd. (Lehnert-Thiel *et al.*, 1978) undertook extensive exploration and drilling on the northern edge of the basin at Fallingsand and Greywillow Points. Although their results in Alberta were disappointing, the exploration in Saskatchewan discovered the Maurice Bay deposit.

A joint venture headed by Golden Eagle Oil and Gas Limited worked on leases on the south shore of Lake Athabasca at Stone Point and Jackfish Creek (Nelson, 1978). Although this work encountered prohibitive thicknesses of sandstone (in excess of 1200 m in some places), it yielded core that has been of tremendous value in unravelling the stratigraphy of the basin. Drilling was undertaken on a smaller scale by Flin Flon Mines Limited on Burntwood Island, by Esso Minerals Canada Limited east of Old Fort Bay (Brown, 1978) and by Chevron Oil and Gas Limited around Agar Lake.

Since 1981, exploration activity has declined to a very low level as a result of a depressed uranium market. The last work was done by Norcen Energy Resources Limited on an outlier of Athabasca Group rocks that straddles the Alberta-Saskatchewan border east of Burstall Lake. A new phase of exploration may be heralded by the acquisition of Permit 6884120001 northeast of Barber Lake by Uranerz Exploration and Mining Ltd. in December 1984.

Several difficulties hamper exploration in Alberta. An often-quoted figure for the effective depth for geophysical methods is 200 m; thus, it is crucial to determine accurately the edge of the sandstone cover. The absence of outcrops in the southwestern portion of the basin makes this difficult, and until the area was drilled in the mid-1970s previously published maps showed the sandstone edge far to the east of its actual position. The overburden, too, presents a problem. Unlike many areas in Saskatchewan, the overburden in the southern portion of the Alberta basin is not locally derived. Thus, surface geochemical sampling and radioactive boulder plotting are not very useful exploration tools, since any uranium-rich detritus is likely to have come from the known deposits of Cluff Lake, not from hidden deposits in Alberta. For that reason also, airborne radiometric anomalies have turned out to be overburden, rather than bedrock features. Other exploration methods, including aeromagnetic interpretation, track etch search for radon and hammer seismic, have also been of limited value so far.

Potential in Alberta

Reconnaissance exploration over much of the Athabasca Basin in Alberta serves to delineate broad areas for worthwhile further work. Areas where there is no sandstone cover and where the sandstone is more than 200 m thick can be eliminated. No areas of thin sandstone cover have been found away from the edge of the basin. Thus, attention can be focussed on the edge of the sandstone.

To the north, the basin edge is covered by the waters of Lake Athabasca (figure 49). Where it onlaps the north shore of the lake, the edge has been extensively drilled with unpromising results (Lehnert-Thiel *et al.*, 1978). The sandstone outcrops on Burntwood Island, but is over 300 m thick (FC-009-162-T, figure 4) indicating that the sandstone/basement contact at the northern edge of the basin has a steep dip and may be faulted. This is supported by examination of the outcrop at Fidler Point, where the sandstone/basement contact is not faulted, but dips at 55°, indicating tectonic activity in the area. The eastern edge of the Athabasca Group is overlain by Devonian sediments and by 90 m of deltaic muds. The southern edge remains as a potential area for exploration, but even this area has its complications. The Athabasca Group is overlain by patches of Devonian carbonates (figure 4) and by thick overburden, which is not locally derived. The unconformity dips gently to the north away from the sandstone edge, hence there is a wide area along the southern edge of the basin where the sandstone is less than 200 m thick (Area A, figure 49). The sandstone edge may be fault-controlled and irregular on a detailed scale (Saracoglu *et al.*, 1983).

Areas where outliers of sandstone may be present are outlined in figure 49 (areas B and C). Area B is an area of possible sandstone outliers beneath thin Devonian cover. The Devonian cover is probably less than 40 m thick in this area as is the overburden.

The discovery of an outlier of Athabasca Group rocks to the north of the basin suggests another area of potential (area C, figure 49). Many sand-filled depressions occur within the Shield area to the north of Lake Athabasca. Some depressions may be underlain by remnants of a once more extensive Athabasca Group (J. Godfrey, pers. comm.). The largest depression is 18 km northeast of Fort Chipewyan. If sandstone occurs in these depressions, it would be thin and a prime exploration target.

Mapping of the crystalline basement below the Athabasca Groups may prove to be a useful exploration tool. Regionally areas of Aphebian metasediments and locally areas of graphitic gneiss would both suggest good localitites for further exploration.

The problem of the thick overburden, particularly over the southern margin of the basin, could profitably be addressed on a regional scale. Available evidence (Laanela, 1977; Fortuna, 1979) suggests that the source of anomalies within the overburden was to the west in Saskatchewan. The possibility that more than one till is present, however, cannot be overlooked. The mapping of other tills in the area and the establishment of a direction of transport for them could be a useful aid to further exploration.

The identification of hydrothermal alteration within the sandstone and the basement would also be good

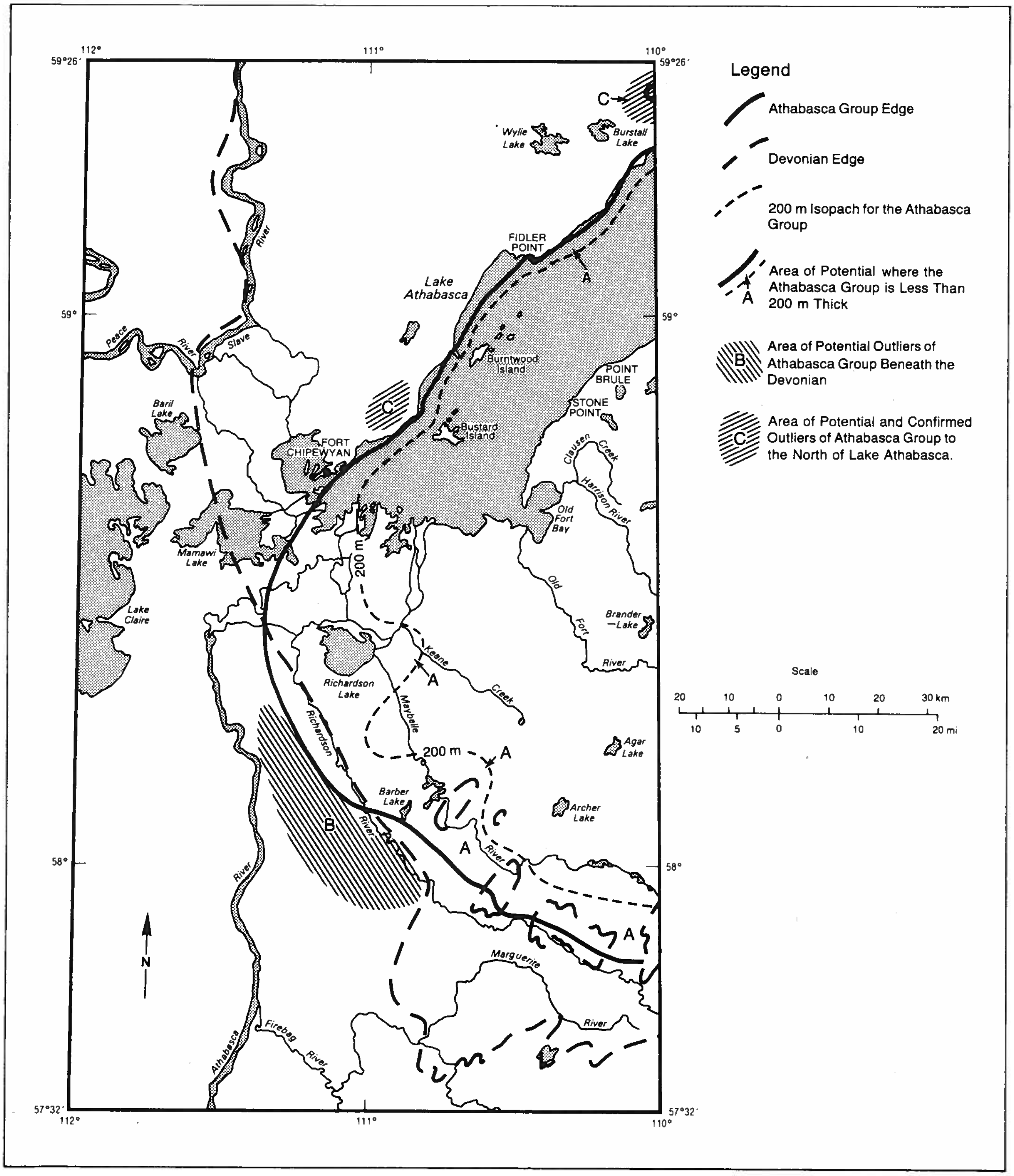

Figure 49. Areas of potential for uranium exploration in the Athabasca Basin in Alberta.

exploration tools. Tremblay (1983) suggests that MgO enrichment may be used to distinguish hydrothermal from regolithic alteration and would, thus, be a good indicator of uranium mineralization.

Geochemical halos are present within the Athabasca Group around both the Deilmann and Midwest deposits in Saskatchewan (Sopuck *et al.*, 1983). Enrichment in B, Mg, S, Pb, Sr and P, Fe depletion, a reduction in the ferric-ferrous ratio, and K_2O/Al_2O_3 ratios of less than 0.04 characterize the 400 m wide halo around the

Deilmann deposit. A similar halo (with a K_2O/Al_2O_3 ratio of 0.18) extends for 500 m around the Midwest deposit. Boron-magnesium metasomatism also forms distinctive geochemical halos around some deposits. Geochemical alteration halos can thus be used to expand drilling targets by as much as 15 times (Sopuck *et al.*, 1983).

Economic deposits other than uranium may be present within the Athabasca Basin. The best possibilites are from lead/zinc deposits, phosphate and bitumen. Galena and sphalerite mineralization occur in the fracture system cutting the Manitou Falls Formation of FC-007-586-T and could be present in economic amounts at some locality. A prime target would be where this fracture system intersects the unconformity. In the region of FC-007-586-T, however, the sandstone is more than 1255 m thick. Walker (1981) suggests "favorable host rock and depositional environment for Pine Point type Pb-Zn mineralization" on S.M.D.C.'s permit 6878110002, although no mineralization was encountered. The occurrence of galena predating the uranium mineralization at Midwest Lake in Saskatchewan is taken to indicate potential for lead mineralization within the basal Athabasca Group by Cumming *et al.* (1984).

The phosphates associated with the tuffs of the upper member of the Wolverine Point Formation consist of pure fluorapatite with no associated radioactivity. Their presence in core is extremely patchy and they do not approach economic quantities. Even if thicker and more continuous areas of phosphatization were to be found, the Wolverine Point Formation outcrops extremely rarely and is usually covered by thick overburden or by the waters of Lake Athabasca.

Bitumen occurs within the pores of the sandstone and within fractures in the Devonian, the Athabasca Group and the basement. An analysis of the bitumen included in appendix G was obtained by extraction of a sample from FC-039-092-T and yielded almost 6 percent tar. Even if deposits of sufficient size and richness exist, the inaccessibility of the area and the indurated nature of much of the sandstone would combine to make extraction uneconomic.

Summary

The Athabasca Group in Alberta is largely the result of erosion of a subaerially weathered crystalline basement. Initial sedimentation occurred in fluvial environments in a restricted subbasin with a northeast to southwest axis, forming the Fair Point Formation. After a depositional hiatus, fluvial transport from the south deposited the Manitou Falls Formation, which overlapped the previously filled subbasin. Fluvial conditions gave way to a restricted marine environment by late Wolverine Point time, when an influx of silica oversaturated pyroclastics produced sequences of bedded tuffs. With the waning of the volcanicity, detrital processes took over and the Locker Lake Formation probably marks a return to fluvial conditions. By Locker Lake time, deposition was occurring in a basin with an east to west axis.

Soon after deposition, the tuffs of the upper member of the Wolverine Point Formation underwent devitrification. The devitrification aided the formation of fluorapatite within the tuffs and probably released silica to the surrounding sandstones. Within the permeable sandstones an early phase of kaolinite and carbonate formation was accompanied by mobilization of hematite. The redistribution of silica from areas of high pH to areas of low pH formed stylolites and solution seams, and quartz overgrowths. Possibly overlapping this phase, and in some cases related to silica dissolution, was a widespread illitization event. This illitization occurred primarily within the permeable sandstones and was probably the result of the migration of potassium-rich alkali fluids from the basement. Authigenic kaolinite formation at about 250 Ma may have been related to uplift of the basin. This uplift may also have been related to one of several post-silica redistribution phases of iron remobilization. After some fracturing of the sandstone, carbonates and sulfides were locally introduced, and finally bitumen migrated into the sandstone, probably from the heavy oil deposits to the south.

The stratigraphy established in Alberta differs from that in Saskatchewan south of township 111. Resolving the difference is complicated by the lack of data on both sides of the border. However, evidence in Alberta suggests a change in facies within the Manitou Falls, possibly an increased aeolian component in the south.

The stratigraphic divisions established on the basis of hand specimens are borne out by detailed petrographic examination. Clay mineral compositions in the rock plotted against depth can also be related locally to the lithostratigraphy. The clay stratigraphy is, however, probably primarily related to the permeability. Except for the tuffaceous beds, kaolinite predominates in impermeable horizons and illite in the permeable. Kaolinite is the original clay, and illite is the result of post-depositional alteration.

The Kübler indices of the Athabasca Group indicate high-grade diagenesis and deep burial. This is in keeping with previous fluid inclusion work and indicates a considerable thickness of sediment removed from the top of the basin.

Economically, the Athabasca Group is extremely important in Saskatchewan. In Alberta it has not fulfilled its potential, partly because the Athabasca Basin in Alberta is not an easy place to work geologically. Study of the distribution of the Athabasca Group suggests that the most promising areas would be the southern edge of the group. Alternatively, if the presence of Athabasca Group outliers to the north or west were proved, these would be good exploration prospects.

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Appendix A

Details of core stored in the Alberta M.E.S.S. facility

ARC hole Number	Location Lsd/Sec/Tp/R/Mer	Units Penetrated	Percentage Retained by ARC	Core condition	Length in metres	Dip in degrees	Company name	Company Hole number	Remarks
FC-001-010	06/01/115/01w4	---/ath/---	8%	good	355.7	90	golden eagle	ddh 78-1	hole abandoned
FC-002-013	06/01/115/01w4	---/ath/---	8%	good	264.3	90	golden eagle	ddh 78-1a	hole abandoned
FC-003-043	15/36/114/01w4	---/ath/bsm	11%	good	906.7	90	golden eagle	ddh 78-2	
FC-004-090	01/01/115/01w4	---/ath/bsm	18%	good	919.5	90	golden eagle	78lajv 003	
FC-005-393-T	06/01/115/01w4	---/ath/bsm	100%	good	847.6	89	golden eagle	79lajv 006	
FC-006-082	12/36/114/01w4	---/ath/bsm	20%	good	922.6	90	golden eagle	79lajv 007	
FC-007-586-T	11/35/113/02w4	---/ath/---	100%	fair	1255	89	golden eagle	78lajv 004	ext. fracs. in part
FC-008-141	13/28/113/02w4	---/ath/---	28%	good	1160	90	golden eagle	78lajv 005	
FC-009-162-T	10/32/114/04w4	---/ath/---	100%	good	359	90	flin flon	ddh-ij-79	hole abandoned
FC-010-004	nw/04/107/09w4	dev/---/bsm	15%	fair	93	90	norcen	r1	core condensed by norcen
FC-011-004	nw/21/104/06w4	dev/---/bsm	30%	fair	59.2	90	norcen	r2	core condensed by norcen
FC-012-004	nw/35/103/07w4	dev/---/bsm	20%	fair	68.6	90	norcen	r3	core condensed by norcen
FC-013-004	ne/12/105/07w4	dev/---/bsm	25%	fair	102.8	90	norcen	r4	core condensed by norcen
FC-014-090	se/26/107/05w4	---/ath/---	100%	good	252.2	90	norcen	r5	hole abandoned
FC-015-102	ne/27/107/06w4	---/ath/bsm	100%	good	233.9	90	norcen	r6	
FC-016-015	ne/28/107/02w4	---/ath/---	20%	fair	184.2	90	norcen	r7	core condensed by norcen
FC-017-027	sw/13/104/02w4	---/ath/---	30%	fair	227.8	90	norcen	r8	
FC-018-008	ne/12/105/07w4	dev/---/bsm	100%	poor	79.5	89	norcen	rr1	poor rec. some core split
FC-019-040	00/23/104/06w4	dev/---/bsm	100%	fair	99.7	72	norcen	rr2	
FC-020-020	00/35/104/06w4	---/---/bsm	100%	fair	69.2	90	norcen	rr3	some core split by norcen
FC-021-006	00/26/104/06w4	---/---/bsm	100%	good	35.6	90	norcen	rr4	
FC-022-030	14/21/104/06w4	dev/---/bsm	100%	good	121	75	norcen	rr5	
FC-023-035	10/29/104/06w4	dev/---/bsm	100%	good	102.7	68	norcen	rr6	some core split by norcen
FC-024-027	04/28/104/06w4	dev/---/bsm	100%	good	117.9	80	norcen	rr7	
FC-025-018	05/28/104/06w4	dev/---/bsm	100%	good	111.8	90	norcen	rr8	some core split by norcen
FC-026-043	00/06/107/06w4	---/ath/---	100%	good	151.5	90	norcen	rr10	abandoned no water
FC-027-101-T	00/06/107/06w4	---/ath/bsm	100%	good	276.4	90	norcen	rr11	
FC-028-114	16/26/107/06w4	---/ath/---	100%	good	307	90	bp minerals	kdh 78-1	
FC-029-065	08/24/108/06w4	---/ath/---	100%	good	206.3	90	bp minerals	kdh 78-1	
FC-030-106-T	16/07/108/05w4	---/ath/bsm	100%	good	292	90	bp minerals	kdh 78-3	
FC-031-035	16/23/103/04w4	dev/ath/bsm	100%	good	118	90	eldorado	508-5	no core 56m to 64m
FC-032-026-T	10/15/103/04w4	dev/ath/bsm	100%	fair	105.5	90	eldorado	508-6	poor recovery in dev
FC-033-068-T	15/29/105/04w4	dev/ath/bsm	100%	good	182	90	eldorado	508-9	
FC-034-037	08/04/105/05w4	dev/ath/---	100%	good	118	90	eldorado	508-10	
FC-035-037-T	13/22/102/02w4	dev/ath/bsm	100%	good	145.6	90	eldorado	508-14	
FC-036-010	10/34/102/05w4	---/---/bsm	100%	good	72.5	90	eldorado	508-15	
FC-037-062	07/26/103/03w4	---/ath/---	100%	good	173.1	90	eldorado	508-16	
FC-038-041	02/12/104/06w4	dev/---/bsm	100%	good	112.7	90	eldorado	508-18	
FC-039-092-T	15/17/104/04w4	---/ath/bsm	100%	good	214.5	90	eldorado	508-19	
FC-040-058	12/08/102/02w4	---/---/bsm	100%	good	153.3	90	eldorado	508-23	
FC-041-031	15/16/102/02w4	dev/ath/bsm	100%	good	108.8	90	eldorado	508-26	
FC-042-009	08/30/102/02w4	dev/ath/bsm	100%	fair	87.5	90	eldorado	508-33	
FC-043-038	02/22/102/02w4	dev/ath/bsm	100%	good	163.4	86	eldorado	508-34	
FC-044-020	12/36/102/03w4	dev/ath/bsm	100%	fair	115.5	90	eldorado	508-35	
FC-045-032	02/01/103/03w4	dev/ath/bsm	100%	fair	124	90	eldorado	508-36	
FC-046-021	03/32/102/02w4	dev/ath/bsm	100%	fair	142.3	90	eldorado	508-37	
FC-047-006	09/03/102/01w4	dev/---/bsm	100%	fair	102.1	87	eldorado	508-40	poor recovery in dev
FC-048-040-T	14/03/103/03w4	dev/ath/bsm	100%	good	148.7	72	eldorado	508-41	
FC-049-006	16/24/106/02w4	---/ath/---	7%	fair	176	90	chevron	77-1	
FC-050-005	05/27/106/01w4	---/ath/---	4%	fair	261	90	chevron	77-2	
FC-051-006	13/36/105/01w4	---/ath/---	5%	fair	246	90	chevron	77-3	
FC-052-106-T	06/08/106/02w4	---/ath/---	90%	good	245.9	90	chevron	77-4	
FC-053-001	04/06/111/03w4	---/ath/---	1%	poor	152.4	90	macleod	ddh-1	core in field/poor condition
FC-054-001	16/36/110/04w4	---/ath/---	1%	poor	152.4	90	macleod	ddh-2	core in field/poor condition
FC-055-024-T	11/35/118/01w4	---/ath/bsm	100%	good	62.4	90	uranerz	gw-8	
FC-056-015	03/02/119/01w4	---/ath/bsm	100%	good	43.5	90	uranerz	gw-11	
FC-057-006	10/34/118/01w4	---/ath/bsm	100%	good	29.5	90	uranerz	gw-18	
FC-058-015	02/34/118/01w4	---/ath/bsm	100%	good	41.7	90	uranerz	gw-19	
FC-059-014	15/21/118/01w4	---/ath/bsm	100%	good	38.7	90	uranerz	fs-48	
FC-060-017	12/21/118/01w4	---/ath/bsm	100%	good	41.7	90	uranerz	fs-60	
FC-061-011	14/21/118/01w4	---/ath/bsm	100%	good	29.5	90	uranerz	fs-79	
FC-062-008	12/21/118/01w4	---/ath/bsm	100%	good	26.5	90	uranerz	fs-86	
FC-063-010	03/28/118/01w4	---/ath/bsm	100%	good	26.5	90	uranerz	fs-97	
FC-064-015-T	15/21/118/01w4	---/ath/bsm	100%	good	38.7	90	uranerz	fs-103	
FC-065-014	15/21/118/01w4	---/ath/bsm	100%	good	38.7	90	uranerz	fs-105	
FC-066-012	01/28/118/01w4	---/ath/bsm	100%	good	32	90	uranerz	fs-106	
FC-067-011	04/27/118/01w4	---/ath/bsm	100%	good	29.6	90	uranerz	fs-111	
FC-068-000	08/05/111/02w4	---/ath/bsm	0%	none	1017.1	90	esso	of78-1	core lost in fire
FC-069-000	12/12/112/01w4	---/ath/---	0%	none	1105.5	90	esso	of78-2	core lost in fire
FC-070-001	15/21/103/03w4	---/ath/---	100%	poor	50.9	90	eldorado	508-4	1.3m core/hole abandoned
FC-071-071-T	00/33/106/07w4	---/ath/bsm	100%	good	215.5	90	norcen	80-e1	
FC-072-042-T	00/34/107/08w4	dev/ath/bsm	100%	good	197.8	90	norcen	80-e2	
FC-073-009	00/14/104/07w4	dev/---/bsm	100%	good	75.3	90	norcen	80-e3	
FC-074-026	00/06/104/06w4	dev/---/bsm	100%	good	102.7	80	norcen	80-e4	
FC-075-047	10/17/108/08w4	---/ath/bsm	100%	good	191	90	s.m.d.c.	wb1	core split
FC-076-054	10/16/104/10w4	dev/---/bsm	100%	good	226.4	90	s.m.d.c.	wb4	core split

Appendix A (continued)

Details of core stored in the Alberta M.E.S.S. facility

ARC hole Number	Location Lsd/Sec/Tp/R/Mer	Units Penetrated	Percentage Retained by ARC	Core condition	Length in metres	Dip in degrees	Company name	Company Hole number	Remarks
FC-077-012	09/15/120/01w4	---/---/bsm	100%	good	41	90	norcen	81-bl-1	
FC-078-020	09/15/120/01w4	---/---/bsm	100%	good	60	63	norcen	81-bl-2	
FC-079-019	15/11/120/01w4	---/---/bsm	100%	good	60	63	norcen	81-bl-3	30.6m to 38.7m core mixed
FC-080-004	01/13/120/01w4	---/---/bsm	100%	good	17	90	norcen	81-bl-4	
FC-081-005	01/13/120/01w4	---/ath/bsm	100%	good	27	90	norcen	81-bl-5	
FC-082-007	01/13/120/01w4	---/ath/bsm	100%	good	35	90	norcen	81-bl-6	
FC-083-003	01/13/120/01w4	---/ath/bsm	100%	good	20	90	norcen	81-bl-7	
FC-084-010	08/13/120/01w4	---/ath/bsm	100%	good	38	90	norcen	81-bl-8	
FC-085-011-T	08/13/120/01w4	---/ath/bsm	100%	good	42.5	90	norcen	81-bl-9	
FC-086-003	01/11/120/01w4	---/---/bsm	100%	good	9.5	90	norcen	81-bl-10	
FC-087-007	14/36/119/01w4	---/---/bsm	100%	good	25	90	norcen	81-bl-11	
FC-088-006	14/36/119/01w4	---/---/bsm	100%	good	22.5	90	norcen	81-bl-12	
FC-089-005	13/24/119/01w4	---/---/bsm	100%	good	29.5	90	norcen	81-bl-13	
FC-090-003	16/23/119/01w4	---/---/bsm	100%	good	19	90	norcen	81-bl-14	
FC-091-011	09/23/119/01w4	---/---/bsm	100%	good	40	50	norcen	81-bl-15	38m to 40m core mixed
FC-092-015	13/24/119/01w4	---/---/bsm	100%	good	60	50	norcen	81-bl-16	

Legend
dev = devonian
ath = athabasca group
bsm = crystalline basement

Appendix B

Drill hole elevations and depths of formation tops

ARC Hole Number	Hole Elevation	Devonian	Otherside	Locker Lake	Upper member Wolverine Point	Lower member Wolverine Point	Manitou Falls	Fair Point	Basement
FC-001-010	~225	-	-	28.7	50.7?	?	>355.7	-	-
FC-002-013	~225	-	-	30.5	58.5?	?	>264.3	-	-
FC-003-043	~230	-	-	28	81.4	~181.4	265.4	515	877.7
FC-004-090	~230	-	-	18.3	84.5	~183.6	~268	528.5	888.2
FC-005-393-T	~220	-	-	30.5	71.9	171.6	255.5	505	823.4
FC-006-082	~225	-	-	25.9	87.4	~200	~284	535	896.2
FC-007-586-T	~230	-	-	3.7	208.4	325.2	503	960	>1255
FC-008-141	~225	-	-	32.6	163.8	~273.1	449.1	906.4	>1160
FC-009-162-T	213	-	-	-	-	-	3	98.6	>359
FC-010-004	229	43.5	-	-	-	-	-	-	83.9
FC-011-040	287	33.6	-	-	-	-	-	-	53.4
FC-012-004	288	27.8	-	-	-	-	-	-	60.7
FC-013-004	282	62.5	-	-	-	-	-	-	96.7
FC-014-090	390	-	-	-	-	-	35.1	230?	>252.2
FC-015-102	226	-	-	-	-	-	13.7	130	219.7
FC-016-015	305	-	-	-	-	-	47.6	-	>184.2
FC-017-027	366	-	-	-	-	-	34.8	-	>227.8
FC-018-008	299	58.5	-	-	-	-	-	-	73.1
FC-019-040	224.3	11.8	-	-	-	-	-	-	22.5
FC-020-020	281.9	-	-	-	-	-	-	-	28.6
FC-021-006	289.5	-	-	-	-	-	-	-	23.7
FC-022-030	262.1	52.4	-	-	-	-	-	-	66.6
FC-023-035	262.1	26.9	-	-	-	-	-	-	31.5
FC-024-027	298.7	57.8	-	-	-	-	-	-	77
FC-025-018	294.1	60.9	-	-	-	-	-	-	83.5
FC-026-043	274	-	-	-	-	-	58.5	137.5	>151
FC-027-101-T	274	-	-	-	-	-	58.3	138.3	267.3
FC-028-114	267	-	-	-	-	-	59	185.6	>307
FC-029-065	259	-	-	-	-	-	64	166.7	>206.3
FC-030-106-T	274	-	-	-	-	-	61.9	204.5	259.2
FC-031-035	342	31.9	-	-	-	-	78	-	81
FC-032-026-T	342.5	49.1	-	-	-	-	79.8	-	98.4
FC-033-068-T	315.3	27.7	-	-	-	-	33.2	116.2	133.3
FC-034-037	307.7	36.9	-	-	-	-	84	-	>118
FC-035-037-T	383.9	59.7	-	-	-	-	67.6	-	131.7
FC-036-010	338.2	-	-	-	-	-	-	-	51.8
FC-037-062	365.7	-	-	-	-	-	33.5	-	>173.1
FC-038-041	301.6	26.5	-	-	-	-	-	-	35.9
FC-039-092-T	319.9	-	-	-	-	-	15.8	-	170.9
FC-040-058	359.5	-	-	-	-	-	-	-	32.6
FC-041-031	379	36.5	-	-	-	-	52.5	-	86.8

Appendix B (continued)

Drill hole elevations and depths of formation tops

ARC Hole Number	Hole Elevation	Devonian	Otherside	Locker Lake	Upper member Wolverine Point	Lower member Wolverine Point	Manitou Falls	Fair Point	Basement
FC-042-009	371.1	42.6	-	-	-	-	~52.5	-	~67.7
FC-043-038	393	54.8	-	-	-	-	76.6	-	147.6
FC-044-020	365.3	~52	-	-	-	-	~80	-	84.9
FC-045-032	366	35.7	-	-	-	-	~94.2	-	110.3
FC-046-021	370.5	57.9	-	-	-	-	86.9	-	113.3
FC-047-006	443.5	64.2	-	-	-	-	-	-	87.4
FC-048-040-T	363.7	37.5	-	-	-	-	106.6	-	130.2
FC-049-006	329	-	-	-	-	-	12	-	>176
FC-050-005	335	-	-	-	-	-	25	-	>261
FC-051-006	341	-	-	-	-	-	6	-	>246
FC-052-106-T	332	-	-	-	-	-	16.1	-	>245.9
FC-053-001	~219	-	-	-	-	75.3?	-	-	>147.5
FC-054-001	~219	-	-	-	-	36.2?	-	-	>152.4
FC-055-024-T	220	-	-	-	-	-	-	11.8	44.1
FC-056-015	225	-	-	-	-	-	-	10.1	34.4
FC-057-006	221	-	-	-	-	-	-	16.3	20.7
FC-058-015	216	-	-	-	-	-	-	7.9	33.2
FC-059-014	216	-	-	-	-	-	-	7.9	38.7
FC-060-017	216	-	-	-	-	-	-	6.1	9.7
FC-061-011	216	-	-	-	-	-	-	7.5	9.7
FC-062-008	216	-	-	-	-	-	-	9.7	10.1
FC-063-010	216	-	-	-	-	-	-	7	8.2
FC-064-015-T	216	-	-	-	-	-	-	6.7	21.7
FC-065-014	216	-	-	-	-	-	-	7.9	20.6
FC-066-012	216	-	-	-	-	-	-	6.4	15.5
FC-067-011	216	-	-	-	-	-	-	6.4	16.2
FC-068-000	~250	-	-	-	46.9	~191.7	~289.6	661.1	1010.1
FC-069-000	~265	-	8.2	~221.6	~266	~438	~568.1	~959.2	>1105.5
FC-070-001	363	-	-	-	-	-	49.6	-	>50.9
FC-071-071-T	274	-	-	-	-	-	61.3	110.6	206.6
FC-072-042-T	247	90.5	-	-	-	-	-	124	192.7
FC-073-009	299.3	50	-	-	-	-	-	-	68
FC-074-026	301.1	39.1	-	-	-	-	-	-	61.4
FC-075-047	219	-	-	-	-	-	-	93.9	154.5
FC-076-054	269	98.7	-	-	-	-	-	-	204.8
FC-077-012	297	-	-	-	-	-	-	-	15.6
FC-078-020	297	-	-	-	-	-	-	-	14.6
FC-079-019	274	-	-	-	-	-	-	-	11.6
FC-080-004	282	-	-	-	-	-	-	-	9.7
FC-081-005	282	-	-	-	-	-	-	13	17.5
FC-082-007	282	-	-	-	-	-	-	20.6	26.7
FC-083-003	282	-	-	-	-	-	-	15.4	15.6
FC-084-010	282	-	-	-	-	-	-	15.7	32.5
FC-085-011-T	282	-	-	-	-	-	-	15.7	38
FC-086-003	274	-	-	-	-	-	-	-	4.5
FC-087-007	267	-	-	-	-	-	-	-	9.7
FC-088-006	267	-	-	-	-	-	-	-	9.9
FC-089-005	256	-	-	-	-	-	-	-	16.5
FC-090-003	256	-	-	-	-	-	-	-	13.4
FC-091-011	256	-	-	-	-	-	-	-	10.8
FC-092-015	256	-	-	-	-	-	-	-	19.4

All depths in metres and corrected for angled holes.

Appendix C

Index of sample depths for thin sections

ARC Hole Number	Locker Lake Formation	Upper Member Wolverine Point Formation	Lower Member Wolverine Point Formation	Manitou Falls Formation	Fair Point Formation
FC-004-090	49.2 84.2	153.7		271.5	
FC-005-393-T	33 45.1 58.5 67.9	73 73.2 73.5 73.7	177.9 181.2 191.6 217	256 263.2 264 289.7	506 512.7 536.5 566

Appendix C (continued)

Index of sample depths for thin sections

ARC Hole Number	Locker Lake Formation	Upper Member Wolverine Point Formation	Lower Member Wolverine Point Formation	Manitou Falls Formation	Fair Point Formation
		74	247.2	335.2	573.3
		86.7		371.6	
		109.7		377.8	
		112		417.4	
		113.1		417.7	
		116		439.6	
		118		472.2	
		119.4		473.8	
		122.2		491.4	
		122.8		503.4	
		125.3		503.5	
		126.6			
		131.5			
		135.8			
		136.6			
		138.5			
		140.4			
		142.6			
		147.5			
		147.6			
		147.8			
		147.9			
		148			
		148.1			
		149.9			
		151.3			
		154.2			
		156			
		165.2			
		168.6			
		169.4(1)			
		169.4(2)			
		169.4(3)			
		169.5			
		169.6			
		169.7			
FC-006-082		121.4			
		136.4			
		146			
		146.8			
		156.5			
		156.7			
		166.8			
		174.7			
FC-007-586-T	8	211	331	528.4	967.6
	32.8	230.2	354.2	595	998.6
	62.4	253	354.8	623	1024.8
	69.7	253.2	374.3	630	1077.9
	105.3	258.2	398.4	639	1120.5
	145.2	261	421	675.5	1136.4
	146.5	265	428.7	703.1	1158.8
	164.8	265.9	450.8	723	1191.3
	168	266	458	736.7	1212.7
	205.1	266.9		762.6	1234
	206	268.7		762.8	1243
		270.8		828.1	1246
		271.1		868.6	1255
		277		894.8	

Appendix C (continued)

Index of sample depths for thin sections

ARC Hole Number	Locker Lake Formation	Upper Member Wolverine Point Formation	Lower Member Wolverine Point Formation	Manitou Falls Formation	Fair Point Formation
		279.6		913.9	
		294.3		958.9	
		307.8			
FC-008-141		215.6			
		216.4			
		224.2			
		228.6			
		236.8			
		237.3			
		240.8			
		242			
		265			
FC-009-162-T				6.6	98.7
				9.9	102.9
				14.9	113.5
				22.4	127.5
				40.3	172.2
				40.5	203
				61	232.4
				64	270.8
				76	283.6
				95.6	335
				97.4	340.6
					342.5
					344
					352
					353
					358.3
FC-014-090				54.3	
				99	
				222	
				228	
				242.9	
				245	
				250.8	
FC-015-102				17.2	148.6
				23.5	197
					205.4
					205.8
					217.8
FC-027-101-T				70.5	138.4
				114.8	157.6
				137.8	170.4
					225.1
					231.4
					235.5
					241.3
					242
					244
					247.3
					248.4
					250
					250.6
					252
					253
					254

Appendix C (continued)

Index of sample depths for thin sections

ARC Hole Number	Locker Lake Formation	Upper Member Wolverine Point Formation	Lower Member Wolverine Point Formation	Manitou Falls Formation	Fair Point Formation
					254.7
					255.2
					255.6
					256.6
					258
					260.4
					260.7
					261.5
					262.8
					264.8
					266.5
					266.6
FC-028-114				64.1	186.6
				74.3	292.6
				106	
				154.2	
				185	
FC-029-065				78.3	167
				90.5	171
				154.9	186.8
					197
					201.8
FC-030-106-T				74.6	206
				88	218.9
				89.8	247.4
				110.2	
				157.3	
				179.8	
				182.4	
				191.2	
				200	
FC-031-035				79	
FC-032-026-T				82.2	
				88.8	
				91.9	
				96.3	
FC-033-068-T				38	120.7
				41.9	129.7
				93.3	
FC-034-037				85	
				89.7	
				94.3	
				107.5	
				110.6	
				117.9	
FC-035-037-T				69.7	
				73.8	
				81	
				82	
				85	
				86.5	
				109	
				116	

Appendix C (continued)

Index of sample depths for thin sections

ARC Hole Number	Locker Lake Formation	Upper Member Wolverine Point Formation	Lower Member Wolverine Point Formation	Manitou Falls Formation	Fair Point Formation
				116.9	
				123.2	
				128.2	
				129.4	
FC-037-062				39.3	
				116.5	
				131.9	
				173.3	
FC-039-092-T				18.6	
				59	
				101.1	
				108.1	
				128.2	
				166.3	
				167.4	
				167.7	
				168.6	
				171.1	
FC-041-031				56.7	
				66.8	
				81.4	
				84.3	
FC-043-038				81.5	
				111.2	
				131.7	
				143.6	
				145.5	
FC-048-040-T				115.7	
				132.2	
				136	
FC-052-106-T				22.3	
				30.5	
				40.6	
				59.1	
				66	
				76.4	
				83.6	
				84.7	
				84.8	
				88.2	
				94.1	
				99.5	
				100.9	
				105.5	
				109	
				113	
				114.5	
				118	
				126	
				131.4	
				132.7	
				133.8	
				137.1	
				147	
				163.8	

Appendix C (continued)

Index of sample depths for thin sections

ARC Hole Number	Locker Lake Formation	Upper Member Wolverine Point Formation	Lower Member Wolverine Point Formation	Manitou Falls Formation	Fair Point Formation
				168.9	
				175	
				179.5	
				183	
				189	
				194.3	
				212.3	
				229.7	
				234.3	
				240.7	
				244.2	
FC-055-024-T					17.3
					31.8
					42.2
FC-064-015-T					8.2
					12.6

All depths in metres

Appendix D

Core descriptions for reference drill holes

Drill hole: FC-005-393-T
Location: Lsd 6, Sec 1, Tp 115, R 1, W 4th Mer
Elevation: ~220 m
Total length: 847.6 m
Date completed: February 18, 1979
Logs run: None

Depth (m) From	to	Lithology
0	30.5	Overburden
		Athabasca Group
30.5	52.1	Light pinkish gray to pale red purple, medium-grained to small-pebble rich sandstone. Cross-bedded, graded-bedded with rare clay intraclasts and minor solution seams. Minor fracturing, vertical and at 30° to core axis.
52.1	52.4	Grayish pink, very coarse-grained to pebbly sandstone. Cross-bedded, graded-bedded with minor fractures at 10° to the core axis. Pebbles of basement present.
52.4	71.9	Grayish red purple to pinkish gray, medium-grained sandstone and minor shale. Cross-bedded, graded-bedded and minor solution seams, with minor fractures vertical and at 30° and 70° to the core axis. Erosional base.
71.9	80.5	Grayish red purple, medium-grained sandstone and minor shale beds. Cross-bedded and graded-bedded with minor fractures at 30° and 45° to the core axis.

Appendix D (continued)

Core descriptions for reference drill holes

80.5	108.2	Grayish pink to red purple medium-grained, friable sandstone with graded-bedding and ovoid intraclasts. Minor fractures vertical and at 45° to the core axis. Very irregular mottled hematite staining.
108.2	155.3	Grayish red purple to pale green tuff with interbedded fine- and very fine-grained sandstone. Graded-bedding, very fine laminations and ovoid intraclasts. Minor fracturing at various angles. Chlorite and muscovite rich in part.
155.3	165.2	Pale red purple to grayish pink, medium-grained, friable sandstone. Graded-bedding, ovoid intraclasts and minor fracturing at 45° and 70° to the core axis. Minor shales up to 5 cm thick. Very irregular mottled hematite staining.
165.2	171.6	Pale red purple to very light gray, fine-grained sandstone. Ovoid intraclasts and minor solution seams with hematite filled fracture at 60° to core axis. Hematite leaching around intraclasts.
171.6	189.9	Very light gray to pinkish gray, medium-grained sandstone. Graded-bedding and many solution seams with minor fractures vertical and at 20° and 45° to the core axis.
189.9	192.0	Pale red purple to pinkish gray, medium-grained sandstone with minor interbedded tuffs. Graded-bedding and solution seams with clay filled fracture horizontal and minor fracture at 10° to the core axis.
192.0	219.9	Light pinkish gray, medium-grained sandstone, with graded-bedding, clay intraclasts and solution seams. Minor fractures vertical and at 20° and 45° to the core axis.
219.9	223.4	Light pinkish gray to pale red purple, medium-grained sandstone with minor interbedded shale. Graded-bedding, cross-bedding and minor fractures at 10° and 30° to the core axis. Shale beds up to 10 cm thick.
223.4	239.0	Very light gray, medium-grained sandstone with graded-bedding. Minor fractures at 10° and 30° to the core axis. Rare shale beds up to 5 cm thick.
239.0	274.2	Light pinkish gray, medium-grained sandstone with minor interbedded grayish red purple to green shale up to 30 cm thick. Graded-bedded, cross-bedded with many solution seams. Clay intraclasts throughout but common below 255.5 m. Minor fracturing at 10°, 30° and 45° to the core axis. Core ground 242.9 m to 246 m, 1.5 m lost.
274.2	301.3	Pale red purple to grayish pink, medium-grained sandstone. Graded-bedded with clay intraclasts and minor fractures at 10° and 30° to the core axis.
301.3	305.4	Grayish red purple to light gray, medium-grained sandstone with minor interbedded grayish red purple to green shale in beds up to 30 cm thick. Graded bedded and clay intraclasts with a bitumen filled fracture at 10° to the core axis and a clay filled fracture at 5° to the core axis.
305.4	312.9	Light pinkish gray to very light gray, medium-grained sandstone. Graded-bedded with bitumen, pyrite and clay filled fractures at 10° to the core axis.
312.9	313.9	Grayish red purple shale. Thinly bedded with fractures at 90° to the core axis and slickensides at 45°.
313.9	328.4	Very light gray to pinkish gray, medium-grained sandstone. Graded-bedded and cross-bedded with minor fractures at 10° and 20° to the core axis and bitumen filled fractures at 30°.
328.4	328.9	Grayish red purple to light gray shale and minor siltstone. Thinly bedded with minor vertical fracturing.

Appendix D (continued)

Core descriptions for reference drill holes

328.9	334.0	Pale red purple to very light gray, medium-grained sandstone. Graded-bedded, with intraclasts and solution seams. Pyrite filled fracture at 10° to core axis with minor vertical fracturing.
334.0	338.0	Pale red purple to very light gray, medium-grained sandstone with grayish red purple shale interbeds up to 30 cm thick. Cross-bedded and graded-bedded with clay intraclasts and solution seams. Minor fracture at 15° to the core axis.
338.0	373.8	Pale red purple to very light gray, medium-grained sandstone. Graded-bedded, with clay intraclasts and solution seams. Bitumen filled fracture at 20° to the core axis and minor fractures at 10° and vertical.
373.8	377.8	Light pinkish gray, medium-grained sandstone with interbedded pale red purple to light pinkish gray shale. Graded-bedded, with clay intraclasts and solution seams. Fracturing at 0°, 10°, 20° and 30° to the core axis.
377.8	447.1	Pale red purple to light pinkish gray, medium-grained sandstone. Graded-bedded with clay intraclasts and solution seams. Becomes coarser to the base. Minor fracturing at 0°, 10° and 20° to the core axis. Ground core from 428.8 to 431.9 m.
447.1	502.6	Pale red purple to light pinkish gray, medium-grained, small-pebble rich sandstone. Graded-bedded with clay intraclasts and solution seams. Minor fracturing at 0°, 20° and 90° to the core axis. Trace light green shales.
502.6	505.0	Grayish red purple, medium-grained, small-pebble rich sandstone with minor interbedded dusky red, iron rich silty shales up to 10 cm thick. Graded-bedded with solution seams. Fracturing at 30° and 80° to the core axis. Small pebbles of basement present.
505.0	640.0	Pale red purple to light pinkish gray, coarse-grained, pebbly sandstone. Pebbles of quartz and up to 35 mm in diameter. Graded-bedded with clay intraclasts and solution seams. Minor fracturing vertical and horizontal. Pebble density increases slightly to the base.
640.0	700.7	Pale red purple, coarse-grained, pebbly sandstone. Pebbles of quartz, regolith and fresh basement up to 35 mm in diameter. Graded-bedded with minor fractures at 90° to the core axis. Pebbles generally well rounded.
700.7	822.6	Pale red purple, coarse-grained, pebbly sandstone. Pebbles of quartz, regolith and fresh basement up to 35 mm in diameter. Graded-bedded and minor fracturing at 10° and 90° to the core axis. Minor sulfide mineralization at 708.9 m.
822.6	823.4	Mottled pale red purple to light pinkish gray conglomerate. Pebbles and cobbles of quartz, regolith and fresh basement in a coarse-grained sandstone matrix.
		Basement
823.4	847.6	Strongly sheared moderate to dusky red to light green regolith grading downward into sheared crystalline basement. Fractures at all angles, often hematite and chlorite filled. Minor patchy sulfide mineralization.
847.6		End of hole FC-005-393-T.

Appendix D (continued)

Core descriptions for reference drill holes

Drill hole: FC-007-586-T
Location: Lsd 11, Sec 35, Tp 113, R 2, W 4th Mer
Elevation: ~230 m
Total length: 1255 m
Date completed: August 1978
Logs run: None

Depth (m) From	To	Lithology
0	3.7	Overburden
		Athabasca Group
3.7	38.9	White to very light gray, medium-grained to pebbly sandstone. Trough cross-bedded, graded-bedded with minor fracturing at 0° and 25° to core axis and clay filled fractures horizontal. Extensive fracturing from 37.5 to 38.9 m with minor sulfides and bitumen.
38.9	41.1	Light pinkish gray, medium-grained sandstone with minor grayish red purple to light green shale beds up to 10 cm thick. Graded-bedded and cross-bedded with solution seams and clay intraclasts. Minor vertical fracturing.
41.1	62.1	Pale red purple to white, medium-grained to pebbly sandstone. Graded-bedded and cross-bedded with solution seams and clay intraclasts. Carbonate and sulfide filled fractures subperpendicular to the core axis. More pebble rich to the base.
62.1	63.1	Moderate to dusky red, very pebbly, medium-grained sandstone with interbedded green shale beds up to 20 cm thick, graded-bedded.
63.1	67.7	Very light gray, medium-grained, pebbly sandstone. Graded-bedded and cross-bedded.
67.7	72.5	Pale red purple to very light gray, medium-grained, pebbly sandstone with minor light green shale beds. Graded-bedded with fractures at 45° and 80° to the core axis.
72.5	76	Very light gray, medium-grained sandstone. Graded-bedded and cross-bedded with minor fracture at 30° to the core axis.
76	78	Pale red purple to very light gray, medium-grained, pebbly sandstone. Graded-bedded with clay intraclasts and clay filled fractures at 80° to the core axis.
78	140.9	Very light gray, medium-grained pebbly sandstone. Graded-bedded and cross-bedded with clay intraclasts. Sulfide filled fractures at 5°, 25° and 30° to the core axis. Possible clay filled, almost horizontal fault at 108.9 m.
140.9	147.1	Pale red purple to dusky red, medium-grained, pebbly sandstone with interbedded pale green siltstone and shale. Graded-bedded and cross-bedded with solution seams and clay intraclasts. Minor fault at 80° to the core axis.
147.1	160.6	Pale red purple to very light gray, medium-grained, pebbly sandstone. Graded-bedded with fractures at 0° and 30° to the core axis and a clay filled fracture at 80°.
160.6	173.1	Pale red purple to very light gray, medium-grained, pebbly sandstone with minor interbedded shale. Graded-bedded and cross-bedded with fractures at 45° and 90° to the core axis.
173.1	198	Pale red purple to very light gray, medium-grained pebbly sandstone. Graded-bedded and cross-bedded with clay intraclasts and solution seams. Fracturing at 70° and 80° to the core axis with minor clay filling.

Appendix D (continued)

Core descriptions for reference drill holes

198	202.7	Moderate to dusky red, medium-grained sandstone with minor shale beds up to 30 cm thick. Graded-bedded and cross-bedded with minor fractures at 20° to the core axis.
202.7	208.4	Very light gray to light pinkish gray, medium-grained, pebbly sandstone. Graded-bedded with solution seams. Clay filled fractures at 0° and 80° to the core axis. Pebbly erosional base.
208.4	214	Grayish red purple, medium-grained sandstone with interbedded siltstones and shales. Graded-bedded with clay intraclasts. Fractures at 0°, 30° and 90° to the core axis.
214	220	Pale red purple, medium-grained, friable sandstone. Graded-bedded with clay intraclasts.
220	223.6	Grayish red purple to grayish pink tuff with interbedded, medium-grained, friable sandstone. Ovoid intraclasts and fractures at 30°, 70° and 90° to the core axis.
223.6	228.4	Mottled pale red purple to pinkish gray, medium-grained, friable sandstone. Ovoid intraclasts and fractures at 0°, 30° and 90° to the core axis.
228.4	230	Grayish red purple, thinly bedded, silty tuff. Extensive fracturing at 90° to the core axis.
230	251.8	Mottled pale red purple to pinkish gray, medium-grained, friable sandstone. Graded-bedded with ovoid intraclasts. Fractures at 5° and 30° to the core axis and with pyrite fill at 45° to the core axis.
251.8	288.1	Mottled grayish red purple to pale green tuff interbedded with very fine-grained sandstone and siltstone. Graded-bedded and ripple cross-bedded with disturbed bedding and ovoid intraclasts. Fractures at 0°, 20°, 70° and 90° to the core axis.
288.1	302	Pale red purple to light pinkish gray, fine-grained sandstone with interbeds up to 2 m thick of grayish red purple to pale green tuff. Graded-bedded with ovoid intraclasts. Minor fractures at 35° and 90° to the core axis.
302	309.3	Mottled pale red purple to grayish pink, medium-grained sandstone. Graded-bedded with ovoid intraclasts and fractures at varying angles.
309.3	310	Grayish red purple tuff, extensively fractured at 90° to the core axis.
310	317.3	Mottled pale red purple to grayish pink, medium-grained friable sandstone. Graded-bedded with clay intraclasts and ovoid intraclasts.
317.3	325.2	Grayish red purple to pale green tuff with minor interbedded very fine-grained sandstone. Graded-bedded with fractures at 5°, 30° and 80° to the core axis.
325.2	353.5	Pale red purple to light pinkish gray, medium-grained sandstone, with minor shale beds up to 30 cm thick. Graded-bedded and cross-bedded with fractures at 0°, 20° and 90° to the core axis.
353.5	354.2	Dusky red shale with extensive fractures at 90° to the core axis.
354.2	360.8	Light pinkish gray, medium-grained sandstone. Graded-bedded with clay intraclasts and a pyrite filled fracture at 80° to the core axis.
360.8	361	Light gray, medium-grained sandstone with minor shale. Extensive clay and pyrite filled fractures at high angles to the core axis.
361	390.9	Pale red purple to very light gray, medium-grained sandstone. Graded-bedded with clay intraclasts. Vertical pyrite filled fracture and minor fracture at 30° to the core axis.

Appendix D (continued)
Core descriptions for reference drill holes

390.9	398.6	Pale red purple to very light gray, medium-grained sandstone with minor pale red purple shale beds up to 30 cm thick. Graded-bedded with clay intraclasts and minor fractures in the shale at 45° and 90° to the core axis.
398.6	474	Pale red purple to very light gray, medium-grained sandstone. Graded-bedded and cross-bedded with clay intraclasts and minor shale beds up to 10 cm thick. Fractures increase to base, are dominantly at 0°, 30°, 70° and 90° to the core axis and may have disseminated sulfide or clay or hematite in them. Possible fault at 454 m.
474	491.9	Pale red purple to very light gray, medium-grained, pebbly sandstone. Graded-bedded with clay intraclasts. Extensive fractures at 0° to 30° and at 70° and 90° to the core axis. Fractures may be lined with galena, pyrite and sphalerite.
491.9	503	Pale red purple to very light gray, medium-grained sandstone, with grayish red purple shale beds up to 30 cm thick. Graded-bedded with clay intraclasts. Extensive sulfide filled fractures at 0° to 30° and 80° to the core axis. Possible fault at l0° to the core axis at 493.7 m.
503	559	Pale red purple to very light gray, medium-grained sandstone with rare 20 cm thick shale beds. Graded bedded with clay intraclasts. Extensive fracturing with sulfide, carbonate and clay fill at 0° to 30° and 90° to the core axis.
559	634.5	Pale red purple to pinkish gray, medium-grained sandstone. Graded-bedded with clay intraclasts and solution seams. Fracturing at 0° to 30° and 70° and 90° to the core axis. Clay and disseminated sulfides present in fractures. Rare shale beds up to 30 cm thick.
634.5	639.6	Pale red purple to light gray, medium-grained sandstone. 20 cm shale at base. Graded-bedded with clay intraclasts. Minor fracture vertical.
639.6	675.3	Pale red purple to very light gray, medium-grained sandstone. Graded-bedded with clay intraclasts. Sulfide filled fractures at 20° to the core axis and clay filled fractures at 30° and 90°.
675.3	676	Mottled grayish red purple to pinkish gray, thinly bedded shale.
676	780.3	Pale red purple to very light gray, medium-grained, pebbly sandstone with rare shale beds up to 5 cm thick. Graded-bedded and cross-bedded with clay intraclasts. Hematite filled fracture at 10° to the core axis and clay filled fractures at 45° and 90°.
780.3	780.5	Pale red purple to light gray, thinly bedded shale.
780.5	839.9	Pale red purple to very light gray, medium-grained, pebbly sandstone. Graded-bedding and clay intraclasts. Fractures at 20°, 30° and 70° to the core axis with minor sulfide and clay filling.
839.9	900.3	Grayish red purple to light gray, medium-grained, pebbly sandstone. Graded-bedded and cross-bedded with clay intraclasts and solution seams. Fractures at 80° to the core axis are clay filled and those at 20° and 50° hematite filled.
900.3	960	Pale red purple to light pinkish gray, medium-grained, pebbly sandstone. Graded-bedded and cross-bedded with clay intraclasts. Clay filled fractures at 0°, 30° and 90° to the core axis.
960	1041	Pale red purple to light pinkish gray, coarse-grained, pebbly sandstone. Pebbles are of quartz and up to 20 mm in diameter. Graded-bedded with clay intraclasts.
1041	1052	Pale red purple to light gray, coarse-grained, pebbly sandstone. Graded-bedded and cross-bedded with clay intraclasts. Vertical hematite filled fracture and clay filled fracture at 20° to the core axis.

Appendix D (continued)

Core descriptions for reference drill holes

1052	1143	Pale red purple to light pinkish gray, coarse- to fine-grained, pebbly sandstone. Graded-bedded, with solution seams and clay intraclasts. Clay filled fractures at 0°, 20° and 90° to core axis. Pebbles increase in number and size toward the base.
1143	1172	Pale red purple to light pinkish gray, coarse to fine-grained, pebbly sandstone. Pebbles are of quartz, regolith and fresh basement and are up to 35 mm in diameter. Graded-bedded and cross-bedded with minor clay filled fracture at 80° to the core axis.
1172	1176	Pale red purple to pinkish gray, coarse-grained, pebbly sandstone with interbedded conglomerate. Pebbles are of quartz, regolith and fresh basement.
1176	1255	Pale red purple to pinkish gray, coarse-grained, pebbly sandstone. Pebbles mainly quartz but proportion of regolith and fresh basement increases with depth. Graded-bedded with minor hematite filled fractures at 30° to the core axis and empty fracture at 60°.
1255		End of hole FC-007-586-T.

Drill hole: FC-009-162-T
Location: Lsd 10, Sec 32, Tp 114, R 4, W 4th Mer
Elevation: 213 m
Total length: 359 m
Date completed: July 20, I979
Logs run: None. Minor sections of core removed for assay throughout.

Depth (m) From	To	Lithology
0	3	Overburden
		Athabasca Group
3	65	Light pinkish gray, medium-grained, pebbly sandstone with minor shale beds up to 30 cm thick. Graded-bedded and planar and ripple cross-bedded with clay intraclasts. Minor fractures at 20° and 70° to the core axis and vertical fracture with disseminated pyrite.
65	98.6	Pale red purple to light gray, medium-grained, pebbly sandstone with rare shale beds up to 5 cm thick. Graded-bedded and planar and ripple cross-bedded with minor vertical fracture.
98.6	329.3	Pale red purple to light gray, coarse- to fine grained, pebbly sandstone. Pebbles of quartz or rarely, fresh basement or regolith, up to 35 mm in diameter. Graded-bedded and planar cross-bedded with solution seams. Minor fractures at 0°, 35° and 60° to the core axis.
329.3	359	Pale red purple to light gray, coarse to fine grained, pebbly sandstone with interbedded grayish red purple siltstones and shales up to 60 cm thick. Pebbles are of quartz, fresh basement and regolith and up to 35 mm in diameter. Graded-bedded and planar cross-bedded with solution seams. Minor fractures at 25°, 45° and 90° to the core axis.
359		End of hole.

Appendix D (continued)

Core descriptions for reference drill holes

Drill hole: FC-027-101-T
Location: Sec 6, Tp 107, R 6, W 4th Mer
Elevation: 274 m
Total length: 276.4 m
Date completed: May 19, 1979
Logs run: None

Depth (m) From	to	Lithology
0	58.2	Overburden
		Athabasca Group
58.2	138.3	Grayish pink to very light gray, medium-grained sandstone. Graded-bedded and cross-bedded with clay intraclasts and solution seams. Fractures at 0°, 10° and 30° to the core axis and filled with pyrite and carbonate. Blebs of pyrite common above 100 m.
138.2	223	Pinkish gray to very light gray, coarse-grained, pebbly sandstone with rare pale green shales. Pebbles are of quartz, regolith and fresh basement and increase in size and number downward. Graded-bedded with solution seams. Minor fractures at 0° to 30° and 75° to core axis with clay or carbonate fill.
223	227.3	Greenish gray to grayish pink, coarse- to fine-grained, pebbly sandstone with interbedded conglomerates up to 1 m thick. Pebbles are of quartz, regolith and basement up to 35 mm in diameter.
227.3	235.5	Grayish pink to greenish gray, coarse-grained, pebbly sandstone. Graded-bedded with solution seams.
235.5	235.8	Dusky red to yellowish gray, silty shale.
235.8	242	As 227.3 to 235.5 m
242	242.6	Dark reddish brown, thin-bedded, silty shale. Fracture at 30° to the core axis.
242.6	248.7	As 227.3 to 235.5 m, becoming shaly toward the base with many shale intraclasts.
248.7	250.7	Dusky red, thin-bedded, silty to sandy shale.
250.7	253.2	Pale red purple, small pebble conglomerate, interbedded with dusky red shales. Shale intraclasts at the base.
253.2	254	Dusky red, thin-bedded, silty shale. Fracture at 10° to the core axis.
254	255.4	Pale red purple, fine-grained sandstone with minor interbedded dusky red shale. Red shale intraclasts common.
255.4	258	Dusky red, thin-bedded, silty to sandy shale with rare pebbles.
258	260.7	Pale red purple, small pebble conglomerate, interbedded with dusky red shales.
260.7	261.3	Dusky red, thin-bedded, sandy to pebbly shale.
261.3	267.3	Pale red purple to greenish gray, coarse-grained, pebbly sandstone interbedded with rare conglomerate and moderate brown siltstone and shale.
		Basement

Appendix D (continued)

Core descriptions for reference drill holes

267.3	276.4	Altered gneissic basement becoming fresher with depth.
276.4		End of hole FC-027-101-T.

Drill hole: FC-030-106-T
Location: Lsd 16, Sec 7, Tp 108, R 5, W 4th Mer.
Elevation: 274 m
Total Length: 292 m
Date completed: November 8, 1978
Logs run: None

Depth (m)		
From	To	Lithology
0	61.9	Overburden
		Athabasca Group
61.9	88.1	Light pinkish gray to light gray, medium-grained, pebbly sandstone. Graded-bedded and cross-bedded with fractures filled with bitumen at 0° to 30° to the core axis and with pyrite at 20°. Sandstone is bleached and heavily bitumen impregnated in part.
88.1	90.5	Pale red purple to light gray, medium-grained, pebbly sandstone with interbedded pale red purple to pale green siltstone and shale. Graded-bedded with clay intraclasts and bitumen filled fractures subparallel to the core axis.
90.5	176.3	Pale red purple to light gray, medium-grained, pebbly sandstone. Graded-bedded and planar cross-bedded with clay intraclasts. Carbonate and bitumen filled fractures subparallel to the core axis.
176.3	194.6	Pale red purple to light gray, medium-grained, pebbly sandstone with minor shale beds up to 10 cm thick. Graded-bedded and cross-bedded with clay intraclasts. Minor fracture at 0° to the core axis.
194.6	204.5	Pale red purple to light gray, medium-grained sandstone. Graded-bedded and cross-bedded. Minor bitumen impregnation.
204.5	259.2	Pale red purple to light gray, coarse- to fine-grained, pebbly sandstone. Pebbles are of quartz and basement and up to 35 mm in size. Minor fractures subparallel to the core axis.
		Basement
259.2	292	Regolith underlain by weathered crystalline basement becoming fresher with depth.
292		End of hole.

Drill hole: FC-032-026-T
Location: Lsd 10, Sec 15, Tp 103, R 4, W 4th Mer
Elevation: 342.5 m
Total length: 105.5 m
Date completed: November 26, 1976
Logs run: Radiometric

Depth (m)		
From	To	Lithology
0	49.1	Overburden

Appendix D (continued)

Core descriptions for reference drill holes

		Devonian
49.1	79.8	Calcareous mudstone and muddy sandstone with a basal breccia of basement fragments and reworked Athabasca Group. Disseminated pyrite and bitumen impregnation present throughout.
		Athabasca Group
79.8	89.3	White to pale pink, medium-grained sandstone. Pyrite filled fracture at 20° and siderite filled fracture at 30° to the core axis. Friable in places.
89.3	98.4	Pale pink to pale red purple, medium-grained, pebbly to cobbly sandstone. Pebbles of basement, quartz and regolith. Large quartz cobble marks the base of the sandstone.
		Basement
98.4	105.5	Regolith.
105.5		End of hole FC-032-026-T.

Drill hole: FC-033-068-T
Location: Lsd 15, Sec 29, Tp 105, R 4, W 4th Mer
Elevation: 315.3 m
Total lenth: 182 m
Date completed: December 4, 1976
Logs run: Radiometric

Depth (m)		
From	To	Lithology
0	27.7	Overburden
		Devonian
27.7	33.2	Muddy sandstone to mudstone with some bitumen impregnation.
		Athabasca Group
33.2	116.2	Pale red purple to light gray, medium-grained sandstone. Graded-bedded and planar cross-bedded with clay intraclasts and solution seams. Bitumen filled fractures at 0° to 30° to the core axis and subparallel sulfide filled fracture. Patchy bitumen impregnation.
116.2	133.3	Mottled pale red purple to pinkish gray, coarse-grained, pebbly sandstone with interbedded conglomerate. Pebbles are of quartz and basement and are up to 35 mm in diameter. Conglomerate predominates below 127 m. Bitumen filled fracture at 20° to the core axis.
		Basement
133.3	182	Regolith overlying altered to fresh gneissic basement.
182		End of hole.

Appendix D (continued)

Core descriptions for reference drill holes

Drill hole: FC-035-037-T
Location: Lsd 13, Sec 22, Tp 102, R 2, W 4th Mer
Elevation: 383.9 m
Total length: 145.6 m
Date completed: February 19, 1977
Logs run: Radiometric

Depth (m) From	To	Lithology
0	59.7	Overburden
		Devonian
59.7	67.6	Muddy calcareous sandstone and mudstone. Base is reworked Athabasca Group.
		Athabasca Group
67.6	78.6	Very light gray to grayish pink, medium-grained, pebbly sandstone. Graded-bedded and cross-bedded with solution seams. Fracture clay filled at 20° to the core axis.
78.6	119.5	Pale red purple to grayish pink, medium-grained, pebbly sandstone with interbeds of 67.6 to 78.6 m toward the top. Graded-bedded and cross-bedded with solution seams and many red shale intraclasts. Fracture clay-filled and subparallel to the core axis. Becomes more pebbly and silty toward the base.
119.5	127.4	Dusky red sandy to shaly siltstone. Quartz pebbles present in thin beds toward the base.
127.4	131.7	Conglomerate with red siltstone or sandstone matrix. Pebbles and cobbles are angular and of quartz, basement and regolith.
		Basement
131.7	145.6	Regolith underlain by altered gneissic basement, which becomes fresh with depth.
145.6		End of hole.

Drill hole: FC-039-092-T
Location: Lsd 15, Sec 17, Tp 104, R 4, W 4th Mer
Elevation: 319.9 m
Total length: 214.5 m
Date completed:
Logs run:

Depth (m) From	To	Lithology
0	15.8	Overburden
		Athabasca Group
15.8	166.5	White to grayish pink, medium- to fine-grained sandstone. Isolated pebbles present below 108.4 m. Graded-bedded and cross-bedded with rare clay intraclasts. Fractures subparallel and bitumen filled. Core bleached with patchy to heavy bitumen impregnation throughout.

Appendix D (continued)

Core descriptions for reference drill holes

166.5	168	Grayish pink, medium-grained, pebbly sandstone with interbedded dusky red pebbly shales up to 40 cm thick. Pebbles are of quartz, regolith and basement and are up to 35 mm in diameter.
168	172.7	Conglomerate and breccia. Pebbles and cobbles of quartz, regolith and fresh and altered basement in a matrix of sandstone or red siltstone. Minor disseminated sulfides.
		Basement
172.7	214.5	Regolith overlying altered and fresh gneissic basement.
214.5		End of hole FC-039-092-T.

Drill hole: FC-048-040-T
Location: Lsd 14, Sec 3, Tp 103, R 3, W 4th Mer
Elevation: 363.7 m
Total length: 148.7 m
Date completed: April 24, 1979
Logs run: Radiometric

Depth (m)		
From	To	Lithology
0	39	Overburden
		Devonian
39	111	Calcareous mudstone and carbonaceous shale that may be sandy in part.
		Athabasca Group
111	135.6	White to grayish pink, medium- to fine-grained sandstone. Rare, scattered pebbles are present toward the base. Graded-bedded and cross-bedded with rare clay intraclasts. Fractures subparallel to the core axis and may be hematite filled. Trace of disseminated pyrite.
135.6	136.2	Dusky red to grayish pink, fine-grained, silicified, pebbly sandstone.
		Basement
136.2	148.7	Regolith overlying altered gneissic basement.
148.7		End of hole.

Drill hole: FC-052-106-T
Location: Lsd 6, Sec 8, Tp 106, R 2, W 4th Mer
Elevation: 332 m
Total length: 245.9 m
Date completed: October 28, 1977
Logs run: none

Depth (m)		
From	To	Lithology
0	16.1	Overburden

Appendix D (continued)
Core descriptions for reference drill holes

		Athabasca Group
16.1	83.5	Light pinkish gray, medium- to fine-grained, pebbly sandstone. Clay intraclasts with subparallel and subperpendicular fractures filled with bitumen.
83.5	84.9	Dusky red, silty shale.
84.9	100.8	Light pinkish gray, medium- to fine-grained, pebbly sandstone with minor shale beds. Clay intraclasts and subparallel fractures filled with bitumen.
100.8	134.8	Light pinkish gray, medium-grained, pebbly sandstone with minor interbedded shales. Graded-bedded and cross-bedded with clay intraclasts. Subparallel fractures filled with bitumen.
134.8	181.3	Light pinkish gray, medium-grained, pebbly sandstone. Pebbles increase in size and number to the base and consist of quartz. Graded-bedded and planar cross-bedded with bitumen filled fractures subparallel and subperpendicular to the core axis. Fractures are extensive between 145 m and 156 m.
181.3	245.9	Pale red purple to light pinkish gray, medium-grained sandstone. Graded-bedded with intraclasts and solution seams. Fractures are subparallel and subperpendicular and bitumen filled with a possible fault at 183.6 m.
245.9		End of hole FC-052-106-T.

Drill hole: FC-055-024-T
Location: Lsd 11, Sec 35, Tp 118, R 1, W 4th Mer
Elevation: 220 m
Total length: 62.4 m
Date completed: February 26, 1978
Logs run: Radiometric

Depth (m) From	To	Lithology
0	11.8	Overburden
		Athabasca Group
11.8	30	Light pinkish gray, coarse-grained, pebbly sandstone. Pebbles of quartz and basement up to 35 mm in diameter. Minor fractures subparallel to the core axis.
30	35.9	Light pinkish gray, coarse-grained, pebbly sandstone with minor interbedded conglomerate. Pebbes are of quartz and basement and are up to 35 mm in diameter.
35.9	44.1	Light pinkish gray, coarse-grained, pebbly sandstone. Pebbles are of quartz and basement. Fracturing hematite filled and subparallel and subperpendicular.
		Basement
44.1	62.4	Regolith underlain by altered and fresh basement.
62.4		End of hole.

Appendix D (continued)

Core descriptions for reference drill holes

Drill hole: FC-064-015-T
Location: Lsd 15, Sec 21, Tp 118, R 1, W 4th Mer
Elevation: 216 m
Total length: 38.7 m
Date completed: February 9, 1978
Logs run: Radiometric

Depth (m) From	To	Lithology
0	6.7	Overburden
		Athabasca Group
6.7	21.7	Pale red purple to light pinkish gray, coarse-grained, pebbly sandstone with minor conglomerates. Pebbles are of quartz and basement and up to 35 mm in diameter. Clay intraclasts are rare. Minor subparallel fracturing. Basal conglomerate well-developed.
		Basement
21.7	38.7	Altered and fresh granitic gneiss basement.
38.7		End of hole.

Drill hole: FC-071-071-T
Location: Sec 33, Tp 106, R 7, W 4th Mer
Elevation: 274 m
Total length: 215.5 m
Date completed: July 23, 1980
Logs run: None

Depth (m) From	To	Lithology
0	61.3	Overburden
		Athabasca Group
61.3	108.3	Pale red purple to light pinkish gray, medium-grained sandstone. Graded-bedded and trough cross-bedded with clay intraclasts, subparallel bitumen filled fractures and a clay filled fracture at 10°. Bitumen impregnation heavy below 103 m and associated with minor disseminated pyrite.
108.3	110.6	Dusky red, silty shale and ironstone. Very rich in hematite, both oxidized and specularite with some magnetite. Rare solution seams are visible.
110.6	184	Pale red purple to light pinkish gray, coarse- to fine-grained, pebbly sandstone with minor interbedded conglomerate. Pebbles are of quartz and basement and up to 35 mm in diameter. Graded-bedded with solution seams. Fractures subparallel and at 80° to the core axis and bitumen filled. Traces of disseminated pyrite.
184	187.4	Pale red purple to light pinkish gray, fine-grained, pebbly sandstone. Pebbles are small and of quartz. Bitumen filled fracture at 30° to the core axis.
187.4	194.7	Light gray to pale green conglomerate. Pebbles are of quartz and basement and are up to 35 mm in diameter and decrease in number toward the base. Matrix is coarse-grained sandstone.

Appendix D (continued)

Core descriptions for reference drill holes

194.7	206.6	Light pinkish gray to light gray, coarse- to medium-grained sandstone with interbedded conglomerates up to 1 m thick. Conglomerates are as 187.4 to 194.7 m. Pebbles are of quartz and basement and cobbles are present at the base.
		Basement
206.6	215.5	Altered basement
215.5		End of hole FC-071-071-T.

Drill hole: FC-072-042-T
Location: Sec. 34, Tp. 107, R. 8, W. 4th Mer.
Elevation: 247 m
Total length: 197.8 m
Date completed: August 2, 1980
Logs run: None

Depth (m) From	To	Lithology
0	90.5	Overburden
		Devonian
90.5	110.3	Calcareous sandstone, mudstone and rare limestone.
110.3	124	Core lost during drilling.
		Athabasca Group
124	191.1	Pale red purple to light gray, coarse-grained, pebbly sandstone with rare thin conglomerate beds and rare 2 cm thick shales toward the base. Pebbles are of quartz, basement and regolith and are up to 35 mm in diameter. Fractures at 0° to 30° to the core axis, rarely sulfide filled.
191.1	192.7	Dusky red to light gray conglomerate. Pebbles are of quartz, basement and regolith and are up to 35 mm in diameter. Matrix is a coarse-grained sandstone.
		Basement
192.7	197.8	Regolith underlain by altered basement.
197.8		End of hole.

Appendix D (continued)

Core descriptions for reference drill holes

Drill hole: FC-085-011-T
Location: Lsd 8, Sec 13, Tp 120, R 1, W 4th Mer
Elevation: 282 m
Total length: 42.5 m
Date completed: 1981
Logs run: none

Depth (m) From	To	Lithology
0	15.7	Overburden
		Athabasca Group
15.7	38	Light gray to pale red purple, coarse-grained sandstone and conglomerate with minor beds of shale. Pebbles are of quartz, basement and regolith and up to 35 mm in diameter. Solution seams are present and a clay filled fracture at 45° to the core axis.
		Basement
38	42.5	Regolith overlying altered basement.
42.5		End of hole.

Appendix E

Point count data for the sandstones of the Athabasca Group

A total of seventy-two point counts were done on the sandstones and conglomerates of the Athabasca Group of Alberta. Three hundred points were taken on each thin section. Criteria were established for selecting the thin sections for point counting.

1. The thin section had to show little or no crushing of grains or clay loss due to the grinding process.
2. Thin sections with many solution seams were not used as it was not possible to measure the silica loss.
3. Preference was given to thin sections with distinct quartz overgrowths with dust rims and little or no distinct bedding on a scale smaller than the size of the section.
4. Rock fragments were taken to include grains of composite quartz.
5. No attempt was made to distinguish authigenic from detrital clay.

Despite these criteria some variability is present in the results. Clay loss during thin section preparation would lead to an apparent increase in the porosity value relative to the clay value. If no dust rim was present within a quartz grain, the entire grain was considered detrital, leading to an underestimate of the percentage of quartz overgrowths.

Locker Lake Formation

Sample Number	Quartz grains	Rock fragments	Sub-total	Quartz overgrowths	Clay	Porosity	Carbonate	Other	Grain Size
JAW81-004-84.2	41%	19%	60%	4%	36%	-	-	Trace	medium- to very coarse-grained
JAW81-005-33	77%	6%	83%	6%	5%	6%	-	Trace	medium- to coarse-grained
JAW81-005-45.1	72%	5%	77%	10%	6%	6%	1%	Trace	medium- to very coarse-grained
JAW81-005-62.9	67%	14%	81%	5%	-	14%	-	Trace	medium-grained to pebbly
JAW81-007-8	68%	11%	79%	9%	-	12%	-	Trace	coarse- to medium-grained
JAW81-007-105.3	58%	19%	77%	5%	7%	11%	-	Trace	medium-grained to pebbly
JAW81-007-205.1	62%	5%	67%	20%	9%	4%	-	Trace	medium-grained
Range	41-77%	5-19%	60-83%	4-20%	0-36%	0-14%			sublitharenite[1]
Average (7)	64%	11%	75%	8%	9%	8%			

[1]Pettijohn *et al.* 1972

Appendix E (continued)

Point count data for the sandstones of the Athabasca Group

Wolverine Point Formation
Upper member

Sample Number	Quartz grains	Rock fragments	Sub-total	Quartz overgrowths	Clay	Porosity	Carbonate	Other	Grain Size
JAW81-004-153.7	51%	7%	58%	4%	35%	1%	-	2%	very fine- to fine-grained
JAW81-005-74	47%	3%	50%	1%	49%	-	-	Trace	fine-grained
JAW81-005-86.7	65%	4%	69%	2%	27%	2%	-	Trace	medium- to coarse-grained
JAW81-005-113.1	41%	2%	43%	-	47%	-	10%	Trace	very fine-grained
JAW81-005-169.6	37%	2%	39%	1%	58%	-	-	1%	fine-grained
JAW81-006-174.7	57%	4%	61%	24%	15%	-	-	Trace	medium-grained
Range	37-65%	2-7%	39-69%	0-24%	15-58%	0-2%			lithic greywacke
Average (6)	50%	4%	54%	5%	39%				

[1]Pettijohn *et al.* 1972

Wolverine Point Formation
Lower member

Sample Number	Quartz grains	Rock fragments	Sub-total	Quartz overgrowths	Clay	Porosity	Carbonate	Other	Grain Size
JAW81-005-177.9	62%	4%	66%	22%	12%	-	-	Trace	medium- to fine-grained
JAW81-005-217.7	68%	4%	72%	13%	15%	-	-	Trace	fine- to coarse-grained
JAW81-007-354.8	68%	5%	73%	18%	-	9%-		Trace	fine- to coarse-grained
JAW81-007-458	67%	4%	71%	21%	-	8%	-	Trace	coarse- to very coarse-grained
Range	62-68%	4-5%	66-73%	13-22%	12-15%	8-9%			sublitharenite[1]
Average (4)	66%	4%	70%	18%	7%	4%			

[1]Pettijohn *et al.* 1972

Manitou Falls Formation (where underlain by crystalline basement)

Sample Number	Quartz grains	Rock fragments	Sub-total	Quartz overgrowths	Clay	Porosity	Carbonate	Other	Grain Size
JAW81-032-96.3	74%	4%	78%	5%	16%	Trace	-	Trace	medium- to very coarse-grained
JAW81-034-85	72%	10%	82%	6%	2%	10%	-	Trace	medium- to very coarse-grained
JAW81-034-94.3	65%	8%	73%	4%	21%	1%	1%	Trace	very coarse-grained to pebbly
JAW81-034-117.9	70%	6%	76%	4%	17%	1%	2%	Trace	fine-grained to pebbly
JAW81-035-69.7	71%	7%	78%	2%	20%	-	-	Trace	very coarse-grained to pebbly
JAW81-037-173.3	74%	8%	82%	1%	10%	Trace	6%	Trace	fine- to very coarse-grained
JAW81-039-166.8	66%	8%	74%	1%	21%	4%	-	Trace	fine - to coarse-grained
JAW81-052-30.5	72%	8%	80%	5%	4%	7%	4%	Trace	medium- to coarse-grained
JAW81-052-94.1	76%	4%	80%	3%	14%	3%	Trace	Trace	fine- to very coarse-grained
JAW81-052-147	71%	7%	78%	19%	-	3%	-	Trace	fine- to coarse-grained
JAW81-052-175	74%	5%	79%	7%	-	15%	-	Trace	fine- to very coarse-grained
JAW81-052-229.7	74%	5%	79%	1%	-	20%	-	Trace	medium- to coarse-grained
Range	65-76%	4-10%	73-82%	1-19%	0-21%	0-20%	0-6%		
Average (12)	72%	7%	79%	5%	10%	5%	1%		sublitharenite[1]

[1]Pettijohn *et al.* 1972

Manitou Falls Formation (basal congolomerate)

Sample Number	Quartz grains	Rock fragments	Sub-total	Quartz overgrowths	Clay	Porosity	Carbonate	Other	Grain Size
JAW81-035-123.2	36%	8%	44%	Trace	56%	-	-	Trace	pebbly to fine-grained
JAW81-039-171.6	9%	34%	43%	-	57%	-	-	Trace	pebbly to fine-grained

Appendix E (continued)

Point count data for the sandstones of the Athabasca Group

Manitou Falls Formation (where underlain by the Fair Point Formation)

Sample Number	Quartz grains	Rock fragments	Sub-total	Quartz overgrowths	Clay	Porosity	Carbonate	Other	Grain Size
JAW81-004-271.5	62%	7%	69%	24%	2%	5%	-	Trace	medium-grained
JAW81-005-263.2	63%	8%	71%	24%	2%	3%	-	Trace	medium-grained
JAW81-005-417.7	57%	14%	71%	22%	3%	3%	-	1%	fine-grained to pebbly
JAW81-005-473.8	60%	13%	73%	14%	5%	-	-	8%	medium-grained
								Hematite	
JAW81-007-595	71%	6%	77%	20%	-	2%	-	1%	medium-grained
JAW81-007-762.6	69%	6%	75%	20%	-	5%	-	Trace	medium-grained to pebbly
JAW81-007-828.1	67%	14%	81%	18%	-	1%	-	Trace	medium- to coarse-grained
JAW81-007-894.8	58%	17%	75%	16%	4%	5%	-	Trace	very coarse-grained to pebbly
JAW81-009-6.6	65%	3%	68%	23%	6%	3%	-	Trace	fine-grained to pebbly
JAW81-009-76	71%	9%	80%	11%	8%	1%	-	Trace	medium-grained to pebbly
JAW-014-99	59%	19%	78%	15%	1%	4%	-	2%	medium-grained to pebbly
								Bitumen	
JAW81-014-222	64%	4%	68%	25%	7%	-	-	Trace	medium- to coarse-grained
JAW81-015-17.2	65%	11%	76%	19%	4%	1%	-	Trace	medium- to fine-grained
JAW81-027-137.8	69%	2%	71%	17%	Trace	11%	Trace	Trace	medium-grained
JAW81-028-74.3	63%	4%	67%	27%	5%	1%	-	Trace	medium- to fine-grained
JAW81-028-185	77%	5%	82%	4%	13%	1%	-	Trace	medium- to coarse-grained
JAW81-029-78.3	60%	9%	69%	29%	-	1%	1%	Trace	medium- to coarse-grained
JAW81-029-90.5	68%	6%	74%	24%	1%	1%	-	Trace	medium- to coarse-grained
JAW81-029-154.9	70%	2%	72%	4%	24%	-	-	Trace	fine- to coarse-grained
JAW81-030-74.6	63%	7%	70%	26%	1%	3%	-	Trace	medium- to coarse-grained
JAW81-030-89.8	60%	7%	67%	32%	1%	-	-	Trace	medium-grained
JAW81-030-191.2	68%	2%	70%	3%	27%	-	-	Trace	fine-grained
Range	57-77%	2-19%	67-82%	3-32%	0-27%	0-11%			sublitharenite[1]
Average (22)	65%	8%	73%	19%	5%	2%			

[1]Pettijohn *et al.* 1972

Fair Point Formation

Sample Number	Quartz grains	Rock fragments	Sub-total	Quartz overgrowths	Clay	Porosity	Carbonate	Other	Grain Size
JAW81-005-512.7	35%	34%	69%	10%	19%	1%	-	1%	coarse-grained to pebbly
JAW81-005-536.5	43%	12%	55%	12%	33%	-	-	Trace	fine-grained
JAW81-005-573.5	41%	28%	69%	9%	22%	-	-	Trace	coarse- to very coarse-grained
JAW81-007-967.6	51%	12%	63%	7%	28%	2%	-	Trace	coarse-grained to pebbly
JAW81-007-1024.8	58%	5%	63%	5%	32%	-	-	Trace	medium-grained
JAW81-007-1136.4	49%	16%	65%	15%	20%	-	-	Trace	coarse- to very coarse-grained
JAW81-007-1191.3	47%	17%	64%	9%	27%	-	-	Trace	coarse- to medium-grained
JAW81-007-1246	49%	22%	71%	6%	23%	-	-	Trace	pebbly to very coarse-grained
JAW81-009-98.7	39%	20%	59%	10%	31%	-	-	Trace	coarse-grained to pebbly
JAW81-009-172.2	41%	26%	67%	9%	24%	-	-	Trace	very coarse-grained to pebbly
JAW81-009-232.4	42%	22%	64%	7%	29%	-	-	Trace	very coarse-grained to pebbly
JAW81-009-342.5	39%	5%	44%	9%	46%	-	-	1%	fine- to very fine-grained
JAW81-009-352	35%	22%	57%	11%	31%	-	-	1%	medium-grained to pebbly
JAW-81-014-242.9	34%	15%	49%	8%	43%	-	-	Trace	coarse-grained to pebbly
JAW81-015-148.6	37%	27%	64%	12%	23%	-	-	1%	coarse- to very coarse-grained
JAW81-027-231.4	27%	44%	71%	3%	21%	5%	-	Trace	very coarse-grained
JAW81-028-292.6	21%	50%	71%	6%	16%	2%	-	5%	very coarse-grained to pebbly
JAW81-029-197	71%	8%	79%	12%	8%	-	1%	Trace	coarse- to very coarse-grained
JAW81-030-247.4	72%	1%	73%	2%	25%	-	-	Trace	fine-grained
Range	21-72%	1-50%	44-79%	2-15%	8-46%	0-5%			
Average (19)	44%	20%	64%	9%	26%				Lithic greywacke[1]

[1]Pettijohn *et al.* 1972

Appendix F
Clay mineral logs

Clay mineral compositions in Athabasca Group core plotted against depth and related to the lithostratigraphy. See also text figures 36 and 37.

Jan Hoeve, of the Saskatchewan Research Council, analysed the clay in the winter of 1981/82 using quantitative x-ray diffraction techniques outlined in Hoeve et al., 1981. Samples were taken every 5 to 10 m depending on availability.

In all the following cases the key below applies.

K kaolinite

I illite

C chlorite

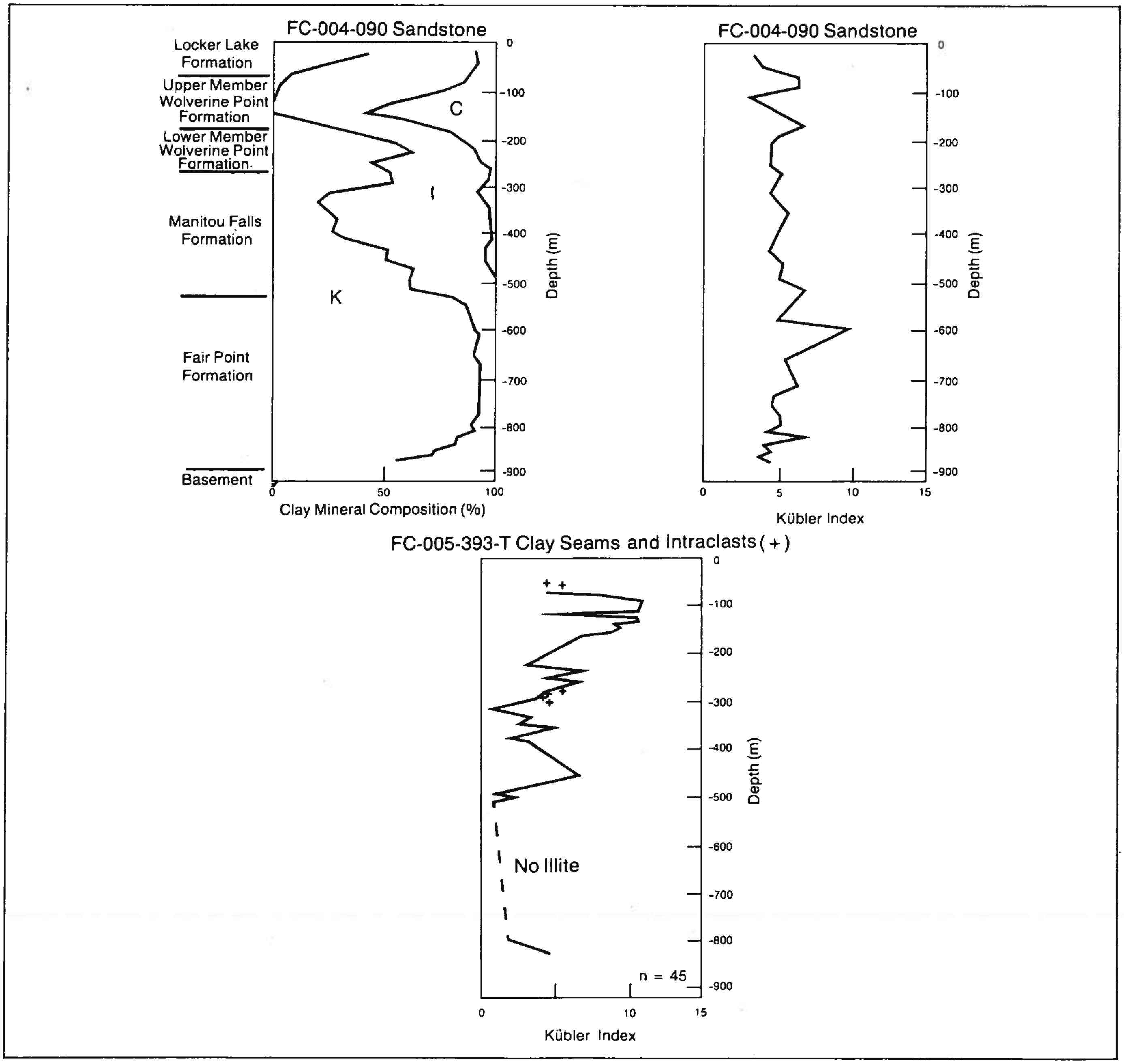
LL Locker Lake Formation

WP_U Upper member Wolverine Point

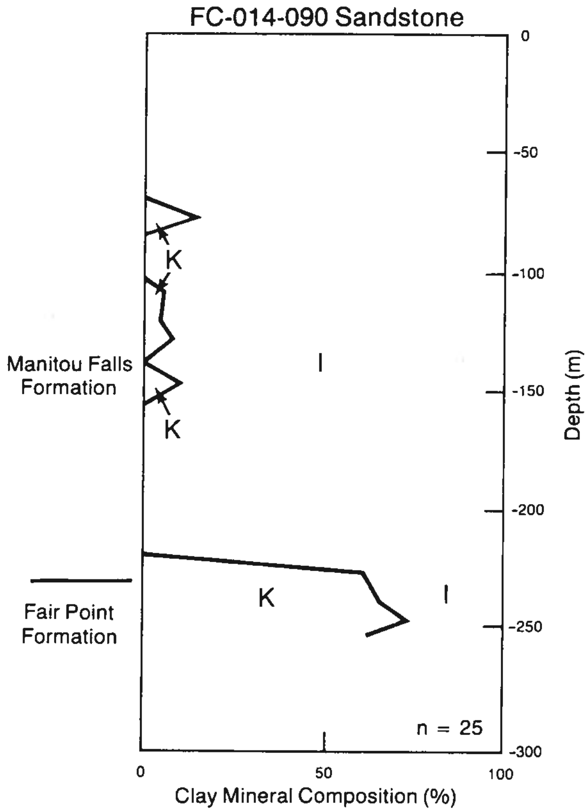
WP_L Lower member Wolverine Point

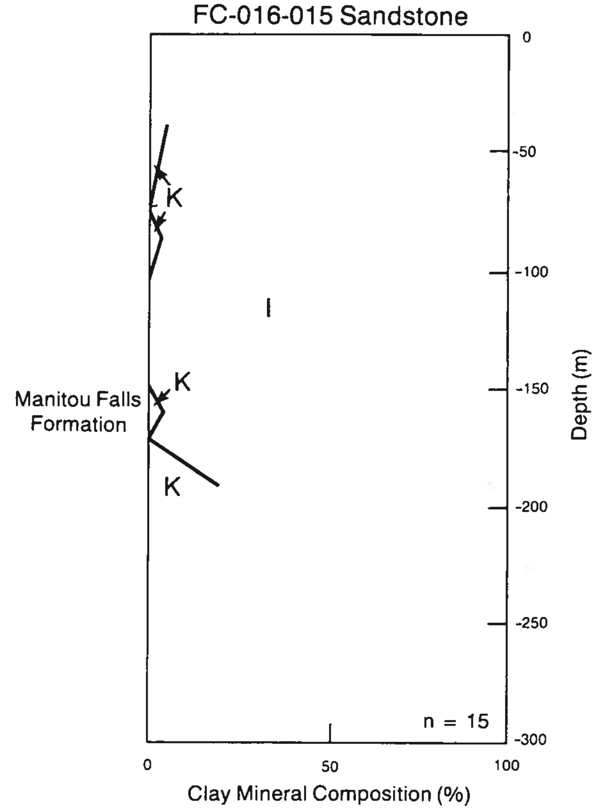
MF Manitou Falls Formation

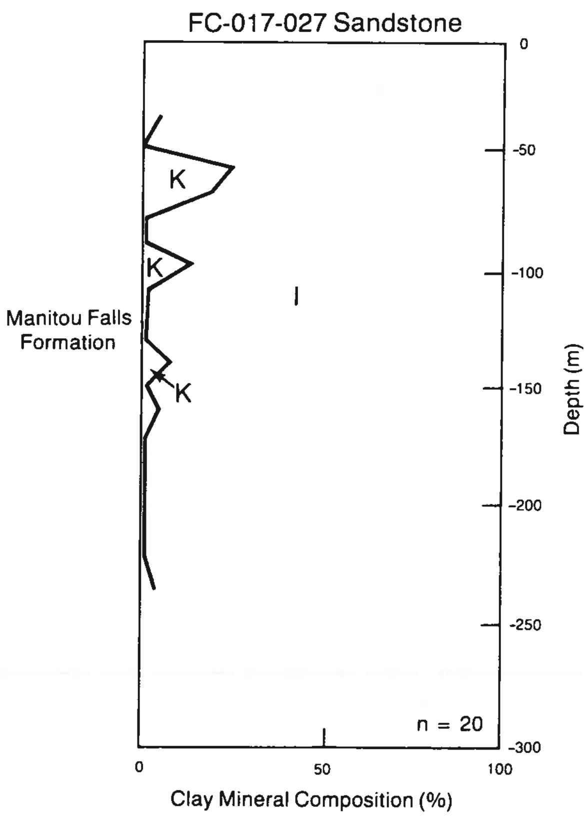
FP Fair Point Formation

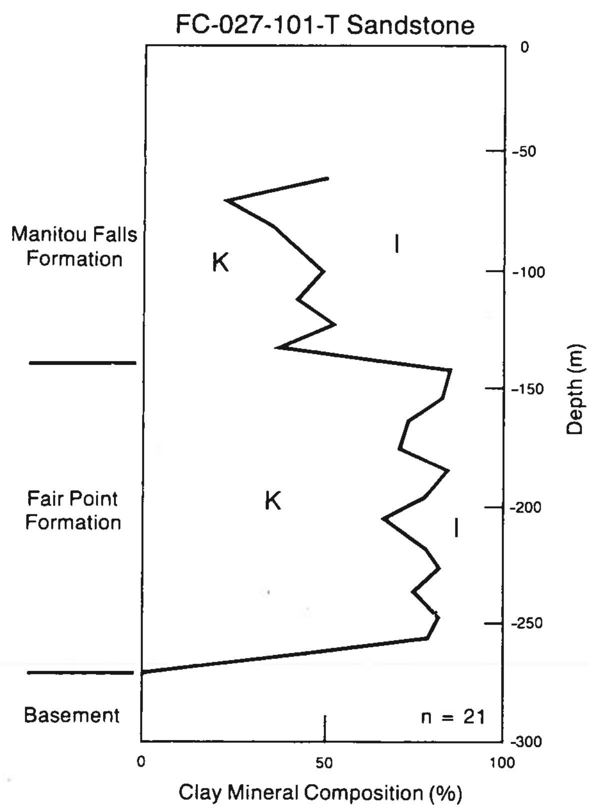


Appendix F (continued)
Clay mineral logs



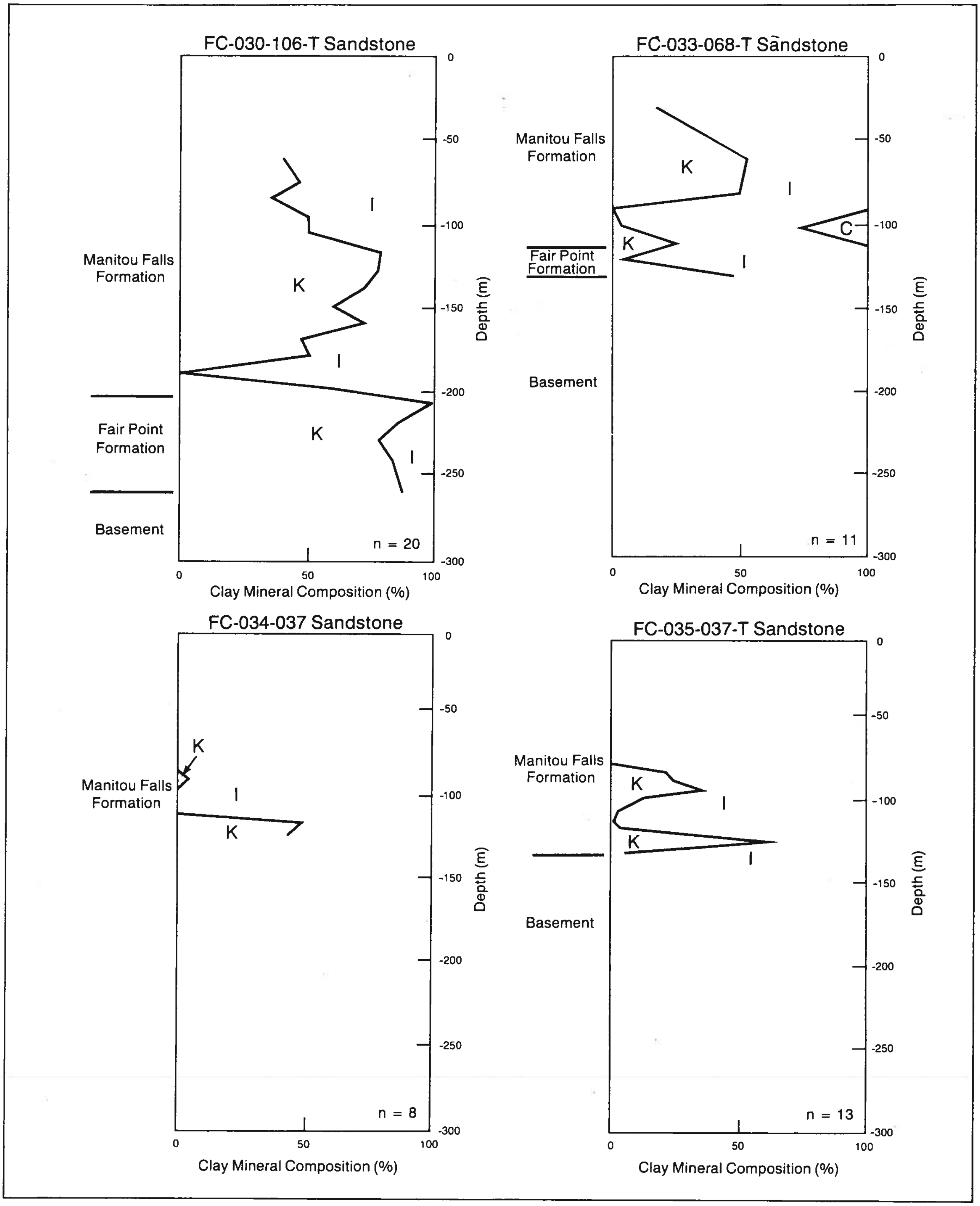






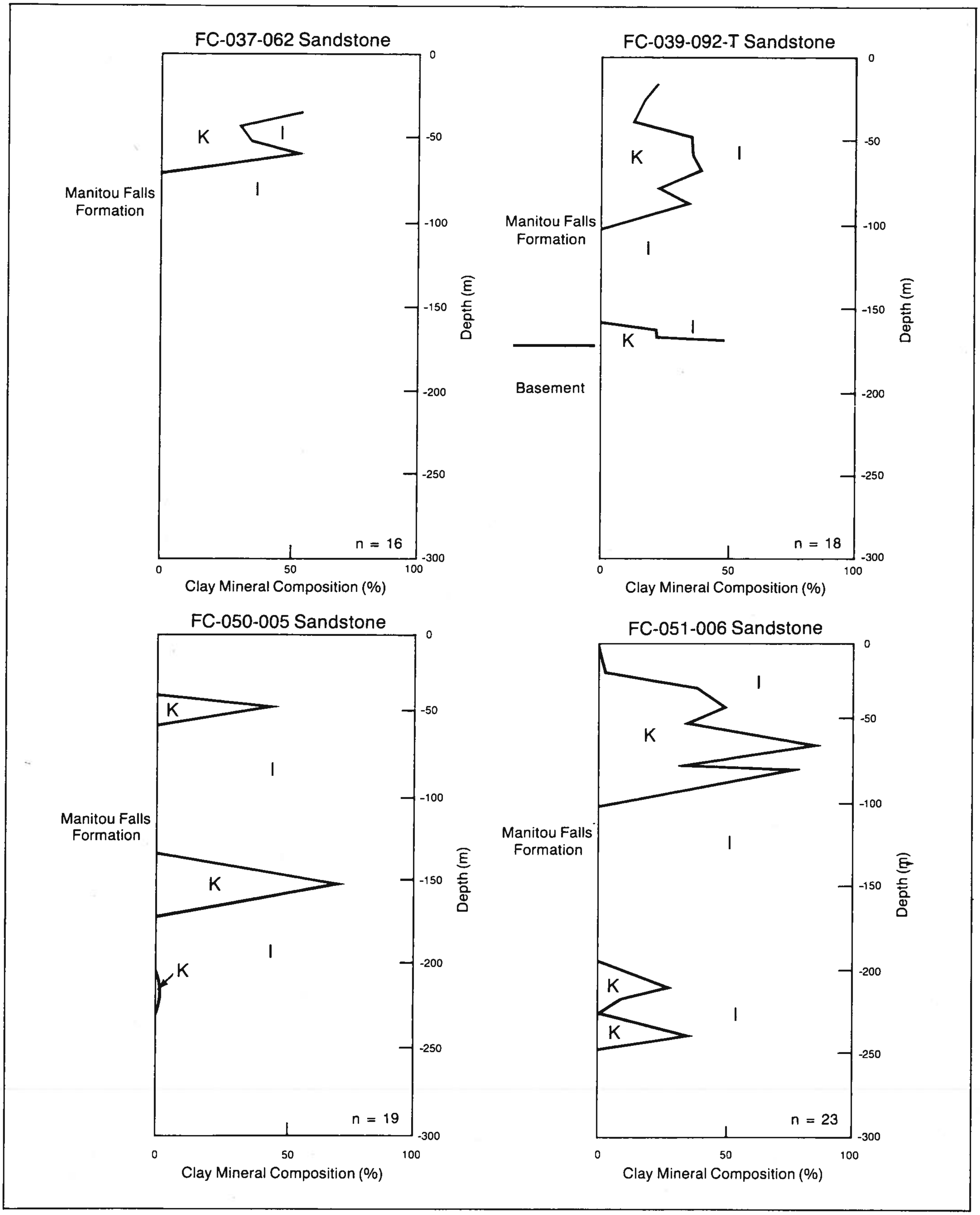
Appendix F (continued)

Clay mineral logs



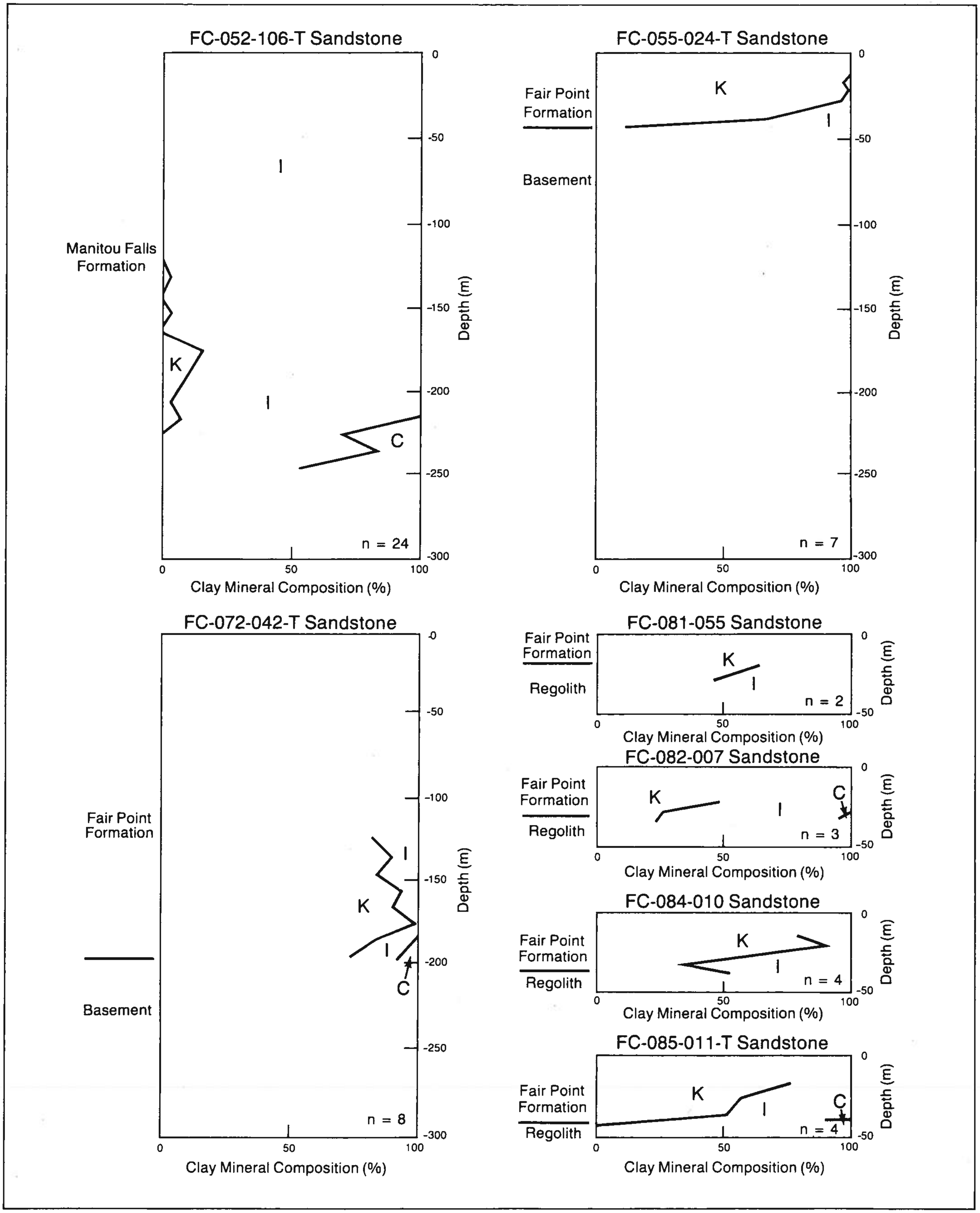
Appendix F (continued)

Clay mineral logs



Appendix F (continued)

Clay mineral logs



Appendix G
Bitumen analysis

The following table is a comparison of an analysis of the bitumen extracted from the Athabasca Group at FC-039-092-T and a typical analysis of bitumen from the Cretaceous McMurray Formation to the south. The results compare closely; however, the bitumen from the Athabasca Group is much heavier. The analyses were done at the Alberta Research Council.

	Bitumen from the Athabasca Group	Typical bitumen from the Cretaceous McMurray Formation
Relative density 15°c/15°c	1.048	1.005
Average molecular weight	683	544
Elemental analysis		
% Carbon	82.85	82.96
% Hydrogen	9.88	10.26
% Nitrogen	1.00	0.50
% Sulfur	5.22	4.64
% Oxygen	1.31	1.21
Vanadium (ppm)	172.6	198.0
Nickel (ppm)	69.1	74.9
Chromatographic separation		
% Saturates	14.7	16.2
% Aromatics	12.0	12.6
% Polar compounds I	19.4	19.6
% Polar compounds II	9.2	10.3
% Polar compounds III	20.1	22.2
% Asphaltenes		
Distillation (vol %)		
IBP (°C)	219	87
% Naphtha (195°C)	0	3
% Light gas oil (195-343°C)	9	15
% Heavy gas oil (343-524°C)	33	50
% Residue (524°C)	67	50

Appendix H
Microprobe analysis of fluorapatite

Microprobe analysis of fluorapatite from the upper member of the Wolverine Point Formation. All elemental analyses were done using energy dispersion except for fluorine, which was analysed using wavelength dispersion.

Carbon and oxygen values are by inference, the remainder of the elemental percentages are by direct measurement.

Sample 1

Element	Percentage of element	Percentage expressed as oxides
C	0.230	0.843
O	37.814	
F	4.279	4.279
Na	0.0	0.0
Mg	0.424	0.703
Al	0.177	0.335
Si	0.0	0.0
P	17.707	40.573
S	0.0	0.0
Cl	0.0	0.0
K	0.0	0.0
Ca	39.225	54.884
Ti	0.0	0.0
V	0.0	0.0
Mn	0.144	0.187
Fe	0.0	0.0
Zn	0.0	0.0
	100.0	101.804

Sample 2

Element	Percentage of element	Percentage expressed as oxides
C	0.112	0.411
O	37.547	
F	4.350	4.350
Na	0.109	0.147
Mg	0.359	0.595
Al	0.194	0.367
Si	0.0	0.0
P	17.700	40.557
S	0.0	0.0
Cl	0.056	0.056
K	0.054	0.065
Ca	39.224	54.882
Ti	0.0	0.0
V	0.070	0.124
Mn	0.139	0.179
Fe	0.085	0.110
Zn	0.0	0.0
	99.999	101.843

LEGEND

CRETACEOUS

- K_{24A} Smoky Group
- K_{22} Dunvegan Formation
- K_{21} Shaftesbury Formation
- K_{17B} Alice Creek Tongue, Grand Rapids Formation
- K_{16B} Clearwater Formation
- K_{15A} McMurray Formation
- Unconformity

DEVONIAN

- D_{12B} Waterways Formation
- D_{11} Caribou Member, Slave Point Formation
- D_{10B} Muskeg Formation
- D_9 Keg River Formation
- D_6 Undivided Middle Devonian
- Unconformity

HELIKIAN ATHABASCA GROUP

- OS Otherside Formation: sandstone with minor siltstone.
- LL Locker Lake Formation: pebbly sandstone and sandstone.
- WP_U Upper / WP_L Lower Wolverine Point Formation: sandstone, siltstone, tuff.
- MF Manitou Falls Formation: pebbly sandstone and sandstone
- FP Fair Point Formation: pebbly, clay-rich sandstone
- Unconformity

APHEBIAN/ARCHEAN

- Ap Aphebian granitoids.
- Ac Archean metasediments and granite gneisses.
- A Undivided Aphebian/Archean.

- FC-074-026 ● Locality and number of drill core stored at the M.E.S.S. facility.
- ○5 Locality and number of Eldorado Nuclear Ltd. drill cores not in the M.E.S.S. facility.
- Geological boundary
- Fault (defined)
- Fault (assumed)
- 55 Bedding for the Athabasca Group (dip).
- + Outcrop of Athabasca Group

NOTES

Cretaceous geology from R. Green *et al.* Bedrock Geology of Northern Alberta (1970).

Devonian geology from drill hole data interpreted by J. Wilson; air photo interpretation by J. D. Godfrey; R. Green *et al.*, (1970).

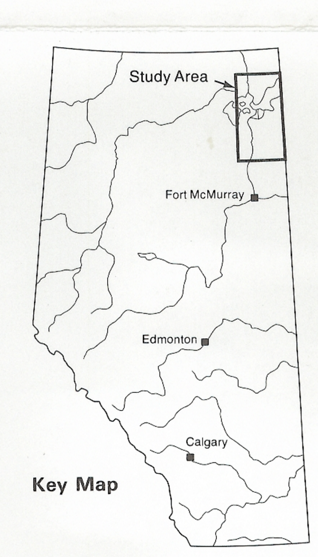
Basement geology by J.D. Godfrey: Alberta Research Council Earth Science Reports 78-1, 78-3, 84-2 and 84-5.

Approximate magnetic declination at Fort Chipewyan is 24° 16′E in 1979, decreasing 6′ annually.

SCALE 1:250,000

Miles 5 0 5 10 15 Miles

Kilometres 5 0 5 10 15 20 25 Kilometres



Key Map

Geological Map of the Athabasca Basin, Alberta

Figure 4

J. Wilson

Published 1985
Map to accompany Alberta Research Council Bulletin 49;
The Geology of the Athabasca Group in Alberta

Any revisions or additional information would be welcomed by the Alberta Research Council

Base maps provided by the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa.
Cartography by Alberta Research Council, Graphic Services, R.D. Hite

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