CAMBRIAN GEOLOGY OF THE MACKENZIE CORRIDOR

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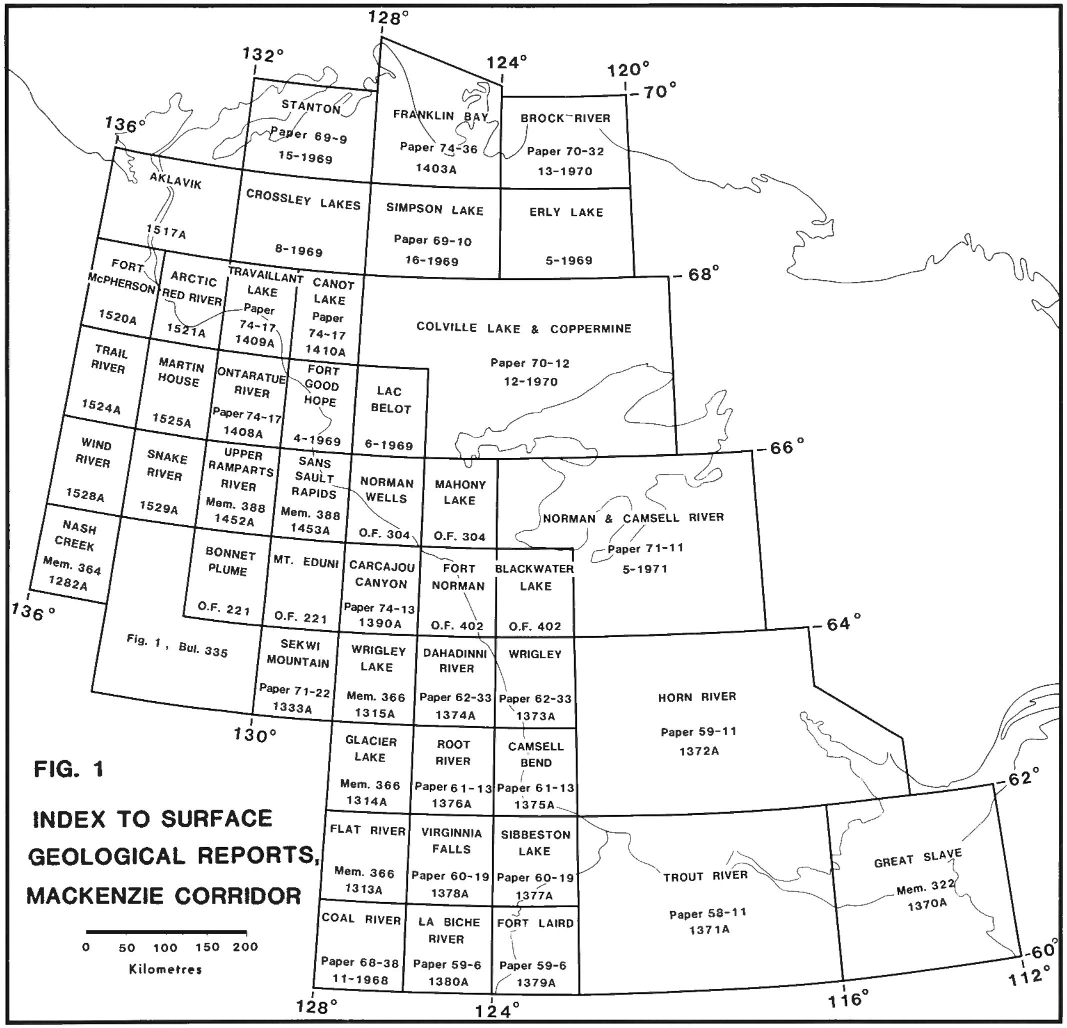


FIG. 1

INDEX TO SURFACE GEOLOGICAL REPORTS, MACKENZIE CORRIDOR

PREAMBLE

Mackenzie Corridor refers to the area between 60°N and the Arctic coast (excluding the Mackenzie Delta) and between the Precambrian on the east and either the Mackenzie Mountains or longitude 136°W on the west. Although this area represents, to some degree, a geological province, the term 'corridor' relates primarily to north-south transportation routes: the Mackenzie River itself, roads, air routes, present and (probably) future pipelines. Within the Mackenzie Corridor there are, at present, three known petroliferous areas: 1) Pointed Mountain area (~60°N, 122°W), gas from Lower-Middle Devonian carbonates, with pipeline connections in place; 2) Norman Wells area, (~65°N, 127°W), oil from a Middle Devonian reef, with pipeline connections in place; and 3) the Tedji Play (~67°N, 127°W), gas in the basal Cambrian sandstone, not connected by pipeline. If and when a gas pipeline is built to tap Mackenzie Delta reserves, the Tedji fields will probably be connected.

This present report on Cambrian rocks is one of a series of open file reports on the Corridor area which will, in the future, be integrated into a single report. Published Corridor reports to date are Williams, 1985a and b, 1986a, b and c.

The primary focus of this report is on the pre-Franklin Mountain Formation Cambrian section of the plains areas east of the Richardson and Mackenzie Mountains, with particular regard to the interests of petroleum explorationists. Hence the emphasis is on the subsurface geology. However, for an appreciation of Cambrian depositional history of the plains, it is essential to have some knowledge of the Mountains. Hence the Cambrian of the mountains is briefly reviewed, this information is presented mainly in graphic form.

This a review paper, based on published as well as unpublished material. For subsurface lithological data I have relied heavily on company well reports and lithologs by Canadian Stratigraphic Service Ltd., as well as published and unpublished subsurface

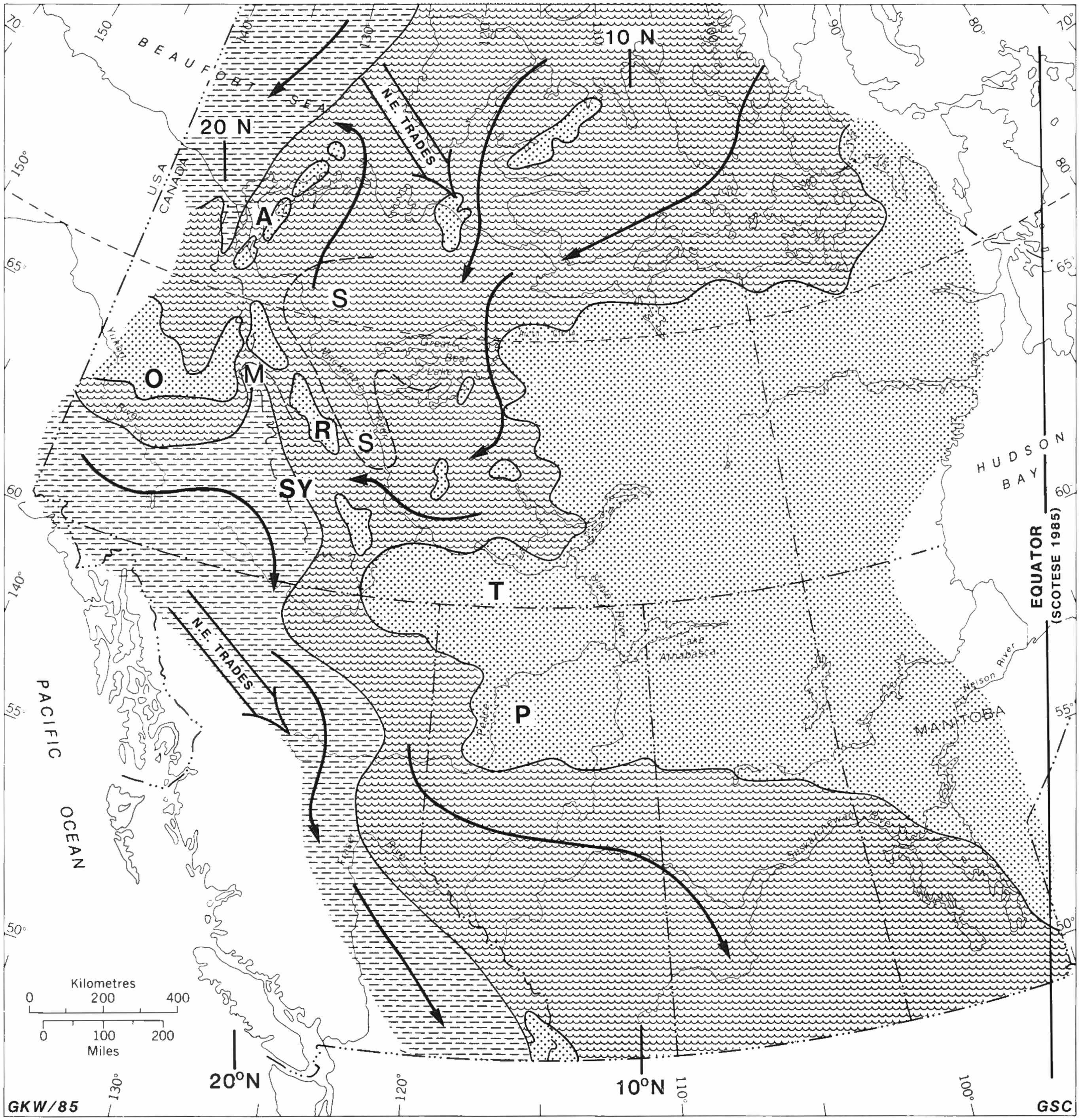


FIG. 2
MIDDLE CAMBRIAN
GEOGRAPHY

LAND

SHALLOW SEA

DEEP SEA

ARCHES

AKLAVIK........A
OGILVIE........O
REDSTONE......R
TATHLINA.......T
PEACE RIVER....P

DEPOCENTRES

MISTY CREEK....M
SALT..........S
SELWYN .....SY

studies. In addition I have logged samples and core of many of the wells. Surface data are derived from Geological Survey of Canada maps and reports shown on the index map (Fig. 1). Here also, over some 15 years of field work in the north, I have visited many of the outcrops of the plains and easternmost mountains.

This report is weighted in favor of interpretation, often reinterpretation, rather than description. Cambrian rocks of the subsurface are well described in reports by Tassonyi (1969), Meijer Drees (1975, 1986) and Gilbert (1973); these, plus pages 23 to 33 of Aitken et al. (1973) should be read in conjunction with this present report. Where I have reinterpreted concepts on depositional history or correlation the reasons are not necessarily to discredit the old, but to introduce rival, competing concepts which may show the petroleum potential of the area in a different light.

This report has been read by M.P. Cecile and G. Macauley, their suggestions are gratefully acknowledged.

GEOLOGICAL SETTING

Cambrian seaways

Figure 2 is a hypothetical reconstruction of the geography during a Middle Cambrian highstand, or transgressive phase. The southern part of this seaway is based on the maps of Aitken (1978, Figs. 8, 9). The extensive shallow sea in the northernmost part of the map is almost entirely hypothetical. The belts labelled 'deep sea' may have extended to oceanic depths in places along their outboard margins, however this is unknown; possibly these areas were entirely intracratonic downwarps.

The eastern landmass was the Canadian Shield, the main source area of the mature basal Cambrian sandstones. Most, but not necessarily all, of the numerous islands within the shallow sea were tectonic arches or ridges. During Cambrian lowstands and/or times of intense tectonic differentiation many of these islands must have coalesced to partially isolate segments of the northern shallow seaway; the Cambrian salt basin is proof that some isolation or restriction did occur. However, there is no faunal evidence to indicate

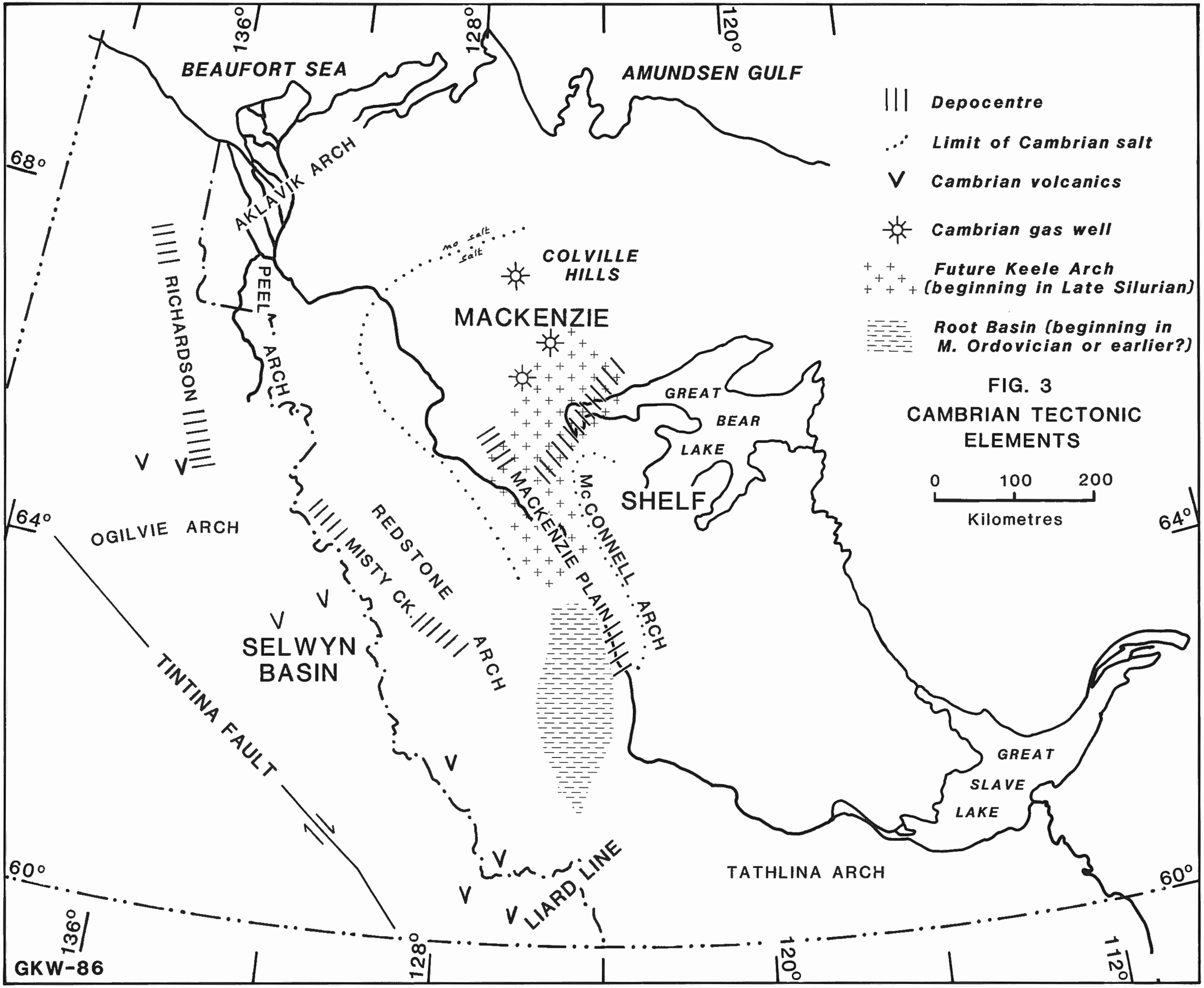


FIG. 3
CAMBRIAN TECTONIC ELEMENTS

any prolonged separation between the southern and northern deep sea belts (Aitken, 1986, pers. comm.).

The limits of preserved Cambrian strata shown on maps 2 and 3 are, in most places, if not everywhere, a result of intra- or post-Cambrian erosion.

Tectonic setting

The main tectonic elements that influenced early Paleozoic sedimentation are shown on Figure 3, these will be discussed in more detail later (Cambrian Tectonics). From his study of Windermere (Late Proterozoic) sediments of the mountains east and north of the Selwyn Basin, Eisbacher (1981) has deduced that a tensional regime – a stretching of epi-cratonic basement – controlled or influenced sedimentation between about 800 and 570 Ma. A tensional regime seems to have remained in effect, or to have been reinstated, in early Paleozoic time in the same general area. The Misty Creek Embayment (here regarded as part of the Selwyn Basin) is the best documented case for Middle Cambrian and later extensional tectonics (Cecile, 1982). The less well documented Richardson Trough is thought to have had a similar history (Cecile et al., 1982; Cecile, 1986).

The area east of the Richardson and Mackenzie Mountains can be interpreted as having undergone a similar, although less dramatic, tectonic history. The geological data, although insufficient to confirm, are compatible with the extensional hypothesis. It has been assumed that the area underlain by Cambrian salt is not merely an area of preservation, but represents a Cambrian sub-basin, here considered as two linked but distinct tectonic entities: the Colville Hills and Mackenzie Plain depocentres.

Depositional units, age

Cambrian strata of the plains and easternmost part of the Mackenzie Mountains fall into three distinctive units:

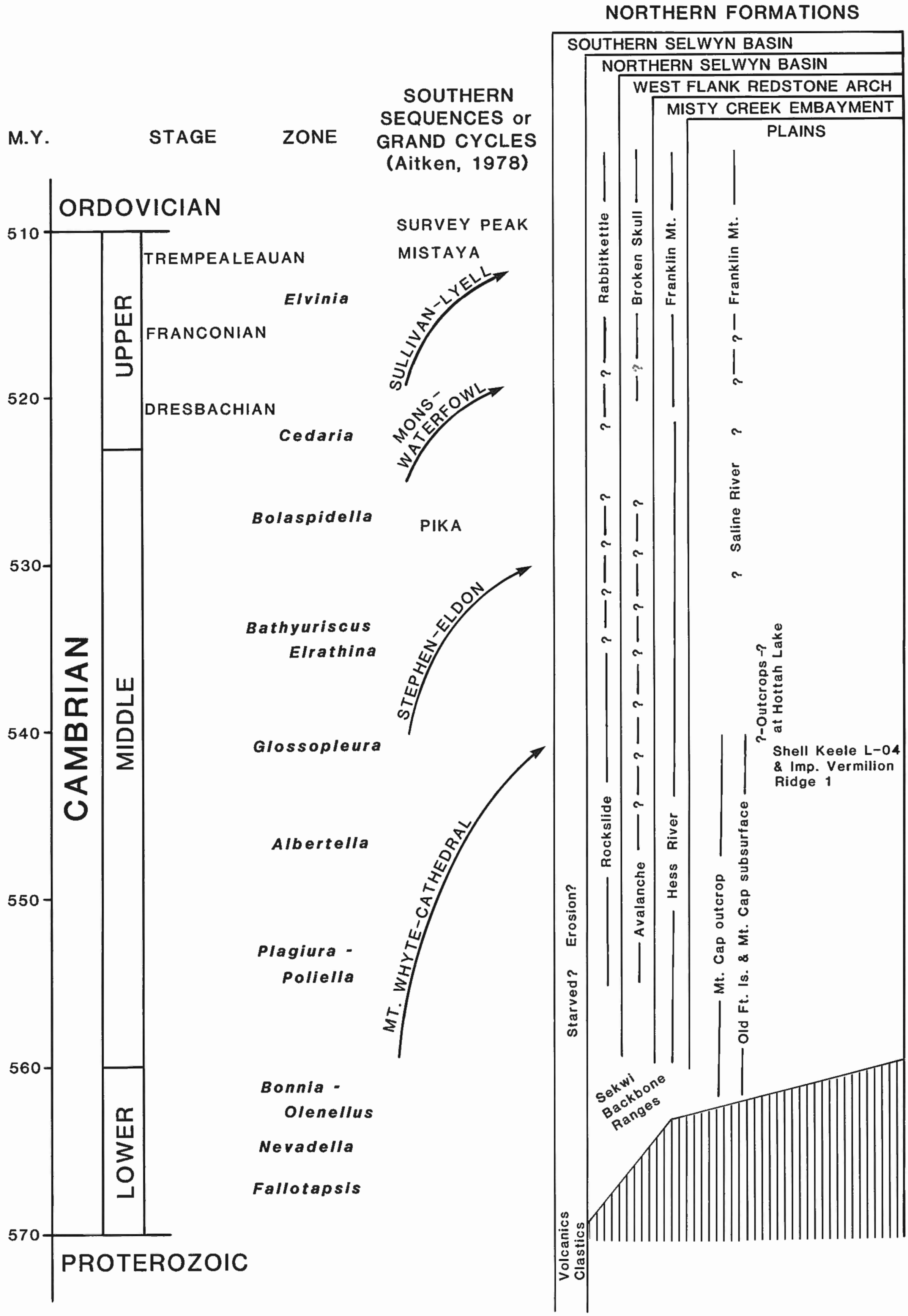


Fig. C-1 Northern Cambrian Formations in relation to southern grand cycles.

1) a lower unit that is dominantly of normal marine origin – shale, siltstone, sandstone, limestone and dolomite (Mount Cap Formation). At the base of this normal marine unit is a discontinuous sandstone (Old Fort Island = Mount Clark Formation).

2) a middle, restricted to evaporitic unit (Saline River Formation); this unit is mostly halite in the main Cambrian depocentres of the plains, elsewhere it consists of mixed and interbedded dolomite, anhydrite and fine clastics.

3) an upper dolomite unit which ranges, with no mappable break, from Cambrian to Ordovician in age, this is the Franklin Mountain Formation.

Fossil collections from unit 1 are summarized in Aitken et al. (1973). The age ranges from late Early Cambrian (*Bonnia-Olenellus* Zone) to Middle Cambrian (*Glossopleura* Zone, possibly into *Bathyuriscus Elrathina* Zone), see Figure C-1. The basal sandstone (Old Fort Island) is thought to be diachronous.

No useful fossils have been found in the evaporitic unit.

Late Cambrian (Dresbachian) faunas occur within but well above the base of the upper dolomite unit, or Franklin Mountain Formation (Norford and Macqueen, 1975; Cecile, 1982). Thus the Saline River Formation may be Middle Cambrian, Late Cambrian, or both; following Tassonyi (1969) it is considered to be Middle Cambrian.

This report is concerned only with the lower two Cambrian units; the Upper Cambrian dolomite will be dealt with in a later report (Williams, in prep. b). Henceforth in this report the term 'Middle and Lower Cambrian' or simply 'Cambrian' can be taken to mean pre-Franklin Mountain strata.

STRATIGRAPHY

For description purposes it is convenient to begin with the Colville Hills area where the section is best known (~ 20 wells), then compare the section with other areas. Also, as this is primarily a subsurface study, it is most convenient to discuss the section from the top down, as it would be viewed by a subsurface geologist.

Colville Hills Depocentre

The basal beds of the Franklin Mountain Formation and the upper beds of the Saline River Formation form a stratigraphic continuum. At the top it is silty, argillaceous, micro- to fine-crystalline dolomite with partings and thin beds of shale. The shale beds increase in thickness and abundance downward until, in most wells, shale and siltstone predominate. Also, colour of the shale changes from grey or green high in the section to varicoloured, including red, in the lower part. The Franklin Mountain/Saline River contact is usually placed at the highest occurrence of red shale. The dolomite and varicoloured shale section of the Saline River Formation is usually about 30 m thick, this is the Upper Clastic member of Meijer Drees (1986, Fig 17); it overlies the halite.

The salt section is up to about 350 m thick in the deepest part of the depocentre, north of Smith Arm (salt thicknesses are shown on Map 4). Thin interbeds consist of green or red dolomitic shale, dolomitic siltstone, anhydrite and dolomite (Meijer Drees, 1986, p. 27).

The sub-salt section is summarized graphically on the log section, Figure L-1; the following discussion, in descending order, is with reference to the informal units on that figure:

Unit A: evaporitic, shaly microcrystalline dolomite, varicoloured shale, minor anhydrite.

Unit B: (homotaxial with unit A): grey and green shale, shaly microcrystalline dolomite, only traces of anhydrite.

(If the Saline River/Mount Cap contact be defined as the change from restricted to normal marine, the contact would lie low in, or at the base, of Unit A, high in, or at the top, of Unit B.

Unit C: limestone, dolomite, grey, green or brown shale and siltstone, rare sandstone; traces to an abundance of glauconite and phosphatic pellets; fossiliferous; dolomites are fine to medium crystalline and often have a distinctive resinous brown colour (high content of organic carbon?).

Unit D: green and grey shale, grey-brown siltstone.

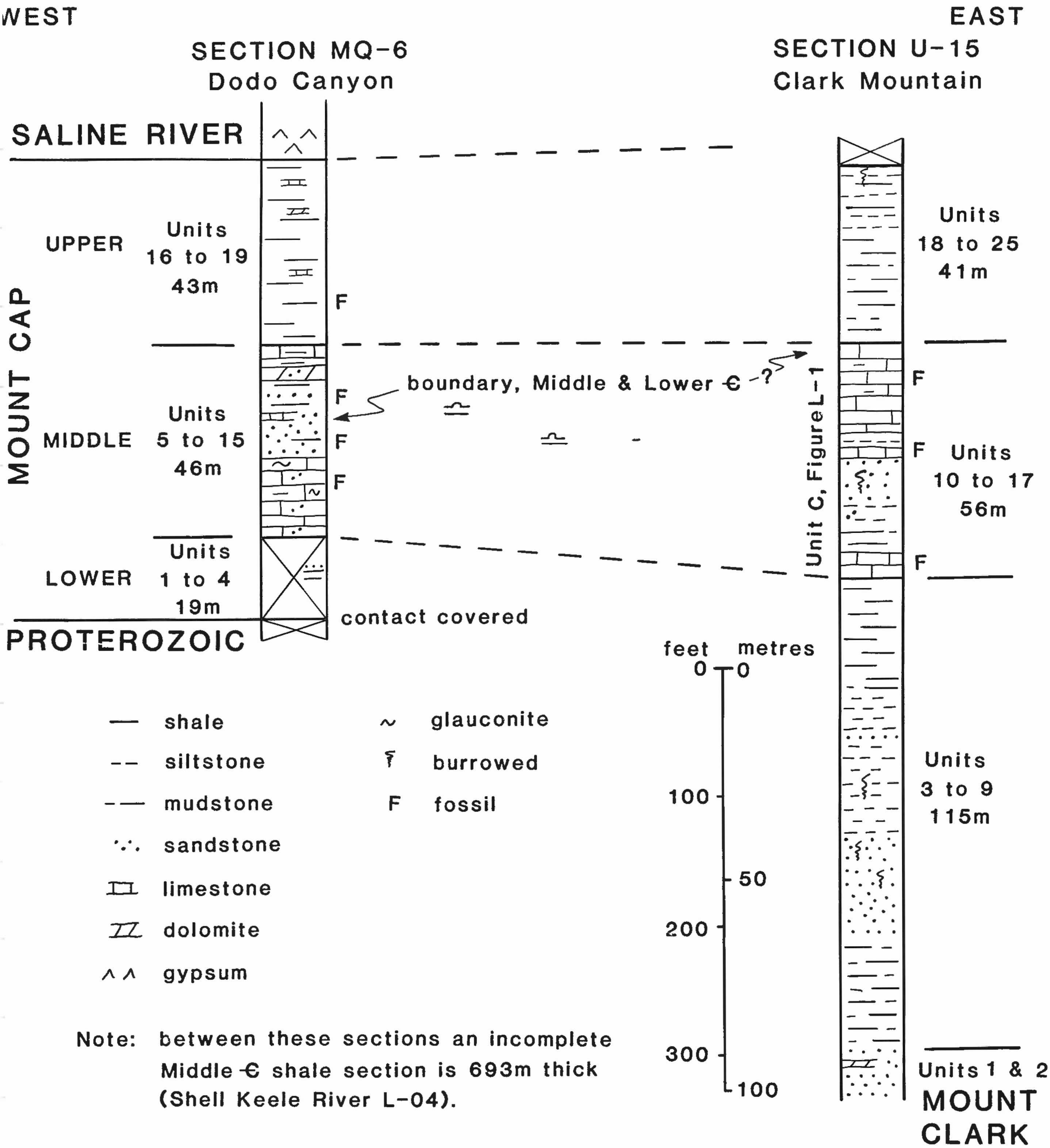
Unit E: (homotaxial with, probably partly equivalent to the Old Fort Island Sandstone): interbedded dolomite, sandstone and green shale; dolomite as in unit C; sandstone fine to coarse grained, quartzose, abundant glauconite and phosphate.

Old Fort Island Sandstone: fine to coarse grained, quartzose, variably siliceous or dolomitic, variably glauconitic; in part well sorted and porous, but more commonly intensely burrowed, which reduces or destroys porosity and permeability. Part of the Old Fort Island sandstone may have been deposited in a fluvial environment (G. Macauley, 1986, per. comm.). As interpreted on Figure L-1 the unit E/Old Fort Island package onlaps topographic irregularities on the eroded Proterozoic surface.

Observation of cores as well as geophysical logs indicate that all contacts (except the Cambrian/Proterozoic contact) are gradational, often highly subjective. Sandstone, shale and dolomite intertongue through the Old Fort island - Mount Cap transition zone; beds of red shale, restricted-marine dolomite (lacustrine?, G. Macauley, 1986, per. comm.) occur in the Mount Cap Formation; thin layers of salt or anhydrite occur up to several tens of metres below the main Saline River salt; and the top of the Saline River Formation, as previously described, is an arbitrary pick.

Mackenzie Plains Depocentre

The Cambrian section here is known from outcrops in the Franklin and Mackenzie Mountains and from incomplete sections of three deep wells. It is convenient first to



ig. C-2 Field section from Aitken et al., 1973, flanks of Mackenzie Plain depocentre.

discuss the outcrop data, next make comparison with the Colville Hills section, and then to discuss the data gleaned from the wells.

Field data

The field sections pertinent to this discussion are described in Aitken et al. (1973), locations are plotted on Map 1. Sections U-11, MQ-6 and U-13 are situated near the boundary between the Redstone Arch and the Mackenzie Plain Depocentre (Fig. 3); the others, MQ-2, U-15, U-14 and AC-541, lie within the depocentre.

The Saline River Formation is seldom well exposed, never completely exposed. Characteristically the outcrops are a jumble of red or green mudstone, gypsum, thin (± 1 m) beds of fine crystalline, sometimes silty dolomite. A transitional contact with the overlying Franklin Mountain dolomite is well exposed in sections MQ-2 and MQ-6 where, as in the Colville Hills area, it is placed at the highest occurrence of red shale (Aitken et al., 1973, p. 119, 124). At section U-11, which is high on the flank of the Redstone Arch, there is an appreciable amount of sandstone, including fine pebbles, above the highest red shale (*ibid.*, p. 98, units 10 to 12 of section U-11).

The one known outcrop of salt (~ 64°30'N, 126°W, Map 3) was first reported by Shell Oil Company of Canada Ltd. (1961), and more recently confirmed by Wissner (1986). This outcrop occurs along the axis of the Summit Anticline where the Franklin Mountain dolomite forms the core (Carcajou map, Aitken and Cook, 1974).

The two best exposures of the Mount Cap Formation are MQ-6, on the west flank, and U-15 within the depocentre. These sections are summarized on Figure C-2 which also shows a tentative correlation between these sections and thence to the Colville Hills subsurface (Fig. L-1). The sole basis for the correlation is the vaguely defined middle, carbonate-rich unit. While the suggested surface to subsurface correlation is tenable, and the section is similar in general, there are some noteworthy differences:

1. The carbonates of the Mackenzie Plain sections are dark, micritic, argillaceous, and mostly limestone; there are none of the resinous brown crystalline dolomites that are so common in the Colville Hills wells.
2. The lower part of the Mount Cap Formation in the Mackenzie Plain depocentre is thicker – 115 m (units 3 to 9, section U-15) versus ~50 m.
3. The basal Cambrian sandstone (here known as the Mount Clark Formation) is also thicker – 218 m (section AC-541), over twice the maximum thickness found farther east.
4. High on the flank of the Redstone Arch, section U-11, there are no beds typical of the Mount Cap Formation. What has been called Mount Cap Formation, plus units 1 and 2 of what was called the Saline River Formation, comprise some 38 m of sandstone with minor shale (Aitken et al., 1973, p. 100). This sandstone could as well be called Old Fort Island (Mount Clark) or basal Saline River sandstone (see Fig. X-9, upper).

Subsurface data

The Saline River Formation drilled in Imperial Vermilion Ridge no. 1 (~65°N, 126°W, Map 1) is lithologically similar to the Colville Hills section; however, the salt is about twice as thick (677 m). This is thought to be a stratigraphic rather than a tectonically increased thickness (Cook and Aitken, 1976b, p. 315). Below the salt in this well are 119 m+ (base not reached) of green or grey, smooth-textured shale, minor dolomitic siltstone, and traces of bituminous shale (Tassonyi, 1969, p. 16). From a core near T.D. Middle Cambrian fossils have been identified (Fritz, 1971, p. 23).

The two Keele River wells L-04 and N-62 (~64°30'N, 125°W, Map 1) drilled about 600 m of a similar shale; this also is an incomplete section. The shale has been dated Middle Cambrian (Fritz, 1970, p. 18). Assuming the Cambrian fossil data of outcrop and subsurface are correctly interpreted, the 600 m+ of shale in the subsurface must equate with the ~45 m shale in outcrop (units 18 to 25, section U-15, Fig. C-2).

As discussed later (Chapter on Problems), we have many problems to solve before we understand the ramifications of the data from the Keele wells. However, taking the subsurface data at face value, we see, in the Mackenzie Plain Depocentre, a localized Middle Cambrian downwarp similar in scale to the Misty Creek Embayment.

Between Great Bear and Great Slave Lakes

Exposures along the outcrop belt (Map 1) are poor. Balkwill (1971) found it impractical to map the Saline River and Mount Cap formations separately; the following is based on Balkwill's report (*ibid.*, p. 14). The total Cambrian section is in the order of 70 m thick. The upper half of the unit consists of red and green shale with very thin beds of fine crystalline dolomite. Evaporitic conditions are indicated by traces of gypsum in thin seams, desiccation marks and salt casts. The lower part consists of red, green and dark grey shale, platy siltstone and fine grained glauconitic sandstone. Within this lower non-evaporitic section there is a 10 m to 30 m thick layer of fine to medium crystalline dolomite (Mazenod dolomite). Middle Cambrian fossils were found in the area from an unspecified horizon (*ibid.*, p. 36). The Old Fort Island sandstone is discontinuous, confined to paleodepressions on the eroded Precambrian surface; it is a mature, quartzose, fine to coarse grained, locally pebbly sandstone up to 20 m thick.

In the southern part of the outcrop belt, along the north arm of Great Slave Lake, the Cambrian section was originally mapped as part of the LaMartre Falls Formation (Norris, 1965); this formation name is obsolete (Williams, 1974). The section here is essentially the same as described by Balkwill (1971) but thinner because of pre-Mount Kindle erosion. This is the type area of the Mazenod dolomite and the Old Fort Island sandstone (Norris, 1965).

The adjacent subsurface section is illustrated on Figure L-1. The lithology is similar to the outcrop section (see sample and core description by Meijer Drees, 1975,

p. 64). In the subsurface, as in outcrop, there is no satisfactory way to map the Saline River/Mount Cap contact. There is no well developed basal Cambrian sandstone in any of the wells in this area.

Tentatively, as indicated on Figure L-1, the Mazenod dolomite may correlate with carbonate-rich unit C of the Colville Hills area, thence, also tentatively, with the carbonate-rich middle unit of the Mount Cap Formation in outcrops of the Franklin Mountains (Fig. C-2).

Outcrops flanking the Brock Inlier

Four outcrop sections in this area are described in Aitken et al. (1973): MQ-20, 22 to 24 (Map 1). Exposures are poor. The Saline River Formation is up to 60 m thick; it consists of red and green shale, minor fine crystalline dolomite, a few gypsum seams. The one measured Mount Cap section (MQ-20, *ibid.*, p. 131) is 70 m thick, of which two thirds are covered. At the top are 12 m of fine to medium grained, glauconitic, quartzose sandstone. Within the basal half of the section is a 10 m thick dolomite - fine crystalline, argillaceous, silty, with shale interbeds . . . the Mazenod dolomite? The Old Fort Island sandstone in this area is up to 60 m thick (*ibid.*, p. 26).

Subsurface, west and north of the salt basin

The two Ontaratue wells, K-04 and L-26 (~66°30'N, 130°30'W, Map 1), are located within but near the northwestern edge of the salt basin. Samples from below the salt are very poor. The section apparently consists of sandstone, siltstone, shale, and dolomite. The position of the Cambrian/Proterozoic contact in these wells is uncertain.

Farther north, beyond the limit of salt, the Tenlen A-73 well (67°52'N, 130°43'W, Map 1) was completely cored. From the well report, an unpublished core description by the late W.S. MacKenzie, and remarks by Meijer Drees (1986, p. 28), the following is extracted. The Cambrian section is 100 m thick. All but the basal 20 m belongs to a restricted facies: red, green or grey shale; many thin, a few thick, beds or lenses of anhydritic dolomite. The lower 20 m of the Cambrian section consist of dark coloured siltstone and shale with traces of fossils; the basal 2 m are sandy and glauconitic.

Farther northeast, also beyond the limit of salt, is Sadene D-02 (68°51'N, 126°47'W, Map 1). Here the Cambrian section is 255 m thick. The upper 129 m are mostly grey to reddish, shaly, silty, microcrystalline dolomite with thin beds of red and green shale, traces of anydrite; the basal few metres are sandy with up to coarse grains of quartz. The lower 126 m also consists mainly of dolomite but it is a resinous brown colour (as is common in the Colville Hills area), is up to medium crystalline, and is slightly glauconitic. There are interbeds of green shale, most are thin, one, possibly unit D, Figure L-1, is 15 m thick. The basal sandstone, 14 m thick, is glauconitic, poorly sorted, up to very coarse grained.

Caribou N-25 is located far to the west of the salt basin, just east of the Richardson Anticlinorium (~66°15'N, 135°W, Map 1). Below the undivided Devonian - Upper Cambrian dolomite unit, 11 264 feet (3433 m) to T.D. 11 812 feet (3600 m), is a siltstone of uncertain age. Pugh (1983) labelled this unit as Proterozoic orthoquartzite. The siltstone is greenish grey, highly dolomitic, chloritic, and rich in muscovite. In my opinion (shared by D.K. Norris, pers. comm., 1982) this unit is part of the Middle Cambrian Slats Creek Formation; it has been so designated on Map 3 and Figure C-5.

Subsurface, McConnell Arch

East of the Mackenzie Plain Depocentre is a broad area where the Cambrian section is thin and represented for the most part only by restricted or evaporitic strata (Map 3). The section in most wells in this area has been described and illustrated by Meijer Drees (1975); for the most part his interpretations have been accepted in the construction of maps 2 and 3. However, it should be stressed, formation identifications below the Mount Kindle Formation in this area are somewhat speculative; there is seldom complete agreement between any two geologists.

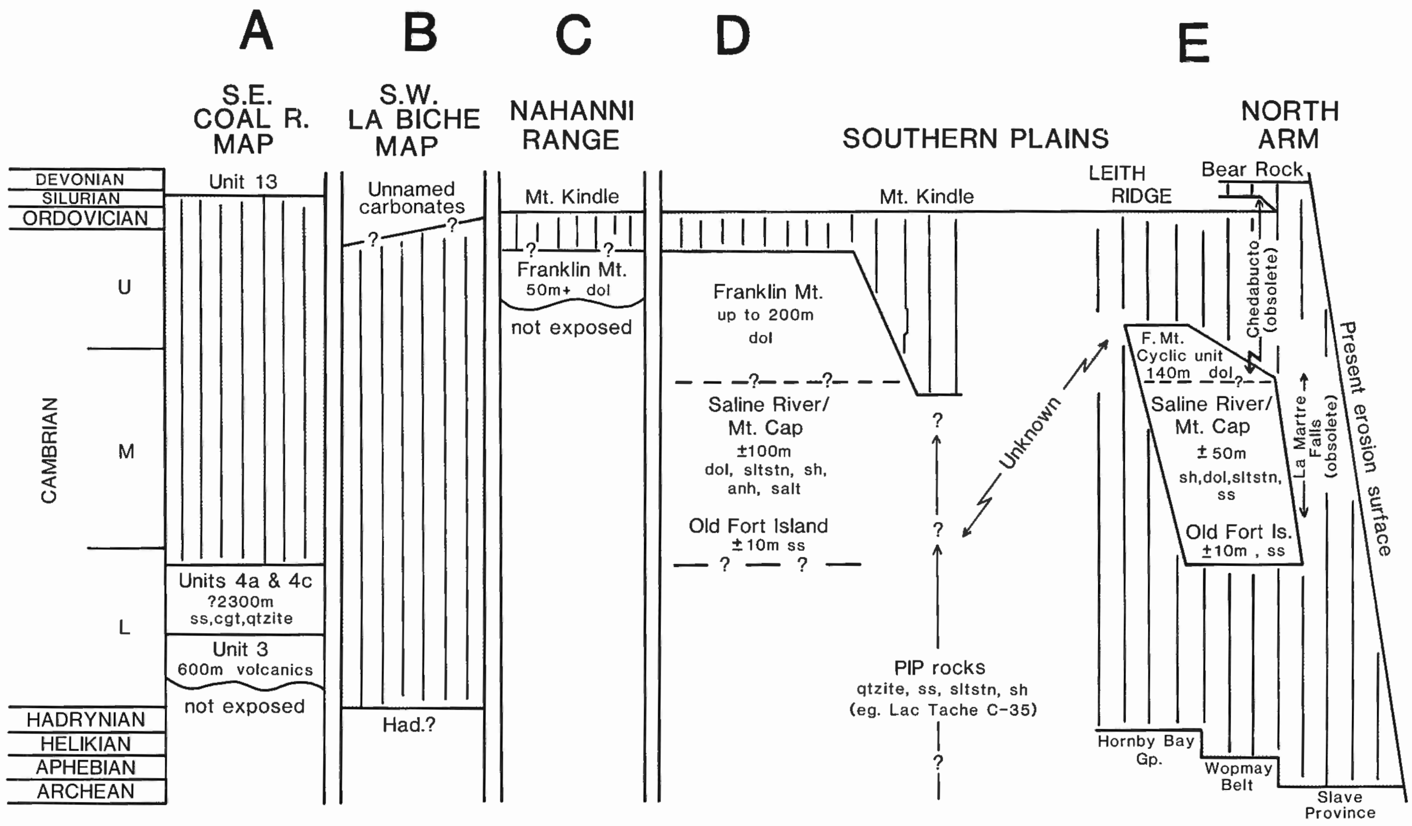


FIG. C-3 CAMBRIAN CORRELATION CHART, SOUTHERN MACKENZIE CORRIDOR

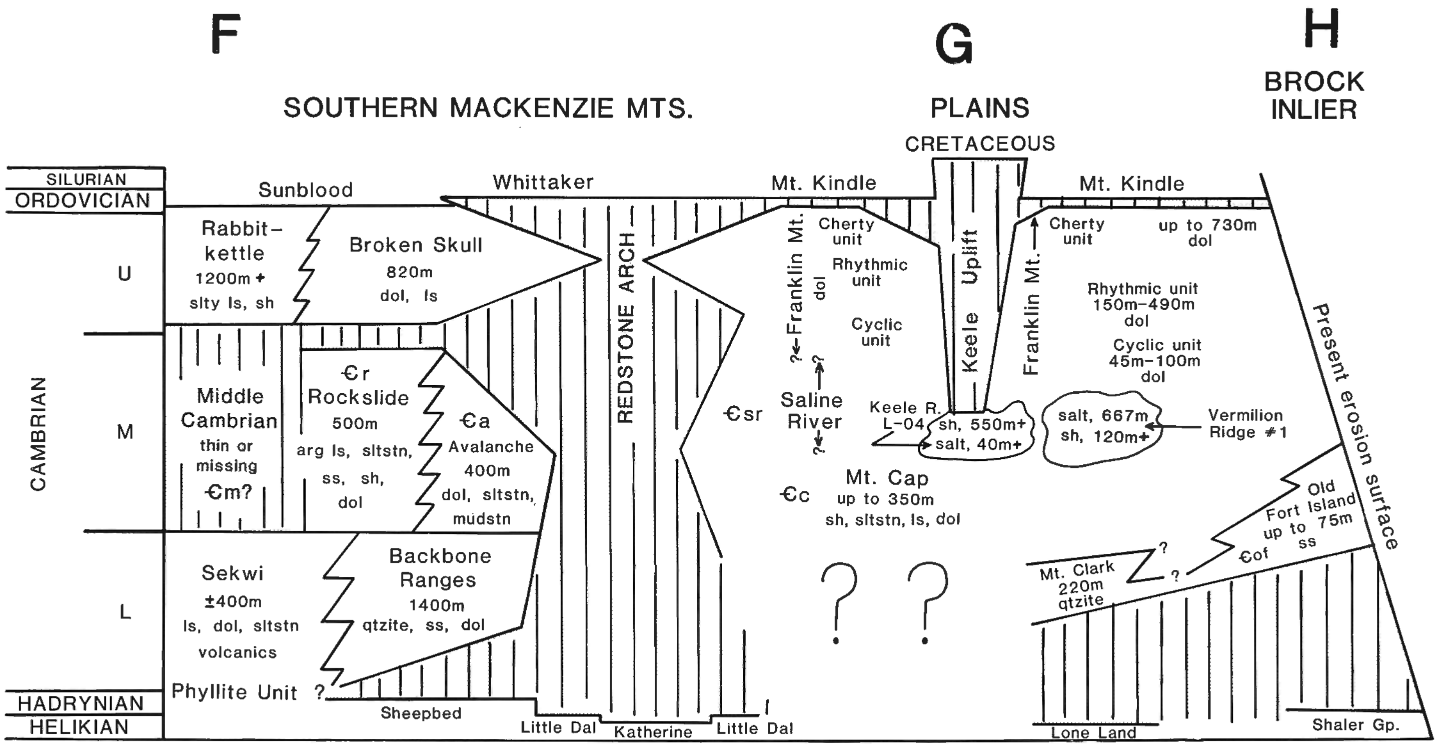


FIG. C-4 CAMBRIAN CORRELATION CHART, CENTRAL MACKENZIE CORRIDOR

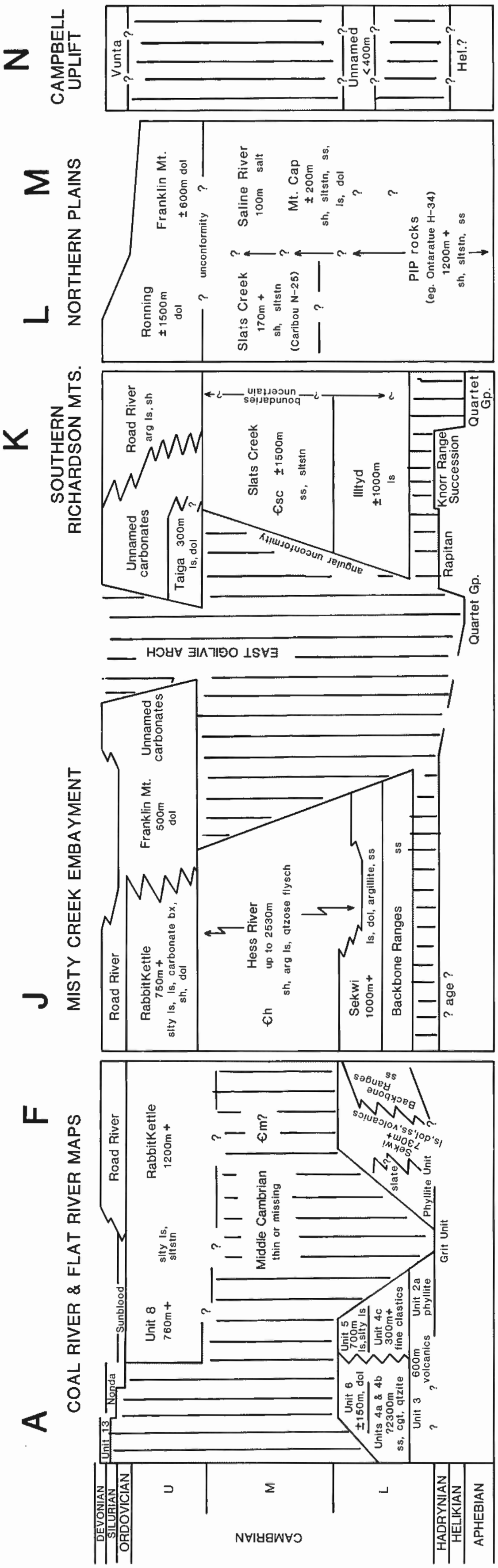


FIG. C-5 CAMBRIAN CORRELATION CHART, WESTERN MACKENZIE CORRIDOR

There are two wells located within, but near the western limit of the salt; these are Whitefish River H-34 (65°33'N, 124°35'W) and Blackwater Lake E-11 (63°40'N, 123°03'W, Map 1). The Cambrian sections of the two wells are similar:

- an upper unit, ~35 m thick, that is similar to the post-salt section of the Colville Hills area, except that there is less dolomite, more anhydrite.
- salt, 10 to 42 m thick.
- a unit, 25 to 45 m thick, similar to the unit above the salt: shaly, silty dolomite, siltstone, shale and anhydrite, red colours are common.
- Old Fort Island sandstone.

The entire section, except for the glauconitic Old Fort Island sandstone belongs to the restricted, evaporitic facies, i.e., the Saline River Formation. In wells to the east, beyond the salt limit, there is no mappable division within what must be the combined pre-salt and post-salt units. Some of the above wells appear on Figure L-2, see also Figure 12 of Meijer Drees (1975). The cycle skip zone on the sonic log of Blackwater Lake G-52 (Fig. L-2) probably indicates the former presence of salt or, possibly, many thin layers of salt.

In the vicinity of the Ebbutt Hills (~62°N, 123°W) some 50 m± of section has been labelled Saline River Formation by Meijer Drees (1975, figs. 12, 13, 14). This section is predominantly varicoloured fine clastics, variably dolomitic with, in most wells, a layer near the middle of dolomite and/or anhydrite. Similar strata in outcrop southeast of the Redstone Arch are mapped as the Late Cambrian Franklin Mountain Formation (see note 4 of next Chapter).

SOME NOTES ON THE CAMBRIAN IN THE WESTERN MOUNTAINOUS BELT

The Cambrian stratigraphy of the mountains is summarized on correlation charts Figs. C-3, C-4 and C-5; areas represented by the various columns are indicated by letters A....N, Map 3. Figs. X-1 to X-4 illustrate some physical relationships.

1) The lower Cambrian Illtyd carbonate unit within the Richardson Trough (Map 2) is not yet well described in published literature. In a short discusson of this unit Fritz (1974) mentions evidence for a sharp, east-facing, north-south trending carbonate/shale front. Along the front bioherms reach a thickness of about 200 m. East of the front (*ibid.*, p. 312) ". . . is postulated a north-south trending trough that was semi-restricted (suggested from faunal content) from the ocean." (Map 2).

2) Lower Cambrian strata west of the Redstone Arch fall into three time-equivalent but lithologically distinct belts (Gabrielse et al., 1973, p. 31 and figs. 5, 7). The dominant rock type of each belt is, from east to west: a) quartzose sandstone (Backbone Ranges Formation), b) carbonates (Sekwi Formation), c) argillite (unnnamed). Only the sandstone belt is emphasized on Map 2; readers interested in the other belts should consult Fritz (1976, 1978) and Cecile (1984a and b).

   Mappable units within the sandstone belt consistently thin towards the Redstone Arch (Gabrielse et al., 1973, p. 34) indicating differential subsidence during deposition, or put another way, the Redstone Arch was positive through early Cambrian time. However, the Early Cambrian Redstone Arch may not have formed a complete barrier to circulation. Sparse paleocurrent data from west of the arch suggest an easterly source for the sands (Gabrielse et al., 1973, p. 37). Thus, prior to post-Early Cambrian erosion the Old Fort Island and Backbone Ranges sands may have formed a more or less continuous sheet, interrupted here and there by islands aligned along the arch.

3) Lower Cambrian volcanics occur within the deeper parts of the Selwyn Basin (Map 2). The southernmost occurrences may be in part Precambrian; these rocks are described as basic flows, breccias and agglomerates (Gabrielse and Blusson, 1969; their units 3 and 7). The volcanic rocks between latitudes 62°N and 63°N (map 2) occur within the Sekwi Formation. They are described as chlorite schist, agglomerate, porphyritic volcanic rocks, possible pillow structures, and waterlain

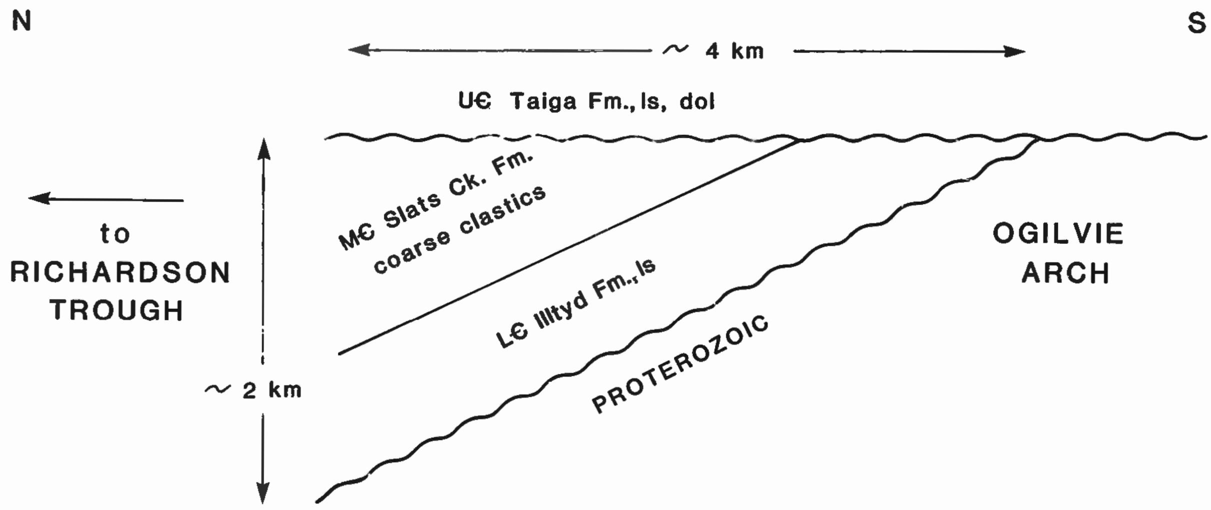


Fig. x-1. Angular unconformity below Upper Cambrian Taiga Formation, Wind River map 1528A, ~65°, 134° 45'.

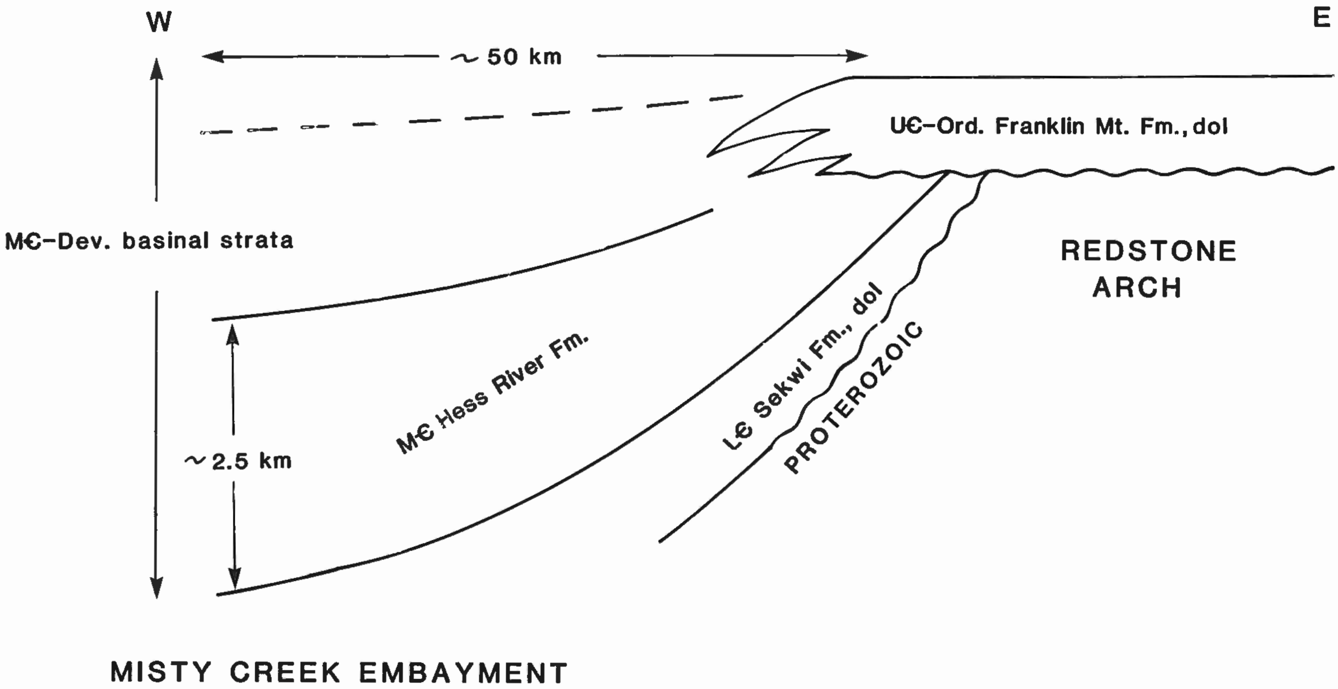


Fig. x-2. Cambrian strata, Misty Creek Embayment to Redstone Arch.

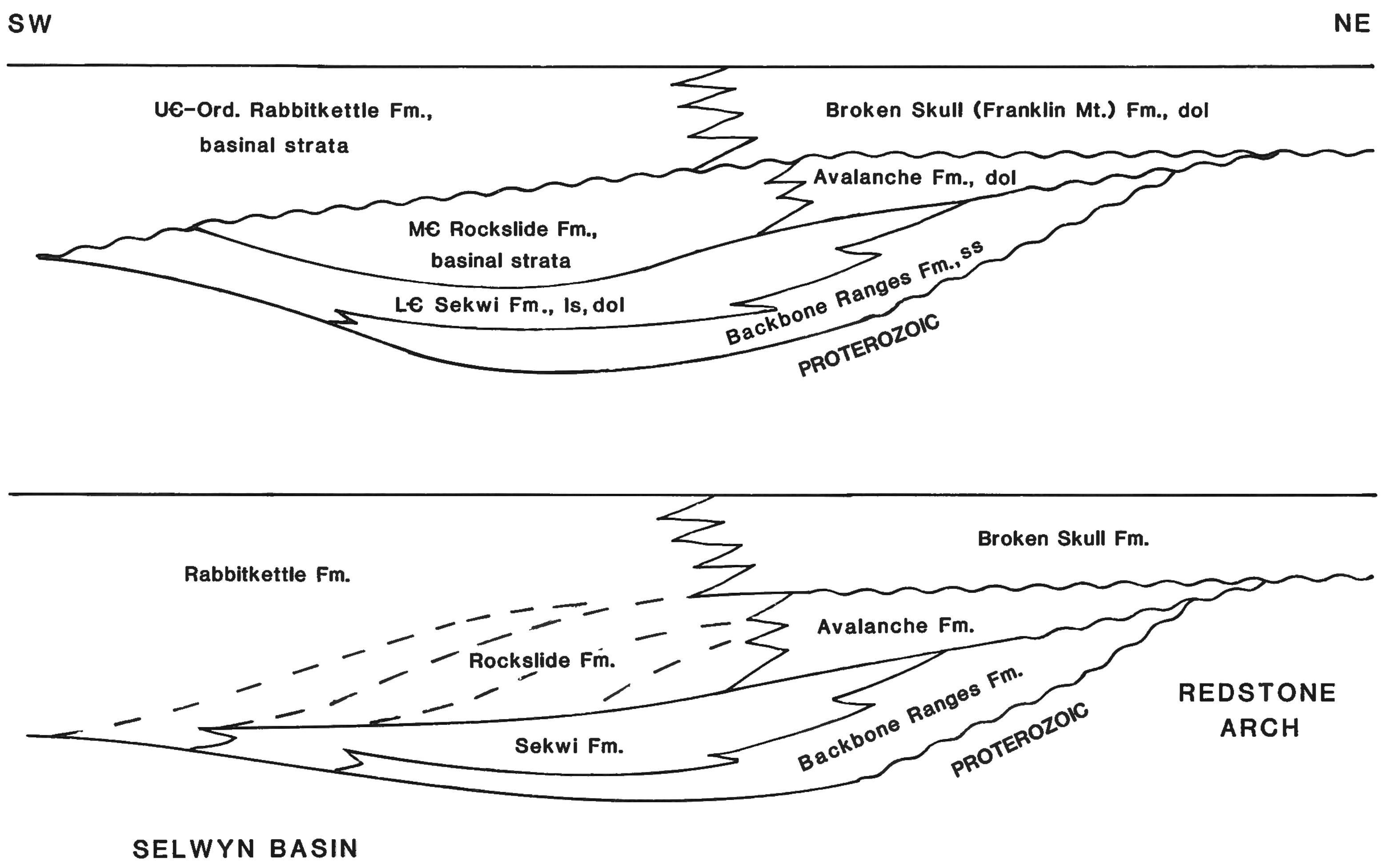


Fig. x-3. Cambrian strata, southern Selwyn Basin to Redstone Arch.
upper: assuming pre-Late Cambrian uplift and erosion;
lower: assuming sediment - starved conditions in Middle Cambrian time.

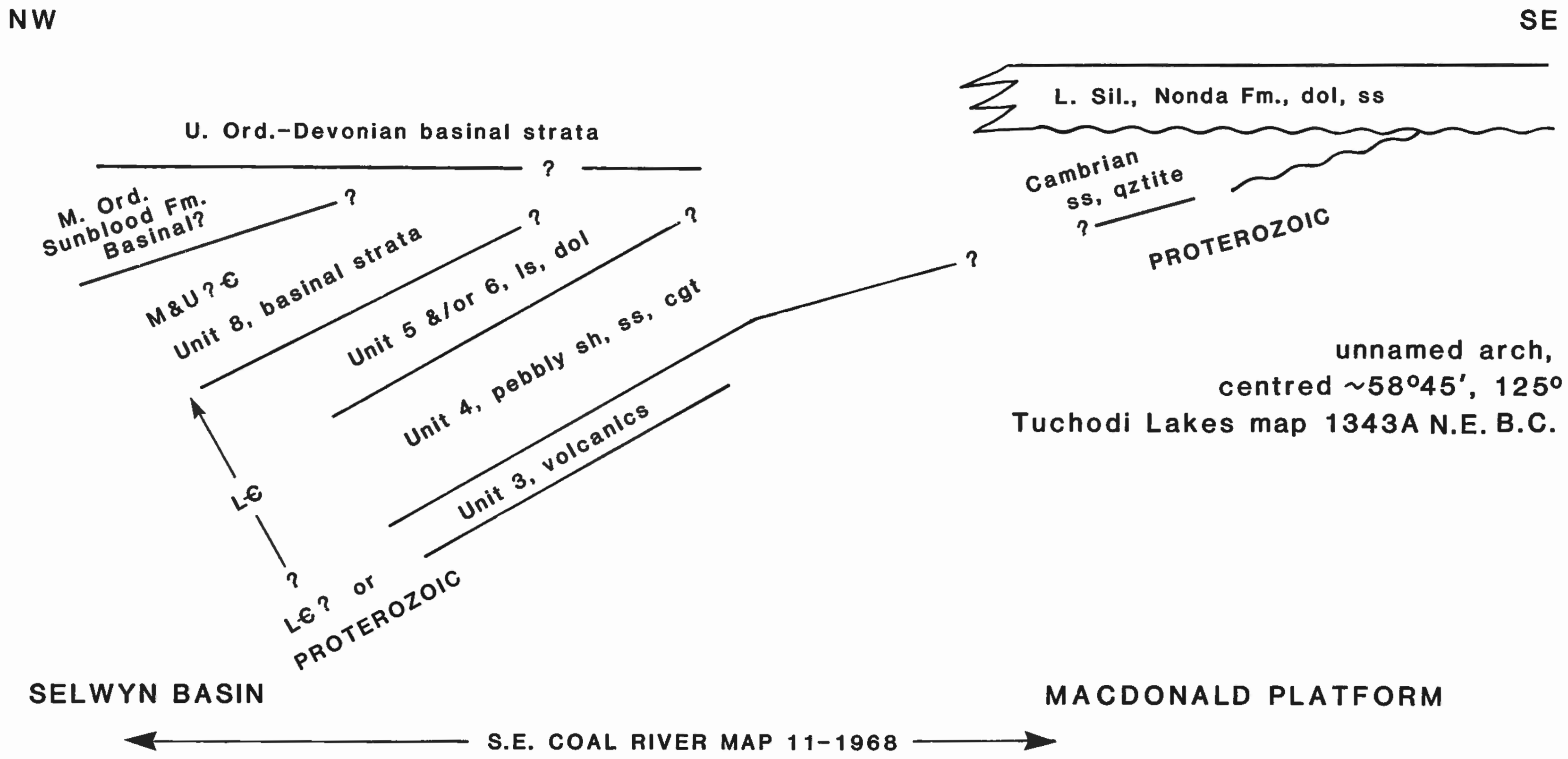


Fig. x-4. Northwest to southeast disappearance of Cambrian strata, southern Selwyn Basin to northeastern British Columbia.

tuff (Gabrielse et al., 1973, p. 35). Farther north (~63°N to 64°N, Map 2) volcanics occur within Lower (?mostly) Cambrian argillite; these are described as volcaniclastic sandstone, breccia or agglomerate, lapilli tuff, basic flows, sills and dykes (Cecile, 1984a).

Volcanic rocks plotted on the Middle Cambrian map (map 3, 65°N, 136°W) occur within an unfossiliferous unit of conglomeratic sandstone (unit 5 of Green, 1972). This unit is contiguous with, and lithologically like the Middle Cambrian Slats Creek Formation in the Wind River map area (Norris, 1982a). The igneous rocks are described as greenstone sills (Green, 1972, p. 25) or as andesite and basalt (*ibid.*, Table VI).

4) It was noted earlier (Subsurface, McConnell Arch) that the identification of pre-Mount Kindle formations (hence correlation) was uncertain in some areas. A similar situation prevails over the southeastern end of the Redstone Arch. On Rouge Range (~63°30'N, 126°W) the pre-Mount Kindle (pre-Whittaker) section consists of fine grained sandy dolomite with occasional salt casts, and interbeds of red and green shale (Gabrielse et al., 1973, p. 47). The authors elected to correlate these beds with the Late Cambrian Broken Skull Formation (Franklin Mountain equivalent) rather than the Middle Cambrian Avalanche dolomite, which has a similar lithology (see below).

5) Middle Cambrian deposits of the Selwyn Basin may be classified as platformal (shallow water), transitional and basinal (deep water) see discussion by Cecile, 1982, p. 3. In figures X-2, X-3 and X-4 I have lumped the transitional and basinal facies together.

The only Middle Cambrian platformal unit is the Avalanche dolomite (Map 3, Fig. C-4). Parts of this unit must have formed in a restricted, somewhat evaporitic environment. In certain exposures mudcracks and salt casts are common (Gabrielse et al., 1973, p. 39).

6) Middle Cambrian deposits are thin or missing in the southern part of the Selwyn Basin (Map 3, Figs. C-3, C-4 and C-5). This has been attributed to an episode of uplift and subaereal erosion during early Late Cambrian time (the sub-Franconian unconformity, Gabrielse et al., 1973, p. 45, 48, 112). An alternative interpretation should be considered here: a Middle Cambrian deepening event followed by sediment-starved conditions over the southern Selwyn Basin; the northern Selwyn Basin, especially the Misty Creek Embayment, provided the upstream sediment trap in this scenario. Both interpretations are depicted on Figure X-3.

TECTONICS

Precambrian tectonics

Ancient structures

A set of ancient northeast and northwest trending conjugate wrench faults cut Precambrian rocks in the general area of Great Bear Lake (Hoffman and St-Onge, 1981). According to Kerans et al. (1981) these (reactivated) faults had a significant influence on the deposition of Middle Proterozoic sediments in the area. Whether or not these ancient faults had any effect on the facies of later sedimentation is unknown, at least there is no obvious relationship to Phanerozoic sediments (Aitken and Pugh, 1984, p. 142). We do know, however, that one of these faults is associated with an island high enough that it was never covered by Cambrian seas - the Leith Ridge (south of Great Bear Lake, Map 2). We can also observe what appears to be a conjugate NE-NW pattern (among other patterns) in some of the present structures, a few such structural trends can be seen on Map 4.

Late Proterozoic structures

Reference has already been made to Eisbacher's (1981) hypothesis of a rifting event beginning in early or pre-Windermere time (Tectonic Setting). [See also Young et al., 1979, p. 128 (Hayhook Orogeny); Aitken, 1982, p. 158 (taphrogeny), and Cecile, 1986 (crustal attenuation)]. This tensional event produced narrow, northwest trending troughs and uplifts within the Selwyn Basin and adjacent mountains. It must be emphasized that there is no known evidence for oceanic crust or oceanic sediments of Late Proterozoic or Phanerozoic age anywhere in the northern Cordillera. The break-up rift, if such existed, must have lain well west of the Selwyn Basin. Perhaps, following Cecile (1986), one should speak only of "crustal attenuation".

Farther east, in the area now occupied by the Colville Hills and the northern Franklin Mountains we have evidence for a broad belt of north-northeast trending basement faults; these are thought to be ancient structures that were reactivated during the Laramide Orogeny (Davis and Willott, 1978; Cook, 1983). The age of the faulted strata is late Proterozoic but pre-Windermere – correlative with the Shaler Group of the Brock Inlier (Davis and Willott, 1978; Aitken and Pugh, 1984). Thus it is possible that these basement faults of the northern Franklin-Colville Hills area were products of the pre-Windermere rifting event (Hayhook Orogeny of Young et al., 1979).

The sub-Cambrian erosion surface

The final Precambrian event that influenced Cambrian history was the craton-wide uplift that produced the sub-Cambrian erosion surface. Within the map area only the deeper parts of the Selwyn Basin may have remained below sea level; there, the Proterozoic/Cambrian transition is recorded by fine clastics, apparently of a fairly deep water origin (Gabrielse and Blusson, 1969; Gordey, 1980; Fritz, 1982).

Erosional relief on the unconformity surface is well documented along the eastern margin of Phanerozoic cover. Hills and ridges with a relief up to 240 m are known along the north arm of Great Slave Lake (Douglas and Norris, 1960, p. 4). The Leith Ridge had a paleorelief of 300 m (Balkwill, 1971, p. 25); this ridge is formed of Proterozoic sediments adjacent to the downthrown side of one of a set of northeast trending faults (discussed above). North of Great Bear Lake the relief on the Proterozoic surface may be up to 60 m (Cook and Aitken, 1969, 1971).

Without seismic data, topographic relief in the subsurface is not easy to document but no doubt is present. The Bulmer Lake Ridge (Map 3) may be a feature similar to the Leith Ridge (Williams, 1986, p. 13). It is probable that the thickness variations of the basal Cambrian sandstone in the subsurface are a consequence of sub-Cambrian topography (Figs. L-1, L-2).

Cambrian tectonics

Tectonic elements that influenced Cambrian deposition and preservation are shown on Figure 3. The early Paleozoic history of some of these features is so poorly known that their nature, or even their existence in Cambrian time, is largely conjecture. Among such are the Aklavik, Peel and Tathlina Arches, the Root Basin, and the Liard Line.

Aklavik Arch

The Aklavik Arch is a composite, complex, and poorly known feature (Norris, 1974). Middle Cambrian strata thin toward the arch (Map 3). Whether this pattern reflects depositional thinning (Middle Cambrian warping) or erosion (Late Cambrian warping) cannot be determined.

Peel Arch

The Peel Arch is shrouded in similar uncertainty. All paleo-reconstructions show a pattern similar to that shown on Map 3 (e.g., Gilbert, 1973, Fig. 5; Pugh, 1983, Figs. 4, 5). However, Kunst (1973, Figs. 6, 8), although showing a broad arch, also suggests that Lower and Middle Cambrian clastics are continuous across the arch, thickening into the Richardson Trough. Uncertainty in this area is a consequence of sparse well control as well as the problem of differentiating Cambrian from Proterozoic strata [e.g., Caribou N-25, discussed earlier (Stratigraphy, west of the salt basin)].

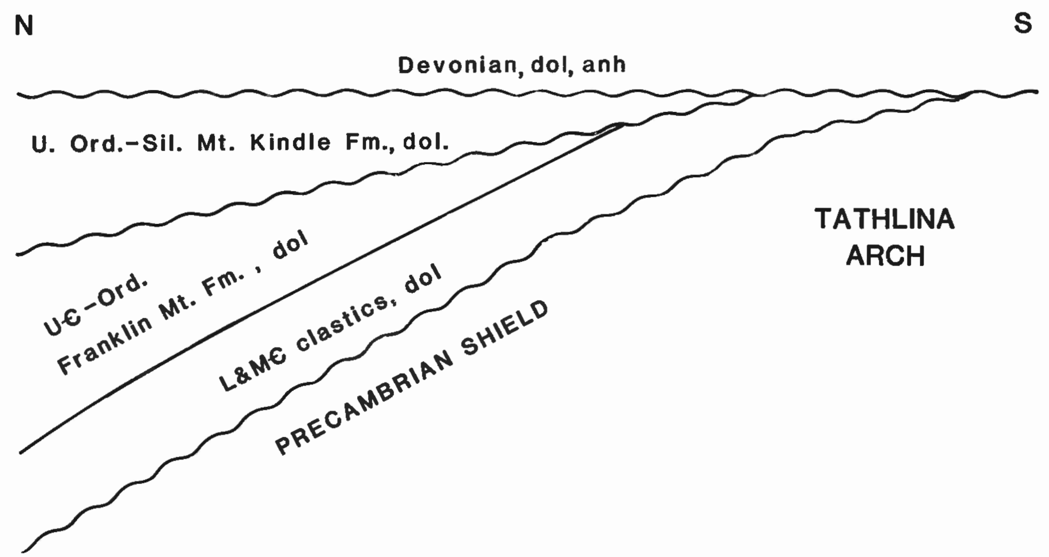


Fig. x-5 North to south truncation of Cambrian strata over Tathlina Arch (~62°, 118°).

Tathlina Arch

The Tathlina Arch probably did not exist as a separate tectonic feature in Cambrian time. More likely it was part of the very large west-jutting promontory that includes the Peace River Arch (Fig. 2). The north to south thinning of Cambrian strata toward the Tathlina Arch is primarily a consequence of post-Cambrian erosion (Figs. X-5). Whether or not there was depositional thinning cannot be determined.

Root Basin

The Root Basin was an active tectonic sag as far back, at least, as Middle Ordovician time (Morrow, 1984). As Middle Ordovician rocks are the oldest on which we have information, either from drilling or outcrops, the Cambrian and Precambrian history of the Root Basin is unknown. However, there must have been a circulation barrier to isolate the brines of the Saline River salt basin from open marine waters of the Selwyn Basin. The barrier may have been a tectonic sill, as suggested on Map 3, or it may have been a carbonate barrier, of which the exposed Avalanche dolomite is but a small example. If the latter case is true, the Root Basin may have been negative through Cambrian time, linking the Selwyn Basin with the Mackenzie Plain Depocentre (Fig. 3).

Liard Line

The Liard Line is a tectonic element of uncertain nature but undoubted significance. The line marks a transverse kink in the Cordillera, whereby the northern belt is offset to the east (see Aitken and Pugh, 1984, Fig. 4). Facies fronts at several Paleozoic horizons display a similar offset. As will be discussed later, there must have been a considerable amount of Cambrian tectonic activity in this area, but the nature, orientation and extent of any Cambrian structures are unknown. This area must have been near the Early Cambrian shoreline (Fig. 2).

Rift-related features

Cecile (1982) has demonstrated that extensional tectonics, beginning near the Early/Middle Cambrian boundary, created the Misty Creek Embayment. This basin, the Richardson Trough, and their flanking arches can be interpreted as rift-related basins and uplifts (*ibid.*, p. 30). Occurrences of Lower Cambrian volcanics are plotted on Map 2. These occurrences, spread along the 350 km axis of the Selwyn Basin, suggest Early Cambrian rifting. The southernmost of these volcanics, which may be in part of Precambrian age (Unit 3 of Gabrielse and Blusson, 1969), are associated with a thick wedge of somewhat immature and poorly sorted Lower Cambrian clastics (*ibid*, Unit 4), a combination that supports a rift valley origin.

As mentioned earlier (Tectonic Setting) Cambrian rocks of the subsurface may be interpreted as having been deposited within an extentional tectonic regime. This is strictly on the basis of proximity to the mountainous belt where extension has been documented or may be inferred; there is no direct subsurface evidence.

Map 3 shows isopachs of the pre-Franklin Mountain Cambrian section; when the salt or the sub-salt sections are treated separately, the patterns are essentially the same. Control points are few, so even in the Colville Hills area the isopach pattern is subjective, but in the Mackenzie Plains Depocentre (Fig. 3) it is largely guesswork. The isopachs reflect the assumption that this was a rift valley.

In Figure X-6 (no doubt simplistic, perhaps naive) the main arches are the high edges of major tilted fault blocks; the sub-basins, or depocentres are the low edges – basically half grabens. Between the blocks, it is assumed, are deep-seated, west dipping listric faults. This structural style is that of intraplate rifting (Lowell, 1985, Table 1-1). A description of rift structures of the Galicia margin, off the Iberian Peninsula (a passive margin between Europe and the North Atlantic Ocean) provides a model for Fig. X-6 (Leg 103 Scientific Party, 1986). Thus the Redstone Arch and Mackenzie Plain Depocentre are the high and low edges of a single tilted block. The McConnell Arch, in this scenario, is the western high edge of another major block.

The analysis is largely speculative, but there are some supporting data:

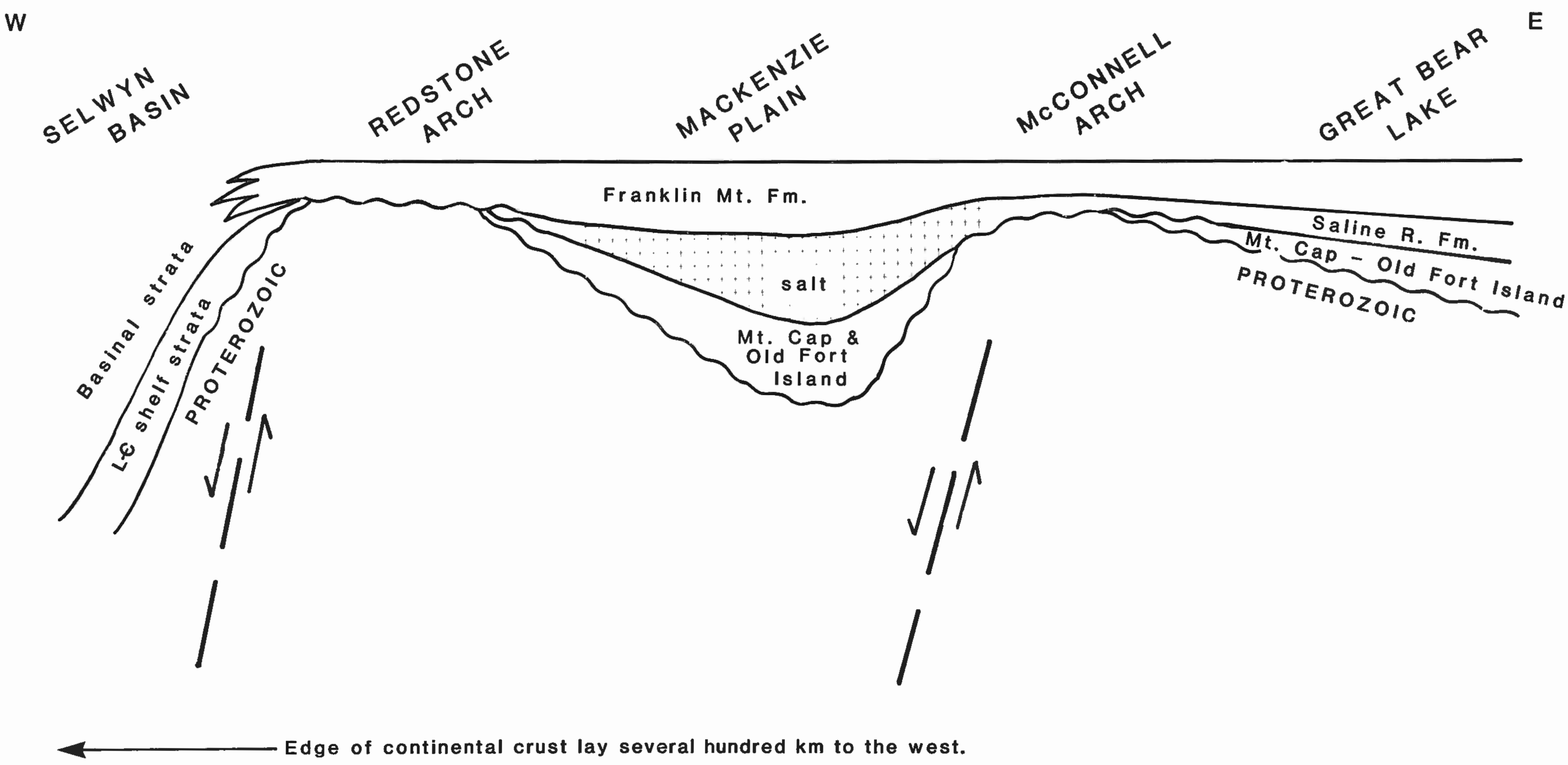
- the similarity, in orientation and scale, between the Mackenzie Plain Depocentre and western basins.
- the anomalous (albeit incompletely known) thickness of Cambrian units within the Mackenzie Plains Depocentre (notes on Map 3).
- the inconclusive but persuasive evidence that the Redstone Arch was an asymmetric, syndepositional uplift, high edge on the west (compare Fig. X-2 with Fig. X-9, upper).
- The coincidence of the Mackenzie Plain Depocentre with Laramide structures (to be discussed later).

How the remainder of the map area fits the extensional model is even more speculative. Isopachs (Map 3) show an abrupt cut-off at the northern end of the McConnell Arch, with another half graben lying north of the arch. The axis of this depression appears to trend northeast, toward the structural saddle (as expressed by the Cambrian/Precambrian contact) south of the Brock Inlier. As suggested by Figure X-6, the McConnell Arch is seen as the western high edge of a major tilted block; the mildly negative area between Great Bear and Great Slave Lakes is seen as the down side of this block. In this scenario, the Leith and Bulmer ridges are considered to have been more or less tectonically inert topographic features. As noted earlier, the Peel Arch lacks adequate control; it may mark the high edge of a major block, separated from the Richardson Trough by a listric fault; the same could be the case with the Aklavik Arch.

Post-Cambrian Tectonics

Pre-Laramide

A thorough discussion of post-Cambrian, pre-Laramide tectonics requires a set of isopach and facies maps for all Phanerozic rocks (reports in preparation). At this time it is sufficient to point out some long lasting features that were, almost certainly, influenced or controlled by tectonic elements that were active through Cambrian time.



Edge of continental crust lay several hundred km to the west.

Fig. **x-6** Hypothetical early Paleozoic tensional tectonic regime.

These are:

1) The Keele Arch (Cook, 1975) – a positive feature that originated in Late Silurian or Early Devonian time over what was, in Cambrian time, the northern part of the Mackenzie Plain Depocentre (Fig. 3; Map 3). Late in Silurian time there was, apparently, a change from a tensional to a compressive regime in this area and, as a result, down-to-the-west movement along part of the McConnell Range listric fault was reversed. The southern part of this feature is discussed later (Petroleum Prospects).

2) The McConnell Arch – in a general way the western margin of this feature marks a hinge line, with more rapid thickening to the west, for several Paleozoic units.

3), 4) The Root Basin and Liard Line – already discussed.

Laramide

There is a relationship, obvious in general, but obscure in detail, between Cambrian depocentres, as outlined by salt distribution, and Laramide structures (Map 4). The Colville Hills, in the northern part of the salt basin, are narrow, tight, generally faulted anticlines exposing Franklin Mountain or younger carbonates in their cores; the broad inter-ridge areas are essentially undisturbed. These are compressive Laramide structures and, as they lie up to 350 km east of the main mountain front, they have always intrigued structural geologists. Before much petroleum exploration had been done in this area, Cook and Aitken (1973), postulated a decollement, at the level of Cambrian salt, to explain these structures. Later, on geophysical evidence, Davies and Willott (1978) demonstrated that Proterozoic strata are also involved, thus negating the decollement hypothesis; they postulated that the folds are a consequence of Laramide rejuvenation of a regional system of northerly trending strike-slip basement faults (*ibid.*, p. 119).

The northern Franklin Mountains are those structures with somewhat arcuate westerly trends lying north of 65°N (Map 4). Aitken et al. (1982) have demonstrated that these structures must be detached, at the level of the salt, from deeper strata. However, Cook (1983, p. 329) has deduced that these northern Franklin Mountains overlie a sub-salt system of northerly trending dextral wrench faults. Presumably these are ancient faults in Proterozoic basement, rejuvenated during the Laramide orogeny, and are part of the same fault system that underlies the Colville Hills. In other words, a deep seated basement fault zone played a role in the localization of Cambrian depocentres and, some 400 my later, in the localization, orientation and structural style of the northern Franklin Mountains and the Colville Hills.

The McConnell Range is the easternmost major fold of the southern Franklin Mountains between 63°N and 65°N (Map 4). Its eastern limb is steep, near vertical in places, with a vertical displacement in the order of 3500 m. A thrust fault (Cap Fault) is mapped along the eastern limb; however, there is no evidence of significant horizontal displacement (see cross-sections AB and CE, Wrigley Map 1373A; Douglas and Norris, 1963). The isopach pattern (Map 3) is based on the assumption that the McConnell Range marks the approximate position of the major down-to-the-west listric fault that forms the eastern boundary of the Mackenzie Plain Depocentre. The northern segment of this fault underwent a reversal of throw, beginning in Late Silurian time, forming the eastern limb of the Keele Arch. The southern segment of the fault, in contrast, did not suffer reversal until the Laramide orogeny; up-on-the-west movement then created the McConnell Range and the high-angle Cap Fault.

The Mackenzie Plain is the physiographic belt lying between the easternmost ranges of the Franklin Mountains on the east and the main ranges of the Mackenzie Mountains on the west, it extends approximately from latitude 61°N to 65°N (map 4). This is a graben-like structural depression, as well as a topographic low, and for much of its length it contains the Mackenzie River valley. Within this depression are several large and many small Laramide structures [e.g. Camsell Range, (Map 4); for details see Douglas and Norris, 1959, 1961 and 1963]. The Keele Arch, positive since Late Silurian time, occupies the northern part of the Mackenzie Plain, the remainder remained negative throughout (at least) late Paleozoic time (Williams, 1986c). Like the McConnell Range, the Nahanni Range in the south (Map 4) coincides approximately with a long-lasting hinge line (faster subsidence on the west) that was active throughout most of Paleozoic time. Without any attempt at a complete analysis, it is herein suggested that there must be a fundamental link between the Colville Hills, the Franklin Mountains and the Mackenzie Plain: an ancient, deep-seated, broad, northerly trending belt of structural weakness.

SOME PROBLEMS

The Keele wells

Shell Keele River L-04 (~64°20'N, 125°E) was drilled in 1965, and immediately below the Cretaceous it drilled into Cambrian shale. This was a surprise – some 2 km of Cambrian to Devonian section which, on regional considerations must once have been present, were missing. This well provided dramatic documentation for a feature that later became known as the Keele Arch (Cook, 1975). Middle Cambrian fossils were collected from a core of this shale (Fritz, 1970, p. 18), revealing that it is part of the Mount Cap Formation. In the well report, page 3, it is stated "The well was abandoned at 4235 feet in salt, after drilling shale with interbedded anhydrite from 4085 feet." One is forced to question this statement, because no sign of evaporites appear in the samples or on the geophysical logs. However, taking the well report at face value, how do we explain the presence of a layer of salt at T.D. ? . . . An overturned section . . . faulting . . . a hitherto unknown layer of Cambrian salt . . . Proterozoic salt . . ?

Decalta et al. Keele N-62, drilled in 1973, is located near by, also near the crest of the Keele Arch. This well produced another problem. Total depth is in shale which, on the basis of lithology, is the same shale encountered in L-04. Between the Cretaceous shale and this Cambrian shale is a layer of dolomite. What is the age of this dolomite?

A summary description is:

Base of Cretaceous Shale . . . 2840 feet

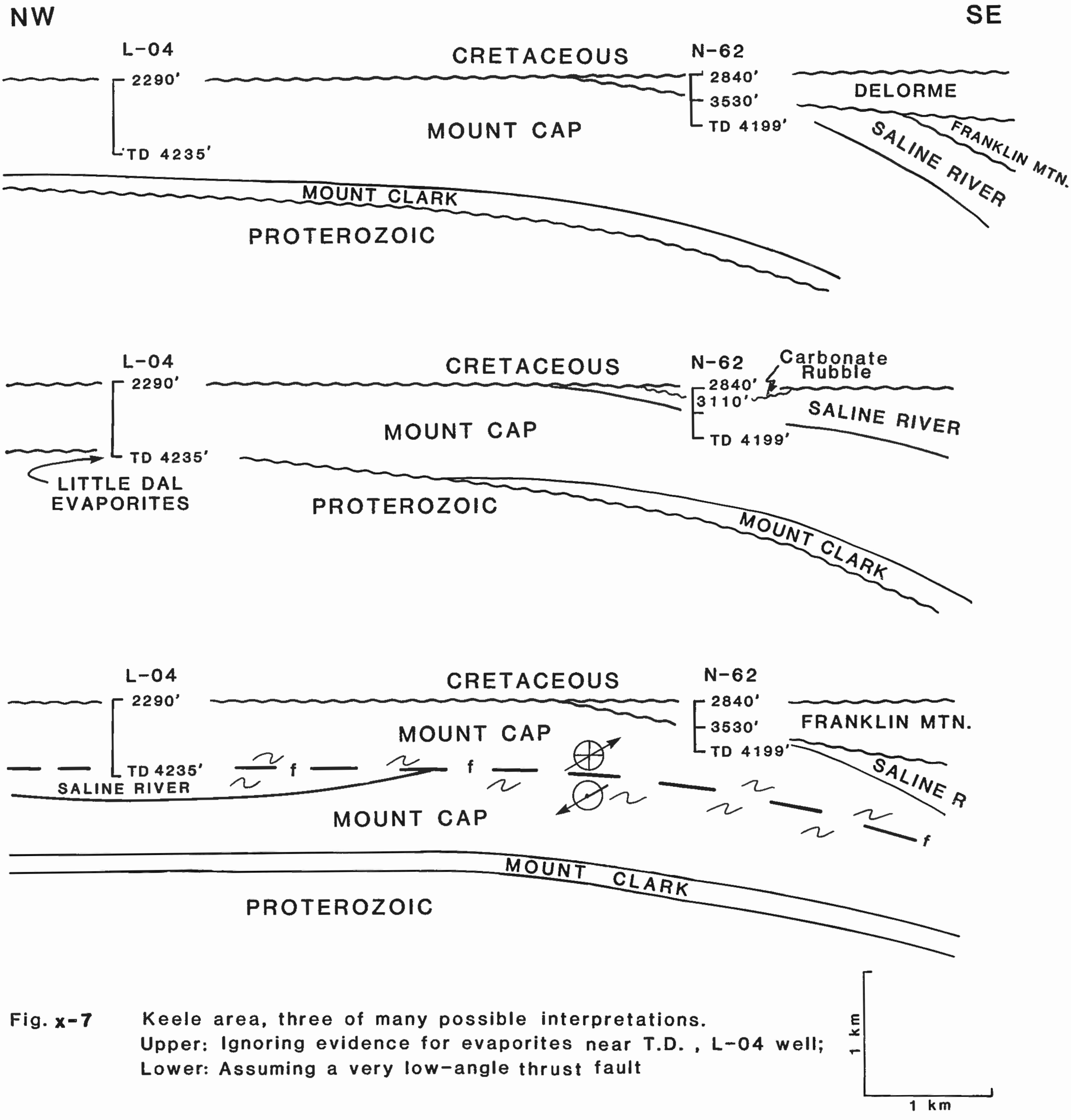


Fig. x-7 Keele area, three of many possible interpretations.
Upper: Ignoring evidence for evaporites near T.D. , L-04 well;
Lower: Assuming a very low-angle thrust fault

2840 ft - 3080 ft	Dolomite and dolomitic limestone – light grey or light brown, microcrystalline, trace of ostracods(?), sandy in basal part: large rounded, frosted grains of quartz, rare chert (pebble?).
3080 ft - 3110 ft	Sandstone – light grey with shades of red, fine to very coarse grained, 5% non-quartz: rock fragments, including red shale.
3110 ft - 3520 ft	Dolomite – light grey to various pastel shades (red, orange, yellow, flesh), micro, rarely fine crystalline, traces of coarse pellets, slightly sandy (up to small pebbles of quartz or quartzite).
3520 ft - 3830 ft	Transitional unit from dolomite as above to shale as below; trace of phosphate pellets, trace of conglomerate(?) texture in dolomite.
3830 ft - T.D. 4199 ft	Shale – dark grey to green; fissile to blocky, traces of *Lingula*-type brachiopods.

The dolomite layer between 2840 feet and 3520 feet could be, in part or in total:

- A detrital carbonate, a talus deposit that accumulated over the eroding Keele Arch at any time between Middle Cambrian and Middle Cretaceous.
- The Delorme Formation (Late Silurian - Early Devonian).
- Basal Franklin Mountain Formation (Late Cambrian).
- Saline River dolomite (atypical).
- Mount Cap dolomite (atypical).

The problems raised by the two Keele wells cannot be solved at present. Figure X-7 presents a range of tenable interpretations; my preference (without conviction) is the upper diagram.

Correlation, local

As noted previously (Depositional Units) Lower to Upper Cambrian strata of the plains fit into three units: 1) a lower, dominantly clastic, normal marine unit (Mount Cap

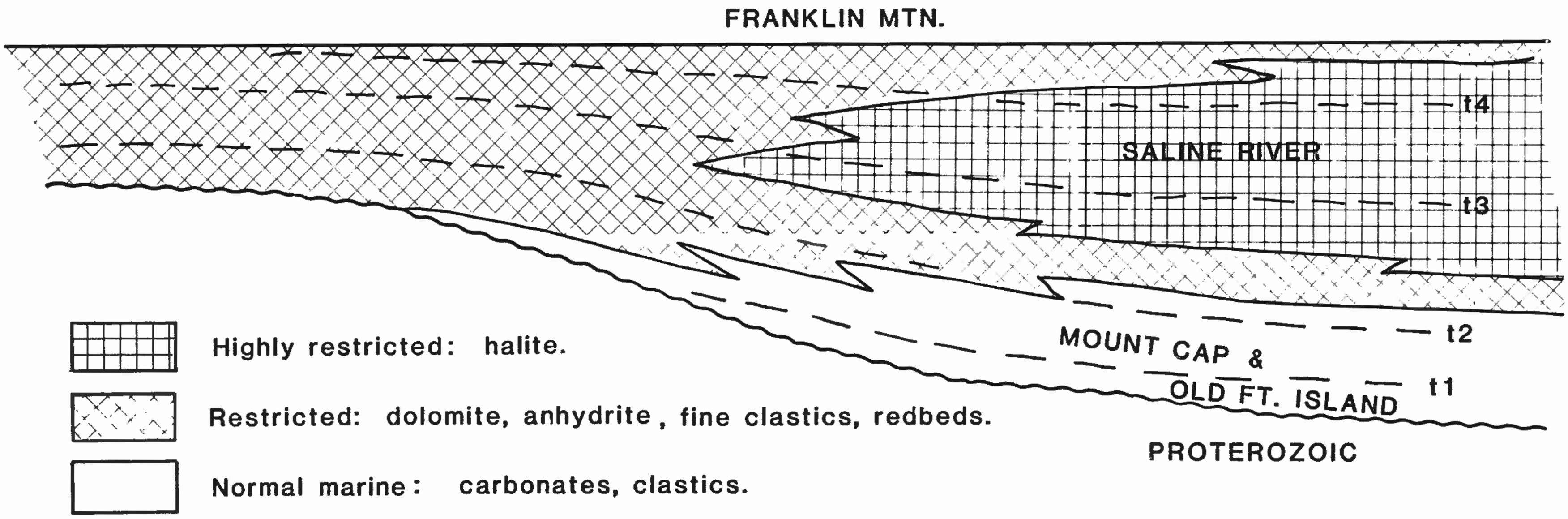


Fig. x-8 Hypothetical Cambrian facies relationships, arch to basin.

Formation), 2) a restricted-evaporitic unit (Saline River Formation), and 3) an upper dolomite (part of Franklin Mountain Formation). Unit 1 is the least extensive, being confined, with rare exceptions, to the main depocentres; unit 2 extends farther up the flanks of arches, or covers some; unit 3 is the most extensive, covering arches and basins alike. This pattern could be interpreted as one major transgressive onlap over pre-existing topography (Fig. X-6). Another possibility (Fig. X-8) involves a combination of syndepositional warping with facies controlled by the resulting variations of water depths: Phase 1 seas (normal marine) may have been more extensive than is apparent but, over the shallows created by the rising arches, only a semi-restricted facies was deposited. During phase 2 (saline phase) the seas may have been equally extensive; however, the brines that formed over the shallows would collect only in the deeps, leading to precipitation of halite only in these deeps.

The crux of the problem is, are the Saline River and Mount Cap formations in part time correlatives, as suggested by Figure X-8, or are they discrete time-stratigraphic units? In favor of the former interpretation are the following: 1) all contacts are gradational and facies intertongue to some extent; 2) field section U-11, high on the Redstone Arch, where the thin Cambrian section is dominated by sandstone (see Figure X-9, upper); 3) the analogue provided by the transition of Avalanche dolomite (semi-restricted) to Rockslide basinal strata (Figs. C-4 and X-3).

Correlation, regional

In the southern Rocky Mountains of Alberta, Aitken (1978) deduced the existence of three, possibly four, Grand Cycles through Middle Cambrian time (Fig. C-1). These would be second or third order sequences in the sense of Vail et al. (1977; 2nd order, 10-80 m.y.; 3rd order, 1-10 m.y.). The beginning of the first of Aitkens' Grand Cycles (Mt. Whyte-Cathedral, Fig. C-1) appears to coincide closely with the carbonate-shale shift that marks the top of the Sekwi Formation. This deepening event, in the north, occurred near but below the Early/Middle Cambrian boundary, within the latter part of

Bonnia-Olenellus Zone time (Fritz, 1976, p. 2; 1978, p. 4). Thus there is fairly strong evidence, on the basis of both faunal and event correlation, for relating the Mount Cap transgression to the Mt. Whyte-Cathedral Grand Cycle (Fig. C-1).

There appears to be no obvious relationship between the remainder of Aitken's Rocky Mountain cycles and the northern stratigraphy. The Cambrian strata of the northern plains seem to represent but one major transgression. It is tempting to attribute the salt to a regressive phase; however, the presence of thick salt indicates continued, possibly rapid, subsidence (or sea level rise). The only firm evidence for regression, in the north, is erosion below the Franklin Mountain Formation on the major arches but this, as discussed later, may not indicate a regional epeirogenic event.

Perhaps one of the reasons for the lack of north-south correlation through Middle and Late Cambrian time is the difference in tectonic style of the two areas. Broad epeirogenic movements were dominant in the south; more local, extensional tectonics were dominant in the north, with no direct causal relationship between the two systems.

Age of the Saline River Formation

No useful fossils have ever been recovered from strata that definitely are part of the Saline River Formation (Norford and Macqueen, 1975, p. 12). Until fairly recently the formation had been considered Middle Cambrian (Tassonyi, 1969, p. 19). The imputed Late Cambrian age (Aitken et al., 1973; Norford and Macqueen, 1975) seems to have been based on the following:

1) the concept of a profound and widespread sub-Franconian (mid-Late Cambrian) event, involving uplift and erosion.
2) observation of an erosional unconformity below the Saline River Formation on the eastern limb of the Redstone Arch.
3) linking the above, hence a post-unconformity, or Late Cambrian age for the Saline River Formation (Fig. X-9, middle).

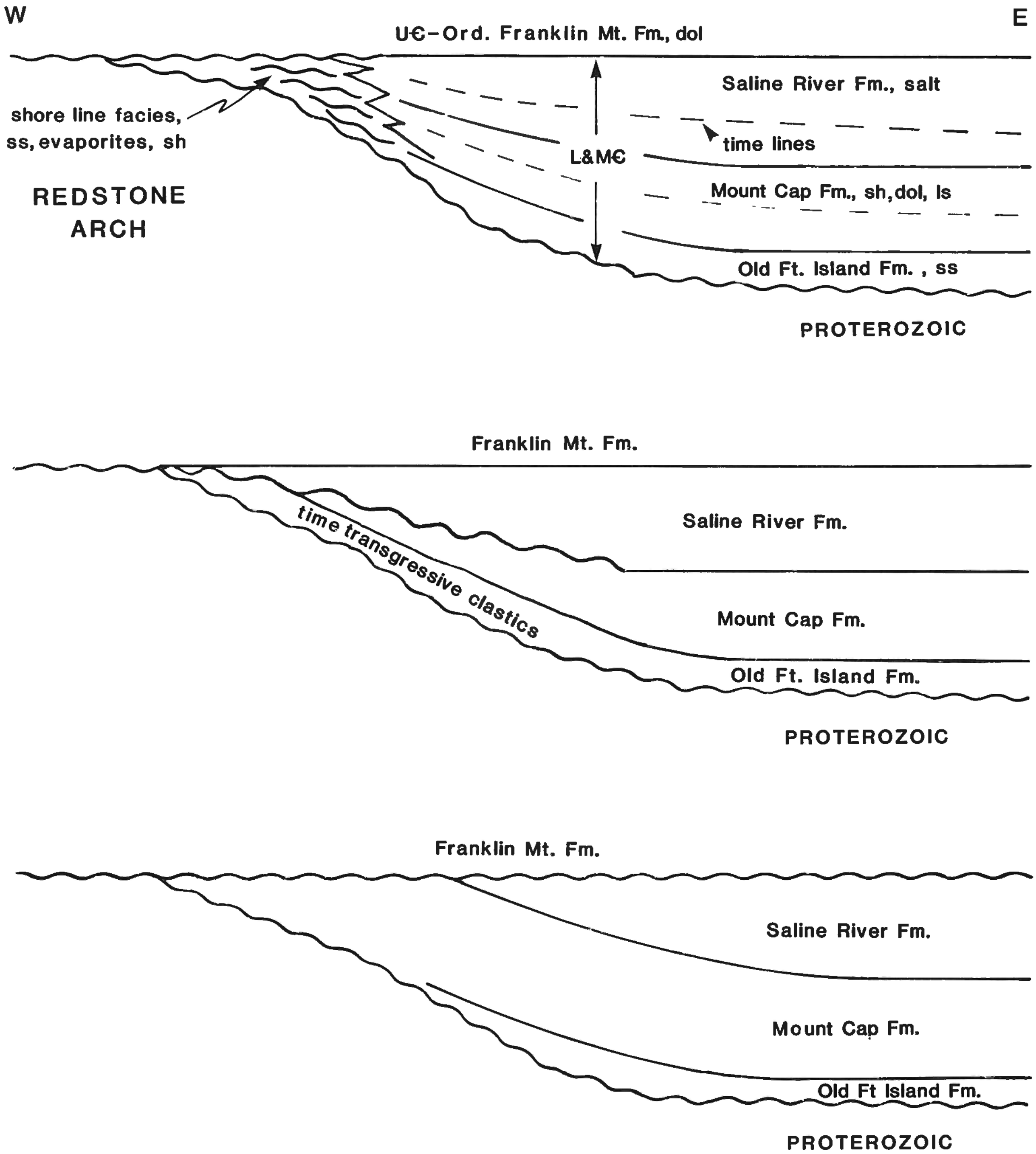


Fig. x-9 East to West disappearance of Cambrian strata over Redstone Arch.
upper: assuming syn-depositional differential subsidence;
middle: assuming pre Saline River erosion.
lower: assuming pre-Late Cambrian uplift and erosion.

There can be no doubt that there is a profound sub-Late Cambrian unconformity over the major arches (Figs. X-1, X-2, X-3, and X-9). However, one may question the concept that this was an epeirogenic event, affecting arches and basin alike. In the Selwyn Mountains, or western part of the Selwyn Basin, Gabrielse (1967, p. 276) reports a spectacular angular unconformity; this is depicted by Plate XXI in Gabrielse et al. (1973). This unconformity is between the Rabbitkettle Formation (Upper Cambrian) and the 'Phyllite unit' [Hadrynian(?) and Lower Cambrian]. There are two items to note here:

1) the timing of the deformation and erosion can be known only within broad limits.
2) assuming a Cambrian extensional tectonic regime, local horsts are to be expected within the Selwyn Basin; for an example within the Misty Creek Embayment see Cecile (1982, p. 29).

Another angular unconformity is reported in the core of the South Nahanni anticline (~62°20'N, 127°50'W) by Gabrielse et al. (1973, p. 112). This must be extremely local because the formations as mapped show no discernible truncation (*ibid.*, Glacier Lk. ~~Flat River~~ map); nor is any evidence given in the description of a measured section (*ibid.*, Part II, section 15, p. 64). As further evidence for basin-wide uplift these authors cite the thin or absent Middle Cambrian section over large areas of the southern Selwyn Basin (*ibid.*, p. 45). This phenomena, as has been noted, can be interpreted as a consequence of drowned but sediment-starved conditions (Fig. X-3, Lower).

The idea of an erosional break between the Saline River and Mount Cap formations is relatively new; it was not mentioned by Tassonyi (1969). There is no convincing subsurface evidence to indicate a break. Some subsurface geologists have accepted the break (e.g. Gilbert, 1973), other have not (e.g. Davis and Willott, 1978). The most frequently cited evidence for an erosional break is outcrop section U-11 on the Imperial River (65°06'N, 127°57'W) described in Aitken et al. (1973, p. 18). The description of this section (some 122 m of combined Saline River and Mount Cap) reads like what one would expect to find in a near-shore environment on the flank of a rising arch: varicoloured shales, impure dolomite, gypsum, sandstone, including pebbly layers. It is not clear from the description why the Saline River/Mount Cap contact was placed where it was, nor why it was thought to be a significant unconformity. Nevertheless, these authors (*ibid.*, p. 31) state that "subsequent mapping has provided incontrovertible evidence for this unconformity by demonstrating that in the Mackenzie Mountains the Saline River Formation successively overlies formations ranging downward from Mount Cap to the Katherine Group".

Even if there is an erosional break within the U-11 section, this site, high on the arch, is not the type of tectonic environment from which one can deduce an unconformity of regional importance. Nor does the onlap of the Saline River Formation as described reveal anything whatever about the nature of the Saline River/Mount Cap contact. A progressive onlap of Early to Late Cambrian seas onto a rising arch would produce the observed relationships (Fig. X-9, upper). Thus the arguments favoring a Late Cambrian age for the Saline River Formation are equivocal, at best.

The age of the Saline River Formation remains unknown . . . Middle Cambrian . . . Late Cambrian . . . or both? I prefer Middle Cambrian, based on the following logic: In the Misty Creek Embayment differential subsidence was much more marked in Middle than in Late Cambrian time (compare Fig. 13 with Fig. 7 of Cecile, 1982). In the plains the salt is part of the Cambrian section that exhibits great thickness variations (Map 3). Therefore, by analogy, the salt was probably deposited in Middle Cambrian time, the time of maximum tectonic differentiation.

Age of the Pre-Identifiable Paleozoic (PIP) sandstones or quartzites

The term PIP rocks is an acronym for Pre-Identifiable Paleozoic (or Phanerozoic) (Williams, 1986). In northeastern British Columbia and southern Northwest Territories (west of ~120°W) identifiable Paleozoic strata, ranging in age from Devonian to

Cambrian, overlie sandstone of undetermined age (see Map 1, Williams, 1981, for the distribution of these rocks; the Northwest Territories distribution is indicated on Map 2 of this report). These rocks are often called quartzites. They are usually tightly cemented by silica, but they are not metaquartzites.

The age that various geologists have given the rocks depends, it would seem, upon the area in which they were working. Approaching from the south, Pugh (1975, Fig. 13) labelled the PIP quartzites as ?Ordovician. Approaching from the west, Torrie (1973, Fig. 8) labelled them ?Cambrian (Fig. X-4). Approaching from the northeast, Meijer Drees (1975) labelled them Proterozoic. All of these age designations are logical and, in certain areas at least, probably correct. The essential point is, when drawing paleogeographic maps, or deducing tectonic and depositional history therefrom, there remains a great deal of uncertainty.

In my opinion, a major Cambrian river, flowing westward over what later became the Tathlina Arch, debouched into the western sea in the vicinity of the Liard Line (Map 2). This would account for the very thick, immature and poorly sorted clastics in the area (unit 4, Gabrielse and Blusson, 1969). Part of the PIP quartzites in this area may be remnants of a Cambrian delta system; this possibility is depicted on Figure X-10 (lower). Several wells of the Fort Simpson area (~60°N, 122°W) encountered green siliceous mudrocks, in some cases associated with basic igneous rocks, below Devonian strata (Williams, 1986); these could be Cambrian tuffs. Until we have a method for dating the PIP rocks these hypotheses remains tenable but untestable.

Cambrian Climate

There seems to be something wrong with the Cambrian paleographic map, Figure 2. The position of the equator is taken from Figure 2 of Scotese (1984), hence the direction of the northeast trade winds. One would assume that these were desiccating winds in view of the extensive salt deposits. It would follow, surely, that these winds did not

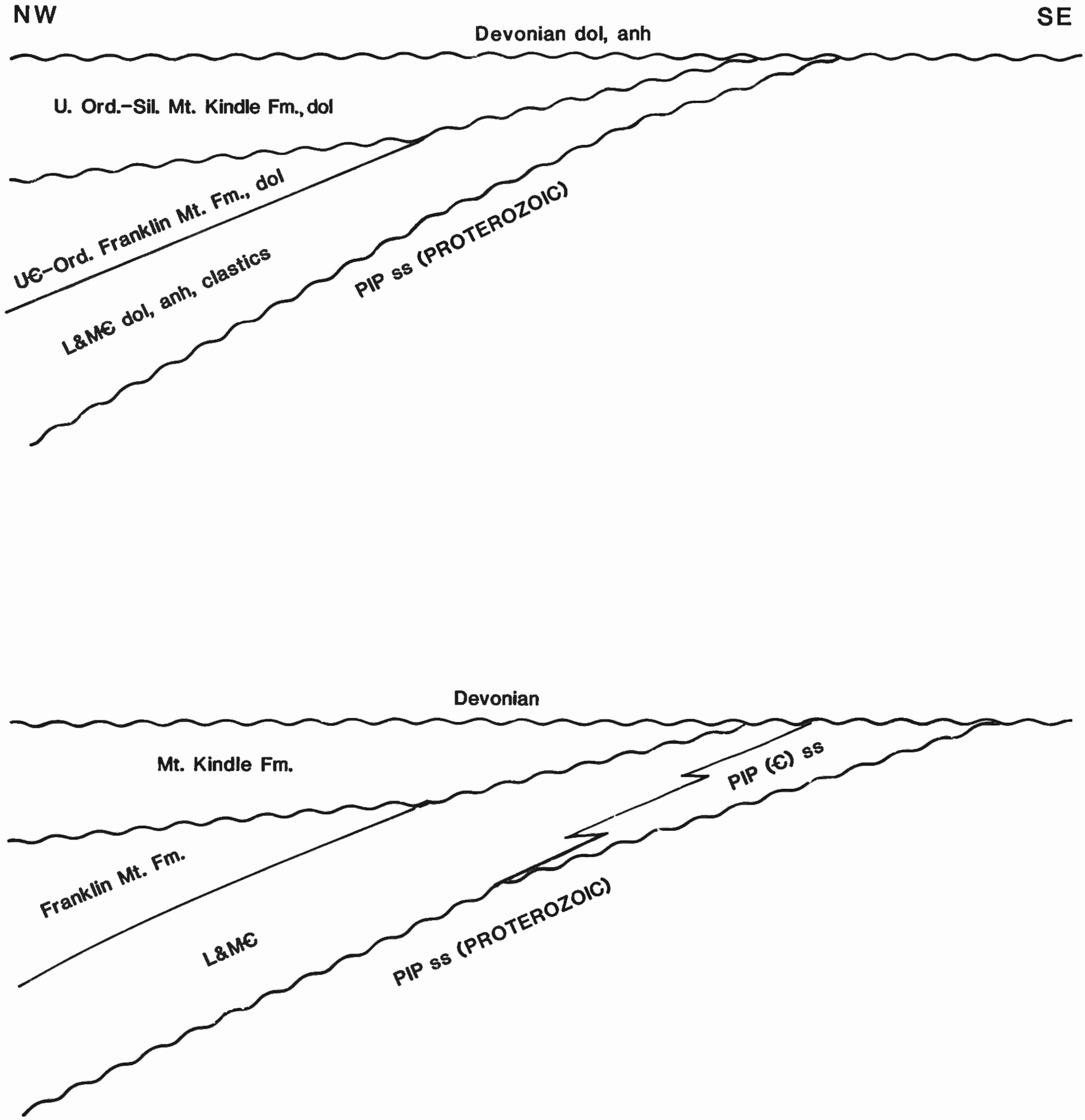


Fig. x-10 Northwest to southeast truncation of Cambrian strata, Fort Simpson area (~62°, 122°).
upper: assuming the PIP clastics are Proterozoic;
lower: assuming the PIP clastics are in part Cambrian.

reach the area after traversing an extensive open sea, as shown. But perhaps they did, and, as discussed by Sloss (1969, p. 779) the importance of aridity in localizing salt deposits has been overrated, and that the major control is the rate of subsidence.

PETROLEUM PROSPECTS

Gas was discovered in the basal Cambrian sandstone in Ashland et al. Tedji Lake K-24, drilled in 1974 (well locations are identified on Map 1; K-24 appears on Fig. L-1). The pay zone is thin (~5 m), depth to the reservoir is 1150 m, the structure is relatively small; reserves are estimated to be at least 0.5 billion cubic metres (18.1 Bcf) by the National Energy Board. Two other gas discoveries have been drilled since: – PCI et al. Tweed Lake M-47, drilled in 1985, and PCI Canterra Bele O-35, drilled in 1986.

The Tedji Play, meaning the search for petroleum in the Colville Hills area in conditions similar to the original discovery, will be discussed at more length by Hamblin (in prep.). In brief, the pay zone is the Old Fort Island sandstone, cap rocks are shales in the Mount Cap Formation, traps of both structural and stratigraphic types are to be expected. Source rocks, it is assumed, occur in the Mount Cap Formation; and possibly, also in Proterozoic sediments of the area. Structures of the area were discussed briefly in the section on Post-Cambrian tectonics; more structural detail has been provided by Cook and Aitken (1973), Haimila (1975), and Davies and Willott (1978). The underlying Proterozoic clastics and carbonates, of unknown but great thickness, are mostly of marine origin, and are not metamorphosed.

There is no published comprehensive study on the source rock potential or thermal history of Cambrian or Proterozoic strata of the Corridor area. What little data is available at the ISPG suggests that, in the Colville Hills area, Cambrian strata range from under mature to mature, i.e., near the top of the oil window (memo from T.G. Powell to L.P. Purcell, Aug. 26, 1974) and that Proterozoic sediments have been heated beyond the oil window but may retain some capability to generate dry gas (Snowdon and Williams, 1986).

TABLE I

Wells of Tedji Play, Drilling Order

Mobil Colville E-15	1970	
Mobil Belot Hills M-63	1972	
Arco Lost Hill Lake F-62	1972	
Union Mobil Colville D-45	1973	
Union IOL E Maunoir M-48	1974	
Ashland et al. Tedji Lake K-24	1974	Discovery, Gas
Union Imperial Stopover K-44	1975	
Union Decalta Good Hope A-40	1975	
BP et al. Losh Lake G-22	1975	
PEX Fina N. Colville L-21	1978	
Foreward IOE Anderson C-51	1983	
Foreward et al. Izok D-11	1983	
Foreward et al. Camp M-61	1984	
Foreward et al. Ewekka C-11	1984	
Foreward et al. Aubry J-13	1984	
EXCO et al. Tunago N-37	1985*	
PCI et al. Tweed Lake M-47	1985	Gas
PCI Westcoast K'Ahabami H-56	1985	
PCI Canterra Tweed Lake A-67	1985	
PCI Canterra Nogha O-47	1986	
PCI Canterra Bele O-35	1986	Gas
PCI et al. N.W. Tweed Lake C-12	1986	

* At time of writing (August, 1986) all wells drilled since 1984 are confidential.

Table 1 lists the wells drilled in the Colville Hills area. These 22 wells represent a drilling density of one well per 3000 km^2 or, if only the most densely drilled area is considered, one well per 1400 km^2. Obviously, there is room for further development in this area.

Maps 2 and 3 suggest that the essential elements of the Tedji play will extend southward into the Root Basin where they will be thicker and much deeper. In the deep part of the Root Basin that lies east of the Mackenzie Mountain front (~63°30'N, 125°W, Map 3) the basal Cambrian sandstone probably lies at depths between 6 and 8 km, based on the following thickness estimates:

Late Paleozoic	0 to 2 km
Nahanni-Headless	0.4 km
Landry-Arnica-Bear Rock	1.0 km
Delorme-Camsell	1.5 km
Ronning	2.0 km
Lower and Middle Cambrian	1.0 km
Total below Nahanni	~6 km

The maximum depth of burial must have been much greater than 8 km; a vitrinite reflectance of 3.09% Ro has been recorded from organic material in the Horn River shale, which overlies the Nahanni Formation, from Ebbutt D-50 (62°19'N, 122°24'W) located a few kilometres east of the Mackenzie Plain Depocentre (Meijer Drees, 1975, p. 65). Obviously, any petroleum that may have been generated by early Paleozoic rocks within the Root Basin has been destroyed or has migrated. Some preliminary time-temperature calculations done by K.G. Osadetz of the I.S.P.G. (pers. comm., 1986) suggest that, at the Cambrian level, oil generation could have commenced at some time in the Devonian Period. For any of this early petroleum to have been trapped, and to have survived to the present, special conditions are necessary: suitable traps must have been present at the time of migration, and such traps must have been spared very deep burial.

In all probability the earliest fluid migration within the deep parts of the Mackenzie Plain Depocentre (and/or Root Basin) was to the east and west, toward the bounding arches. The Redstone Arch, to the west, is now within the Mackenzie Mountains. To the east, the ancient boundary between the depocentre and the McConnell Arch is now occupied by the easternmost ranges of the Franklin Mountains (Map 4). These ranges and associated folds, as far as we know now, are primarily Laramide structures, hence too young to have collected Cambrian petroleum.

Furthermore, the above-cited high vitrinite reflectance suggests that this belt has been heated beyond the oil window.

The South Keele Arch experienced a very different history. An outline of the arch, as it is expressed by the truncated edge of the Mt. Kindle Formation, is shown on Maps 3 and 4. A report dealing with this feature in some detail is in preparation (Williams, in prep. a); for present purposes, the following summary, largely undocumented, should suffice.

The South Keele tectonic feature (Map 3) occupies part of what was, in Cambrian time, the Mackenzie Plain Depocentre. It probably remained negative through Ordovician and much of Silurian time. Its life as an arch began at about the Silurian-Devonian boundary; it probably remaned positive (i.e. subsided at rates less than adjacent areas) until Cretaceous time. Whether the arch grew steadily or in spasms cannot be determined. Several erosional unconformities are known or suspected: pre-Late Ordovician, near the Silurian-Devonian boundary, near the Early-Middle Devonian boundary, and pre-Cretaceous. Each of these were regional events, not limited to the arch. The deepest known erosion is where Cretaceous rocks lie on the Mt. Cap Formation (Fig. X-7); here the Cambrian salt has been removed. Over most of the arch, Cambrian salt remained buried by at least 300 m of Early Paleozoic strata. As far as can be determined, salt tectonics were not the cause of the arch. In Late Cretaceous-Tertiary time the area of the former arch became part of a foredeep east of the rising Laramide orogen - a depocentre for the Summit Creek Formation. Over much of the South Keele Arch, Cambrian strata may never have been cooked beyond the oil window (Conodont Alteration Index of 1.5 to 2, Franklin Mountain Formation, Brackett Lake C-21 [65°10'N, 125°05'W], E. Mackay B-45 [64°44'N, 125°38'W]; [I.S.P.G. reports 2-TTU-73; 2-TTU-83]). Thus the South Keele Arch, or at least parts of it, may meet the conditions necessary for the preservation of Cambrian petroleum: early trap formation and a suitable thermal history. Much more field mapping, more geochemical studies, as well as more drilling will be required to evaluate this potential area.

With regard to the deeper part of the Mackenzie Plain Depocentre, south of the South Keele Arch, it may be worth noting that gas has been produced from as deep as 8 km (!) from a Late Cambrian - Early Ordovician carbonate (Ellenburger Formation) in the Texas panhandle; this is a current depth record (International Petroleum Encyclopedia, 1984, p. 293); should Canada try for a new record?

If the extensional tectonic hypothesis is correct, one might reasonably expect to find more sub-basins, or rift valleys, than are currently known. Their detection would require extensive seismic coverage with good quality deep reflections. To some extent isopachs of Upper Cambrian - Silurian carbonates mimic Cambrian isopachs (report in preparation, Williams, in prep. b); there is a hint that a sub-basin may be present in an area east of the Peel Arch, centred about 67°N, 132°W. The depth to the Cambrian here would be in the order of 3.5 km. Other areas where sub-basins may lie hidden are east and west of the Brock Inlier; the stratigraphic section and burial history here should resemble that of the Tedji area.

In the Richardson Trough the possibility of an east-facing carbonate/shale front (east of the patterned areas, Map 2) with thick Lower Cambrian bioherms (Fritz, 1974) must be considered as a remote but possible petroleum play; one could even dream of a matching west-facing front lying somewhat farther east. If this play exists, it would lie at great depths along the structurally complex, eastern limb of the Richardson Anticlinorium. For example, such a front may lie below Total Depth (3600 m) of Caribou N-25 (~66°15'N, 135°W).

In this report only cursory attention has been paid to the area west of longitude 136°. Looking at this area from afar, Cambrian petroleum prospects appear to be low.

SUMMARY OF PERTINENT NEW CONCEPTS

1) Middle and Lower Cambrian strata of the Mackenzie Corridor represent part of a single depositional sequence. The basal Cambrian sandstone, in part fluvial, in part marine, grades upward and laterally to an open marine facies that includes shale, siltstone, sandstone and carbonates; this open marine facies grades upwards and to some degree laterally to a restricted marine facies which, in the main depocentres, consists primarily of halite. The formation names - Old Fort Island, Mount Cap, and Saline River - are facies terms for the basal sandstone, the open marine and the evaporitic strata, respectively; they are all, to some extent, time equivalents of each other.

2) The concept of an erosional unconformity between the Mount Cap and Saline River formations is rejected, as is the concept of a profound, areally extensive sub-Late Cambrian episode of uplift and erosion. In consequence, the evidence for a Late Cambrian age for the Saline River Formation is rejected; The Saline River Formation is (probably) Middle Cambrian in age.

3) Cambrian strata of the Mackenzie Corridor, as well as part of the post-Cambrian stratigraphic section, were deposited in a tensional tectonic regime. Additional exploration will probably reveal a complex network of horsts, grabens and half grabens, with many local and rapid changes in thickness and facies.

4) The essential elements of the Tedji play, i.e. Cambrian petroleum prospects under conditions similar to the three known gas fields, will probably continue southwards into the Mackenzie Plain. The southern portion of this physiographic province has been too deeply buried to offer any petroleum potential, but in the northern part, including part of the Keele Arch, the burial history was such that petroleum generated from Cambrian strata may have been preserved.

5) In view of the early Paleozoic tensional tectonic regime, hitherto unsuspected grabens may be hidden within the Corridor area; this has ramifications for post-Cambrian, as well as Cambrian, petroleum exploration.

6) An ancient (Late Proterozoic?), deep seated, broad (~150 km) zone of structural weakness extends in a north-south direction through the Mackenzie Corridor from (at least) the Colville Hills in the north to the southern end of the Mackenzie Plain in the south. Adjustments of basement blocks within the zone occurred in response to regional tectonic stresses, which varied through time and, at any given time, from north to south, influenced subsidence and structure, and hence thickness and facies of sediments from Early Cambrian time to the present.

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