W. Langenberg

EDMONTON GEOLOGICAL SOCIETY

EGS

EDMONTON SECTION OF THE GEOLOGICAL ASSOCIATION OF CANADA
c/o Department of Earth and Atmospheric Sciences
University of Alberta
Edmonton, Alberta T6G 2E3

1999 FIELD TRIP

Investigation of Volcanism in the Western Sedimentary Basin Northwest Alberta

Box 1170
4653-53 St. T0G 1E0

Field Trip Leaders:

Mike Dufresne (APEX Geoscience Ltd.) and Chris Collom (Mt. Royal College - Bad Heart Fm. expert)

Itinerary:

High Prairie Dreamcatcher 523-5022
Peace River Travellers Motor Inn 1-800-661-3227

September 25

STOP 1: Mountain Lake Kimberlite (Monopros Limited)

STOP 2: Quaternary Sections along the Smoky River (time permitting)

STOP 3: Exposures of Shaftsbury, Westgate and Paddy/Cadotte along Peace River/Shaftsbury Trail/Ferry Areas

STOP 4: Preglacial gravel/Grimshaw

September 26

STOP 1: Kaskapau Formation: Iron Ooids on North Side of Dunvegan Crossing.

STOP 2: Spirit River Road Cut : exposure of Bad Heart Formation

STOP 3: Bad Heart Formation Exposure @ "Tipper's Coulee" (private land). Possible exposure of First White Specs along Little Smoky River.

STOP 4: Kleskun Hill hoodoos and bentonites.

STOP 5: Simonette River: pre-glacial gravels.

Time permitting: A visit to the Peace River Iron Deposit at Worsely.

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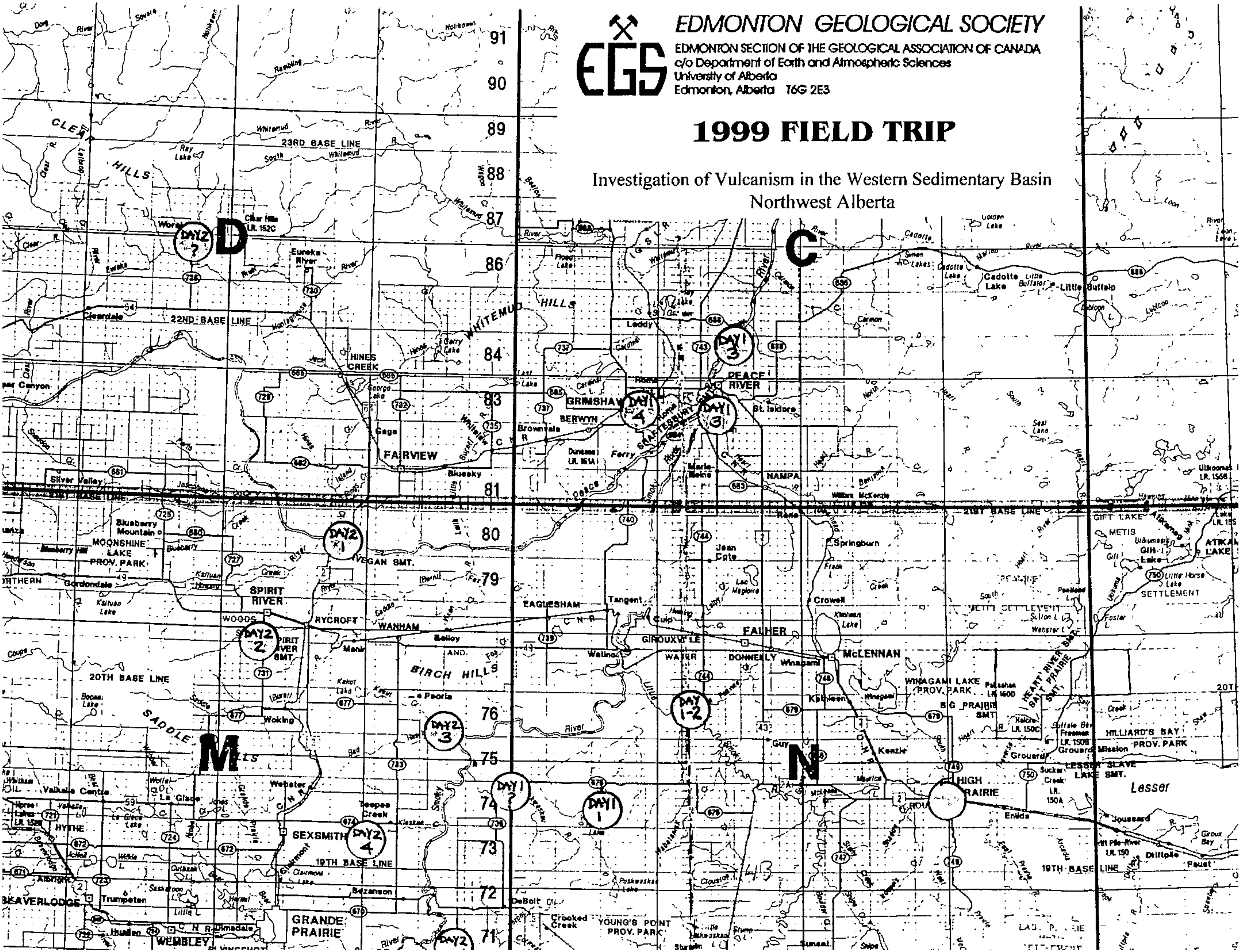
1999 FIELD TRIP

Investigation of Vulcanism in the Western Sedimentary Basin
Northwest Alberta



may be important in the exploration for diamondiferous kimberlite or lamproite diatremes in Alberta. This study was undertaken on behalf of the Canada-Alberta Partnership Agreement on Mineral Development (MDA project M93-04-037) in order to summarize and synthesize some of the key existing data that pertain to the geological potential of Alberta to contain important diamond deposits.

The objectives of preparing this regional synthesis of structural, stratigraphic, geophysical, geochemical and diamond indicator mineral data for Alberta were:

(1) To identify favourable geological anomalies and target areas for diamond exploration that would encourage and assist exploration by industry.

(2) To provide information about certain geologic and geographic domains in Alberta, based upon selected criteria such as: (a) potential for kimberlite versus lamproite diatremes based on the underlying Precambrian basement rocks; (b) timing of possible kimberlite or lamproite magmatism; (c) regional structures with potential to provide conduits for kimberlite or lamproite magmas; (d) stratigraphic data that may be indicative of local diatreme extrusion; and (e) state of preservation of kimberlite or lamproite intrusions.

(3) To identify existing exploration methods which may be useful for application in Alberta. This information is important to diamond exploration in Alberta because: (a) Phanerozoic kimberlite or lamproite diatreme activity in Alberta would probably have occurred under marine to subaerial conditions and would likely have been subsequently buried by further sedimentation; (b) there has been extensive reworking of sediments by Tertiary erosion and drainage systems originating in the Cordillera; and (c) the glacial history of western Alberta is complex, due to the interaction between Cordilleran and Continental glacier complexes.

Kimberlites and Lamproites

Kimberlites and lamproites are currently the only two known economic primary sources of diamonds. However, the Parker Lake discovery of a diamondiferous lamprophyre dyke in the eastern NWT may change current concepts regarding favourable diamondiferous host rocks (Northern Miner, 1995a). Diamonds in the kimberlite or lamproite magma occur as xenocrysts and are classified as either E-type (eclogitic) or P-type (peridotitic).

Two types of kimberlites are recognized worldwide, Group I and Group II, corresponding to the original classification by Wagner (1914) of olivine kimberlites and micaceous kimberlites. **Group I kimberlites** are petrographically complex rocks, containing material derived from three different sources: (1) upper mantle xenoliths; (2) primary mineral phases crystallizing directly from the kimberlite magma; and (3) the megacryst/macrocryst or discrete nodule suite (Mitchell, 1989, 1991; Skinner, 1989; Scott Smith, 1995). Xenocrysts in Group I kimberlites include G9 and G10 peridotitic garnets, olivine, chromium-diopside, high-chromium chromites and diamond (Mitchell, 1989, 1991; Skinner, 1989; Gurney and Moore, 1993). Megacrysts are large (1 to 20 cm) single crystals of G1 or G2 garnets, magnesian (picro) ilmenite, subcalcic to calcic diopside, olivine, titanium-poor chromite, enstatite, phlogopite and zircon. Macrocrysts are smaller crystals, that are rounded to subrounded and compositionally similar to the megacryst mineral suite, but with abundant olivine. The megacryst/macrocryst mineral suites are either xenocrysts or cognate phenocrysts, or a combination of both. They are believed to form in the upper mantle, and are indicative of kimberlite magmatism. Primary phenocryst and groundmass minerals include olivine, phlogopite, perovskite, spinel, monticellite, apatite, calcite and primary serpentine. Group I kimberlites are characterized by the presence of abundant olivine, the characteristic megacryst/macrocryst suite and minor phlogopite.

Group II kimberlites are comprised principally of rounded olivine macrocrysts in a matrix of abundant phlogopite and diopside, with spinel, perovskite and calcite (Mitchell, 1989, 1991; Skinner, 1989; Scott Smith, 1995). Group II kimberlites lack the megacryst suite and minerals such as monticellite and ulvöspinel. In addition, spinels and perovskite are relatively rare. To date, Group II kimberlites have been found only in southern Africa.

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There are three textural-genetic groups or facies of kimberlites recognized worldwide (Figure 1): (1) crater facies; (2) diatreme facies; and (3) hypabyssal facies (Mitchell, 1986, 1989, 1991). The crater facies includes epiclastic deposits and tuffs that form a low ring around the kimberlite vent. Diatremes are upright, 'carrot-shaped' bodies comprised of tuffisitic kimberlite breccia or volcaniclastic kimberlite breccia (Mitchell, 1991). Kimberlite diatremes grade downward into irregularly-shaped root zones of hypabyssal facies kimberlite. Crater facies rocks can be significant sources of diamonds (Helmstaedt, 1992, 1993). Diamond grades can be highly variable in the diatreme and root zones.

Lamproites are petrographically complex, hybrid rocks consisting of complex mixtures of magmatic phenocrysts with upper mantle xenoliths and xenocrysts (Helmstaedt, 1993). Lamproites are referred to as ultrapotassic, peralkaline mafic to ultramafic rocks that exhibit a characteristic exotic mineralogy and distinctive geochemical signature (Bergman, 1987; Mitchell, 1989, 1991; Scott Smith, 1992). Mineralogically similar to kimberlites, lamproites are distinguished from kimberlites by the presence of leucite, amphibole (K-Ti richterite), sanidine, priderite, wadeite, armalcolite and jeppeite (Bergman, 1987; Mitchell, 1989, 1991; Scott Smith, 1992). Lamproites also differ from kimberlites by having matrix glass and a relatively low calcite content (Mitchell, 1991). Geochemically, lamproites typically contain 6 to 8 weight per cent (wt%) K_2O in comparison to 2 wt% or less for Group I kimberlites. They are peralkaline ($K_2O+Na_2O+Al_2O_3 \geq 1$), and they are enriched relative to kimberlites in incompatible elements such as barium, rubidium, strontium, zirconium and light rare earth elements (REE's) and depleted in cobalt, chromium and nickel.

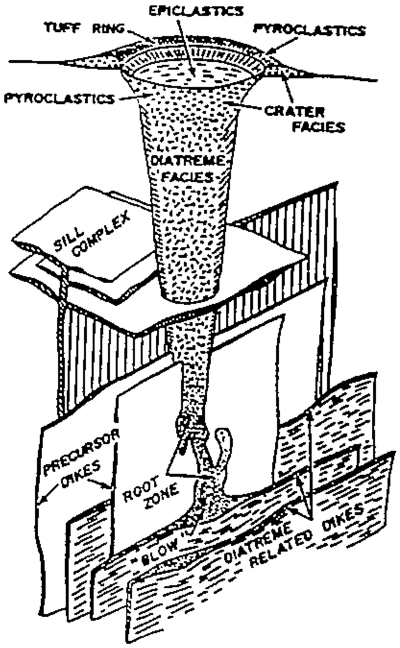
Lamproites occur primarily as extrusive, subvolcanic and hypabyssal rocks (Mitchell, 1991). They rarely form diatremes and root zones analogous to kimberlites. Their vents are shallow and wide, and commonly are fluted like a champagne glass (Figure 1). Composite craters with associated bedded volcaniclastic deposits and volcanic debris are common where craters are preserved. The crater facies is commonly intruded by magmatic lamproite. Diamonds occur mainly in the pyroclastic crater facies rocks (Scott Smith, 1995). The diamond tonnage potential of lamproites tends to be related to the volume of pyroclastics preserved (Helmstaedt, 1992, 1993).

It is generally accepted that diamonds form at pressures equivalent to 150 km to 300 km below the Earth's surface, and at temperatures less than 1,200 degrees Celsius (°C). These conditions occur within cool lithospheric roots, where the downward deflection of isotherms causes a corresponding upward expansion of the diamond stability field in the upper mantle. Macro-diamonds in kimberlite and lamproite host rocks are derived from the disaggregation of source rocks in the lithospheric upper mantle (Kirkley *et al.*, 1991, 1992; Gurney and Moore, 1993). Kimberlite and lamproite magmas, which originate in the upper mantle or deeper, then provide the transport medium to move diamonds formed in the upper mantle to the surface.

Four major factors influence whether a kimberlite or lamproite may contain an economic diamond deposit: (1) the source rock must originate in or below the diamond stability field; (2) the ascending kimberlite or lamproite magma must sample the diamond-bearing source region(s); (3) the host magma must ascend quickly and adiabatically for diamonds to survive the transport to the Earth's surface; and (4) there must be emplacement sites conducive to the formation of large pipes (Helmstaedt, 1993).

Kimberlites and lamproites occur within both Archean cratons and Proterozoic mobile belts, but 'Clifford's Rule', which is based on empirical observation (Clifford, 1966, 1970; Janse, 1991), states that economically viable diamond deposits are confined to Archean cratons. However, an exception to Clifford's Rule is the Argyle deposit in Western Australia, which is hosted in a lamproite that intrudes a Proterozoic fold belt and contains mostly E-type diamonds of Proterozoic age (Jaques *et al.*, 1986). The Argyle example illustrates that large accumulations of post-Archean, E-type diamonds can occur outside of, but adjacent to, Archean cratons (Helmstaedt, 1993).

a) Model of an idealized kimberlite magmatic system (not to scale) illustrating the relationships between crater, diatreme and hypabyssal facies rocks. The diatreme root zone is composed primarily of hypabyssal rocks (Mitchell 1986).



b) Plan and cross-sections of the Ellendale 4 lamproite vent. Note the distinctly different morphology as compared with kimberlite diatremes (Figure 1a) and the presence of hypabyssal magmatic rocks within the crater facies pyroclastic rocks.

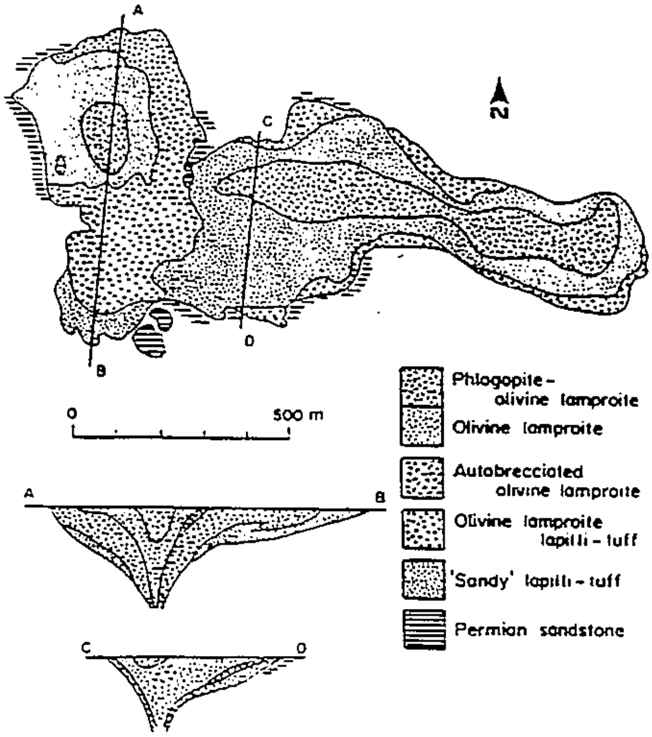
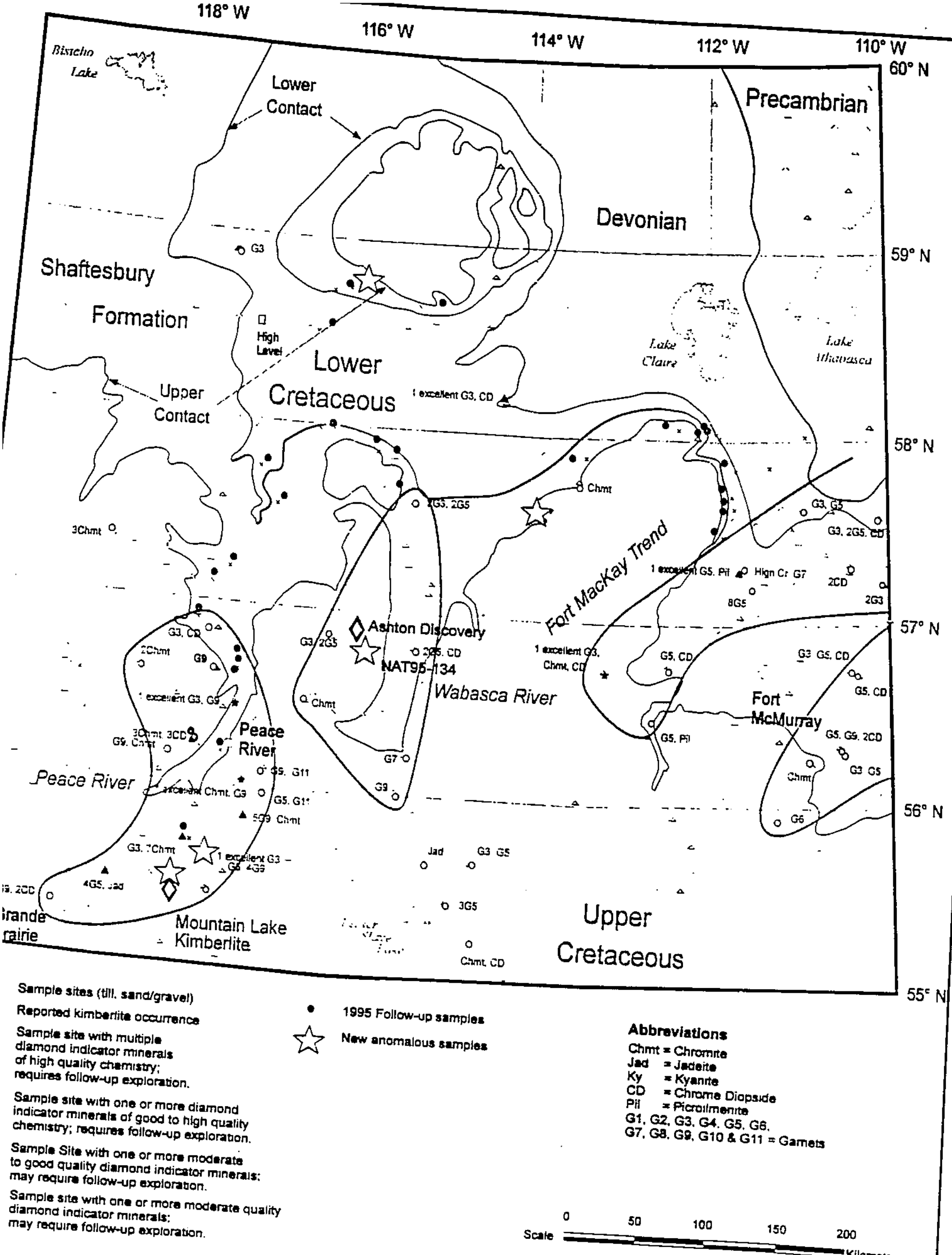


Figure 1. Model of an idealized kimberlite with plan view and cross-sections of the Ellendale 4 lamproite. Australia.



ous Diamond Indicator Sites - Shaftesbury Project

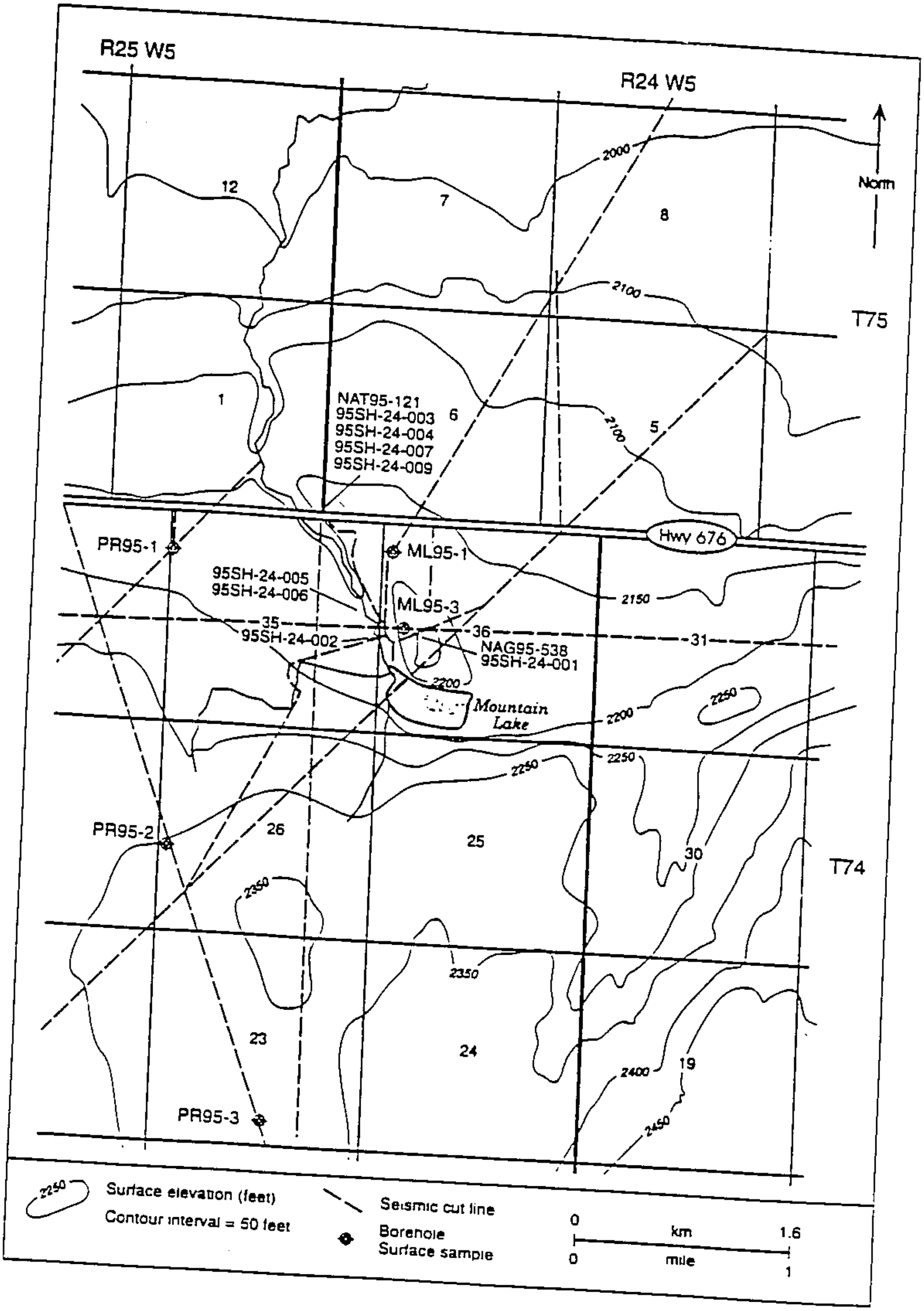


Figure 4. Sample locations.

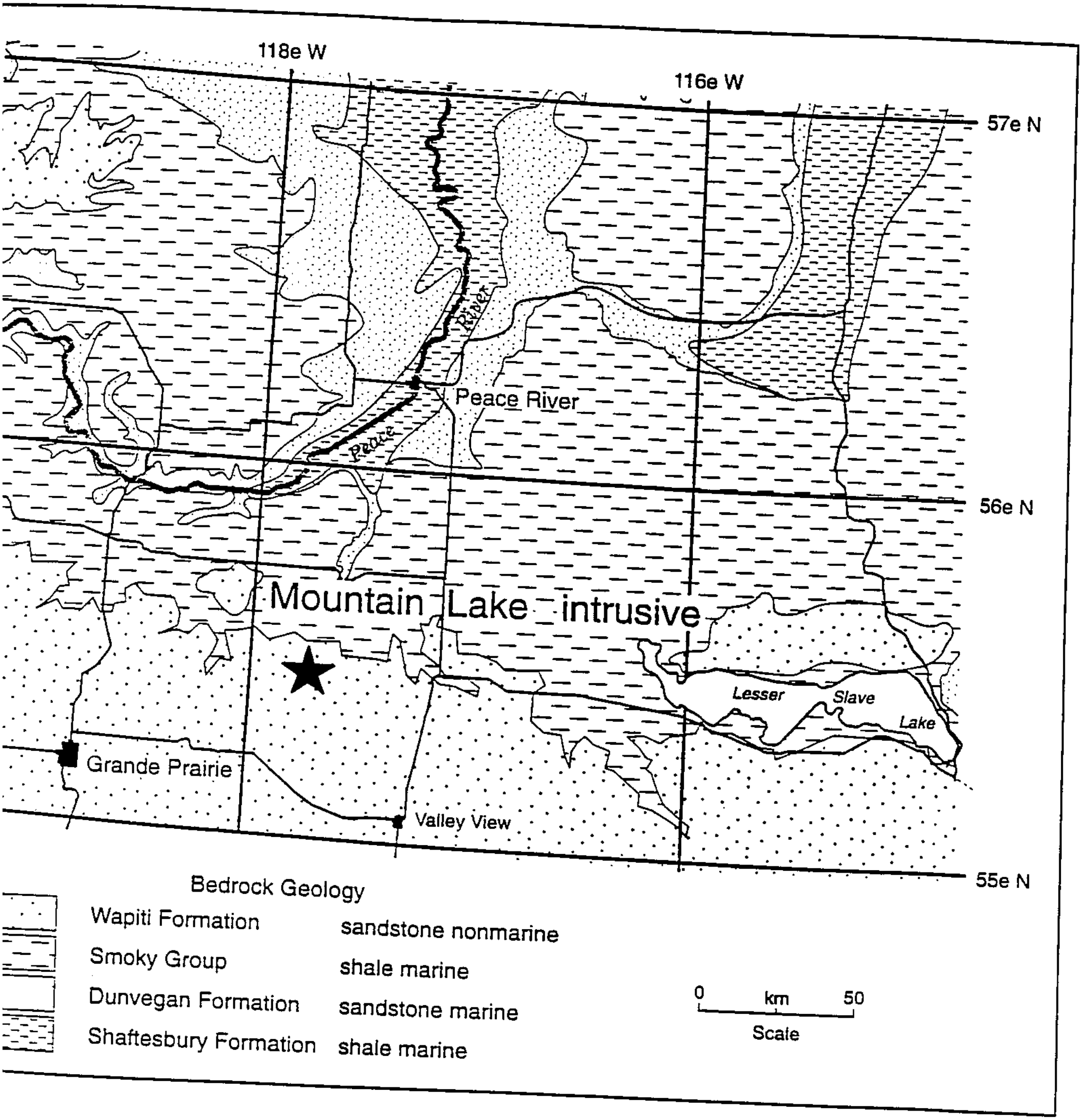


Figure 7. Geology of area around the Mountain Lake volcanics.

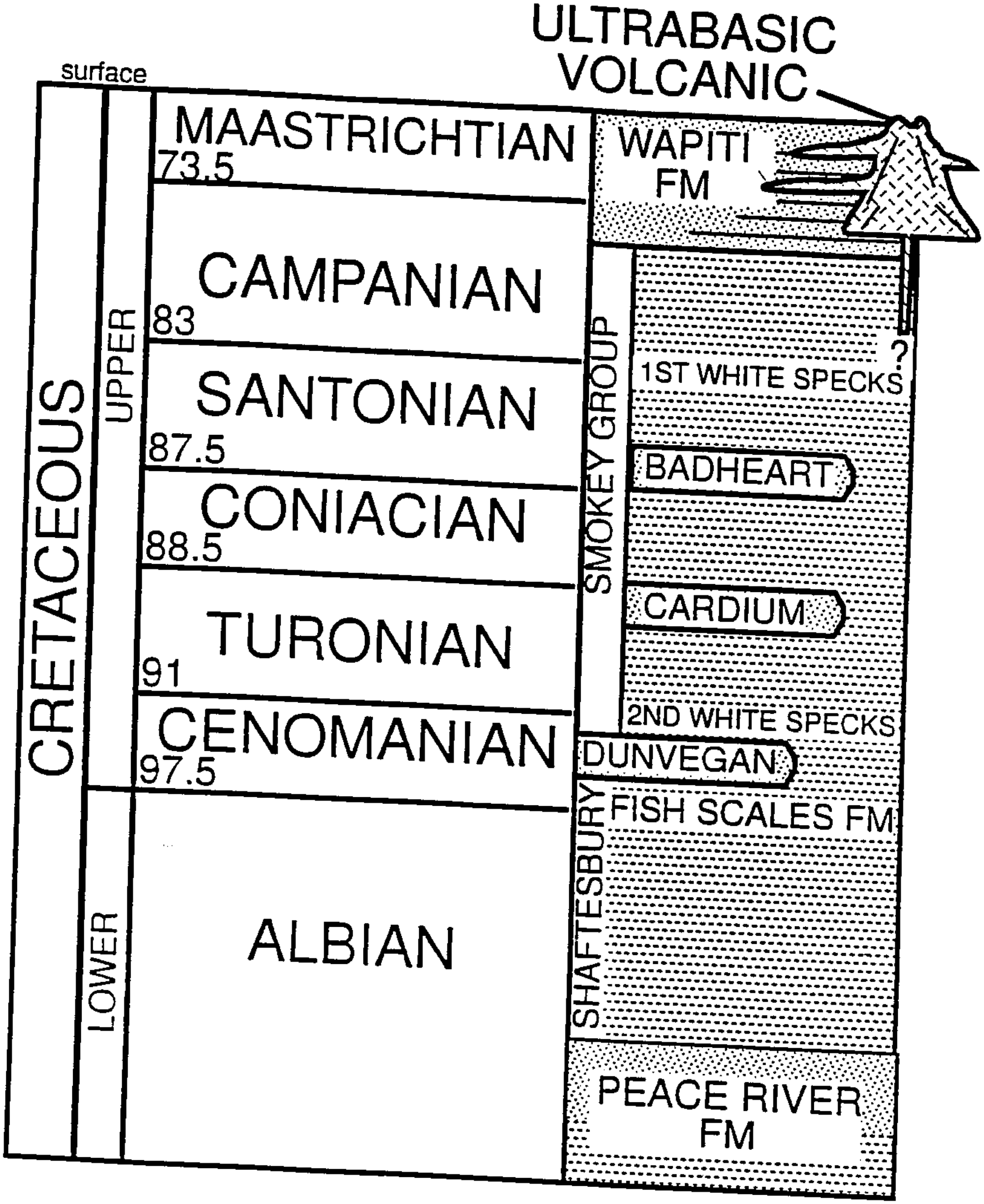


Figure 6. Stratigraphic position of the Mountain Lake volcanics. Fission track dating of apatite indicate an age of emplacement of 72 ± 7 to 78 ± 9 Ma. Palynological analyses suggest an age of 75 Ma.

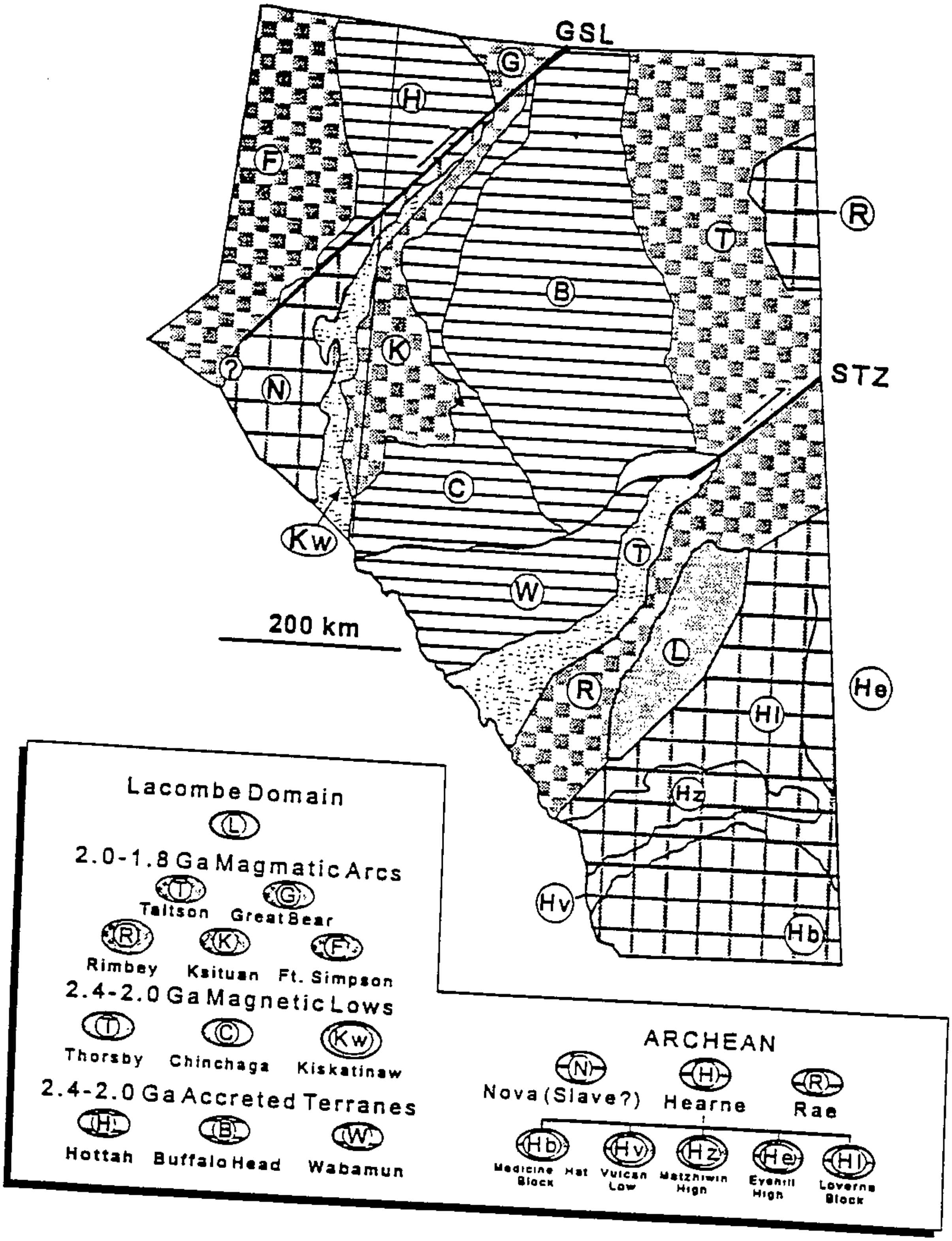


Figure 5. Basement domains in Alberta (from Villeneuve et al., 1993).

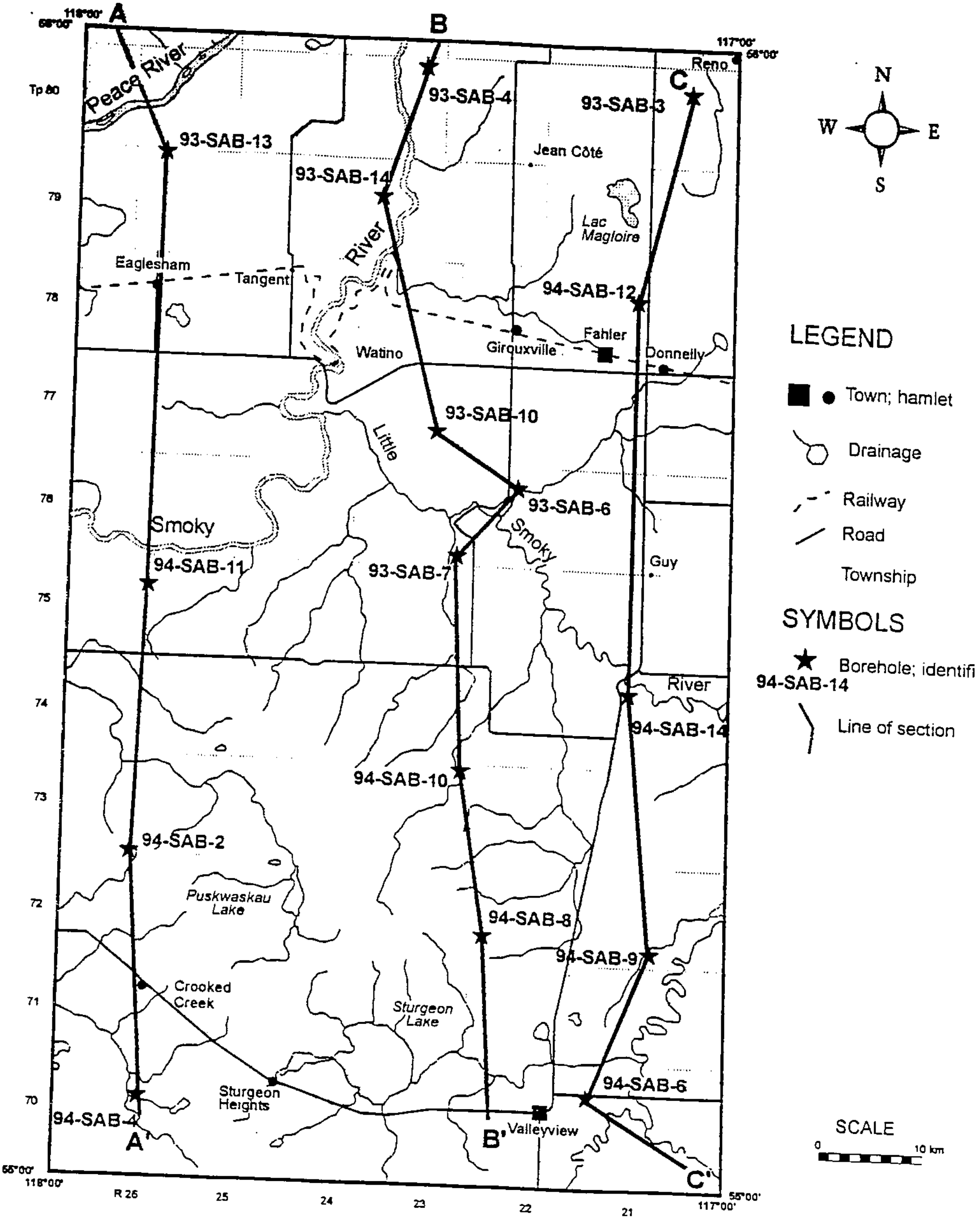
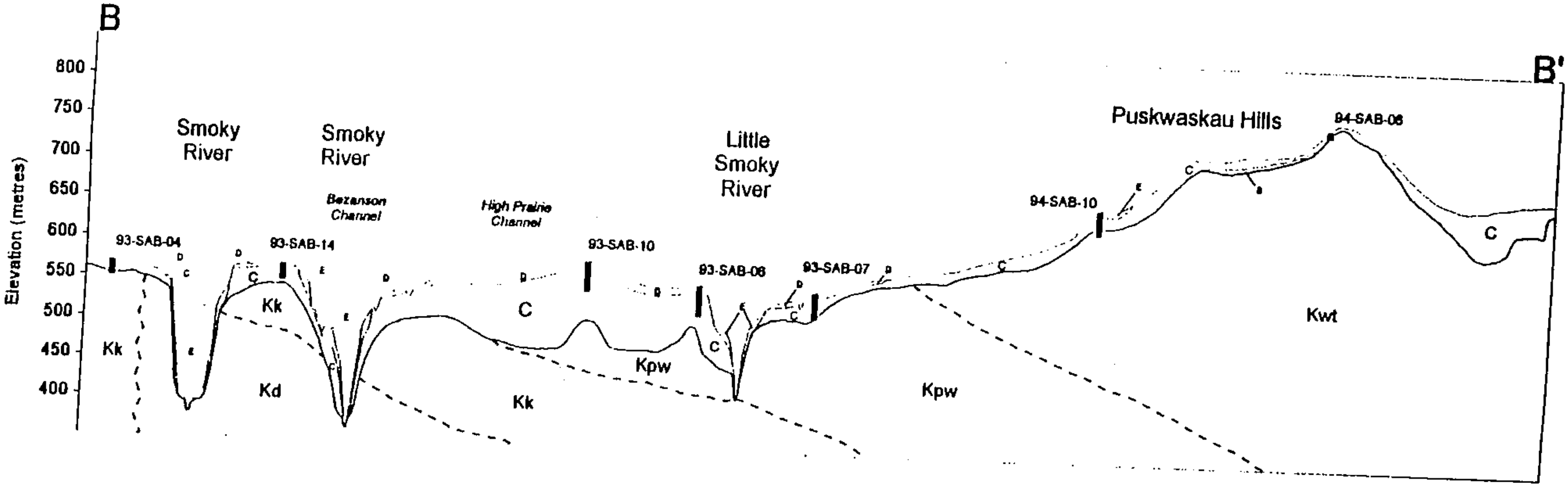


Figure 4 - Location of cross-sections and boreholes, Winagami sheet (83N).



LEGEND

Ksh = Shaftesbury Fm.
Kd = Dunvegan Fm.
Kk = Kaskapau Fm.
Kpw = Puskwaskau Fm.
Kwt = Wapiti Fm.

A = unit A
B = unit B
C = units C-1 to C-3
D = unit D
E = unit E

Bedrock surface based on Maps 3 and 4 (This report).
Dashed lines represent approximate contacts for individual units. See text for descriptions.

Figure 9 - Winagami cross-section B-B' (north - south). Horizontal axis is not drawn to scale.

E.G.S. Field Trip Guidebook

contribution of

Christopher Collom

Dept. of Earth Sciences, Mount Royal College

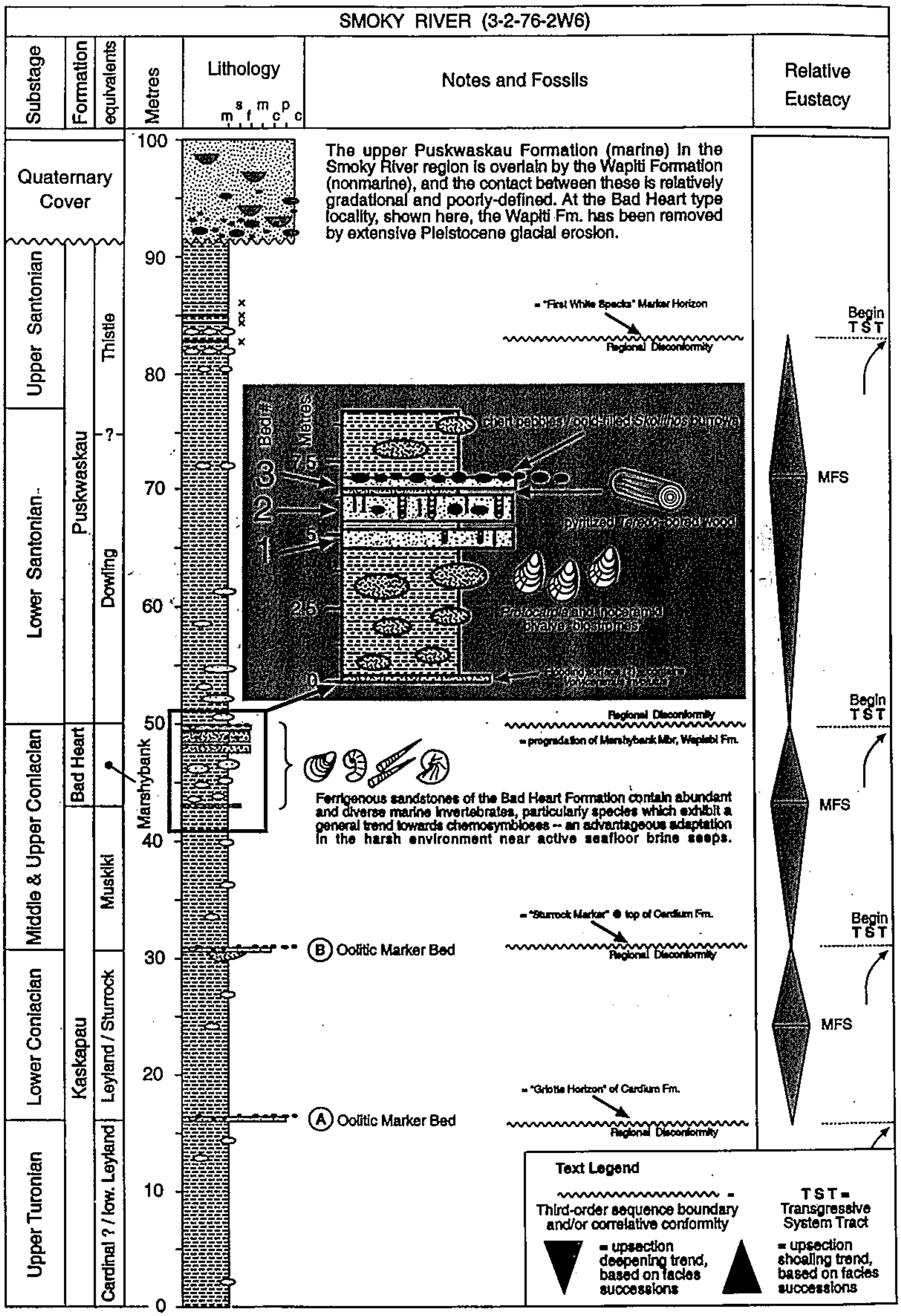
OOLITIC IRONSTONE - STOP No. 1

Name: Dunvegan Crossing Locality
[Section 16–Township 80–Range 4:W6th Meridian]
Strata exposed: upper Dunvegan Formation, Kaskapau Shale (?), glacial deposits
Outcrop type: man-made, for Alberta Highway 2 (to Fairview and Peace River)
Age: Turonian stage? (Upper Cretaceous): approx. 91 to 88 million years ago

The bridge at Dunvegan Crossing is steeped in lore and remains one of the important historical sites in Western Canada. There's even geology to be seen here! Green and Mellon (1962) first indicated that there was the presence of iron ooids at this otherwise unspectacular outcrop (the underlying Dunvegan Fm. deposits are better exposed and considerably thicker!), but not from within the Bad Heart Formation. If their correlation is correct (and this remains to be verified), then the iron ooids we'll see here are relatively OLDER than the Upper Coniacian Bad Heart oolitic ironstone at Tipper's Coulee and Spirit River roadcut. They are presently mapped as part of the Kaskapau Formation, which is dominantly composed of dark marine mudstone and minor sandstone (mostly in the lower half). Again, . . . the "how old are these ooids?" problem could be very easily solved with the discovery of an index fossil -- so keep your eyes open!

Note that the iron ooid deposits at this site along the north side of the Peace River are not as well cemented as those encountered at Sites 1 & 2. As illustrated in **Figure N**, there are at least two prominent oolitic marker beds within the upper Kaskapau Shale, which C. Collom has given the informal names "Oolitic Marker Bed A" and "Oolitic Marker Bed B" to. [How about that for creativity!] Perhaps the similar-looking deposits at Dunvegan Crossing are correlative to one of these?! These two beds, exposed along the Smoky River (48 km to the southeast), are clearly older than the Bad Heart *sensu stricto*, and may be lateral equivalents to part of the>500 million metric tonnes of oolitic iron deposits in the Clear Hills.

Figure N. Stratigraphy of the Smoky Group (in part) at the type section of the Bad Heart Formation, Smoky River, Alberta. Detail of Bad Heart Formation provided to illustrate the internal lithofacies, particularly as they occur near the junction of the Bad Heart and Smoky rivers. Considerable lateral facies variations are observed both within and immediately below the Bad Heart (in the upper Kaskapau Formation). For example, thick accumulations of phyllosilicate ooids occur at marker beds A and B within the Kaskapau, and at the "Muskiki-Bad Heart" contact both downriver from the type locality and towards the Clear Hills in west-central Alberta. The occurrences of various key molluscan macrofossils are also shown (particularly for scaphitid and baculitid ammonites, and inoceramid bivalves). Modified from Collom (1999).



The upper Puskwaskau Formation (marine) in the Smoky River region is overlain by the Wapiti Formation (nonmarine), and the contact between these is relatively gradational and poorly-defined. At the Bad Heart type locality, shown here, the Wapiti Fm. has been removed by extensive Pleistocene glacial erosion.

Ferrigenous sandstones of the Bad Heart Formation contain abundant and diverse marine invertebrates, particularly species which exhibit a general trend towards chemosymbioses -- an advantageous adaptation in the harsh environment near active seafloor brine seeps.

Text Legend

〰〰〰 = Third-order sequence boundary and/or correlative conformity

TST = Transgressive System Tract

▼ = upsection deepening trend, based on facies successions

▲ = upsection shoaling trend, based on facies successions

OOLITIC IRONSTONE - STOP No. 2

Name: Spirit River Roadcut Locality
[Section 16–Township 78–Range 6:W6th Meridian]
Strata exposed: uppermost Kaskapau Shale, Bad Heart Formation
Outcrop type: man-made, for Alberta Highway 731
Age: Upper Coniacian stage (Upper Cretaceous): approx. 85.5 million years ago

Of all the Bad Heart localities in Grande Prairie County, this is the only one even remotely close to a paved road! Just a few steps from the vehicle bring one to an excellent but still enigmatic exposure of Coniacian oolitic ironstone. The differences between this site and the next stop (at Tipper's Coulee) are evident and striking. This locality contains considerably more of the "iron ooid facies" that has attracted so much interest to this otherwise thin stratigraphic unit. It is thought that the much thicker (although less lithified or cemented) iron ooid accumulations of the Clear Hills region of Alberta, north of Worsley, are the same age as the oolitic facies visible at the Spirit River site. Evidence to support such a correlation is yet to be found, though! In the absence of any diagnostic biostratigraphic index fossils in the Clear Hills sedimentary iron ore deposits, this correlation remains tentative and preliminary. Perhaps we can find a specimen of *Scaphites depressus* (ammonite) or *Volviceramus involutus* (bivalve) at the roadcut, and take the first step towards solving this 'little mystery of Silentia' (Latin: "the Peace country")!

OOLITIC IRONSTONE - STOP No. 3

Name: Tipper's Coulee Locality
[Section 34–Township 75–Range 2:W6th Meridian]
Strata exposed: Kaskapau Shale, Bad Heart Sandstone, Puskwaskau Shale
Outcrop type: small stream-cut valley, slumping due to gravity & ice heave
Age: Coniacian stage (Upper Cretaceous): approx. 86 to 84 million years ago

This stop will give participants an opportunity to see the classic Bad Heart Formation "sandy facies" along the banks of the Smoky River. In 1919 F.H. McLearn (geologist for the Geological Survey of Canada) designated the steep cliffs overlooking the Smoky, near its confluence with the Bad Heart River, as the type locality of the Bad Heart Formation. Some 40 years previous, G.M. Dawson had become the first Canadian to collect fossils from the Bad Heart while navigating the length of the Smoky River to its joining with the Peace River.

The vegetated coulee we will hike down is on private ranchland (owned by the Boese family), and the site was named after their small (but very energetic!) cow-herding dog Tippy. The marine sediments visible along the north side of this same tributary were sampled by J. Wall in the 1950's for foraminifera (microscopic plankton). Large blocks of Bad Heart sandstone that have tumbled down into the coulee often contain concentrations of invertebrate fossils, particularly molluscs. Common inoceramid bivalves and scaphitid ammonites should be encountered and collected during our ~1.0 hour visit, if everything hasn't been covered with mud!

Stratigraphy , petrology, and geochemistry of the Bad Heart Sandstone (Smoky Group: Upper Cretaceous), Peace River Arch region, Alberta: evidence for possible syndepositional hydrothermal seeps

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E-mail: *collom@geo.ucalgary.ca*

ABSTRACT

The discovery of deep-water chemosymbiotic communities clustered around hydrothermal vents of the mid-Atlantic and Pacific ridges, together with our rapidly-increasing understanding of the Archaea (particularly sulfur-oxidizing chemosymbiotic forms), has led to a reconsideration of our most cherished beliefs on the origin of life. The fossil record of such environments, however, is sparse. Because all pre-Jurassic seafloor has been subducted and ancient spreading ridges are relatively rare, the search for ancient hydrothermal communities has, of necessity, focused on continental-margin ophiolites and tectonically-active basins formerly covered by epiric seaways. Surface exposures of the Bad Heart Formation (Upper Coniacian) along the Smoky River and in the Clear Hills region of Alberta display an association of important features exclusive to hydrothermally-derived deposits. Shoals of oolitic nontronite ($(Fe,Al)_2O_3 \cdot 3SiO_2 \cdot nH_2O$) up to 8.0 m thick, massive sulfide deposits (pyrite, FeS_2 and pyrrhotite, $Fe_{1-n}S$), glauconite ($K(Fe,Al)_2(SiAl)_4O_{10}(OH)_2$), and anomalous $\delta^{34}S‰$ isotopic values are documented from the Bad Heart Fm. above the reactivated Precambrian-age Peace River Arch tectonic salient. It will be shown that the geographic distribution of these unusual sedimentary and early diagenetic features is not random: they occur on and near northwest-southeast trending strike-slip faults originating in the Precambrian basement. Hydrothermal deposits of the Bad Heart Fm. accumulated in a tectonically-active shallow marine epicontinental setting, and are interpreted as precipitates from fault-related passive seeps on the seafloor. The saline brines providing the sulfurous compounds for these deposits were likely derived from Middle Devonian evaporites (*e.g.* Prairie, Muskeg formations).

For: 1997 GSA National Meeting, October 20-23, Salt Lake City, Utah

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Table 1. Succession of Strata in the Clear Hills Area, Alberta (from Green and Mellon, 1962).

ROCK UNIT			THICKNESS (m)	LITHOLOGY
	Wapiti Formation		0-120	soft, whitish sandstone; grey, blocky, carbonaceous shale; thin coal seams (continental)
Smoky Group	Puskwaskau Formation		90-180	dark grey, fissile shale (marine)
	Bad Heart Sandstone		0-9	green, ferruginous, oolitic sandstone and mudstone (marine)
	Kaskapau Formation	upper member	45-125	dark grey, fissile shale (marine)
		lower member	12-47	whitish sandstone; grey, sandy shale; oolitic siderite (marine)
	Dunvegan Formation		150-235	soft, grey sandstone with calc. concretions; grey, silty, carbonaceous shale (deltaic)
	Shaftesbury Formation	upper member	90-170	grey, silty shale; thin, laminated siltstone (marine)
		lower member	180-320	black, fissile shale; numerous fish scales (marine)

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River- and wave-dominated depositional systems of the Upper Cretaceous Dunvegan Formation, northwestern Alberta

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Department of Geology
McMaster University
Hamilton, Ontario
L8S 4M1

ABSTRACT

This paper documents the detailed sedimentological aspects of the Dunvegan Formation based on examination of about 130 core and 500 well logs. Nineteen facies have been grouped into 7 successions. In combination with sand isolith maps, these facies successions are further linked into lithofacies assemblages that define distinct, large-scale depositional systems.

Facies Successions 1, 2, and 3 coarsen upward and represent the progradation of storm-dominated shorefaces, river-dominated delta lobes, and mixed-influence deltaic lobes, respectively. Facies Successions 4, 5, and 6 fine upward and comprise the deposits of fluvial-dominated distributaries, estuaries, and barrier inlets. Facies Succession 7 is irregular and comprises the deposits of the delta plain, including interdistributary bays and lagoons.

Facies Successions 2, 4, and 7 define the river-dominated deltaic depositional systems, which show lobate geometries fed by channelized shoestring sands. The wave-dominated deltas also show lobate geometries but are characterized by a linkage of Successions 1, 5, and 7, which show more marine influence. The wave-influenced deltas are characterized by a linkage of Successions 3, 4, and 7 and are intermediate in shape and facies between the wave-dominated and river-dominated end members. The wave-dominated barriers are elongate and oriented shore parallel, and are characterized by a linkage of Successions 1, 6, and 7.

The Dunvegan Formation cannot be characterized as a single delta. Rather, it is interpreted here as a stacked series of different types of depositional systems. These prograded to the southeast, with shorelines trending approximately northeast–southwest. Overall there apppears to be a decrease in the importance of fluvial processes upward.

RÉSUMÉ

L'exposé qui suit donne une description sédimentologique détaillée de la formation Dunvegan, basée sur l'examen d'approximativement 130 carottes et 500 diagraphies de forage. Dix-neuf faciès ont été groupés en 7 successions de faciès. En association avec des cartes isolithes, ces successions de faciès sont à leur tour regroupées en assemblages de lithofaciès qui définissent dans un cadre plus large des ensembles de milieux sédimentaires distincts.

Les successions de faciès 1, 2 et 3 montrent une granulométrie qui augmente vers le haut et représentent la progression vers la mer de zones infratidales dominées par les tempêtes, des lobes deltaïques dominés par les forces fluviatiles, et des lobes deltaïques à influence multiple, respectivement. Les successions de faciès 4, 5 et 6 montrent une granulométrie qui diminue vers le haut et comprennent les sédiments d'effluents dominés par les forces fluviatiles, d'estuaires, et de chenaux d'entrée de crêtes d'avant-plage émergées. La succession de faciès 7 est irrégulière et comprend les sédiments de la plaine deltaïque, incluant les baies et les lagunes situées entre les effluents.

Les successions de faciès 2, 4, et 7 définissent les ensembles de milieux sédimentaires deltaïques dominés par les forces fluviatiles, qui montrent des formes de lobes nourries par des grès en lacet déposés dans des chenaux. Les deltas dominés par la vague ont aussi des formes de lobe mais sont caractérisés par un lien des successions 1, 5, et 7, qui accusent une plus forte influence marine. Les deltas influencés par la vague sont caractérisés par un lien des successions 3, 4, et 7 et sont de forme et de faciès intermédiaires entre les extrêmes dominés par la vague et par les forces fluviatiles. Les crêtes d'avant-plage émergées dominées par la vague sont allongées et orientées parallèles à la ligne du rivage et sont caractérisées par un lien des successions 1, 6, et 7.

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ent adddress: Alberta Geological Survey, P.O. 8330, Stn F, Edmonton, Alberta T6H 5X2

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Canadian Mineralogist
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MFN # 020497

MINERALOGICAL CHARACTERISTICS OF AN OOLITIC IRON DEPOSIT IN THE PEACE RIVER DISTRICT, ALBERTA*

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ABSTRACT

A minette-type oolitic iron deposit in the Peace River district, Alberta, occurs as flat-lying ironstone beds up to 10.6 m thick which contain 32-34 wt. % Fe *in situ* or 36–38 wt. % Fe after drying for 3 hours at 105°C. The ironstone beds consist of ooliths, siderite, and clastic material embedded in a clastic matrix and ferruginous cement. The ooliths consist of concentric layers of intimately intergrown goethite, nontronite, and amorphous phosphate around cores which are generally quartz. The goethite contains 46–56 wt. % Fe (mean 49 wt. %) and about 1.6 wt. % P_2O_5, the nontronite contains about 36.7 wt. % Fe and 0.8 wt. % P_2O_5, and the amorphous phosphate contains 4.4–22.9 wt. % Fe and 15.4–35.0 wt. % P_2O_5. The clastic matrix and cement are largely a ferruginous opal that contains 24 wt. % Fe. About 44% of the iron in the ironstone beds occurs as goethite, 35% as nontronite, 13% as ferruginous opal, and 8% as siderite. The ironstone beds *in situ* are greenish black, difficult to break, and have high water and ferrous iron contents. Upon exposure to atmospheric conditions the ferrous iron is apparently oxidized and causes the material to turn brown. Concurrent with oxidation, the adsorbed water escapes and causes shrinkage cracks in ferruginous opal.

SOMMAIRE

Un gisement de fer oolitique du type minette, situé dans la région de Peace River, en Alberta, se présente sous forme de couches ferrifères horizontales dont l'épaisseur va jusqu'à 10.6 m. La teneur en fer varie de 32 à 34% en poids *in situ*, soit de 36 à 38% après séchage de trois heures à 105°C. Les couches ferrifères se composent d'oolites, de sidérite et d'un matériau clastique dans une pâte clastique et un ciment ferrugineux. Les oolites sont formés d'une fin: intercroissance de goethite, nontronite et phosphate amorphe, en couches concentriques autour d'un noyau généralement quartz. Les teneurs, en poids, sont les suivantes: [illegible]–56% Fe (moyenne, 49%) et ~1.6% P_2O_5; nontronite: ~36.7% Fe et 0.8% P_2O_5; phosphate amorphe: 4.4–22.9% Fe et 15.4–35.0% P_2O_5. La pâte clastique et le ciment ferrugineux consistent principalement en opale ferrugineuse tenant 24% de fer en poids. Le fer se répartit comme suit: 44% dans la goethite, 35% dans la nontronite, 13% dans l'opale et 8% dans la sidérite. Les couches ferrifères, d'un noir verdâtre *in situ*, sont difficiles à briser; elles contiennent une forte proportion d'eau et de fer ferreux. Ce dernier s'oxyde à l'air et le minerai passe au brun. Au cours de cette oxydation, le départ de l'eau adsorbée provoque des fissures de retrait dans l'opale ferrugineuse.

INTRODUCTION

Oolitic iron deposits in the Clear Hills area, Peace River district, Alberta were discovered in 1924 (Bertram & Mellon 1975), but were not seriously investigated as a source of iron until they were encountered in 1953 during exploration for oil and gas. However, the deposits have not been brought into production because of metallurgical problems in recovering the iron.

Renewed interest in establishing a steel industry in western Canada resulted in an agreement between the Provincial Government of Alberta and the Federal Government of Canada to evaluate the potential of the Peace River oolitic iron deposits. The evaluation included an assessment of the deposits by Krupp Industries Limited of Germany, studies of the mineralogy, ore dressing and smelting of the ore by CANMET, and ore dressing research by CANMET and Alberta Research Council. This paper gives the characteristics and mineralogy of the deposits. The mineralogy was determined from material obtained through a sampling program by the Alberta Research Council. The geological setting of the deposits summarizes reported geological data (Kidd 1959; Mellon 1962; Green & Mellon 1962; Bertram & Mellon 1975), and the chemical analyses are from unpublished industrial, Alberta Research Council, and Mines Branch reports.

LOCATION AND GENERAL GEOLOGY

The Peace River iron deposits are in northeastern Alberta, about 80 km northwest of Peace River, and about 485 km northwest of Edmon-

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*Mineral Research Program, Processing Contribution No. 27.

20

ORGANIC-RICH, RADIOACTIVE MARINE SHALE: A CASE STUDY OF A SHALLOW-WATER CONDENSED SECTION, CRETACEOUS SHAFTESBURY FORMATION, ALBERTA, CANADA[1]

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ABSTRACT: Organic-rich radioactive shales are a common regional feature resting on Cretaceous transgressive surfaces in western Canada. The basal shale in the Shaftesbury Formation (Late Albian) from the Peace River area of northern Alberta is characterized by high gamma-ray, high resistivity, and low neutron wireline log signatures. Three facies, in ascending order, are present within the basal Shaftesbury Formation: 1) a brackish-water estuarine shale; 2) a restricted, marginal-marine shale which is radioactive; and 3) an open-marine, normal salinity shale. The radioactive shale contains an abundance of large, lenticular algal cysts (cf. *Lancettopsis lanceolata* Mädler 1963) which are rare in overlying and underlying shale. The algal cysts and high organic content may be the locus of the radioactivity. The total organic carbon content (~6%) and sulphur content (~3.4%) of the radioactive shale also are higher than the shale above and below, with a different mineralogy as well. The radioactive portion of the basal Shaftesbury shale has the characteristics of a condensed section; it is directly above a ravinement surface and transgressive-lag deposit which, in turn, locally overlie estuarine sediments deposited within an incised valley. Other characteristics include evidence of low oxygen values, low concentrations of benthonic foraminifera, and evidence of a slow sedimentation rate. Palynological, micropaleontological, and geochemical results indicate that the radioactive shale was deposited in restricted, marginal marine conditions and that overlying shale shows a progressive deepening to nearshore, open-marine conditions. This radioactive shale does not represent the deepest water sediments of the transgression but is a condensed section deposited in relatively shallow water.

INTRODUCTION

Organic-rich, radioactive shale units are generally considered to represent worldwide anoxic events and condensed sections formed during marine transgressions (Jenkyns 1980; Legget 1980; Loutit et al. 1988). Condensed sections are considered to be marine hemipelagic or pelagic sediments deposited at very slow rates and are areally most extensive at the time of maximum regional transgression (Loutit et al. 1989). The water depth at which condensed sections form may vary from shallow marine to bathyal, although they are generally considered to be deep water in origin. The purpose of this paper is to 1) describe and interpret the stratigraphic and sedimentological position of an organic-rich radioactive marine shale at the base of the Shaftesbury Formation in northern Alberta, Canada (Fig. 1); 2) document the palynological, micropaleontological, organic geochemical, and organic petrological characteristics of this shale; and 3) interpret the radioactive shale in terms of recent sequence stratigraphic concepts. Although this radioactive shale unit regionally varies from 1 to 8 m in thickness and can be traced for several hundred kilometers using gamma-ray logs, the samples collected for this study are from a single measured section. The shale outcrop studied is the basal 17 m of the Shaftesbury Formation (Fig. 2) exposed along the west bank of the Peace River, near the town of Peace River, northern Alberta (Fig. 1).

GEOLOGICAL SETTING AND STRATIGRAPHIC POSITION OF THE SHALE

The basal Shaftesbury shale is late Late Albian in age, based on the similarity of the microfossil assemblages to fauna of the *Verneuilina canadensis* Subzone of the *Miliammina manitobensis* Zone (Caldwell et al. 1978). The combined presence of the dinoflagellates *Luxadinium propatulum* Brideaux and McIntyre, 1975, *Nyktericysta davisii* Bint, 1986, and *Wigginsiella grandstandica* Lucas-Clarke, 1987, and the conifer pollen *Rugubivesiculites rugosus* Pierce, 1961 along with the angiosperm pollen *Tricolporoidites subtilis* Pacltová, 1971 further indicate a Late Albian age (Leckie et al. 1989a). The shale of the Shaftesbury Formation was deposited during a major transgressive event which inundated the North American Western Interior Seaway (Williams and Stelck 1975), during which time marine waters extended north from the Gulf of Mexico and connected with marine water extending south from the Arctic Ocean (Fig. 1B).

In order to understand the nature of the basal shale of the Shaftesbury Formation fully, the stratigraphic context of the shale relative to the underlying units is first described. A vertical measured section of the outcrop of the Peace River and basal Shaftesbury formations from near the town of Peace River is shown in Figure 2. Detailed descriptions of the Peace River Formation are in Leckie (1988b) and Leckie and Reinson (in press).

Contact between the Paddy and Cadotte Members

Description.—The Cadotte Member represents deposition of a northerly prograding, high-energy shoreline

21

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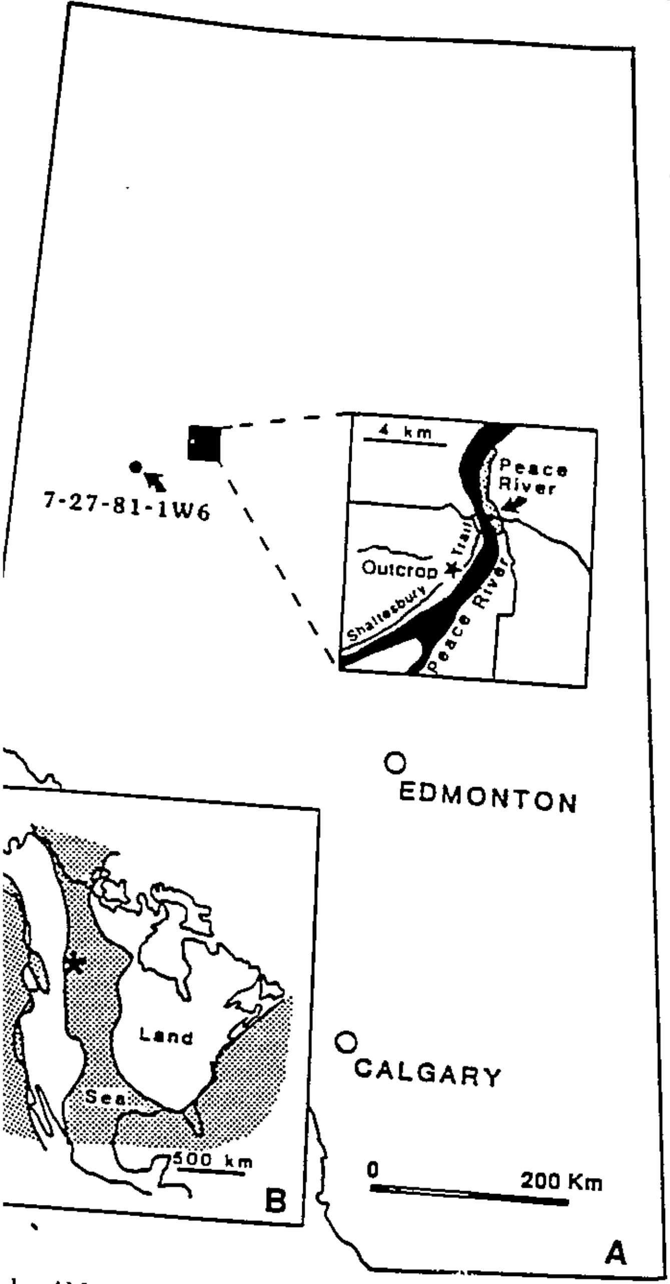
JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 60, NO. 1, JANUARY, 1990, P. 101–117



1.—A) Location map of outcrop of basal Shaftesbury Formation ted by star in inset) in Alberta. 7-27-81-1W6 refers to the suite line logs illustrated in Figure 11. B) Paleoenvironmental recon- n of North America during the Late Albian (modified from ns and Stelck 1975). Asterisk shows location of outcrop.

nani and Smith 1988; Leckie and Reinson, in press). aracter of the top of the Cadotte Member is highly le. In the subsurface and Foothills outcrop, it can formably overlain by carbonaceous shale, coal, and ifteen paleosols (Leckie et al. 1989b). However, in areas, including the Peace River outcrop area de- herein, the upper portion of the Cadotte Member n erosionally truncated. The contact between the and Cadotte Members at the Peace River outcrop nconformable, irregular surface, with several me- elief. Directly above the contact, the basal Paddy r contains siderite nodules, intraformational-shale andstone clasts of the underlying Cadotte Mem- concentrations of wood and shell debris.

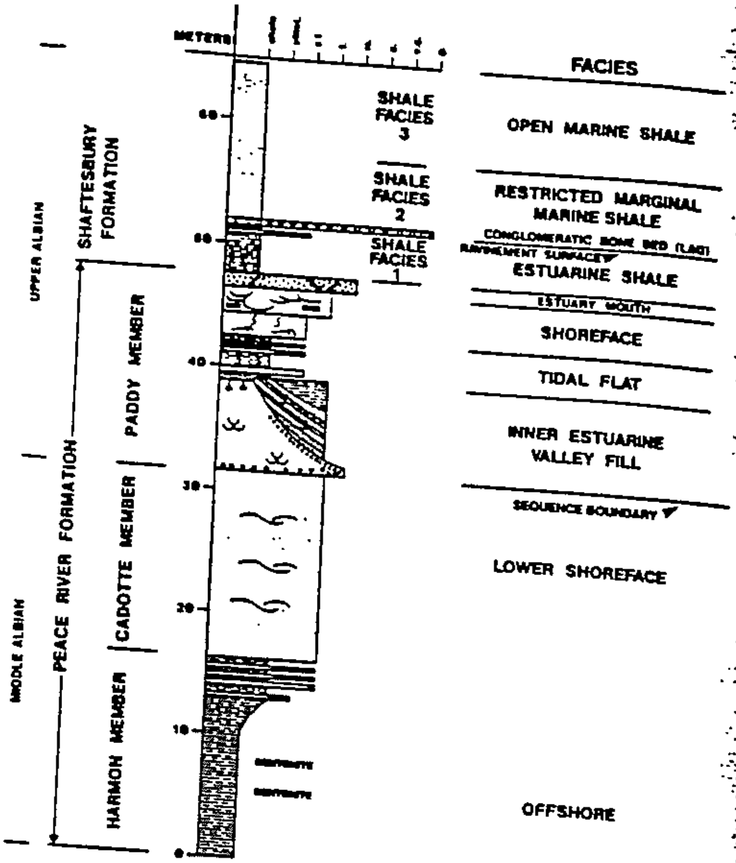


FIG. 2.—Composite measured section of the Peace River Formation and basal Shaftesbury Formation from near the town of Peace River. Modified from Leckie and Reinson (in press).

Interpretation.—The Paddy-Cadotte contact in the Peace River area is an erosional surface caused by fluvial incisement associated with a Middle Albian lowering of relative sea level (Leckie 1988b; Leckie and Reinson, in press). The contact represents a sequence boundary created during a low stand of relative sea level.

Paddy Member

Description.—The Paddy Member (Fig. 2) is 13 to 16 m thick and has been divided into three subunits by Leckie and Reinson (in press). The lowermost unit is 7 m thick and characterized by sandstone containing inclined heterolithic stratification (low-angle dipping, laterally accreting sand-mud couplets), millimeter-scale mud couplets, tidal bundles, reactivation surfaces, and a low diversity assemblage of trace fauna. Sandstones are laterally replaced by carbonaceous mudstone 4 to 5 m thick and several tens of meters wide. The middle unit, which is about 3 m thick, consists of finely interbedded sandstone, siltstone, and shale containing ripple-laminated sandstones, flaser beds, linzen beds, synaeresis cracks, and a low-diversity trace fossil assemblage. The upper unit of the Paddy Member is 3 to 6 m thick and consists of a lower wave-rippled and swaley cross-stratified, fine-grained sandstone. The top 0.3 to 3 m of the upper unit consists of medium to coarse-grained, pebbly sandstone which is high-angle crossbedded with mud drapes on toe-

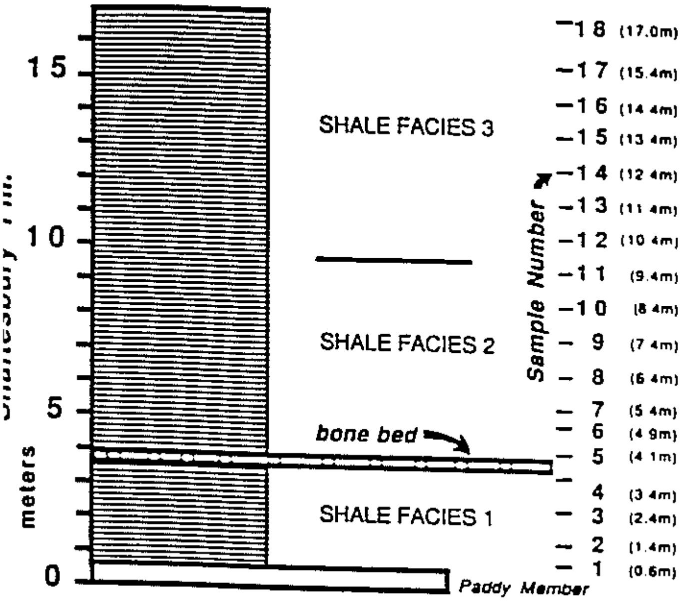


FIG. 3.—Measured section of the basal Shaftesbury Formation show- g the three shale facies and location of samples.

ts. A low diversity dinoflagellate assemblage occurs in uds throughout the Paddy Member (Leckie et al. 1989a).

Interpretation.—The sedimentary structures, burrows id the low diversity of dinoflagellates in the Paddy ember are indicative of deposition within an estuarine mplex which includes estuarine channel, tidal flat/la- on and tidal shoals/spit (Fig. 2). The Paddy Member diments represent deposition during a sea-level rise, llowing the low-stand event which incised the valley.

Shaftesbury Formation

The Paddy Member is abruptly overlain by the shale the basal Shaftesbury Formation, of which 17 m is posed. For descriptive purposes, the shale interval is bdivided into three subunits (Figs. 2 and 3): Shale Fa- s 1, interpreted as a brackish/estuarine facies; Shale cies 2, interpreted as a stressed, restricted nearshore allow-marine facies with a basal conglomeratic layer; d Shale Facies 3, interpreted as an open-marine facies. ale Facies 2 is local in nature, only occurring in the cinity of Peace River town. The environmental inter- etations of the shale are based on sedimentological, lynological and micropaleontological descriptions which ll be detailed below. The general palynological criteria ed for the environmental interpretations (i.e., the de- e of marine influence) are shown in Table 1. The con- merate layer at the base of Shale Facies 2 (Figs. 2 and demarcates a sharp change in many of the geochemical, lynological and micropaleontological characteristics of ale Facies 1 and 2.

General Interpretation of the Peace River and Basal Shaftesbury Formations

TABLE 1.—*General palynological indicators of degree of marine influence*

Environment	Description
1. Continental	Palynoflora composed exclusively of land derived microspores, megaspores and pollen.
2. Slightly Brackish	Slight introduction of saline water in essentially fresh-water environment, e.g., coastal lakes with outlets to the sea, inlets, upper estuaries, and interdistributary channels. Littoral. Contains rare specimens of ceratioid dinoflagellates (e.g., *Nyktericysta*, *Vesperopsis* and *Balmula*) and a few acritarchs. Land derived spores and pollen abundant.
3. Brackish	Marginal marine conditions found in bays, estuaries, lagoons, and barrier-associated backwaters. Increase in saline water. Dinoflagellate species diversity low. Certain species of ceratioid or peridinioid dinoflagellates (e.g., *Palaeoperidinium cretaceum*, *Luxadinium primulum*) appear in abundance. Assemblage often monospecific. Land derived spores and pollen abundant.
4. Nearshore Marine	Inner neritic environment. Shallow marine. Dinoflagellate diversity higher due to increased salinity but assemblage still dominated by land derived spores and pollen grains.
5. Open Marine	Outer neritic environment. Close to the margin of the shelf. Fully saline water. Dinoflagellate diversity highest. Land derived spores and pollen grains reduced in quantity. Assemblage dominated by dinoflagellates.

The vertical succession represented by the Harmon, ddy, and Cadotte members near the town of Peace ver is that caused by relative sea-level fall or stillstand followed by marine transgression. The Harmon to Cadotte relationship represents the progradation of a wave-dominated shoreline during a relative sea-level fall or stillstand. The thin transition zone between the shale of the Harmon Member and sandstone of the Cadotte Member is inferred to represent a rapid rate of sea level fall with accompanying rapid shoreline progradation or, alternatively, a slow rate of sea level rise where the rate of sediment supply overwhelmed the rate of accommodation so that progradation rapidly accelerated (cf. Posamentier and Vail 1988). The top of the Cadotte Member at the Peace River outcrop has been eroded by valley incisement during relative sea-level lowstand, and the contact between the Paddy and Cadotte Members represents a sequence boundary. The Paddy Member represents the estuarine fill of this broad, shallow incised-valley system during relative sea-level rise. Shale Facies 1 of the basal Shaftesbury Formation is also interpreted on palynological and micropaleontological grounds to be part of the estuary-fill sequence.

METHODS

The outcrop of the basal Shaftesbury exposed along the Peace River was trenched to about 30 cm to remove the most highly weathered, surficial material. Samples (Fig. 3) were analyzed for palynomorphs, foraminifera, total sulfur, total carbon, whole rock and trace elements. Mineralogy was approximated by measuring the most intense x-radiograph peak of each mineral. Palynological results are tabulated and interpreted in Table 2; detailed faunal lists and conclusions are available in Leckie et al. (1989a).

ELSEVIER

Palaeogeography, Palaeoclimatology, Palaeoecology 119 (1995) 301–320

PALAEO

Isotopic and chemical compositions of bentonites as paleoenvironmental indicators of the Cretaceous Western Interior Seaway

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Abstract

Oxygen and hydrogen isotopic compositions of volcanic ashes, extensively deposited in the Cenomanian–Turonian Greenhorn and Campanian Claggett seas of the Cretaceous Western Interior Basin, are commonly at variance with the isotopic compositions of the seas themselves as inferred from well-preserved fossils. The $\delta^{18}O$ values of montmorillonite from bentonite beds in Manitoba, Montana, South Dakota, Wyoming, Colorado, Kansas, Oklahoma, and New Mexico range from 13 to 28 and translate into values for the Greenhorn and Claggett seas of −14 to 4‰ at 10 25°C. These values are significantly more variable than the $\delta^{18}O$ values of fossils, which translate into values of −8 to −2‰ for the same seas. The discrepancies are attributed to post-formational alteration of the bentonites. The δD values of Turonian and Campanian bentonites are unusually low at −120 to −110‰ relative to those to be expected from the respective late Greenhorn and Claggett seas, whereas some samples of the Cenomanian "X" bentonite seem to be in oxygen- and hydrogen-isotopic equilibrium with the earlier Greenhorn sea. Mg and Ca contents of montmorillonite from the bentonites vary regularly with $\delta^{18}O$ values but not with δD values, and SEM analyses show the presence of neoformed fibrous smectite in bentonites with the highest $\delta^{18}O$ and Mg and Ca contents. The chemical and isotopic data indicate that the variations in mineralogy and alteration of the bentonites result from widely disparate depositional environments and alteration of smectites by interaction with basinal brines.

1. Introduction

During the Late Cretaceous Epoch, the Western Interior of North America was the site of an asymmetrical foreland basin, elongated north–south and covered by a shallow sea. The sea extended for approximately 5000 km, from what is now the Beaufort Sea to the Gulf of Mexico, and approximately 1600 km, from western Ontario to the Rocky Mountain Trench in British Columbia (Fig. 1). Kauffman (1977) proposed that this Western Interior seaway in the United States was subject to five, eustatically controlled, transgressive–regressive marine cycles between Early Albian and Early Maestrichtian time and designated these as T_5–R_5 to T_9–R_9 in his global series. Two of these cycles are central to this paper. The first is the Greenhorn cycle (T_6–R_6), which began in Late Albian, peaked in Early Turonian, and ended in Middle Turonian time (Kauffman, 1977). It encompassed the most extensive flooding of the Cretaceous Period when more than one-

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An anoxic event at the Albian–Cenomanian boundary: the Fish Scale Marker Bed, northern Alberta, Canada

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ABSTRACT

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The Fish Scale Marker Bed (FSMB) of the Shaftesbury Formation, which marks the Albian–Cenomanian boundary, is a regional stratigraphic marker in the Western Interior of Canada. At the outcrop studied on the Smoky River in northwestern Alberta, three major shale units can be distinguished in the FSMB and contiguous strata. The lowermost shale (Unit 1) is bioturbated and contains high-diversity dinoflagellate and moderate-diversity foraminiferal assemblages. It has dominantly Type III (terrestrial) organic matter (OM) and low total organic carbon content (TOC). The unit was deposited in an open-marine, neritic environment of normal salinity. The FSMB (Unit 2) represents a zone of condensed bioclastic accumulation composed of abundant fish remains. The dinoflagellate species diversity is drastically reduced in this unit and it lacks benthonic foraminifera and bioturbation. Unit 2 is characterized by mainly Type II (marine) OM and high TOC values. Unit 2A contains rippled sandstone related to either a shallowing or to deeper water currents. A fish-hash conglomerate making up Unit 2B can alternatively be interpreted as a bioclastic, condensed and winnowed deposit or as a transgressive lag. Unit 2C consists of black, platy shale with abundant fish remains and represents a minor peak of marine transgression during the deposition of FSMB, when the bottom waters were dominantly anoxic. Collectively, the features of Unit 2 suggest deposition under a stratified water column with moderate productivity of planktonic and nektonic organisms in the upper oxygenated layers but with anoxic bottom waters. Unit 3, overlying the FSMB, consists of blocky shale with reduced concentration of fish remains. Due to increased rate of sedimentation during its deposition, the organic-rich sediment of Unit 3 was progressively diluted by clastic material and there was an increase in the dissolved oxygen content of the bottom waters. The anoxic event at the FSMB is related to a relative rise in sea level and possibly to the mixing of waters of different salinities and temperatures from the Arctic Ocean and the Gulf of Mexico in the Western Interior seaway.

Introduction

The Fish Scale Marker Bed (FSMB) has a widespread distribution in the Western Interior of Canada from northeastern British Columbia to Manitoba. The base of the unit is used as a boundary between the Lower and Upper Cretaceous. The FSMB (also called "Fish Scales Sandstone", "Base of Fish Scales" and "Fish Scales Zone") commonly occurs as a persistent sandstone, or sandstone and siltstone bed, containing abundant fish remains (Price, 1964; Caldwell, 1984) and is extensively used as a stratigraphic marker in subsurface correlation. In the northwestern plains of Alberta and British Columbia, the FSMB is well developed in the Shaftesbury Formation and correlative strata. It is also quite prominent in southern Alberta. However, the base of the FSMB marks a regional paraconformity (Stelck et al., 1958; North and Caldwell, 1975) and it is missing

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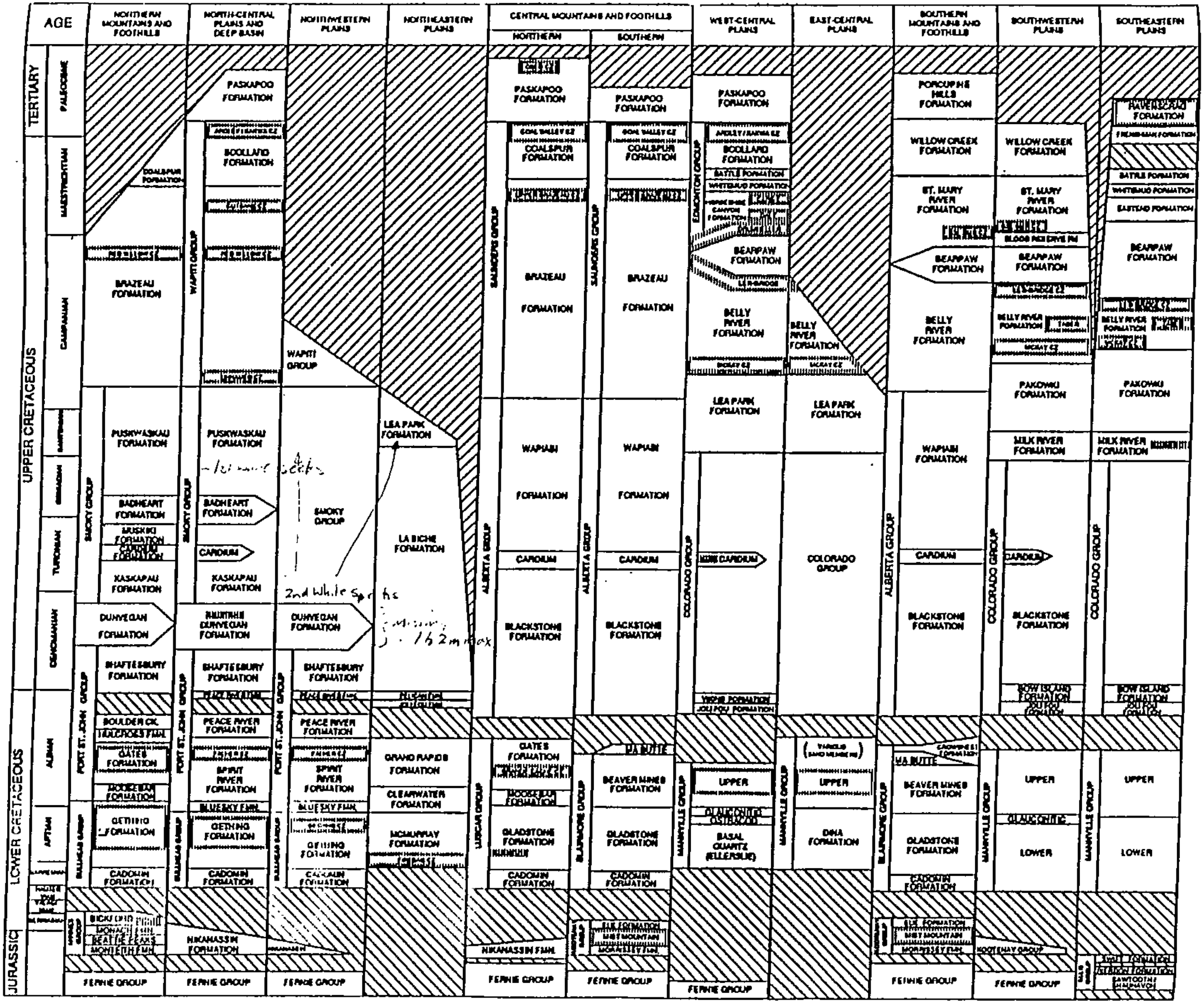
AGE
NORTHERN MOUNTAINS AND FOOTHILLS
NORTH-CENTRAL PLAINS AND DEEP BASIN
NORTHWESTERN PLAINS
NORTHEASTERN PLAINS
CENTRAL MOUNTAINS AND FOOTHILLS
NORTHERN
SOUTHERN
WEST-CENTRAL PLAINS
EAST-CENTRAL PLAINS
SOUTHERN MOUNTAINS AND FOOTHILLS
SOUTHWESTERN PLAINS
SOUTHEASTERN PLAINS
TERTIARY
UPPER CRETACEOUS
LOWER CRETACEOUS
JURASSIC
PALEOCENE
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
PASKAPOO FORMATION
PORCUPINE HILLS FORMATION
WILLOW CREEK FORMATION
ST. MARY RIVER FORMATION
BLOOD RESERVE FM
COALSPUR FORMATION
SCOLLARD FORMATION
BATTLE FORMATION
WHITEMUD FORMATION
EASTEND FORMATION
FRENCHMAN FORMATION
RAVENSCRAG FORMATION
BEARPAW FORMATION
BELLY RIVER FORMATION
BRAZEAU FORMATION
WAPITI GROUP
EDMONTON GROUP
SAUNDERS GROUP
LEA PARK FORMATION
PAKOWKI FORMATION
MILK RIVER FORMATION
PUSKWASKAU FORMATION
BADHEART FORMATION
MUSKIKI FORMATION
CARDIUM
KASKAPAU FORMATION
SMOKY GROUP
LA BICHE FORMATION
WAPIABI FORMATION
COLORADO GROUP
ALBERTA GROUP
BLACKSTONE FORMATION
DUNVEGAN FORMATION
SHAFTESBURY FORMATION
BOW ISLAND FORMATION
JOLI FOU FORMATION
PEACE RIVER FORMATION
BOULDER CK.
GATES FORMATION
MOOSEBAR FORMATION
SPIRIT RIVER FORMATION
BLUESKY FMN.
GETHING FORMATION
CADOMIN FORMATION
FORT ST. JOHN GROUP
BULLHEAD GROUP
GRAND RAPIDS FORMATION
CLEARWATER FORMATION
MCMURRAY FORMATION
BEAVER MINES FORMATION
GLADSTONE FORMATION
LUSCAR GROUP
BLAIRMORE GROUP
MANNVILLE GROUP
MILL CREEK
UPPER
LOWER
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OSTRACOD
BASAL QUARTZ (ELLERSLIE)
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NIKANASSIN FMN.
KOOTENAY GROUP
ELK FORMATION
MIST MOUNTAIN
MORRISSEY FMN.
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