AER/AGS Open File Report 2018-13

On the Origin of Oil Sand and Related Bedrock Erratics in Glacial Sediments of Central Alberta

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Abstract

This report is a compilation of both published and unpublished observations of hydrocarbons (bitumen) in glacial sediments and landforms in central Alberta. Its purpose is to map and describe the distribution of bituminous (and related non-bituminous) erratics in glacial sediments, and to draw attention to the likelihood of other, as yet undiscovered, examples. These erratics are natural occurrences of hydrocarbon bitumen near the surface. A summary discussion of genesis provides some insights into sources of bitumen and related bedrock erratics, transport pathways, and mechanisms of emplacement.

1 Introduction

The occurrence of hydrocarbons in the near surface of Alberta's central plains sparked such great interest in the initial days of oil exploration in the nineteenth century that the Geological Survey of Canada chose to highlight the discovery of bitumen erratics in glacial sediments in the introduction of its 1898 Annual Report (Dawson, 1901). Subsequent observations of hydrocarbons in near-surface glacial sediments similarly continued to generate interest in the exploration industry (Rutherford, 1928), but by the mid-twentieth century interest in these types of occurrences waned. Recently, there is renewed interest in understanding the occurrence and distribution of hydrocarbons in near-surface sediments, primarily from the perspective of impact on the environment and land use, and assessment of the liability associated with the presence of hydrocarbons on Alberta's landscape.

Although the occurrence of bituminous sandstone erratics is not unique to Alberta's landscape, with erratics documented in northern Saskatchewan as well (Kupsch, 1954), this study is a compilation of previously published and unpublished observations of naturally occurring hydrocarbons (bitumen) in glacial sediments and landscapes specific to central Alberta. Its purpose is to map and describe the distribution of bitumen occurrences in glacial sediments, and to draw attention to the likelihood of other, as yet undiscovered, natural deposits. A summary discussion of genesis provides some insights into sources of bitumen and related bedrock erratics, transport pathways, and mechanisms of emplacement.

2 Oil sand (bitumen) deposits in Alberta

Oil sand deposits in Alberta occur in four stratigraphic units of the Lower Cretaceous Mannville Group (McMurray, Clearwater, Grand Rapids, and Gething/Blue Sky formations (Figure 1)) and are distributed in four geographic regions: the Cold Lake Deposit, Athabasca Deposit, Wabasca Deposit, and Peace River Deposit (Figure 2).

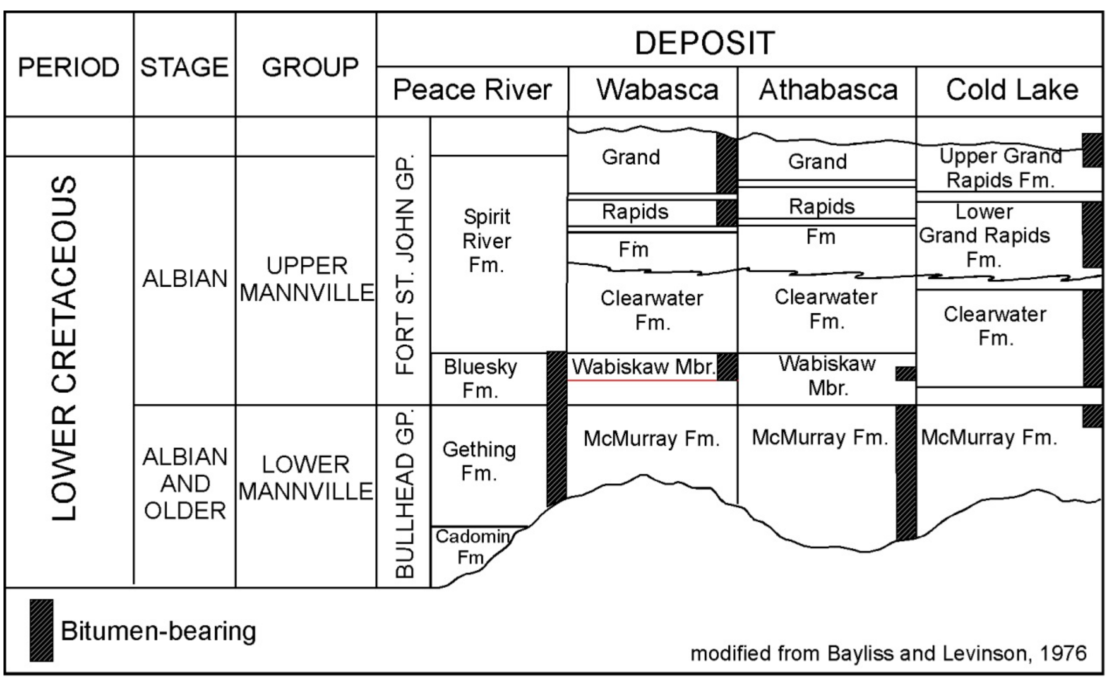

Figure 1. Bitumen-bearing formations of the Mannville Group in Alberta

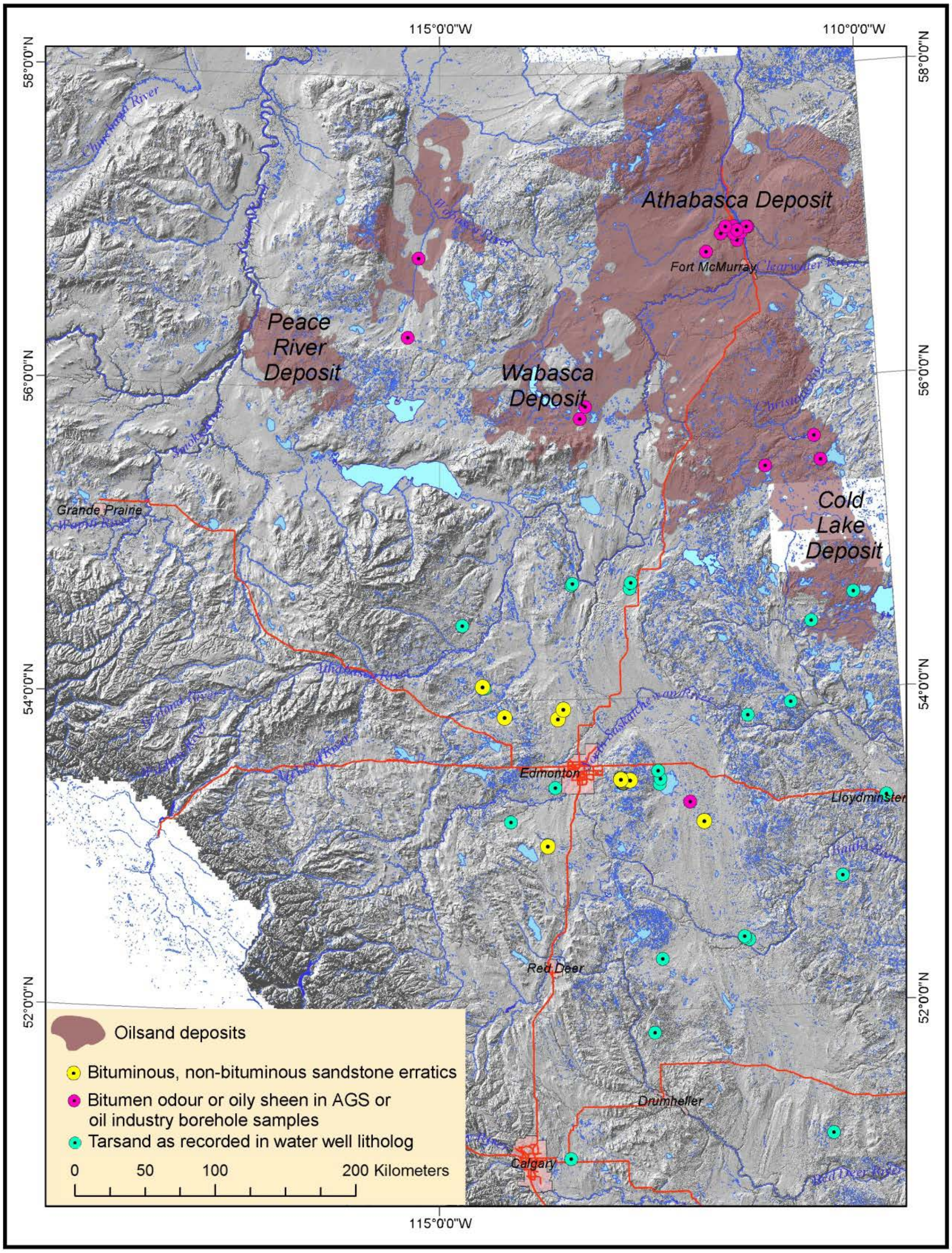

Figure 2. Distribution of oil sand deposits in Alberta, and location of bituminous and non-bituminous sandstone erratics (yellow circles) as well as other observations of bitumen or bitumen odours in non-hydrocarbon-bearing zones (pink, blue circles). Locations are superposed on a 15m LiDAR digital elevation model. Some of the erratic sites were visited by the AGS in 2017-2018 to confirm their presence in the landscape.

In addition to stratigraphic position and geographic location, geological units hosting bitumen deposits can also be differentiated by petrology, as shown in Figure 3. Although there are differences in the classification of the same formations between the various studies that perhaps reflect the subjectivity of visual estimations, or the spatial variability of petrology within a formation, some generalizations can be made. While detrital quartz dominates the McMurray Fm. (~80-90%), the amount of feldspathic and lithic fragments differ geographically, as well as between formations. Generally, potassium and plagioclase feldspars increase from the Lower Mannville to the Upper Mannville formations (particularly the Grand Rapids Fm. in the Wabasca deposit (Bayliss and Levinson, 1976) as well as the amount of volcanic rock fragments and clay minerals. Kaolinite shows a marked increase in the Bluesky/Gething formations in the Peace River deposit (Bayliss and Levinson, 1976). Within the Athabasca deposit, Wabiskaw Member sand can be differentiated from the underlying sand of the McMurray Fm. by a lower quartzose content (~40-50%), an increase in feldspars, and more notably, an increase in other rock fragments including volcanic, sedimentary, and metamorphic grains, reflecting a western source due to uplift associated with Columbian orogeny (Hein and Fairgrieve, 2012).

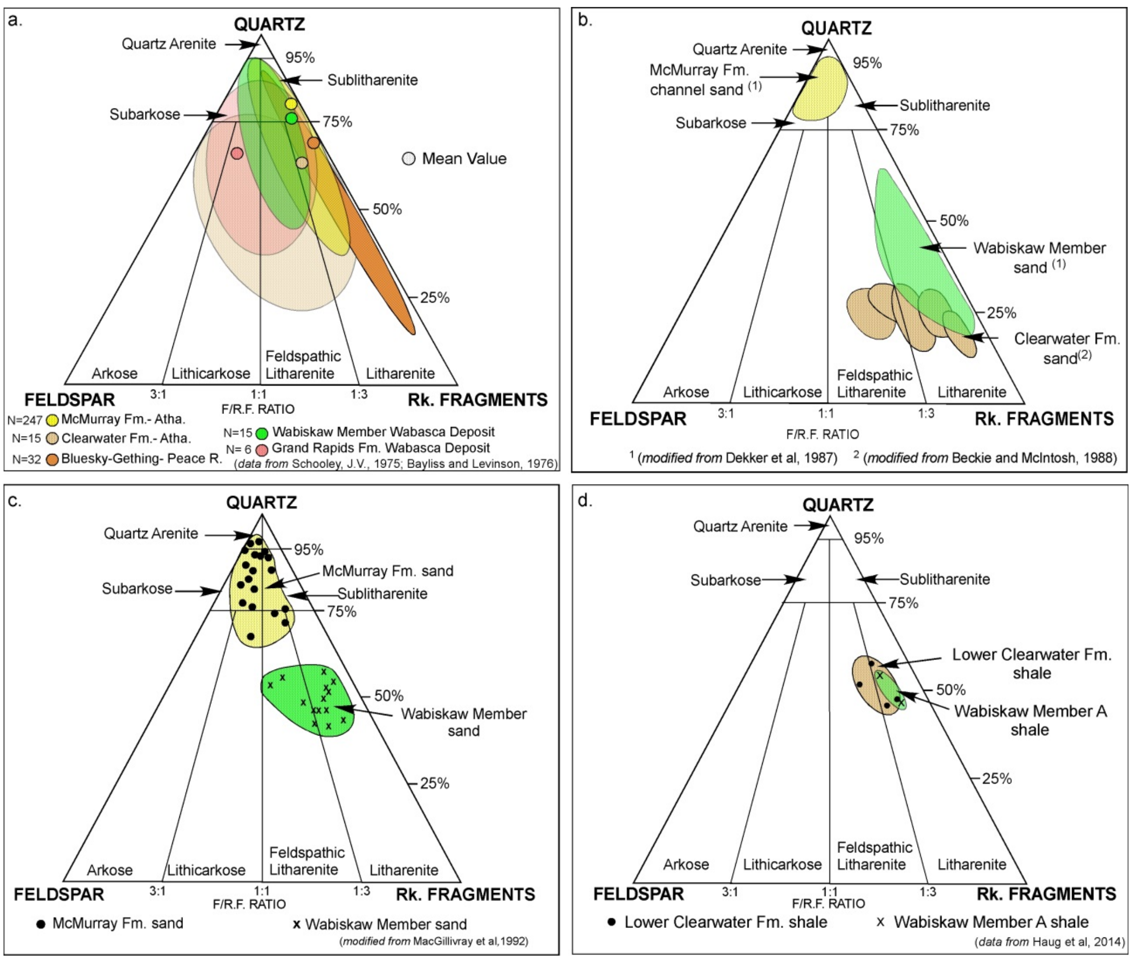

Figure 3. Petrological classifications of bitumen-bearing geological formations in northeast Alberta. In all figures the oblong shaded polygons encapsulate the range of values for each formation.a. Petrological results from Schooley, 1975, and Bayliss and Levinson, 1976. Colored circles represent the mean values of the petrology of numerous samples for the different

formations; b. Petrological results from Dekker et al, 1987, and Beckie and McIntosh, 1988; c. Petrological results from MacGillivray et al, 1992; d. Petrological results from Haug et al, 2014.

3 Bituminous sandstone erratics

This section provides a brief discussion of the discovery and findings of known bitumen saturated, and related non-bituminous sandstone erratics, as well as naturally occurring hydrocarbon odours and oily sheens in glacial sediments in central Alberta.

3.1.1 Manawan (Egg) Lake bitumen, and bituminous sandstone erratics

3.1.1.1 Tyrell-Selwyn-Dawson bitumen discovery (ca.1893)

The first reference to bitumen occurrences in the central part of Alberta appears in the Geological Survey of Canada (GSC) 1898 Annual Report, in which the director, G.M. Dawson (1898), reported on J.B. Tyrell and A.R. Selwyn's discovery of 'petroleum' (bitumen) in the Egg Lake (Manawan Lake) area northwest of Edmonton in 1893 and 1894 respectively (site 1, Figure 4, Figure 5, Table 1). The site is located at Dominion Land Survey co-ordinates (DLS) L.S.D. 13, Sec. 30, Twp. 56, Rge. 25, W 4th Mer. (abbreviated 13-30-056-25W4). A site visit by Alberta Geological Survey geologists in the fall of 2017 did not reveal any evidence of bitumen at the surface of the agricultural field.

The site is located on a generally featureless till plain that slopes gently northward to Manawan Lake. Sediment thickness in the region ranges between 5 to 20 m (Figure 6). A tarry substance was originally observed at surface during ploughing, and several small, shallow (1–3 m) hand-dug excavations over a distance of about 200 m subsequently revealed 2–3 cm thick veins of hardened bitumen, or bitumen-saturated sand (Dawson, 1898). A borehole was drilled to a depth of about 36 m in which a 15–20 cm thick bed of bitumen-saturated sand was encountered after drilling through about 2.5 m of soil and clay. Below the bitumen saturated sand, 'boulder clay' (interpreted here as till) occurred to a depth of 12 m, which was underlain by stratified sand and gravel, and bedrock (Figure 6). No other bitumen occurrences were reported below the 2.5 m depth.

The observations predate any oil and gas development in the region, thus an anthropogenic source such as an accidental release from an oil well can be discounted. Initial interpretations by GSC geologists were that the bitumen may have originated from Cretaceous formations at >750 m depth that propagated upward along a fault, following deposition of glacial sediments. This interpretation for the source of petroleum hydrocarbon product sparked great interest in the potential for locating a commercial source of petroleum, but the great depth to a deep Cretaceous oil-bearing horizon at that time made this site unfavourable for further investigation.

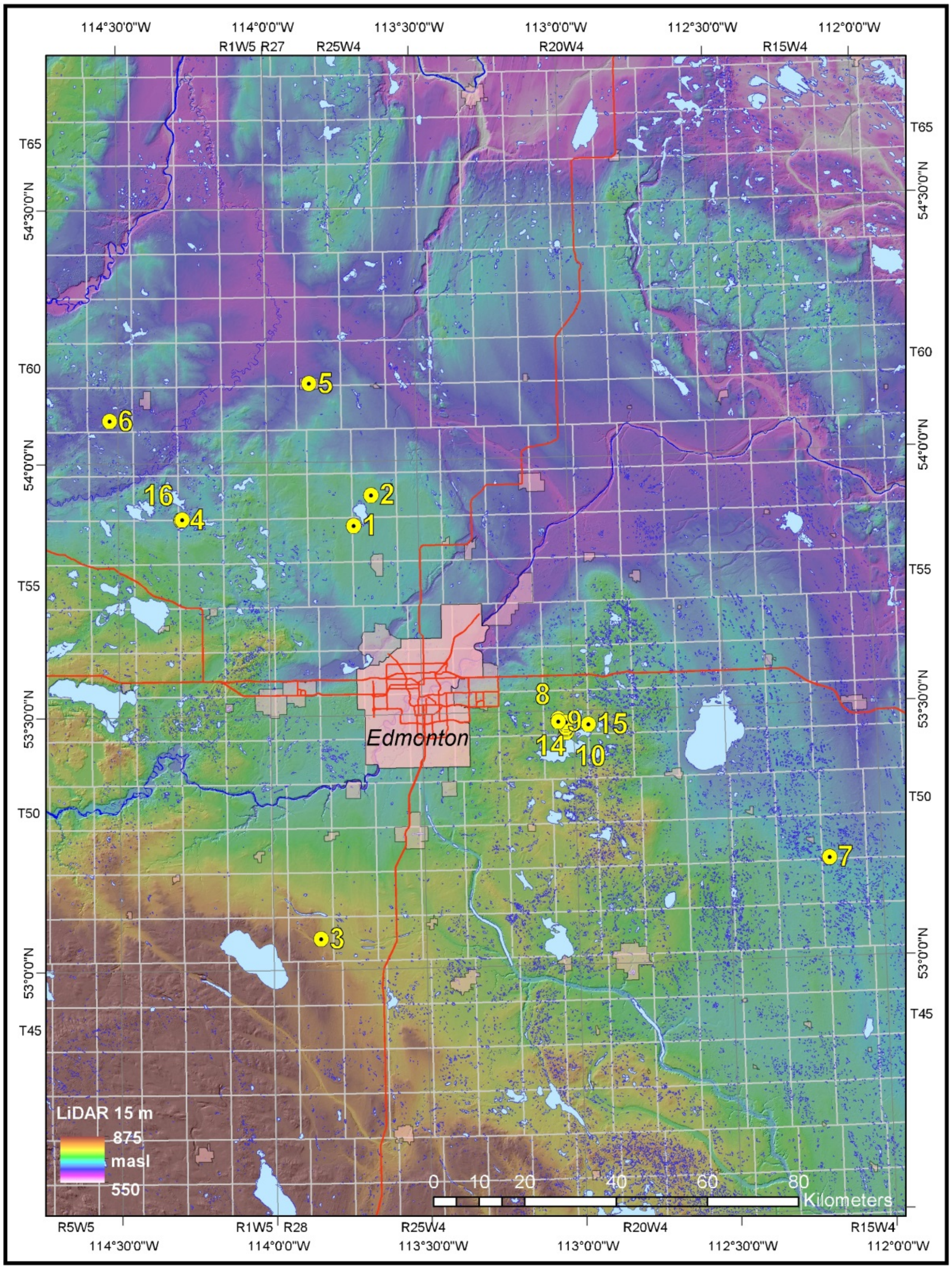

Figure 4. Location of bituminous and associated non-bituminous sandstone erratics, and site numbers used in Table 1.

Table 1. Erratic names, locations and year of discovery or reporting

Site	Name	Discoverer/reporting period	Latitude	Longitude	Elev (masl)	DLS
1	Manawan (Egg Lake) bituminous erratic	Tyrell-Selwyn-Dawson (1898)	53.8743	-113.7151	706.3	13-30-056-25W4
2	Manawan (Egg Lake) bituminous erratic	Tartan Energy (2003, 2010)	53.9341	-113.6556	707.6	15-16-057-25W4
3	Bonnie Glen bituminous erratic	Ells (1914), Rutherford (1928)	53.0610	-113.8457	820.2	14-14-047-27W4
4	Nakamun bituminous erratic	Ells (1914), Rutherford (1928)	53.8896	-114.2905	696.8	14-31-056-02W5
5	Westlock bituminous erratic	Ells (1914)	54.1560	-113.8567	650.1	SE-05-060-26W4
6	Barrhead bituminous erratic	Feniak (1944)	54.0861	-114.5272	656.9	08-09-059-04W5
7	Holden bituminous erratic	Andriashek AGS (1980)	53.1954	-112.1717	689.8	04-05-041-15W4
8	Cooking Lake non-bituminous erratic 1	Westgate et al (1976), Emerson (1977), AGS (2017)	53.4850	-113.0497	753.1	01-17-052-21W4
9	Cooking Lake non-bituminous erratic 2	Westgate et al (1976), Emerson (1977), AGS (2017)	53.4799	-113.0498	764.5	13-09-052-21W4
10	Cooking Lake non-bituminous erratic 3	Westgate et al (1976), Emerson (1977), AGS (2017)	53.4579	-113.0251	748.2	05-03-052-21W4
11	Cooking Lake non-bituminous erratic 4	Westgate et al (1976), Emerson (1977), AGS (2017)	53.4646	-113.0252	761.8	12-03-052-21W4
12	Cooking Lake non-bituminous erratic 5	Westgate et al (1976), Emerson (1977), AGS (2017)	53.4676	-113.0252	757.6	16-04-052-21W4
13	Cooking Lake non-bituminous erratic 6	Westgate et al (1976), Emerson (1977), AGS (2017)	53.4740	-113.0251	751.1	05-10-052-21W4
14	Cooking Lake non-bituminous erratic 7	Westgate et al (1976), Emerson (1977), AGS (2017)	53.4780	-113.0252	754.4	12-10-052-21W4
15	Cooking Lake non-bituminous erratic 8	Westgate et al (1976), Emerson (1977), AGS (2017)	53.4730	-112.9513	751.2	08-12-052-21W4
16	Nakamun non-bituminous concretion	AGS (2017)	53.8904	-114.2872	693.2	02-06-057-02W5

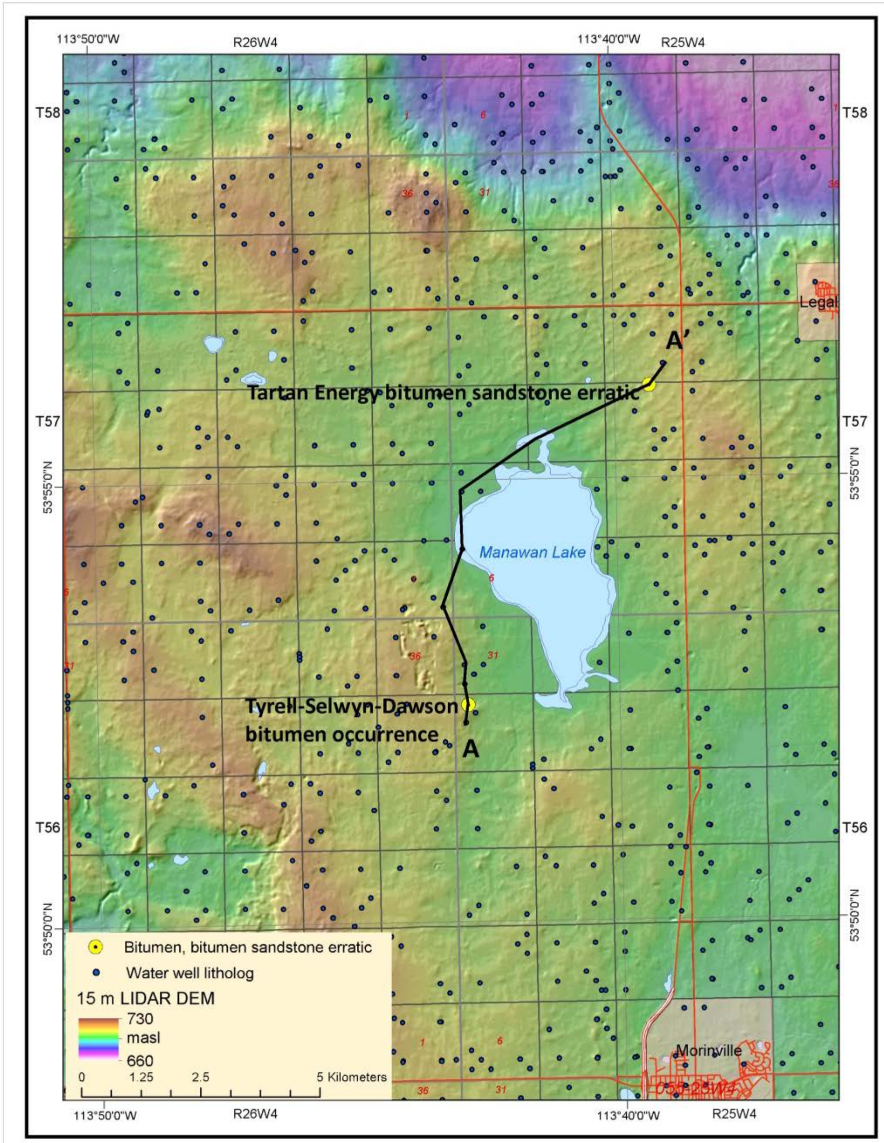

Figure 5. Location of bitumen and bituminous sandstone erratic near Manawan (Egg) Lake. The Tyrell-Selwyn-Dawson bitumen occurrence was described in 1893 as veins of bitumen in glacial sediment (till). The Tartan Energy bituminous sandstone erratic was discovered in borehole samples in 2005. Line of section A-A′ (shown in Figure 6).

3.1.1.2 Tartan Energy Inc. oil sand erratics

The Tartan oil sand erratics are located approximately 2 km northeast of Manawan Lake, and about 8 km northeast of the Tyrell-Selwyn-Dawson erratic site (DLS 15-16-057-25W4; Figure 5). The sites are located in an undulating landscape comprising a 10 to 15 m thick succession of glaciolacustrine sediment and till overlying bedrock (Figure 6). Initial land use at this site was agricultural until 1952 after which time an oil well was drilled and operated for about 26 years (Tartan Energy, 2010a). In 1978 the land was reclaimed back to agricultural use. Because of concerns raised about the release of crude oil and produced water from neighbouring well sites and pipelines, a 2003 environmental evaluation of the Tartan site was undertaken that showed concentrations of hydrocarbon and salt above Alberta environmental guidelines.

Consequently, the company was required to identify and delineate all deleterious substances present beneath the site, which included the installation of about 40 shallow (8 m) testholes and monitoring wells (Figure 7; Tartan Energy Inc., 2005, 2010a, 2010b). Hydrocarbons, including oil-saturated sand, were found nested within glacigenic sediment (till) in at least 4 holes at depths between 3 and 8m.

Oily-saturated sand was sampled for geochemical analysis (Tartan Energy, 2011) using a gas chromatography – mass spectrometric procedure. The results showed that hydrocarbon at the Tartan Energy site was highly biodegraded, and that the chemical composition was comparable to that of bitumen from the Grosmont Formation and the Athabasca oil sands, rather than that from an oil well. Based on the geochemical results, the investigation suggested three possibilities for the source of the hydrocarbon:

1) The oil sand represented a glacial erratic that was transported south from the Athabasca region and deposited with till,
2) A local seep of Exshaw-sourced oil which subsequently biodegraded in situ to produce bitumen,
3) Biodegraded Exshaw-sourced oil due to a release from a production facility, pipeline or tanker

The final conclusion (Tartan Energy, 2012) was that the most likely source of the hydrocarbons in near-surface sediment at the site was glacially transported oil sand erratics from deposits in the Athabasca oil sand region. It is noteworthy that none of the submission reports to the energy and environmental regulators referenced literature on hydrocarbons in glacigenic sediments in the area, as reported south of Manawan Lake more than 100 years earlier in the GSC's annual report of 1898 (Dawson, 1898).

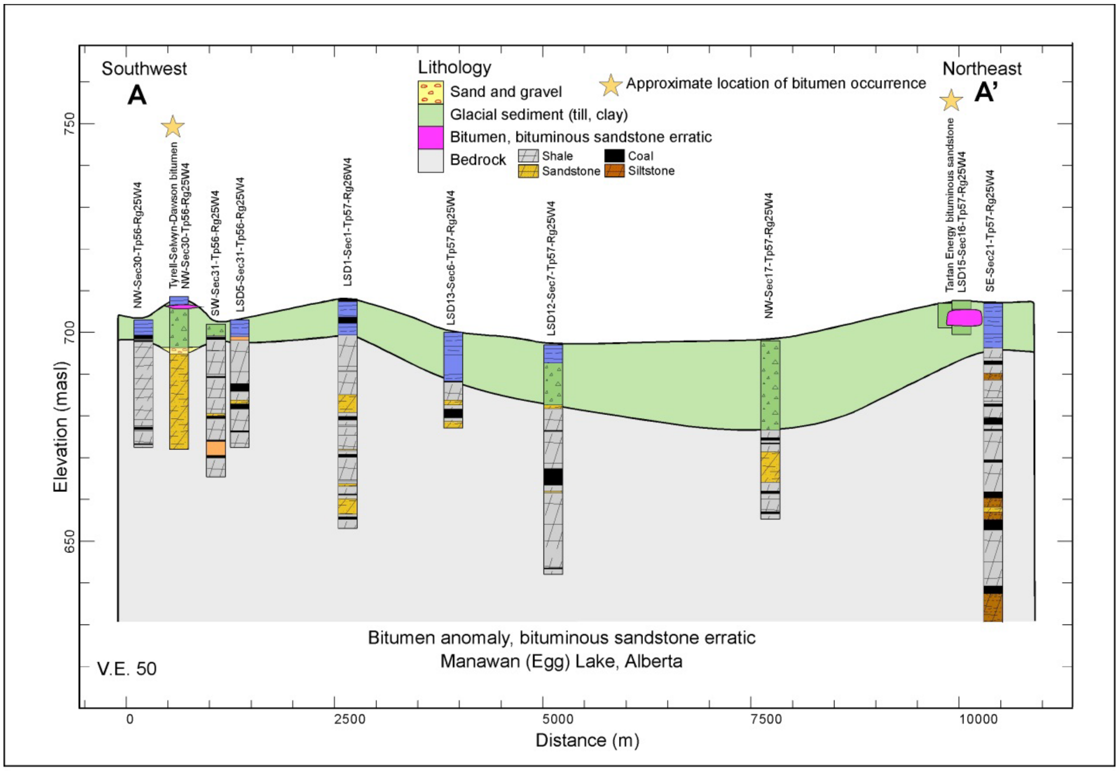

Figure 6. Geological cross-section A-A′ constructed from GSC, water-well, and environmental test hole logs in the area around Manawan (Egg) Lake, Alberta. Bitumen in the Tyrell-Selwyn-Dawson site occurred as veins within till, whereas bitumen-bearing sand (sandstone) entrained within glacial sediment was encountered in a few boreholes at the Tartan Energy site.

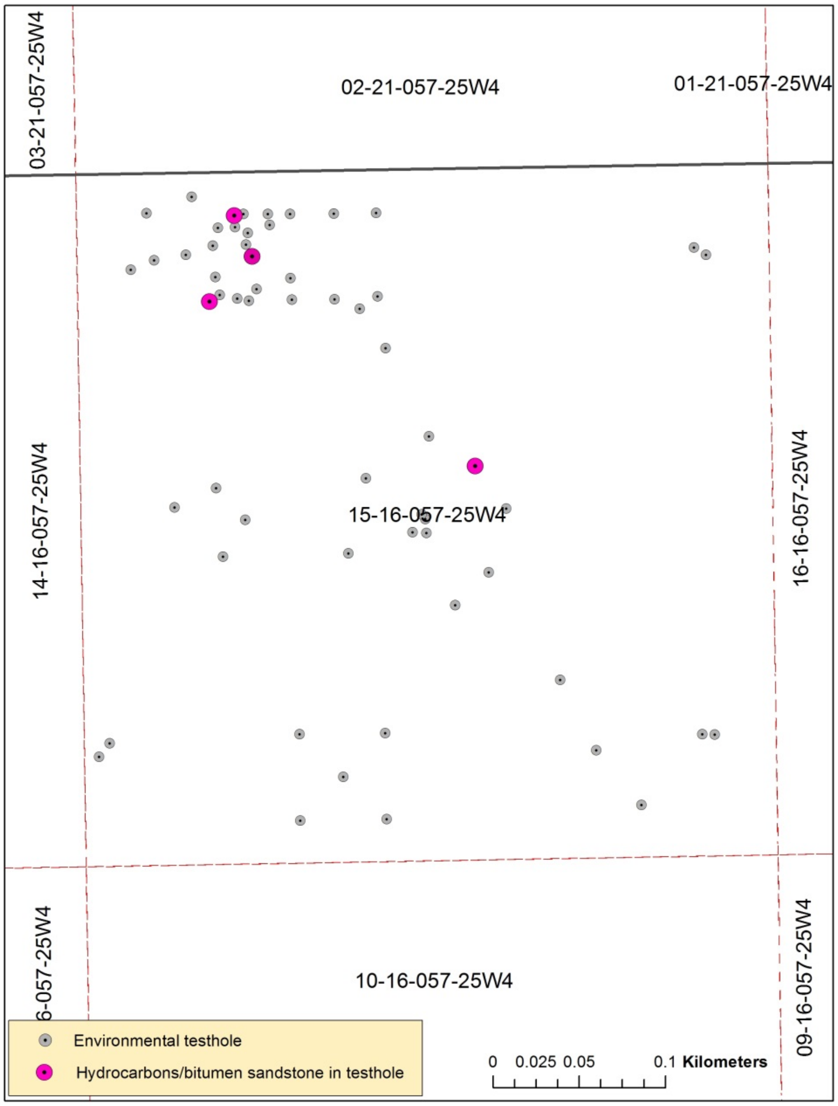

Figure 7. Location of environmental boreholes and monitoring wells at Tartan Energy site, DLS 15-16-057-25W4. Pink circles denote boreholes where hydrocarbons or bitumen-bearing sand (sandstone) were encountered.

3.1.2 Bonnie Glen bituminous sandstone erratic (1914, 1928)

The Bonnie Glen bituminous sandstone erratic site is located on the northern edge of Long Lake, (DLS 14-14-047-27W4), about 20 km west of the town of Millet, Alberta (Figure 8). During deglaciation, the area was characterized by the erosion of meltwater channels that are now partially occupied by Long Lake to the south and Wizard Lake to the north (Figure 8). Based on water well log information, sediment thickness is generally less than 10 m, except for infills of pre-existing valleys on the surface on the underlying bedrock (Figure 9).

The occurrence of bitumen anomalies was first documented by Ells (1914), but described in more detail by Rutherford (1928) who characterized the site location as agricultural land, with an erratic buried beneath vegetation and shallow soil. Removal of the surface soil cover revealed thin (~0.1 m thick) sheets of bitumen about 5 to 8 m in lateral extent, underlain by soil and ‘rock debris’. An analysis of bitumen content reported a value of about 16.5%, which is somewhat higher than that of bitumen-bearing geological formations in the Ft. McMurray area (Rutherford, 1928). There have not been any recent AGS visits to the site, nor is it expected that much evidence will remain, as the site was disturbed by prospectors and local visitors following its discovery (Rutherford, 1928).

Rutherford (1928) commented that petroleum exploration companies interpreted this bitumen to have originated from an oil seep, which prompted the drilling of an oil exploration well to a depth of about 335 m. However, Rutherford and his contemporaries who also examined the site (J.A. Allan, K.A. Clark, S.C. Ells), concluded that this hydrocarbon occurrence was an erratic of bituminous sandstone that was glacially transported from the McMurray area of northeast Alberta. Rutherford (1928) speculated that many more erratics likely were transported into central Alberta, but that only the most saturated parts of the bitumen-bearing sediments, and only the largest blocks, could survive such a large transport distance. In his final comments, Rutherford (1928) reproached the oil exploration industry’s investment of many thousands of dollars to drill a well at this site, stating that, ”Two or three days’ labor with a few inexpensive tools would have proved… that these were not oil seepages.”

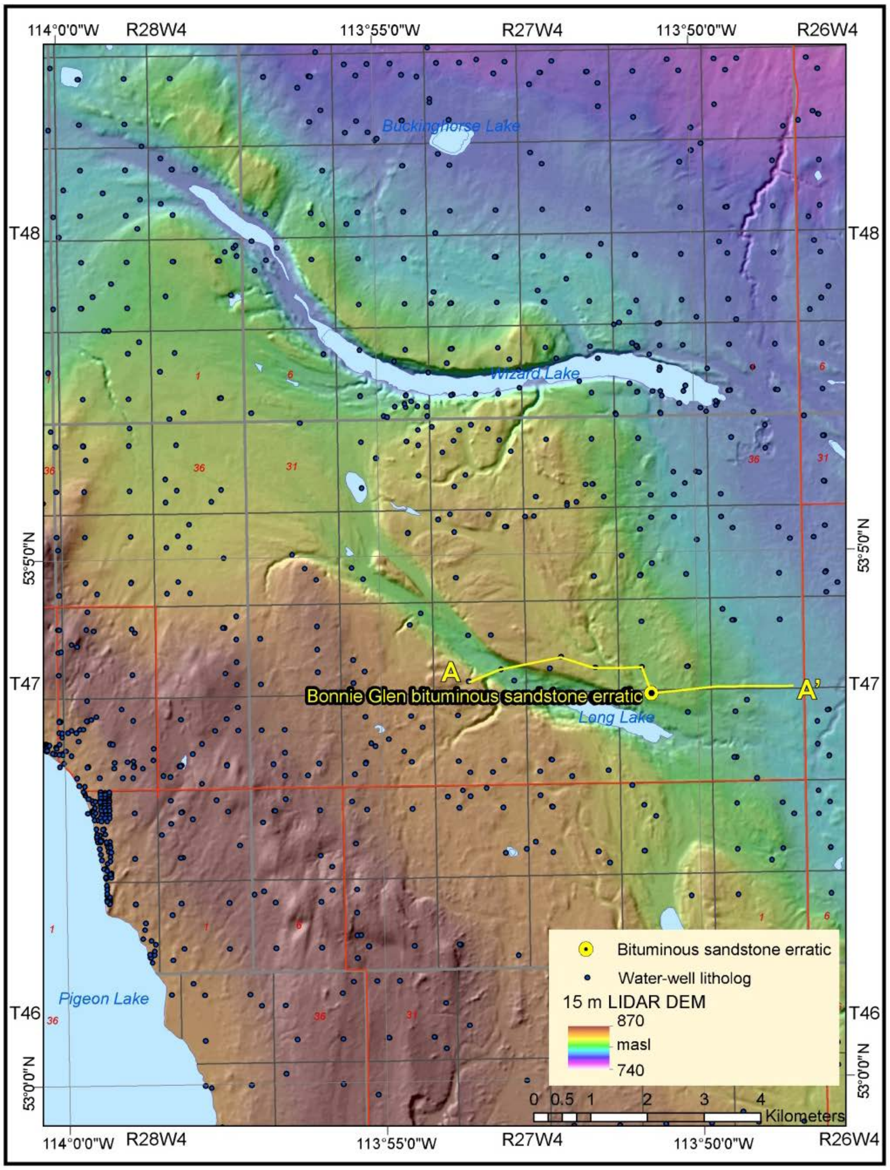

Figure 8. Location of the Bonnie Glen bituminous sandstone erratic and line of section A-A′ (shown in Figure 9).

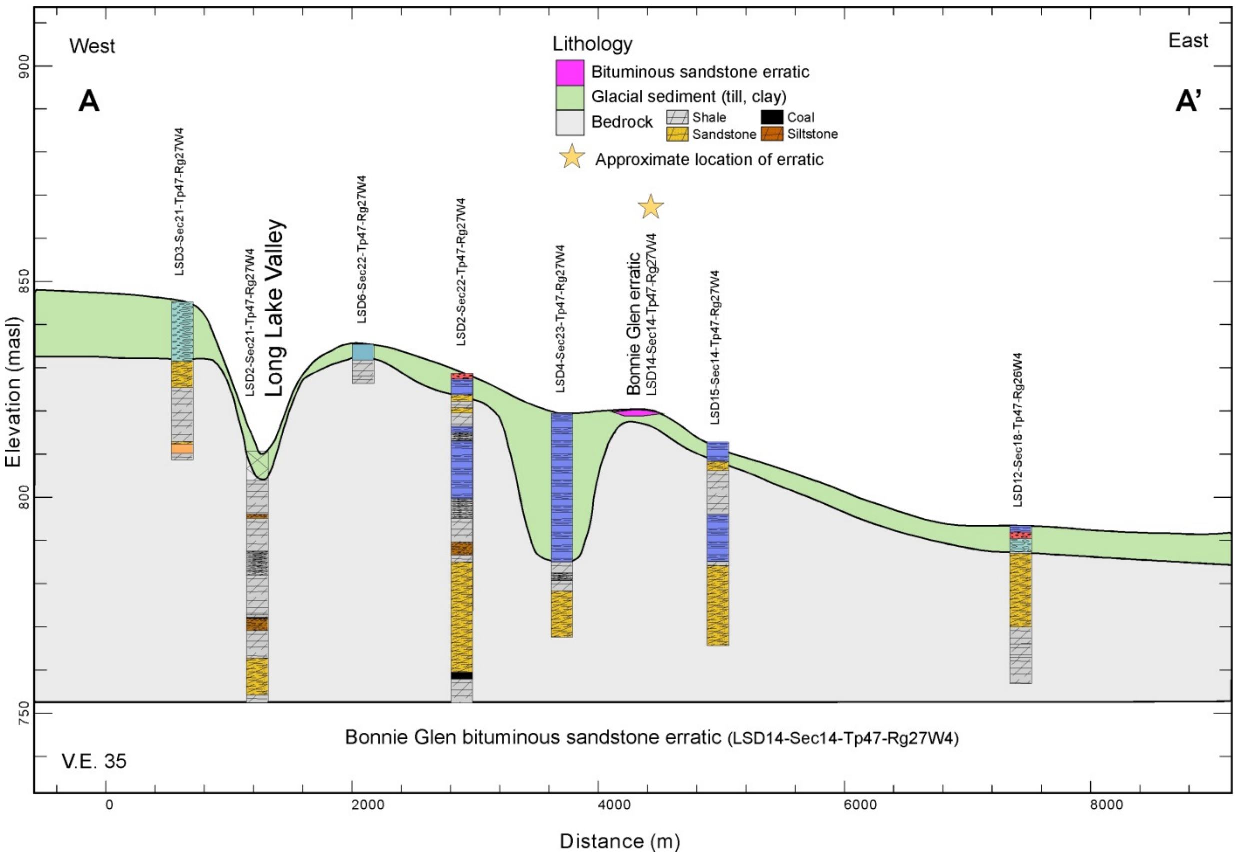

Figure 9. Geological cross-section A-A′, constructed from water well lithologs, located in the area around Long Lake, Bonnie Glen, Alberta. Bitumen occurred in the form of thin, laterally extensive blocks of bitumen-saturated sandstone lying just beneath the surface soil, underlain by glacial sediment.

3.1.3 Nakamun bituminous sandstone erratic (1914, 1928)

The Nakamun bituminous sandstone erratic site is located directly west of Nakamun Lake, Alberta (DLS 14-31-056-02W5; Ells, 1914; Rutherford, 1928). The site occupies agricultural land with a hummocky to rolling topography (Figure 10). Morphological features discerned on LiDAR imagery, and outcrops of deformed bedrock along some roadside exposures, indicate the region was subject to glaciotectonism during the last, or perhaps previous, glaciation. Based on water-well logs, the erratic is located above relatively thick (up to 40–50 m) accumulations of sediment (Figure 11).

The Nakamun bituminous sandstone erratic was first documented by Ells (1914) but described in more detail by Rutherford (1928). The erratic was encountered during the excavation of a domestic cellar where it was described as a lens-shaped body about 3.5 m across and thinning from 0.75 m at its thickest to a few centimetres at the edges. Rutherford described the lens of bituminous sandstone as being overlain by less than a metre of “a mixture of residual sands and silts and fragments of pre-Cambrian rocks”, and overlying about 1 m of similar material. A well dug within 30 m of the cellar showed no evidence of bituminous sandstone. A hydrocarbon analysis conducted by K.A. Clark indicated about 14.7% bitumen content in the erratic (Rutherford, 1928). As with the Bonnie Glen site, Rutherford (1928) interpreted the bituminous sandstone as an erratic ‘boulder’ brought into the region by glacial ice from the Ft. McMurray area. The Nakamun erratic was similarly interpreted by the oil industry to be local oil seepage; this initiated an exploration drilling operation about 4 km from the site, with a negative result (Rutherford, 1928).

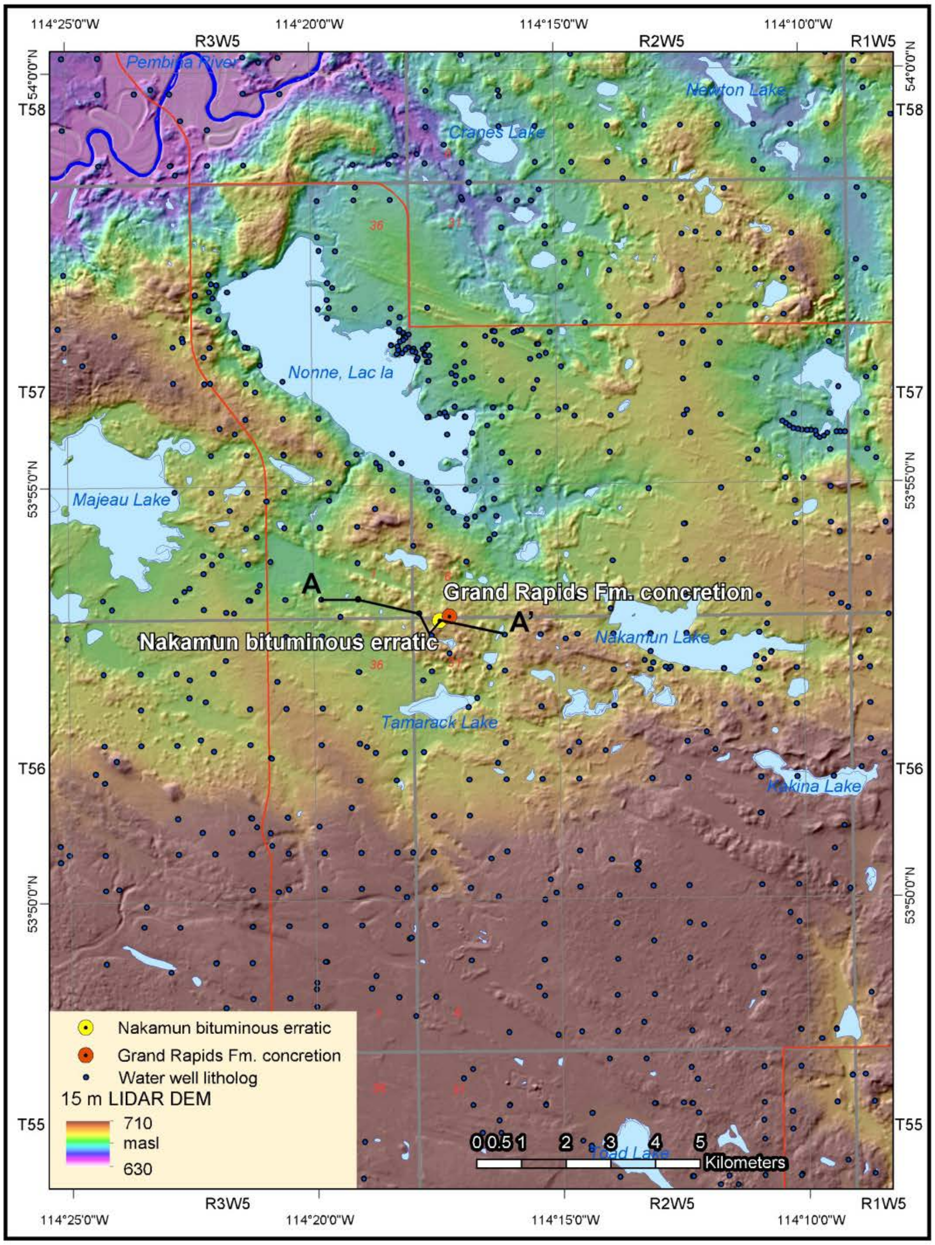

Figure 10. Location of the Nakamun bituminous sandstone erratic and line of section A-A′ (shown in Figure 11)

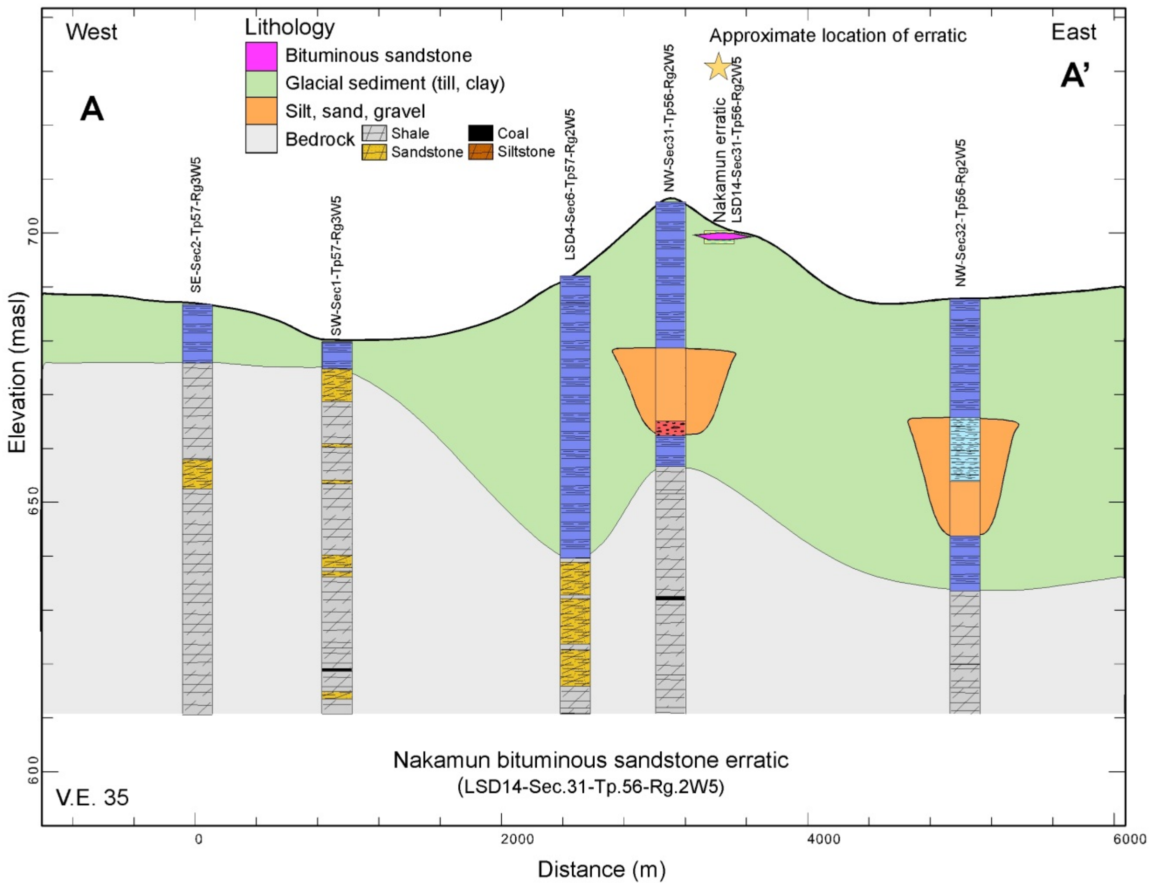

Figure 11. Geological cross-section A-A′ of the region near the Nakamun bituminous sandstone erratic site.

Rutherford (1928) referenced Ells (1914), who recorded three other bituminous sandstone observations within 40 km of the Nakamun erratic site (two of which were likely located by J. Tyrell (Dawson, 1901) at Manawan Lake to the east). At the time, Rutherford (1928) correctly attributed the source of these erratic ‘boulders’ to be from the oil sand deposits that outcrop in the Ft. McMurray area.

A recent (2017) field examination by AGS geologists failed to locate the Nakamun bituminous sandstone site. However, a 1m-diameter spherical sandstone concretion similar to those in the Grand Rapids Formation, was found in a boulder pile in the corner of an agricultural field located ~400 m from the Nakamun site (Figure 12a). This occurrence raises the possibility that the Nakamun bituminous erratic may be sourced from bitumen-bearing units within the younger Grand Rapids Formation, which outcrops along the Athabasca River about 275 km north. The Grand Rapids Fm. is the only geological unit located up-ice of the Nakamun site that contains comparable concretions and also has bitumen-bearing horizons. The significance of this observation to the origin and distribution of hydrocarbon erratics in central Alberta is discussed later.

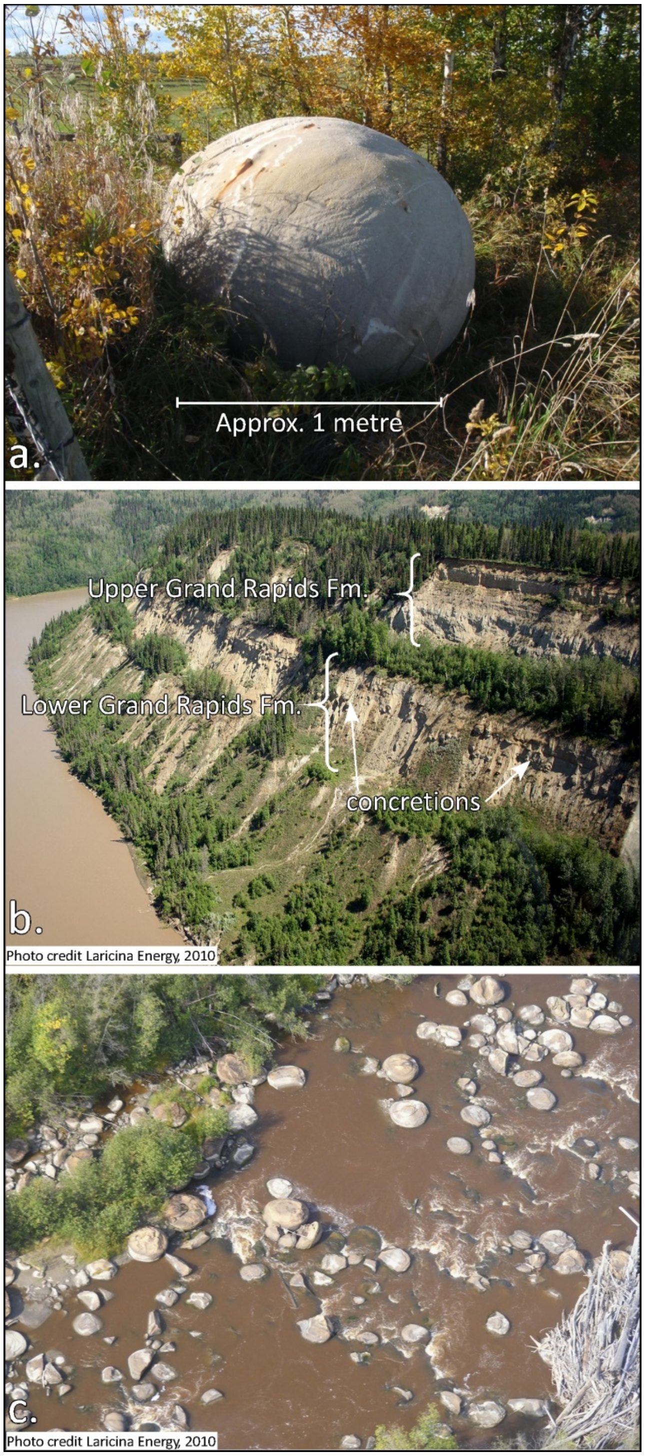

Figure 12. Concretions of the Grand Rapids Formation. a. Sandstone concretion, interpreted to be sourced from the Grand Rapids Fm., located in pile of fieldstones (53.89032N, 114.28722W) about 400 m from the site where bitumen-bearing sandstone was encountered in a basement excavation (Figure 10; Rutherford, 1928); b. Outcrop of concretionary bed at the contact between the upper and lower units of the Grand Rapids Fm., Athabasca River valley; c. Concretion lag on the Athabasca River valley floor, forming the Grand Rapids.

3.1.4 Barrhead and Westlock bituminous erratics

The Barrhead bituminous sandstone erratic was located by Feniak (1944) near the hamlet of Mosside (DLS Sec. 9 and 10, Tp. 59, Rge. 4, W 5th Mer.), approximately 9 km southwest of the town of Barrhead, Alberta (Figure 13). The precise location of the erratic is unknown, but presumably it was exposed within a road cut located on a southwest trending ridge that rises about 15 m above the surrounding topography (Figures 13, 14). The ridge is a compositional moraine, as reflected by the greater sediment thickness above bedrock beneath the site (Figure 14). Based on a series of shallow (1.7 m deep) auger testholes drilled at increasingly closer distances to the exposure (Feniak, 1944), the erratic appears to have been an isolated block with limited extent; a hole located just 1.3 m away failed to intersect bituminous sand. The AGS recently (2018) visited roadside outcrops along the county road through this area, but was not able to confirm exposures of the erratic.

Feniak (1944) also described bituminous sandstone erratics at depth, based on water-well litholog records in the area. A review of water well lithologs (Alberta Environment Water Well Database) indicated the presence of ‘tarsand’ at the base of the glacial sediment sequence at a site about 1.5 km southeast of the surface exposure, in DLS 10-03-059-04W5 (Figures 13 and 14). Feniak (1944) commented that erratics of bituminous sand were also found in glacial sediments near communities to the northeast, including Jarvie, Hondo, and Vega, as well as further east near Boyle. No maps or any other land-location information of these erratic sites were provided.

There is very little information about the Westlock bituminous sand other than its location (DLS S.E. Sec. 5-060-26-W4, Figure 4), and that it was interpreted by Ells (1914) to not be ‘in place’ and therefore of limited extent.

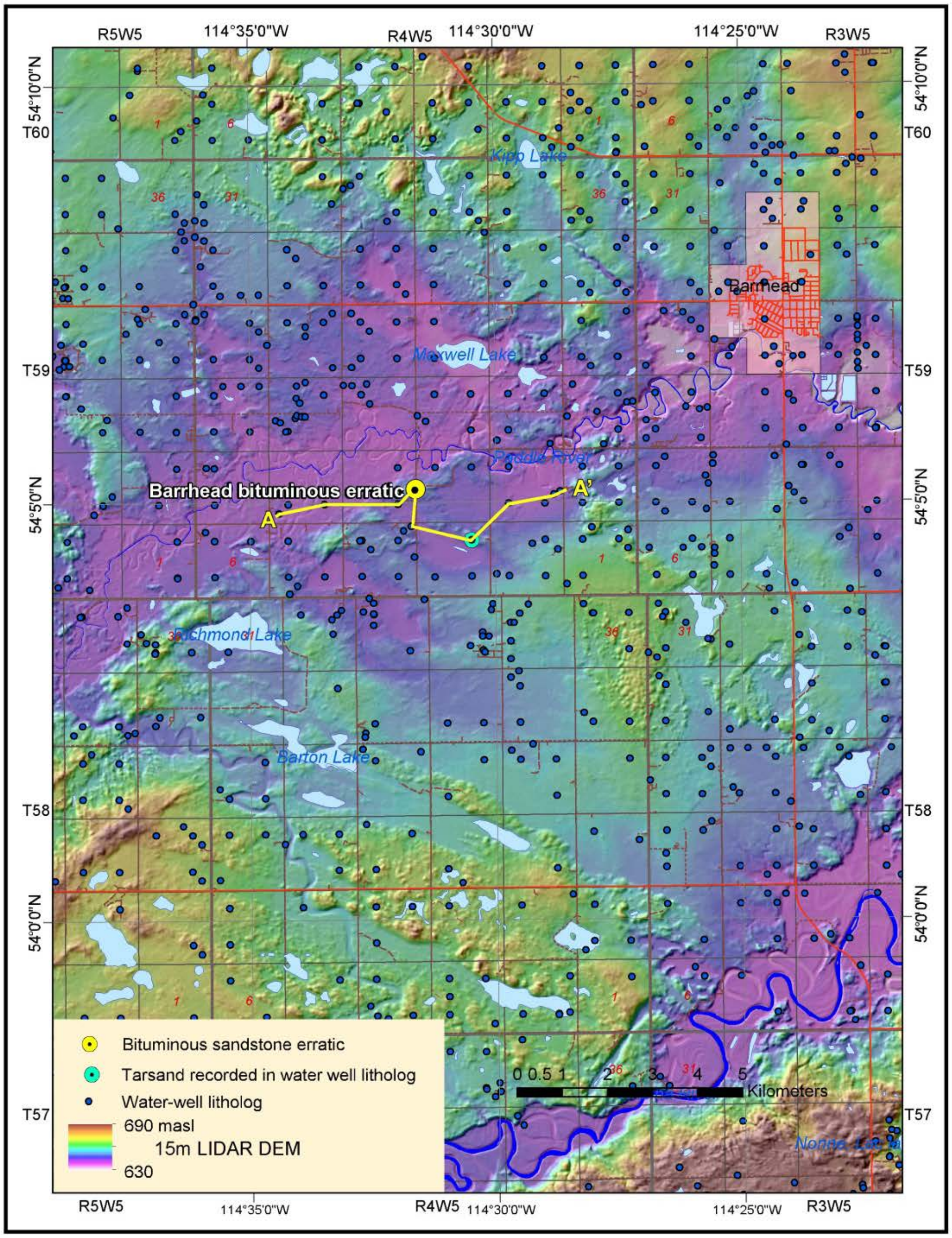

Figure 13. Location of the Barrhead bituminous sandstone erratic and line of section A-A′ (shown in Figure 14).

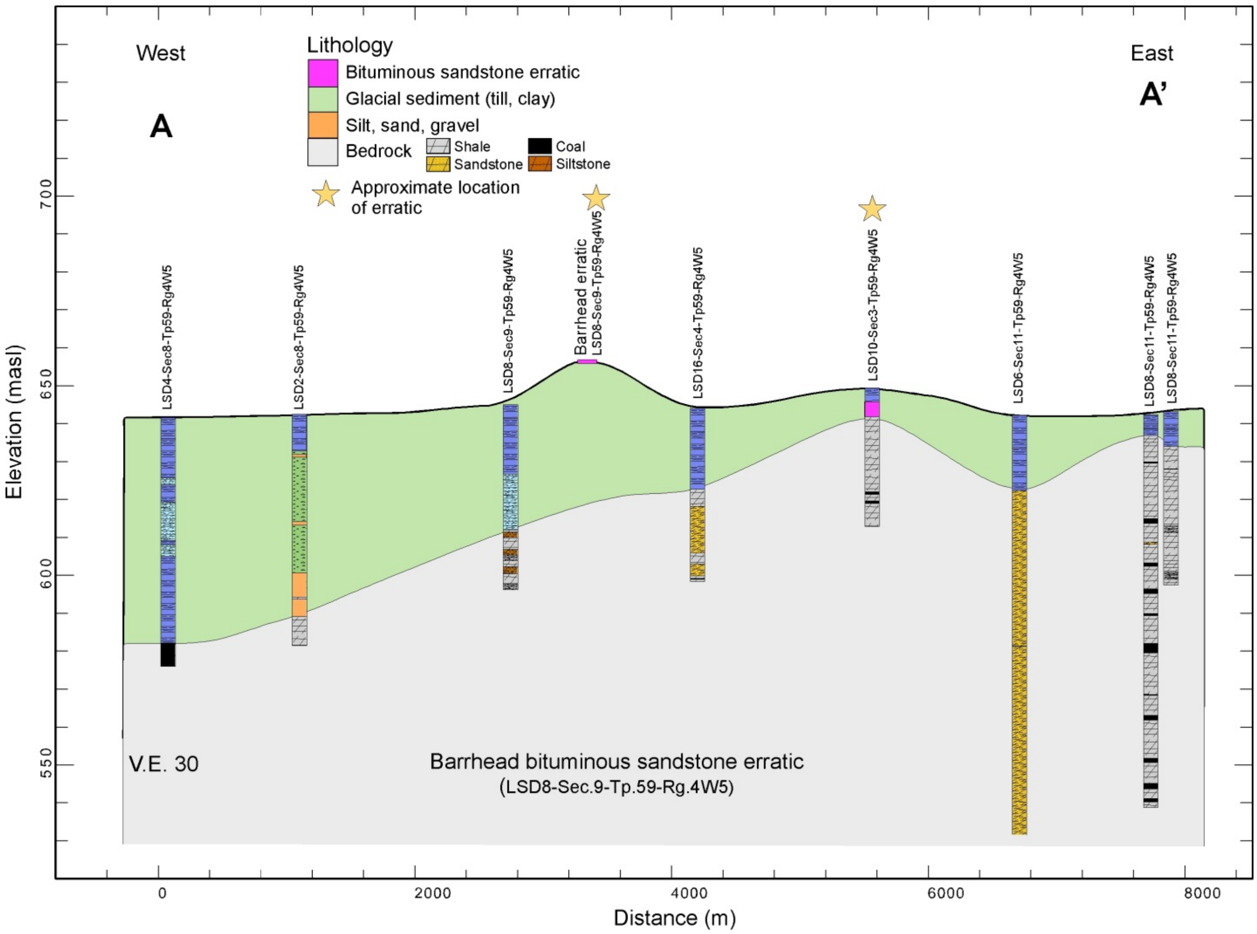

Figure 14. Geological cross-section A-A′ located in the region near the Barrhead bituminous erratic.

3.1.5 Holden bituminous sandstone erratic

During the period 1978-1981, the AGS conducted a deep auger-testhole program in the Edmonton map area (NTS83H) where 84 dry-auger testholes were drilled to bedrock, and sediments sampled to define the Quaternary stratigraphy (Andriashek, 1983, 1988). At a location approximately 4 km southeast of Holden, Alberta (DLS 4-5-049-15W4), a 4 m-thick erratic of bituminous sandstone was encountered in two of those testholes (AGS-R80-ED4, AGS-R80-ED8, Figures 15 and 16). Both holes were located along the roadside on a low relief, east-west trending linear ice-disintegration ridge, in which sediments are interpreted to have melted out of stagnant ice and collapsed into crevasses to form a pattern of intersecting ridges (Gravenor and Kupsch, 1959, Gravenor et al. 1960, Atkinson et. al, 2018). Sediment thickness in this ridge is about 10 to 12 m (Figure 16). In both testholes, bituminous sandstone was found directly on shale (interpreted to be in situ bedrock) and was covered by about 6 to 8 m of till, silt, and sand. At the time of drilling the first hole, R80-ED4, the source and extent of the hydrocarbon was unknown, so a second testhole (R80-ED8) was located about 30 m south in which bituminous sandstone was also encountered. An additional testhole drilled about 250 m farther south (R80-ED9, Figure 16) did not encounter the erratic. Ten Shelby samples were collected from testhole R80-ED8 for hydrocarbon, grain size, and petrographic analysis. The results from samples collected at 9, 10, and 11 m depths respectively, are included in Appendix 3. Oil content in the three samples ranged from about 1 to 6%, which is less than the approximately 15% content of the Bonnie Glen and Nakumun erratics (Rutherford, 1928).

A visual estimate of the petrology from a thin-section examined by J. Kramers of the AGS (pers. comm., 1981) showed the sandstone to be a lithic arenite to a lithic greywacke (Appendix 1) , characteristic not of the McMurray Fm., but rather of sediments from the Wabasca oil sand deposit, either the Wabiskaw Mbr. of the Clearwater Fm., or, the stratigraphically higher Grand Rapids Fm. A re-examination of those thin sections by T. Playter and H. Corlett (AGS) in 2018 confirmed the initial petrological characterization, though estimates of feldspar and quartz abundance differed slightly (Figure 17, Appendix 3A, Plate 1– 3). The significance of this to the interpretation of the source of hydrocarbon and other bedrock erratics found in central Alberta is discussed in more detail in section 6 of this report.

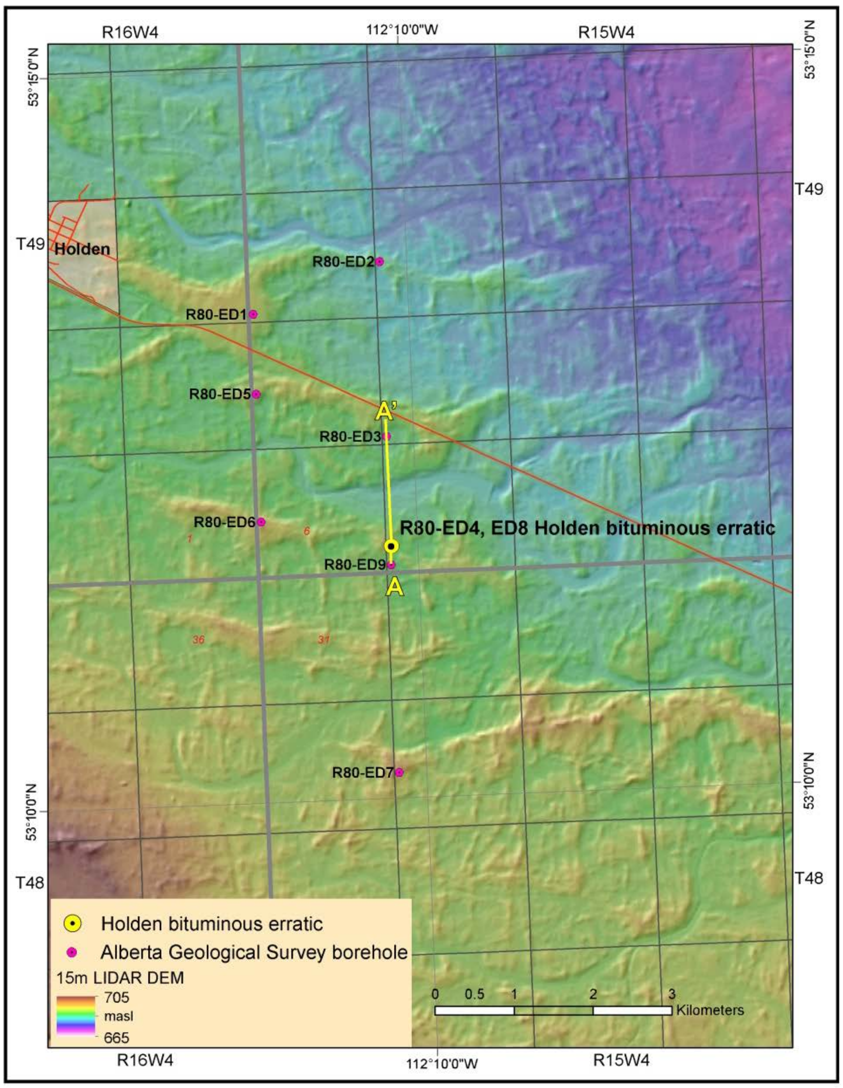

Figure 15. Location of dry-auger testholes R80-ED4 and R80-ED-8 where a 4 m-thick bituminous sandstone erratic was encountered near Holden, Alberta. Line of section A-A′ (cross-section shown in Figure 16).

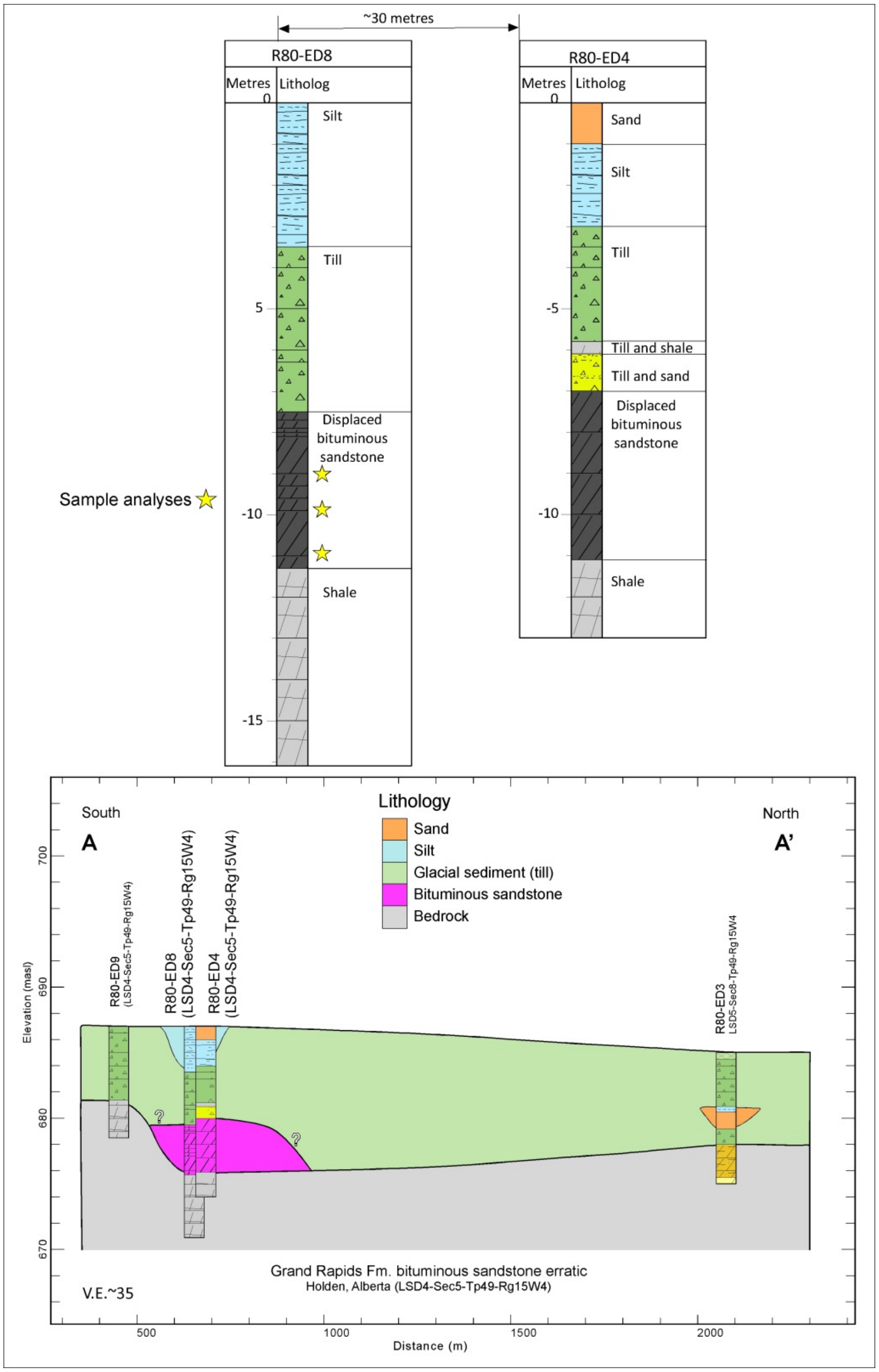

Figure 16. Geological cross-section A-A′ through bituminous sandstone within a very low-relief, glacial disintegration ridge. Testholes R80-ED4 and R80-ED8 are located about 30 m apart.

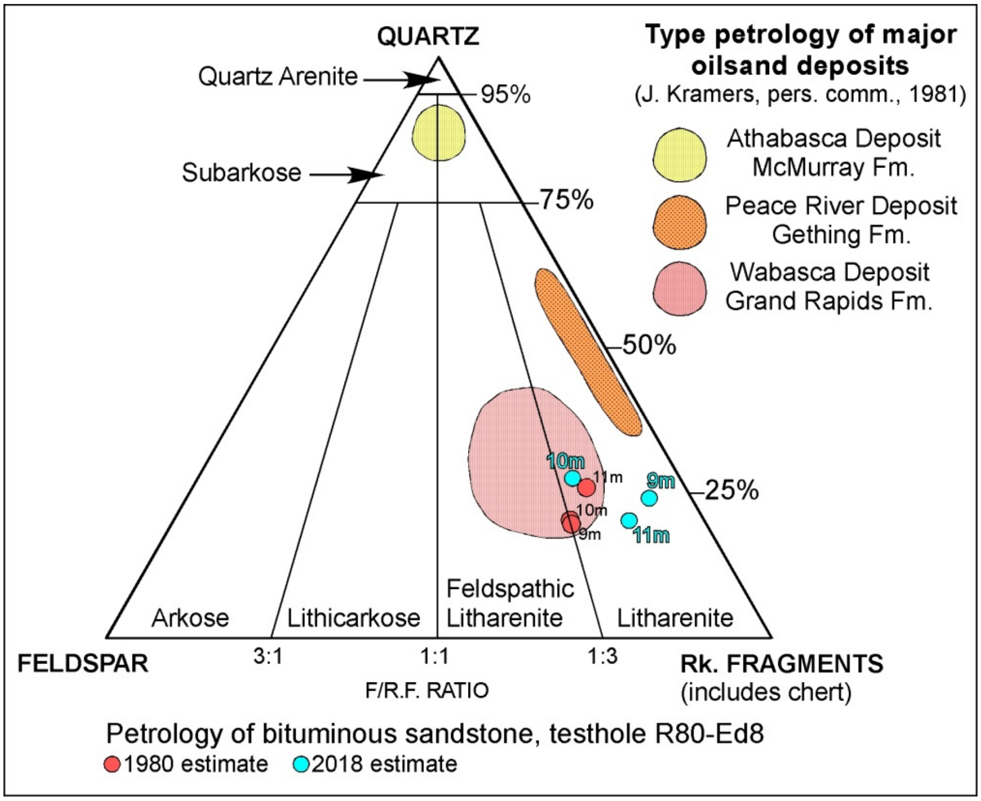

Figure 17. Petrological classification of the bituminous sandstone erratic at Holden. Three bituminous sandstone samples from testhole R80-ED8 are classed as litharenites, based on microscopic examination of thin sections by J. Kramers (AGS, 1981) and T. Playter and H. Corlett (AGS, 2018). The mineralogical composition indicates the sandstone is not derived from the McMurray Formation, which is dominantly quartz, but more likely from formations within the Wabasca oil sand deposit, possibly the Grand Rapids Formation.

4 Non-bituminous sandstone erratics: Cooking Lake Grand Rapids Fm. erratics

In the course of mapping Quaternary geology in the Edmonton region, Bayrock (1972) noted a number of near-vertical road-side exposures of buff-colored sandstone near Cooking Lake in the Beaver Hills (Cooking Lake) moraine east of Edmonton that appeared atypical of the bedrock in the region. Individual exposures of this buff-colored sandstone are about 3–5 m high, extend laterally for about 5 to 10 m, and are distributed over an area of more than 14 km^2 (Figure 18). C. Singh of the AGS conducted a palynological examination of samples from those exposures in the mid-1970s, and confirmed that they were not from the local Horseshoe Canyon Formation, but rather from the stratigraphically lower Grand Rapids Formation of the Mannville Group (the palynological results were published in the GAC/MAC Field trip C-8 guide book (Westgate et al., 1976); an excerpt is included in Appendix 2 of this report). These erratics were further described in subsequent studies by Emerson (1977), who mapped the extent of visible erratics in the moraine, and later by Mussieux and Nelson (1998), as well as AGS staff in 2017.

The erratics are found at or near the surface of hummocky terrain, interpreted to be stagnant-ice moraine, deposited by the retreating Laurentide Ice Sheet at the end of the last glaciation. Sediment thickness in the region is generally between 15 and 20 m (Figure 19). Road-allowance exposures through the hummocky terrain show that they comprise massive diamicts containing erratics exhibiting evidence of brittle fracture and ductile deformation, including imbricated tabular bedrock rafts that have been sheared southward, and wavy, deformed sedimentary beds (Figures 20, 21, 22). In many cases the erratics are covered by a veneer or layer of varied thickness of diamict and laminated sediment (Figure 20).

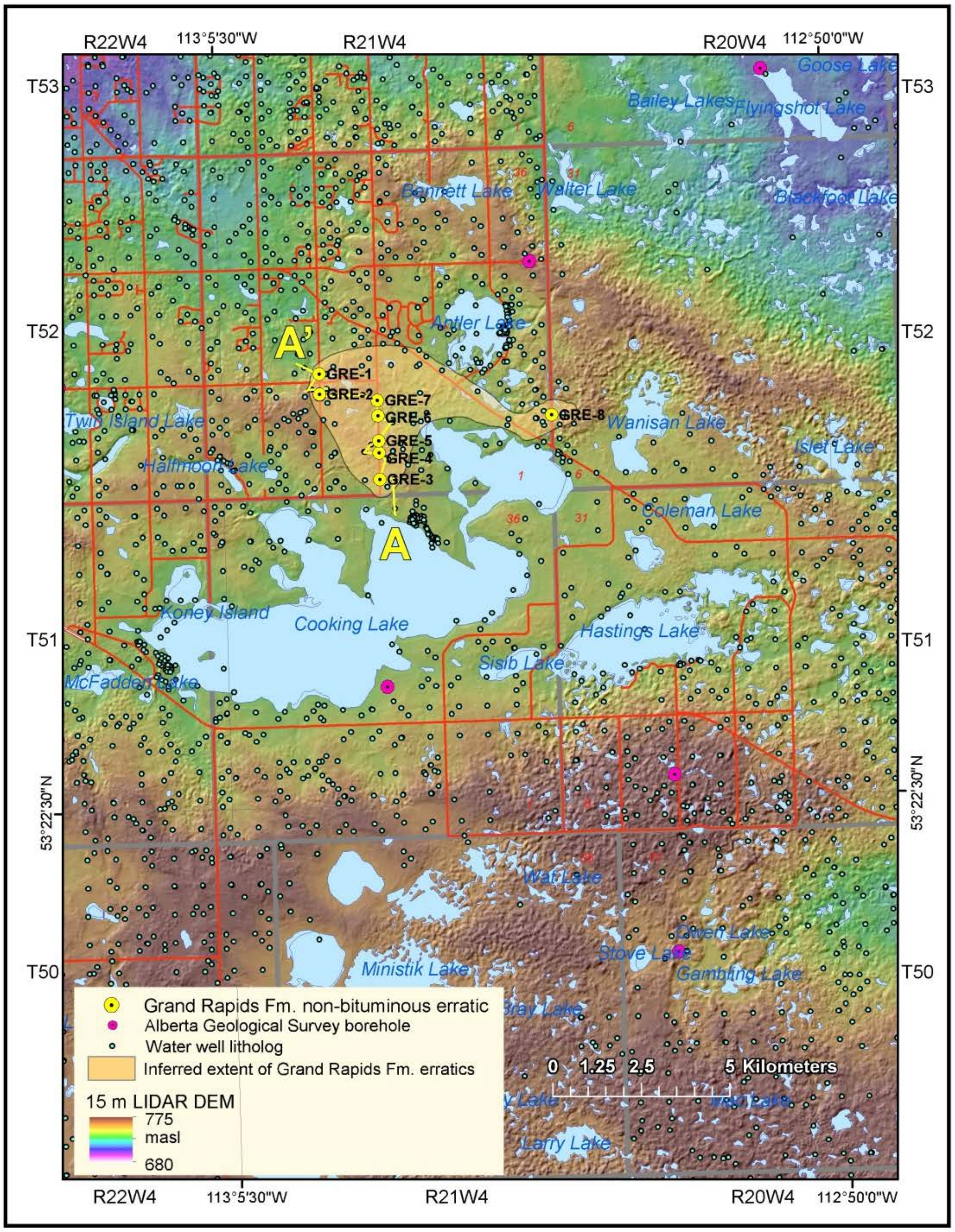

Figure 18. Location of observed Grand Rapids Fm. erratics in the Cooking Lake area east of Edmonton. Orange-colored polygon showing inferred extent of erratics is modified from Emerson (1979). Line of section A-A′ (cross-section shown in Figure 19).

The sandstone is generally poorly lithified and easily excavated, as evidenced by avian burrows and human diggings visible on the faces of some outcrops (Figures 20, 22). Petrological examination of thin sections of samples from two nearby exposures of the erratics (sites 1 and 2, Figure 18), shows that the sandstone is a glauconite-rich litharenite (Figure 23, Appendix 3A, Plate 4, 5), which is dissimilar in composition (excluding the glauconite) to that of the bitumen erratics at Holden. More on this is discussed in following sections.

There is also evidence of other far-travelled sediment associated with the till that drapes some of the erratics. Deformed layers or beds of pinkish colored diamict are visible in some of the roadside outcrops (Figure 24; Emerson (1977)), a color that is atypical of sediments in most of Alberta, particularly central Alberta, but which is common for near-surface glacigenic sediments in northeast Alberta (Figure 25). Possibly, these pink-colored sediments have also been transported south by Laurentide glacial ice.

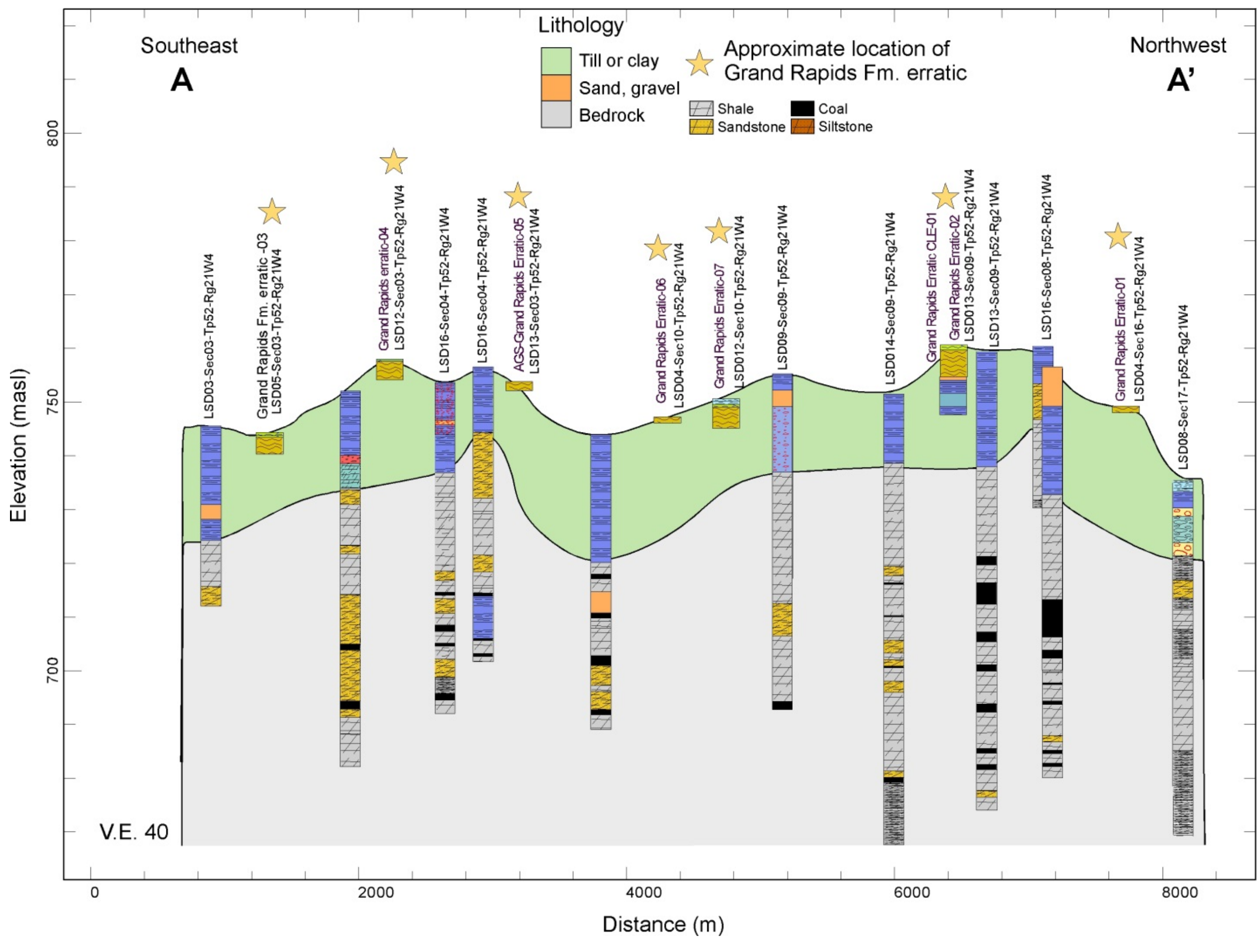

Figure 19. Geological cross-section A-A′ through outcrops of Grand Rapids Fm. erratics in the Cooking Lake Moraine, east of Edmonton.

Figure 20. Outcrop of Grand Rapids Fm. erratic 2 showing north-inclined glaciotectonic deformation structures in iron-oxide rich bedding planes. Diamict and water-laid sediments drape the erratic.

Figure 21. Glacially induced microfaults in bedding planes within Grand Rapids Fm. erratic 2.

Figure 22. Pock-marked human excavations on massive outcrop of Grand Rapids Fm. erratic 4.

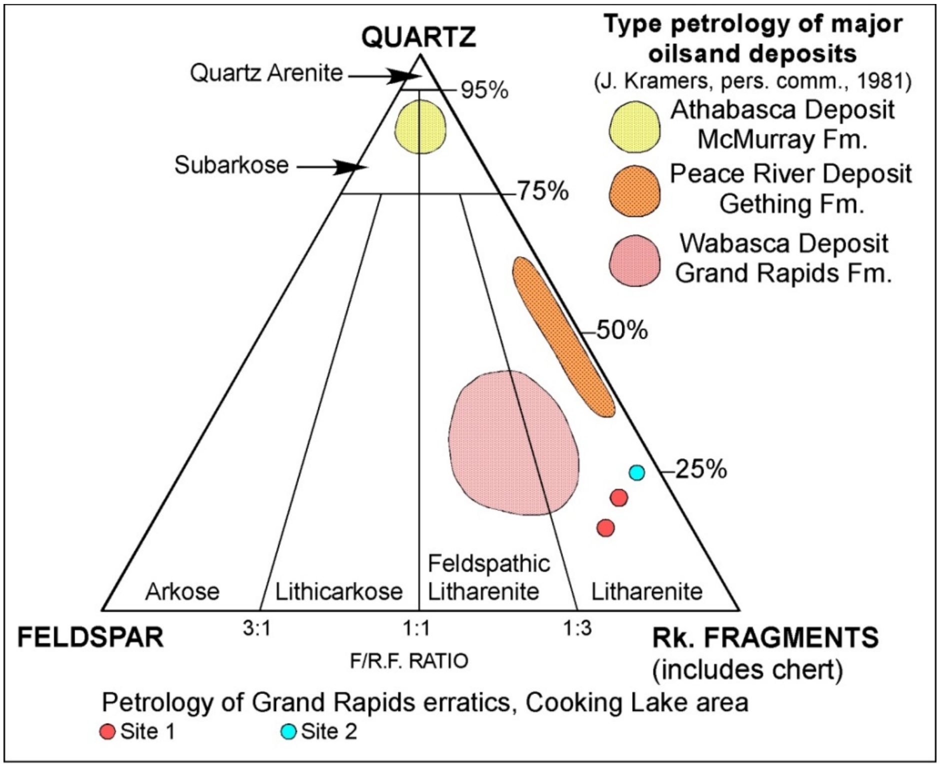

Figure 23. Petrological classification of sandstone erratics of the Grand Rapids Fm. in the Beaver Hills Moraine, near Cooking Lake east of Edmonton. The three samples from two nearby exposures of the erratics (Sites 1 and 2: Figure 17, 18) are classed as litharenites, based on microscopic examination of thin sections. Glauconite is abundant in samples from both sites (Plate 4 and 5, Appendix 3B). The paucity of feldspar observed in these samples, in comparison to the composition of the Grand Rapids Fm. recorded in other studies, may reflect a higher degree of alteration to sericite.

Figure 24. Wavy, pink-colored beds of diamict draped on Grand Rapids Formation erratic 3 (GRE3) sandstone.

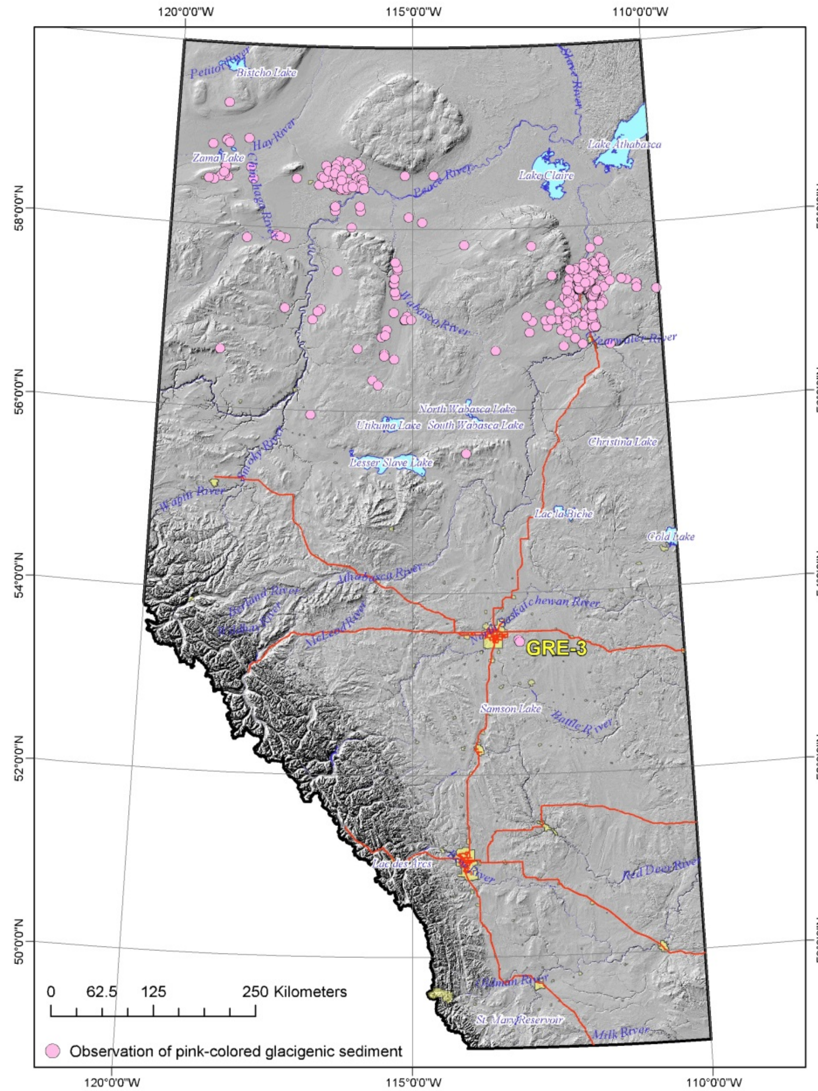

Figure 25. Distribution of near-surface pink-colored sediment. Pink-colored glacigenic sediments (clay, diamict), or clasts of pink sediment embedded in clay or diamict, are commonly observed in the northern part of the province. The data points reflect observations of sediments at surface, as well as outcrop observations and deeper drill core. The occurrence of a pink-colored diamict draped over Grand Rapids Fm. erratic 3 (GRE3; Figure 24) in the Beaver Hills moraine is atypical of the color of sediments elsewhere in central-south Alberta, and may reflect the southward transport of sediment from northeast Alberta along much the same glacial flow path as the bitumen erratics.

5 Bitumen odours in borehole samples, and 'tarsand' recorded in water well lithologs

There are other, less visible, occurrences of hydrocarbon in glacigenic sediment of central Alberta besides erratics of bituminous sandstone. Some have been well documented, such as finely disseminated bitumen in glacial diamicts (till) that is expressed as odours or oily sheens on drilling fluids (Andriashek and Pawlowicz, 2002), whereas others are reported as 'tarsand' in water well driller's lithologs. The distribution of both types of occurrences is shown in Figure 2. With a few exceptions, bitumen odour in glacial sediments has been encountered mainly in boreholes in the northern part of the province. Tarsand occurrences, as recorded in water well lithologs, are found more in the east-central part of the province, with some records located as far south as Calgary, Alberta (Figure 2). The distribution of these recordings relative to the locations of observed bitumen erratics suggests that, though uncommon, bituminous hydrocarbon occurrences may be widespread in central Alberta and perhaps more rarely found in southern Alberta.

6 Source of bituminous sandstone and related bedrock erratics

There is little doubt that the occurrence of bituminous sandstone erratics in central Alberta is a product of glacial quarrying and transport from the northern part of Alberta by one, or possibly more, Laurentide glaciations. Given that most erratics are found at, or near-surface (<10 m depth) and not deeply buried within the glacigenic succession, it is assumed that most were deposited by southward flowing Laurentide ice during the Late Wisconsinan glaciation. The fact that erratics were transported as far south as Pigeon Lake, indicates that the weakly lithified blocks of bituminous sandstone must have remained relatively intact and preserved within active flowing ice, until their release during the final stages of glaciation. In this regard, their occurrence as discrete blocks within the glacial sediments of central Alberta likely attests to emplacement by melting of stagnant-ice rather than basal lodgement processes. Perhaps the more interesting questions are: where did this quarrying occur, what formation was the source for these erratics, and what path did these erratics take during glacial transport.

Without petrological or some other geological confirmation, it is difficult to say that all bitumen erratics were derived from the same source area. There are seven formations (Figure 1) represented in four oil sand regions of Alberta (Figure 2) that are potential candidates. Many, however, can be excluded as the source of the erratics. For example, although somewhat similar in petrological composition, (Figure 3 and 17) the Holden oil sand erratic is unlikely to be sourced from any of the formations within the Peace River deposit (Gething, Bluesky) because; 1) the formations are too deeply buried and therefore have not been exposed to subglacial erosion and 2) surface ice-flow indicators show no evidence of glacial transport from the northwest part of the province into central Alberta (Figure 26). The petrology of the Holden erratic is similar to that of the Grand Rapids Fm. in the Cold Lake oil sand deposit (Figures 17 and 23), but all formations in the Cold lake region can be excluded as a source because of their great depth of burial, at least 150 to 200 m below the bedrock surface (Parks et al, 2005).

Three bitumen-bearing formations, all of which outcrop at or are near the surface in northeast Alberta remain as the possible sources for the bitumen erratics and the finely disseminated bitumen encountered in glacial diamicts: the McMurray Fm., the Wabiskaw Mbr. of the Clearwater Fm., and the Grand Rapids Fm (Figure 26). The McMurray Fm. is the thickest and most extensive bitumen-bearing formation that presently subcrops (and outcrops) in northeast Alberta, and it is reasonable to consider it as the primary source of the erratics. Furthermore, ice-flow indicators show well-defined flowlines extending from the

Ft. McMurray area into central Alberta, highlighting the path that the erratics may have taken during transport. However, the petrology of the McMurray Fm. sand is quartz dominated, with little feldspathic or lithic component (Figure 3). This is in sharp contrast to the quartz-poor, lithic-rich composition of the Holden erratic. Therefore, the McMurray Fm. is not the source for the Holden erratic, and possibly not for any of the other bitumen erratics in the plains. That does not preclude the possibility, however, that the finely disseminated bitumen encountered in borehole samples of glacial sediment is derived from the McMurray Fm.

Two other bitumen-bearing formations remain as possible sources of the erratics: the Wabiskaw sandstone member of the Clearwater Fm., and the exposed, bitumen saturated parts of the overlying Grand Rapids Fm. The Wabiskaw Mbr. is certainly a viable source of the bitumen erratic in central Alberta. For example, the petrology of the Holden erratic is similar in composition to the Wabiskaw Mbr. (Figure 3b). However, a stronger argument can be made that the erratics in central Alberta (both bituminous and non-bituminous) are derived from Grand Rapids Formation. Bituminous sandstone of the Grand Rapids Fm. is exposed in at least two areas: the Alice Creek Tongue along the northern edge of the Birch Mountains (Figure 26 and 27a), and along the banks of the Athabasca River, directly east of the Wabasca oil sand deposit (Connelly, 2010; Figure 26 and 27 b, c). On the basis of sand petrology, J. Kramers of the Alberta Geological Survey (1981, pers. comm.) considered the Holden bituminous erratic to be from the Grand Rapids Fm., derived from the Wabasca oil sand deposit (Figure 17). Certainly, the dispersal pattern of bitumen erratics in central Alberta is consistent with ice-flow patterns above the Wabasca deposit (Figure 26). A postulated bituminous quarry site somewhere along the Athabasca River would be the southernmost exposure of bituminous sandstone in Alberta, and would result in the shortest transport distance (minimizing degradation and comminution) for erratics into central Alberta. Palynological criteria establish that the sandstone erratics near Cooking Lake in the Beaver Hills Moraine are also derived from the Grand Rapids Fm. Similarities in petrology between the non-bituminous Cooking Lake erratics and the bituminous erratics at Holden (Figures 17 and 23), provide evidence that both are derived from the same source. Additionally, the occurrence of the large Grand Rapids Fm. concretion in the Nakamun Lake area (Figure 12a), located within 400 m of a previously described bituminous sandstone erratic (Rutherford, 1928), provides circumstantial evidence that other bituminous erratics in central Alberta are also derived from the Grand Rapids Fm. In summary, a Grand Rapids Fm. source is preferred over a Wabiskaw Mbr. source on the basis of sand petrology, palynological evidence and the location of large Grand Rapids concretions near bitumen erratics.

Thus, if the mapped distribution of bitumen erratics is a reflection of glacial ice dispersal (Atkinson et al., 2018) of blocks of bitumen-bearing sandstone quarried from exposures of the Grand Rapids Fm., then the pink-shaded patterns shown in Figure 26 highlight areas having a greater likelihood of bituminous erratics being encountered within glacial sediments in central Alberta.

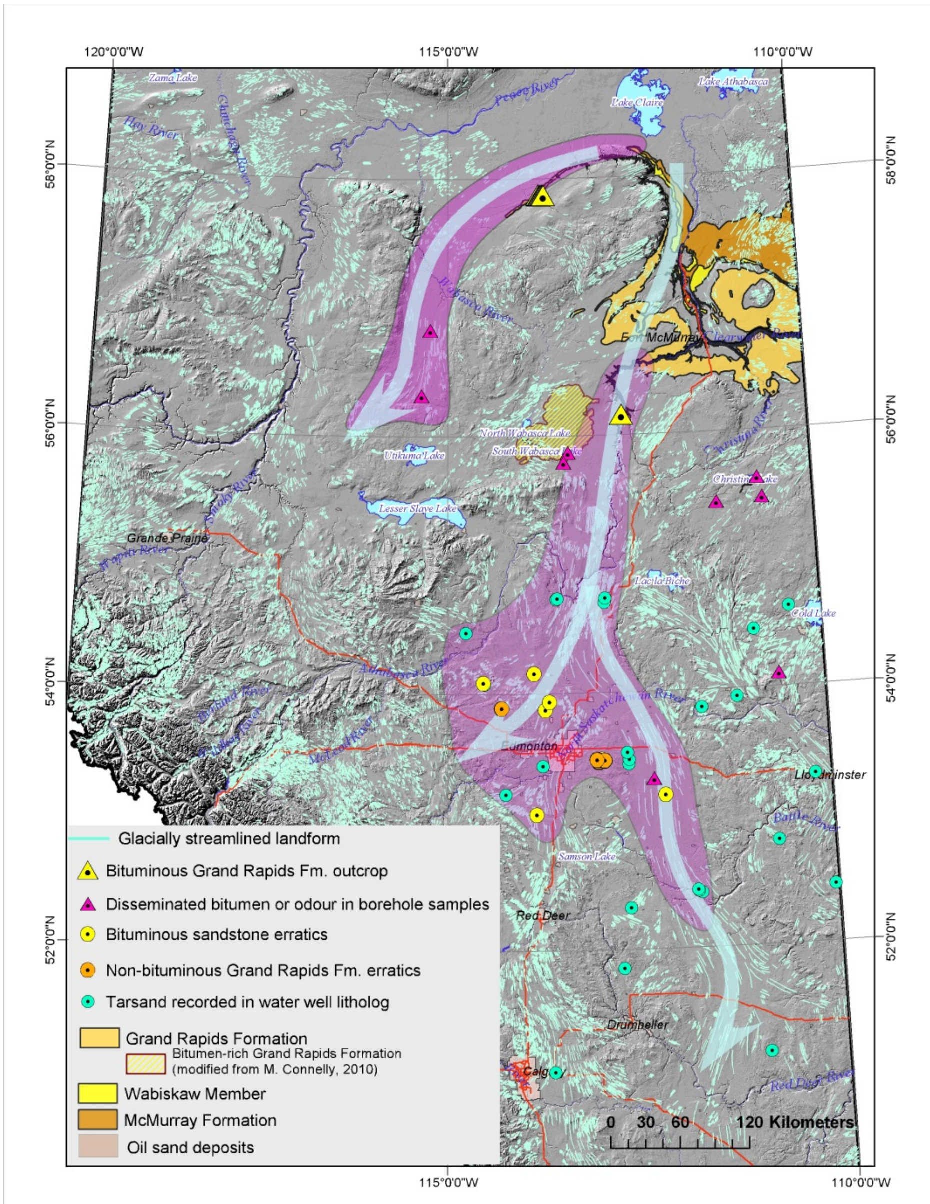

Figure 26. Subcrops of bitumen-bearing formations in northern Alberta and dispersal of bitumen erratics in central Alberta. The figure shows streamlined lineaments on Alberta's land surface, interpreted as indicators of glacial flow (Atkinson et al., 2018) with the broad, light-blue colored arrows highlighting major glacial flow paths that likely dispersed erratics (bituminous and non-bituminous) throughout central Alberta. Based on glacial flow paths, distribution of known erratics, and inferred Grand Rapids Fm. source, there is a greater probability of encountering bitumen erratics in the areas shaded pink.

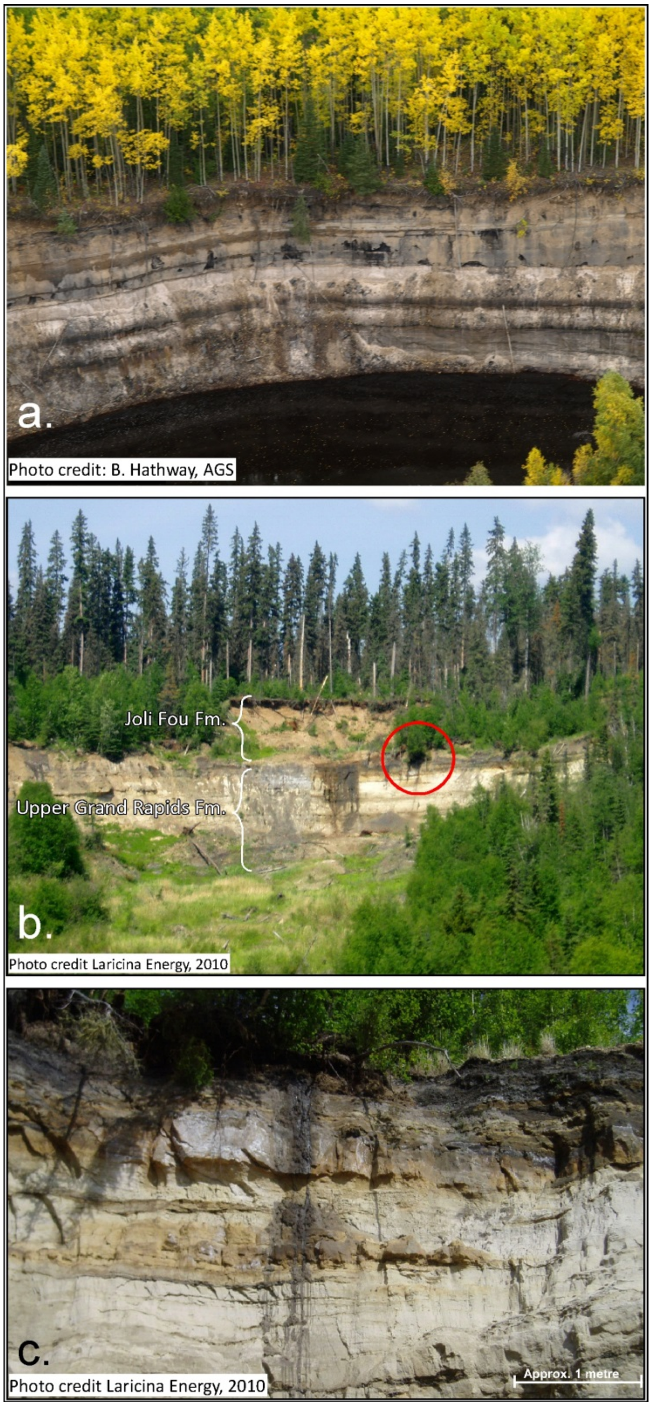

Figure 27. Bitumen-stained or saturated outcrops of the Grand Rapids Formation. a. Alice Creek Tongue of the Grand Rapids Formation along the Birch River, north flank of the Birch Mountains, northeast Alberta; b. Upper Grand Rapids Formation outcrop along the west bank of the Athabasca River (N. 56.158488°, 112.583198°); c. Close-up view of bitumen-saturated outcrop in photo b (denoted by red circle).

7 Summary and Conclusions

The recognition of bituminous and non-bituminous sandstone erratics in central Alberta spans more than a century of observations. Yet, their distribution both spatially and stratigraphically is poorly understood, and, when encountered within glacial sediments, bituminous erratics have been historically viewed as an anomalous and rare occurrence. Converging lines of petrological, palynological, and field-observational evidence suggest many bituminous, and non-bituminous, sandstone erratics in central Alberta were derived from glacial quarrying and plucking of the Grand Rapids Fm., specifically from the Wabasca oil sand deposit. These were transported into central Alberta relatively intact within southwest flowing ice-streams, and emplaced by glacial melt-out sedimentary processes.

The knowledge that bituminous deposits can be naturally occurring within glacial sediments in central Alberta should preclude the immediate assumption that near-surface hydrocarbons are anthropogenic in origin, resulting from inadvertent releases of industrial product into natural systems. It is likely that future excavations or borings in glacial sediments of central Alberta will encounter more bituminous sandstone 'anomalies', as commented almost a hundred years ago by Rutherford (1928) who stated, "There are perhaps many more occurrences of bituminous sand within the glacial deposits of Alberta, but since they weather comparatively readily and become covered with soil, they are not likely to be detected unless by accident as in the case of excavating a cellar … or cultivating land …".

Time has shown Rutherford's prediction to be true. At the very least, this report should move knowledge of the occurrence of bituminous erratics in central Alberta out of the realm of the unknown, to that of a known, and perhaps more predictable, geological phenomena.

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Appendix 1 - Petrological and lithological analyses of Holden bituminous sandstone erratic

Sand Petrology

Sample Name	Depth (m)	% Quartz	%Feldspar	%Chert	%Rock frag-ments	Classification
R80-ED8	9	20	20	40	20	Lithic grey-wacke
R80-ED8	10	20	20	30	30	Lithic arenite
R80-ED8	11	25	15	40	20	Lithic arenite

Clay Mineralogy

Sample Name	Depth (m)	%Montmo-rillonite	%Illite	%Kaolinite	%Chlo-rite
R80-ED8	9	~90	~10	~<5 (trace)	-
R80-ED8	10	~95	-	-	~5
R80-ED8	11	~95	-	-	~5

Heavy Mineral Content

Sample Name	Depth (m)	Sample wt. (+325 µm) (gm)	Wt. light minerals (gm)	Wt. heavy minerals (gm)	% Heavy minerals
R80-ED8	9	71.89	71.83	0.22	0.31
R80-ED8	10	78.88	78.81	0.12	0.15
R80-ED8	11	86.28	86.25	0.08	0.09

Bitumen Content

Sample Name	Depth (m)	Wt. oil sand (gm)	Wt. oil and water (gm)	Wt. water (gm)	Wt. oil (gm)	%Water	%Oil
R80-ED8	9	115.67	12.41	11.1	1.31	9.6	1.13
R80-ED8	10	131.85	15.8	13.2	2.6	10.01	1.97
R80-ED8	11	115.81	17.15	10.5	6.65	9.07	5.74

Grain size

Sample Name	Depth (m)	%Sand (>62.5 µm)	%Silt (2-62.5 µm)	%Clay (<2µm)
R80-ED8	9	68	21	11
R80-ED8	10	68	17	17
R80-ED8	11	87	9	5

Appendix 2 – Palynological interpretation of samples of Grand Rapids Formation erratics in the Cooking Lake area, Alberta

The following information regarding the palynological evidence for a Grand Rapids Formation source of the sandstone erratics in the Cooking Lake area east of Edmonton is published in the 1976 Geological Association of Canada – Mineralogical Association of Canada-Edmonton Geological Society Field Trip C8 Guide Book on the Geology of the Edmonton area (Westgate et al, 1976). The text is extracted as written for the description of Site 8 in the guidebook.

Stop 8: at Lsd. 12, S. 10, Tp. 52, R. 21, W. 4th (53° 28’ 30” N. lat., 113° 01’ 30” W. long.)

Numerous outcrops of Cretaceous bedrock – similar to that visible at this stop – are present in this part of the Cooking Lake hummocky moraine, located 4 to 6 miles to the south of Stop 7. (Fig. 8 *(in guide book)*). For many years these rocks were thought to be in situ and related to Edmonton Group strata. However, their microfloral content, as determined from samples collected by L.A. Bayrock, indicates derivation from the Grand Rapids Formation, whose nearest outcrop is located about 200 miles to the northeast. It follows, therefore, that huge bedrock erratics exist in the glacial drift here.

The microfloral analyses were carried out by C. Singh, Research Council of Alberta, and his conclusions are summarised below.

(1) A Barremian to Albian age is indicated by the following diagnostic species: Distaltriangulisporites perplexus, Asteropollis sp., Liliacidites reticulatus, Couperisporites complexus, Trilobosporites marylandensis, Trilobosporites trioreticulosus, Pilosisporites verus, Minerisporites marginatus and Arcellites reticulatus. However, an Albian age is more likely as some of the diagnostic species, viz. D. perplexus, Asteropollis sp., and A. reticulatus make their entrance during this time.

(2) D. perplexus and A. reticulatus are present only in the upper part of the Mannville Group (Clearwater and Grand Rapids formations) or younger strata. Their presence indicates that the sample is not from the lower part of the Mannville Group.

(3) There are no marine elements (dinoflagellate and acritarch) in this assemblage. This strongly suggests that the sediments were deposited under continental conditions. Insofar as the Clearwater and the lower part of the Grand Rapids Formation are marine to brackish in origin, the sample is more likely from the upper parts of the Grand Rapids Formation.

(4) Two most primitive and earliest form of angiosperm (flowering plant) pollen viz. Asteropollis sp. and Liliacidites reticulatus are present in the assemblage. Although angiosperm pollen has not been found in the Grand Rapids Formation or older strata of central Alberta, the uppermost beds of the Grand Rapids Formation in the lower Athabasca River area and the upper part of the Loon River Formation in the Peace River area contain rare angiosperm pollen. Thus, the sample is more likely from the uppermost part of the Grand Rapids Formation. A younger age for the sample can be ruled out as the dicotyledonous tricolpate pollen (appearing in the late middle Albian and late Albian time) and distinctive Cenomanian megaspore genera are not present in this assemblage.

Appendix 3 – Photomicrographs of thin sections from erratics

A. Photomicrographs of samples from the Holden oil sand erratic

Plate 1: 9 m sample

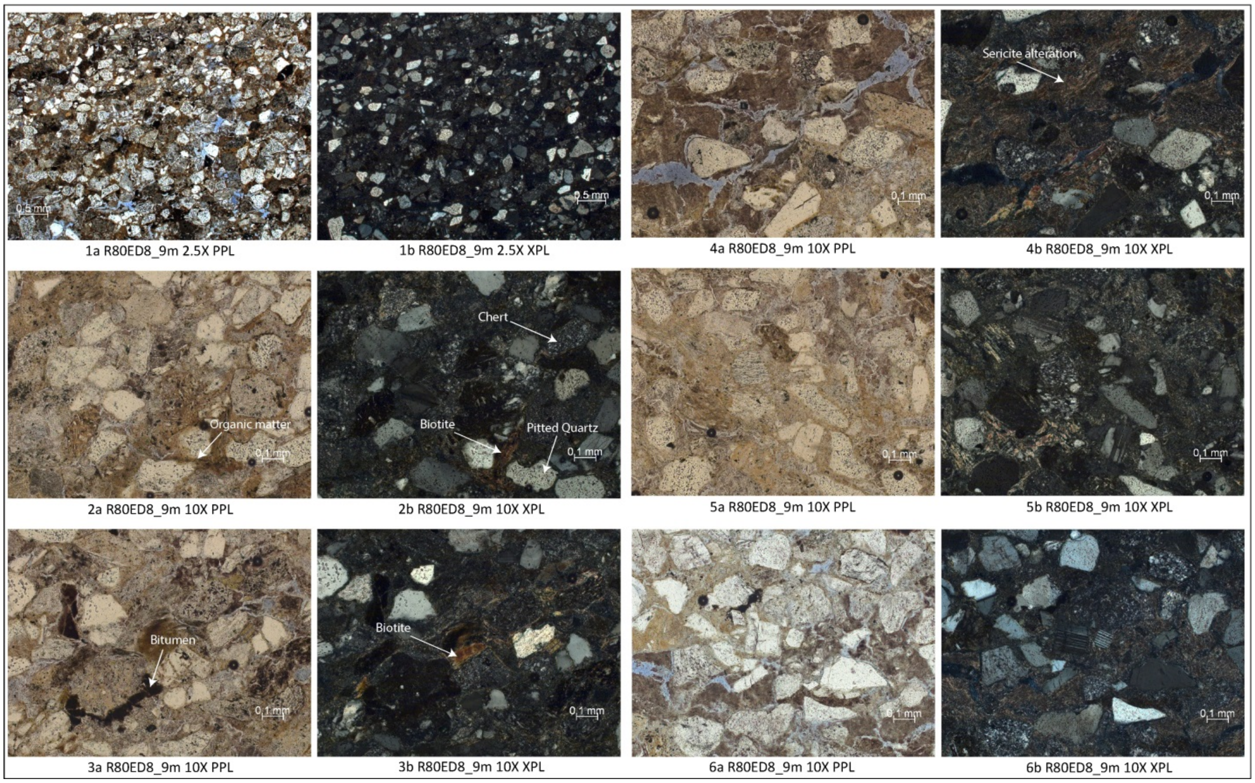


Plate 2: 10 m sample

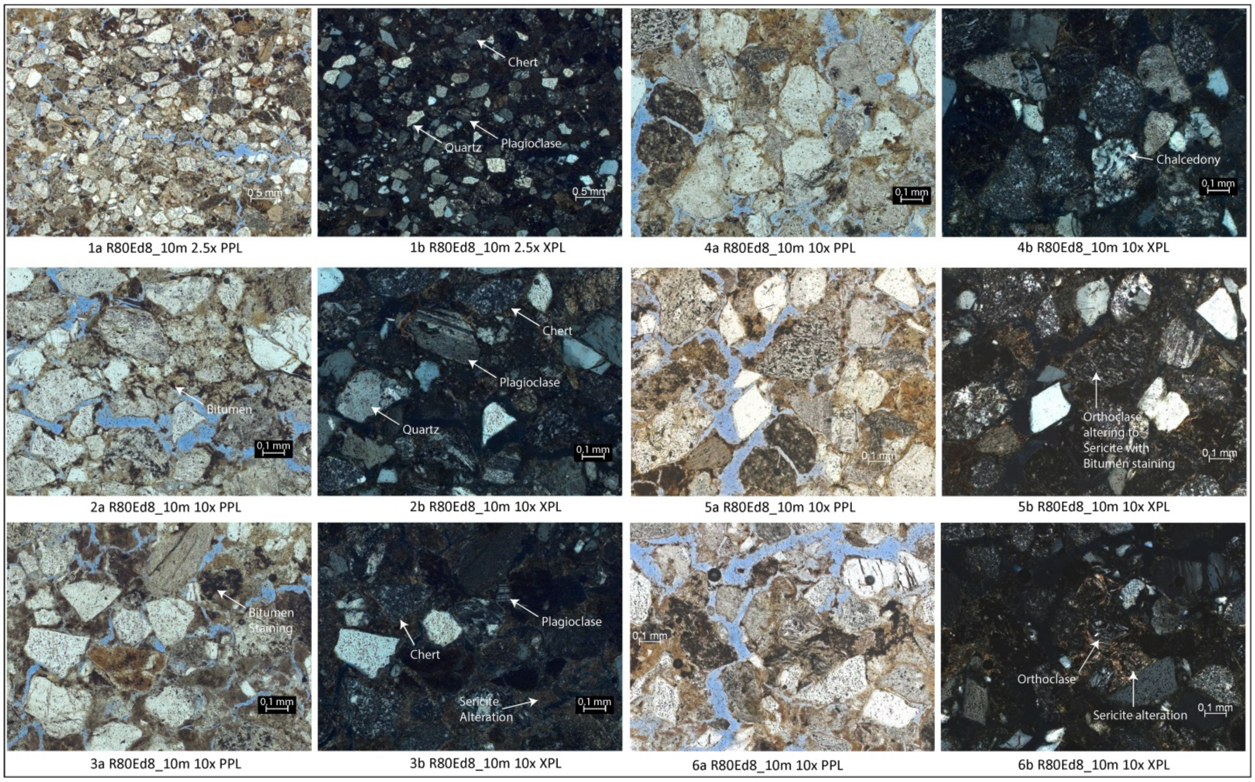
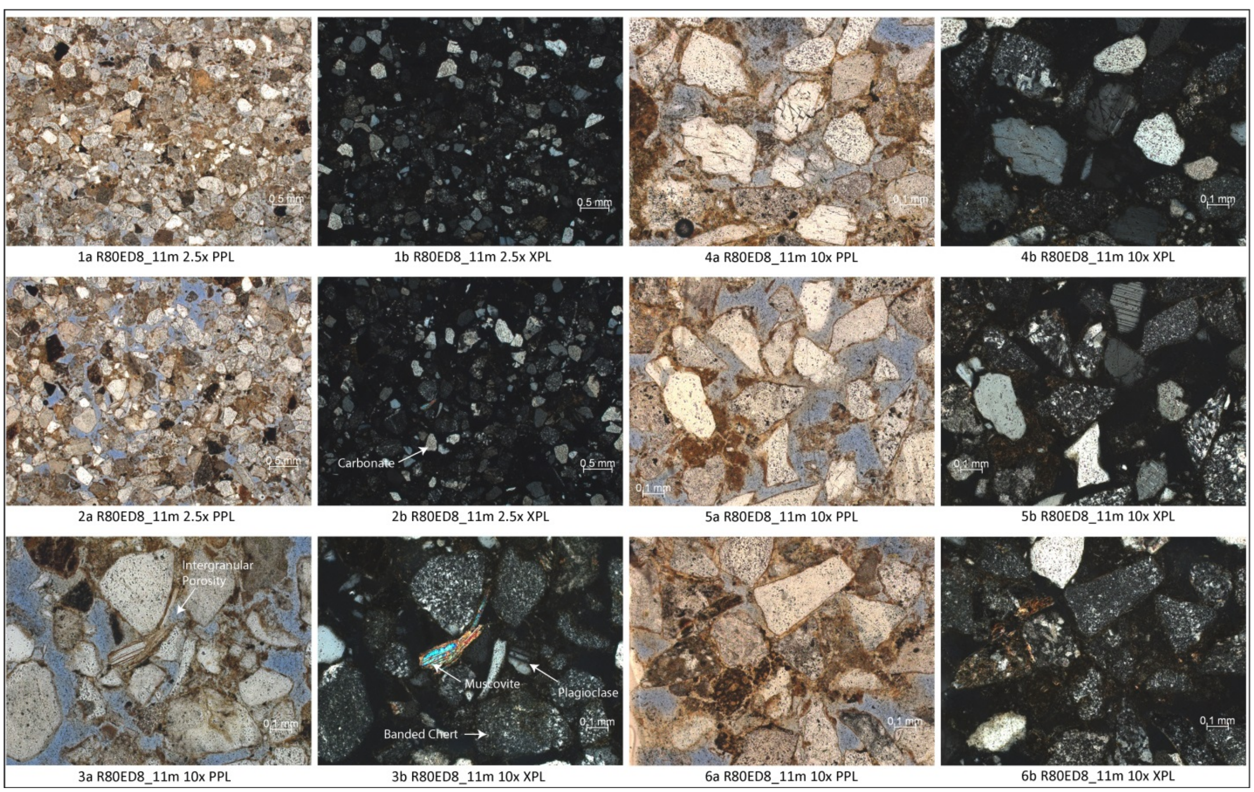
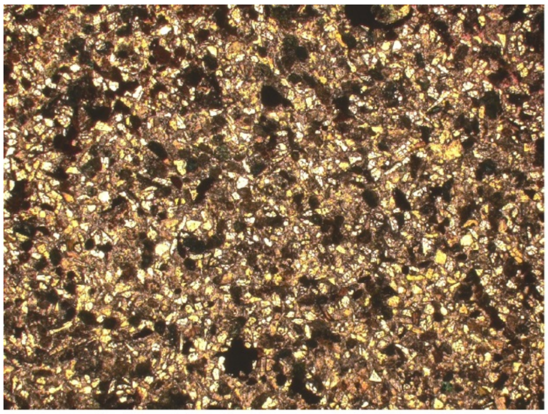


Plate 3: 11 m sample

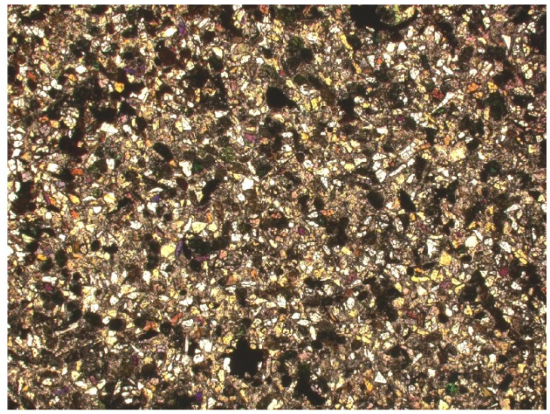


B. Photomicrographs of samples from the Grand Rapids Formation erratics, Cooking Lake Moraine

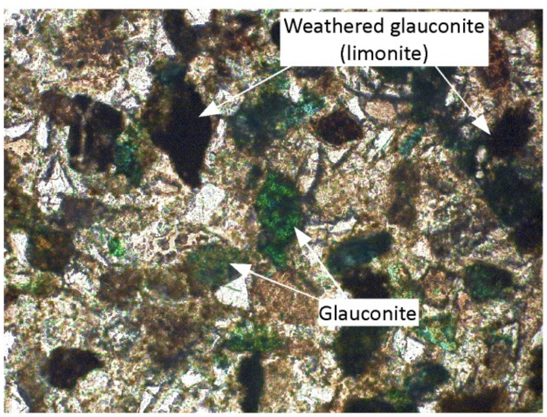
Plate 4: Grand Rapids Formation sandstone: Erratic 1



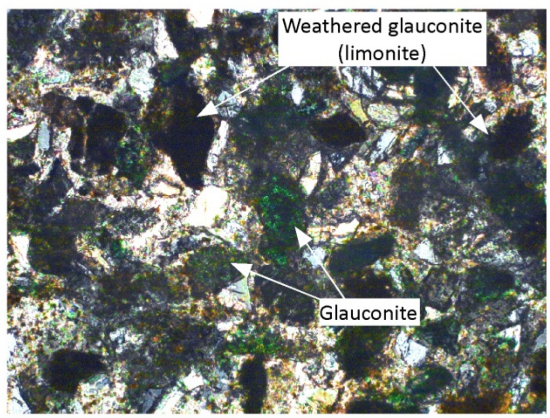
1a Grand Rapids Fm. erratic 1, 2.5x, PPL



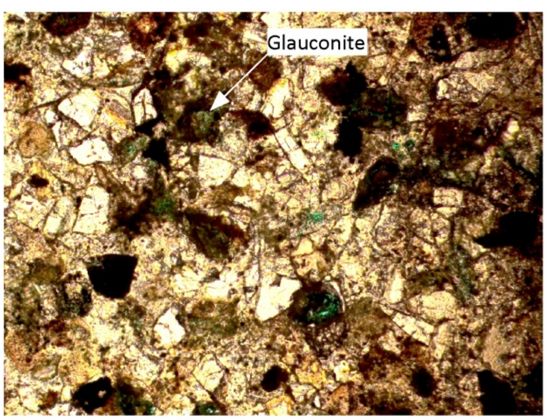
1b Grand Rapids Fm. erratic 1, 2.5x, XPL



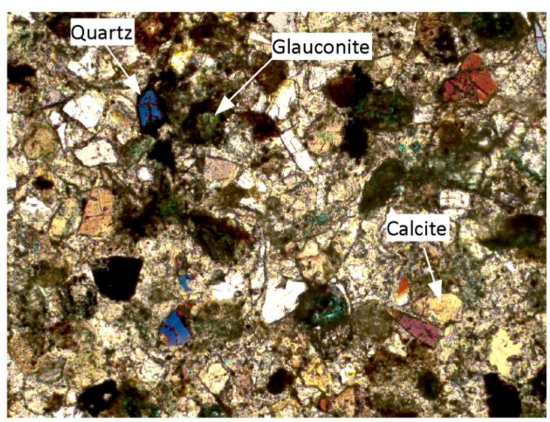
2a Grand Rapids Fm. erratic 1, 10x, PPL



2b Grand Rapids Fm. erratic 1, 10x, XPL

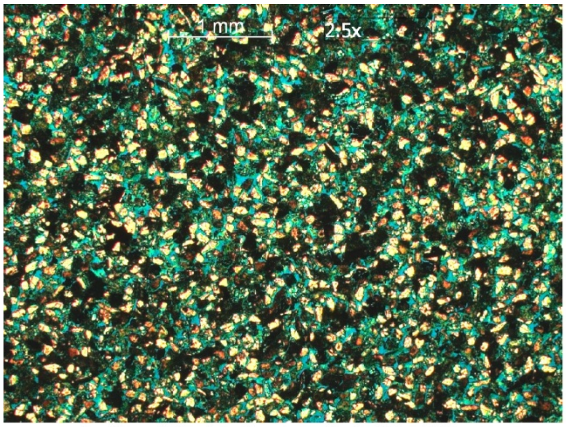


3a Grand Rapids Fm. erratic 1, 10x, PPL

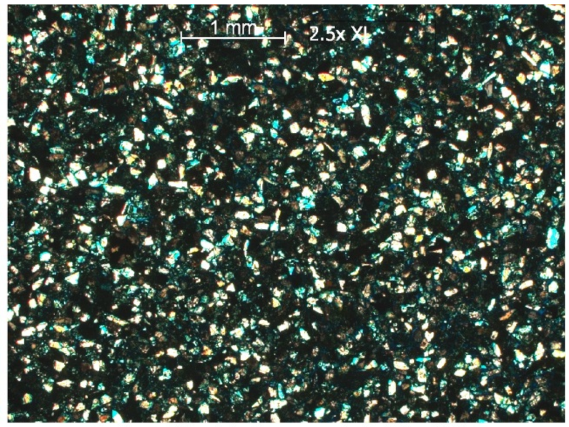


3b Grand Rapids Fm. erratic 1, 10x, XPL

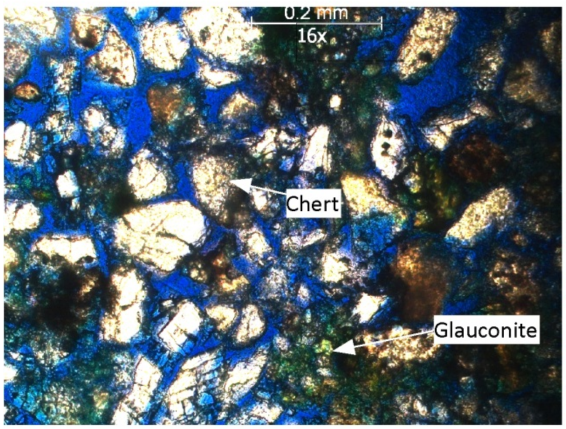
Plate 5: Grand Rapids Formation sandstone: Erratic 2



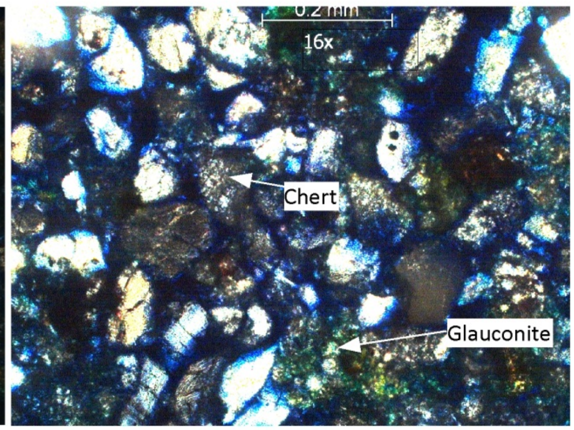
1a Grand Rapids Fm. erratic 2, 2.5x, PPL



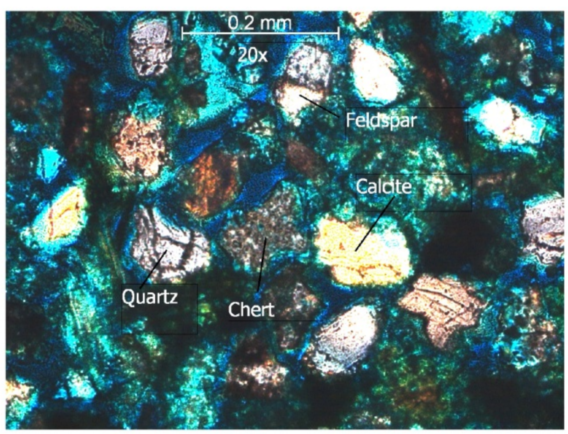
1b Grand Rapids Fm. erratic 2, 2.5x, XPL



2a Grand Rapids Fm. erratic 2, 16x, PPL



2b Grand Rapids Fm. erratic 2, 16x, XPL



3 Grand Rapids Fm. erratic 2, 20x, XPL