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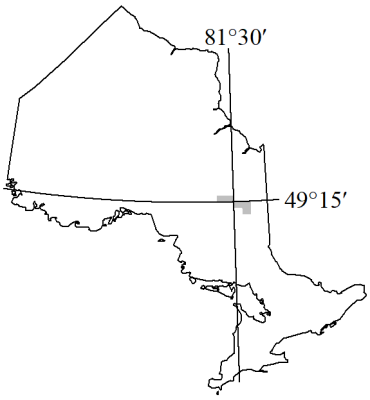
13. Project NE-18-001. Quaternary Geology Mapping in the "Great Clay Belt" of Northeastern Ontario



A.S. Marich[1]

[1]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey

INTRODUCTION

The "great clay belt" occupies much of northeastern Ontario, yet little is understood about the timing of events which led to its formation. The purpose of this project was to expand the existing knowledge of the surficial geology in this part of Ontario, as well as to provide highly detailed mapping which would aid in the Ontario Ministry of Agricultural Food and Rural Affairs (OMAFRA) updates to agricultural suitability mapping, to encourage the development of new agricultural ventures. Previous work in the area was at a reconnaissance scale (1:506 880 and 1:100 000 scales) and focussed on mapping surface sediments in a regional context, whereby much of the required detail for municipal planning, aggregate resource mapping and mineral exploration, for example, was lost (Boissonneau 1965, 1966; Lee 1989a, 1989b, 1989c; Lee and Scott 1989a, 1989b, 1989c). The current project has resulted in the publication of 5 Quaternary geology maps, at a scale of 1:50 000, spanning an area along the Highway 11 corridor between Kapuskasing and Iroquois Falls (Preliminary Maps P.3836–3840: Marich 2019a, 2019b, 2019c, 2020a, 2020b). The availability of high-resolution aerial photography and LiDAR digital elevation models (DEMs) have aided in the production of the most detailed mapping in the region to date.

The study area encompasses an area of greater than 4800 km^2 within the "great clay belt" of northeastern Ontario (Figure 13.1). The study area is represented by 5 National Topographic Series (NTS) maps, at 1:50 000 scale, Kapuskasing (42 G/8), Smooth Rock Falls (42 H/5), Cochrane (42 H/3), Abitibi (42 H/2) and Iroquois Falls (42 A/15); in this article, references to these NTS map areas by area name, for example, "Cochrane map area", will omit "NTS". Field work was conducted during the summers of 2016 through 2019, and a total of 5000 observations were made of the surficial materials and landforms, and 52 till and 20 esker sand samples were collected (Marich 2016, 2017, 2018). The till and sand samples were collected for heavy mineral analysis, and the till samples were analyzed for the suite of major and trace elements, carbonate content and grain size. All methods followed standard field collection and laboratory protocols used by the Ontario Geological Survey. Additional detail regarding the analyses and results can be found in forthcoming report and digital data publications by the author (Marich, in press-a, in press-b).

The study area is located within a region of very subtle topography that is a result of deposition of fine-textured sediments within a large proglacial lake: in this case, glacial Lake Barlow–Ojibway, which later merged with glacial Lake Agassiz to the west. These proglacial lakes had a very strong influence on the deposition of sediments and the development of landforms in the region.

Occurrences of base and precious metals in bedrock have been observed throughout the study area, but very little exploration work has been conducted over the last couple of decades. The sampling

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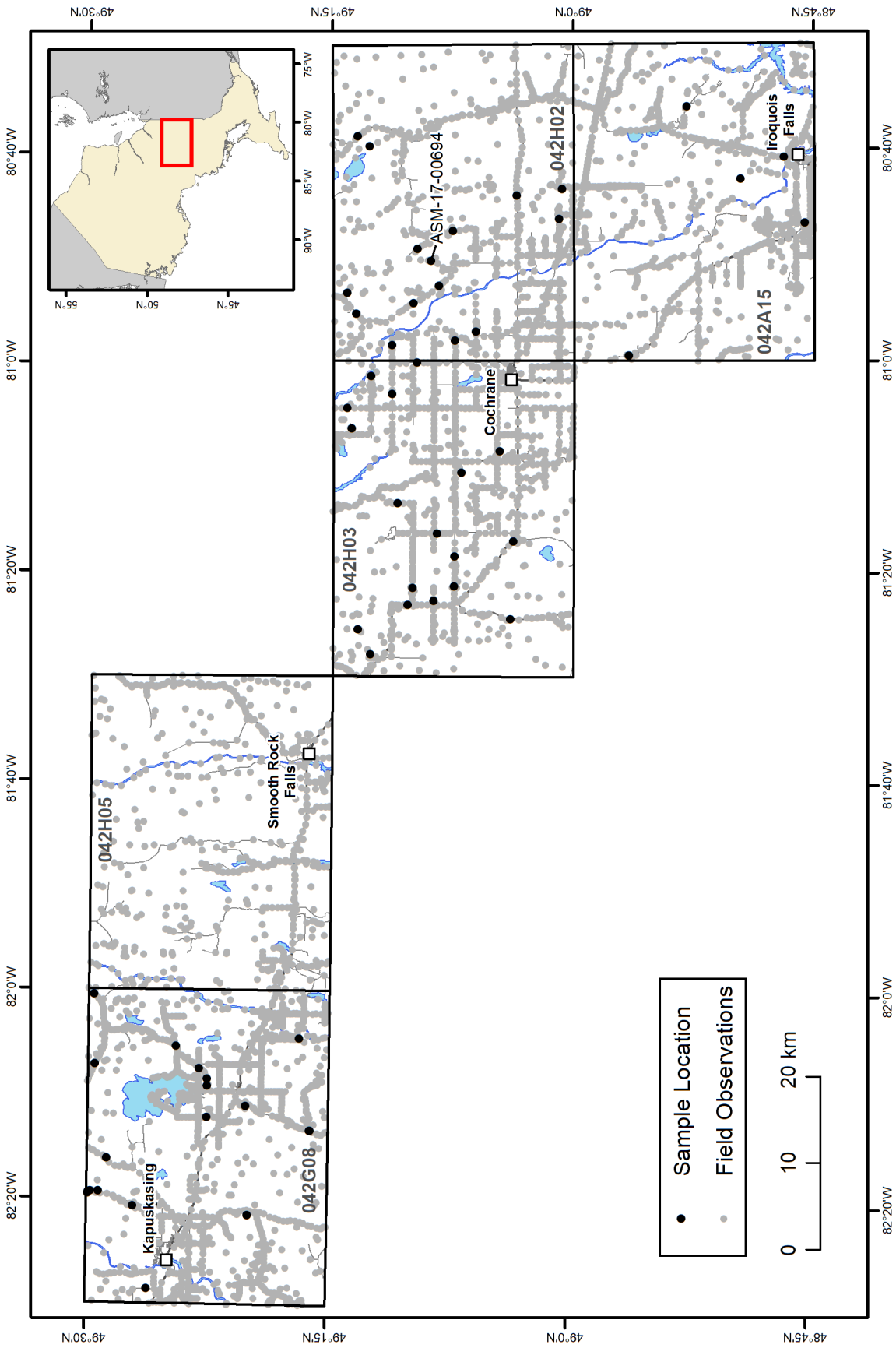

Figure 13.1. Study area location and locations of field observations and sampling conducted during the summers of 2016 to 2019.

conducted for this study has provided some additional data regarding geochemistry and heavy mineral content of tills in the region, which may be useful to the mineral exploration community. One sample site in particular returned gold results (mentioned herein) of possible exploration interest that may be worthy of follow up.

BEDROCK GEOLOGY

The bedrock geology of the study area is dominated by both supracrustal and intrusive suites and their gneissic and migmatized equivalents of Archean age. To the southeast, the study is underlain by parts of the Abitibi Subprovince, the Quetico Subprovince in the central part of the study area, and the Kapuskasing Structural Zone and the Wawa gneiss domain to the northwest. The oldest rocks in the region, located in the southern portions of the Cochrane and Abitibi map areas and throughout the Iroquois Falls map area, are Mesoarchean (3.2–2.8 Ga) metavolcanic rocks, consisting of dacite and andesitic flows, tuffs and breccias with minor chert and iron formation (Figure 13.2). The central part of the study area is underlain by highly metamorphosed metasedimentary rocks, consisting of paragneiss and migmatites, wacke, siltstone, arkose, slate, marble, chert and iron formation (Ontario Geological Survey 2011).

In the southeast corner of the Kapuskasing map area are migmatized supracrustal rocks, including metavolcanic rocks and lesser metasedimentary rocks as well as mafic gneisses. These rocks form part of the Kapuskasing Structural Zone, for which the eastern boundary is east of the Kapuskasing map area and the western boundary (which trends northeast) is located east of the town of Kapuskasing (Ontario Geological Survey 2011).

Locally, within the Cochrane map area and throughout much of the central Iroquois Falls map area, are massive granodioritic to granitic intrusive rocks. Archean mafic and ultramafic intrusive rocks are located to the southwest in the Cochrane map area and around the rim of massive granodioritic rocks in the Iroquois Falls map area (Ontario Geological Survey 2011) (*see* Figure 13.2).

QUATERNARY GEOLOGY

Glacial Deposits and Associated Landforms

A simple stratigraphic sequence was observed within the study area. Although each stratigraphic unit was not observed at every location, the relative position of these units with respect to one another did not change. The sequence is as follows (from oldest to youngest): 1) pre-Wisconsinan sediments, 2) Matheson Till, 3) ice-contact stratified deposits associated with Matheson Till, 4) Cochrane Till, 5) glaciolacustrine deposits and 6) non-glacial organic materials.

Sediments older than Wisconsinan age were not observed during this study, but have been described in the literature for this part of Ontario. These sediments were rarely encountered in a series of boreholes drilled from Timmins, to the east and north of Kapuskasing (Smith 1992). The older sediments that have been described include 3 tills interbedded with silt and sand overlain by an interglacial peat and organic-rich silt and clay (the Sangamonian Missinaibi Formation) (Skinner 1973; Smith 1992; Dubé-Loubert et al. 2013). The Missinaibi Formation is a significant regional interglacial marker that has been attributed to Marine Isotope Stage (MIS) 5e, approximately 130 000 to 115 000 years ago (e.g., Dalton et al. 2016).

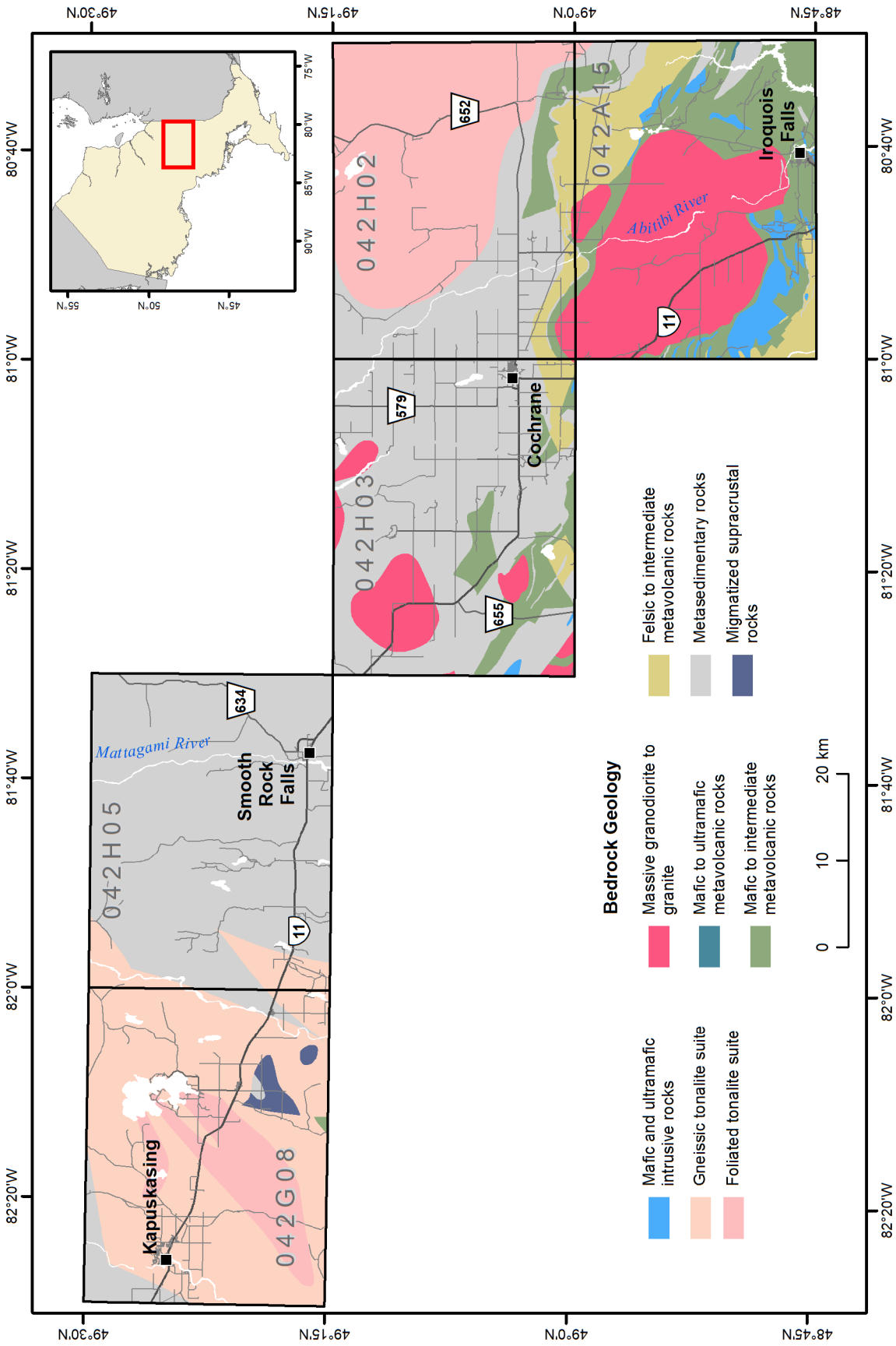

Figure 13.2. Bedrock geology of the Highway 11 corridor between Kapuskasing and Iroquois Falls (*modified from* Ontario Geological Survey 2011).

Table 13.1. Average content of various lithologies in the pebble fraction of the Matheson and Cochrane tills.

Material Type	Cochrane Till (n=35)	Matheson Till (n=12)
Intermediate to Felsic Intrusive Rocks (%)	6.3	32.2
Mafic Intrusive Rocks (%)	1.1	5.3
Intermediate to Felsic Volcanic Rocks (%)	0.9	0.0
Basalt (%)	7.6	9.4
Foliated Metamorphic Rocks (%)	1.3	0.0
Hornfels (%)	0.3	0.2
Quartz (%)	0.7	1.3
Carbonate (%)	50.8	19.0
Sandstone (%)	9.7	3.9
Fine-textured Sedimentary Rocks (%)	4.1	6.5
Chert (%)	0.6	0.0
Unknown (%)	2.5	3.3
Number of Pebbles	81	137

The oldest sedimentary unit observed within the study area is the Matheson Till. The till was observed at 12 locations, always to the south or southeast of a topographic high and sitting directly on bedrock. Matheson Till is a pale grey, silty sand diamicton with approximately 5 to 10% granule- to pebble-sized clasts, predominantly of Precambrian rock types (Table 13.1). Many clasts are striated, bulleted and/or faceted and are mostly subrounded. Matheson Till varies in thickness significantly throughout the region, but, within the study area, the maximum thickness observed was 2 m. A series of streamlined landforms in the southeast corner of the Kapuskasing map area are composed of reworked Matheson Till resulting from the ice movement responsible for the deposition of Cochrane Till (described below).

Ice-contact stratified deposits associated with Matheson Till have been identified throughout the study area. They are most commonly observed in a series of large and continuous esker systems that cross the study area and extend well south of it (Figure 13.3) (Marich 2019a, 2019b, 2019c, 2020a, 2020b). Sediment thickness within these eskers is 20 m or greater based on face heights in sand and gravel pits and are commonly draped with several metres of fine-textured glaciolacustrine sediments. The eskers consist primarily of variably textured sands with minor gravel. Gravel beds are commonly open work and range in grain size from granule to gravel to small boulders. Clasts are locally derived Precambrian lithologies, as well as far-travelled Paleozoic lithologies from the Hudson Bay Lowland. These include cobbles from the Proterozoic Omarolluk formation (omars), which are likely from the Belcher Islands in southern Hudson Bay. These dark grey greywacke cobbles contain deep circular cavities resulting from the preferential dissolution of carbonate concretions (Prest, Donaldson and Mooers 2000). Structures observed in the ice-contact stratified deposits include ripples, truncated laminae, heavy mineral accumulations at the base of ripples and some highly deformed sections. Subaqueous fans were also observed within the study area. Several of these occur along the length of esker ridges as broad bulbous mounds, marking stillstand positions of the retreating ice margin within the proglacial lake. A large subaqueous fan at least 3 km wide is located south of Remi Lake in the Kapuskasing map area.

The next sediment in the sequence is Cochrane Till. It is a fine-textured clayey silt diamicton, averaging 29% sand, 51% silt and 19% clay with minor (<5%) granule- to cobble-sized clasts. Clasts are predominantly of carbonate lithologies and are subangular and faceted (*see* Table 13.1). The till is commonly massive with some inclusions of undeformed silt and clay, although some blocky and fissile examples exist. The till owes its fine texture to the incorporation of large volumes of glaciolacustrine sediments during the advance of the ice sheet. On at least one, if not multiple, occasions, the Laurentide ice sheet surged into and south of the glacial Lake Barlow–Ojibway basin (e.g., Hughes 1965; Veillette 1994), disturbing and subsequently entraining glaciolacustrine sediments. Three facies of Cochrane Till were observed during this study: deformation till facies, lodgement till facies and subaquatic flow facies.

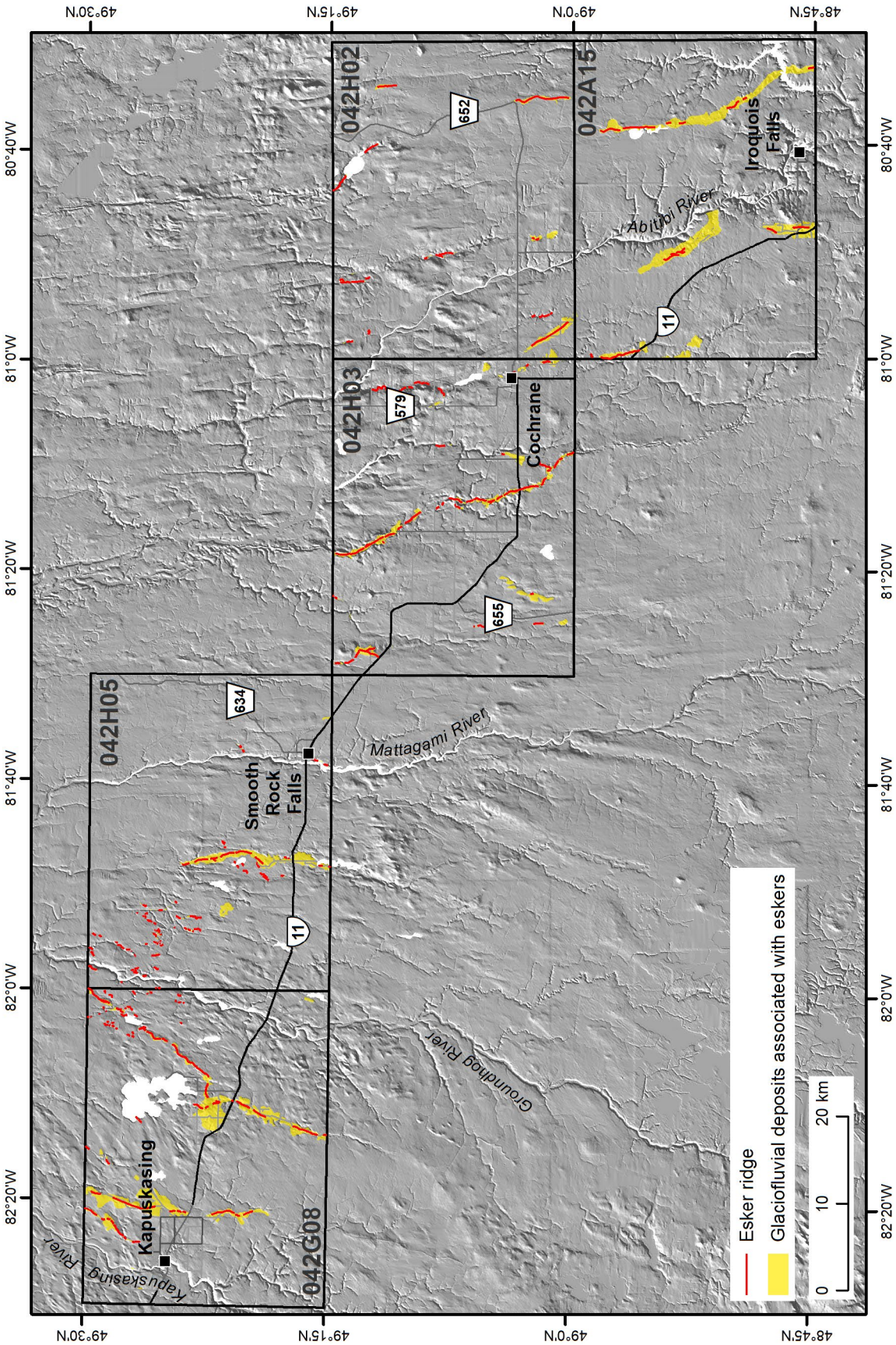

Figure 13.3. Image showing the locations of eskers identified within the study area. The high-resolution digital elevation surface (" hillshade") is based on Provincial digital elevation model data *from* Ministry of Natural Resources (2013).

The deformation facies is massive and structureless and is often difficult to distinguish from the associated glaciolacustrine sediments. Generally, the till is more massive and contains a greater number of clasts than the glaciolacustrine sediments. The lodgement till facies is found lower in the stratigraphic sequence and is compact, blocky and fissile. Finally, the subaquatic flow-till facies is softer than the other facies and contains silt and clay lenses, and minor silt caps, as well as ice-rafted debris. The Cochrane Till was observed most commonly at surface on topographic highs; elsewhere, it is capped with fine-textured glaciolacustrine sediments. The thickness of this unit may exceed 35 to 40 m in some locations, based on water-well records in the area.

Deep-water glaciolacustrine sediments, consisting of massive to laminated silt and clay, as well as varved sediments, occupy much of the Highway 11 corridor. These sediments are carbonate rich (effervesce with 10% HCl), and are often greater than 1 m thick and possibly up to 30 m thick (based on water-well records). Varved silts and clays were observed throughout the study area and are commonly interbedded with massive clayey silt to silty clay. The varves consist of distinct dark grey clay (winter) beds and pale tan silt (summer) beds (Photo 13.1). Varve couplets vary in thickness from 0.5 cm to greater than 5 cm, and a maximum of 25 couplets were counted at any sample location. The thickness of these couplets varies across the study area. The varve couplets tend to thin upward indicating a decrease in sedimentation resulting from a retreating ice margin during their cycle of deposition (e.g., Stroup, Lowell and Breckenridge 2013). Thin beds of ice-rafted debris were commonly observed and, within these beds, red granules were regularly observed. It is suggested that these granules are derived from the Silurian Kenogami River Formation, a red mudstone that crops out approximately 250 km directly north along the Albany River (Bajc, Lee and Yeung 2014; Gao, Lee and Yeung 2015). Iceberg keel marks are the dominant landform associated with glaciolacustrine sediments in the region. Thousands of these features were identified on LiDAR DEMs and they occur throughout the study area cutting into surface materials in great swaths. These linear depressions on the land surface are a result of grounded icebergs being pushed along the lakebed by prevailing winds (Photo 13.2). These features vary in length and width, with widths ranging from a couple of metres to approximately a half kilometre, and lengths ranging from several metres to several kilometres. It is common for iceberg keel marks to dramatically change orientation along their lengths. This occurs with shifts in wind direction and when an iceberg is deflected off a topographic high and continues to cut into the surface sediments. The orientation of keel marks can appear random upon initial observation, but, regionally, their predominant direction is to the southeast, suggesting a prevailing northwesterly wind direction. This wind direction is reflected in the orientation of parabolic dunes located to the east of the study area within the Burntbush area (Gao 2013) and to the south near Timmins (Boissonneau 1965, 1966.)

Peat, with varying degrees of decomposition, has been observed throughout the study. Since much of northeastern Ontario is flat, low lying, and most of the overlying sediment is fine textured, wetlands occupy a large proportion of the study area. These wetlands are dominated by open low shrub bogs with an abundance of moss (Geo-analysis Ltd. 1986). Peat thicknesses range between 0 and greater than 6 m.

Glacial History

The landscape and surficial sediments of northeastern Ontario are a direct result of glacial and deglacial events. The oldest deposits are generally of a pre–Late Wisconsinan age. The series of 3 tills interbedded with sands may be associated with a fluctuating Illinois Episode ice sheet (Skinner 1973). Following this glaciation was an ice-free period in which the Missinaibi Formation as deposited (approximately 130 000 to 71 000 years ago) (Skinner 1973; Dalton et al. 2016). Organic deposits are commonly found underlying till of the Hudson Bay Lowland. Most have ages older than 50 000 years old. Recent studies suggest there may have been a second ice-free period during MIS 3 (29 000 to 57 000 years ago), but additional work is required to constrain the timing of this event because it would require a significant adjustment to the ice margin which is not currently supported by the deep-sea isotope records.

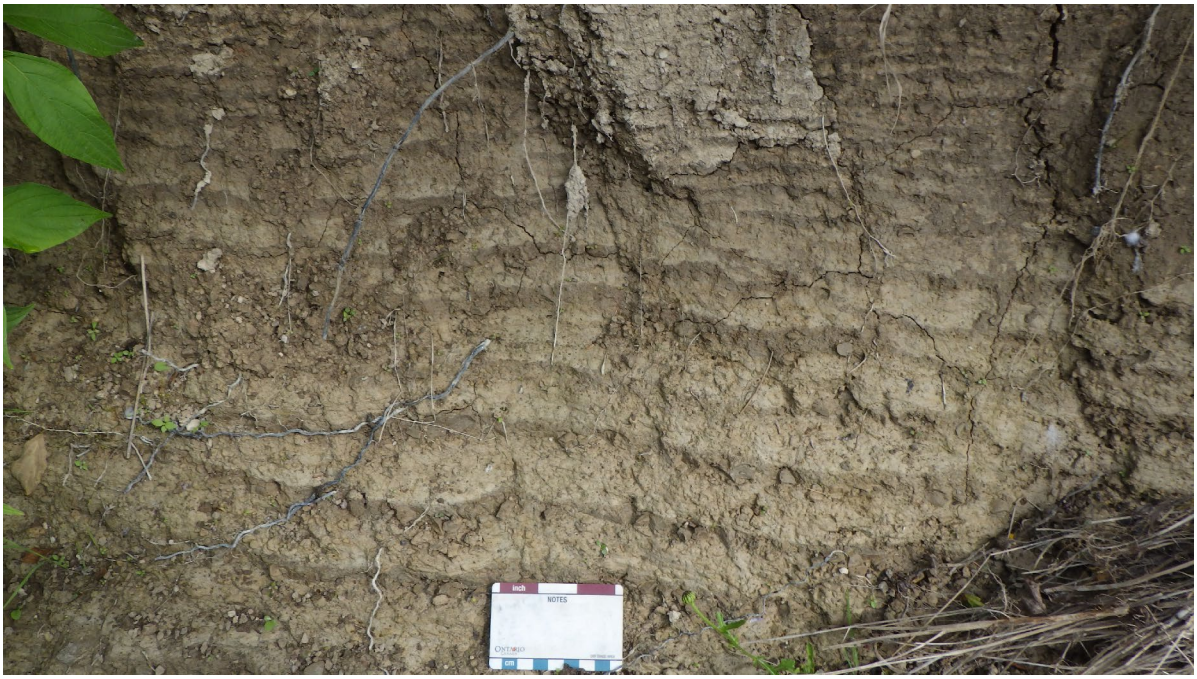

Photo 13.1. Varves: dark grey clay (winter beds) and pale tan silt (summer beds) located in a ditch southeast of Moonbeam.

Photo 13.2. Subaerial photograph showing intersecting iceberg keel marks now occupied by a meandering stream, southeast of Kapuskasing.

Wisconsinan-age glacial events are well documented in the region and several ice-flow events and glacial lake stages have been identified (e.g., Hughes 1965; Boissonneau 1966; Veillette 1994; Smith 1992; Evans 2011). At the last glacial maximum (25 000 years ago), glacial ice extended well south of the study area into the northern United States. Retreat began in northeastern Ontario approximately 10 000 years ago (Breckenridge et al 2012; Dyke 2004). Prior to this initial retreat stage, Matheson Till was deposited. As the ice began to retreat from the area, the large esker systems traversing the study area formed (Boissonneau 1966). Initially, glacial Lake Barlow formed in the southern part of the Hudson Bay watershed followed by the development of glacial Lake Ojibway to the north of glacial Lake Barlow and the 2 lakes coalesced after the ice had retreated well to the north (Veillette 1994).

The resulting glacial Lake Barlow–Ojibway occupied an area greater than 230 000 km^2 (e.g., Agterberg and Banerjee 1969). Varve chronologies indicate that the large lake existed for approximately 2110 years (Breckenridge et al 2012; Hughes 1965; Hardy 1976; Antevs 1925). The ice front continued to retreat northward until it reached the Pinard moraine and glacial Lake Barlow–Ojibway expanded to well north of the study area. The timing of this ice retreat and the following events is unclear. It has been proposed that several cycles of advance and retreat of the ice margin into the proglacial lake occurred (the Cochrane readvances).

The final retreat and break up of ice out of the study area occurred around 8470 years ago (Andrews, Shilts and Miller 1983; Roy et al. 2011) based on radiocarbon analyses of marine shells overlying the youngest glaciolacustrine sediments. The Tyrell Sea expanded into northern Ontario because there was no longer ice to act as a dam against flow of water from Hudson Bay into the isostatically depressed Barlow–Ojibway basin. It is thought that the final drainage of glacial Lake Barlow–Ojibway occurred catastrophically after an ice dam failed to the north in the vicinity of James Bay. An estimated volume of 114 000 km^3 of cold fresh water from the coalesced glacial Lake Agassiz and glacial Lake Barlow–Ojibway basin was discharged into the Tyrell Sea, raising sea level by 30 cm (Veillette 1994). This discharge has been proposed as a trigger for the 8200 cal yr BP climate event (Barber et al. 1999; Bauer, Ganopolski and Montaya 2004; Alley and Agustsdottir 2005), which resulted in a decrease in global temperatures for several centuries.

APPLIED QUATERNARY GEOLOGY

The thick sequences of drift (particularly clay) within the study area has hindered mineral exploration, therefore, the region is largely underexplored for mineral potential. A fulsome assessment of mineral potential utilizing glacial drift methods was beyond the scope of this study. The work required to fully assess the possible mineral deposits in the area would include a systematic drift prospecting program, including reverse circulation drilling (>5 m drift) or trenching (<5 m drift) to target the older tills, in particular, Matheson Till. The Matheson Till is locally derived and was developed from glacial scouring of bedrock and, therefore, can more reliably reflect the composition of the underlying (and up-ice direction) bedrock. The younger Cochrane Till (developed from glacier ice scouring a landscape of drift materials, including lake clays) and esker sands have much broader source areas that limit their usefulness for backtracking to potential bedrock sources. The last flow directions of ice depositing the Matheson Till were south and southeast, therefore, drift prospecting activities should look to the north and northwest of the samples containing the highest analytical values.

As part of this study, Matheson Till and esker sand samples were analyzed for gold grain counts, metamorphic/magmatic sulphide indictor mineral (MMSIMs[1]), and kimberlite indicator mineral (KIMs) grains. Matheson Till and Cochrane Till were analyzed for major and trace element geochemistry. The results were plotted and samples with relatively higher values for each analyte were identified

[1] *MMSIM is a registered trademark of Overburden Drilling Management Limited, Nepean, Ontario.*

(Marich, in press-a, in press-b). The significance of the relatively higher concentrations is uncertain, but may be helpful if combined with other lines of evidence, such as the results of modern alluvium sampling undertaken by the OGS in the early 2000s (Ontario Geological Survey 2001a, 2001b).

Despite the limited geochemical data set for this study, perhaps the most compelling results worthy of follow-up consideration is for the area in the vicinity of sample ASM-17-0694 within the northeast quadrant of the Abitibi map area (*see* Figure 13.1). This sample returned relatively high gold and base metal pathfinder concentrations and was notable with respect to gold grains, MMSIMs and KIMs. The complete set of results and a more detailed interpretation will be available in 2 forthcoming publications (Marich, in press-b, in press-a, respectively).

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