NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

# Phase 1 Geoscientific Desktop Preliminary Assessment, Processing and Interpretation of Geophysical Data

**TOWNSHIP OF EAR FALLS, ONTARIO**

**APM-REP-06144-0021**

**NOVEMBER 2013**

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*ADVANCED GEOPHYSICAL INTERPRETATION CENTRE*

**PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT**

# PROCESSING AND INTERPRETATION OF GEOPHYSICAL DATA

## Township of Ear Falls, Ontario

**Prepared for**

**Golder Associates Ltd.**

**and**

**Nuclear Waste Management Organization (NWMO)**

**By**

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NWMO Report Number: APM- REP-06144-0021

**Vancouver, Canada** **November, 2013**

## EXECUTIVE SUMMARY


In February, 2012 the Township of Ear Falls, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Ear Falls area for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process.

The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated report (NWMO, 2013). The objective of the desktop geoscientific preliminary assessment is to determine whether the Township of Ear Falls and its periphery, referred to as the “Ear Falls area”, contain general areas that have the potential to meet NWMO’s geoscientific site evaluation factors.

This report presents the findings of a geophysical data interpretation assessment completed as part of the desktop geoscientific preliminary assessment of the Ear Falls area (Golder, 2013). The purpose of this study was to perform a detailed interpretation of all available geophysical data (e.g., magnetic, electromagnetic, gravity and radiometric) for the Ear Falls area, Ontario. The aim is to identify additional information that can be extracted from the data, particular that relating to the coincidence of geophysical features with mapped lithology and structural features in the Ear Falls area.

Low to moderate resolution geophysical data (magnetic, radiometric, and gravity) are available for the entire Ear Falls area. Additional magnetic/electromagnetic surveys provided higher resolution coverage over 11.5% of the Ear Falls area (north central portion). One seismic line and two magnetotelluric stations from the Lithoprobe program are also available in the Ear Falls area. Additional magnetic data were found in the AFRI database in the form of raster maps, and the raster dataset for the Goldpines South Property (Laurentian Goldfields Ltd., 2010) were used in this review.

The coincidence between the geophysical data and mapped lithology and structural features was interpreted using all the available geophysical data sets (e.g., magnetic, electromagnetic, gravity and radiometric). In particular, the pole reduced magnetic field (RTP) and its first vertical derivative (1VD) were found to be the most reliable for mapping variations in geological contacts, and identifying heterogeneity and foliation.

The coincidence between the geophysical interpretations and the published geological maps is relatively good for some of the intrusions in the Ear Falls area, such as the Bluffy Lake batholith and the Bruce Lake pluton. However, the lack of magnetic contrast between some of the

intrusions (e.g. Wenasaga Lake batholith) and the surrounding metasedimentary rocks makes it difficult to distinguish the contact between these geologic units. Also, while the aeromagnetic data shows a generally subdued response over large areas of the English River metasedimentary belt, several extremely high magnetic responses are seen as anomalies with sharp contacts that coincide with iron formations within the metasedimentary rocks.

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| | |
|---|---|
| 1VD | First Vertical Derivative |
| AFRI | Assessment File Research Imaging |
| AGIC | Advanced Geophysical Interpretation Centre |
| amsl | above mean sea level |
| AS | Analytic Signal |
| BA | Bouguer Anomaly |
| CGDB | Canadian Gravity Database |
| DAP | Geosoft server technology for distributing data |
| EM | Electromagnetic |
| eU | Equivalent Uranium |
| eTh | Equivalent Thorium |
| FA | Free Air |
| FDEM | Frequency Domain Electromagnetic |
| Ga | Billions of Years |
| GDAL | Geospatial data abstraction library |
| GRS80 | Geodetic Reference ellipsoid 1980 |
| GSC | Geological Survey of Canada |
| Hz | SI unit cycles per second |
| IAG | International Association of Geodesy |
| K | Potassium |
| Ka | Thousands of Years |
| L | Litre - SI unit of volume |
| m | Metre - SI unit of length |
| Ma | Millions of Years |
| Mira | Mira Geoscience Ltd. |
| Moho | Mohorovicic Discontinuity |
| mGal | milli-Gal |
| MNDM | Ontario’s Ministry of Northern Development and Mines |
| n/a | not applicable |
| nGy/h | nano Grays per hour (SI derived unit of absorbed dose) |
| NAD83 | North American Datum 1983 |
| NOEGTS | Northern Ontario Engineering Geology Terrain Study |
| NRCan | Natural Resources of Canada |
| nT | Nanotesla - Magnetic Field Strength |
| NWMO | Nuclear Waste Management Organization |
| OGS | Ontario Geological Survey |
| ppm | parts per million concentration |
| RMI | Residual Magnetic Intensity |
| RMF | Reduced Magnetic Field |
| RTP | Reduced to pole (magnetic data) |
| SRK | SRK Consulting (Canada) Inc. |
| TDEM | Time Domain Electromagnetic |
| TMI | Total Magnetic Intensity |

| | |
|---|---|
| TMF | Total Magnetic Field |
| UTM | Universal Transverse Mercator projection |
| VLF EM | Very Low Frequency Electromagnetic |
| 3D | 3-dimensional |

# 1 INTRODUCTION

In February, 2012 the Township of Ear Falls, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process (NWMO, 2010) and requested that a preliminary assessment be conducted to assess potential suitability of the Ear Falls area for safely hosting a deep geological repository (Step 3). The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations (NWMO, 2013).

This report presents the findings of a geophysical data processing and interpretation assessment completed as part of the desktop geoscientific preliminary assessment of the Ear Falls area (Golder, 2013). The objective of the desktop geoscientific preliminary assessment is to determine whether the Ear Falls area contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors. The assessment focused on the Township of Ear Falls and its periphery, referred to throughout the report as the "Ear Falls area".

## 1.1 Study Objective

Geophysical data represents an important source of information for assessing a region for its potential suitability to host a deep geological repository, and to assist in the identification of general potentially suitable areas.

The purpose of this assessment was to perform a review of available geophysical data for the Ear Falls area, followed by a detailed interpretation of all available geophysical datasets (e.g., magnetic, gravity, electromagnetic, magnetotelluric, seismic and radiometric) to identify additional information that could be extracted from the data, in particular regarding the coincidence of geophysical units with mapped lithology and structural features in the Ear Falls area.

The primary role of geophysics is to extrapolate the surface analysis derived from geological maps, topography and satellite imagery into the subsurface. Boreholes, wells and other underground information may be available at individual points to supplement geological data acquired on surface. However, where these individual data points are limited (or unavailable), such as for the Ear Falls area, the critical advantage of airborne and ground geophysical data are that it provides a basis for interpreting the subsurface physical properties across the area. This is particularly important in areas where bedrock exposure is limited by surface water bodies and/or overburden cover (i.e., glacial sediments), as it occurs in parts of the Ear Falls area where numerous lakes are present. A secondary role of geophysics is that it often elucidates certain characteristics of geological formations and structures that may not be easily discerned from surface mapping and analysis. Thirdly, it highlights tectonic and regional-scale features that may not be easily extracted from studies of a particular area on a more detailed scale.

### 1.2 Ear Falls Area

The Township of Ear Falls is approximately 350 km² in size, situated in the District of Kenora in northwestern Ontario (MMAH, 2004). The settlement area is shown on Figure 1 at the northwestern end of Lac Seul, approximately 98 km northwest of Vermillion Bay and 65 km southeast of Red Lake. The Ear Falls area is approximately 3,688 km2 in size (Figure 1).

### 1.3 Qualifications of Geophysical Interpretation Team

The team responsible for the geophysical review, processing and interpretation investigation component of the Phase 1 – Geoscientific Preliminary Assessment of Potential Suitability study for the Ear Falls area consisted of qualified experts from Mira Geoscience Ltd. (Mira). The personnel assigned to this study were as follows.

**Thomas Campagne**, M.Sc. Geophysics is a consultant with the Advanced Geophysical Interpretation Centre (AGIC) at Mira Geoscience. Thomas has a Bachelor degree in Geosciences from the University of Strasbourg, France, and a Master/Engineering degree in Geophysics from the School of Engineering Geophysics within the Department of Earth Sciences of the University of Strasbourg, France. Thomas has worked as an undergrad geophysicist for Southern Geoscience Consultants in Perth, Australia, and as a project geophysicist for S.J.V. Consultants in Delta, Canada, prior to joining Mira Geoscience in May 2011. Thomas brings strong international experience, with specialization in geophysical modelling and inversions, focused on constrained inversions of potential field, electrical, and EM methods. He is part of a team of consultants whose experience ranges from modelling and interpretation of airborne gravity and magnetic data for large scale basin modelling studies, to integrated deposit targeting based on electrical, MT, and magnetic modelling, to environmental and geotechnical applications. Thomas is fluent in spoken and written French and English.

**Nigel Phillips**, M.Sc. Geophysics is a Senior Geophysicist and Manager of the Advanced Geophysical Interpretation Centre (AGIC) at Mira Geoscience in Vancouver, Canada. Nigel is focused on advancing the effectiveness of geophysics by specializing in the advanced processing and modelling of geophysical data to produce integrated solutions. He has over 15 years of experience in mineral exploration and in many different exploration environments, his background ranges from field safety, acquisition, and logistics, to the development of data processing, modelling techniques, and software, to the communication of concepts and results through reports, publications, talks, and training. At AGIC, Nigel manages a group of highly skilled geophysicists providing specialized geophysical solutions to the mining industry.

**Peter Kowalczyk**, P.Geo. is a Principal Consultant in Exploration Geophysics. Peter joined Mira Geoscience from Barrick Gold. Prior to Barrick purchasing Placer Dome, Peter was chief geophysicist for Placer Dome Inc. He joined Placer Dome in 1970 and has worked in porphyry copper, uranium, base metal and gold exploration. Peter coordinated Placer's geophysical research and was deeply involved in the introduction and implementation of digital processing, visualization and geophysical inversion methods in exploration at Placer. As chief geophysicist Peter worked with exploration, mine operations, academic research and government groups world-wide. Although an exploration generalist, he has particular experience in the processing and interpretation of electrical data. Peter graduated from UBC with a B.Sc. (geophysics) and is a registered geophysicist in British Columbia. He is currently associated with Ocean Floor Geophysics and Geoscience British Columbia.

# 2 SUMMARY OF PHYSICAL GEOGRAPHY AND GEOLOGY

A detailed discussion of the geological setting of the Ear Falls area, including bedrock geology and structural history, is provided in a separate report (Golder, 2013), and a summary is presented below.

The Township of Ear Falls is situated mainly within the English River Subprovince. The English River Subprovince is an east-west trending, 30 to 100 km wide by 650 km long belt of metasedimentary and metamorphosed intrusive rocks extending from Manitoba to the Moose River Basin in the James Bay Lowlands. The English River Subprovince is bordered to the north by the Uchi Subprovince and, in the Ear Falls area, by the Winnipeg River Subprovince to the south.

The Uchi Subprovince is a relatively narrow, east-west trending region dominated by belts of metasedimentary and metavolcanic rocks that interweave intrusive complexes up to 3 billion years old (Stott and Corfu, 1991).

The Winnipeg River Subprovince is a terrane more than 500 km long and composed of Mesoarchean metaplutonic rocks variably intruded by Neoarchean plutons (Beakhouse, 1991).

The northern part of the Ear Falls area is within the Uchi Subprovince, while the southern limit falls within the Winnipeg River Subprovince. Provincial-scale mapping by Percival and Easton (2007) and Stott et al. (2010) place the boundary between the English River Subprovince and the Winnipeg River Subprovince to be south of the Township of Ear Falls, although the contact between the two subprovinces is not sharply defined by any specific mappable geological feature.

## 2.1 Physical Geography

The physical geography of the Ear Falls area is described in detail in JDMA (2013). A summary of the main features is provided here for reference. The Township of Ear Falls is situated in the District of Kenora in northwestern Ontario, at the northwestern end of Lac Seul, as shown on

Figure 1. The Township of Ear Falls is located approximately 98 km northwest of Vermilion Bay, and approximately 65 km southeast of Red Lake and covers approximately 350 km2 (Ear Falls Official Plan, 2004).

The Township of Ear Falls is located in the Canadian Shield physiographic region, a low-relief, dome-like, gently undulating land surface with an elevation range within the physiographic region of about 150 metres above sea level (masl) in the north, increasing to about 450 masl towards the south.

The Township of Ear Falls lies within the Severn Uplands, a broadly rolling surface of Precambrian bedrock that occupies most of northwestern Ontario and which is either exposed at surface or shallowly covered with Quaternary glacial deposits.

The land surface elevation within the Ear Falls area ranges from a low of about 316 m at the shores of Oak Lake in the southwest to a high of 452 m on a hill about 8 km south of Celt Lake. The northern part of the Township of Ear Falls is an area of low relief dominated by Bruce and Pakwash lakes and their associated watercourses. In the central portion of the Township, there is an area of high relief that trends roughly east-northeast to west-southwest. Further to the south, the topography is still moderately high, although the terrain has been eroded in places by tributaries of the Chukuni River. Surface topography is also high at the southernmost end of the Township of Ear Falls, in the immediate vicinity of the settlement area of Ear Falls. The southwest boundary of the Township is dominated by the low topography of the Chukuni and English rivers, which partially form the Township's boundary. At the periphery of the Township of Ear Falls, higher elevations are identified mostly to the east.

The north-south trending Lac Seul moraine is a dominant topographic feature in the Ear Falls area and represents the western extent of glacial ice during a re-advance of the Hudson Bay ice lobe, approximately 9,900 years ago (Teller, 1985). The moraine passes immediately to the east of the settlement area of Ear Falls in a north-south orientation and extends north and south of the Township.

The Township of Ear Falls is located within the English River watershed, which is in turn part of the Winnipeg River sub-basin, which drains into the Nelson River basin, and eventually, Hudson Bay (Lake of the Woods Control Board, 2010). Surface water generally flows through the Township of Ear Falls from the north and east, to the southwest. At the northeast corner of the Township, the Trout Lake River flows into Bruce Lake from the northeast and then into Pakwash Lake to the west. The outflow of Pakwash Lake is the Chukuni River, which flows to the south along the southwestern township boundary, where it joins the English River. The English River is the outflow from Lac Seul and it exits the lake at the southeast corner of the Township of Ear Falls. Water levels in Lac Seul are controlled by a hydroelectric dam operated by Ontario Power Generation. The English River flows to the west, to where it joins the Chukuni River and then flows south into Camping Lake, and further to the southwest, where it is joined by the Wabigoon River, eventually joining the Winnipeg River.

## 2.2 Bedrock Geology

### 2.2.1 Gneissic metasedimentary rocks of the English River Subprovince

The Ear Falls area is dominated by gneissic metasedimentary rocks of the English River Subprovince formed as a result of high-grade metamorphism of sedimentary rocks deposited between approximately 2.704 and 2.696 billion years ago (Sanborn-Barrie et al., 2004) in a foreland sedimentary setting (van de Kamp and Beakhouse, 1979; Breaks, 1991; Breaks and Bond, 1993). The generation of migmatites is attributed to low to medium pressure, high-temperature metamorphism that occurred at approximately 2.691 billion years ago (Corfu et al., 1995). The sedimentary protoliths have been interpreted as being mainly greywacke and mudstone/shale derived from reworked volcanic source rocks within the Uchi Subprovince (Breaks and Bond, 1993). In a small sector of the Township of Ear Falls, between the Bruce Lake and Pakwash Lake plutons, metasedimentary rocks also comprise chert-magnetite ironstone (Sanborn-Barrie et al., 2004). Along the western shore of Bruce Lake, the metasedimentary rocks include an 80 m thick banded iron formation (Griffith deposit). Metavolcanic rocks are not common, accounting for only about 2 % of the English River Subprovince.

Nitescu et al. (2006) infer that the metasedimentary rocks are on the order of less than 1 km thick where they are underlain by intrusions, and up to 4 km thick, where they are not. These depth estimates are based on the integration of surface geologic mapping with gravity and magnetic data, and Lithoprobe seismic data.

## 2.3 Plutonic Rocks

Five large plutonic bodies occur within the Ear Falls area: the Wenasaga Lake batholith, the Bruce Lake pluton, the Bluffy Lake batholith, the Wapesi Lake batholith, and the Pakwash Lake pluton (Figure 2). Other smaller granitic and tonalitic intrusions are mapped in the southern portion of the Ear Falls area.

The Wenasaga Lake batholith is estimated to be of a similar age to the surrounding metasedimentary rocks, between approximately 2.700 and 2.691 billion years old (Breaks, 1991; Nitescu et al., 2006). It consists of a peraluminous granite mass approximately 7 km wide by 26 km long that likely formed by the partial melting of the sedimentary host rock in conjunction with local injections of fresh magma (Breaks, 1991). The Wenasaga Lake batholith is well exposed in a blast cut along the former Griffith iron mine rail line near Detector Lake (Breaks et al., 2003). At this location, biotite-muscovite pegmatitic leucogranite grades into a biotite-rich granite containing inclusions of metasedimentary gneiss incorporated from the surrounding country rock. The Wenasaga Lake batholith has been examined for potential linkage with a metasedimentary-hosted, rare-element pegmatite mineralization (the Sandy Creek beryl deposit) located adjacent to the southwestern flank of the batholith (Breaks et al., 2003). The gravity field over the Wenasaga Lake batholith exhibits a slight negative response contrasting with the surrounding country rock suggesting that the batholith extends to substantial depth.

The Bruce Lake pluton, which covers approximately 200 km$^2$, intrudes clastic metasedimentary rocks near the contact between the Uchi and English River subprovinces. The presence of at least one schistosity pre-dating the Bruce Lake pluton in the metasedimentary rocks around the intrusion (Shklanka, 1970), and the timing of the regional deformation described by Breaks (1991) and Stott and Corfu (1991), suggests emplacement between approximately 2.690 and 2.670 billion years ago. The Bruce Lake pluton is composed of various phases including biotite-hornblende-bearing diorite, quartz diorite, monzodiorite, and gabbro. Enclaves of metasedimentary and metavolcanic rocks, including mafic metavolcanic rocks and hornblendite, commonly occur within the pluton (Breaks and Bond, 1993; Sanborn-Barrie et al., 2004). Enclaves of intermediate metavolcanic rocks, trondhjemite, or quartz-diorite also occur but are not common. The gravity field shows no discernible response to the Bruce Lake pluton and cannot be differentiated from the regional trend. Therefore, the thickness of the Bruce Lake pluton is unknown.

The approximately 2.698 billion years old Bluffy Lake batholith (Corfu et al., 1995) is located approximately 12 km east of the Township of Ear Falls and has a surface extension of approximately 705 km$^2$. The Bluffy Lake batholith is an intrusive complex composed of several units, with composition ranging from trondhjemite to quartz-diorite, and textures ranging from massive to foliated and locally exhibits a gneissic texture. Contacts with the metasedimentary rocks are typically sharp (Breaks, 1991). Breaks and Bond (1993) noted that heterogeneous, multicyclic intrusions and intrusive complexes are mainly found in the Winnipeg River Subprovince and that the Bluffy Lake batholith is an example of these in the English River Subprovince. The Bluffy Lake batholith shows a slight negative gravity response relative to the surrounding rocks within the Ear Falls area. Based on available gravity data, Gupta and Wadge (1986) suggest a sheet thickness of 1.5 to 3 km for the Bluffy Lake batholith.

The Wapesi Lake batholith covers an area of approximately 635 km$^2$, though only a portion of the batholith (approximately 50 km$^2$) occurs within the extreme southeast of the Ear Falls area. Breaks and Bond (1993) describe the batholith as a southwesterly-tapering massive, coarse-grained to pegmatitic muscovite-biotite and biotite-muscovite quartz-monzonite diatexite, and suggest that the batholith is the result of anatectic melting of the metasedimentary country rock. The age of the Wapesi Lake batholith is reported by Breaks (1991) as between approximately 2.692 and 2.668 billion years old. No information regarding the thickness of the Wapesi Lake batholith has been found in the available literature.

Several small elongated granitic bodies are mapped along the Sydney Lake fault zone and a number of elliptical 4 to 6 km long granitic bodies are mapped within the gneissic rocks south of Ear Falls and between Ear Falls and Manitou Falls (Figure 2). For example, the Pakwash Lake pluton is relatively small (10 km$^2$) and is located in the northwestern section of the Township of Ear Falls (mostly beneath Pakwash Lake). The Pakwash Lake pluton is similar in mineralogy to the Bruce Lake pluton, with composition ranging from quartz-diorite to diorite. Compared to the Bruce Lake pluton, the Pakwash pluton has less quartz and more mafic minerals. Shklanka (1970) suggests a common parentage and contemporaneous age for the Bruce Lake and Pakwash

Lake plutons based on their mineralogical similarities. The smaller bodies are concordant to the ductile fabric of the gneissic belt and may have been generated during the migmatization of the surrounding sedimentary rocks. An unnamed granitic pluton is present in the extreme southeast portion of the Ear Falls area within rocks belonging to the Winnipeg River Subprovince. No information on the thickness of these smaller intrusive bodies was found in the literature. Other relatively large intrusive bodies occur in the northwestern and southwestern parts of the Ear Falls area, and are documented as tonalite to diorite and tonalite to granodiorite, respectively (Sanborn-Barrie et al., 2004).

### 2.3.1 Mafic Dykes

A series of Proterozoic mafic dykes crosscuts all earlier rock types in the areas bordering the Ear Falls area. Such dykes have not been identified nor mapped within the Ear Falls area. However, mafic dykes referred to as the "Ear Falls dykes" were documented at the former Griffith mine. While there is evidence of Mesozoic-age emplacement of kimberlitic pipes and dykes elsewhere in northern Ontario, no post-Precambrian rocks are known to be present within the Ear Falls area (Stott and Josey, 2009).

### 2.3.2 Faults and Shear Zones

Two km-scale east-trending shear zones have been mapped within the Ear Falls area: the Sydney Lake fault zone and the Long Legged Lake fault zone (Figure 2). The Sydney Lake fault is 0.5 to 2 km wide (Bethune et al., 2006) and separates the metavolcanic and felsic plutonic rocks of the Uchi Subprovince to the north from the migmatized metasedimentary rocks of the English River Subprovince to the south. Displacement along the Sydney Lake fault is interpreted to have evolved from reverse (south over north) motion to dextral motion. The displacement magnitude of the dextral component is estimated to vary from 6 km (Stott and Corfu, 1991) to 30 km (Stone, 1981) along strike, whereas the displacement magnitude of the reverse component is estimated to be between 2 and 3 km (Stott and Corfu, 1991; Corfu et al., 1995). The Long Legged Lake fault runs along the northeast margin of the Bruce Lake pluton (Figure 2) and is interpreted to be related to the Sydney Lake fault. Cataclastic textures are superimposed on mylonitic textures indicating that brittle deformation followed ductile deformation (Stone, 1981).

### 2.3.3 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in a few publications since the 1970s, including Fraser and Heywood, (1978); Kraus and Menard (1997); Menard and Gordon (1997); Berman et al. (2000); Easton (2000a and 2000b) and Berman et al. (2005). The thermochronologic record for major parts of the Canadian Shield are given in a number of studies such as those by Berman et al. (2005), Bleeker and Hall (2007), Corrigan et al. (2007), and Pease et al. (2008).

The Superior Province largely preserves low to medium pressure –high temperature Neoarchean metamorphism from approximately 2.710 to 2.640 billion years ago, but there is a widespread tectonothermal overprint of Archean crust by Paleoproterozoic deformation and typically amphibolite facies metamorphism across the Churchill Province through northernmost Ontario under the northern Hudson Bay lowland, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski et al., 2002; Berman et al., 2005).

In the Archean Superior Province, the relative timing and grade of regional metamorphism corresponds to the lithologic composition of the subprovinces (Easton, 2000a; Percival et al., 2006). Granite-greenstone subprovinces contain the oldest, Neoarchean metamorphism of lower greenschist to amphibolite facies in volcano-sedimentary assemblages and synvolcanic to syntectonic plutons. Both metasedimentary and associated migmatite-dominated subprovinces, such as the English River and Quetico subprovinces, and dominantly plutonic and orthogneissic subprovinces, such as the Winnipeg River Subprovince, display younger, syntectonic middle amphibolite to granulite facies metamorphism (Breaks and Bond, 1993; Corfu et al., 1995).

Sub-greenschist facies metamorphism in the Superior Province is restricted to limited areas, notably within the central Abitibi greenstone belt (e.g., Jolly, 1978; Powell et al., 1993) and locally within the Uchi Subprovince (Thurston and Paktunc, 1985). Most late orogenic shear zones in the Superior Province experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through $^{40}Ar/^{39}Ar$ dating to approximately 2.500 billion years ago (Powell et al., 1995). The distribution of contrasting grades of metamorphism is a consequence of relative uplift, block rotation and erosion from Neoarchean orogenesis and subsequent local Proterozoic orogenic events and broader epeirogeny during Proterozoic and Phanerozoic eons. In northwestern Ontario, the concurrent post-Archean effects are limited to poorly documented reactivation along faulted Archean terrane boundaries (e.g., Kamineni et al., 1990 and references therein).

Overall, most of the Canadian Shield, outside of unmetamorphosed late tectonic plutons, contains a complex episodic history of tectonometamorphism largely of Neoarchean age with broad tectonothermal overprints of Paleoproterozoic age around the Superior Province and culminating at the end of the Grenville Orogeny approximately 950 million years ago.

Major regional deformation and metamorphism within the English River Subprovince culminated approximately 2.691 billion years ago with two later episodes of metamorphism and pegmatite emplacement approximately 2.680 and approximately 2.669 billion years ago (Corfu et al., 1995; Sanborn-Barrie et al., 2004). Corfu et al. (1995) consider the timing (short lived and apparently cyclical) of metamorphism in the English River Subprovince to be consistent with thermal perturbations related to injection of granitic magmas generated through partial crustal melting.

Metamorphic grades are lower within the Uchi Subprovince in the north part of the Ear Falls area where lower amphibolites facies dominate along the contact with the adjacent English River strata grading to greenschist facies over most of the remainder of the Uchi Subprovince (Breaks et al., 1978).

Upper-greenschist facies metamorphic grade in the English River Subprovince is rather restricted to near its contact with the greenstone belts at the north of the subprovince. Metamorphic grade rapidly increases southward reaching upper-amphibolite facies (Breaks et al., 1978; Breaks and Bond, 1993), although variable uplift of the English River Subprovince and the extensive fault systems frequently obscure this trend (Stone, 1981; Breaks and Bond, 1993). Two main occurrences of hornblende-granulite facies metamorphism occur near the Ear Falls area: one proximal to left side of the Miniss River fault, approximately 80 km east of the Ear Falls area, and the other about 30 km west of the settlement area of Ear Falls. Thermobarometry indicates pressure-temperature conditions of 4-6 Kbar and approximately 700-725°C for the granulite facies indicating granulite metamorphism of low to medium pressure and high temperature (Chipera and Perkins, 1988; Breaks and Bond, 1993). Potential exists for the granulite isograds to extend eastward into the Ear Falls area, given the relative proximity of granulite facies metamorphism to the area. This could result in a possible lateral gradation of granulite-amphibolite facies within the Ear Falls area. Confirmation of the existence of lateral gradation in metamorphic grade across the Ear Falls area would need to be investigated in future stages of the evaluation process.

## 2.4 Geological and Structural History

Direct information on the geological and structural history of the Ear Falls area is limited. The geological and structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the region of the Ear Falls area. It is understood that there are potential problems in regional correlation of specific structural events within a $D_x$ numbering system and in the application of such a system to the local geological history. Nonetheless, the summary below represents an initial preliminary interpretation for the Ear Falls area, which may be modified after site-specific information has been collected.

Rocks of the English River Subprovince have been subjected to multiple Archean deformation events (Westerman, 1977; Breaks et al., 1978; Breaks, 1991) as summarized in Table 1. These deformation events have been traditionally interpreted as involving three folding events and one faulting event (Breaks, 1991) but this interpretation has recently been revised by Hrabi and Cruden (2006). Hrabi and Cruden (2006) interpreted the deformation events as components of a single, protracted, and complex orogeny. The work of Hrabi and Cruden (2006), which considers $D_1$ to $D_5$ events to be components of a single protracted and complex orogeny, offers a descriptive summary of the deformation events in the English Subprovince and is regarded as the most applicable interpretation of the structural geology of the Ear Falls area. Along with a protracted younger history of brittle deformation, herein termed $D_6$, these six deformation events form the basis of the following description of the structural history.

The first deformation event ($D_1$) is interpreted to have generated a weak foliation ($S_1$) oriented parallel to bedding in low-grade metamorphic rocks located in the north and south margins of the English River Subprovince (Hrabi and Cruden, 2006). At higher metamorphic grades, $S_1$ is enhanced by migmatitic leucosomes (Hrabi and Cruden, 2006). $D_1$ is interpreted to have overlapped with the initial migmatization stages of sedimentary rocks and is bracketed between the time of deposition of sedimentary rocks, before approximately 2.704 billion years ago, and the age of a suite of tonalite intrusions dated at approximately 2.698 billion years old and deformed by $D_2$ (Hrabi and Cruden, 2006). Folds related to this fabric are not commonly found and have only been documented by Breaks (1991) and Hynes (1997, 1998).

The second deformation event ($D_2$) was the most pronounced, and generated an east-trending moderate to intense foliation ($S_2$) and a stretching lineation ($L_2$) of varying orientation (Hrabi and Cruden, 2006). $F_2$ folds are isoclinal and fold the $S_1$ foliation and migmatitic leucosomes (Hrabi and Cruden, 2006). Migmatization of sedimentary rocks continued during $D_2$ and the resulting migmatitic layering is interpreted to represent a composite $S_0$-$S_1$-$S_2$ foliation (Hrabi and Cruden, 2006). The maximum approximate age of the $D_2$ deformation is constrained by the approximately 2.698 billion year old suite of tonalite intrusions which are overprinted by the $S_2$ foliation (Hrabi and Cruden, 2006).

Hrabi and Cruden (2006) attribute $D_3$ deformation to a period of extension. Extensional faults are indirectly evident from Lithoprobe seismic reflection profiles and are attributed to $D_3$. This extensional phase is consistent with the presence of approximately < 2.701 billion year old conglomeratic basins distributed along the south margin of the English River Subprovince and the three-dimensional geometry of the Uchi and English River subprovinces inferred from Lithoprobe profiles (Calvert et al., 2004) with upwarp of the Moho beneath the English River Subprovince. Based on the timing of the $D_2$ event, $D_3$ is therefore constrained to have occurred between approximately 2.691 and 2.68 billion years old.

The fourth deformation event ($D_4$) is attributed to curved east- to northeast-trending sinistral shear zones (Hrabi and Cruden, 2006). Upright moderately east- to southeast-plunging $F_4$ folds associated with a steeply-dipping penetrative S4 foliation are also attributed to $D_4$ (Hrabi and Cruden, 2006). In terms of geometry and kinematics, $D_4$ shear zones are similar to the well-documented Miniss River fault located about 80 km east of the Ear Falls area (Hrabi and Cruden, 2006). The Miniss River fault is 1 to 2 km wide (Breaks, 1991), with a long history of ductile and brittle deformation (Bethune et al., 1999). The approximate age of a portion of the mylonitic ductile strain along the Miniss River fault is constrained by the age of a granitic dyke dated at approximately 2.681 billion years old, which is deformed and offset by a sinistral shear band within the fault (Bethune et al., 2006). Dextral reactivation of the southwestern portion of the Miniss River fault is interpreted to have occurred approximately 2.670 billion years ago (Bethune et al., 2006). The age of titanite porphyroblasts generated during retrograde metamorphism was linked to the reactivation of the fault (Corfu et al., 1995), and may be attributed to $D_5$ (see below). Therefore an age range of between approximately 2.68 and 2.669 billion years ago is considered a suitable approximation for the timing of $D_4$.

Geometric and kinematic relationships strongly suggest a protracted history of late fault movement that is collectively ascribed to a $D_6$ phase of deformation. For example the latest displacement of the Sydney Lake fault crosscuts the Miniss River fault (Bethune et al., 2006).

This interpretation is consistent with Ar-Ar geochronology indicating that motion along the Sydney Lake fault continued until approximately 2.640 billion years ago (Hanes and Archibald, 1998). However these regional fault systems are known to have a protracted displacement history and early thrust faulting along the Sydney Lake fault zone is likely to have pre-dated the most significant component of displacement on the Miniss fault (Stone, 1981). Hrabi and Cruden (2006) hence assign faults associated with the Sydney Lake fault to a fifth deformation event ($D_5$). Bethune et al. (2006) propose that dextral reactivation of the Miniss River fault about 2.670 billion years ago was effectively driven by the stress regime of the younger Sydney Lake fault. Hrabi and Cruden (2006) consider $D_1$ to $D_5$ events to be components of a single protracted and complex orogeny. In addition, Hanes and Archibald (1998) suggest that approximately 2.400 billion years ago regional differential uplift was associated with movement along major fault zones throughout the Superior Province. Therefore the $D_5$ episode is considered to have been a protracted event of shear zone activation and re-activation that occurred until approximately 2.400 billion years ago.

Further episodes of brittle deformation are inferred to have caused the formation of brittle fractures and faults, and to have reactivated pre-existing faults and fractures in the region. Numerous generations of fracture formation or reactivation have been identified post-dating approximately 2.5 billion years in northwestern Ontario (Brown et al., 1995; Kamineni et al., 1990).

**Table 1. Summary of the geological and structural history of the Ear Falls area**

| **Time Period (billion years ago)** | **Geological Event** |
|---|---|
| ca. 3.4 to 2.8 | Progressive growth of the North Caribou and Winnipeg River terranes through the additions of magmatic and crustal material in continental arcs and through accretion of allochthonous crustal fragments (Tomlinson et al., 2004). |
| ca. 2.740 to 2.735 | Emplacement of early plutons in the Uchi Subprovince. |
| ca. > 2.704 to 2.69 | Timing of collision between the North Caribou terrane and the Winnipeg terrane (Corfu et al., 1995; Hrabi and Cruden, 2006; Sanborn-Barrie and Skulski, 2006). [$D_1$]<br><br>Emplacement of late granitic to granodioritic plutons within the Winnipeg River Subprovince between approximately 2.71 and 2.69 billion years ago (Breaks and Bond, 1993).<br><br>Accumulation and syn-depositional deformation of sediments in the English River Subprovince between approximately 2.704 and 2.699 billion years ago (e.g., (Sanborn-Barrie et al., 2004). |
| ca. 2.698 | Timing of intrusion of calc-alkaline plutons into sedimentary rocks of the English River Subprovince (Hrabi and Cruden, 2006). Their emplacement provides |

| Time Period (billion years ago) | Geological Event |
|---|---|
| | constraint on the maximum age of $D_2$ deformation. [2.698 > $D_2$ > 2.691 billion years ago] |
| ca. 2.691 to 2.68 | Major regional deformation, amphibolite to granulite facies metamorphism, anatexis and emplacement of peraluminous granitic intrusions (Sanborn-Barrie et al., 2004). [$D_3$] |
| ca. 2.68 to > 2.67 | Dextral semi-brittle movement in the Sydney Lake fault zone (Sanborn-Barrie et al., 2004; Hrabi and Cruden, 2006). [$D_4$]<br>Granulite facies metamorphic event approximately 2.680 billion years ago within the Winnipeg River Subprovince (Corfu et al., 1995).<br>Continued metamorphism and pegmatite emplacement within the English River Subprovince (Sanborn-Barrie et al., 2004). |
| ca. 2.67 to 2.64 | Late fault (re)activation (Hrabi and Cruden, 2006). [$D_5$] |
| ca. < 2.64 to > 1.9 | Post-2.6 billion years old regional faulting and brittle fracturing (Kamineni et al., 1990). [$D_6$] |
| ca. 1.9 to 1.7 | Emplacement of the Ear Falls dykes (Symons et al., 1983). [$D_6$ con't] |
| Post-1.7 | A complex interval of erosion, brittle fracture, repeated cycles of burial and exhumation, and glaciations, particularly from the latest Miocene to the present. [$D_6$ con't] |

## 2.5 Quaternary Geology

Quaternary geology in the Ear Falls area is described in detail in JDMA (2013). A summary of the main features is provided here for reference.

The contact between bedrock and the overlying unconsolidated Quaternary sediments in the Ear Falls area represents an unconformity exceeding one billion years. Figure 3 illustrates the extent and type of Quaternary deposits in the Ear Falls area. The Quaternary geology of the area is dominated at surface by deposits of glaciolacustrine silts and clays that accumulated with the progressive retreat of the ice sheet during the end of the Wisconsinan glaciation. This period of glaciation began approximately 115,000 years ago and peaked about 21,000 years before present, at which time the glacial ice front extended south of Ontario into what is now Ohio and Indiana (Barnett, 1992). At surface there are also minor amounts of glaciofluvial (sand and gravel) deposits as well as post-glacial deposits of peat, muck, organic-rich silts, and clays found in bogs and swamps throughout the area. Recently deposited alluvial silts and clayey silts are also present along parts of the English River and some small streams.

Ice from the Wisconsinan glaciation laid down the oldest known Quaternary deposit in the Ear Falls area: a stratum of sandy, stoney till mapped by Ford (1981), who described the unweathered till as massive to fissile with poor to moderate matrix cohesion. Unweathered till is usually olive-grey, whereas the weathered till is brown to greyish brown. The extent of till over the Ear Falls area is unknown due to the extensive overlying mantle of glaciolacustrine clays and silts at the surface. The till is not exposed at the surface within the township limits except for a small area near the northeast corner of Bruce Lake. While earlier glacial and interstadial deposits are encountered in a few northern Ontario locations (e.g., the interstadial or interglacial Missinaibi Beds of the Moose River drainage or the interstadial Owl Creek Beds of the Timmins area), none are known to be present in the Ear Falls area, and it is likely that any earlier deposits in the Ear Falls area have been largely or entirely removed by glacial erosion that stripped away the pre-existing overburden and eroded the crystalline bedrock. Glaciofluvial deposits are exposed in several areas within the Township of Ear Falls and include a number of small eskers, portions of the Lac Seul moraine, and numerous sand bodies scattered about the area. The sands are typically fine- to medium-grained and are moderately well-sorted and quartz-rich (Ford, 1981). The northward retreat of the ice sheet in the Ear Falls area started approximately 12,000 years ago and the Ear Falls area first became ice-free approximately 10,500 years ago (Dyke et al., 2003). Ice front fluctuations during the deglaciation resulted in the deposition of the Lac Seul moraine, which forms a prominent northwest-trending linear feature that can be traced for more than 200 km across northwestern Ontario.

During the waning of the Wisconsinan glaciation, drainage was blocked from flowing northward by the residual ice mass still remaining over the Hudson Bay Basin. This created a large ice-dam lake, known as Lake Agassiz that covered much of northwestern Ontario and the majority of the Ear Falls area. Lake Agassiz was the largest of several glacial lakes that bordered the southern margin of the retreating ice sheet during the late Wisconsinan glaciations and covering a maximum area of approximately 1 million km$^2$ (Bajc et al., 2000). Clays and silts were laid down as Lake Agassiz gradually inundated the area approximately 9,900 years ago and these fine-textured glaciolacustrine deposits cover much of the Ear Falls area to thicknesses exceeding 4 m, as indicated in water well records. Wave action in Lake Agassiz also produced a series of well-developed terraces on the Lac Seul moraine and sandy aprons bordering the moraine (Shklanka, 1970).

Information on the thickness of Quaternary deposits in the Ear Falls area was inferred from terrain evaluation and measured thicknesses are limited to a small number of water well records for rural residential properties, a small number of water well records along the highways, and from diamond boreholes in the former Griffith mine and in the periphery of the Township to the north. Recorded depths to bedrock in the Ear Falls area range from 0 to 45 m and are typically less than 10 m. The thickest overburden is inferred along the axis of the Lac Seul moraine, a north-south trending glaciofluvial ice deposit and topographic high that runs along the easternmost portion of the Township of Ear Falls (Figure 3).

### 2.6 Land Use

Land use in the Ear Falls area is described in detail in Golder (2013). A small portion of the Township of Ear Falls is covered by domestic and industrial infrastructure, with developments limited mainly to roadways and the settlement area itself (Figure 1). The areas at the periphery of the Township of Ear Falls are also largely undeveloped, with limited natural or physical constraints such as major infrastructure or permanent water bodies.

## 3 GEOPHYSICAL DATA SOURCES AND QUALITY

For the Ear Falls area, geophysical data were mainly obtained from available public-domain sources, particularly the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC). To supplement these data, geophysical raster maps based on surveys performed in the Ear Falls area by the mining industry (particularly Laurentian Goldfields Ltd., Fronteer Development Group Inc. and Grandcru Resources Corp.) were retrieved from the provincial assessment files but no original digital data sources were obtained. Geophysical coverage for the Ear Falls area is summarized in Table 2 and presented on Figure 4.

The quality of the available data was assessed to determine which datasets were suitable for inclusion in this assessment. The geophysical surveys covering the Ear Falls area show variability in dataset resolution, which is a function of the flight line spacing, the sensor height, and equipment sensitivity. Where datasets overlapped, the highest quality coverage was used. Various geophysical data processing techniques were applied to enhance components of the data most applicable to the current assessment. The resolution of the higher quality data was maintained throughout the applied processing.

### 3.1 Data Sources

Low to moderate resolution geophysical data, particularly the magnetic, radiometric, gravity data obtained from the GSC cover the entire Ear Falls area (Figure 4). Additional magnetic/electromagnetic surveys were obtained from the Ontario Geological Survey (OGS) and provided higher resolution coverage over approximately 455.7 km$^2$ or 11.5% of the Ear Falls area in its north central portion (Figure 4). The OGS surveys focused primarily on exploration in the greenstone belts, but also encompassed small amounts of plutonic rocks, particularly the Pakwash Lake and Bruce Lake plutons, and parts of the Wenasaga Lake batholith. Gravity measurements presented a similar focus as station density is higher in the greenstone belts.

Data from the Lithoprobe program, one seismic line (WS2B) and two magnetotelluric stations (WST062 and WST074), are also located within the Ear Falls area providing some insight into deep structures.

Relevant Assessment files archived at the Ministry of Northern Development and Mines (MNDM) Assessment File Research Imaging database (AFRI) were reviewed. The AFRI airborne and ground assessment files coverage is shown on Figure 4, and details of the retrieved AFRI assessment files are presented in Table 2.

### 3.1.1 Magnetic Data

Magnetic data were collected by various surveys (nine fixed-wing and two helicopter based) using different survey parameters, as outlined in Table 2. Magnetic surveys help identify geological and structural variations because rocks differ in their content of magnetic minerals, such as magnetite and pyrrhotite, and in their remnant magnetic signature to which magnetometers are sensitive. Magnetic maps are particularly useful for delineating spatial geometry of rock units, and the presence of faults and folding.

The quality and reliability of the retrieved magnetic datasets varies greatly within the Ear Falls area. Surveys were flown over a period of 51 years, over which time the quality and precision of the equipment as well as the quality of the processing improved consistently. Variability in the survey coverage also influenced the ability of the magnetic data to identify geological structures of interest relevant to this assessment.

Low-resolution magnetic data from the GSC provides complete coverage over the entire Ear Falls area (GSC, 2012). Magnetic data from these surveys form part of the GSC Regional Magnetic Compilation data. These two grids were generated using data from the Ontario #6 and Ontario #7 survey acquired by the GSC in 1960 and 1965, respectively. These surveys were flown at elevations of 152 and 305 m and a flight line spacing of 805 m, resulting in relatively low resolution survey coverage. Moreover the data from both surveys were hand digitized along the flight paths from contour maps, adding error to the data. Where survey areas overlapped, these datasets are locally superseded by higher resolution OGS surveys.

An additional low-resolution, Dryden-Kenora, Dryden block survey was flown as an exploration reconnaissance survey at 5,000 m line spacing with a 120 m terrain clearance. The wide line spacing influenced the resolution of the data and also hindered the ability to provide a detailed geological interpretation, nevertheless the survey covers the entire Ear Falls area.

The high-resolution OGS surveys, Uchi-Bruce Lakes Area (GDS1026; OGS, 2003), Pakwash Lake Area (GDS1218; OGS 2002a) and Trout Lake River Area (GDS1222; OGS, 2002b), are all available as magnetic data leveled to the GSC magnetic datum. These surveys were flown at a low terrain clearance (respectively; 60 m, 120 m and 73 m) compared to the Canada magnetic compilation, with tighter flight line spacing (respectively; 200 m, 250 m and 200 m), providing these surveys with a relatively high spatial resolution. Moreover all three surveys were digitally recorded and the digital data were available by request to the OGS. However, these surveys focused primarily on exploration in the greenstone belts in the north, covering approximately 11.5% of the Ear Falls area. Data from these surveys are considered to be highly reliable due to well-detailed survey parameters (such as survey design and sensor specifications), their good coverage of the Ear Falls area and the high precision of the data.

Three private aeromagnetic surveys, Goldpines South Property (Laurentian Goldfields Ltd., 2010), Red Lake, Dixie North Area (Fronteer Development Group Inc., 2004) and Dixie East/South Properties (Grandcru Resources Corp., 2005), were retrieved from the AFRI database in the form of raster maps that were extracted from the reports and georeferenced. Digital data were not available for these surveys. In particular, the Goldpines South Property survey extends the high resolution magnetic coverage towards the northwestern portion of the Ear Falls area, previously covered by lower resolution magnetic data (Laurentian Goldfields Ltd., 2010). The magnetic survey was flown with 100 m line spacing at 30 m terrain clearance (for the magnetic sensor) which are the lowest sensor elevation and tightest line-spacing of all retrieved datasets. This survey also measured the magnetic gradient with the use of four magnetic sensors arranged in an orthogonal array with a 3 m sensor separation from the nose sensor to those at the end of each arm (Scott Hogg & Associates, 2010).

The magnetic data from Fronteer Development Group and the Grandcru Resources surveys were flown at 75 m line spacing with 100 m and 60 m terrain clearance, respectively. These two surveys are relatively small and slightly extend the Pakwash Lake survey (GDS1218) approximately 5 km further to the west. Although the raster images from the Fronteer Development Group and Grandcru Resources Corporation surveys are high resolution, they are both small and located within the greenstone belt units. A large portion of both surveys are also overlapping with the Pakwash Lake survey. As a result, only the raster maps from the Goldpines South Property maps were used for the interpretation in this report.

Data from the GSC Regional Magnetic Compilation data, and the high resolution OGS surveys (GDS1026, GDS1218 and GDS1222) were used for the processing stage of this assessment described in Section 4.1. The magnetic data was also used to identify geophysical lineaments, which are presented and discussed in the lineament report for the Ear Falls area (SRK, 2013).

### 3.1.2 Gravity Data

Gravity data are measurements of variations in the strength of the Earth's gravitational field. Measurements are made in units of milliGals (mGal) and are acquired using gravimeters at a grid of stations over an area of interest. Gravity data can be modeled to infer density variations in the subsurface.

Gravity data for the Ear Falls area (GSC, 2012) consists of an irregular distribution of 730 station measurements, comprising roughly a station every 2 to 3 km in the northern portion, and a station every 5 to 15 km along the southern and southeastern portion of the Ear Falls area. Details and extents are given in Table 2.

The raw gravity measurements were retrieved as well as the Free Air (FA) and Bouguer corrected data. The FA correction effectively adjusts measurements of gravity taken at different elevations to what would have been measured at a datum elevation, typically the geoid. The Bouguer correction is applied to the FA corrected data to compensate for the gravity effect of the material between the measurement station and the datum elevation and for the contribution to the measurement of the gravity effects of the surrounding topographic features.

Despite the fact that data are of good quality, the sparseness of the measurement locations in the southern half of the Ear Falls area, while their density increases in the north, means that the gravity data can only be used to provide information about large scale geologic features over half of the Ear Falls area. The resolution of the retrieved gridded data is 2 km by 2 km. This implies that features with wavelengths shorter than 8 km cannot be defined by the data in the southern half of the Ear Falls area. The gravity dataset is therefore considered to be of moderate resolution.

### 3.1.3 Radiometric Data

A single radiometric dataset, Dryden-Kenora (Dryden block), was retrieved from the GSC (GSC, 2012). This radiometric survey measured the concentration of natural radioactive elements at surface: uranium (U), thorium (Th) and potassium (K). Radiometric maps or grids are useful to show the distribution of radioactive elements in the Ear Falls area, which can be linked to mineralogical and geochemical information about bedrock, surficial geology and alteration associated with mineral deposits, often indicating geological features that may not be revealed by other techniques.

Retrieved radiometric data consisted of measurements of three measured variables, and calculated dose rate:

- Potassium, K (%);
- Equivalent uranium, eU (ppm);
- Equivalent thorium, eTh (ppm); and
- Total Air Absorbed Dose Rate (nGy/h).

Radiometric surveys have a few important limitations: the surveys have a depth of penetration of only a few centimetres into the ground surface and the presence of even a small amount of water on the ground surface is enough to reduce the signal level to a point where accurate data cannot be recorded. The presence of widespread glacial till cover and the presence of numerous water bodies such as lakes and swamps in the Ear Falls area makes interpretation of radiometric data difficult. In addition, the elevated flight height of 120 m combined with a wide line spacing of 5 km limit the level of interpretation to regional structures.

### 3.1.4 Electromagnetic Data

#### *3.1.4.1 VLF-EM Data*

The retrieved Very Low Frequency Electromagnetic (VLF EM) datasets were acquired as raster images from the OGS AFRI database from the Goldpines South Property (Laurentian Goldfields Ltd.). Digital data were not available for these surveys. Data were acquired using Herz Totem 2A VLF-EM system to measure the total field and vertical quadrature signal from a set of VLF transmitter stations recorded on two channels named, respectively, Line and Ortho for the purpose of this survey. The locations of these transmitting stations were selected to be approximately orthogonal with respect to the incident angle of the respective VLF signals measured at the survey location. The line stations consisted of NAA 24.0 kHz (Cutler, Maine) when available, and NLK 24.8 kHz (Jim Creek, Washington) at times when Cutler, Maine was not available. The Ortho station consisted solely of NML 25.2 kHz (Lamour, North Dakota).

The VLF data from the Goldpines South Property survey was flown at 100 m line spacing with a terrain clearance of 34 m. The close line spacing and the measure of two stations give this survey a good spatial accuracy to help in better identifying structures.

#### *3.1.4.2 FDEM and TDEM Data*

A frequency domain electromagnetic (FDEM) survey carried out by the OGS using the DIGHEM$^{IV}$ system was retrieved from the Uchi-Bruce Lakes Area survey (GDS1026; OGS, 2003, Figure 4). The FDEM system used for this survey measured the in-phase and quadrature components of four coil pairs towed below a helicopter on a 30 m long cable with a sensor nominal terrain clearance of 30 m. The coplanar geometry measured the vertical component of the EM field from a transmitter coil with a vertically oriented dipole moment and is sensitive to lateral variations in the bulk earth conductivity in a 1D or layered earth scenario. Conversely the coaxial geometry measured the horizontal component of the EM field from a transmitter coil with a horizontally oriented dipole moment and is useful when interpreting the location and dip of sub-vertical structures. Data from the coplanar geometry were used by the OGS to produce an apparent resistivity grid from the 7,200 Hz coplanar coil pair, a conductance (conductivity thickness) grid from the 900 Hz coaxial coil pair (vertical dyke model), and a conductance (conductivity thickness) grid from the 900 Hz coplanar coil pair (horizontal sheet model).

Each grid was calculated using a single frequency and therefore investigated a slightly different range of depths. The depth of investigation depends on the conductivity of the ground and the system frequency. In general lower EM frequencies penetrate deeper into the Earth. The depths below surface to the top of the vertical dyke model, and to the top of the horizontal sheet were calculated. A detailed report contains information on survey design, equipment sensitivity and survey parameters (OGS, 2003). Most of the parameters, such as survey design and sensor specifications, are well described and the survey has a fine spatial resolution, and the lowest flight height of the public datasets available.

Two Time Domain Electromagnetic (TDEM) surveys carried out within the Ear Falls area by the OGS, both using the GEOTEM® system, were retrieved for the Pakwash Lake Area (GDS1218; OGS 2002a, Figure 4), and Trout Lake River Area (GDS1222; OGS, 2002b, Figure 4). The retrieved TDEM datasets from these surveys have well detailed parameters and high-resolution over the Ear Falls area, but the sensitivity of their equipment varies greatly. The smaller Trout

Lake River Area (GDS1222) survey overlaps almost entirely with the Pakwash Lake Area (GDS1218) survey, with the exception of a small area outside of the Ear Falls area, therefore this survey will not be considered further in this report as its similar characteristics make the information redundant.

EM anomalies were identified by the OGS on all three surveys. Their location and type such as bedrock, surficial or cultural conductor were provided in a database.

### 3.1.5 Seismic Reflection Data

One seismic reflection line, WS2B, surveyed by the GSC was retrieved from the Western Superior Lithoprobe transect (Asudeh et al, 1996; GSC, 2012). This seismic data was acquired to image the deep structure of the Western Superior Province, particularly where the greenstone belts are well developed. The objective was to investigate the relationships between and within subprovinces at depth in order to understand the late Archean crust and to understand the deep structure beneath subprovinces of different tectonic origin. The seismic reflection method images the interior of the Earth using a controlled seismic source and a geophone array (Telford et al., 1990).

The entire WS2B seismic reflection line was 228 km long and generally followed Highway 105, trending approximately NNW. A section of approximately 55 km of the seismic line is contained within the Ear Falls area. The survey parameters were selected to optimize the acquisition of information to image deep structures (i.e., to approximately 40 to 50 km deep), so shallower structures, on the order of a few kilometres deep, are not well resolved. The seismic line WS2B was recorded with a 963-channel telemetry acquisition system using 25 m long linear arrays of nine geophones deployed every 25 m. Four vibrators, each with a peak force of 22,400 kgf, were deployed in a six-sweep, 60 m source array; the vibration point spacing was 100 m. A linear frequency sweep from 10 to 56 Hz was employed for 28 seconds, and the data were diversity-stacked to attenuate environmental noise. Seismic data quality was monitored continuously during field acquisition (Asudeh et al, 1996; Calvert et al, 2004).

### 3.1.6 Magnetotelluric Data

Magnetotelluric (MT) soundings were also carried out by the GSC as a part of the Western Superior Lithoprobe transect (GSC, 2012). The MT soundings are passive EM surveys that take advantage of naturally occurring, time varying EM fields created by the interaction of solar wind with the Earth’s magnetosphere, along with the EM energy released by lightning strikes. MT soundings were collected at two locations, monitoring data over a wide range of frequencies which enable the conductivity structure or its measured effects from near the surface to mantle depths to be detailed; where high frequencies are used to investigate the near surface geology, while low frequencies penetrate to greater depths. The dataset from the GSC consisted of measurement location, survey parameters, range of frequencies measured, set of rotation angles used to rotate impedances to the impedance strike angle, rotated impedance data blocks and complex tipper components. The conductivity structure of the rocks underlying the MT soundings was not available.

Two MT measurements are located within the Ear Falls area (WST062 and WST074). All soundings were acquired in December 1998 and are available through the GSC Lithoprobe Data Archive.

### 3.2 Data Limitations

There is a strong contrast between the high resolution of the airborne geophysical surveys that cover the Archean Uchi granite-greenstone belt and intrusive crystalline rocks (Bluffy Lake batholith, Wenasaga Lake batholith, Bruce Lake pluton, and Pakwash Lake pluton) and the older low and medium resolution coverage elsewhere in the Ear Falls area. Nevertheless, the data as a whole provides a response that is generally coincident with the mapped geology in the Ear Falls area and is useful to extend the interpretation of rock units to areas of limited bedrock exposure.

In some cases, compositional differences and zonation are seen within the plutonic and metasedimentary rocks in the Ear Falls area and an attempt can be made to differentiate the rock units in areas where higher resolution data are available. Similarly, the main structural regimes are clearly delineated by the magnetic, VLF, TDEM and FDEM data, but at different levels of detail depending upon the spatial resolution of the survey.

All four data types considered, magnetic, gravity, radiometric and electromagnetic, contribute to the geophysical interpretation. Limitations in applying these data types to the Ear Falls area are governed mainly by the following factors:

- Coverage and quality of data – types of data available, density of coverage, vintage, and specifications of the instrumentation;
- Overburden – areal extent, thickness and physical properties; and
- Bedrock lithologies – physical properties and homogeneity (e.g., batholith contacts can be easily mapped but batholiths themselves are sometimes quite homogeneous, making geophysical characterization of internal structure difficult).

The user of the geophysical information must bear in mind that each method relies on characterizing a certain physical property of the rocks. The degree to which these properties can be used to translate the geophysical responses to geological information depends mainly on the amount of contrast and variability in that property within a geological unit and between adjacent geological units. The utility of each dataset also depends on its quality and resolution.

**Table 2. Summary of the characteristics for the geophysical data sources in the Ear Falls area**

| Product | Source | Type | Line Spacing/ Sensor Height | Flight Line Azimuth | Coverage | Date | Additional Comments |
|---|---|---|---|---|---|---|---|
| Dryden-Kenora, Dryden block | GSC | Fixed Wing - Magnetic, Radiometric data | 5,000m/120m | 0° | Entire Ear Falls area | 1996 | Quality control and initial processing applied by GSC. |
| Ontario #06 | GSC | Fixed Wing - Magnetic | 805m/152m | 0° | Ear Falls area north of 5,594,200mN | 1960 | Data digitized from contour maps along flight lines flown at a higher elevation than other datasets with a low spatial resolution. Original quality altered by extracting interpolated survey data from a map. |
| Ontario #07 | GSC | Fixed Wing - Magnetic | 805m/305m | 0° | Ear Falls area south of 5,594,200mN | 1965 | Data digitized from contour maps along flight lines flown at a higher elevation than other datasets with a low spatial resolution. Original quality altered by extracting interpolated survey data from a map. |
| Canada - 200m - Compilation | GSC | Magnetic - Residual Total Field | 805m/305m | 0° | Entire Ear Falls area. | 1960-1965 | August 2010 updated compilation of GSC magnetic surveys. |
| Uchi-Bruce Lakes Area (GDS1026) | OGS | Heliborne - Magnetic, FDEM | Magnetic 200m/60m FDEM 200m/30m | Block A1: 0° Block A2: 45° | Covers the north central part of the Ear Falls area | 1991 | Quality control and correction of bad data were applied by OGS. |
| Pakwash Lake Area (GDS1218-REV) | OGS | Fixed Wing – Magnetic, TDEM | Magnetic 250m/120m TDEM 250m/40m | North Block: 178° South Block: 83° | Covers a small area in the north northwest central part of the Ear Falls area | 1992 | Quality control and initial processing applied by OGS. |
| Trout Lake River Area (GDS1222-REV) | OGS | Fixed Wing – Magnetic, TDEM | Magnetic 200m/73m TDEM 200m/64m | Block A: 334° Block B: 0° Block C: 15° | Covers a small area in the north northeast central part of the Ear Falls area. | 1997 | Quality control and initial processing applied by OGS. |
| Red Lake, Dixie North Area AFRI 52K13NE2008 | Fronteer Development Group Inc. | Fixed Wing – Magnetic | 75m/100m | 0° | ~62km$^2$ in the northwest corner of the Ear Falls area | 2003 | No digital data available, only images of maps of total magnetic intensity, first vertical derivative and transverse magnetic gradient were available. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Dixie East/South Properties AFRI 20001087 | Grandcru Resources Corp. | Fixed Wing – Magnetic | 75m/60m | 0° | ~50km$^2$ in the northwest corner of the Ear Falls area | 2005 | No digital data available, only images of maps of the measured total magnetic intensity was available. |
| Goldpines South Property AFRI 20000006808 | Laurentian Goldfields Ltd. | Heliborne - Magnetic, VLF | 100m/34m | 0° | ~681km$^2$ in the northwest quarter of the Ear Falls area. | 2010 | No digital data available, only images of maps of reduce to pole magnetic intensity, first and second vertical derivative, apparent susceptibility and VLF were available. |
| GSC Gravity Coverage | GSC | Ground Gravity Measurements | 2-15km/surface | n/a | Stations density varies from sparse in southern, and moderate in northern portions of the Ear Falls area. | 1947-1997 | Despite a good data quality at stations the sparse coverage of the Ear Falls area makes the 2 km grid unable to define gravity anomalies of wavelength smaller than 8 km in the southern half of the Ear Falls area. A denser coverage in the northern half allows for finer gridding at 500 m. |
| Lithoprobe - Western Superior | GSC | Magnetotelluric, Seismic | Along roads or at stations/surface | n/a | Seismic line crossing central part of the Ear Falls area with a ~315°N azimuth. Two MT stations located within Ear Falls area. | 1996 | |

# 4 GEOPHYSICAL DATA PROCESSING

All geophysical datasets for the Ear Falls area were assessed, processed and imaged using the following software packages:

- GOCAD Mining Suite (GOCAD Mining Suite, 2012) for data compiling and filtering;
- WinDisp from Scientific Computing and Applications for data filtering and format conversion (WinDisp, 2012);
- The GDAL library (GDAL, 2012) for data format and coordinate reference system conversions; and
- QGIS for georeferencing raster images.

## 4.1 Magnetic

The magnetic survey data acquired from the GSC and OGS consists of total magnetic field (TMF) and reduced magnetic field (RMF) grids. The RMF was determined by removing the Earth's ambient magnetic field, based on the International Geomagnetic Reference Field (IGRF), recorded at the time of the survey from the data (see Table 3 for details). The retrieved grids of the magnetic datasets have also been leveled to a common elevation datum of 305 m used by the Geological Survey of Canada (GSC). While the upward continuation transformation acted in part as a low pass filter to the magnetic data, it was deemed to be the best approach to leveling these particular datasets and did not adversely affect the geophysical interpretation. The essential theoretical aspects of the leveling methodology are fully discussed in Gupta et al. (1989), and Reford et al. (1990).

The resulting survey data were integrated to form a single GSC-leveled RMF grid defined by 40 m grid cells covering the entire Ear Falls area. Gridding of the data was generated through minimum curvature interpolation based on points extracted from the 200 m compiled grid from the GSC and from the various retrieved OGS surveys covering the Ear Falls area.

Additional magnetic data processing was performed on GSC-leveled gridded data using filters to perform Reduction to Pole (Figure 5), First Vertical Derivative of RTP (Figure 6), Second Vertical Derivative of RTP (Figure 7), Analytic Signal of RMF (Figure 8), Tilt angle of RTP (Figure 9).

**Table 3. IGRF magnetic field characteristics for retrieved surveys**

| Source | Name | X (m) | Y (m) | Date (dd/mm/yyyy) | Declination (°) | Inclination (°) | Field Strength (nT) |
|---|---|---|---|---|---|---|---|
| GSC | Dryden-Kenora, Dryden block | 481800 | 5624000 | 28/06/1996 | 1.109 | 76.953 | 59,489 |
| GSC | Ontario #6 | 481800 | 5585400 | 15/10/1959 | 5.484 | 78.607 | 60,943 |
| GSC | Ontario #7 | 481800 | 5611000 | 01/07/1961 | 4.675 | 78.66 | 60,959 |

| Source | Name | X (m) | Y (m) | Date (dd/mm/yyyy) | Declination (°) | Inclination (°) | Field Strength (nT) |
|---|---|---|---|---|---|---|---|
| OGS | Uchi-Bruce Lakes Area | 488900 | 5634300 | 19/01/1991 | 1.748 | 77.15 | 59,948 |
| OGS | Red Lake Area | 456100 | 5642600 | 15/01/1978 | 4.364 | 77.795 | 60,903 |
| OGS | Pakwash Lake Area | 467000 | 5632700 | 15/12/1992 | 1.85 | 77.238 | 59,865 |
| OGS | Trout Lake River Area | 497400 | 5638800 | 02/02/1997 | 1.092 | 76.835 | 59,400 |

Reduction to Pole (RTP)

Reduction to pole (RTP) recalculates total magnetic intensity data as if the inducing magnetic field had a 90° inclination, such as it does at the Earth's magnetic poles. This transforms asymmetric magnetic anomalies to symmetric anomalies centered over their causative bodies which can simplify the interpretation of the data (Baranov, 1957). The IGRF magnetic field characteristics at the time of each survey, shown in Table 3, were used to identify the geomagnetic inclination and declination used to perform the RTP.

The RTP filter, computed from the residual magnetic field after it is transformed to the Fourier domain, is defined as follows:

$$L(\theta) = \frac{[\sin(I) - i \cdot \cos(I) \cdot \cos(D - \theta)]^2}{[sin^2(I_a) + cos^2(I_a) \cdot cos^2(D - \theta)] \cdot [sin^2(I) + cos^2(I) \cdot cos^2(D - \theta)]} \quad eq. 4.1$$

If: $(|I_a| < |I|),\ I_a = I$

Where: *L(θ)* = pole-reduced magnetic field for wavenumber *θ*
*I* = geomagnetic inclination
$I_a$ = inclination for amplitude correction (never less than *I*).
*D* = geomagnetic declination
*i* = imaginary number in the Fourier domain

First Vertical Derivative of the Pole Reduced Field

First vertical derivative (*1VD*) of RTP data computes the vertical rate of change in the magnetic field and tends to sharpen the edges of anomalies and enhance shallow features (Telford et al., 1990). The 1VD in the spatial domain is shown as

$$1VD = \frac{dRTP}{dZ} \quad eq. 4.2$$

where $Z$ is the vertical offset. The computation was done using a 5x5 spatial filter in the software package WinDisp from Scientific Computing and Applications. The weights were computed by transforming the 1VD operator defined in the Fourier domain into the spatial domain.

Second Vertical Derivative of the Pole Reduced Field

Second vertical derivative (*2VD*) of RTP data is a measure of curvature and large curvatures are associated with shallow anomalies (Telford et al., 1990). The 2VD enhances near-surface effects at the expense of deeper anomalies and is shown as

$$2VD = \frac{d^2RTP}{dZ^2} \quad eq. 4.3$$

where $Z$ is the vertical offset. The computation was done using a 5x5 spatial filter in the software package WinDisp from Scientific Computing and Applications. The weights were computed by transforming the 2VD operator defined in the Fourier domain into the spatial domain.

Tilt Angle of the Pole Reduced Field

The tilt angle (Miller and Singh, 1994) calculates the arctangent of the angle between the vertical gradient and the horizontal gradient of the magnetic field to normalize data and to help discriminate between signal and noise. The tilt angle in the spatial domain is shown as

$$TILT = \tan^{-1} \frac{\frac{dRTP}{dZ}}{\sqrt{\left(\frac{dRTP}{dX}\right)^2 + \left(\frac{dRTP}{dY}\right)^2}} \qquad eq. 4.4$$

where $X$ and $Y$ are the horizontal offsets in the east and north directions. The first vertical derivative, as well as horizontal derivatives in $X$ and $Y$ directions are computed in the spatial domain. The computation was applied to the reduced to pole magnetic field data using a 5x5 spatial filter in the software package WinDisp from Scientific Computing and Applications. The weights were computed by transforming the TILT operator defined in the Fourier domain into the spatial domain.

Analytic Signal Amplitude

Analytic Signal (AS) of the residual magnetic field (RMF) is calculated by taking the square root of the sum of the squares of the derivatives in the horizontal ($X$ and $Y$), and vertical ($Z$) directions of the magnetic field at a given location. The resulting shape of the analytic signal is independent of the orientation of the magnetization of the source for 2D bodies and is centered on the causative body (Nabighian, 1972). This has the effect of transforming the shape of the magnetic anomaly from any magnetic inclination to one positive, body-centered anomaly. The Analytic Signal in the spatial domain is shown as

$$AS = \sqrt{\left(\frac{dRMF}{dX}\right)^2 + \left(\frac{dRMF}{dY}\right)^2 + \left(\frac{dRMF}{dZ}\right)^2} \quad eq. 4.5$$

where RMF is the reduced magnetic field from the magnetic survey data. The computation was done using a 5x5 spatial filter in the software package WinDisp from Scientific Computing and Applications. The weights were computed by transforming the AS operator defined in the Fourier domain into the spatial domain.

A low-pass (Butterworth) filter was applied to the 1VD, 2VD, and Tilt angle of the RTP magnetic field, and the analytic signal of the RMF grids. This filtering was performed in the Fourier domain using GOCAD and is based on a Gaussian curve defined by a cut-off frequency twelve times the grid cell size and a roll-off frequency six times the grid cell size. Users of the above filtering products for interpretation often assume the absence of remnant magnetization and self-demagnetization. Their effects are commonly ignored or assumed to be insignificant.

Laurentian Goldfields Ltd. magnetic data were collected and processed by Scott Hogg & Associates Ltd., (2010) and used as raster images in this report, which were georeferenced to the Ear Falls area using QGIS. Processing steps applied by Scott Hogg & Associates involved data leveling to eliminate differences at the intersections between traverse and control lines using a piecewise linear function between intersections and a final microlevel correction was applied where necessary. As the vertical magnetic gradient was surveyed the 1VD of magnetic field did not need to be calculated as they represent the same physical quantity. The recorded pitch, roll and yaw of the towed bird holding the magnetic sensors were used to mathematically rotate the measured basic gradients to an orthogonal array oriented north, east and down. All magnetic data were leveled to a common ideal flight surface generated from the GPS altitude measurements of the towed bird. All magnetic data were then reduced to the pole and the 2VD was calculated from the measured vertical gradient.

### 4.2 Gravity

The retrieved gravity data are from the Canadian Gravity Anomaly Database (CGDB) and consists of 730 gravity measurements distributed throughout the Ear Falls area (GSC, 2012). All gravity measurements were leveled to the Canadian Gravity Standardization Network (CGSN), which is itself based on the International Gravity Standardization Network of 1971 (IGSN71). Both networks use the ellipsoid GRS80 as reference. FA and Bouguer anomalies for each gravity station were calculated from the observed gravity by the GSC.

The FA anomaly incorporates a correction to the observed gravity to account for the difference in elevation between the observed station and the reference ellipsoid. The FA anomaly is detailed in equation 4.6 as

$$FA = g_0 - g_t + \frac{dg}{dz}h \qquad eq. 4.6$$

where $g_0$ is the observed gravity, $g_t$ is the theoretical gravity at the surface of the reference ellipsoid (GRS80), $h$ is station elevation above mean sea level in metres, and *dg/dz* equals 0.3086 mGal $m^{-1}$ which reflects the average vertical gravity gradient per metre of elevation above sea level).

The Bouguer anomaly includes a further correction for the mass between the station and the reference ellipsoid (GRS80). The Bouguer anomaly (BA) is detailed in equation 4.7 and shown on Figure 10.

$$\begin{aligned} BA &= g_0 - g_t + \left(\frac{dg}{dz} - 2\pi G\rho_c\right)h + TC \qquad eq. 4.7 \\ &= FA - 2\pi G\rho_c h + TC \end{aligned}$$

where the constant of gravitation $G$ equals 6.672 x $10^{-6}m^3kg^{-1}s^{-2}$ (IAG, 1975), $\rho_c$ is the average density of crustal rock (2670 kg $m^{-3}$), $TC$ is the terrain correction in mGal, and *dg/dz* equals 0.3086 mGal $m^{-1}$ which reflects the average vertical gravity gradient per metre of elevation above sea level (Telford et al 1990).

The calculated Bouguer gravity anomaly was gridded over the Ear Falls area using a minimum curvature algorithm with a 500 m by 500 m cell size to achieve a finer resolution than the retrieved GSC grid. As there is only a station every 5 to 15 km along the southern and southeastern portion of the Ear Falls area, the interpretation takes into account the variable distribution of stations. All gravity grids were projected to the local NAD83 UTM15N coordinate system. The first vertical derivative of the Bouguer gravity was calculated using the same methodology applied to the magnetic field data and is shown on Figure 11.

## 4.3 Radiometric

The following radiometric grids (radioelement concentrations and ratios) were acquired for the Ear Falls area from the GSC's nationwide radiometric compilation at 1000 m grid cell size (GSC, 2012). No additional processing beyond typical survey quality control was applied to the retrieved radiometric data set.

The data consisted of measurements of three radioelement concentrations and a dose rate:

- Potassium, K (%)
- Equivalent uranium, eU (ppm)

- Equivalent thorium, eTh (ppm)
- Total Air Absorbed Dose Rate (nGy/h)

Three additional grids were calculated from these measurements by the GSC based on the ratios of radioelement concentrations:

- Equivalent Uranium/equivalent Thorium ratio (eU/eTh)
- Equivalent Uranium/Potassium ratio (eU/K)
- Equivalent Thorium/Potassium ratio (eTh/K)

The grids were previously merged by the GSC consisting of high and low resolution datasets. The determination of the radioelement concentrations, dose rate and ratios followed the methods and standards published by the International Atomic Energy Agency (IAEA, 2003), many of which were developed at the GSC. The dose rate is a calibrated version of the measured "total count", and reflects the total radioactivity from natural and man-made sources. Typical survey quality control was applied to the retrieved radiometric dataset and a ternary radiometric image was generated by Mira (Figure 12).

## 4.4 Electromagnetic

### 4.4.1 Very Low Frequency Electromagnetic (VLF-EM)

The VLF-EM data was acquired in the form of raster images from a Laurentian Goldfields assessment file archived at the Ministry of Northern Development and Mines (MNDM). The total field (Line and Ortho) of the VLF data were originally gridded using a cell size of 20 m, and were projected in NAD83 UTM 15N coordinates. The acquired raster images were georeferenced to the Ear Falls area in QGIS.

VLF-EM sources alternated between Cutler, Maine, (24 kHz) and Seattle, Washington, (24.8 kHz) for the Line channel (Figure 13), and remained set on Lamour, North Dakota, (25.2 kHz) for the Ortho channel (Figure 14). Leveling and filtering of the data was performed by Scott Hogg & Associates Ltd., as detailed in the Laurentian Goldfields assessment file report (Laurentian Goldfields Ltd., 2010).

### 4.4.2 Frequency Domain and Time Domain Electromagnetic (FDEM and TDEM)

Quality control and processing of the Frequency Domain Electromagnetic (FDEM) data from the GDS1026 survey were completed by the OGS (OGS, 2003) and are summarized in this section. The profile EM data were adjusted to within the noise level of the instrument and system frequency. The inphase and quadrature data were individually gridded and inspected for leveling errors. A frequency of 7,200 Hz was used to calculate the apparent resistivity at each valid EM data sample using the homogeneous half-space model (e.g. Fraser, 1978). The choice of frequency was primarily geared towards identifying conductive bedrock targets within the survey area, and to minimize the impact of surficial and cultural signals.

The OGS performed quality control and processing of the Time Domain Electromagnetic (TDEM) data and is summarized in the Pakwash Lake area (GDS1218; OGS, 2002a) and Trout Lake area (GDS1222; OGS, 2002b) survey reports. The Pakwash Lake Area profile EM data were leveled and the apparent conductivity of thin sheet model was derived from channel 20 in-pulse data. These data are lagged 12 samples less than the off-time data. The measured EM signal was reduced by subtracting the theoretical secondary field response produced by a chosen geological model which was a vertical plate model (600 m strike length by 300 m depth) in this survey. The apparent conductivity was provided in millisiemens/metre (mS/m) and converted to apparent resistivity in ohm-metres (ohm-m).

The Trout Lake River Area profile EM data were processed to reduce noise, improve base level estimates and increase the signal to noise ratio of selected EM profile data channels for the purpose of obtaining reliable and unambiguous resistivity and decay constant calculations. On-time channel 20 and the off-time channels 1 to 14 from the vertical coil data were used for apparent conductivity computation based on a homogeneous half-space model. The apparent conductivity was provided in mS/m and converted to apparent resistivity in ohm-m.

The EM data were gridded by the OGS using an Akima spline algorithm at 40 m cell size. Although minimum curvature is typically well suited for potential field data, the Akima spline provided best results for the high-amplitude, short wavelength anomalies recorded in the EM data. For practical reasons, data from the Pakwash Lake and Uchi-Bruce Lake apparent resistivity grids were merged to form a single grid with a 40 m cell size shown on Figure 15.

All the above surveys are delivered with an EM anomaly database, where individual anomalies have been picked along flight lines and then classified by the OGS as bedrock source, surficial source (e.g., overburden) or cultural (e.g., hydro line) source. Bedrock anomalies usually incorporate a vertical plate or similar model to provide an estimate of depth-to-top and conductivity. In some cases the source of the EM response was undetermined.

### 4.5 Seismic Reflection

The retrieved seismic line WS2B data was acquired and processed through the Lithoprobe program (Asudeh et al 1996; Calvert et al., 2004). The data were recorded uncorrelated with a 47.1 second post-sweep listen time, which permitted the extended correlation of field records to 32 s. Data were processed at the Lithoprobe Seismic Processing facility in Calgary using a pre-migration sequence consisting of refraction statics, crooked line binning, gapped deconvolution, velocity analysis, normal moveout, surface-consistent residual statics, crossdip correction, stack, and projection onto a north–south line, which removed some significant changes in apparent dip due to the crooked line geometry. Wave-equation migrations and segment migration (Calvert, 2004) were computed, and displayed at a variety of gains for interpretation (Calvert et al., 2004).

The interpreted seismic reflection section is shown on Figure 16 with minor vertical exaggeration (2:1). Further processing was not completed as part of this assessment.

## 4.6 Magnetotelluric

The retrieved MT data shown on Figure 17 are from the GSC Lithoprobe Data Archive (GSC, 2012), and consist of a data file in EDI format (Wight, 1987) for each MT sounding collected. Each MT dataset contained processed data that underwent quality control checks. Two characteristics of MT soundings can be calculated: the impedance skew (eq. 4.9) and the magnetic tipper magnitude (eq. 4.11). The impedance skew defines the asymmetry of the impedance tensor and gives information about the heterogeneity of the underground conductivity. The magnetic tipper magnitude is a measure of the tipping of the magnetic field out of the horizontal plane (Vozoff, 1991) and helps in defining the direction of a lateral change in conductivity.

Horizontal components, $E_x$ and $E_y$, of the electric field $E$ and the horizontal components, $H_x$ and $H_y$, of the magnetic field $H$ satisfy the impedance relation defined by:

$$\begin{aligned} E_x &= Z_{xx}H_x + Z_{xy}H_y \\ E_y &= Z_{yx}H_x + Z_{yy}H_y \end{aligned} \quad \textit{eq. 4.8}$$

Where $Z_{xx}$, $Z_{xy}$, $Z_{yx}$ and $Z_{yy}$ are the impedance tensor components.

The impedance skew, $ZSKEW$, is defined by:

$$ZSKEW = \left|\frac{Z'_{xx}+Z'_{yy}}{Z'_{xy}-Z'_{yx}}\right| \quad \textit{eq. 4.9}$$

Where $Z'_{xx}$ , $Z'_{xy}$, $Z'_{yx}$ and $Z'_{yy}$ are the impedance tensor components rotated to the impedance strike angle.

As a general practice rule an impedance skew $ZSKEW > \sim 0.25$ indicates that underlying structures are not 2D but this has an ambiguity as small values can also be observed along symmetry axes of 3D structures (Thiel, 2008). 2D structures are considered to be very long in a given horizontal direction and a uniform cross-section is observed in any plane perpendicular to that direction, this is different from 3D structures which have non-uniform cross-section being observed in any of these perpendicular planes. Despite the impedance skew being a good tool to understand inhomogeneities at depth, it can be affected by small near-surface structures with smaller dimensions than the skin-depth of the shortest period used for sounding. Components, $H_x$ , $H_y$ and $H_z$, of the magnetic field $H$ satisfy the tipper relation defined by:

$$H_z = T_x H_x + T_y H_y \quad \textit{eq. 4.10}$$

Where $T_X$ and $T_Y$ are the complex tipper components.

The magnetic tipper magnitude, $TIPMAG$, is defined by:

$$TIPMAG = \sqrt{|T_x|^2 + |T_y|^2} \quad eq.\ 4.11$$

The tipper magnitude is zero for the 1D Earth case and typically increases between 0.1 and 0.6 as it responds to vertical and sub-vertical structures. Values greater than 1 can be reached when close to the source of the perturbation, however directly over the source the tipper can cross-over and become zero.

# 5 GEOPHYSICAL INTERPRETATION

## 5.1 Methodology

The coincidence of geophysical features with mapped lithology and structural features were identified and interpreted for the Ear Falls area using all available geophysical data sets. In particular, the reduced to pole and vertical derivatives of the magnetic field data were the most reliable for mapping variations in geological contacts, identifying heterogeneity, and delineation and classification of structural lineaments (faults, dykes). The methodology and results from the structural lineament interpretation are presented in the lineament report for the Ear Falls area (SRK, 2013). Enhanced grids of the total magnetic field data were also used to assist in the interpretation, as follows:

- Pole reduced magnetic field - distribution of magnetic units (Figure 5);
- Pole-reduced first and second vertical derivative - boundaries, texture, foliation (Figure 6 and Figure 7);
- Analytic signal (Figure 8) - anomaly character, texture, boundaries; and
- Tilt angle (Figure 9) – subtle magnetic responses. In particular, tilt angle maps allow the identification of contacts and magnetic lineaments in the presence of a varying magnetic background.

Gravity data are typically not used for detailed interpretation of geological units and boundaries. However, an interpretation of general characteristics of some regional scale geologic units were made using the Bouguer gravity data and its first vertical derivative. Similar comments apply to the radiometric data as only regional observations could be made due to their poor spatial resolution and shallow depth of investigation. The electromagnetic data were not used for the interpretation as the magnetic data proved greatly superior from a mapping perspective. However, certain geological features of a structural nature were evident in the electromagnetic data, and are discussed below.

The magnetic characteristics and geophysical contacts were compared to the current mapped bedrock geology in order to identify similarities and/or changes in the lithological contact locations. These geophysical data were evaluated against the 1:250 000 Scale Bedrock Geology of Ontario, Miscellaneous Release Data 126-Revision 1 (OGS, 2011), shown on Figure 2. The coincidence of the lithological units with the geophysical data was mainly based on the magnetic data, considering the amplitude, texture, width, and orientation characteristics of the magnetic response. In general, the geophysical interpretation for the Ear Falls area is consistent with the mapped geology, since the regional scale geophysical data was used by the OGS to develop the current bedrock maps for the Ear Falls area. In some cases, difference in the contacts between the magnetic data and the mapped boundaries may reflect a subsurface response which may not match the mapped surface contacts (e.g., dipping unit) and/or a contact extended through locations with limited outcrop exposure (e.g., under overburden and drainage cover). The geophysical interpretation presented in this report uses the recent high resolution magnetic survey data to refine geological contacts where better coverage was available (i.e., the northern half of the Ear Falls area). Similarities and differences noted between the geophysical interpretation and currently mapped bedrock geology are discussed in the following sections.

## 5.2 Results

The following section presents a regional-scale description and interpretation of each geophysical dataset in the Ear Falls area, followed by detailed interpretations of geophysical responses associated with major geologic units, including the English River gneissic belt, the major intrusives (i.e., Bluffy Lake batholith, Bruce Lake pluton, Pakwash Lake pluton and Wenasaga Lake batholith), as well as smaller intrusives identified within the Ear Falls area (Figure 2). The interpretation also discusses how well the geophysical data relates to the Bedrock Geology of Ontario map (OGS, 2011, MRD126-REV).

### 5.2.1 Magnetic

The reduced to pole (RTP) residual magnetic field (Figure 5) shows a generally subdued response over large areas of the English River gneissic belt, the Pakwash Lake pluton, the Bruce Lake pluton, the Wenasaga Lake batholith, the Winnipeg River Subprovince plutonic suite within the Ear Falls area, and other smaller or unnamed granitic intrusions. The low magnetic amplitude response of the English River metasedimentary rocks is likely a result of relatively low magnetic susceptibility (Beakhouse, 1977; Hall and Brisbin, 1982). RTP lows are supported by a fairly consistent amplitude response of the first vertical derivative (1VD) (Figure 6) and low values of the analytic signal (Figure 8), which indicates fairly homogeneous bodies. The low, and in some cases, complete lack of magnetic contrast between some of the granitic intrusives and the surrounding metasedimentary rocks makes it difficult to distinguish the contact between them (Nitescu et al., 2006).

There is moderate to elevated magnetic responses in the RTP magnetic data (Figure 5), such as the Bluffy Lake batholith and the northern portion of the Wapesi Lake batholith. Within the Ear Falls area the observed high magnetic responses correspond to granitic and granodiorite intrusions identified by field mapping (Nitescu et al., 2006). The 1VD (Figure 6), 2VD (Figure 7) as well as the analytic signal (Figure 8), support these observations as a high magnetic response where their boundaries are shown as moderate to sharp magnetic contacts. The fact that only portions of some intrusions are highlighted by the magnetic data could be explained by the presence of a more magnetic phase reflecting variations in mineralogical composition or lithological heterogeneity.

The high resolution magnetic survey from the Goldpines Property (Laurentian Goldfields Ltd., 2010) shows several elevated magnetic responses observed on the western end of the Wenasaga Lake batholith, as well as between the Sydney Lake and Long Legged Lake fault zones west of the Pakwash Lake pluton (Figure 5). Most significantly, the strong magnetic unit immediately west of the Wenasaga Lake batholith, exhibits a rim of strong magnetization along its contact margin. Although field mapping over this anomaly by Laurentian Goldfields is limited to an individual outcrop, the observed high magnetic response is coincident with the location of potassium-feldspar rich granitic bedrock with elevated magnetite content (Laurentian Goldfields Ltd., 2010). The other minor magnetic high responses noted between the Sydney Lake and Long Legged Lake fault zones correspond to a large-scale fold structure consisting of gneissic metasedimentary rock regularly interlayered with magnetite-rich granitic pegmatite, which makes up a tight antiformal structure (Laurentian Goldfields Ltd., 2010). Several extremely high magnetic responses are observed within the northern portion of the Ear Falls area. These responses are shown as particularly well-defined magnetic anomalies with sharp contacts within the RTP data and its vertical derivative grids. These anomalies coincide with iron formations located on the northern portion of the English River Subprovince within metasedimentary units, and are typically bordering various granitic intrusions. The most significant is the former Griffith Iron Mine, located along the western edge of the Bruce Lake pluton, which is clearly visible as a magnetic high in all datasets.

### 5.2.2 Gravity

The Bouguer gravity anomaly and the 1VD Bouguer gravity results are presented on Figures 10 and 11, respectively. A large positive gravity anomaly is associated with the English River Subprovince, bordered by a lower gravity response over the Uchi Subprovince and the Sydney Lake fault zone in the north, and by the north-east trending Wapesi Lake fault to the south in the south-east corner of the Ear Falls area. This higher gravity anomaly was noted by Nitescu et al., (2006) and inferred to correspond to the gneissic metasedimentary rocks. Others have interpreted this gravity high as a uniform gneissic metasedimentary unit which extends to depths greater than 8 to 10 km (Runnals and West, 1978; Gupta and Barlow, 1984; Gupta and Wadge, 1986). Although it is suggested that the presence of a gneissic to felsic intrusive unit beneath the gneissic metasedimentary rocks is an explanation of the gravity anomaly, there is a recognized lack of information at depth to constrain this interpretation (Nitescu and Cruden, 2001).

Based on forward modeling from Nitescu et al. (2006), the metasedimentary gneissic belt seems to be relatively thin (less than 1 km) in the areas where it is inferred to be underlain by felsic intrusions. In some cases metasedimentary rocks reach greater depths (up to about 4 km) in narrow regions along the boundaries of the belt and between clusters of intrusive bodies (Winnipeg River plutons, Bruce Lake and Pakwash Lake plutons, Wenasaga Lake and Bluffy

Lake batholiths), where they appear to be underlain by rocks that may be similar to the gneissic rocks exposed in the Winnipeg River belt (Nitescu et al., 2006). Forward modeling was carried out using average densities ranging from 2,680 – 2,700 kg/m$^3$ for the Uchi and Winnipeg River subprovinces and 2,730 to 2,740 kg/m$^3$ for the English River Subprovince (Gupta and Wadge, 1984).

A low gravity response is observed in the northern part of the Ear Falls area below the Birch-Uchi greenstone belt and associated felsic intrusive units. This transition to a gravity low is somewhat abrupt and occurs generally along the area between the Sydney Lake and Long Legged Lake fault zones. This low response to the north of this fault zone is inferred to be due to the presence of a less dense complex of metavolcanic and felsic intrusive rock units associated with the Uchi Subprovince, compared to the gneissic metasedimentary rocks of the English River Subprovince, where there is a contrast in the average rock density of approximately 40 kg/m$^3$ (Nitescu et al., 2006).

### 5.2.3 Radiometric

The radiometric data (potassium, uranium and thorium) observed in the Ear Falls area reflect subtle variations in lithology observed between the granitic intrusive rocks which are typically elevated in radiometric elements compared to volcanic and metasedimentary rocks. The lower resolution radiometric data and presence of surficial soils and lakes in the Ear Falls area limits the usefulness of this data for interpreting geological units and their contacts. In the case where the overburden is thin or is locally derived from the underlying bedrock, the radiometric data does provide some lithological insight. A ternary plot of the airborne radiometric data for the Ear Falls area is provided on Figure 12 as a composite RGB ternary diagram representing the three radiometric parameters (Red – Thorium, Green – Uranium, and Blue – Potassium). The variability in the radiometric values over the Ear Falls area are presented in Table 4. These radiometric values are typical of felsic to mafic metavolcanics, felsic to mafic intrusives and gneissic rocks (IAEA, 2003).

Elevated potassium levels in the Ear Falls area are predominantly associated with the occurrence of tonalites and muscovite-bearing granitic rocks. These intrusive units tend to be defined by a subtle gradation in the potassium levels marking the contact with the adjacent metasedimentary and felsic to mafic metavolcanic rocks. Subtle variations of the radiometric responses are also observed within the intrusive units perhaps reflecting different intrusive phases or differentiated internal lithologies, although such variations may also reflect variability in the composition of the overburden deposits. Uranium levels tend to be generally low throughout the Ear Falls area. Elevated thorium levels in the Ear Falls area generally correlate to the metasedimentary rocks of the English River gneissic belt and the intrusive units of the Winnipeg River terrane. The numerous large water bodies present in the Ear Falls area appear as dark colours on the radiometric ternary image, indicating low potassium, uranium and thorium concentrations (Figure 12).

**Table 4. Radiometric responses for gamma-ray spectrometry parameters within the Ear Falls area**

| Radioelement | Minimum | Maximum | Mean |
|---|---|---|---|
| Potassium (%) | 0.06 | 2.31 | 1.09 |
| Thorium (ppm) | 0.26 | 11.45 | 4.10 |
| Uranium (ppm) | 0.02 | 1.56 | 0.72 |
| Natural air absorbed dose rate (nGy/h) | 1.63 | 62.78 | 28.55 |

The low uranium levels suggest low radon risk. However, radon risk is also quite dependent on soil permeability and should be verified by soil gas measurements (IAEA, 2003).

### 5.2.4 Electromagnetic

The VLF-EM, FDEM and TDEM electromagnetic surveys provide insight into the electrical properties and therefore the lithologies of the bedrock units and overlying Quaternary cover. Electromagnetic response is also strongly influenced by variations in topography, particularly abrupt topographic changes, and by the presence of water bodies.

#### *5.2.4.1 VLF-EM*

The VLF-EM Line and Ortho total field data from the Laurentian Goldfields survey are presented on Figure 13 and Figure 14, respectively. The total field VLF-EM data typically shows a maximum response over conductors, and shows some linear structures within the various bedrock units. The eastern trending linear structures observed on the Line total field VLF-EM data tend to be coincident with units also observed in the magnetic data, and provides corroborating evidence with respect to the location and orientation of previously mapped structures.

The boundaries of the geological units are not particularly well resolved by the VLF-EM dataset. High magnitude total field VLF-EM responses are found to generally correlate to areas of good bedrock exposure and topographic highs, while low magnitude responses generally correlate to low-lying areas with Quaternary sediment or water cover. Two prominent linear units trending in a northwest direction are observed in the Line dataset in the eastern side of the VLF-EM survey area (Figure 13), which correspond to a high voltage power line located along the Highway 105 corridor.

#### *5.2.4.2 FDEM and TDEM*

The Frequency Domain Electromagnetic (FDEM) and Time Domain Electromagnetic (TDEM) data for the Ear Falls area is presented as apparent resistivity on Figure 15. Several high resistivity anomalies occur to the south and east of the Bruce Lake pluton and to the north of the former Griffith Iron Mine west of Bruce Lake (Figure 15). These correspond to exposures of mafic to intermediate metavolcanic bedrock associated with the Birch-Uchi greenstone belt. These resistivities are within the range of expected values for greenstone belt formations (e.g. Telford et al., 1990).

The low resistivity responses within the survey area are predominantly associated with the presence of Quaternary-aged glaciolacustrine deposits and water bodies. The low resistivity cover in these areas limits the ability to detect and image the underlying bedrock. Some Quaternary structures, such as the end moraines shown on Figure 3, are evident as high resistivity linear features, including the Lac Seul moraine.

The OGS EM anomaly database identified a large number of EM responses indicative of bedrock conductors (see Figure 15), most of which are located over metavolcanic units, iron formations or along the contact with intrusive bodies, such as the Bruce Lake pluton, or the Wenasaga Lake and Bluffy Lake batholiths.

### 5.2.5 Seismic Reflection

Calvert et al. (2004) and Zeng and Calvert (2006) provide a comprehensive interpretation of the WS2B Lithoprobe seismic reflection line shown on Figure 16, which shows a transect through the English River metasedimentary units and the Uchi greenstone belt in the Ear Falls area. The Pakwash Lake and the Sydney Lake fault zones (labeled PLFZ and SLFZ on Figure 16) are intersected by the WS2B seismic line at geophone stations 6300 and 6800, respectively. On Figure 2 and Figure 18 the Pakwash Lake fault zone is labeled as Long-Legged Lake fault zone based on the OGS bedrock geology map. The remaining labeled features within the Ear Falls area consist of the boundary zone between the confederation assemblage (BCMS) and the metasedimentary rocks, and an unnamed fault zone (FZ).

Calculation of the velocity structure to a depth of 1.5 km showed a significant velocity reduction in the near surface within the interval located between the two fault zones compared to the gneissic metasedimentary rocks to the south and the metavolcanics to the north (Zeng and Calvert, 2006). Extensive fracturing and mylonitization of the rock between the two fault zones (Stott and Corfu, 1991) provides the most plausible explanation for the low velocity zone (Zeng and Calvert, 2006). An alternative explanation is the presence of granitic plutons, which are observed in outcrop; however, these plutons are not present throughout the entire width of the low velocity interval.

### 5.2.6 Magnetotelluric

Two magnetotelluric (MT) soundings (WST062 and WST074) were carried out within the Ear Falls area as part of the Lithoprobe project, at the locations shown on Figure 17. The impedance skew (skew) and magnetic tipper magnitude (tipper) plots for these soundings are also presented on Figure 17. Results from the two MT soundings located within the English River gneissic belt (WST062 and WST074) possess variability in their tipper and skew response characteristics.

Interpretation of the MT skew response may provide an indication of vertical heterogeneity, which may reflect changes in lithology and/or the presence of structure, such as faults and folds in the subsurface. A higher skew response for a given frequency indicates that geological structures are not explained by a 2D earth structure, but by a 3D structurally heterogeneous earth (Telford et al, 1990).

The MT station located north of Lac Seul (WST062) shows a low and un-perturbed skew response corresponding to frequencies ranging from $3x10^{-3}$ Hz to $10^{-1}$ Hz. The skew response at approximately $3x10^{-3}$ Hz shows a marked increase followed by a gradual reduction and increased variability in values at lower frequencies.

The skew response from the MT station located south of Pakwash Lake (WST074) shows variability in values at frequencies between $10^{-2}$ Hz to 1 Hz as the skew response first increases to a maximum with a frequency of approximately $0.5x10^{-2}$ Hz, then quickly decreases and generally stabilizes at low values for frequencies less than $10^{-2}$ Hz.

The skew response for sounding WST074 suggests that underlying rocks may show an increase in 3D heterogeneity to a skin depth corresponding to a frequency of $10^{-1}$ Hz, followed by a decrease in 3D heterogeneity to a skin depth corresponding to a frequency of $2x10^{-3}$ Hz. The opposite is observed for sounding WST062 where rocks seem to represent 2D geological structures to a greater depth corresponding to a skin depth with lower frequency ($3x10^{-3}$ Hz), below which the rocks seem more 3D heterogeneous.

Observed skew maximums identified at both MT stations for different frequencies correspond to a change in heterogeneity which may reflect the top of a different geological unit at depth. If so, the results may indicate a transition from the metasedimentary rocks to the underlying unit and that the metasedimentary layer is thicker at WST062 relative to WST074.

An overall low tipper magnitude of less than 0.2 coincides with the peaks in skew response for both MT stations. This may suggest the 3D heterogeneities in the earth are not composed of steeply dipping structures, and a possible contact between the metasedimentary rocks and the underlying unit may have a shallow dip.

## 5.3 Geophysical Interpretation of the Batholiths, Plutons and Gneissic Metasedimentary Rocks in the Ear Falls Area

The following section provides more detailed geophysical interpretations of the English River gneissic belt, Wenasaga Lake batholith, Bruce Lake pluton, Bluffy Lake batholith, Wapesi Lake batholith, Pakwash Lake pluton, and other smaller intrusives in the Ear Falls area. The interpretations include a description of the geophysical characteristics of each unit, as well as a refinement of geologic contacts, where possible, and the identification of internal heterogeneities within the structures, if present. These interpreted units are presented alongside the current bedrock geology mapping on Figure 18, noting that the interpretations are preliminary and require future geologic validation. The refined contacts and identified units are labeled A to Q on Figure 18, and discussed further in the sections below.

### 5.3.1 English River Gneissic Metasedimentary Rocks

Almost all of the aeromagnetic coverage over the English River gneissic metasedimentary rocks in the Ear Falls area south of the Sydney Lake fault zone is low resolution, with the exception of the northwestern margin of the gneissic belt, where the high resolution Laurentian Goldfields dataset is available. Generally, the English River gneissic metasedimentary rocks exhibit a subdued magnetic response and are typically the least magnetically responsive rocks in the Ear Falls area. There are however, areas of elevated magnetic response within this unit. Some of these magnetic units are coincident with mapped geologic features, such as granites or granodiorites, but are more frequently mapped as an undifferentiated unit of gneissic metasedimentary rocks.

Interpreted geophysical units A to P within the English River gneissic metasedimentary rocks are shown on Figure 18, and all show an elevated magnetic response when compared to the balance of the gneissic metasedimentary rocks. The type of rock units these magnetic highs may correspond to is speculative, but they likely represent magnetite-bearing granitic or granodioritic rocks in most cases based on the similar magnetic response seen in the Bluffy Lake batholith and the presence of small mapped intrusions in some of the magnetically responsive areas. Where these anomalies extend into high resolution datasets, such as that of Laurentian Goldfields, they are much better resolved.

The largest unmapped magnetic high (unit A) is situated within the western half of the gneissic belt, west of Manitou Falls, and is on the order of 15 by 10 km in size. This unit may reflect magnetite enrichment in the gneissic metasedimentary rocks during migmatization. A small portion of this unit extends into the high resolution coverage of the Laurentian Goldfields survey where the presence of banding and folding is suggested by high resolution response. We speculate that the balance of unit A may be similar. Units D, E, G, F, and I also appear to reflect differential enrichment in magnetic minerals (e.g., magnetite and phyrrhotite) during migmatization. Another large unmapped magnetic high (unit B) is found to the northeast of Lac Seul, and is on the order of 5 by 10 km in size. This unit may reflect mineral enrichment of the metasedimentary rocks during migmatization or it may be caused by a western extension of the magnetic McKenzie Bay stock beneath the metasedimentary rocks. If so, units B and K may also reflect the magnetic response of this hypothetical underlying intrusive. Geophysical unit C corresponds to an intrusive unit mapped by Laurentian Goldfields Ltd. (2010). Geophysical units D to K also represent areas of elevated magnetic response within the gneissic metasedimentary rocks. Geophysical units N and O are magnetic highs along the contact between the gneissic metasedimentary rocks and the southwest part of the Bluffy Lake batholith. These units appear to represent the western extension of the Bluffy Lake batholith beneath the gneissic metasedimentary rocks. Such an interpretation is consistent with the presence of elliptical gneissic layering visible on satellite imagery in the area southeast of Celt Lake which suggests the possible doming of the metasedimentary rocks over some kind of basement structural feature. Geophysical unit P is a refinement of the mapped foliated tonalite unit within the metasedimentary rocks mapped to the northwest of the Wenasaga Lake batholith.

The English River gneissic belt represents a gravity high in comparison to the surrounding rocks north of the Sydney Lake fault zone, and the intrusive rocks to the southeast proximal to the Wapesi Lake fault zone. The western half of the gneissic belt west of Hwy 105 has moderate resolution gravity data, with stations frequently on the order of 2 to 3 km apart, whereas the eastern half of the gneissic belt has very few gravity stations. The highest gravity response in the area occurs in the southwest corner of the gneissic belt and does not appear to correlate to a mapped geologic feature or a magnetic anomaly. There is also a moderate gravity high on the eastern side of the gneissic belt, but it should be noted that this anomaly is defined by only two data points.

Radiometric coverage for the entire Ear Falls area is low resolution. The radiometric response over the English River gneissic belt is quite variable and does not appear to correlate particularly strongly to mapped geology or magnetic anomalies. Response over Lac Seul, a large water body, is very low. The response over the majority of the land mass is generally white, indicative of a comparable response in all three radiometric components. There is an elevated U-Th response in the central part of the gneissic belt, just west of Highway 105. There are three areas of slightly elevated U response, none of which appear to correlate well to distinct mapped geology or magnetic response.

There is no significant VLF coverage within the English River gneissic belt south of the Sydney Lake fault zone, only a very small area surveyed by Laurentian Goldfields. The VLF response within the gneissic metasedimentary rocks is generally low and there is little structure visible. VLF EM structures observed tend to be orthogonal to the transmitter direction.

There is no EM coverage within the English River gneissic belt.

### 5.3.2 Wenasaga Lake Batholith

Aeromagnetic coverage over the Wenasaga Lake batholith consists of approximately 60% high resolution coverage and 40% low resolution coverage from three different datasets. Magnetic response is generally observed to be low in the central part of the batholith. The unit C is evident as a distinct geological unit in the high resolution dataset to the west of the batholith. There is also a strong magnetic response at the east end of the batholith, which continues east of the mapped geologic contact (unit Q). There are some additional elevated magnetic responses observed in both the high and low resolution datasets along the northern contact with the metasedimentary rocks. These magnetic highs correspond to or are on strike with known iron formations. The southern margin of the batholith generally does not show a magnetic response at its mapped contact margin.

There is moderate resolution gravity coverage over the Wenasaga Lake batholith, with stations on the order of 2 km apart at the east and west ends of the batholith, but no stations in the central part of the batholith. The gravity response is moderate, as it is situated along the transition zone between the English River and Uchi subprovinces. The gravity response of this batholith generally blends in with the regional trend toward increasing gravity response as one moves southward from the Uchi Subprovince. It does appear as a very slight gravity low, but this could be a gridding artifact. A local gravity high is observed at the far east end, where the batholith is in contact with the Bruce Lake pluton.

Radiometric coverage for the entire Ear Falls area is low resolution. The radiometric response of the Wenasaga Lake batholith is generally distinct from adjacent formations to the north and south, while the response blends in with the adjacent formations to the east and west. The central part of the batholith has an elevated U response, while the western end of the batholith has an elevated K-Th response. The eastern end of the batholith has a neutral response, with neither K, U or Th prominent.

Approximately 30% of the Wenasaga Lake batholith (its western end) has VLF EM coverage. The VLF EM structures observed tend to be orthogonal to the transmitter direction and no clear southwest margin can be discerned for the Wenasaga Lake batholith.

EM coverage over the Wenasaga Lake batholith is limited to about 15%, focussed on the northeast corner of the batholith. The Lac Seul moraine is evident in the EM dataset as a resistivity high. There are a number of conductors identified along northern contact with the metasedimentary rocks. There is also a local resistivity high along eastern edge of the batholith.

### 5.3.3 Bruce Lake Pluton

The Bruce Lake pluton has high resolution aeromagnetic coverage over its entire area. It has a generally low magnetic response but the magnetics reveal some subtle structures oriented west-east and northwest-southeast. There are some high magnetic responses along the western margin of the pluton due to iron formations, the former Griffith Iron Mine and its tailings dam. The contact margin of the pluton is generally evident in the magnetic response, although the contact margin to the east with the metavolcanic unit is not well defined. Bedrock structure within the pluton is most evident on 1VD dataset.

There is moderate resolution gravity coverage for the Bruce Lake pluton, with stations on the order of 1 to 2 km apart in some areas, and on the order of 5 km apart in other areas. The gravity response over the pluton is moderate to low; it is situated along the transition zone between the English River and Uchi subprovinces. The gravity response is observed to vary from moderate in the south-southwest to low in the north-northeast. The gravity response over the pluton generally blends in with the regional trend. There is a small local gravity high where this pluton is in contact with the Wenasaga Lake batholith; it is evident as a strong high in the 1VD gravity dataset.

Radiometric coverage for the entire Ear Falls area is low resolution. The Bruce Lake pluton is generally radiometrically distinct from the formations to the north, south and east. The western two-thirds of the pluton have a low radiometric response due to the presence of the lake. The eastern third of the pluton is shaded white, indicative of a comparable response in all three radiometric components and possibly reflecting thick, uniform overburden cover. There is a slightly elevated U trend at the eastern margin of the pluton that continues into the metavolcanics.

The western 20% of the Bruce Lake pluton has VLF EM coverage. The pluton shows a moderate VLF response; some structures are visible along the lake margins, but the VLF response is subdued in areas of water cover. VLF EM structures observed tend to be orthogonal to the transmitter direction.

There is full EM resistivity coverage of the Bruce Lake pluton. There is a low resistivity response on west side of pluton, presumably due to the presence of water cover and thick glaciolacustrine sediments associated with the wetland area. There are some linear conductors identified on the western margin of the pluton associated with iron formations. End moraines are visible on the EM dataset as high resistivity linear features. There is a zone of moderate resistivity east of Lac Seul moraine, an outcrop area, with no major lineament trends noted. There is a cluster of conductor targets along the south margin of the pluton that coincide with the location of the local gravity high previously noted. Generally, the contact margin of the Bruce Lake pluton is not particularly well defined by the EM data, as it is gradational.

### 5.3.4 Bluffy Lake Batholith

Almost all of the aeromagnetic coverage over the Bluffy Lake batholith is low resolution, with the exception of a small area of high resolution coverage along the northwestern edge of the batholith. The Bluffy Lake batholith generally has a high magnetic response in comparison to the gneissic metasedimentary rocks. There are two prominent area of high magnetic response immediately adjacent to the Bluffy Lake batholith. The first area is a strong magnetic response immediately north of the batholith associated with Whitemud Lake and the Sydney Lake fault zone, which reflects the presence of iron formation. The second area is a strong magnetic response immediately to the south in an area mapped as massive granodiorite (geophysical units N and O).

Units N and O appear to represent the western extension of the Bluffy Lake batholith beneath the gneissic metasedimentary rocks as discussed in Section 5.3.1. Unit N exhibits the stronger response and corresponds in part to a mapped granodioritic phase of the batholith. Unit O is more subdued but still forms a marked contrast to the gneissic metasedimentary rocks further to the south. It is possible that the difference between units N and O results in part from contrasting magnetic susceptibility of different intrusive phases of the Bluffy Lake batholith.

The Bluffy Lake batholith has moderate resolution gravity coverage, approximately half of the area has stations spaced on the order of 2 km apart, while the remaining areas have stations spaced on the order of 5 km apart. The batholith straddles a regional trend from high gravity response to the south in the English River Subprovince to low gravity response in the north in the Uchi Subprovince. The Bluffy Lake batholith does not stand out as a distinct gravity anomaly; rather, it blends into regional gravity field trend. The 1VD gravity response suggests only a very slight distinction from the surrounding geologic units. The massive granodiorite unit to the south of the batholith is a slight gravity high.

Radiometric coverage for the entire Ear Falls area is low resolution. The radiometric response of the Bluffy Lake batholith is generally distinct from adjacent geologic formations to the north, south and west. The southeastern part of the batholith is observed to be K-Th enhanced, whereas the northwestern part of the batholith is U enhanced. The U enhanced zone blends into the adjacent geologic formation to the northwest, whereas the change radiometric response at the contact of the batholith to the south and northeast is somewhat abrupt.

EM coverage over the Bluffy Lake batholith is limited to a small area along the northwestern contact margin, where the EM resistivity response is observed to be high, and several EM conductors are also found to be present. There is no VLF coverage for the Bluffy Lake batholith.

### 5.3.5 Wapesi Lake Batholith

Most of the Wapesi Lake batholith is located outside of the Ear Falls area to the southeast. Within the Ear Falls area, the Wapesi Lake batholith has low resolution aeromagnetic coverage. The mapped extent of the batholith does not correlate well to the magnetic response, which is high at the northern end of the batholith, and low to the south. A prominent magnetic unit (L) extends to the southwest along the margin of the Wapesi Lake batholith. This unit appears to be an extension of the magnetically responsive McKenzie Bay stock (also discussed in Section 5.3.7). It is possible that the apparently high aeromagnetic response observed in the north portion of the Wapesi Lake batholith is the result of an unrecognized northeasterly extension of the McKenzie Bay stock.

The Wapesi Lake batholith has a low gravity field in comparison to the English River gneissic metasedimentary rocks to the north, although the gravity data coverage in this part of the Ear Falls area is quite sparse. The radiometric data for the area is low resolution and does not show a distinguishing response over the batholith. There is no VLF EM or EM coverage over the Wapesi Lake batholith.

### 5.3.6 Pakwash Lake Pluton

The Pakwash Lake pluton is approximately 80% covered by lake, and is situated along a north-northeast trending splay associated with the Long Legged Lake fault zone. It has high resolution aeromagnetic coverage over its entire area, and exhibits a steady moderate magnetic response. There is a high magnetic response along the western and southern margins of the pluton. There is a relatively low magnetic response along the eastern margin of the pluton where it has a poorly defined contact with the adjacent gneissic metasedimentary rocks. The high resolution magnetic dataset can be used in this area to refine the geological contact. The 1VD magnetic dataset shows some lineaments which have a north-northeast trend that parallel the mapped faults to the north.

There is moderate resolution gravity coverage over most of the Pakwash Lake pluton area, with stations on the order of 2 km apart. The observed gravity response is moderate, as it is located along the transition zone between the English River and Uchi subprovinces. The gravity response over the pluton is slightly higher than the regional trend surrounding it, which is evident in the positive 1VD gravity response.

Radiometric coverage for the entire Ear Falls area is low resolution. The radiometric response over the Pakwash Lake pluton is generally very low, as the lake covers most of the area. There is a slightly elevated K-Th response in the northeast corner of the pluton.

The Pakwash Lake pluton has VLF EM coverage across its entire area. A moderate to strong VLF EM response is observed in most areas in comparison to surrounding metasedimentary rocks, noting that there is an attenuated response over the lake due to water cover, particularly in the Ortho dataset. VLF EM structures observed tend to be orthogonal to the transmitter direction.

EM coverage over the Pakwash Lake pluton is limited to a small area at the northern tip of the pluton, where the EM resistivity response is observed to be high, and a strong EM conductor is noted at the contact with the metavolcanic unit.

### 5.3.7 Smaller or Unnamed Intrusives

In the southeast corner of the Falls area adjacent to the Wapesi Lake batholith is the McKenzie Bay stock, which has low resolution magnetic, gravity and radiometric coverage, and no VLF EM or EM coverage.

The McKenzie Bay stock has a relatively strong magnetic response, and if the magnetic high correlates to the stock, it suggests it is considerably more extensive than currently mapped (unit L). A similarly elevated magnetic response observed further to the west (unit B) may represent part of this speculative larger unit.

In the southwest corner and along the southern margin of the Ear Falls area within the Winnipeg River Subprovince are found the Winnipeg River plutons, a collection of smaller intrusive bodies of various sizes and shapes. This area has low resolution magnetic, gravity and radiometric coverage, and no VLF EM or EM coverage. It is generally characterized by a low magnetic response, a moderate to high gravity response and a generally neutral radiometric response, although two areas within the plutons exhibit a slight U response and one area exhibits a slight K-Th response.

To the northwest is the Long Legged Lake dome, which has low resolution aeromagnetic and radiometric data, and moderately good gravity coverage, although there is no VLF EM or EM coverage for that area. The Long Legged Lake dome is characterized by a high magnetic response, and a low gravity response, noting there is a local gravity high associated with the metavolcanics immediately to the east. The radiometric response is distinct and elevated in K-Th.

## 6 SUMMARY OF RESULTS

This report presents a compilation and review of available geophysical data (e.g., magnetic, gravity, electromagnetic, magnetotelluric, seismic and radiometric) for the Ear Falls area. The review included a detailed interpretation of all available geophysical datasets, to identify additional information that could be extracted from the data, in particular regarding the coincidence of geophysical units with the current bedrock geology mapping.

Low to moderate resolution geophysical data (magnetic, radiometric, and gravity) are available for the entire Ear Falls area. Additional magnetic/electromagnetic surveys (Uchi-Bruce Lakes Area (GDS1026; OGS, 2003), Pakwash Lake Area (GDS1218; OGS, 2002a), and Trout Lake River Area (GDS1222; OGS, 2002b)) provided higher resolution coverage over 11.5% of the Ear Falls area (north central portion). Data from the Lithoprobe program, one seismic line (WS2B) and two magnetotelluric stations (WST062 and WST074), are also available for the Ear Falls area (GSC, 2012). Additional magnetic and VLF-EM data were found in the AFRI database in the form of raster maps, and the raster dataset for the Goldpines South Property (Laurentian Goldfields Ltd., 2010) were used in this review.

The geophysical data was compared to the mapped geology using the most appropriate geophysical datasets (e.g., magnetic, gravity, electromagnetic and radiometric). In particular, the pole reduced magnetic field and its first vertical derivative were found to be the most reliable for mapping variations in geological contacts, identifying heterogeneity, identifying foliation, and delineation and classification of structural lineaments (faults, dykes).

In general the coincidence between the geophysical interpretations and the published geological maps is good, but in a number of locations the geophysical data provides additional insight. The geophysical interpretation included a description of the geophysical characteristics of the main geological units (i.e., gneissic metasedimentary rocks, batholiths, plutons and other intrusions), as well as a refinement of geologic contacts, where possible, and the identification of internal heterogeneities within the structures, if present.

The magnetic data shows a generally subdued response over large areas of the English River gneissic belt, the Pakwash Lake pluton, the Bruce Lake pluton, the Wenasaga Lake batholith, the Winnipeg River Subprovince plutonic suite within the Ear Falls area, and other smaller granitic intrusions. The frequent lack of magnetic contrast between some of the intrusions and the surrounding metasedimentary rocks makes it difficult to distinguish the contact between them in many instances. There is a moderate to elevated aeromagnetic response over the Bluffy Lake batholith, the northern portion of the Wapesi Lake batholith and several smaller intrusions.

The high resolution magnetic survey from the Goldpines Property shows several elevated magnetic responses observed on the western end of the Wenasaga Lake batholith, as well as between the Sydney Lake and Long Legged Lake fault zones west of the Pakwash Lake. Most significantly, the strong magnetic unit immediately west of the Wenasaga Lake batholith, exhibits a rim of strong magnetization along its contact margin.

The other minor magnetic high responses noted between the Sydney Lake and Long Legged Lake fault zones correspond to a large-scale fold structure consisting of gneissic metasedimentary rock regularly interlayered with magnetite-rich granitic pegmatite, which makes up a tight antiformal structure.

Several extremely high magnetic responses are seen as anomalies with sharp contacts that coincide with iron formations located on the northern portion of the English River Subprovince within metasedimentary units, typically bordering various granitic intrusions. The most significant is the former Griffith Iron Mine, located along the western edge of the Bruce Lake pluton, which is clearly visible as a magnetic high in all datasets.

A large positive gravity anomaly is associated with the English River Subprovince, bordered by a lower gravity response over the Uchi Subprovince and the Sydney Lake fault zone in the north, and by the north-east trending Wapesi Lake fault to the south in the south-east corner of the Ear Falls area. This gravity distribution was noted by Nitescu et al., (2006) and inferred to correspond to the gneissic metasedimentary rocks. The gravity data could also be indicative of the presence of felsic intrusive rocks at depth underlying the English River Subprovince. Others have interpreted this gravity high as a uniform gneissic metasedimentary unit which extends to depths greater than 8 to 10 km (Runnals and West, 1978; Gupta and Barlow, 1984; Gupta and Wadge, 1986). Although it is suggested that the presence of a gneissic to felsic intrusive unit beneath the gneissic metasedimentary rocks is an explanation of the gravity anomaly, there is a recognized lack of information at depth to constrain this interpretation (Nitescu and Cruden, 2001).

The radiometric data (potassium, uranium and thorium) observed in the Ear Falls area reflect subtle variations in lithology observed between the granitic intrusive rocks which are typically elevated in radiometric elements compared to volcanic and metasedimentary rocks. The lower resolution radiometric data and presence of surficial soils and lakes in the Ear Falls area limits the usefulness of this data for interpreting geological units and their contacts.

A comprehensive interpretation of the WS2B Lithoprobe seismic reflection line shows a transect through the English River metasedimentary units and the Birch-Uchi greenstone belt. The Pakwash Lake and the Sydney Lake fault zones are intersected by the WS2B seismic line at geophone stations 6300 and 6800, respectively. Calculation of the velocity structure to a depth of 1.5 km showed a significant velocity reduction in the near surface within the interval located between the two fault zones. Extensive fracturing and mylonitization of the rock between the two fault zones provides the most plausible explanation for the low velocity zone. An alternative explanation is the presence of granitic plutons, which are observed in outcrop; however, these plutons are not present throughout the entire width of the low velocity interval.

Respectfully Submitted,

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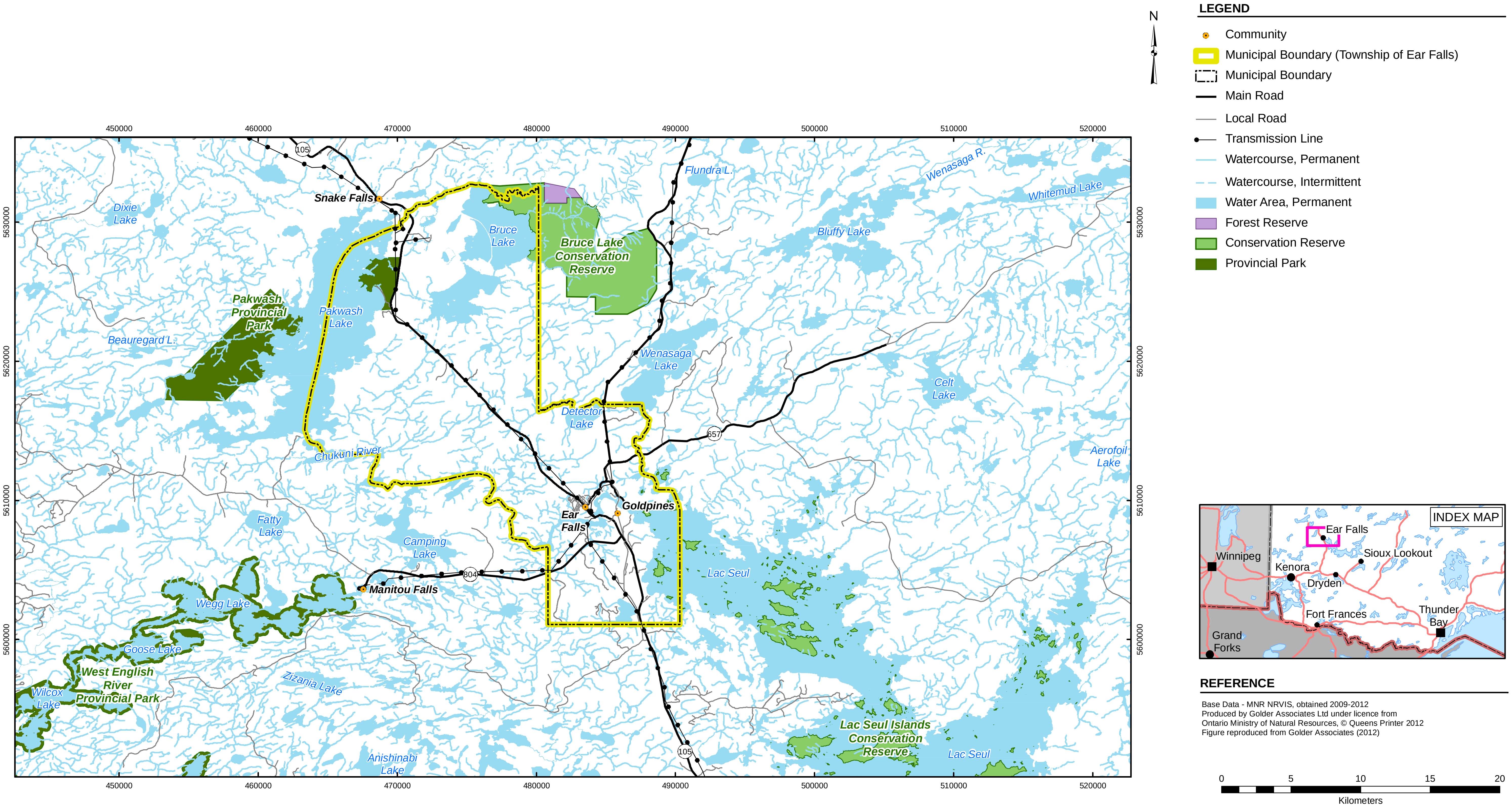
# FIGURES




Mira Geoscience

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment,
Geophysical Study, Ear Falls Area, Ontario

TITLE
Township of Ear Falls and surrounding area

| | | | | |
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| DESIGN | PRM | 11 May 2012 | Figure 1 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
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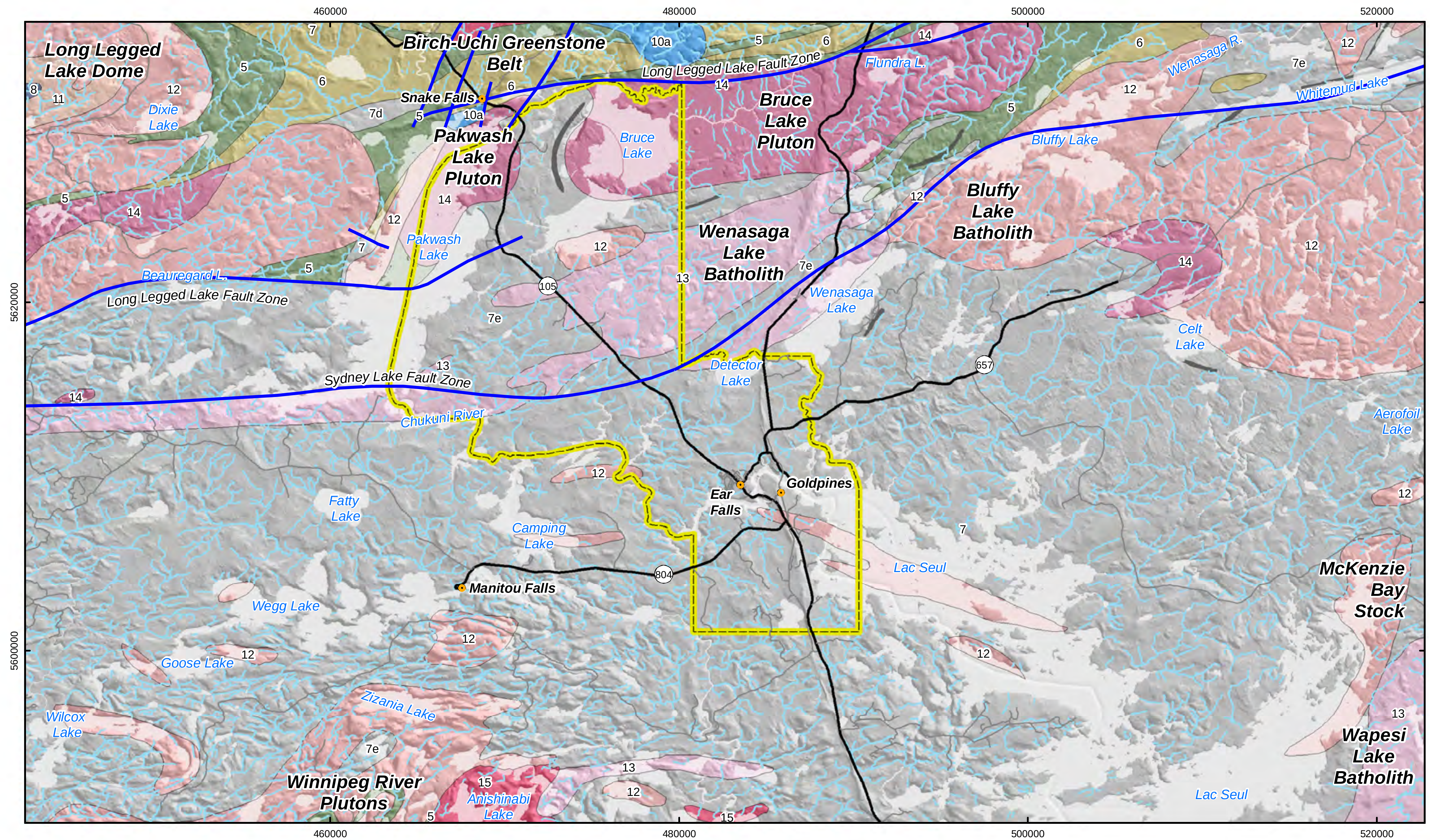
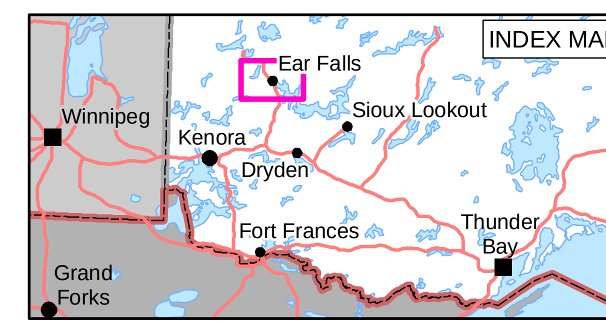



## LEGEND

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Faults

**Bedrock Geology**

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
  - 10a Gabbro
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
  - 7d Conglomerate and arenite
  - 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- Iron Formation

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Geology - MRD126-Bedrock Geology of Ontario, 2011
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Mira Geoscience

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE
Local Bedrock Geology of the Ear Falls Area

| | | | | |
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| DESIGN | PRM | 11 May 2012 | Figure 2 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
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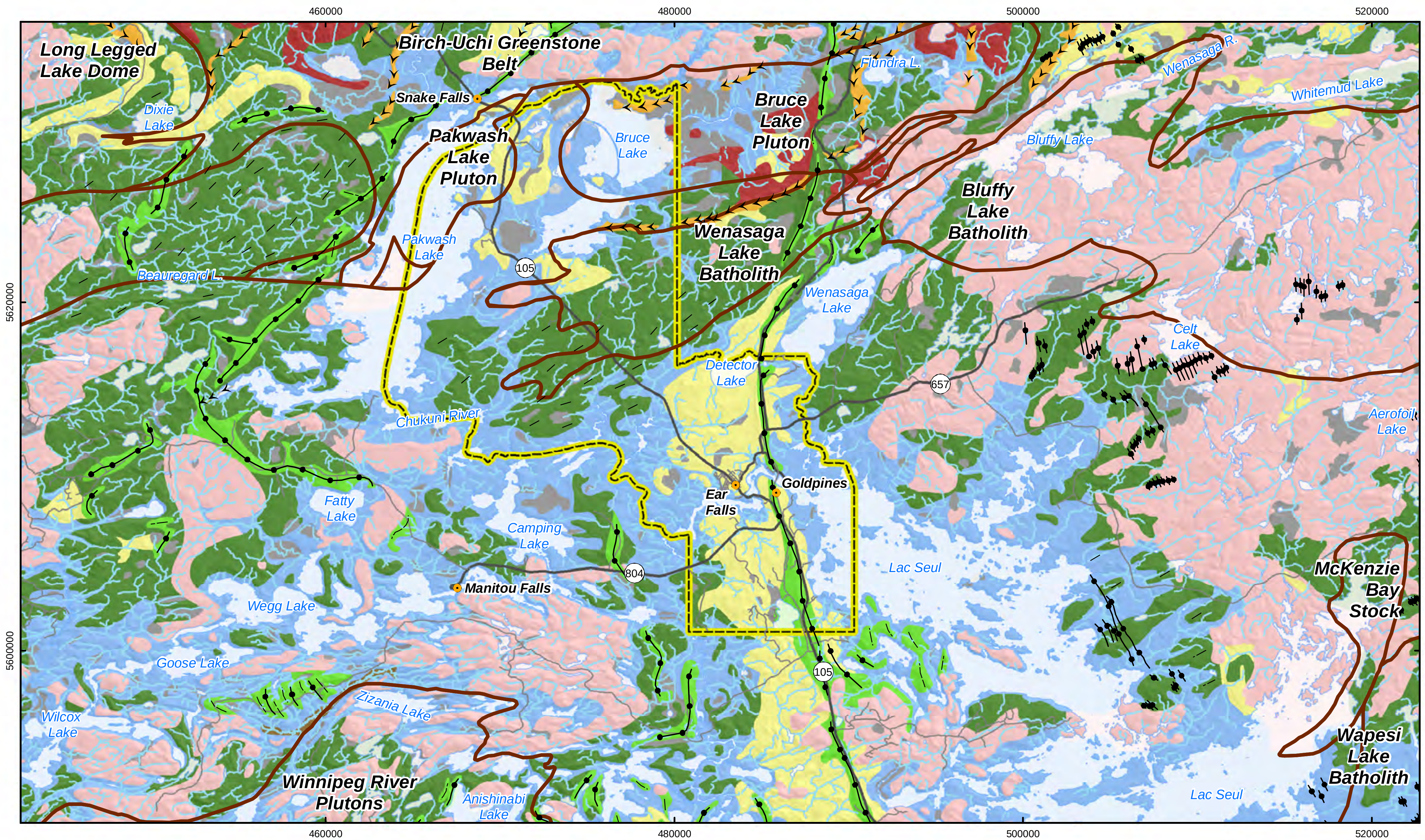



N

## LEGEND

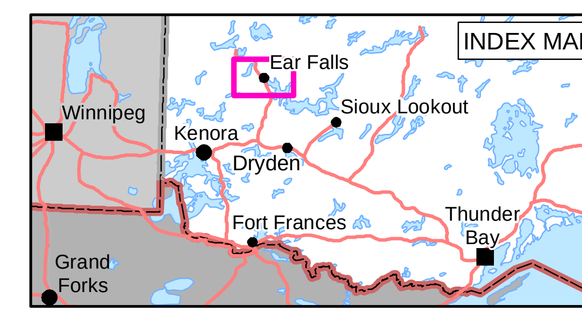
- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Outline of Major Batholith/Pluton

**Surficial Landforms**

- Esker
- Major End Moraine
- Drumlin
- Other Linear Ice-Flow Features

**Surficial Geology**

- Ground moraine
- End moraine
- Esker
- Outwash
- Ice-contact delta
- Glaciolacustrine
- Alluvial plain
- Organics
- Bedrock

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Mira Geoscience

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE
Terrain Features of the Ear Falls Area

| | | | | |
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| DESIGN | PRM | 11 May 2012 | Figure 3 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
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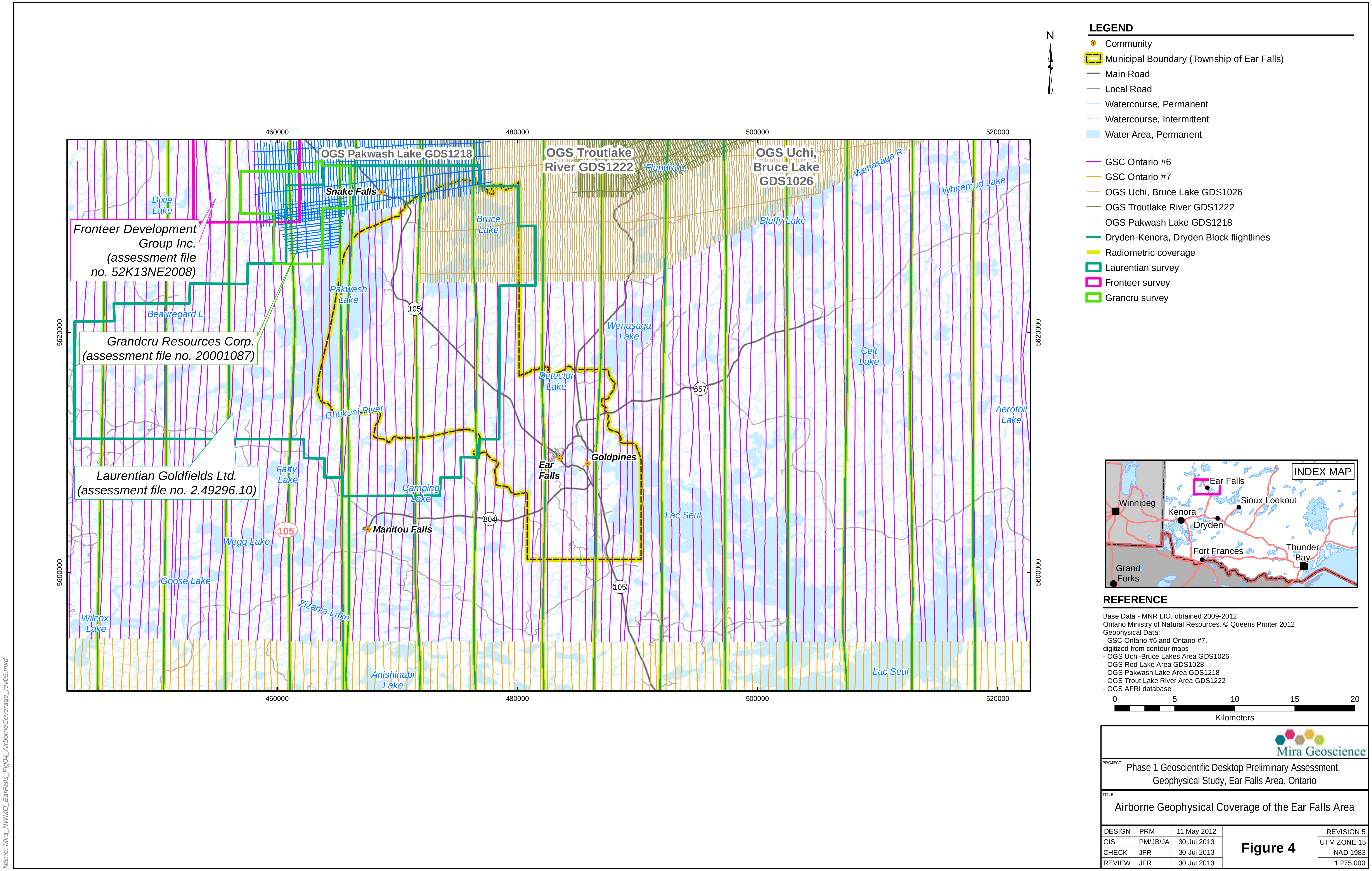

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OGS Troutlake River GDS1222
OGS Uchi, Bruce Lake GDS1026
Fronteer Development Group Inc. (assessment file no. 52K13NE2008)
Grandcru Resources Corp. (assessment file no. 20001087)
Laurentian Goldfields Ltd. (assessment file no. 2.49296.10)
Snake Falls
Ear Falls
Goldpines
Manitou Falls
Dixie Lake
Bruce Lake
Pakwash Lake
Beauregard L.
Wenasaga Lake
Detector Lake
Chukuni River
Fatty Lake
Camping Lake
Lac Seul
Wegg Lake
Goose Lake
Zizania Lake
Wilcox Lake
Anishinabi Lake
Celt Lake
Aerofoil Lake
Bluffy Lake
Whitemud Lake
Wenasaga R.
Flundra L.
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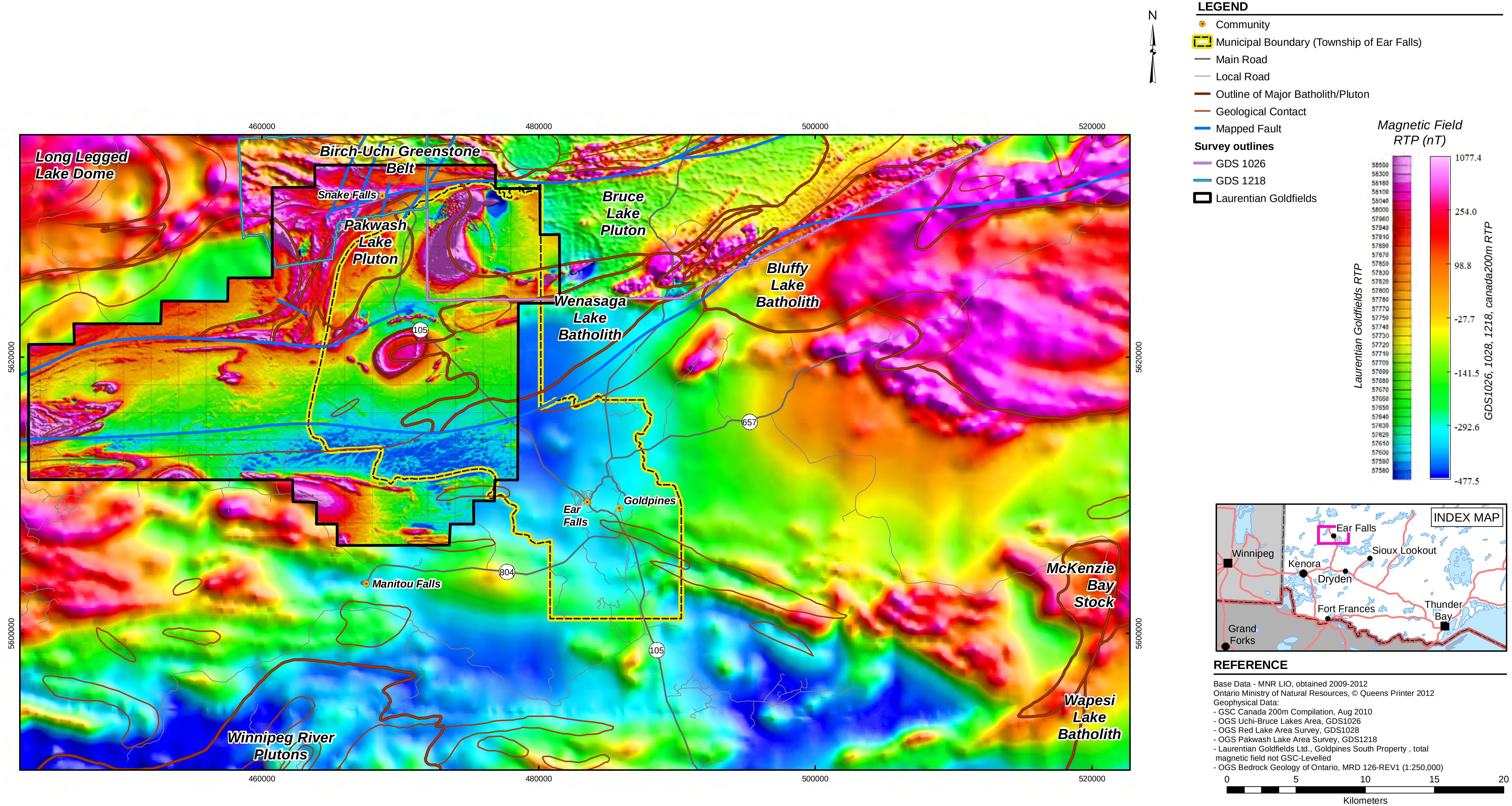
LEGEND
Community
Municipal Boundary (Township of Ear Falls)
Main Road
Local Road
Watercourse, Permanent
Watercourse, Intermittent
Water Area, Permanent
GSC Ontario #6
GSC Ontario #7
OGS Uchi, Bruce Lake GDS1026
OGS Troutlake River GDS1222
OGS Pakwash Lake GDS1218
Dryden-Kenora, Dryden Block flightlines
Radiometric coverage
Laurentian survey
Fronteer survey
Grancru survey
INDEX MAP
Ear Falls
Sioux Lookout
Winnipeg
Kenora
Dryden
Fort Frances
Thunder Bay
Grand Forks
REFERENCE
Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
Geophysical Data:
- GSC Ontario #6 and Ontario #7, digitized from contour maps
- OGS Uchi-Bruce Lakes Area GDS1026
- OGS Red Lake Area GDS1028
- OGS Pakwash Lake Area GDS1218
- OGS Trout Lake River Area GDS1222
- OGS AFRI database
0 5 10 15 20
Kilometers
Mira Geoscience
PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario
TITLE Airborne Geophysical Coverage of the Ear Falls Area
DESIGN PRM 11 May 2012
GIS PM/JB/JA 30 Jul 2013
CHECK JFR 30 Jul 2013
REVIEW JFR 30 Jul 2013
Figure 4
REVISION 5
UTM ZONE 15
NAD 1983
1:275,000
Name: Mira_NWMO_EarFalls_Fig04_AirborneCoverage_rev05.mxd



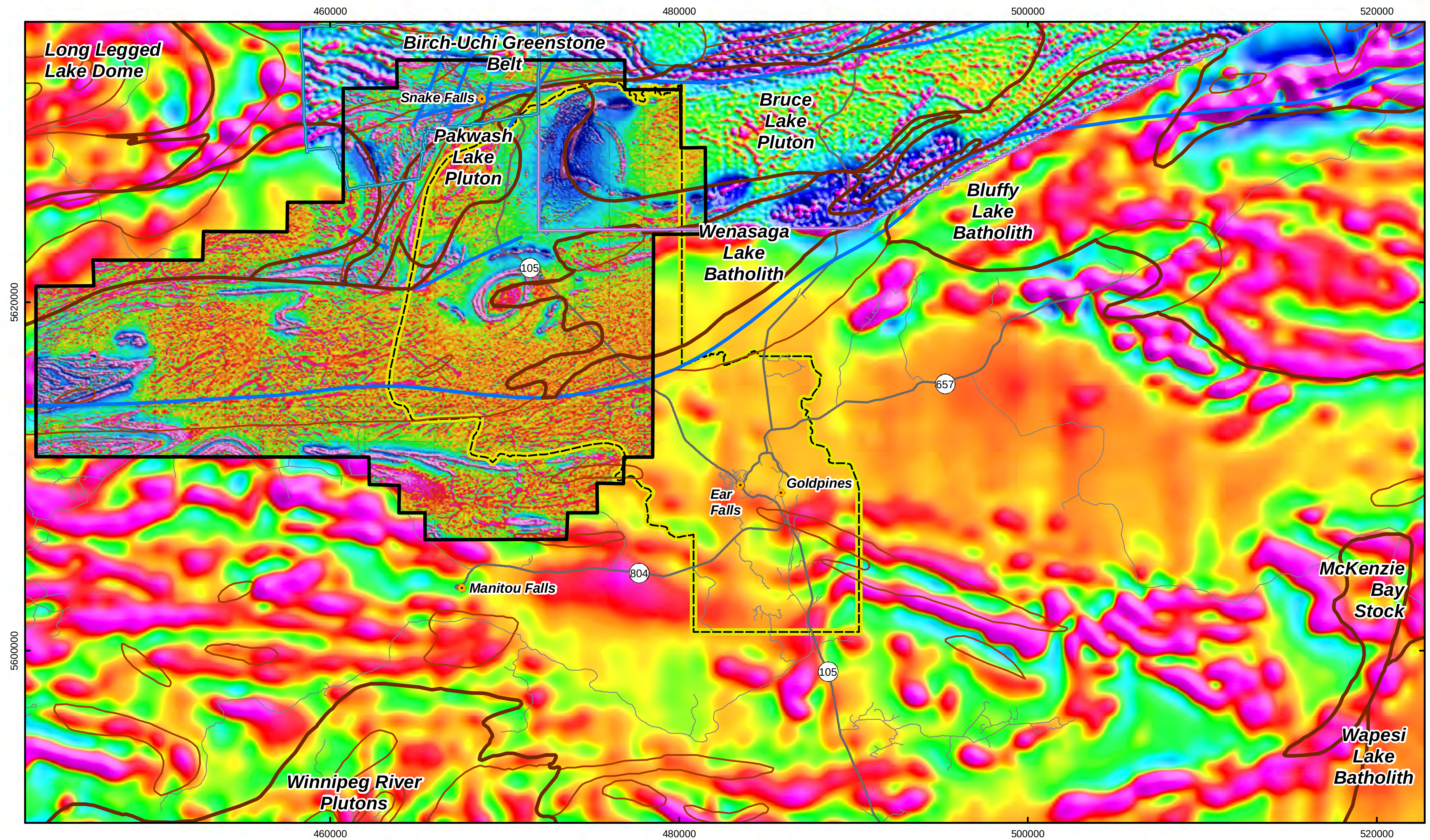

Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE Reduced to pole total and residual magnetic field data of the Ear Falls Area

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 5 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

Name: Mira_NWMO_EarFalls_Fig05_MagRTP_rev05.mxd




N

**LEGEND**

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Outline of Major Batholith/Pluton
- Geological Contact
- Mapped Fault

**Survey outlines**

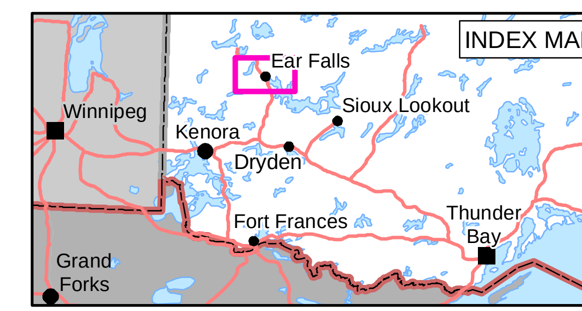
- GDS 1026
- GDS 1218
- Laurentian Goldfields

First Vertical Derivative (nT/m)

Laurentian Goldfields RTP

GDS1026, 1028, 1218, canada200m RTP

0.9
0.1
0.0
-0.1
-0.1
-0.2
-1.3




**REFERENCE**

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
Geophysical Data:
- GSC Canada 200m Compilation, Aug 2010
- OGS Uchi-Bruce Lakes Area, GDS1026
- OGS Red Lake Area Survey, GDS1028
- OGS Pakwash Lake Area Survey, GDS1218
- Laurentian Goldfields Ltd., Goldpines South Property , total magnetic field not GSC-Levelled
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE First vertical derivative of the pole reduced magnetic field data of the Ear Falls Area

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | **Figure 6** | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

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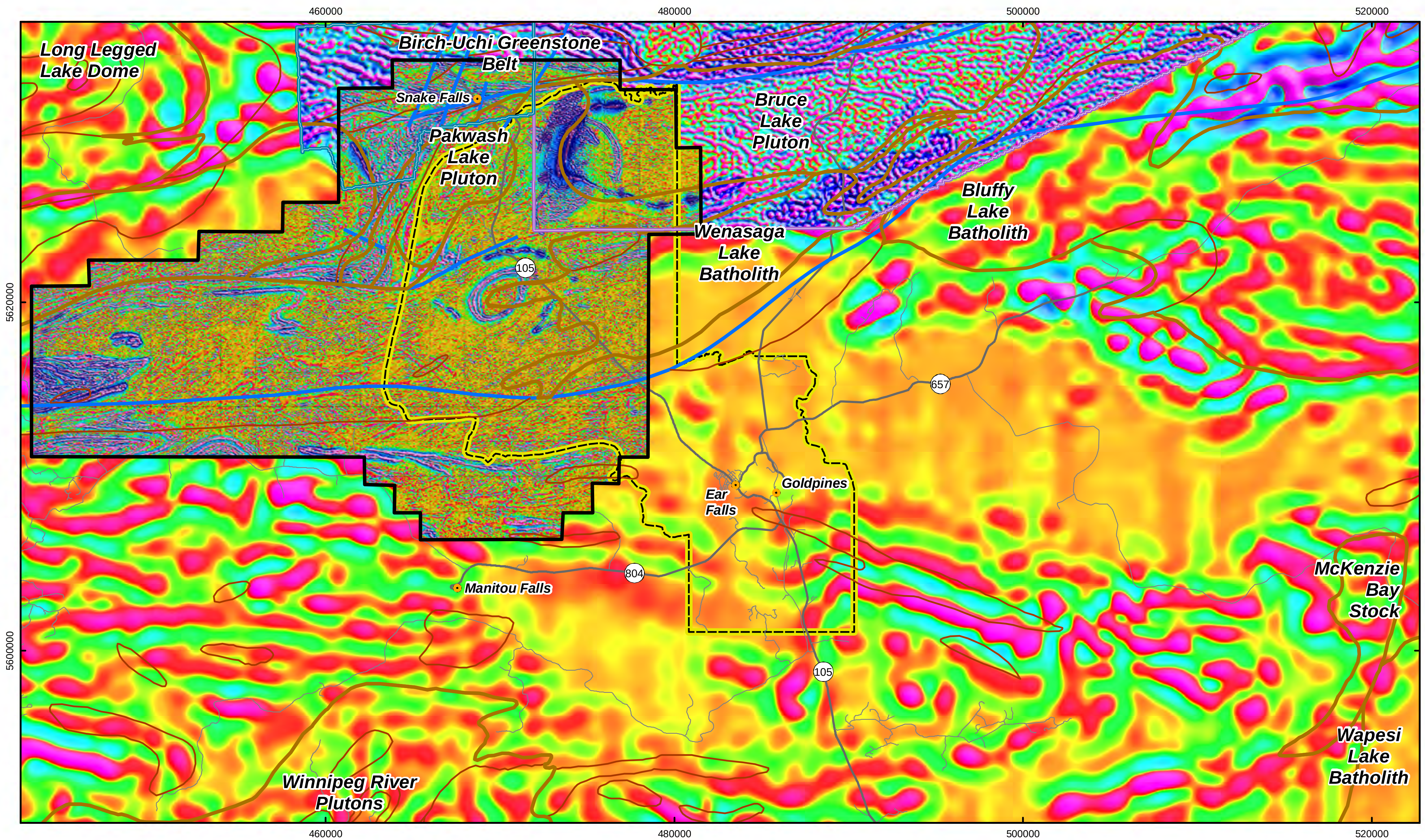



N

**LEGEND**

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Outline of Major Batholith/Pluton
- Geological Contact
- Mapped Fault

**Survey outlines**

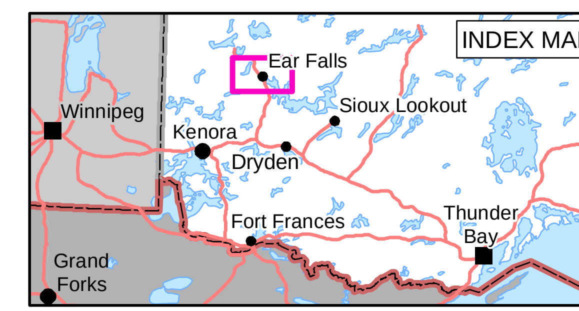
- GDS 1026
- GDS 1218
- Laurentian Goldfields

*Second Vertical Derivative (nT/m²)*

Laurentian Goldfields RTP

GDS1026, 1028, 1218, canada200m RTP

0.007
0.000
0.000
0.000
0.000
0.000
-0.001
-0.010




**REFERENCE**

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
Geophysical Data:
- GSC Canada 200m Compilation, Aug 2010
- OGS Uchi-Bruce Lakes Area, GDS1026
- OGS Red Lake Area Survey, GDS1028
- OGS Pakwash Lake Area Survey, GDS1218
- Laurentian Goldfields Ltd., Goldpines South Property , total magnetic field not GSC-Levelled
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

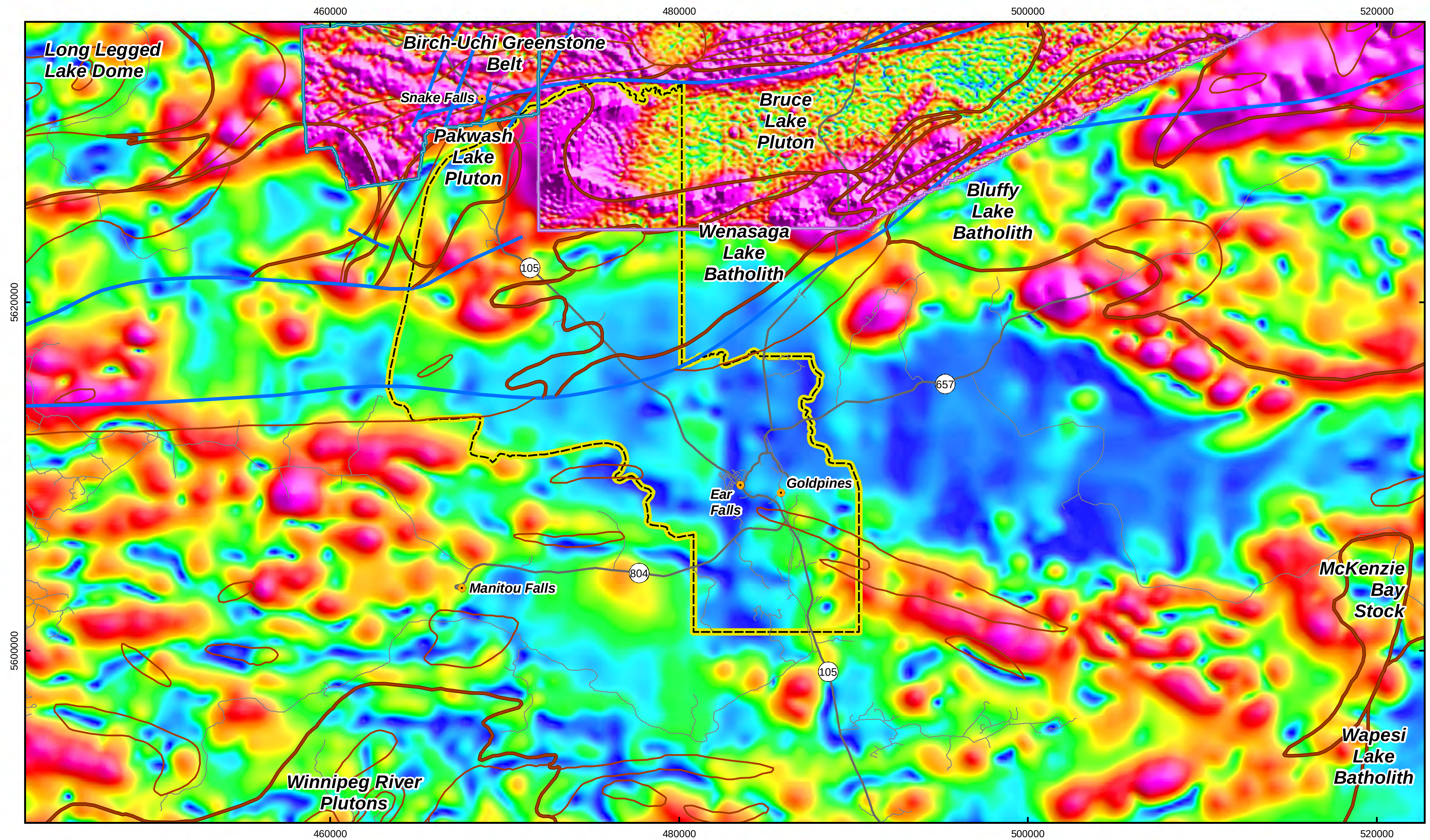
Mira Geoscience

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE
Second vertical derivative of the pole reduced magnetic field data of the Ear Falls Area

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 7 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

Name: Mira_NWMO_EarFalls_Fig07_MagVD2_rev05.mxd




N

## LEGEND

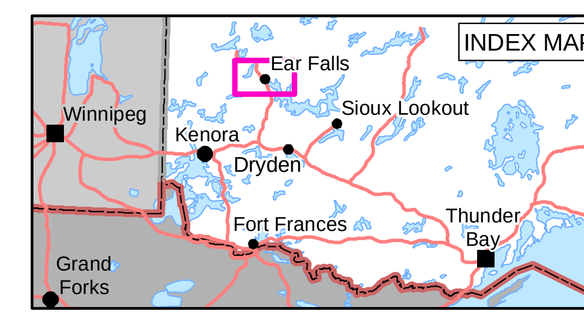
- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Outline of Major Batholith/Pluton
- Geological Contact
- Mapped Fault

**Survey outlines**

- GDS 1026
- GDS 1218

*Analytic signal amplitude (nT/m)*

1.5
0.4
0.3
0.2
0.1
0.1
0.0




## REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
Geophysical Data:
- GSC Canada 200m Compilation, Aug 2010
- OGS Uchi-Bruce Lakes Area, GDS1026
- OGS Red Lake Area Survey, GDS1028
- OGS Pakwash Lake Area Survey, GDS1218
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

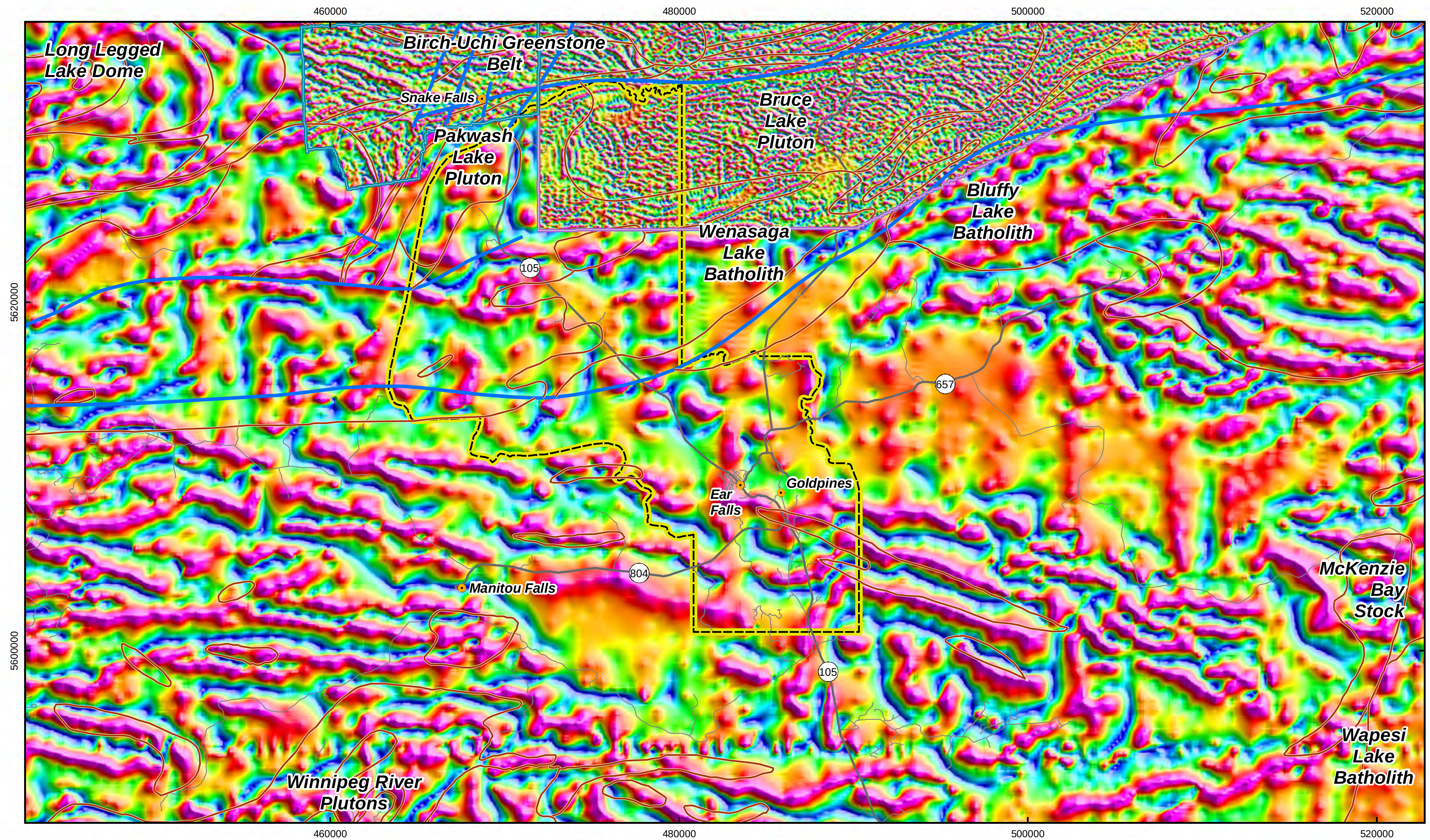
Mira Geoscience

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE
Analytic signal amplitude of residual magnetic field data of the Ear Falls Area

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 8 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

Name: Mira_NWMO_EarFalls_Fig08_MagAnalytic_rev05.mxd




N

**LEGEND**

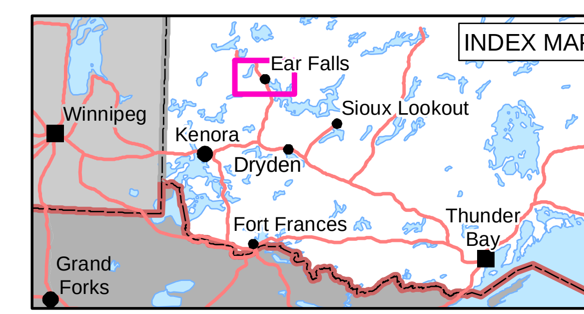
- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Geological Contact
- Mapped Fault

**Survey outlines**

- GDS 1026
- GDS 1218

*Tilt Angle (° degrees)*

69.7
21.0
5.6
-3.7
-13.0
-26.6
-69.6




**REFERENCE**

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
Geophysical Data:
- GSC Canada 200m Compilation, Aug 2010
- OGS Uchi-Bruce Lakes Area, GDS1026
- OGS Red Lake Area Survey, GDS1028
- OGS Pakwash Lake Area Survey, GDS1218
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

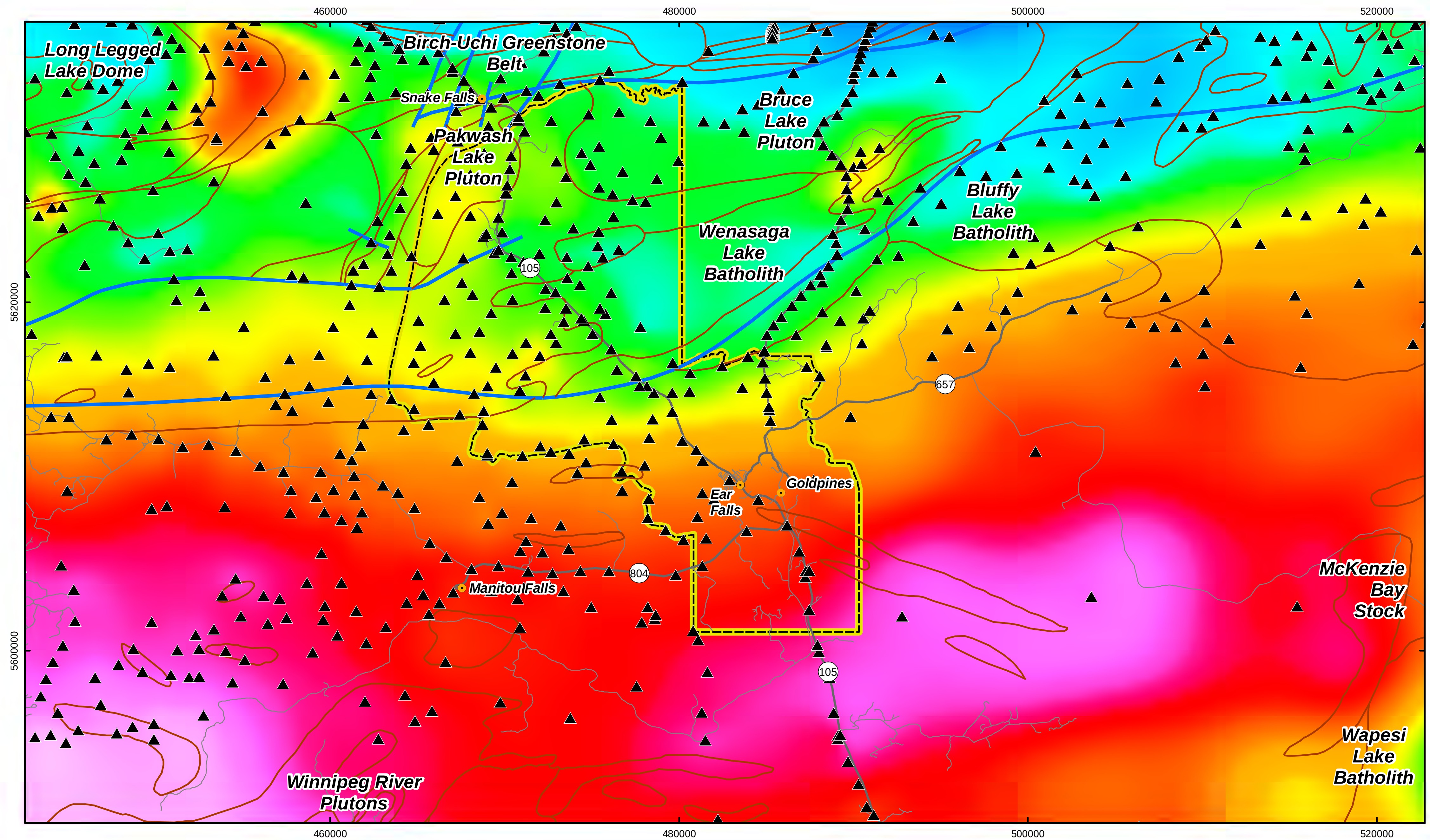
Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE Tilt angle of the pole reduced magnetic field data of the Ear Falls Area

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | **Figure 9** | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

Name: Mira_NWMO_EarFalls_Fig09_MagTILT_rev05.mxd



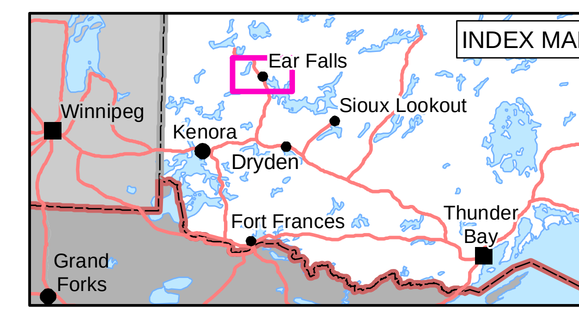

N

**LEGEND**

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Geological Contact
- Mapped Fault
- Gravity Station

*Bouguer Gravity (mGal)*

-19.8
-28.3
-34.4
-40.0
-44.8
-49.4
-65.6




**REFERENCE**

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
- GSC Canadian Gravity Database (CGDB)
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

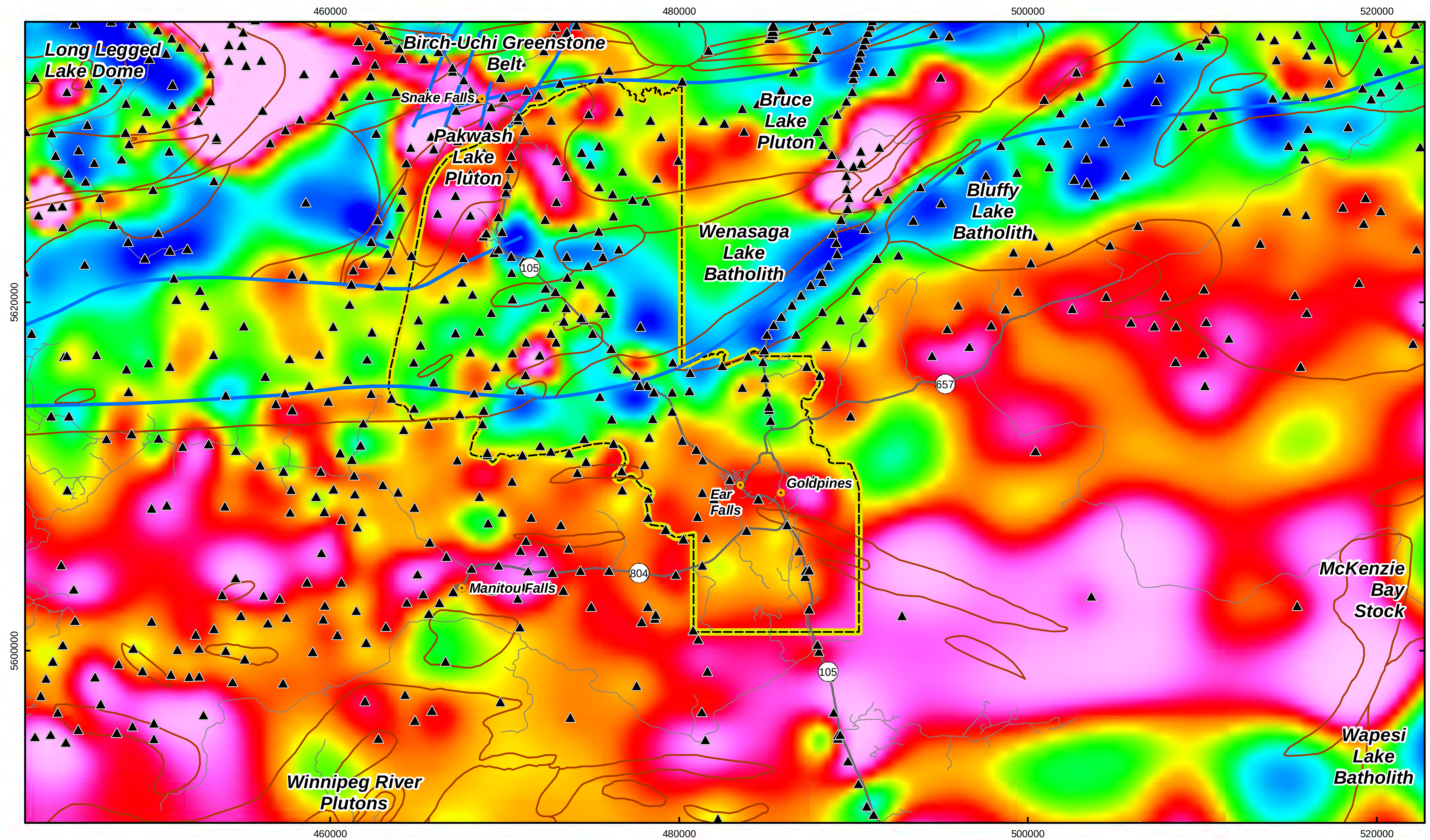
Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE Bouguer gravity field with station locations in the Ear Falls area

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 10 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

Name: Mira_NWMO_EarFalls_Fig10_GRAV_rev05.mxd

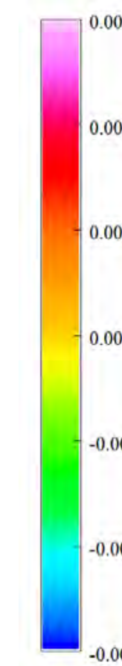


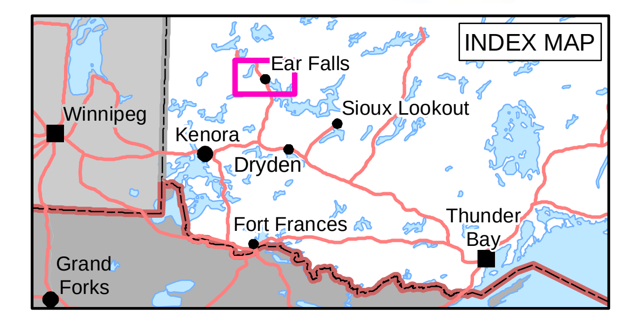

N

## LEGEND

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Geological Contact
- Mapped Fault
- Gravity Station

Bouguer Gravity VD1 (mGal/m)




## REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
- GSC Canadian Gravity Database (CGDB)
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

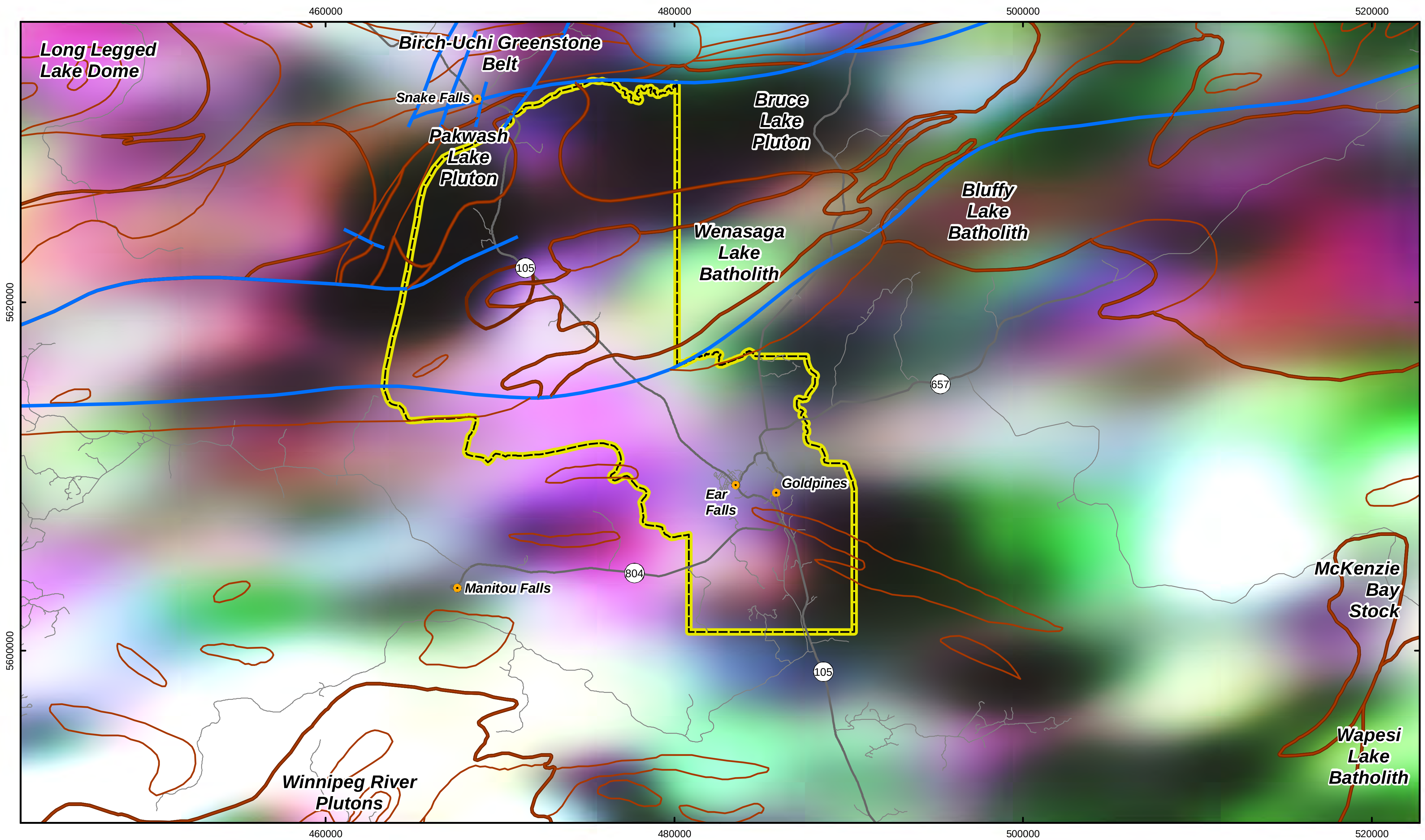
Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE First vertical derivative of the Bouguer gravity field with station locations in the Ear Falls area

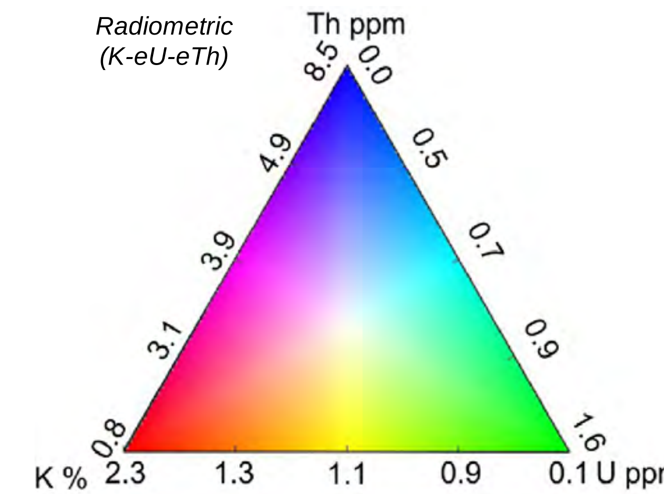
| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 11 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

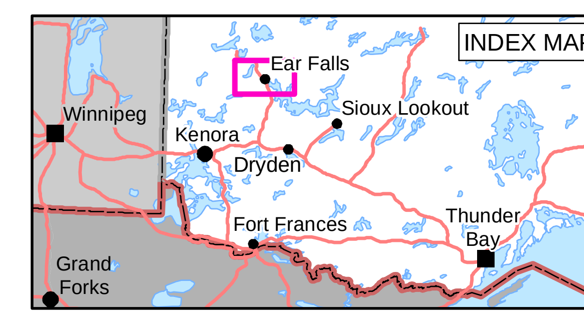
Name: Mira_NWMO_EarFalls_Fig11_GRAVvd1_rev05.mxd




## LEGEND

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Outline of Major Batholith/Pluton
- Geological Contact
- Mapped Fault




## REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
- GSC Dryden-Kenora, Dryden Block Survey
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

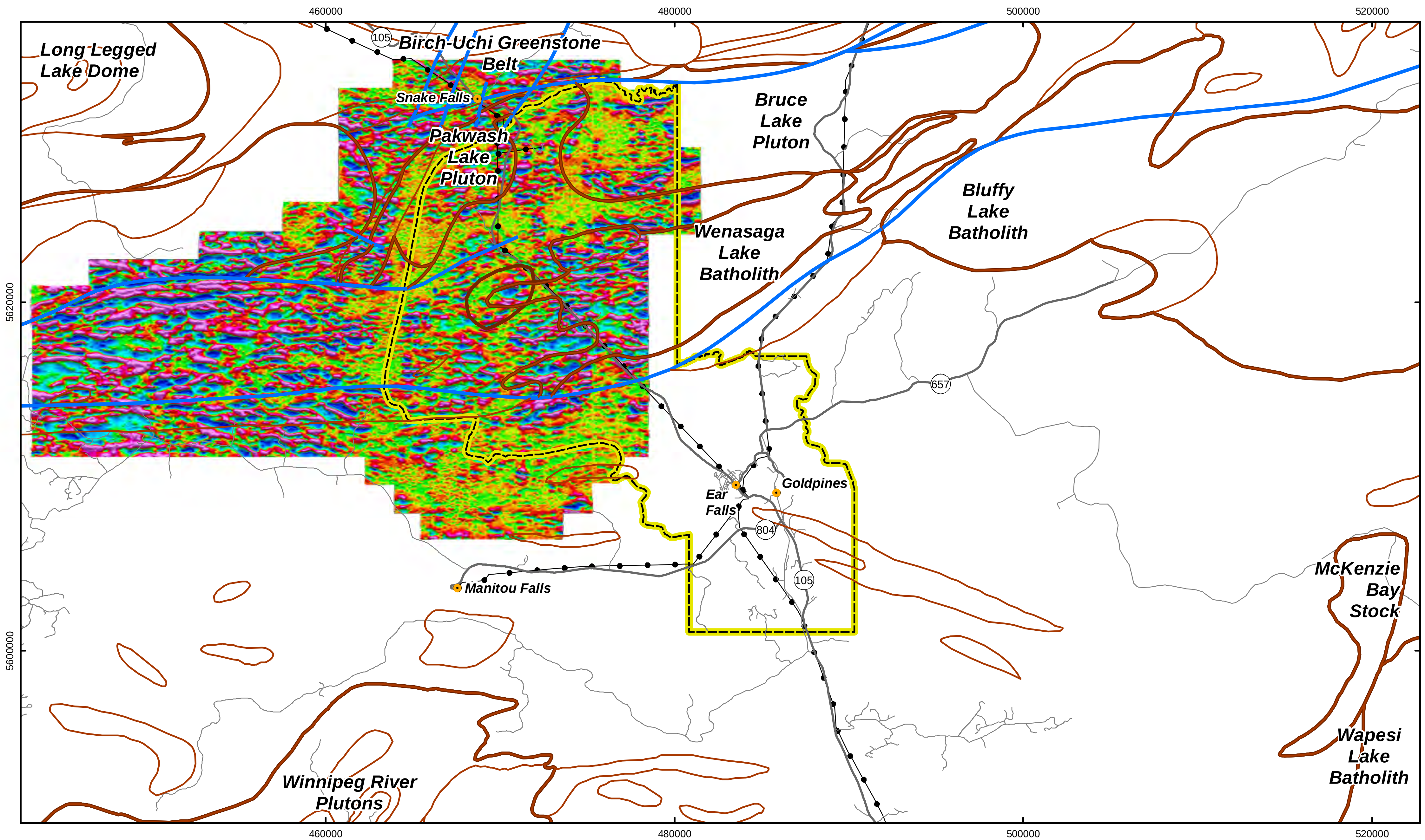
Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE Radiometric ternary image of the Ear Falls area (RGB = K-eU-eTh)

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 12 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

Name: Mira_NWMO_EarFalls_Fig12_RADternary_rev05.mxd

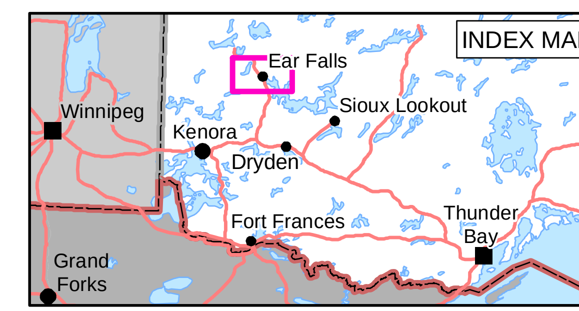



N

## LEGEND

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Transmission Line
- Outline of Major Batholith/Pluton
- Geological Contact
- Mapped Fault

VLF-EM (%)




## REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
- Laurentian Goldfields Ltd., Goldpines South Property
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

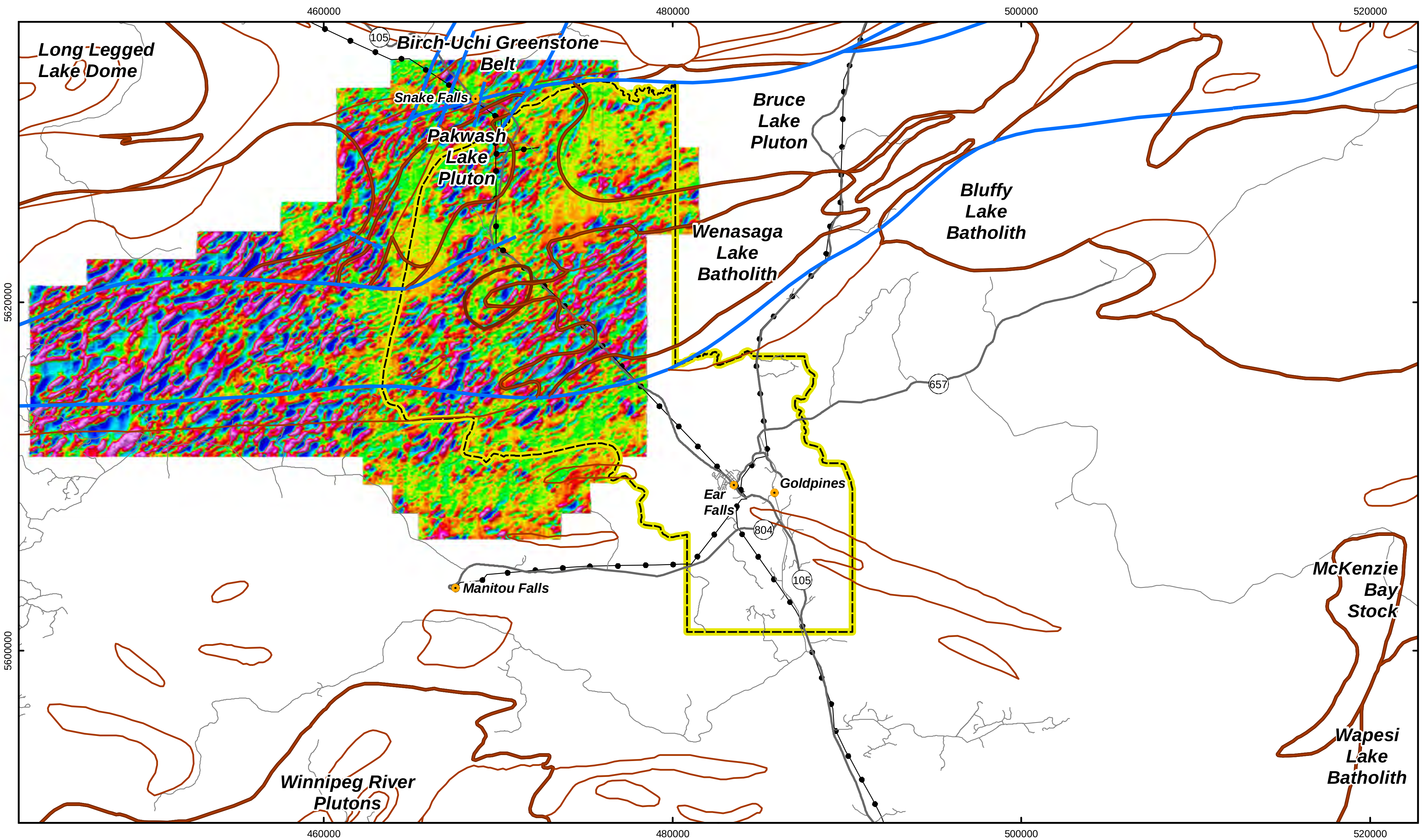
Mira Geoscience

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE
Very low frequency electromagnetic (VLF EM), line data in the Ear Falls area (Laurentian Goldfields)

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 13 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

Name: Mira_NWMO_EarFalls_Fig13_VLFEMline_rev05.mxd

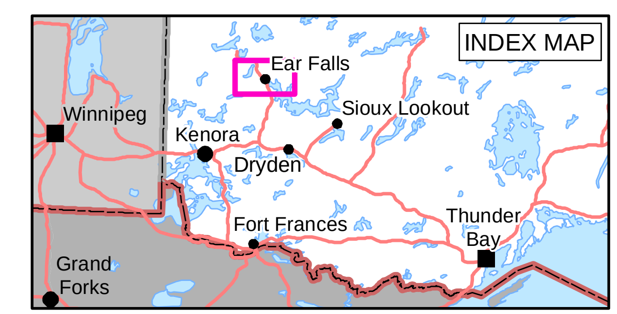



N

## LEGEND

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Transmission Line
- Outline of Major Batholith/Pluton
- Geological Contact
- Mapped Fault

VLF-EM (%)




## REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
- Laurentian Goldfields Ltd., Goldpines South Property
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE Very low frequency electromagnetic (VLF EM), ortho data in the Ear Falls area (Laurentian Goldfields)

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 14 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

Name: Mira_NWMO_EarFalls_Fig14_VLFEMortho_rev05.mxd

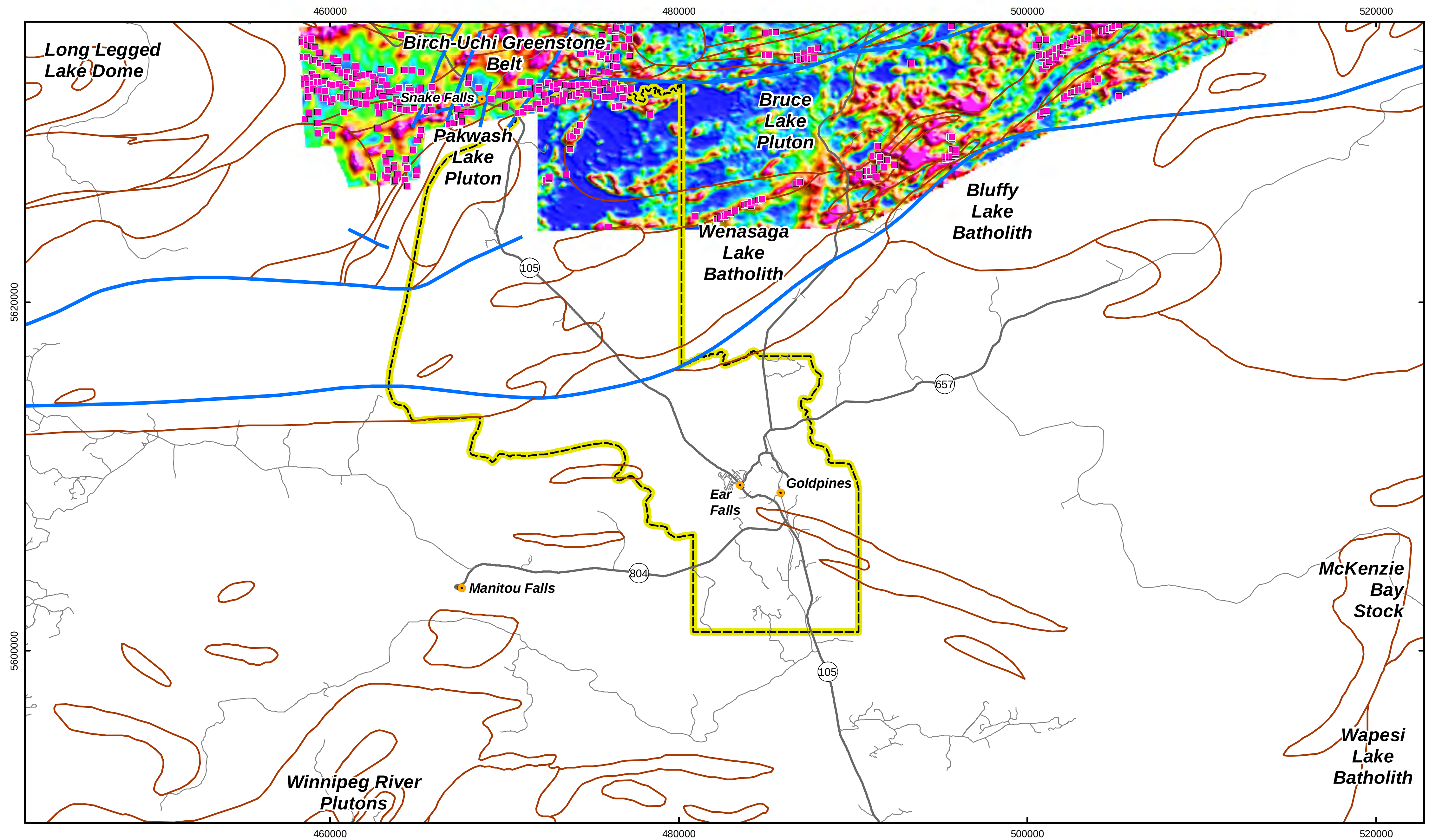
N

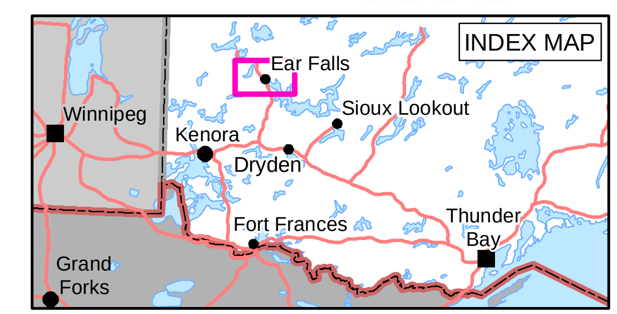
## LEGEND

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Geological Contact
- Mapped Fault
- Bedrock Conductor

Apparent Resistivity
(ohm-metre)

153135.9
6341.4
2354.1
1038.0
573.4
341.1
-5426.9




## REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Ontario Ministry of Natural Resources, © Queens Printer 2012
Geophysical Data:
- GSC Canada 200m Compilation, Aug 2010
- OGS Uchi-Bruce Lakes Area, GDS1026
- OGS Red Lake Area Survey, GDS1028
- OGS Pakwash Lake Area Survey, GDS1218
- OGS Bedrock Geology of Ontario, MRD 126-REV1 (1:250,000)

0 5 10 15 20
Kilometers

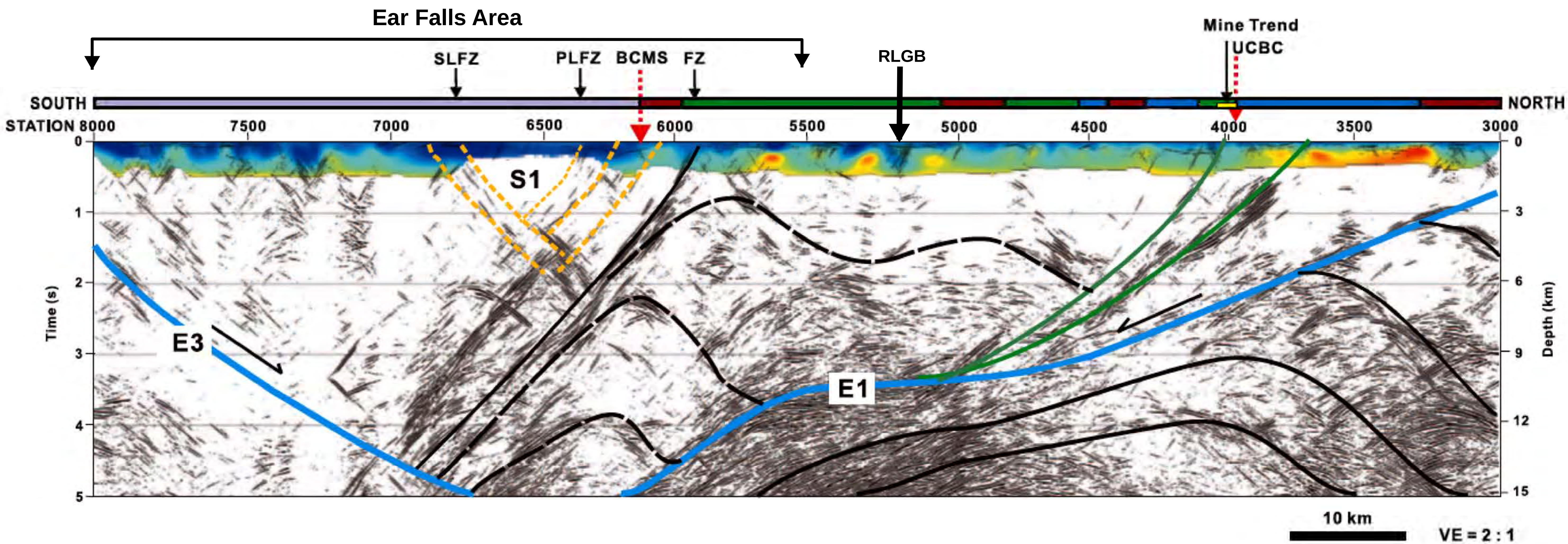
Mira Geoscience

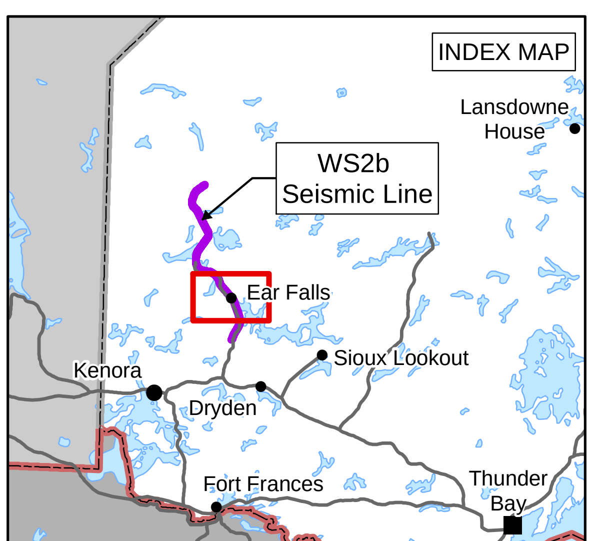
PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE Apparent resistivity from FDEM (GDS1026) and TDEM (GDS1218) surveys in the Ear Falls Area

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 15 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

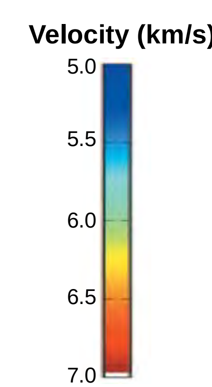
Name: Mira_NWMO_EarFalls_Fig15_AppRes_rev05.mxd




**LEGEND**

- Reflector Truncations
- Interpreted Reflectors
- Strike-slip
- Extensional Fault
- Reflections Associated with Shear Zones
- Metasedimentary Rocks
- Felsic-Intermediate Volcanics
- Mafic Volcanics
- Granite, Granodiorite




**REFERENCE**

Zeng, F., and A.J. Calvert, 2006. Imaging the upper part of the Red Lake greenstone belt, northwestern Ontario, with 3-D traveltime tomography: Canadian Journal of Earth Science 43: 849-863

Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE Interpreted Lithoprobe Section

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 16 | REVISION 4 |
| GIS | PM/JB | 26 Aug 2013 | | UTM ZONE 15 |
| CHECK | TC | 26 Aug 2013 | | NAD 1983 |
| REVIEW | JFR | 26 Aug 2013 | | 1:275,000 |

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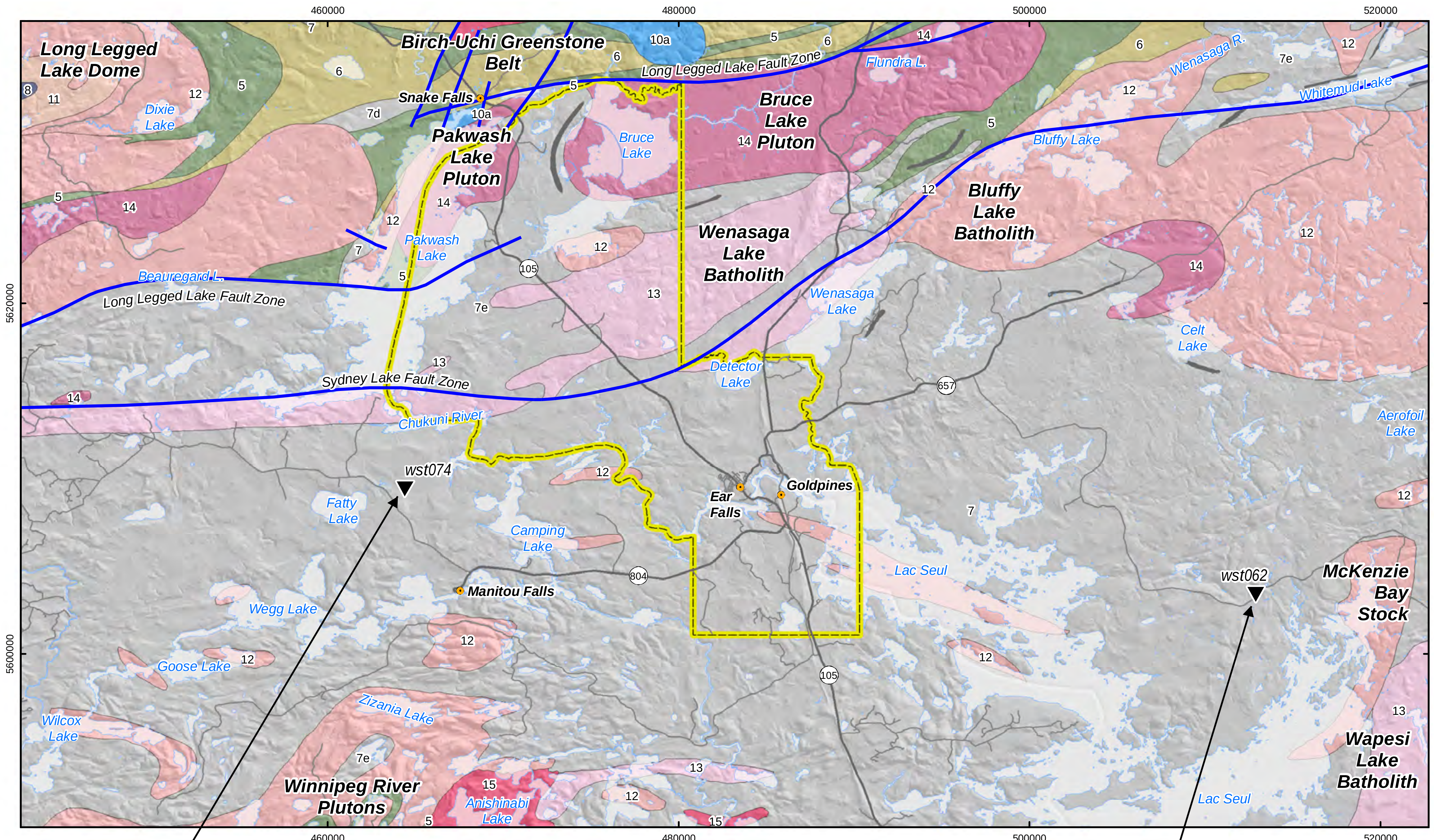
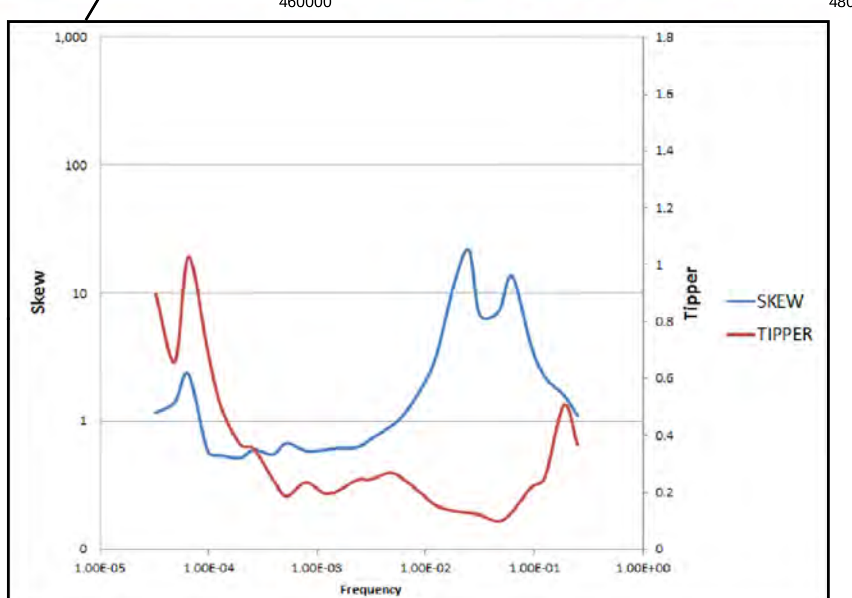
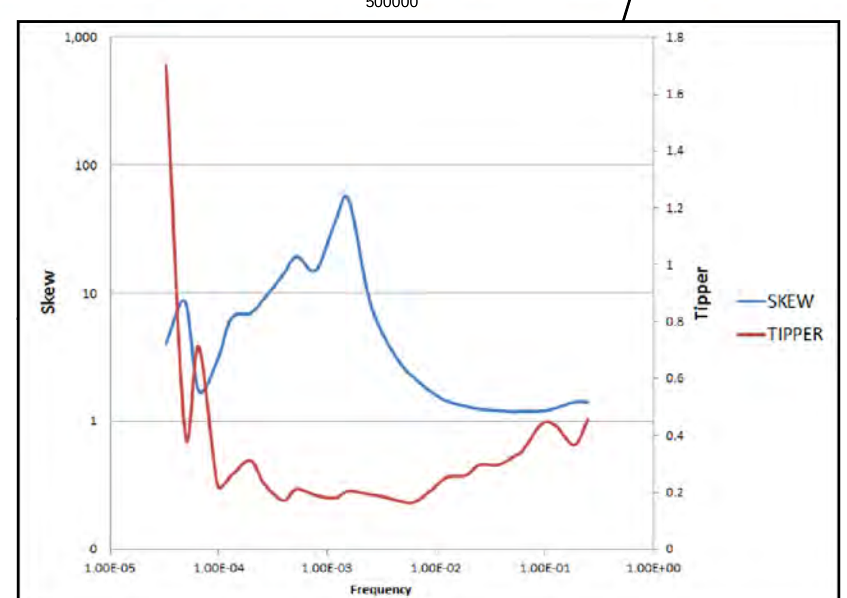


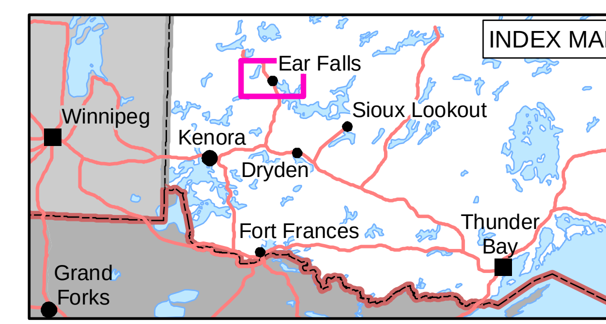




N

## LEGEND

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Lithoprobe MT sounding
- Water Area, Permanent
- Mapped Faults
- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 10a Gabbro
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
- 7d Conglomerate and arenite
- 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- Iron Formation




## REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Geology - MRD126-Bedrock Geology of Ontario, 2011
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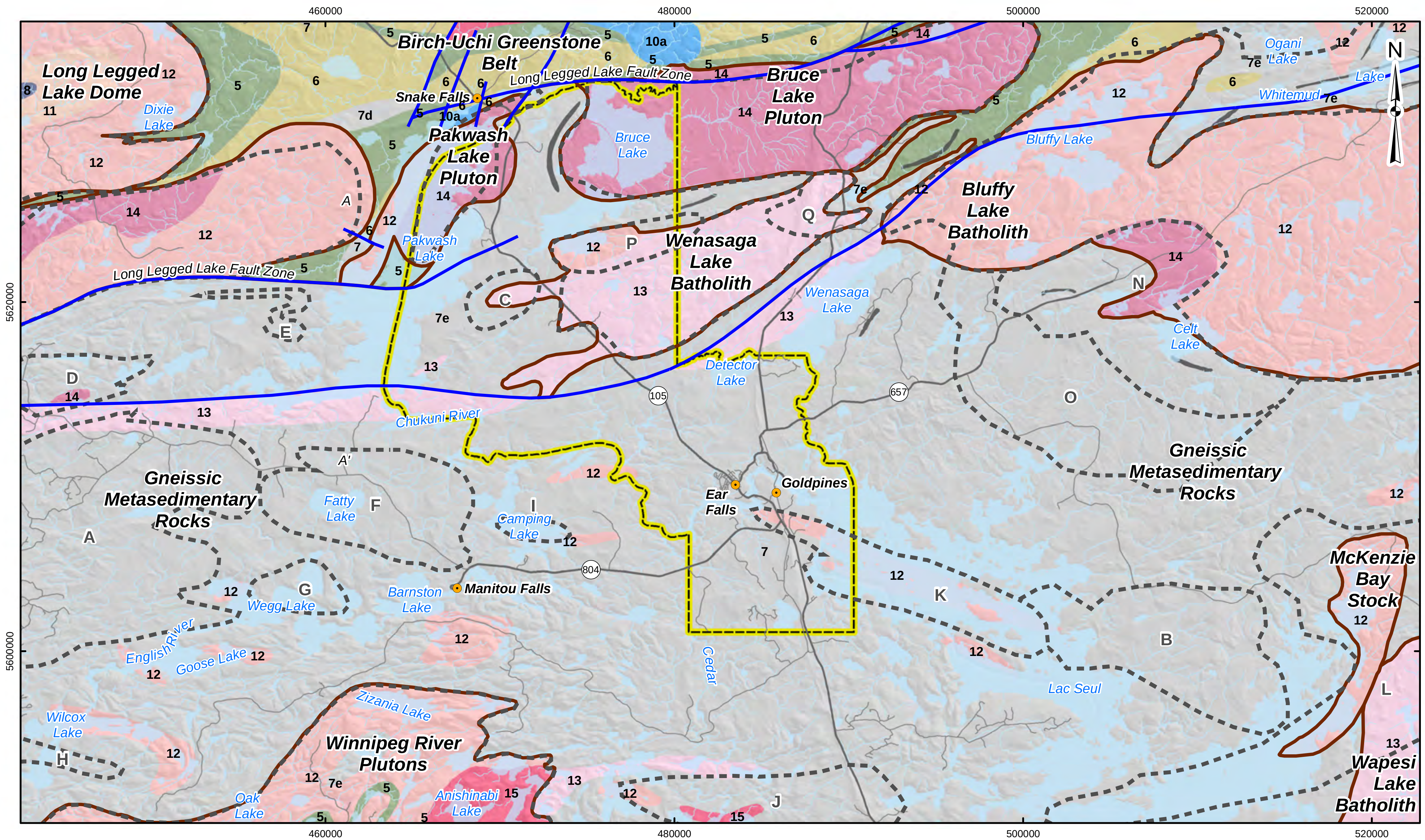
0 5 10 15 20
Kilometers

Mira Geoscience

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE
Lithoprobe Western Superior survey, MT soundings with skew and tipper plots

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 17 | REVISION 5 |
| GIS | PM/JB/JA | 30 Jul 2013 | | UTM ZONE 15 |
| CHECK | JFR | 30 Jul 2013 | | NAD 1983 |
| REVIEW | JFR | 30 Jul 2013 | | 1:275,000 |

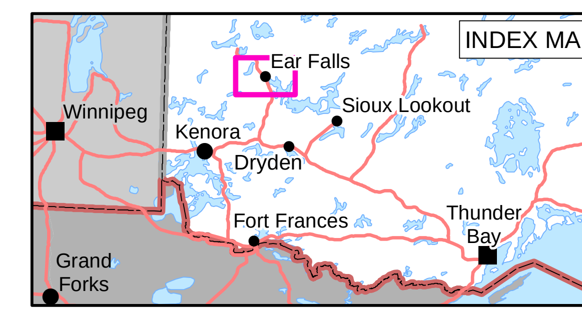



**LEGEND**

- Community
- Municipal Boundary (Township of Ear Falls)
- Main Road
- Local Road
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Outline of Major Batholith/Pluton
- Iron Formation
- Geologic Unit Interpreted from Geophysics

**Bedrock Geology**

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
  - 10a Gabbro
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
  - 7d Conglomerate and arenite
  - 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks




**REFERENCE**

Base Data - MNR LIO, obtained 2009-2012
Geology - MRD126-Bedrock Geology of Ontario, 2011
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0 5 10 15 20
Kilometers

Mira Geoscience

PROJECT Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study, Ear Falls Area, Ontario

TITLE Geophysical Interpretation for the Ear Falls area

| | | | | |
|---|---|---|---|---|
| DESIGN | PRM | 11 May 2012 | Figure 18 | REVISION 4 |
| GIS | PM/JB | 26 Aug 2013 | | UTM ZONE 15 |
| CHECK | TC | 12 Nov 2013 | | NAD 1983 |
| REVIEW | JFR | 12 Nov 2013 | | 1:275,000 |

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