NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Interpretation

TOWNSHIP OF WHITE RIVER, ONTARIO

APM-REP-06144-0086

NOVEMBER 2014

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Phase 1 Geoscientific Desktop Preliminary Assessment

Lineament Interpretation

Township of White River, Ontario

Report Prepared for:

AECOM Canada Ltd.

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Nuclear Waste Management Organization
NWMO Report Number: APM-REP-06144-0086

Report Prepared by:

SRK Consulting (Canada) Inc.

SRK Project Number: 3CA041.001

October, 2014

Lineament Interpretation

Township of White River, Ontario

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Executive Summary

In January, 2013, the Township of White River in northwestern Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process, and requested that a preliminary assessment be conducted to assess potential suitability of the White River area for safely hosting a deep geological repository (Step 3). This request followed a successful completion of an initial screening conducted during Step 2 of the site selection process.

The preliminary assessment is a multidisciplinary desktop study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, social, economic, and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated report (NWMO, 2014). The objective of the desktop geoscientific preliminary assessment is to determine whether the Township of White River and its periphery, referred to as the "White River area", contains general siting areas that have the potential to meet the NWMO's geoscientific site evaluation factors.

This report presents the findings of a lineament investigation study completed as part of the desktop geoscientific preliminary assessment of the White River area (AECOM 2014a). The lineament study focused on identifying surficial and geophysical lineaments and their attributes using publicly-available digital data sets, including geophysical (aeromagnetic with the support of electromagnetic) and surficial (satellite imagery, digital elevation) data sets for the White River area. The assessment of interpreted lineaments in the context of identifying siting areas that are potentially suitable for hosting a repository is provided in the desktop preliminary geoscientific assessment report (AECOM 2014a). The lineament investigation interprets the location and orientation of potential bedrock structural features (e.g., individual fractures or fracture zones) within the context of the local and regional geological setting. The approach undertaken in this desktop lineament investigation is based on the following:

- Lineaments were interpreted from multiple, readily-available data sets (aeromagnetic, electromagnetic where available, CDED, Landsat and SPOT);
- Lineament interpretations were made by documented specialist observers and using a standardized workflow;
- Lineament interpretations were analyzed based on an evaluation of the quality and limitations of the available data sets;
- Interpreted lineaments were separated into three categories (ductile, brittle, dyke) based on their character.
- Lineament interpretations were analyzed using reproducibility tests, particularly the coincidence of lineaments extracted by different observers, coincidence of lineaments extracted from different data sets, relative ages and/or documentation in literature; and
- Final classification of the lineament interpretation was done based on length and reproducibility.

The distribution of lineaments in the White River area reflects the bedrock structure, resolution of the data sets used, and surficial cover. Lineament density, as demonstrated in this study, is closely associated with the resolution of the interpreted data sets, and with the distribution and thickness of overburden cover that masks the surficial expression of bedrock structures. Surface lineament density throughout the White River area varies considerably. The greatest density of lineaments occurs in areas underlain by the Dayohessarah greenstone belt. Other zones of high lineament density occur throughout large parts of the White River area, and commonly correlate with small zones of high resolution geophysical data. The lack of high resolution geophysical data and a significant distribution of overburden cover hindered the ability to interpret lineaments throughout the White River area. These limitations resulted in a lineament interpretation where high density zones were biased towards areas of high resolution geophysics and low overburden, and lineament density was not necessarily reflective of the distribution of bedrock structures.

A total of 2839 brittle lineaments were interpreted in the White River area. The lineaments exhibit three dominant orientations, northwest, northeast, and north, and several minor orientations including east-northeast and greenstone belt-parallel. In addition, a total of 442 dyke lineaments were interpreted in the White River

area. Although the lineament density in the White River area is variable due to low resolution geophysics and overburden, several areas with a relatively low density of lineaments related to bedrock structures were identified. These are restricted to select zones within the Black-Pic batholith, the Pukaskwa batholith, the Anahareo pluton, the Strickland pluton and the gneissic tonalite east of the township of White River.

On the basis of the structural history of the White River area, a framework was developed to constrain the relative age relationships of the interpreted lineaments.

Important Notice

AECOM Canada Ltd. (AECOM), on behalf of the Nuclear Waste Management Organization (NWMO), commissioned SRK Consulting (Canada) Inc. (SRK) to compile a structural lineament interpretation of remote sensing data for the White River area in Ontario. The opinions expressed in this report have been based on the information supplied to SRK by AECOM and NWMO. These opinions are provided in response to a specific request from NWMO, and are subject to the contractual terms between SRK and AECOM. SRK has exercised all due care in reviewing the supplied information. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them. Opinions presented in this report apply to the site conditions and features as they existed at the time of SRK’s investigations, and those reasonably foreseeable. These opinions do not necessarily apply to conditions and features that may arise after the date of this report.

All title and beneficial ownership interests to all intellectual property, including copyright, of any form, including, without limitation, discoveries (patented or otherwise), software, data (hard copies and machine readable) or processes, conceived, designed, written, produced, developed or reduced to practice pertaining to this study shall vest in and remain with NWMO. For greater certainty, (a) ownership of all rights, title and interest, including intellectual property, in the work or deliverables are owned by NWMO and (b) ownership of all intellectual property created, developed or reduced to practice in the course of conducting this study and creating this report are exclusively owned by NWMO. SRK hereby grants NWMO a fully paid up irrevocable licence for all such intellectual property for its own non-commercial use.

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1 Introduction

In January, 2013, the Township of White River in northwestern 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 the potential suitability of the Township of White River and its periphery for safely hosting a deep geological repository (Step 3),. This request followed a successful completion of an initial screening conducted during Step 2 of the site selection process.

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This report presents the findings of a lineament investigation study completed by SRK Consulting (Canada) Inc. (SRK) as part of the desktop geoscientific preliminary assessment of the White River area (AECOM 2014a). The lineament study focussed on identifying surficial and geophysical lineaments and their attributes using publicly-available digital data sets, including surficial (satellite imagery, digital elevation) and geophysical (aeromagnetic, electromagnetic) data sets for the White River area. The assessment of interpreted lineaments in the context of identifying general areas that have the potential to meet NWMO's geoscientific factors is provided in the desktop preliminary geoscientific assessment report (AECOM 2014a).

1.1 Scope of Work and Work Program

The scope of work includes the completion of a desktop structural lineament interpretation of remote sensing (AECOM 2014b) and geophysical (PGW 2014) data for the White River area in northwestern Ontario (Figure 1).

The White River area used for the interpretation is approximately 5000 square kilometers (km^2) and was provided by NWMO as a shape file (Figure 1). The northwest corner and northern boundary of the study area are bounded by the southeast extent of the Manitouwadge lineament interpretation area (AECOM 2014c) and the southern boundary of the Hornepayne lineament interpretation area (Geofirma Engineering Ltd. 2013), respectively.

The lineament investigation interprets the location and orientation of possible individual faults or fracture zones and helps to evaluate their relative timing relationships within the context of the local and regional geological setting. For the purposes of this report, a lineament was defined as, 'an extensive linear or arcuate geologic or topographic feature'. The approach undertaken in this desktop lineament investigation is based on the following:

- Lineaments were mapped from multiple, readily-available data sets that include aeromagnetic geophysical survey data, satellite imagery (LandSAT; SPOT), and digital elevation models (Canadian Digital Elevation Data; CDED);
- Lineament interpretations from each source data type were made by two specialist observers for each data set using a standardized workflow;

- Lineaments were identified as brittle, dyke or ductile features by each observer;
- Lineaments were analyzed based on an evaluation of the quality and limitations of the available data sets;
- Lineaments were evaluated using: age relationships, reproducibility tests, particularly the coincidence of lineaments extracted by different observers, coincidence of lineaments extracted from different data sets, and comparison to literature; and
- Classification was applied to indicate the significance of lineaments based on length and reproducibility.

These elements address the issues of subjectivity and reproducibility normally associated with lineament investigations and their incorporation into the methodology increases the confidence in the resulting lineament interpretation.

At this desktop stage, the interpreted features were classified into three general categories based on a working knowledge of the structural history and bedrock geology of the White River area. These categories include ductile, brittle, and dyke lineaments, described as follows:

- **Ductile lineaments**: Features which were interpreted as being associated with the internal fabric of the rock units (including sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation) were classified as ductile lineaments. This category also includes recognizable penetrative shear zone fabric.
- **Brittle lineaments**: Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets), including those that offset the continuity of the ductile fabric described above, were classified as brittle lineaments. This category also includes brittle-ductile shear zones, and brittle partings interpreted to represent discontinuous re-activation parallel to the ductile fabric. At the desktop stage of the investigation, this category also includes features of unknown affinity. This category does not include interpreted dykes, which are classified separately (described below).
- **Dyke lineaments**: Features which were interpreted, on the basis of their distinct character, e.g., scale and composition of fracture in-fill, orientation, geophysical signature and topographic expression, were classified as dykes. Dyke interpretation is largely made using the aeromagnetic data set, and is often combined with pre-existing knowledge of the bedrock geology of the area.

1.2 Qualifications of SRK and SRK Team

The SRK Group comprises of more than 1,400 professionals, offering expertise in a wide range of resource engineering disciplines. The independence of the SRK Group is ensured by the fact that it holds no equity in any project it investigates and that its ownership rests solely with its staff. These facts permit SRK to provide its clients with conflict-free and objective recommendations on crucial issues. SRK has a proven track record in undertaking independent assessments of mineral resources and mineral reserves, project evaluations and audits, technical reports and independent feasibility evaluations to bankable standards on behalf of exploration and mining companies, and financial institutions worldwide. Through its work with a large number of major international mining companies, the SRK Group has established a reputation for providing valuable consultancy services to the global mining industry.

The following is a brief description of the qualifications and roles of project team members.

Mr. Simon Craggs, MSc is a Senior Consultant (Structural Geology) with SRK who has a broad background in geoscience and specializes in regional mapping and detailed analysis of fracture/fluid flow mechanics and the structural controls on epithermal ore deposit formation. Mr. Craggs holds a bachelor's degree in Geological Science from the University of Leeds, UK, and a master's degree in Structural Geology from the University of New Brunswick, Canada. In this study, Mr. Craggs was the lead interpreter.

Dr. Julia Kramer Bernhard is a Senior Consultant (Structural Geology) with SRK who has more than 16 years of experience in regional- to deposit-scale field mapping and remote sensing data interpretation for the analysis of structurally controlled, polyphasely deformed mineralized deposits. Dr. Kramer Bernhard has conducted numerous regional and detailed-scale structural satellite image interpretations in Switzerland, South Africa, Kyrgyzstan, Peru, Chile, and China, on projects involving gold and PGE-copper-nickel deposits. Dr. Kramer Bernhard holds a PhD from the University of Basel, Switzerland, and an MSc from the University of Karlsruhe, Germany. In this study, Dr. Kramer was a second interpreter.

Mr. Carl Nagy, MSc is a Consultant (Structural Geology) with SRK who specializes in regional bedrock mapping and structural analysis in complex tectonic environments. He has recently completed a structural analysis of crustal-scale shear zones in the Himalaya and regional bedrock mapping of poly-deformed terranes in southwest USA and northern Canada. Mr. Nagy holds a bachelor's degree in Geological Sciences from McGill University, Canada, and a master's degree in Structural Geology from Queen's University, Canada. In this study, Mr. Nagy was also a second interpreter, and the primary author on the report.

Dr. James Siddorn, PGeo is a Practice Leader and Principal Consultant (Structural Geology) with SRK who has a broad background in geoscience. Dr. Siddorn specializes in building 4D deposit- to district-scale models to evaluate the structural controls on ore distribution, rock stability, and hydrogeology, and is highly proficient in computer based 2D/3D GIS and geological modelling. He has more than 18 years of experience in the consulting field, including the management of a number of high profile and multidisciplinary projects. He has managed and completed numerous studies involving the structural and geological interpretation of remote sensing data in Northern Ontario for mineral exploration and geotechnical/hydrogeological studies. Dr. Siddorn holds a bachelor's degree in Geology from the University of Durham, UK, a master's degree in Geology and a doctoral degree in Structural Geology from the University of Toronto. In this study, Dr. Siddorn supervised all work completed and reviewed drafts of this report prior to their delivery to AECOM and NWMO as per SRK internal quality management procedures.

Mr. Jason Adam is an Associate Consultant (GIS) who has a broad experience in GIS. Mr. Adam provided GIS support for the study, mainly for the preparation of figures, under the direction of Mr. Nagy.

1.3 Acknowledgements

SRK would like to thank Mr. Cam Baker and Mr. Bob Leech from AECOM and Mr. Stephen Reford from Paterson, Grant and Watson (PGW) for a fruitful collaboration on this project.

1.4 Report Organization

The report is organized into sections that describe the geological setting of the White River area, the methodology used in identifying lineaments, the findings of the lineament interpretation, and a discussion of the results in the context of the local and regional geological framework.

Section 1 of this report includes an introduction and background for the completed structural lineament investigation.

Section 2 provides an overview of the geological setting of the White River area and documents its structural history on the basis of available literature. A brief outline of the physical geography, Quaternary geology, and land use in the White River area are also included in this section.

Section 3 documents the methodology applied for the lineament investigation for the White River area. The source data used for the lineament interpretation are outlined and the interpretation workflow for the subsequent steps of the investigation is described.

Section 4 documents the findings of the lineament investigation in the White River area. This includes a description of interpreted lineaments by data set and describes the classification of the integrated data set by major geological unit.

Section 5 discusses lineament length, density, and reproducibility, as well as their relative age relationships, and fit with mapped features.

Section 6 is a brief summary of the main findings of this investigation.

2 Summary of Physical Geography and Geology

2.1 Physical Geography

Physical geography in the White River area is described in detail in AECOM (2014b). A summary of the main features is provided here for reference.

The White River area is located within the Abitibi Upland physiographic region (Thurston, 1991), a subdivision of the extensive James physiographic region (Bostock, 1970). The region is generally characterized by abundant bedrock outcrop with shallow drift cover and a rugged topography.

Bedrock-controlled terrain dominates the majority of the area and results in significant differences in elevation over short distances; the maximum relief within the White River area is approximately 311 metres. The highest point of land within the area, 622 metres above sea level (masl), occurs approximately 13 kilometres northeast of the settlement area of White River, and the lowest point (311 masl) is the level of Kabinakagami Lake in the northeast corner of the White River area. Notable variations in elevation caused by the relief of the bedrock surface are prevalent throughout the majority of the White River area. The White River area can be viewed as consisting of a broad, dissected plateau which has higher elevations in the western and southern regions and a lower ground surface along its northern boundary.

Within the White River area the upland regions, consisting of bedrock hills and ridges, are typically characterized by moderate relief of (approximately 60 to 80 metres) over distances of hundreds of metres to a few kilometres. The uplands are scattered throughout the area and form the dominant terrain type. Glaciolacustrine, organic, and to a lesser degree, glaciofluvial deposits and areas of ground moraine, represent areas of limited relief, although many of these deposits are characterized by protrusions of bedrock. The glaciolacustrine deposits in the northern third of the area display relief in the range of 20 to 40 metres over the majority of their surface area. Limited relief is present within organic deposits, except where their surface is disrupted by hummocks of bedrock.

The White River area straddles the Atlantic-Arctic watershed boundary with approximately equal amounts of land on either side of the divide. The area’s drainage network is contained within four tertiary level watersheds, two of which flow southward into Lake Superior, and two which drain northward to James/Hudson Bay.

Shallow groundwater flow systems exist across the area, with discharge to creeks, rivers, lakes and wetlands or surficial deposits occupying lowlands and valleys. Groundwater flow within drift deposits and in shallow bedrock aquifers in the White River area is expected to mimic the pattern of surface flow, with groundwater divides coinciding with drainage divides. Information on shallow aquifers in the region is cursory and completely lacking for deep bedrock flow systems.

The orientation of the drainage network within the White River area is largely controlled by bedrock structural features (faults and lineaments) and the irregular topography of the terrain. Due to this control, the majority of waterways, including lakes, have, in order of dominance, a northeast, north or northwest orientation. While the overall drainage direction in the Atlantic and Arctic watersheds are southwest and northeast, respectively, the catchment areas of individual lakes within the watersheds have stream segments with multiple flow directions (Figure 1).

The larger rivers draining the area's watersheds are fed by numerous smaller creeks and streams that effectively drain all parts of the White River area. While there is generally a high density of stream and rivers in the area, it is somewhat lower in the region surrounding Kabinakagami Lake where glaciolacustrine, glaciofluvial and organic deposits occupying a significant percentage of the landscape.

Typically, segments of the waterways in the White River area are on the order of 2 to 10 kilometres, as they flow into and out of lakes occurring along the drainage paths. A relationship exists between the length of stream segments and relief: shorter segments are present in highland regions, and longer segments in lower relief regions associated with glaciolacustrine deposits. Gradients of the watercourses vary; those of smaller streams are generally moderate, while longer rivers, such as the, Kabinakagami, Shabotik and White rivers, have lower gradients. Rapids and small waterfalls are common in the White River area.

The numerous lakes within the White River area occupy approximately 10 percent (514 square kilometres) of the land surface. While the lakes are widespread, lake density is greatest in areas of high elevation and relief and, as such, more lakes occur in bedrock-dominated terrain in the southern and west-central portions of the area. Lower lake density is present in a large zone to the north of an arching line that runs from Matthews Lake, on the northern boundary, to north of Oba Lake in the east. This zone corresponds with the most extensive deposits of glaciolacustrine, glaciofluvial and organic sediments. Local concentrations of small lakes' however, are present in this zone within some large glaciofluvial deposits.

2.2 Bedrock Geology

The White River area is within the Wawa Subprovince, which is a volcano-sedimentary-plutonic terrane bounded to the east by the Kapuskasing structural zone and to the north by the metasedimentary-dominated Quetico Subprovince. The Wawa Subprovince is composed of well-defined greenstone belts of metamorphosed volcanic rocks and associated metasedimentary rocks, separated by granitoid rock units. The granitoids that separate the greenstone belts comprise 20 to 30 percent of the landmass of the Wawa Subprovince, and consist of massive, foliated and gneissic tonalite-granodiorite, which is cut by massive to foliated granodiorite and granite. The majority of the granitoids were emplaced during or after the deposition of the greenstone belts with which they are associated (Williams et al. 1991).

Within the Wawa Subprovince there are two semi-linear zones of greenstone belts, the northern of which includes the Shebandowan, Schreiber-Hemlo, Manitouwadge-Hornepayne, Dayohessarah and Kabinakagami greenstone belts (Figure 2). The southern zone comprises the Michipicoten, Mishibishu and Gamitagama greenstone belts which are located west of the Kapuskasing structural zone, well southeast of the White River area. The Dayohessarah greenstone belt and the western portion of the Kabinakagami belt are within the White River area (Figures 2 and 3); a small portion of the Schreiber-Hemlo belt is located along the western boundary of the White River area, while the Michipicoten greenstone belt is situated approximately 25 kilometres to the southeast. The Dayohessarah and Kabinakagami greenstone belts have been interpreted by Williams et al. (1991) and Stott (1999) as being part of a once continuous supracrustal belt now represented by the Manitouwadge-Hornepayne and the Black River assemblage of the Schreiber-Hemlo belts.

Several generations of Paleo- and Meso-proterozoic diabase dyke swarms, ranging in age from 2.473 to 1.14 Ga, cut all bedrock units in the White River area. The most prominent of these dyke swarms include the northwest-trending Matachewan Swarm, ca. 2.473 Ga (Buchan and Ernst, 2004); the northeast-trending Biscotasing dyke swarm, ca. 2.167 Ga (Hamilton et al., 2002); and the north-trending Marathon dyke swarm ca. 2.121 Ga (Buchan et al., 1996; Hamilton et al., 2002). Less numerous dykes belonging to the west-northwest-trending Sudbury (ca. 1.238 Ga; Krogh et al. 1987) and northeast-trending Abitibi (ca. 1.14 Ga; Ernst and Buchan, 1993) dyke swarms also crosscut the area.

The main geological units occurring in the White River area are further described below.

2.2.1 Black-Pic Batholith

The Black-Pic batholith is a large, regionally-extensive intrusion that encompasses roughly a 3,000 square kilometres area within the Wawa Subprovince and underlies the northwest portion of the White River area (Figures 2 and 3). It is bounded to the south by the Pukaskwa batholith and the Danny Lake stock, and to the east by the Dayohessarah greenstone belt.

The Black-Pic batholith comprises a multi-phase suite that includes hornblende-biotite, monzodiorite, foliated tonalite and pegmatitic granite with subordinate foliated diorite, granodiorite, granites and crosscutting aplitic to pegmatitic dykes (Williams and Breaks, 1989; Zaleski and Peterson, 1993). In the White River area the batholith is described as a gneissic tonalite in a compilation map of Santaguida (2001); however, Fenwick (1967), similarly to Milne (1968), mapped the batholith as uniform, biotite granitic gneiss and biotite granite which becomes gneissic near the boundary with the Dayohessarah greenstone belt (noting that terminology used was before Streckeisen’s (1976) standard classification). Fenwick (1967) also noted the occurrence of migmatites (noting that terminology used was prior to either Mehnert’s (1968) or Sawyer’s (2008) classifications) composed of highly altered remnants of pre-existing volcanic and sedimentary rocks mixed with variable amounts of granitic material. The migmatites occur either as a breccia type, in which fragments of the older rocks are cemented by dykes; or veins of granitic rock or a banded type, in which layers of the older material alternate with layers of granitic material.

Several generations of intrusions are present within the batholith, yielding geochronological ages ranging from ca. 2.720 Ga (Jackson *et al.*, 1998) for the earliest recognized phase to ca. 2.689 Ga for a late-stage recognized monzodioritic phase located in the Manitouwadge area, about 70 km northwest of the White River area (Zaleski *et al.*, 1999). In addition, there are also younger granitic phases within the Black-Pic batholith in the Manitouwadge area which, despite a lack of geochronological information, are thought to be part of the regional suite of ca. 2.660 Ga, post-tectonic “Algoman granites” (Zaleski *et al*., 1999). Within the batholith, intrusive relationships are typically destroyed, and only metamorphic textures and associated mineral assemblages are preserved. Inclusions of relatively melanocratic members of the suite occur as foliated inclusions within later, leucocratic members (Williams and Breaks, 1989; 1996).

The Black-Pic batholith is interpreted as containing regional scale domal structures with slightly dipping foliations radiating outward from its centre (Williams and Breaks, 1989; Lin and Beakhouse, 2013). At least one such smaller-scale structure potentially exists in the White River area immediately north of the Danny Lake stock where semi- circular faults outline the position of a possible dome several kilometres in width (Figures 2 and 3). The origin and geologic description of these semi-circular features is largely unknown.

Structurally deeper levels of the tonalite suite in the Black-Pic batholith are strongly foliated with a sub-horizontal planar fabric that exhibits a poorly developed, north-trending rodding and mineral-elongation lineation (Williams and Breaks, 1989). Upper structural levels of the tonalite suite are cut by abundant granitic sheets of pegmatite and aplite, and are more massive (Williams and Breaks, 1989; Zaleski and Peterson, 1993). Just to the north of the White River area are zones of migmatized volcanic rocks, and zones of massive granodiorite to granite embodied in the Black-Pic batholith. The contact between these rocks and the tonalitic rocks of the Black-Pic batholith is relatively gradational with extensive sheeting of the tonalitic unit (Williams and Breaks, 1989; Williams et al. 1991).

No readily available information regarding the thickness of the batholith is available; however, its size and the geological history of the region suggest it may extend to a significant depth.

2.2.2 Pukaskwa Batholith

The Pukaskwa batholith (also referred to as the Pukaskwa gneissic complex) is a large, regionally-extensive intrusion covering an area of at least 5,000 square kilometres in the Wawa subprovince (Figure 2). Mapping of the intrusion in the White River area was completed at a reconnaissance scale resulting in crudely defined boundaries of the batholith (Milne et al. 1972; Santaguida, 2001). As mapped by Santaguida (2001), the batholith is bounded to the north by the Strickland pluton, the Danny Lake stock and the Black-Pic batholith. The contact with the Black-Pic batholith is located along a line extending from the west end of the Danny Lake stock running northwest to White Lake. The Pukaskwa batholith surrounds the western extent of the Anahareo Lake pluton and west-trending septa of the Dayohessarah greenstone belt.

The Pukaskwa batholith extends over a large portion of the south-central portion of the White River area (Figures 2 and 3) and is described in the compilation map as comprising foliated tonalite and gneissic tonalite suites (Santaguida, 2001). Regionally, the Pukaskwa batholith is a multi-phased intrusion emplaced over an extended period of time (Stott, 1999; Beakhouse and Lin, 2006; Beakhouse et al. 2011).

Knowledge of the Pukaskwa batholith is primarily obtained from regional studies conducted to the west, in the vicinity of the Hemlo greenstone belt. An investigation of the batholith by Beakhouse et al. (2011) identified a number of lithologic associations (rock groupings) based on petrological and geochemical characteristics, three of which were volumetrically significant. The oldest association and most abundant of the three are a group of gneissic, well-foliated tonalite to granodioritic rocks. The gneissic nature of these rocks is a composite fabric formed by: flattening or transposition of heterogeneities; metamorphic segregation or partial melting; and emplacement of sheet-like intrusive phases controlled by pre-existing anisotropy (Beakhouse et al. 2011). This lithologic association is interpreted to represent rocks derived from melting of a mafic crust and emplaced during the period ca. 2.720 to 2.703 Ga (Corfu and Muir, 1989; Jackson et al. 1998; Stott, 1999; Beakhouse et al. 2011; Lin and Beakhouse, 2013). It is likely that the foliated tonalite and gneissic tonalite suites as described by Santiaguida (2001) in the White River area are part of this rock group.

The Pukaskwa batholith’s second lithologic association, emplaced in the period between ca. 2.703 and 2.686 Ga, consists of foliated granodiorite to quartz-monzodiorite that is widespread but volumetrically limited (Beakhouse et al. 2011). Corfu and Muir (1989) reported a weakly foliated granodiorite from the Pukaskwa batholith having an inferred magmatic crystallization age of ca. 2.688 Ga. Geochemical analysis indicates that the rocks of the lithological association were derived from, or due to some sort of interaction with, an ultramafic source. These rocks cut the older lithologic association described above and have a weakly to moderate foliation which is generally sub-parallel to parallel to pre-existing rock units. The geometrical, age and field relationships are interpreted as indicative of a syn-tectonic emplacement of the second lithologic association of the Pukaskwa batholith (Beakhouse et al. 2011). Following the emplacement of the syn-tectonic phases, the Pukaskwa batholith was uplifted at approximately 2.680 Ga as a structural regional dome relative to flanking greenstone belts synchronously with ongoing regional sinistral transpressive deformation (Beakhouse et al. 2011; Lin and Beakhouse, 2013).

The youngest lithologic association comprises a group of granodioritic to granitic units that form large, homogeneous plutons and small dikes; the geochemical signature of the rocks suggests that they are derived from melting of older intermediate to felsic crust (Beakhouse et al. 2011). The rocks are dated at ca. 2.667 Ga and, therefore, are interpreted as late to post-tectonic intrusions (Davis and Lin, 2003; Beakhouse et al. 2011).

As a result of mapping in the Hemlo area to the west, Jackson et al. (1998) and Muir (2000) have identified an intrusion termed the Bremner pluton and indicated that it may extend into the White River area south of where Highway 17 crosses the western boundary of the area. Muir's mapping (Muir, 2000) does not delineate an eastern boundary of the pluton and although Jackson et al. (1998) do outline the pluton, they note that the geometry of the intrusion should be regarded as preliminary. As the boundary of the pluton is uncertain and it is likely to extend only a limited distance into the White River area, it is not depicted on Figure 2 (i.e., the area is shown as being within the Pukaskwa batholith). Muir (2000) described the pluton near the boundary of the White River area as consisting of biotite-hornblende tonalite and biotite-hornblende granodiorite. Jackson et al. (1998) dated the Bremner pluton at ca. 2.677 Ga.

No readily available information regarding the thickness of the Pukaskwa batholith was found; however, its size and the geological history of the region suggest it may extend to a significant depth.

2.2.3 Strickland Pluton

The Strickland pluton occurs in the northeast portion of the White River area bordering the Dayohessarah and Kabinakagami greenstone belts. The pluton occupies an area of approximately 600 square kilometres and has maximum dimensions in the area of 34 kilometres north-south and 55 kilometres east-west (Figure 2). Stott (1999) described the Strickland pluton as a relatively homogeneous, quartz porphyritic granodiorite; although, near the outer margin of the pluton, adjacent to the greenstone belt, granodiorite to tonalite and diorite are present. In the area west of the Kabinakagami greenstone belt, Siragusa (1977) noted that massive quartz monzonite (i.e., monzogranite in modern terminology) intrudes the granodioritic and trondhjemitic rocks in the form of medium-grained to pegmatitic dykes and small sills and irregular bodies.

Some degree of post-emplacement deformation and metamorphism of the Strickland pluton is indicated by the observed presence of fine- to medium-grained titanite and the widespread presence of hematite-filled fractures and weak alteration of silicate minerals (Stott, 1999). Stott (1999) noted that the pluton is petrographically similar to the ca. 2.697 Ga Dotted Lake batholith located in the northwestern corner of the White River area and suggested that these plutons are members of an intrusive suite commonly found along the margins of greenstone belts in this part of the Wawa Subprovince.

No readily available information regarding the thickness of the Strickland pluton was found, although it may extend to a significant depth.

2.2.4 Anahareo Lake Pluton

The Anahareo Lake pluton (informal name adopted in this report) is a large felsic intrusion of which approximately 690 square kilometres is located within the southern and southeastern parts of the White River area (Figures 2 and). The pluton extends over 51 kilometres north-south and 71 kilometres east-west. The intrusion was mapped by Siragusa (1977, 1978) as being dominantly granodiorite and quartz monzonite (i.e., monzogranite in modern terminology). Distal from the contact with the Kabinakagami greenstone belt, these rock types are relatively uniform and appear to represent multi-phase intrusions. Migmatites of trondhjemitic composition, the least dominant granitic rock within the intrusion, are present along the pluton's boundaries and as syntectonic intrusive sheets that locally exhibit a variably developed cataclastic fabric (Siragusa, 1978).

Quartz monzonite is the youngest recognized phase of the Anahareo Lake pluton and commonly intrudes the granodioritic and trondhjemitic rocks in the form of large, coarse-grained pegmatitic dykes, sills and discordant bodies of variable size (Siragusa, 1977; 1978). This phase of the pluton is described as massive, which prompted Siragusa (1978) to suggest that these young intrusive phases post-date the major period of tectonism in the White River area. However, no geochronological information is currently available to test this interpretation and the age of the pluton is unknown.

No detailed information is available regarding the thickness of the Anahareo Lake pluton, although it is possible the intrusion may extend to a significant depth.

2.2.5 Danny Lake Stock

The Danny Lake stock is an east-west-elongated intrusion (5 kilometres wide by 22 kilometres long) located approximately 4 kilometres north of the Township of White River (Figure 3). The Danny Lake stock consists of hornblende porphyritic quartz monzonite to quartz monzodiorite, and is classified by Stott (1999) as a probable sanukitoid suite. Crosscutting relationships suggest that this intrusion is the youngest intrusion in the White River area, although no absolute age is available. The Danny Lake stock locally crosscuts tonalite gneiss and envelopes amphibolite slivers that outline a tonalite gneiss dome west of Dayohessarah greenstone belt.

Considering its limited size the intrusion may only extend to a modest depth.

2.2.6 Foliated Tonalite Suite

On the southeast side of Kabinakagami Lake, Santaguida (2001) outlined two packages of rock, bisected by greenstone, described as a foliated tonalite suite that occur between the Kabinakagami greenstone belt and the Anahareo Lake pluton (Figures 2 and 3). The tonalite packages extends over a distance of 29 kilometres north-south and 25 kilometres east-west. This suite of rocks is similar to the Anahareo Lake pluton mapped by Siragusa (1977; 1978). Siragusa (1977) described outcrops of the foliated tonalite suite within the White River area as consisting of biotite trondhjemite, trondhjemite, granodiorite and biotite granodiorite. Biotite trondhjemite is the dominant granitic rock in contact zones between the granitic and supracrustal rocks of the Kabinakagami greenstone belt and also occurs as syntectonic intrusive sheets concordant to the foliations observed in the metavolcanic rocks. The biotite trondhjemite appears as strongly gneissic, grey to brownish grey, medium-grained rock and is locally porphyritic owing to the presence of eye-shaped quartz and feldspar porphyroblasts (Siragusa, 1977).

No absolute age is available for this foliated tonalite suite, although it may be of the same age as other lithologically similar intrusions in the region. No information is available regarding the thickness of the suite.

2.2.7 Dotted Lake Batholith

The Dotted Lake batholith (referred to in some literature as a pluton) is located north of White Lake and straddles the western boundary of the White River area; only a small portion of the batholith is within the White River area (Figure 3). The Dotted Lake batholith is of irregular shape, approximately 20 kilometres long and 10 kilometres wide; no information exists on the depth to which the pluton extends. The batholith is primarily a coarse-grained, homogeneous, biotite leucotonalite to leucogranodiorite that is massive to weakly foliated to lineated away from its margin

(Milne, 1968; Beakhouse, 2001). The margin of the batholith is highly strained with a well-developed penetrative fabric. Localized narrow zones of high strain also occur in the interior of the batholith associated with narrow, brittle-ductile shear zones. The Dotted Lake batholith has been dated at ca. 2.697 Ga (Beakhouse, 2001), and is interpreted to pre-date the imposition of the regional deformational fabric (Jackson et al. 1998).

2.2.8 Tedder Granite Pegmatite

Immediately south of the Dayohessarah greenstone belt, in the area surrounding Round Lake, Stott (1999) identified an intrusive body he termed the Tedder granite pegmatite. This late stage intrusive body is a massive pegmatite containing local amphibolite and clastic metasedimentary inclusions, and very local tonalite gneiss inclusions. The tonalite gneiss inclusions are similar to the gneiss present to the west and southwest of the greenstone belt suggesting a wider distribution of this unit prior to the emplacement of the pegmatite (Stott, 1999).

The amphibolite inclusions appear to be structurally non-rotated relative to the orientation of the schistosity in the greenstone belt. Based on regional deformation patterns in the surrounding tonalite gneiss and the Dayohessarah greenstone belt, Stott (Written comm., 2014) interpreted the pegmatite to post-date at least the main phase of regional deformation and noted that there exists no evidence of subsequent regionally related penetrative deformation within the pegmatite. Consequently, it appears that the pegmatite is a late phase that intruded after the granodiorite plutons were emplaced into the regional tonalite gneisses and adjacent to the greenstone belt.

The extent of Tedder granite pegmatite is likely minor and only the northern boundary, adjacent to the greenstone belt, has been defined. Mapping by Stott (1999) has shown that the intrusion has dimensions of greater than 8 kilometres east-west and 3 kilometres north-south. Due to the small size and undefined shape, the outline of the pegmatite is not shown on Figure 3.

2.2.9 Dayohessarah Greenstone Belt

The Dayohessarah greenstone belt is centred on Dayohessarah Lake in the north-central part of the White River area, and forms a narrow, north-trending arcuate belt, approximately 36 kilometres in length and from 1.5 to 5 kilometres in width (Figures 2 and 3).

The Archean-aged greenstone belt has been mapped by Fenwick (1967), Stott et al. (1995a, b, c) and Stott (1999). The following description of the greenstone belt is taken from Stott (1999). The greenstone belt is a south-plunging syncline composed of a basal sequence of massive to pillowed basalt overlain in succession by:

- A local unit of komatiitic flows, typified by spinifex-texture, and accompanying gabbro to peridotite bodies;
- Dacite to rhyolite flows and pyroclastic units; and
- A metasedimentary sequence centered on Dayohessarah Lake.

The metasedimentary assemblage of the Dayohessarah greenstone belt is the youngest supracrustal sequence in the greenstone belt and unconformably overlies the ultramafic flow sequence. This metasedimentary package is composed of basal metaconglomerate, containing metavolcanic and metasedimentary clasts, overlain by metamorphosed wacke-siltstone beds. The metasedimentary rocks appear to be derived from volcanic, sedimentary and felsic plutonic sources.

The structure of the belt appears to be dominated by the strain regime related to the emplacement of the syn-tectonic Strickland Pluton to the east (Stott, 1999). The southern end of the belt transitions into amphibolite inclusions within granite pegmatite and granodiorite intrusions, one of which trends westward toward the settlement area of White River.

No published information on the thickness of the Dayohessarah greenstone belt is available; however, exploration drilling has shown it extends to a depth of greater than 400 metres. It is likely that the belt may extend to a depth of 2 to 3 kilometres (G. Stott, Pers. Comm, 2013).

2.2.10 Kabinakagami Greenstone Belt

The Kabinakagami greenstone belt occurs in the northeastern part of the White River area as a northeast-trending irregularly shaped body between the Anahareo Lake and Strickland plutons (Figures 2 and 3). Within the White River area the belt has a length of approximately 40 kilometres and varies in width from 4 to 23 kilometres. General lithological descriptions of the Kabinakagami greenstone belt can be found in Siragusa (1977, 1978) and Wilson (1993). No internal subdivision of the belt has been completed (Williams et al. 1991).

The belt is a metavolcanic-metasedimentary belt dominated by mafic metavolcanic rocks locally interbedded with mafic pyroclastic rocks and minor thin, felsic metavolcanic units, and subordinate clastic metasedimentary rocks. Locally, massive metagabbro, metapyroxenite, and minor peridotite, are in contact with the mafic metavolcanic rocks. These rocks were intruded, and locally assimilated, by trondhjemitic intrusions (Siragusa, 1977, 1978).

The metasedimentary rocks include metaconglomerate, metasandstone and paragneiss. The principal sources of clasts within the metasedimentary rocks are local metavolcanic rocks, suggesting that metasedimentary rocks were derived from a source proximal to where they were deposited (Siragusa, 1977). Metasandstones and associated paragneiss flank the east side of the metavolcanic rocks. Minor occurrences of pyrite-bearing biotite-rich paragneiss and hornblende-biotite paragneiss are found at several localities along the eastern shore of Kabinakagami Lake near the boundary of the greenstone belt and are interpreted as sulphide facies iron formation bands. At the southern end of Kabinakagami Lake, the fine- and medium-grained metasedimentary rocks grade along strike into metaconglomerate (Siragusa, 1977).

The supracrustal rocks in the Kabinakagami greenstone belt were metamorphosed to middle-greenschist to upper amphibolite facies conditions. The rocks were uplifted, deformed, and partially assimilated by the emplacement of granodioritic plutons at their margins. Subsequently, both the supracrustal and the granitic rocks were intruded by numerous diabase dykes (Siragusa, 1977, 1978). The main mapped structural feature of the belt is a northeast-trending syncline, immediately west of Kabiskagami Lake (Siragusa, 1978, Santaguida, 2001). Siragusa (1977) also noted, but did not delineate, the axis of another northeast-trending syncline between Nameigos Lake and the northeastern corner of the White River area.

2.2.11 Other Units

Numerous small lenses of mafic metavolcanic rock occur in the area to the west of the Dayohessarah greenstone belt from the northern boundary of the White River area southward to the Ruthie Lake area (Fenwick, 1967; Santaguida, 2001; Figures 2 and 3). These supracrustal rocks are surrounded by the Black-Pic batholith or the Danny Lake stock and likely represent remnant fragments of what was once a far more extensive greenstone terrain.

A gabbroic body, the mapped boundaries of which are geophysically defined, is interpreted as being located in the Bulldozer Lake area in the northwestern corner of the White River area (Santaguida, 2001). Mineral exploration mapping and drilling suggest that additional, smaller gabbroic intrusions are present to the south of this unit. Approximately 5 kilometres southeast of the intrusion, eight boreholes encountered units described variously as mafic to ultramafic dykes and hornblende-quartz biotite gabbro which occurred as thin dykes to intrusions >60 metres thick (MNDM, 2013a; AFRI files 42C14NW0003 and 42C14NW0007). The dykes were observed as being hosted by granite-tonalitic gneiss.

2.2.12 Mafic Dykes

Several generations of Paleoproterozoic and Mesoproterozoic diabase dyke swarms crosscut the White River area (Figures 2 and 3), including:

- Northwest-trending Matachewan Suite dykes (ca. 2.473 Ga; Buchan and Ernst, 2004). This dyke swarm is one of the largest in the Canadian Shield and most predominant of all dyke swarms recognized in the White River area. Individual dykes are generally up to 10 metres wide, and have vertical to subvertical dips. The Matachewan dykes comprise mainly quartz diabase dominated by plagioclase, augite and quartz (Osmani, 1991);
- Northeast-trending Biscotasing Suite dykes (ca. 2.167 Ga; Hamilton et al., 2002). These dykes are not numerous in the White River area;
- North-trending Marathon Suite dykes (ca. 2.121 Ga; Buchan et al., 1996; Hamilton et al., 2002). These form a fan-shaped distribution pattern around the northern, eastern, and western flanks of Lake Superior, and are fairly minor in the White River area. The dykes vary in orientation from northwest to northeast, and occur as steep to subvertical sheets, typically a few metres to tens of metres thick, but occasionally up to 75 metres thick (Hamilton et al. 2002). The Marathon dykes comprise quartz diabase (Osmani, 1991) dominated by equigranular to subophitic clinopyroxene and plagioclase;
- West-northwest-trending Sudbury Suite dykes (ca. 1.238 Ga; Krogh et al. 1987). These dykes are not numerous in the White River area; and
- Northeast-trending Abitibi Suite dykes (ca. 1.14 Ga; Ernst and Buchan, 1993). These dykes are not numerous in the White River area.

The five dyke swarms in the White River area are generally distinguishable by their unique strike directions, crosscutting relationships and, to a lesser extent, by magnetic amplitude.

2.2.13 Faults

In the White River area a limited number of unnamed faults are indicated on public domain geological maps (Fenwick, 1966; Siragusa, 1977, 1978; Stott, 1995a, 1995b, 1995c; OGS, 2011); the largest of these parallels the axis of Esnagi Lake in the east-central part of the area (Siragusa, 1978; Figures 2 and 3). Mapped faults generally have either a northwest or northeast-trending orientation, although a grouping of semi-circular faults is present west of Dayohessarah Lake (OGS, 2011).

Stott (1999) found that fault displacements in the Dayohessarah greenstone belt were not significant but noted that additional faults (i.e., unmapped) may exist along the narrow, northeast trending bay of Strickland Lake and along a northwest trending lineament through Strickland Lake (Stott, 1995b); however, no lateral offsets along these features could be confirmed. In the Kabinakagami greenstone belt, Siragusa (1977) reported that it is likely that a northeast-trending strike-slip fault with horizontal displacement of 240 metres is present in a narrow valley, to the north of the inlet of Kabinakagami River.

Fenwick (1967) and Siragusa (1977) noted that lineaments parallel the trend of two sets of diabase dikes, which strike either northeast or northwest, and assumed that the lineaments formed from the weathering of diabase dykes or from vertical joints. It is also noteworthy that there is a clear southerly deflection in the northwesterly trend of Matachewan dykes, across a mapped northeast-trending fault, in the southeastern corner of the White River area (Figure 3). This may be related to a regional scale pattern of crustal deformation and faulting associated with the development of the Kapuskasing structural zone.

2.2.14 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in a few publications since the 1970s (e.g., Fraser and Heywood,1978; Kraus and Menard, 1997; Menard and Gordon, 1997; Berman et al. 2000; Easton, 2000a; 2000b; and Berman et al. 2005) and the thermochronological record for large parts of the Canadian Shield is documented in a number of studies (Berman et al. 2005; Bleeker and Hall, 2007; Corrigan et al. 2007; and Pease et al. 2008).

The Superior Province of the Canadian Shield largely preserves low pressure – high temperature Neoarchean (ca. 2.710-2.640 Ga) metamorphic rocks. The relative timing and grade of regional metamorphism in the Superior Province corresponds to the lithological composition of the subprovinces (Easton, 2000a; Percival et al. 2006). Subprovinces comprising volcano-sedimentary assemblages and synvolcanic to syntectonic plutons (i.e., granite-greenstone terranes) are affected by relatively early lower greenschist to amphibolite facies metamorphism. Subprovinces comprising both metasedimentary- and migmatite-dominated lithologies, such as the English River and Quetico, and dominantly plutonic and orthogneissic domains, such as the Winnipeg River, are affected by relatively late middle amphibolite to granulite facies metamorphism (Breaks and Bond, 1993; Corfu et al. 1995). Subgreenschist 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). Most late orogenic shear zones in the Superior Province and Trans-Hudson (Penokean) Orogen experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through Ar/Ar dating to ca. 2.500 Ga the value of which remains unclear (Powell et al. 1995).

A widespread Paleoproterozoic tectonothermal event, the Trans-Hudson (Penokean) Orogeny, involved volcanism, sedimentation, plutonism and deformation that affected the Churchill Province through northernmost Ontario, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski et al. 2002; Berman et al. 2005). This event was associated with ca. 1.84 to 1.8 Ga collisional convergence of the Archean Hearne domain and Superior Province (Kraus and Menard, 1997; Menard and Gordon, 1997; Corrigan et al. 2007). Associated metamorphism at moderate to high temperatures and low to moderate pressures resulted in amphibolite facies metamorphism that overprinted Archean metamorphic signatures in Archean rocks of the Churchill Province, and a complex brittle overprint in Archean rocks of the Superior Province (e.g., Kamineni et al. 1990)

Along the eastern flank of the Canadian Shield, the Grenville Province records a complex history of episodic deformation and subgreenschist to amphibolite and granulite facies metamorphism, from ca. 1.300 Ga to 950 Ma (Easton, 2000b; Tollo et al. 2004 and references therein). Lower greenschist metamorphism was documented along faults in the vicinity of Lake Nipigon and Lake Superior and is inferred to be the result of ca. 1.0 Ga far-field reactivation during the Grenville Orogeny (Manson and Halls, 1994).

In northwestern Ontario, the concurrent post-Archean effects, including the Penokean Orogen, are limited to poorly documented reactivation along faulted Archean terrane boundaries (e.g., Kamineni et al. 1990 and references therein). Most late orogenic shear zones in the Superior Province and Penokean Orogen experienced lower to middle greenschist retrograde metamorphism (e.g., Kamineni et al. 1990 and references therein).

Overall, most of the Canadian Shield preserves a complex episodic history of Neoarchean metamorphism overprinted by Paleoproterozoic tectonothermal events culminating at the end of the Grenville orogeny ca. 950 Ma. The distribution of contrasting metamorphic domains in the Canadian Shield is a consequence of relative uplift, block rotation and erosion resulting from Neoarchean orogenesis, subsequent local Proterozoic orogenic events and broader epeirogeny during later Proterozoic and Phanerozoic eons.

All Precambrian rocks of the White River area display some degree of metamorphism. The Dayohessarah greenstone belt is typically characterized by amphibolite facies metamorphism (Stott, 1999). This amphibolite facies metamorphic grade may be a manifestation of an amphibolite grade contact metamorphic aureole bordering the Strickland pluton (Stott, 1999). Little information regarding the metamorphic grade of the exposed rocks of the Kabinakagami greenstone belt is available in the reviewed literature. Based on ages obtained from metamorphic monazites, Zaleski et al. (1995; 1999) suggested that near-peak metamorphism of the Manitouwadge-Hornepayne greenstone belt occurred between 2.675 and 2.669 Ga. It can be inferred that the Dayohessarah and Kabinakagami belts may have been subjected to metamorphism during this period, as the age constraints given by Zaleski (1995; 1999) correspond well with the 2.675 ±1 and 2.661 ±1 Ga periods of regional metamorphism recognized by Schandl et al. (1991) and Davies et al. (1994).

Typical metamorphic grades in plutonic rocks within the White River area are variable from non-metamorphosed to amphibolite grade in metamorphic contact aureoles. No records exist that suggest that rocks in the White River area may have been affected by thermotectonic overprints related to post-Archean events.

2.3 Structural History

Information on the structural history of the White River area is based predominantly on insights derived from structural investigations of the Manitouwadge and Dayohessarah greenstone belts (Polat, 1998; Zaleski et al. 1994; Peterson and Zaleski, 1999) and the Hemlo gold deposit and surrounding region (Muir, 2003). Additional studies by Lin (2001), Percival et al. (2006), Williams and Breaks (1996) and Lin and Beakhouse (2013) have also contributed to the structural understanding of the area. These studies were performed at various scales and from various perspectives. Consequently, the following summary of the structural history of the White River area should be considered as a “best-fit” model that incorporates relevant findings from all studies.

Few detailed investigations of the structural history of the White River area have been completed; however, the structural history of the Manitouwadge and nearby Schreiber-Hemlo greenstone belts are generally well characterized and suggests up to of six phases of deformation (Polat, 1998; Peterson and Zaleski, 1999; Lin, 2001; Muir, 2003). Polat et al. (1998) interpreted that the Schreiber-Hemlo and surrounding greenstone belts represent collages of oceanic plateaus, oceanic arcs and subduction-accretion complexes amalgamated through subsequent episodes of compressional and transpressional collision. On the basis of overprinting relationships between different structures Polat et al. (1998) suggested that the Schreiber-Hemlo greenstone belt underwent at least two main episodes of deformation. This can be correlated with observations from Peterson and Zaleski (1999) and Muir (2003), who reported at least five and six generations of structural elements, respectively. Two of these generations of structures account for most of the ductile strain, and although others can be distinguished on the basis of crosscutting relationships, they are likely the products of progressive strain events. Integration of the structural histories detailed in Williams and Breaks (1996), Polat (1998), Peterson and Zaleski (1999), Lin (2001), and Muir (2003) suggests that six deformation events occurred within the White River area. The first four deformation events (D_1-D_4) were associated with brittle-ductile deformation and were typically associated with deformation of the greenstone belts. D_5 and D_6 were associated with a combination of brittle deformation, and fault propagation through all rock units in the White River area. The main characteristics of each deformation event are summarized below.

The earliest recognizable deformation phase (D_1) is associated with rarely preserved small-scale isoclinal folds, ductile faults that truncate stratigraphy and a general lack of penetrative foliation development. Peterson and Zaleski (1999) reported that planar D_1 fabrics are only preserved locally in outcrop and in thin section. Locally in the White River region D_1 deformation may have produced a strain aureole within the margins of the Pukaskwa batholith and surrounding country rocks which formed a local S_1 fabric. D_1 deformation is poorly constrained to between ca. 2.719 and ca. 2.691 Ga (Muir, 2003).

D_2 structural elements include prevalent open to isoclinal F_2 folds, an axial planar S_2 foliation and mineral elongation L_2 lineations (Peterson and Zaleski, 1999). Muir (2003) interpreted D_2 to have resulted from progressive north-northeast- to northeast-directed compression that was coincident with the intrusion of various plutons, including phases of the Pukaskwa batholith. The S_2 foliation is the dominant meso- to macro-scale regional fabric evident across the study area. Ductile flow of volcano-sedimentary rocks between more competent batholiths (e.g., Pukaskwa) may also have occurred during this deformation phase (e.g., Lin and Beakhouse, 2013). D_2 deformation is constrained to between ca. 2.691 and ca. 2.683 Ga (Muir, 2003).

D_3 deformation comprised northwest-southeast shortening as a result of on-going regional-scale dextral transpression and produced macroscale F_3 folds, and local shear fabrics that exhibit a dextral shear sense and overprint of D_2 structures (Peterson and Zaleski, 1999; Muir, 2003). D_3 deformation did not develop an extensive penetrative axial planar and (or) crenulation cleavage. D_3 deformation is constrained to between ca. 2.682 and ca. 2.679 Ga (Muir, 2003).

D_4 structural elements include isolated northeast-plunging F_4 kink folds with a Z-asymmetry and a moderate, northeast plunge, and associated small-scale fractures and faults overprinting D_3 structures. D_3-D_4 interference relationships are best developed north of the White River area in the Manitouwadge greenstone belt and in rocks of the Quetico Subprovince. D_4 deformation is roughly constrained to between ca. 2.679 and ca. 2.673 Ga (Muir, 2003).

Details of structural features associated with the D_5 and D_6 deformation events are limited in the literature; however, where described, they manifest as brittle and brittle-ductile faults of various scales and orientations (Lin, 2001; Muir, 2003). Within the Hemlo greenstone belt, Muir (2003) suggested that local D_5 and D_6 faults offset the Marathon, and Biscotasing dyke swarms (all ca. 2.2 Ga), and as such, suggested that in the Hemlo region, D_5 and D_6 faults propagated after ca. 2.2 Ga. However, since there are no absolute age constraints on specific events, the entire D_5-D_6 interval of brittle deformation can only be constrained to a post-2.673 Ga timeframe that may include many periods of re-activation attributable to any of several post-Archean tectonic events, as summarized in Table 1.

Table 1: Geological and Structural History of the White River area (adapted from AECOM, 2014a)

Approximate Time period (years before present)	Geological Event
2.89 to 2.77Ga	Progressive growth and early evolution of the Wawa-Abitibi terrane by collision, and ultimately accretion, of distinct geologic terranes.
2.770 – 2.673 Ga	- ca. 2.720 Ga: Onset of volcanism and subordinate sedimentation associated with the formation of the Dayohessarah and Kabinakagami greenstone belts. - ca. 2.720 Ga: Emplacement of oldest recognized phase of Black-Pic batholith. - ca. 2720-2.703 Ga: Emplacement of oldest lithologic association of Pukaskwa batholith. - ca. 2703-2.686 Ga: Emplacement of second lithologic association of Pukaskwa batholith. - ca. 2.697 Ga: Intrusion Dotted Lake pluton, and possibly of Strickland pluton. - ca. 2.689 Ga: Emplacement of younger recognized phase of Black-Pic batholith. - ca. 2.677 Ga: emplacement of Bremner pluton. - ca. 2.719 to 2.673 Ga: Four periods of ductile-brittle deformation (D_1-D_4). - D_1: ca. 2.719 – 2.691 Ga - D_2: ca. 2.691 – 2.683 Ga → Main phase of coalescence of the Wawa and Quetico subprovinces (Corfu and Stott, 1996) - D_3: ca. 2.682 – 2.679 Ga → sinistral transpressive deformation, structural domal uplift of Pukaskwa batholith - D_4: ca. 2.679 – 2.673 Ga - ca.2.688 to 2.675: Regional metamorphism
2.675 and 2.669 Ga	Peak metamorphism of regional greenstone belts.
2.667 Ga	Youngest lithologic association of Pukaskwa batholith.
2.5 to 2.1 Ga	- ca. 2.5 Ga: Supercontinent fragmentation and rifting in Lake Superior area. Development of Southern Province - ca. 2.473 Ga: Emplacement of the Matachewan dyke swarm. - ca. 2.167 Ga: Emplacement of Biscotasing dyke swarm. - ca. 2.121 Ga: Emplacement of the Marathon dyke swarm.
1.9 to 1.7 Ga	Penokean Orogeny in Lake Superior and Lake Huron areas; possible deposition and subsequent erosion in the Manitouwadge area.
1.238 Ga	- ca. 1.238 Ga emplacement of the Sudbury dyke swarm
1.150 to 1.090 Ga	Rifting and formation of the Midcontinent Rift. - ca. 1.14 Ga: Emplacement of the Abitibi dyke swarm.
540 to 355 Ma	Possible coverage of the area by marine seas and deposition of carbonate and clastic rocks subsequently removed by erosion.
145 to 66 Ma	Possible deposition of marine and terrestrial sediments of Cretaceous age, subsequently removed by erosion.

2.6 to 0.01 Ma	Periods of glaciation and deposition of glacial sediments.

2.4 Quaternary Geology

The Quaternary sediments, commonly referred to as drift, soil or overburden, are glacial and post-glacial materials which overlie the bedrock in the White River area. Their distribution, thickness and physical characteristics have an important influence on several aspects of the current assessment. Areas of thicker drift can hinder the interpretation of lineaments by masking their presence in satellite imagery or muting the response obtained from geophysical surveys. Coarser-grained surficial sediments typically have a moderate to high transmissivity and can serve as local aquifers as well as being a potential source of mineral aggregates for use in building and road construction.

All glacial landforms and related materials within the White River area are associated with the Late Wisconsinan. The Quaternary (i.e., surficial) geology of the area has been mapped at different scales as discussed in AECOM, 2014b.

Geddes et al. (1985) and Geddes and Kristjansson (1986) reported that glacial striae in the White River area reveal an early north to south ice movement that was followed by a strong, regional flow of approximately 220°. Bedrock erosional features indicate that ice flow, likely in the waning stage of glacial cover, was influenced by local topographic conditions as demonstrated by striae measurements ranging from 180° to 245°. For the large parts of the White River area drift thickness over bedrock is limited and the ground surface reflects the bedrock topography (Kristjansson and Geddes, 1985). Over the majority of the area bedrock outcrops are common and the terrain is classified, for surficial mapping purposes, as a bedrock-drift complex, i.e., thin drift cover that only locally achieves thicknesses that mask or subdue the bedrock topography (Figure 4). Valleys and lowland areas typically have extensive and thicker surficial deposits that frequently have a linear outline.

The remote sensing and terrain evaluation completed as part of the Phase 1 preliminary assessment (AECOM, 2014b) provides a detailed assessment of the type, distribution and thickness of surficial deposits in the White River area (Figure 4).

The most common glacial deposit in the White River area is stony, sandy till (ground moraine) which forms a veneer in rocky upland areas. In the White River area the till composition is variable and two types are regionally recognizable (Geddes et al. 1985; Geddes and Kristjansson, 1986). A moderately loose, very stony variety with a sandy texture that is of local derivation dominates in areas of thin till cover in the western part of the area. A calcareous, silty till, rich in "exotic" carbonate lithologies derived from the James Bay Lowland, is common in the northern part of the White River area (Geddes and Kristjansson, 1986). This latter till occurs in two facies, one of which is stone poor, massive, silty and quite dense. The other more dominant facies is less compact and slightly sandier, and has a variable stone content. In some areas, the calcareous till is capped by coarser, locally derived till or till-like material. Geddes and Kristjansson (1986) noted that in areas where there is little relief on the land surface, the calcareous till in usually prominent, especially in areas on the leeside of significant topographic features. It is typical of the stony till to have a more hummocky, or moranic surface expression.

Till thickness is variable; while depths of several metres are present locally; thicknesses are typically is less than 3 metres (A. Bajc, pers. comm., 2013). Gartner and McQuay (1980a, 1980b) reported that the till is seldom more than 1 metre thick on the crests of the hills, but can thicken to 5 metres or more on the flanks and in the valleys between the bedrock hills.

Areas of ground moraine shown on Figure 4 are zones of lesser relief indicating the till thickness may be sufficient to subdue the bedrock topography. In the area south and west of Dayohessarah Lake, the till forms a patchy blanket over highland areas (OGS, 1997) and is, in places, gently fluted (Kristjansson and Geddes, 1986). Although the ruggedness of the surface in this area suggests that the till thickness is generally of limited depth, it may locally mask the relief of the underlying bedrock surface.

2.5 Land Use

The vast majority of the White River area is undeveloped Crown Land with privately held residential and business properties located almost exclusively within the settlement area of White River. Private land, held as mineral patents, also occurs in Lizar Township, west of Kabinakagami Lake and in and Derry Township in the northeast corner of the White River area. Several small parcels of land designated as Crown Reserves are scattered across the area.

Mineral exploration is active in the area and numerous active mining claims, and a small number of patents, are held by prospectors and mining companies (MNDM, 2013b). The majority of the mining claims occur in three areas: a large rectangular shaped block centred on Dayohessarah Lake (primarily over the Dayohessarah greenstone belt); a northeast trending group between Nameigos Lake and Kabinakagami Lake (over the central part of the Kabinakagami greenstone belt); and west of White River, south of Highway 17. A range of exploration work is conducted on the claims to assess the mineral potential including geologic mapping, drilling, and geochemical and geophysical surveys. A number of aggregate operations are extracting sand and gravel in the area (MNR, 2013a). The majority of the pits are located adjacent to the routes of Highways 17 and 631. Natural resources are discussed further in Section 5.

Forestry is a long-standing use of the land and has been an economic mainstay of the White River area. The area falls within MNR's Magpie, Nagagami and White River forestry management units (MNR, 2013b). Timber harvesting has occurred over large expanses of the White River area.

Forestry sector activities result in the development of an extended road and/or trail network, although some of this access is of a temporary (e.g., open only while logging is on-going) or seasonal nature (e.g., winter roads). Access to the many lakes and remote areas within the White River area allows use of the land for hunting and fishing by the local population and visitors to the region.

3 Methodology

3.1 Source Data Descriptions

The lineament interpretation of the White River area was based on publicly available remote sensing data sets, including airborne geophysical (aeromagnetic with the support of electromagnetic), topographic (CDED elevation models), and satellite imagery data (SPOT and Landsat).

Available data were assessed for quality, processed and reviewed before use in the lineament interpretation (PGW, 2014). The geophysical data were used to evaluate deeper bedrock structures and proved invaluable to identify potential bedrock structures beneath areas of surficial cover and to aid in establishing the age relationships among the different lineament sets. Topography (CDED) and satellite imagery (SPOT and Landsat) data sets were used to identify surficial lineaments expressed in the topography, drainage, and vegetation. Comparing surficial lineaments to aeromagnetic lineaments allows for the comparison of subsurface and surficial expressions of the bedrock structure. Throughout this study, the best resolution data available was used for the lineament interpretation.

Table 2 provides a summary of the source data sets, including their resolution, coverage and acquisition dates that were used for the lineament interpretation. The geophysical surveys listed were acquired from variably oriented survey flight lines (details available in PGW 2014).

The lineament interpretation was built in two-dimensions in ArcGISTM in UTM NAD83, Zone 16 North. Each data set used in the interpretation required manipulation in ErMapperTM, including creating ErMapper. ECW compressed raster images as end products for each data set prior to import into ArcGIS.

Table 2: Source Data Information for the Lineament Interpretation, White River area

Data Set	Product	Source	Resolution	Coverage	Acquired
Geophysics	Single master gravity and aeromagnetic data for Ontario (SMGA; GDS 1036)	Ontario Geological Survey	805 m line spacing; Sensor height 305 m	Entire study area	1959 (reprocessed in 1999)
	Ontario airborne geophysical surveys, magnetic and electromagnetic data (GDS1205)	Ontario Geological Survey	200 m line spacing; Sensor height 45 m	Covers 160 km^2 (~3%) of study area, located in northwest corner	1989 (published in 2002)
	Ontario airborne geophysical surveys, magnetic and electromagnetic data, Hemlo Area (GDS1207-REV)	Ontario Geological Survey	100 m line spacing; Sensor height 55 m	Covers 140 km^2 (~3%) of study area, located along the western boundary	1983 (published in 2002)
	OBA-Kapuskasing area, Ontario airborne magnetic and electromagnetic surveys, (GDS1024-REV)	Ontario Geological Survey	200 m line spacing; Sensor height 45 m	Covers 75 km^2 (~1.5%) of study area, located in northeast corner	1986 (published in 2003)
	AFRI No. 20004804	Ontario Geological Survey	100 m line spacing; Sensor height 30 m	Covers 180 km^2 (~3.5%) of study area, located in northeast corner	2008
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	8-23 m (0.75 to 3 arc seconds) depending on latitude	Entire study area	1995 (published in 2003)
Satellite Imagery	SPOT 4/5; Orthoimage, multispectral/ panchromatic	Geobase	10m (panchromatic) 20 m (multispectral)	Entire study area	2005-2010
	LandSAT 7 orthorectified imagery	Geobase	30 m (multispectral)	Entire study area	2001-2002

3.1.1 Geophysical Data

PGW identified and evaluated all available geophysical data sets for the White River area (PGW 2014). This evaluation highlighted the presence of the following high-resolution geophysical data sets: GDS1025, GDS1207-REV and GDS1024-REV, which cumulatively cover approximately 7.5 percent or 375 square kilometres of the study area. These high resolution data sets are located along the central western border, and the northwest and northeast corners of the study area. In addition, PGW supplied SRK with a high resolution image of an aeromagnetic survey covering the Dayohessarah greenstone belt (equivalent to ~3.5 percent of the study area). The remaining 89 percent of the study area is covered by the lower-resolution single master gravity and aeromagnetic data for Ontario (SMGA - GDS1036).

For the lineament investigation, gridded data for total magnetic field and several filters including first vertical derivative and tilt filters, both reduced to the pole (RTP) were used (PGW 2014). From these gridded data, a series of compressed raster images was created for the total magnetic intensity (RTP), first vertical derivative (RTP), and tilt derivative (RTP), including colour-draped and shaded images. Figure 5 shows the first vertical derivative of combined aeromagnetic data for the White River area.

A frequency domain electromagnetic survey was also collected from the aforementioned high resolution geophysical surveys carried out by the Ontario Geological Survey (GDS1025, GDS1207-REV, GDS1024-REV). PGW provided grids and raster images at a frequency of 4186 Hz for survey GDS1024; 900 Hz, 7200 Hz and 56000 Hz for survey GSD1205; and a frequency of 4500 Hz for survey GDS1207. No data was available for the remaining area. Due to this lack of high resolution coverage, electromagnetic data was used only in support of the aeromagnetic data, and was not interpreted as a separate data set.

The resolution of each available data set has a strong impact on the resolution and number of interpreted lineaments. The GDS1025, GDS1207-REV, GDS1024-REV and AFRI No. 20004804 data sets have a high resolution (100-200 metre line spacing; ~ 30-metre grid cells) and covers approximately 11 percent of the White River area (Figure 5). The remainder of the study area is covered by the lower resolution SMGA (GDS1036) data set (805 metre line spacing; 200-metre grid cells). In the areas covered by the high-resolution data sets, it is considered that other available data sets with lower resolution were not favorable for use in the lineament analysis.

A summary of survey acquisition parameters for the geophysical surveys used during the lineament study is provided in Table 3.

Table 3: Geophysical Survey Acquisition Parameters for the Lineament Interpretation

Survey	Flight Line Spacing (m)	Grid Cell Size (m)	Sensor Height (m)	Flight Line Azimuth (0-359°)
Single Master Gravity and Aeromagnetic data for Ontario (SMGA; GDS1036)	805	200	305	0°
Ontario airborne geophysical surveys, magnetic and electromagnetic data, White River Area (GDS1205)	200	30	45	170°
Ontario airborne geophysical surveys, magnetic and electromagnetic data, Hemlo Area (GDS1207-REV)	150-200	N/A	55	0°
OBA-Kapuskasing area, Ontario airborne magnetic and electromagnetic surveys, (GDS1024-REV)	200	N/A	45	176°
AFRI No. 20004804	100	N/A	30	123° (north) / 69° (south)

3.1.2 Surficial Data

Canadian Digital Elevation Data (CDED)

CDED served as an important data source for analyzing and interpreting lineaments in the White River area. The digital elevation model (DEM) used for this study was constructed by the Ontario Ministry of Natural Resources (MNR). The source data were acquired through the Ontario Base Mapping program, which was a major photometric program conducted across Ontario between 1978 and 1995. Four main data sets were used: contours, spot heights, stream networks, and lake elevations derived using spot heights and water features. CDED data sets are provided in geographic coordinates, referenced horizontally using North American Datum 1983 (NAD83) and vertically based on the Canadian Geodetic Vertical Datum 1928 (CGVD28). Ground elevations are recorded in metres relative to mean sea level. It was determined that the resolution of the DEM data set was sufficient to undertake the lineament interpretation.

The CDED topography data for the White River area, including a reasonable buffer zone (approximately 20 kilometres or more) extending in all directions outside the study area, is available in 32 USGS DEM format individual tiles, each tile covering approximately 1200 square kilometres. A summary of the CDED tiles used in the lineament interpretation is provided in Table 4.

These files are accurate to within five metres and a resolution of 0.75 arc seconds (Table 4), which is equivalent to approximately 16 to 23 metres in the White River area. The 32 individual tiles were merged, levelled, and a colour mosaic, shaded digital elevation model (DEM) was created in ErMapper and saved as a compressed raster image. The colour image of the DEM for the White River area is shown in Figure 6.

Table 4: 1:50,000 Scale CDED Tiles Used for Lineament Interpretation

Identifier	NTS Tiles	East/West Coverage	Ground Resolution (arc sec.)
042c05_0100_deme	042c/ 05	East	0.75
042c05_0100_demw	042c/ 05	West	0.75
042c06_0100_deme	042c/ 06	East	0.75
042c06_0100_demw	042c/ 06	West	0.75
042c07_0100_deme	042c/ 07	East	0.75
042c07_0100_demw	042c/ 07	West	0.75
042c08_0100_deme	042c/ 08	East	0.75
042c08_0100_demw	042c/ 08	West	0.75
042c09_0100_deme	042c/ 09	East	0.75
042c09_0100_demw	042c/ 09	West	0.75
042c10_0100_deme	042c/ 10	East	0.75
042c10_0100_demw	042c/ 10	West	0.75
042c11_0100_deme	042c/ 11	East	0.75
042c11_0100_demw	042c/ 11	West	0.75
042c12_0100_deme	042c/ 12	East	0.75
042c12_0100_demw	042c/ 12	West	0.75
042c13_0100_deme	042c/ 13	East	0.75
042c13_0100_demw	042c/ 13	West	0.75
042c14_0100_deme	042c/ 14	East	0.75
042c14_0100_demw	042c/ 14	West	0.75
042c15_0100_deme	042c/ 15	East	0.75
042c15_0100_demw	042c/ 15	West	0.75
042c16_0100_deme	042c/ 16	East	0.75
042c16_0100_demw	042c/ 16	West	0.75
042f01_0100_deme	042f/ 01	East	0.75
042f01_0100_demw	042f/ 01	West	0.75
042f02_0100_deme	042f/ 02	East	0.75
042f02_0100_demw	042f/ 02	West	0.75
042f03_0100_deme	042f/ 03	East	0.75
042f03_0100_demw	042f/ 03	West	0.75
042f04_0100_deme	042f/ 04	East	0.75
042f04_0100_demw	042f/ 04	West	0.75

Systeme Pour l'Observation de la Terre (SPOT) and Landsat Imagery

SPOT multispectral and panchromatic orthoimagery were used for identifying surficial lineaments and exposed bedrock within the White River area. SPOT multispectral data consist of several bands, each band recording the reflected radiation within a particular spectral range, displayed with a radiometry of 8-bits (or a value ranging from 0 to 255). SPOT 4 and 5 images were acquired using the High Resolution Geometric (HRG) sensor. Each image covers an area of approximately 8,500 square kilometres.

For quality control, Natural Resources Canada (NRCan) provides images that have a maximum of 5 percent snow and ice cover, 5 percent cloud cover and a maximum viewing angle of 15 degrees. NRCan orthorectified the SPOT images using three data sources: 1:50,000 scale Canadian Digital Elevation Data (CDED), National Road Network (NRN), and Landsat 7 orthoimagery. The orthoimages are provided in GeoTIFF format, and projected using Universal Transverse Mercator (UTM) projection referenced to the North American Datum 1983 (NAD83).

The SPOT 4/5 Geobase OrthoImage for the White River area, including a reasonable buffer zone (greater than 10 kilometres) extending in all directions outside the study area, is available as seven tiles (Table 5). Each tile contains five Geotiff images representing spectral bands B1, B2, B3, MIR and a panchromatic band. A natural colour image was created for this tile in ErMapper and saved as a compressed raster image.

Table 5: SPOT Imagery Scenes Used for the Lineament Interpretation

Scene ID	Satellite	Date of Image
s5_08355_4828_20070805_m20_utm16	SPOT 5	12-October-2007
s5_08426_4857_20070503_m20_utm16	SPOT 5	17-March-2008
s5_08438_4828_20070503_m20_utm16	SPOT 5	18-December-2007
s5_08509_4857_20060911_m20_utm16	SPOT 5	16-September-2008
s5_08522_4828_20060609_m20_utm16	SPOT 5	17-September-2007
s5_08551_4857_20060901_m20_utm16	SPOT 5	23-March-2007
s5_08602_4828_20060901_m20_utm16	SPOT 5	9-February-2007

The Landsat 7 Orthorectified Image for the White River area, including a reasonable buffer zone (greater than 25 kilometres) extending in all directions outside the study area, is available as two tiles from the Canadian Council of Geomatics (http://www.geobase.ca; Table 6). The tile contains ten Geotiff images representing spectral bands 1 through 8 (two versions of band 6) and a multispectral image with bands 7, 4, and 3 combined. The individual tile covers an area of approximately 75,000 square kilometres. A natural colour image (Landsat bands 3, 2, and 1), false colour image (Landsat bands 4, 3, and 2) and image combining Landsat bands 7,4 and 1 were created for this tile in ErMapper and saved as compressed raster images. The Landsat 7-4-1 multispectral image was used as the main reference for the lineament interpretation from satellite imagery (Figure 7). Different materials reflect and absorb solar radiation differently at different wavelengths and therefore have varying intensities within each of the Landsat bands. When bands 7, 4 and 1 are combined into a single image, the colour assignment enhances the presence of major geological units and topographical features.

Table 6: Landsat 7 Imagery Scenes Used for the Lineament Interpretation

Scene ID	Date of Image
023026_0100_001010_l7	6-November-2001
022026_0100_010531_l7	9-April-2002

The SPOT satellite, Landsat satellite, and CDED topography data cover the entire White River area with a good resolution (e.g., SPOT, 20-metre resolution). However, the bedrock structural information available from these three data sets is limited in in various sectors of the study area due to Quaternary cover (Figure 4).

The sectors of the study area where bedrock structures are concealed by Quaternary cover include a large area in the northeast of the study area, and significant portions of the northeast corner and north boundary of the study area (Figure 4). The total area of Quaternary cover where the satellite (SPOT and Landsat) and CDED topography data were of limited use is roughly 1000 square kilometres or 20 percent of the White River area (very approximate estimate, see Figure 4). In addition, the vast majority of the area affected by Quaternary cover is not covered by high resolution geophysics. Consequently, in this area few lineaments associated with bedrock features were identified with certainty, resulting in a low lineament density.

3.2 Lineament Interpretation Workflow

Lineaments were interpreted using a workflow designed to address issues of subjectivity and reproducibility that are inherent to any lineament interpretation. The workflow follows a set of detailed guidelines using the publicly available surficial (DEM, SPOT) and geophysical (aeromagnetic and electromagnetic) data sets described above. The interpretation guidelines involved three steps:

- Step 1: Independent lineament interpretation by individual interpreters for each data set and assignment of certainty level (1, 2, or 3);
- Step 2: Integration of lineament interpretations for each individual data set and determination of reproducibility and first determination of reproducibility (RA_1; Figures 9, 10, and 11); and
- Step 3: Integration of lineament interpretations for all data sets and determination of coincidence (RA_2; Figure 12).

Each identified lineament feature was classified in an attribute table in ArcGIS. The description of the attribute fields used is included in Table 7. Fields 1 to 9 are populated during Step 1. Fields 10 and 11 are populated during Step 2. Fields 12 to 19 are populated during Step 3, the final step. In addition, ductile geophysical lineaments (Figure 8) were interpreted using the aeromagnetic geophysical survey data by two specialist observers.

A detailed description of the three workflow steps is provided below. This includes the methodology for populating the associated attribute field for an interpreted lineament.

Table 7: Attribute Table Fields Populated for the Lineament Interpretation

ID	Attribute	Brief Description
1	Rev_ID	Reviewer initials
2	Feat_ID	Feature identifier
3	Data_typ	Data set used (MAG, CDED, SAT)
4	Feat_typ	**Type of feature used to identify each lineament** **Satellite Imagery:** A. Lineaments drawn along straight or curved lake shorelines; B. Lineaments drawn along straight or curved changes in intensity or texture (i.e., vegetation); C. Lineaments drawn down centre of thin rivers or streams; D. Lineaments drawn along a linear chain of lakes; or E. Other (if other, define in comments). **Digital Elevation Model:** A. Lineaments drawn along straight or curved topographic valleys; B. Lineaments drawn along straight or curved slope walls; or C. Other (if other, define in comments). **Airborne Geophysics (magnetic and electromagnetic data):** A. Lineaments drawn along straight or curved magnetic high; B. Lineaments drawn along straight or curved magnetic low; C. Lineaments drawn along straight or curved steep gradient; or D. Other (if other, define in comments).
5	Name	Name of feature (if known), includes names of dyke swarms
6	Certain	Value describing the interpreters confidence in the feature being related to bedrock structure (1-low, 2-medium or 3-high)
7	Length*	Length of feature is the sum of individual lengths of mapped polylines (not end to end) and is expressed in kilometres
8	Width**	**Width of feature. This assessment is categorized into 5 bin classes:** A. < 100 m B. 100 – 250 m C. 250 – 500 m D. 500 – 1,000 m E. > 1,000 m
9	Azimuth	Lineament orientation expressed as degree rotation between 0 and 180 degrees
10	Buffer_RA_1	Buffer zone width for first reproducibility assessment
11	RA_1	Feature value (1 or 2) based on first reproducibility assessment
12	Buffer_RA_2	Buffer zone width for second reproducibility assessment
13	RA_2	Feature value (1, 2 or 3) based on second reproducibility assessment (i.e., coincidence)
14	Geoph	Feature identified in geophysical data set (Yes or No)
15	DEM	Feature identified in topography data set (Yes or No)
16	SAT	Feature identified in satellite data set (Yes or No)
17	F_Width	Final interpretation of the width of feature
18	Rel_age	Relative age of feature, in accord with regional structural history
19	Comment	Comment field for additional relevant information on a feature
20	Unique_ID	Unique identification code for each lineament, written as: “data set (CDED, MAG, SAT) - initials of interpreter (CN, JK, SC) - lineament type (F for fault, and D for dyke) – Feature_ID (1, 2, 3 …)” For example, “MAG-SC-F-124” corresponds to the lineament number 124 interpreted from the magnetic data set by Simon Craggs as a fault

*The length of each interpreted feature is calculated based on the sum of all segment lengths that make up that lineament.

**The width of each interpreted feature is determined by expert judgement and utilization of a GIS-based measurement tool. Width determination takes into account the nature of the feature as assigned in the Feature type (Feat_typ) attribute.

3.2.1 Step 1: Lineament Interpretation and Certainty Level

To accommodate the generation of the best possible, unbiased lineament interpretation, two individual interpreters followed an identical process for structural lineament analysis during Step 1. The first step of the lineament interpretation was to have each individual interpreter independently produce GIS lineament maps, and detailed attribute tables, for each of the three data sets. The following components were addressed in the order specified:

- Magnetic Data

  Throughout the interpretation of magnetic data sets, priority was given to the highest resolution data set available (Figure 5). For this study, these were the Ontario airborne geophysical surveys, magnetic and electromagnetic data set (GDS1205), the Ontario airborne geophysical surveys, magnetic and electromagnetic data, Hemlo Area (GDS1207-REV), and the OBA-Kapuskasing area, Ontario airborne magnetic and electromagnetic surveys (GDS1024-REV). Where this data set was not available, the Single master gravity and aeromagnetic data for Ontario (GDS1036) data set was used. The interpretation of magnetic data included two steps:

  - Interpretation of Ductile Lineaments
    - Drawing of stratigraphic and structural form lines using first vertical derivative and tilt derivative magnetic data. The form lines trace the geometry of magnetic high lineaments and represent the geometry of stratigraphy within metavolcanic and metasedimentary rocks or the internal fabric (foliation) within granitoid batholiths and gneissic rocks. This process highlighted discontinuities between form lines, particularly in stratigraphic form lines (e.g., intersecting form lines) that represent structural lineaments (e.g., faults, folds, unconformities, or intrusive contacts).
    - For this study, form lines were drawn using the first vertical derivative and the tilt derivative from the Ontario airborne geophysical surveys, magnetic and electromagnetic data set (GDS1205), the Ontario airborne geophysical surveys, magnetic and electromagnetic data, Hemlo Area (GDS1207-REV), and the OBA-Kapuskasing area, Ontario airborne magnetic and electromagnetic surveys (GDS1024-REV). For the majority of the White River area, which is not covered by these high resolution data sets, form lines were interpreted from the low-resolution Single master gravity and aeromagnetic data for Ontario (GDS1036).
  - Interpretation of Structural Lineaments
    - This part of the interpretation involved the drawing of lineaments, representing all interpreted faults regardless of interpreted age, style (e.g., brittle versus ductile) or kinematics. Evidence for interpreted brittle lineaments was derived from several sources in the magnetic data, including discontinuities between form lines (as outlined above), offset of magnetic units, or the presence of linear magnetic lows. Lineaments were drawn using the first vertical derivative image, with the tilt derivative image for validation and enhancement.
  - Electromagnetic Data
    - In the White River area, electromagnetic data are only available from the regions covered by the high resolution geophysical data sets (GDS1205, GDS1207-REV, and GDS1024-REV). Consequently, electromagnetic data was only used to support lineaments identified in the aeromagnetic data, and was not interpreted as a separate data set. When a lineament was observed in electromagnetic data, typically along discontinuities and linear zones of low resistivity, it was noted in the "comments" column of the attribute table.

- CDED Topography Data
  - The lineament interpretation of topography data involved the drawing of lineaments along topographic valleys, slope walls or escarpments, drainage patterns and abrupt changes in topography that were visible in a colour mosaic constructed from the CDED topography data. Attention was paid to not draw lineaments associated with glacial features.
- Satellite Imagery
  - The lineament interpretation of satellite imagery involved the drawing of lineaments along linear features including changes in bedrock colour (changing lithology), vegetation cover, and drainage patterns, such as rivers and streams and linear chains of lakes that were visible in Landsat (primary dataset) and SPOT (supplementary dataset) satellite image data. Attention was paid to not draw lineaments associated with glacial features.

All lineaments were drawn up to a maximum of 10 kilometres outside the White River area boundary, to express their full extent, or in the case of longer lineaments, to better estimate their maximum length around the White River area. Lineaments displayed on maps are truncated at the boundary of the margins of the White River area; however, the full length of the lineaments was included in the attribute table (Length; Table 7).

The higher resolution of the topography and satellite imagery data sets helped identify a greater density of smaller scale lineaments that were not evident in the geophysical data sets, particularly in the areas covered by low-resolution geophysical data sets.

The Step 1 lineament analysis resulted in the generation of one interpretation for each data set, including magnetic (supported by electromagnetic), satellite imagery (Landsat and SPOT) and topography (CDED) for each interpreter, resulting in a total of six individual GIS layer-based interpretations. Within these data sets, crosscutting relationships between individual lineaments were assessed. Following this assessment, based on the expert judgment of each interpreter, lineament segments were merged, resulting in lineament length corresponding to the sum of all parts.

During Step 1, identified lineaments were attributed with fields one to nine as listed in Table 7. For attribute field six, each interpreter assigned a certainty/uncertainty descriptor (attribute field ‘Certain’ = 1-low, 2-medium or 3-high) to each lineament feature in their interpretation based on their judgment concerning the clarity of the lineament within the data set. Where a surface lineament could be clearly seen on exposed bedrock, it was assigned a certainty value of 3. Where a lineament represented a bedrock feature that was inferred from linear features, such as orientation of lakes or streams or linear trends in texture, it was assigned a certainty value of either 1 or 2. For geophysical lineaments, a certainty value of 3 was assigned when a clear magnetic susceptibility contrast could be discerned and a certainty value of either 1 or 2 was assigned when the signal was discontinuous or more diffuse in nature. The certainty classification for all three data sets ultimately was based on expert judgment and experience of the interpreter.

In the determination of azimuth, SRK used ET™ EasyCalculate 10, an add-in extension to ArcGIS. This add-in provides a function (polyline_GetAzimuth.cal) that calculates the azimuth of each polyline at a user-specified point and populates an assigned attribute field. SRK used the mid-point of each interpreted lineament to calculate the azimuth.

It is understood that some of the lineament attributes (e.g., relative age) will be further refined as more detailed information becomes available in subsequent stages of characterization, should the community be selected by the NWMO and remain interested in advancing in the site selection process.

3.2.2 Step 2: Reproducibility Assessment 1 (RA_1)

During Step 2, individual lineament interpretations produced by each interpreter were compared for each data set (Figures 9, 10, and 11). This included a reproducibility assessment (RA_1) based on the coincidence, or lack thereof, of interpreted lineaments within a data set-specific buffer zone. For example, if a lineament was identified by both interpreters within an overlapping buffer zone, then it was deemed coincident. The two individual lineament interpretations for each data set were then integrated to provide a single interpretation for the aeromagnetic (Figure 9), topographic (Figure 10) and satellite (Figure 11) data that included the results of the first stage reproducibility assessment (RA_1). A discussion of the parameters used during this step follows.

Buffer Size Selection

Buffer sizes for lineaments in each data set were initially based on the (grid) resolution of each data set. It was determined using trial-and-error over a selected portion of the lineament interpretation that buffer sizes of five times the grid cell resolution of each data set provided a balanced result for assessing reproducibility.

A buffer of 150 metres (either side of the lineament) was generated for the area covered by high-resolution magnetic data, which represents approximately 7.5 percent of the White River area. This buffer value is equivalent to five times the data set grid cell resolution (30 metres) of the high resolution data sets (GDS1205, GDS1207-REV, and GDS1024-REV). A buffer of 1000 metres (either side of the lineament) was generated for the area covered by low-resolution magnetic data. This value is equivalent to five times the data set grid cell resolution (200 metres) of the Single Master Gravity and Aeromagnetic data for Ontario (GDS1036).

A buffer of 150 metres (either side of the lineament) was generated for the satellite data. This value is equivalent to five times the resolution of the Landsat data (30 metres), which is the coarser of the two available satellite data sets.

A buffer of 125 metres (either side of the lineament) was generated for the topographic data. This value is approximately equivalent to five times the resolution of the CDED topographic data (23 metres).

The buffers were used as an initial guide to determine coincidence between lineaments, with the expert judgement of the interpreter ultimately determining which lineaments were coincident. The buffer size widths were included in the attribute fields of each interpretation file (Table 7).

Reproducibility Assessment

The generation of an integrated lineament interpretation for each data set, including the reproducibility assessment, utilized a three step process to combine the first interpreter’s lineaments (lead interpretation) and second interpreter’s lineaments, as follows:

- Lineament buffers, described above, were overlain on top of the lead interpretation data set. The second interpreter’s lineaments were overlain on top, and all lineaments that occurred within overlapping buffers were carried forward and copied into a new file for the next step.

These lineaments were attributed with a reproducibility value (RA_1; Table 7) of two in the Step 2 attribute table.

- The remaining lineaments of the lead interpreter's Step 1 interpretation were then manually analyzed by both interpreters on the basis of the available imagery for each data set. In some instances, this included adapting the shape and extent of individual lineaments to increase the accuracy of spatial location or length of the lineament, and carrying the adapted lineament forward into the Step 2 interpretation file. These lineaments were attributed a RA_1 value of one in the Step 2 attribute table.
- Finally, the remaining lineaments of the second interpreter's Step 1 interpretation were then manually analyzed by both interpreters on the basis of the available imagery for each data set. In some instances, this included adapting the shape and extent of individual lineaments to increase the accuracy of spatial location or length of the lineament, and carrying the adapted lineament forward into the Step 2 interpretation file. These lineaments were attributed a RA_1 value of one in the Step 2 attribute table.

The decision on whether or not to adapt the shape and extent of an individual lineament and (or) whether the lineament was carried forward to the next step was based on expert judgement. The following guidelines were applied:

- If a lineament was drawn continuously by one interpreter but as individual, spaced or disconnected segments by the other interpreter, a single continuous lineament was carried forward to the Step 2 interpretation with a RA_1 value of two, if expert judgement deemed the continuous lineament to be more correct.
- If more than two thirds of a lineament were identified by one interpreter compared to the other interpreter, the lineament was carried forward to the Step 2 interpretation with a RA_1 value of two. If less than two thirds of a lineament were identified by one interpreter compared to the other interpreter, the longer lineament was segmented, and each portion was attributed with RA_1 values accordingly.

The resulting Step 2 interpretations for each data set (magnetics, topography, and satellite imagery) were then refined using expert judgement to avoid any structurally inconsistent relationships. This included adapting the lineaments within the limits of the assigned buffer zone to avoid any mutually crosscutting relationships, and updating the attribute fields.

3.2.3 Step 3: Coincidence Assessment 2 (RA_2)

During Step 3, the integrated lineament interpretations for each data set were amalgamated into one final interpretation, as shown in Figure 12, following a similar methodology as described above in Stage 2. In this second assessment, reproducibility (RA_2) is based on the coincidence, or lack thereof, of interpreted lineaments between different individual data sets within an assigned buffer zone (Buffer_RA_2). A discussion of the parameters used during this step follows below.

High-resolution geophysical data can supply vital information about structures in the subsurface, whereas surficial data only provide information about the surface expression of structures and may include lineaments that may not be related to the bedrock structural framework (e.g., lineaments related to glacial features). For these reasons, it would be ideal that during this step of the interpretation the lineaments derived from geophysical data would be given precedence over lineaments derived from surficial data. However, for the White River area, high-resolution geophysical data is only available for a small fraction of the study area and does not provide a representative data set. The remainder of the area is covered by low-resolution geophysical data, which was largely ineffective in resolving lineaments on a scale appropriate for this study. Considering this, and consistent with the approach taken in Step 2 above, the lineaments derived from surficial data sets would be given precedence over lineaments derived from geophysical data. Between surficial data sets, lineaments derived from the CDED topography data set were given precedence over lineaments derived from satellite data, as lineaments were better defined within the topography data set.

On this premise, all lineaments derived from the topography data were included in the final interpretation. A buffer (125 metres either side) was generated around these lineaments, which was used for comparison with lineaments derived first from satellite, and then from geophysical data. This buffer size was included as an attribute field for all interpreted lineaments (Buffer RA_2; Table 7). As part of this comparison, coincident lines were identified and attributed. Next, non-coincident lineaments were evaluated against the magnetic data by both interpreters, and if required, were adapted and carried forward to the final Step 3 data set. During this process, each lineament was attributed with a text field highlighting in which data sets it was identified. This resulted in a combined interpretation with lineaments derived from surficial (topography and satellite) and geophysical data.

The following rules were applied for determining reproducibility between the data set-specific lineament maps:

- If any coincidence of lineaments occurred between two lineament data sets, the longest lineament was carried forward to the Step 3 interpretation and attributed as derived from two (or more) data sets, regardless of the length of overlap between the lineaments. This meant that if any part of a lineament derived from one data set was identified in another data set, it was considered that this lineament was reproduced.
- In the case that a lineament derived from satellite imagery or geophysical data was longer than a coincident lineament derived from topography data, the former lineament was cut and the non-coincident portion was carried forward into the final Step 3 interpretation as a single entity. Both the lineament in the geophysical data and the non-coincident portion derived from another data set were then attributed accordingly in terms of reproducibility.
- A lineament derived from satellite imagery and (or) geophysical data that would fall within the buffer of a lineament derived from topography data would be attributed as reproduced in the relevant data sets if the orientation of the lineaments did not deviate significantly.
- Short (less than 500 metres) discontinuous satellite imagery and geophysical data lineaments that are at low angles to topography data lineaments but extending outside the topography lineament buffer were considered to be coincident.
- Short (less than 500 metres) satellite imagery and geophysical data lineaments that are at high angles to topography data lineaments, largely overlapped with the buffer zone from the topography data lineament, and had no further continuity (i.e., singular elements), were not carried forward to the final interpretation. This was done on the basis that these short segments represent a subsidiary lineament that is related to a broader fault zone already included as a brittle lineament in the final interpretation based on identification in the topography data.

The final reproducibility value (RA_2; Table 7) was then calculated as the sum of the number of data sets in which each lineament was identified (i.e., a value of 1-3).

The resulting lineament framework interpretation, representing the integration of all data sets, was then evaluated and modified (within the limits of relevant buffers) in order to develop a final lineament interpretation that is consistent with the interpreted structural history of the White River region. This included defining the age relationships of the interpreted lineaments on the basis of crosscutting relationships between different generations of brittle lineaments and populating attribute field for each lineament for the relative age (Rel_Age; Table 7). This incorporated a working knowledge of the structural history of the White River area, combined with an understanding of the fault characteristics in each brittle lineament population (e.g., brittle versus ductile). The structural history of the area is defined in Section 2.3.

The interpreted crosscutting and age relationships between different families of brittle lineaments and within individual families of brittle lineaments were refined using the available data. Crosscutting relationships were evaluated based on the through-going nature and termination of brittle lineaments and evaluated against the regional structural history as described below.

- D_1 deformation:
  - Development of S_1 compositional layering and localized isoclinal (overturned) F_1 folds and associated D_1 thrust faults in greenstone rocks; and
  - Not recognized in lineament analysis.
  - Constrained to before ca. 2691 Ga, as discussed below
- D_2-D_4 Deformation:
  - Present in greenstone rocks;
  - Represents protracted north-south to northwest-southeast compression and transpression;
  - Brittle-ductile structures constrained between ca. 2.691 Ga and ca. 2.673 Ga; and
  - Interpreted to form foliations, D_2-D_3 isoclinal folds, D_2-D_4 thrust faults and D_4 kink folds.
- D_5 Deformation:
  - Present in greenstone and granitic supracrustal rocks;
  - Only described in literature as “post-D_4 brittle structures subparallel to S_2 foliation in the Hemlo greenstone belt” (Lin, 2001);
  - Muir (2003) suggested that in the Hemlo region, D_5 occurred after emplacement of granites and Proterozoic dykes (post ca. 2.121 Ga), absolute age constraints are not available for this phase; and
  - Interpreted to form brittle faults.
- D_6 Deformation:
  - Present in greenstone and granitic supracrustal rocks;
  - Only described in literature as “post-D_4 southeasterly trending dextral strike-slip faults in the Hemlo greenstone belt” (Lin, 2001);
  - Absolute age constraints are not available/ambiguous for this phase; and
  - Interpreted to form brittle faults.

Interpreted lineaments were amended by applying this structural framework where required. This resulted in a cohesive interpretation representing clearly-defined, consistent lineament network for the White River area.

Finally, following the amendment of selected lineaments, the azimuth and length attribute fields were recalculated. The attribute field for the final interpretation of the width of each lineament (F_Width; Table 7) remains unpopulated, since no information is available on the width of the known faults in the White River area.

Additional analyses described further below in this report were carried out using the final interpretation. The final lineament interpretation shows a moderately dense network of lineaments in areas of exposed bedrock throughout the majority of the White River area (Figures 12, 13 and 14). This interpretation is preliminary and would need to be verified by field investigations.

4 Findings

4.1 Description of Lineaments by Data Set

4.1.1 Geophysical Data

Interpretation of geophysical data allows for the distinction between lineaments associated with ductile fabrics, dykes and brittle faults. Features interpreted as ductile lineaments from the aeromagnetic geophysical data set are shown on Figure 8. Features interpreted as brittle and dyke lineaments from geophysical data sets are shown on Figure 9. The ductile features are included primarily to provide context for the discussion of interpreted brittle and dyke features in the following paragraphs.

A total of 762 lineaments comprise the data set (RA_1) of merged lineaments identified by the two interpreters from the aeromagnetic data (Figure 9). Of the 762 lineaments, 330 are interpreted as brittle lineaments and 432 as dyke lineaments. The length of the aeromagnetic lineaments ranges from 180 metres up to 83.5 kilometres, with a geometric mean length of 5.6 kilometres and a median length of 3.3 kilometres. Azimuth data, weighted by length, for the aeromagnetic lineaments interpreted as brittle lineaments exhibit two dominant orientations trending to the northwest and northeast, and two minor orientations trending to the north and east-northeast. All orientations are sharply defined, with the exception of the northeast trend, which is slightly diffuse (Figure 9 inset). Lineaments interpreted as dykes exhibit one dominant orientation trending to the northwest, one minor orientation trending to the northeast, and one very minor orientation trending to the north. Dyke lineaments trending to the north and northeast appear very minor on the rose diagram (Figure 9 inset) due to a dominance of northwest trending dyke lineaments. All orientations of dyke lineaments are sharply defined, including the very minor north orientation (Figure 9 inset). Each orientation of dyke lineament likely corresponds to a separate suite of dykes.

Of the brittle lineaments interpreted from aeromagnetic data, 135 (41 percent) lineaments were assigned the highest level of certainty (certainty = 3), while 52 (16 percent) and 143 (43 percent) were given certainty values of two and one, respectively. For lineaments interpreted as dykes, 186 (43 percent) were assigned a certainty value of 3, while 184 (43 percent) and 62 (12 percent) were given certainty values of two and one, respectively. The reproducibility assessment identified coincidence for 98 brittle lineaments (30 percent; RA_1 = 2) and a lack of coincidence for 232 of the interpreted brittle lineaments (70 percent; RA_1 = 1). The reproducibility assessment identified coincidence for 263 of the interpreted dykes (61 percent; RA_1 = 2) and a lack of coincidence for 169 of the interpreted dykes (39 percent; RA_1 = 1).

On the basis of their orientation, the 432 dyke lineaments were divided into four groups:

- 284 dyke lineaments are interpreted to belong to the northwest-trending Matachewan dyke swarm (ca. 2.473; Buchan and Ernst 2004). This group of dykes may also contain west-northwest-trending dykes of the Sudbury dyke swarm (ca. 1.238 Ga; Krogh et al. 1987), however this could not be determined from the lineament analysis and therefore all dykes of similar orientations are grouped together. A similar approach is taken for the surficial data interpretation;
- 80 dyke lineaments are interpreted to belong to the northeast-trending Biscotasing dyke swarm (ca. 2.167 Ga; Hamilton et al., 2002);

- 58 dyke lineaments are interpreted to belong to the north-trending Marathon dyke swarm (ca. 2.121Ga; Buchan et al., 1996; Hamilton et al., 2002); and
- 10 dyke lineaments are interpreted to belong to the northeast-trending Abitibi dyke swarm (ca. 1.14 Ga; Ernst and Buchan 1993). These dykes share the same orientation as the Biscotasing dyke swarm and were identified based on coincident Abitibi aged dykes identified on the Ontario Geological Survey (2011) bedrock compilation map.

4.1.2 Surficial Data (CDED topography and satellite imagery)

Interpreted brittle and dyke lineaments from the CDED topography and satellite imagery data sets are shown on Figure 10 and Figure 11, respectively. Very few dykes were initially interpreted from surficial data. However, during the reproducibility / coincidence process, it was observed that certain surficial lineaments initially interpreted as brittle lineaments were coincident with dyke lineaments identified from the geophysical data sets. In this case, these surficial lineaments were characterized as dyke lineaments. The following paragraphs provide an overview of these surface-based interpretations.

A total of 1957 lineaments comprise the data set (RA_1) of merged lineaments identified by the two interpreters from the CDED topography data (Figure 10). Of the 1957 lineaments, 1905 are interpreted as brittle lineaments, and 52 as dyke lineaments. These lineaments range in length from 220 metres to 83.5 kilometres, with a geometric mean length of 3.6 kilometres and a median length of 2.3 kilometres. Azimuth data, weighted by length, for the CDED lineaments interpreted as brittle lineaments exhibit three dominant orientations trending to the northwest, north and northeast, and one minor orientation trending east-northeast. The north and east-northeast trending lineaments are sharply defined, while the northwest and northeast trending lineaments are slightly more diffuse (Figure 10 inset). Lineaments interpreted as dykes exhibit one dominant orientation trending to the northwest, and two very minor orientations trending to the north-northeast and northeast (Figure 10 inset). All orientations of dyke lineaments are sharply defined (Figure 10 inset). Each orientation of dyke lineament likely corresponds to a separate suite of dykes.

Of the brittle lineaments interpreted from the CDED topography data, 946 (50 percent) lineaments were assigned the highest level of certainty (certainty = 3), while 344 (18 percent) and 615 (32 percent) were given certainty values of two and one, respectively. For lineaments interpreted as dykes, 39 (75 percent) were assigned a certainty value of 3, while 7 (13 percent) and 6 (12 percent) were given certainty values of two and one, respectively. The reproducibility assessment identified coincidence for 621 brittle lineaments (33 percent; RA_1 = 2) and a lack of coincidence for 1284 of the interpreted brittle lineaments (67 percent; RA_1 = 1). The reproducibility assessment identified coincidence for 29 of the interpreted dykes (56 percent; RA_1 = 2) and a lack of coincidence for 23 of the interpreted dykes (44 percent; RA_1 = 1).

On the basis of their orientation, the 52 dyke lineaments were divided into four groups:

- 30 dyke lineaments are interpreted to belong to the northwest-trending Matachewan dyke swarm (ca. 2.473; Buchan and Ernst 2004);
- 12 dyke lineaments are interpreted to belong to the northeast-trending Biscotasing dyke swarm (ca. 2.167 Ga; Hamilton et al., 2002);
- 9 dyke lineaments are interpreted to belong to the north–trending Marathon dyke swarm (ca. 2.121Ga; Buchan et al., 1996; Hamilton et al., 2002); and
- 1 dyke lineament is interpreted to belong to the northeast-trending Abitibi dyke swarm (ca. 1.14 Ga; Krogh et al. 1987).

A total of 1608 lineaments comprise the data set (RA_1) of merged lineaments identified by the two interpreters from the satellite (Landsat and SPOT) data (Figure 11). Of the 1608 lineaments, 1560 are interpreted as brittle lineaments, and 48 as dyke lineaments. These lineaments range in length from 220 metres to 83.5 kilometres, with a geometric mean length of 4.1 kilometres and a median length of 2.8 kilometres. Azimuth data, weighted by length, for the satellite imagery lineaments interpreted as brittle lineaments exhibit three dominant orientations trending to the northwest, north and northeast, and one minor orientation trending east-northeast. All orientations are sharply defined, with the exception of the northeast trend, which is slightly diffuse (Figure 11 inset). Lineaments interpreted as dykes exhibit two dominant orientations trending to the northwest and northeast, and one very minor orientations trending to the north-northeast (Figure 11 inset). All orientations of dyke lineaments are well defined (Figure 11 inset). Each orientation of dyke lineament likely corresponds to a separate suite of dykes.

Of the brittle lineaments interpreted from the satellite data, 438 (27 percent) lineaments were assigned the highest level of certainty (certainty = 3), while 282 (17 percent) and 903 (56 percent) were given certainty values of two and one, respectively. For lineaments interpreted as dykes, 25 (52 percent) were assigned a certainty value of 3, while 16 (33 percent) and 7 (15 percent) were given certainty values of two and one, respectively. The reproducibility assessment identified coincidence for 568 brittle lineaments (36 percent; RA_1 = 2) and a lack of coincidence for 992 of the interpreted brittle lineaments (64 percent; RA_1 = 1). The reproducibility assessment identified coincidence for 34 of the interpreted dykes (71 percent; RA_1 = 2) and a lack of coincidence for 14 of the interpreted dykes (29 percent; RA_1 = 1).

On the basis of their orientation, the 48 dyke lineaments were divided into three groups:

- 25 dyke lineaments are interpreted to belong to the northwest-trending Matachewan dyke swarm (ca. 2.473; Buchan and Ernst 2004);
- 6 dyke lineaments are interpreted to belong to the northeast-trending Biscotasing dyke swarm (ca. 2.167 Ga; Hamilton et al., 2002);
- 13 dyke lineaments are interpreted to belong to the north–trending Marathon dyke swarm (ca. 2.121Ga; Buchan et al., 1996; Hamilton et al., 2002); and
- 4 dyke lineaments are interpreted to belong to the northeast-trending Abitibi dyke swarm (ca. 1.14 Ga; Ernst and Buchan 1993).

4.2 Description and Classification of Integrated Lineament Coincidence (RA_2)

The integrated lineament data set produced by merging all lineaments interpreted from the CDED topography, satellite imagery, and geophysical (aeromagnetic with the support of electromagnetic) data sets is presented on Figure 12 and Figure 13. Figure 12 displays the lineament classification based on Coincidence Assessment 2 (RA_2). Figure 13 displays the lineament classification based on length of interpreted lineaments. The merged lineaments were classified by length using four length bins: >10 kilometres, 5-10 kilometres, 1-5 kilometres and <1 kilometre. These length bins were provided by NWMO.

The merged lineament data set contains a total of 3281 lineaments (2839 brittle and 442 dyke) that range in length from 180 metres to 83.5 kilometres. The geometric average length of these lineaments is 3.7 kilometres and the median length is 2.5 kilometres. Of all merged lineaments, 180 lineaments are greater than 10 kilometres in length (6 percent), 504 lineaments are equal to or between 5-10 kilometres in length (15 percent), 2227 lineaments are between 1-5 kilometres in length (68 percent), and 370 lineaments are equal to or less than 1 kilometre in length (11 percent).

Azimuth data, weighted by length, for all brittle and dyke lineaments from the merged lineament data set exhibit three dominant orientations trending to the northwest, north and northeast, and one minor orientation trending east-northeast. All orientations are well defined, including the northeast trending orientation which is more diffuse in the non-merged data sets (Figure 12 inset).

Results from the Reproducibility Assessment 2 (RA_2), shown in Figure 12, for the merged lineament data set (ductile, brittle and dyke) show 111 lineaments (3 percent) were identified and coincident in all three data sets (RA_2 = 3), and 803 lineaments (25 percent) were coincident with a lineament from one other data set (RA_2 = 2). A total of 2367 lineaments (72 percent) lacked a coincident lineament from the other data sets (RA_2 = 1). A total of 289 lineaments observed in aeromagnetic data (38 percent of all aeromagnetic lineaments) were coincident with a mapped interpreted surficial lineament. A total of 756 surficial lineaments (27 percent of the 2809 surficial lineaments) were coincident in both CDED topography and satellite imagery data.

Of the total 2839 lineaments interpreted to represent brittle lineaments (Figure 12), 88 (3 percent) were identified and coincident in all data sets (RA_2 = 3), and 760 brittle lineaments (27 percent) were coincident with a brittle lineament from one other data set (RA_2 = 2). A total of 1991 brittle lineaments (70 percent) lacked a coincident brittle lineament from the other data sets (RA_2 = 1).

In total, 442 dyke lineaments have been interpreted, including 286 Matachewan Suite dykes, 87 Biscotasing Suite dykes, 59 Marathon Suite dykes, and 10 Abitibi Suite dykes. Of these, 376 (85 percent) have reproducibility values of one (RA_2 = 1), as they were only observed in the aeromagnetic data. A total of 43 dyke lineaments (10 percent) were coincident with a lineament from one other data set (RA_2 = 2), and a total of 23 lineaments (5 percent) were coincident in all three data sets (RA_2 = 3).

4.3 Description of Lineaments by Lithological units in the White River Area

The following subsections describe the characteristics of the interpreted lineaments for selected lithological units/areas (as described in Section 2.2), including the Black-Pic batholith, the Pukaskwa batholith, the Anahareo pluton, the gneissic tonalite east of the township of White River, and the Strickland pluton. Rose diagrams for interpreted lineaments for these lithological units/areas are presented on Figure 14.

Black-Pic Batholith

A total of 789 lineaments (673 brittle and 116 dyke) were interpreted in the Black-Pic batholith, an area that covers the northwest portion of the White River area. This includes all lineaments that are contained within and crosscutting the boundary of the batholith. Of the 673 brittle lineaments, 8 are interpreted as D_2-D_4 faults, 206 as D_5 faults, and 459 as D_6 faults. The interpreted lineaments within the Black-Pic batholith range in strike length from 180 metres to 83.5 kilometres.

Orientation of interpreted brittle and dyke lineaments exhibits two distinct northwest trends, a diffuse northeast trend and a minor north trend (Figure 14 inset).

Pukaskwa Batholith

The characteristics of the interpreted lineaments for two areas of the Pukaskwa batholith were described separately. These areas are: the foliated tonalite suite, and lesser areas of gneissic tonalite, located west of the settlement area of White River and south of the Anahareo pluton; and the gneissic tonalite suite east of White River (Figures 2, 3 and 14). The lineament orientation trends for the zones are discussed separately to demonstrate that the orientation of lineaments within the gneissic tonalite suite do not appear to have been affected by the emplacement of the surrounding late stage intrusions (i.e., the Anahareo Lake and Strickland plutons, Danny Lake stock, Tedder granite pegmatite).

Foliated Tonalite Suite

The foliated tonalite of the Pukaskwa batholith covers the southwest portion of the White River area (Figure 14), and contains a total of 595 lineaments (523 brittle, 72 dyke) . These lineaments include all lineaments that are contained within and crosscutting the boundary of the foliated tonalite. Of the 523 brittle lineaments, 225 are interpreted as D_5 faults and 298 as D_6 faults. The interpreted lineaments within the foliated tonalite range in strike length from 270 metres to 49.8 kilometres. In combination, the interpreted brittle and dyke lineaments exhibit a dominant orientation to the northwest and additional minor northeast and north trends (Figure 14 inset).

Gneissic Tonalite

The gneissic tonalite of the Pukaskwa batholith is located east of the Township of White River, and is bounded by the Anahareo pluton to the south and east, and the Strickland pluton and Danny Lake stock to the north (Figure 14). A total of 523 lineaments (479 brittle and 44 dyke) were interpreted in the gneissic tonalite suite. These lineaments include all lineaments that are contained within and crosscutting the boundary of the gneissic tonalite. Of the 479 brittle lineaments, 11 are interpreted as D_2-D_4 faults, 177 as D_5 faults and 291 as D_6 faults. The interpreted lineaments within the gneissic tonalite range in strike length from 290 metres to 40.0 kilometres. In combination, the interpreted brittle and dyke lineaments exhibit a dominant orientation to the northwest and an additional minor northeast trend (Figure 14 inset).

Anahareo Pluton

A total of 748 lineaments (673 brittle and 75 dyke) were interpreted in the Anahareo pluton, an area that covers the southeast portion of the White River area. This includes all lineaments that are contained within and crosscutting the boundary of the batholith. Of the 673 brittle lineaments, 3 are interpreted as D_2-D_4 faults, 292 as D_5 faults and 378 as D_6 faults. The interpreted lineaments within the Anahareo pluton range in strike length from 240 metres to 27.5 kilometres.

In combination, the interpreted brittle and dyke lineaments exhibit a dominant diffuse orientation to the northeast, a bimodal peak to the northwest and additional minor north and east trends (Figure 14 inset).

Strickland Pluton

A total of 415 lineaments (318 brittle and 97 dyke) were interpreted in the Strickland pluton, an area extending from the Dayohessarah greenstone belt in the centre of the White River area to the northeast corner of the study area. This includes all lineaments that are contained within and crosscutting the boundary of the batholith. Of the 318 brittle lineaments, 17 are interpreted as D_2-D_4 faults, 88 as D_5 faults and 213 as D_6 faults. The interpreted lineaments within the Anahareo pluton range in strike length from 340 metres to 40.0 kilometres.

In combination, the interpreted brittle and dyke lineaments exhibit dominant orientations to the northwest and northeast, and less-dominant northeast and north trends. The dominant northwest trend and northeast trend are slightly diffuse, while the less dominant northwest and north trends are well-defined (Figure 14 inset).

5 Discussion

The following sections are provided to discuss the results of the lineament interpretation in terms of lineament density, reproducibility and coincidence, and lineament length, the relationship between mapped faults and interpreted lineaments, and the relative age relationships of the interpreted lineaments.

5.1 Lineament Density

The density of all interpreted lineaments in the White River area was determined by examining the statistical density of individual lineaments using ArcGIS Spatial Analyst. A grid cell size of 50 metres and a search radius of 1.25 kilometres (equivalent to half the size of the longest boundary of the minimum area size of a potential siting area) were used for this analysis. The spatial analysis used a circular search radius examining the lengths of polylines intersected within the circular search radius around each grid cell, following this equation:

$$\text{Density} = (L1 + L2) / (\text{area of circle})$$

Where L1 represents the length of Line 1 within the circle and L2 represents the length of Line 2 in the circle, assuming that only two lineament polylines intersect the circle search radius.

The density of lineaments in the White River area is highly variable, primarily due to the distribution of high resolution geophysical data (Figure 5) and extensive Quaternary and lake cover (Figure 4). Lineament density is low throughout a large area covering the northeastern sector of the White River area, and in smaller areas in the northwest corner (Black-Pic batholith) and near the central southern boundary of the study area. The majority of low lineament density areas are likely due to low resolution geophysics and extensive Quaternary and lake cover, which decreases the density of lineaments interpreted from geophysical and surficial data sets, respectively. In particular, the northeastern quarter of the White River area is dominated by Quaternary and lake cover, resulting in the interpretation of very few lineaments related to bedrock structures (Figure 4).

Conversely, several low lineament density areas are present in zones with significant bedrock exposure, and are interpreted to represent areas with low densities of bedrock structures. Such areas are located in the Pukaskwa batholith near the southwestern corner of the White River area, the Black-Pic batholith in the northwestern corner of the White River area, the Strickland pluton between the Dayohessarah and Kabinakagami Lake greenstone belts, and in and along the boundaries of the Anahareo pluton near the southern boundary of the White River area.

The greatest density of lineaments occurs in areas covered by high resolution geophysical data (e.g., the Dayohessarah greenstone belt, and small areas along the western, northwestern and northeastern borders of the study area - see outline of high resolution geophysics in Figure 5). Several areas not covered by high resolution geophysical data also show high lineament densities. Such high lineament density areas are present in the northwestern portion of the Black-Pic batholith, along the eastern portion of the southern boundary of the study area, and near the northeastern boundary of the Pukaskwa batholith. These zones occasionally correlate with high density clusters of dyke lineaments.

5.2 Lineament Reproducibility and Coincidence

Reproducibility values assigned to the lineaments provide a measure of the significance of the bedrock structures expressed in the different data sets. The approach used to assign reproducibility values involved checking whether lineament interpretations from different interpreters (RA_1), and from different data sets (RA_2), were coincident within a specified buffer zone radius. Reproducibility values are discussed in detail in Sections 4.1 and 4.2.

The findings from the reproducibility assessment RA_1 indicate that approximately 31 percent of surficial lineaments were identified by both interpreters (see Figures 10 and 11). Importantly, longer lineaments with higher certainty values were identified more often by both interpreters. The reproducibility assessment of the geophysical lineaments shows that over 45 percent of the lineaments (includes both brittle and dyke lineaments combined) were identified by both interpreters (see Figure 9). As with the surficial lineaments, longer geophysical lineaments with higher certainty values were also recognized more often by both interpreters.

There are some differences in the individual Step 1 lineament interpretations. These differences can be explained by two main factors: 1) the person carrying out the interpretation, and 2) the lineament information that can be derived from specific data sets. The lineament interpretations carried out by two different interpreters is subjective and, in part, may be affected by the interpreter’s experience. The lineament information that can be derived from each data set may have a strong impact on the quality and resolution of an interpretation. As discussed earlier in this report, topographic and satellite data only provide information about the potential surficial expressions of lineaments. However, these data sets may include lineaments that are related to erosional features, such as glacial features, that do not have a structural origin. It can be challenging to distinguish such features from structural features, and careful evaluation, combined with a working knowledge of the glacial history of the area is required. For the final lineament interpretation in the White River area, lineaments that were interpreted during Step 1 and Step 2 that strike roughly northeast (i.e., parallel to the ice flow direction), with relatively short lengths and discontinuous in nature, were considered as suspect and likely to represent glacial features that were incorrectly interpreted as structural features. Therefore these lineaments were not included in the final Step 3 interpretation.

Coincidence between features identified in the various data sets was evaluated for the second Reproducibility Assessment (RA_2). Of the 2809 lineaments observed on surficial data sets (2733 brittle and 76 dyke), 756 lineaments (27 percent) were coincident in both CDED topography and satellite imagery data. The coincidence between these data sets is in part explained by the fact that lineaments interpreted from the satellite imagery and the digital elevation data represent surficial expressions of the same bedrock feature. For example, a lineament drawn along a stream channel shown on the satellite imagery is expected to be coincident with a lineament that captures the trend of the associated topographic valley expressed in the digital elevation data. The lack of coincidence between the two surficial datasets can be attributed to a significant quantity of structures observed in the topography data that are obscured by vegetation and other surficial elements in the satellite data.

Of the 762 lineaments observed in aeromagnetic data, 289 lineaments (38 percent) were reproduced in at least one surficial data set. The lack of coincidence between the aeromagnetic data and the surficial data is largely due to the contrast in resolution between data sets (explained below). Additional factors contributing to the lack of coincidence between data sets include: deeper structures identified in geophysics that may not have a surface expression; surficial features that may not extend to great depth; and, certain structural features that may not possess a magnetic susceptibility contrast with the host rock. In particular, geophysical data was very effective in identifying dykes.

The resolution of each available data set has a strong impact on the reproducibility and number of interpreted lineaments. The Ontario airborne geophysical surveys magnetic and electromagnetic data (GDS 1205) has a high resolution (30-metre grid cells) but covers less than ten percent of the study area. An additional high resolution magnetic image was available, but only covered the Dayohessarah greenstone belt. The majority of the White River area is covered by the lower resolution (200-metre grid cells) Single Master Gravity and Aeromagnetic data for Ontario (SMGA; GDS1036). The SPOT satellite, Landsat satellite, and CDED topography data cover the entire White River area with a 30-metre (and less) grid cell resolution. The higher resolution of the surficial data sets over the entire study area may explain why a larger number of lineaments are identified from the combination of these data sets compared to the geophysical data sets.

The bedrock structural information available from surficial data sets (topography and satellite data) is limited across the entire northern portion of the White River area, as well as near the central southern boundary, due to the presence of significant Quaternary and lake cover. In addition, very little high resolution geophysical data are available throughout these areas. This limits the ability to complete a suitable structural lineament interpretation for certain zones of the White River area, in particular in the northeastern quarter of the study area. The absence of thick or extensive bedrock cover sequences elsewhere in the White River area facilitates the practical interpretation of lineaments from surficial data.

SRK infers that the resolution and distribution of the data sets used, in combination with the final interpretation originating from two individual interpreters, form a suitable basis to conduct a robust lineament interpretation in the majority of the White River area. Regardless of the degree of coincidence, the observed overlap in dominant lineament orientations between all data sets (see insets on Figures 9, 10, and 11) suggests that all data sets are identifying the same regional sets of structures.

For these reasons, it is necessary to objectively analyze the results of the RA_2 assessment with the understanding that RA_2 = 1 does not necessarily imply a low degree of confidence that the specified lineament represents a true geological feature (i.e., a fracture). The true nature of the interpreted features will need to be investigated further during subsequent stages of the site evaluation process, if the community is selected by the NWMO, and remains interested in continuing with the site selection process.

5.3 Lineament Length

There is no information available on the depth extent of the lineaments interpreted for the White River area. In the absence of available information, the interpreted length may be used as a proxy for the depth extent of the identified structures (Figure 13). A preliminary assumption may be that the longer interpreted lineaments in the White River area may extend to greater depths than the shorter interpreted lineaments.

As discussed in Section 5.2, longer interpreted lineaments generally have higher certainty and reproducibility values. Although the existence of interpreted lineaments would need to be confirmed through field observations, certainty and reproducibility values provide a preliminary indication that the longer features are related to bedrock structures. Figure 13 shows the interpreted lineaments classified by lineament length. Four lineament length bins (0-1 kilometres, 1-5 kilometres, 5-10 kilometres, > 10 kilometres) were used for this analysis, and a length-weighted frequency rose diagram indicates the dominant lineament orientations (inset of Figure 13). Azimuth data, weighted by length, for all brittle and dyke lineaments from the merged lineament data set exhibit three dominant orientations trending to the northwest, north and northeast, and one minor orientation trending east-northeast. All orientations are well defined, including the northeast trending orientation which is more diffuse in the non-merged data sets (Figure 13 inset).

5.4 Fault and Lineament Relationships

As discussed, in total 3281 lineaments (2839 brittle and 442 dyke) were interpreted in the White River area. Regional geological maps (Figure 3) identified multiple (approximately 15) northeast, northwest, and semi-circular trending faults fault in the White River area. No large scale faults or shear zones have been recorded within the White Rivers study area. Northeast and northwest trending faults are consistent with the orientations of, and potentially related to the final D_5-D_6 brittle deformation. The semi-circular faults located north of the township of White River (Figure 3) may reflect the overall dome-and-basin style three-dimensional structure of the region, and/or brittle parting parallel to a pre-existing ductile fabric. These faults were likely documented due to regional field mapping in the area, and are not believed to significantly impact the lineament study.

All northeast and northwest trending mapped faults shown on Figure 3 were reproduced to some degree during the lineament analysis. Certain mapped faults were reproduced in their entirety, while others were partially reproduced and (or) were interpreted as multiple lineament segments. Certain mapped faults were also interpreted as dykes, and dykes coincident with faults. Where a dyke was interpreted to be coincident with a fault, a single dyke lineament was drawn, and a comment stating it was coincident with a fault was documented in the “comment” column of the attribute table. For many of the mapped faults, the dominant segment reproduced during the lineament analysis carried a reproducibility rating (RA_2) of two or three, indicating that at least a segment of the fault was observed in a minimum of two data sets.

The principal neotectonic stress orientation in central North America is generally oriented approximately east-northeast (63º ± 28º; Zoback 1992) although anomalous stress orientations have also been reported in the mid-continent that include a 90º change in azimuth of the maximum compressive stress axis (Brown et al. 1995) and a north-south maximum horizontal compressive stress (Haimson 1990). Local variations, and other potential complicating factors involved in characterizing crustal stresses, including, the effect of shear stress by mantle flow at the base of the lithosphere (Bokelmann 2002; Bokelmann and Silver 2002), the degree of coupling between the North American plate and the underlying mantle (Forte et al. 2010), the effects of crustal depression and Holocene rebound, and the influence of the thick lithospheric mantle root under the Canadian Shield, make it premature to correlate the regional neotectonic stress orientation with the orientation of mapped lineaments at the desktop stage.

However, it is possible to broadly speculate on the potential behavior of the identified lineaments if they were to be reactivated by the regional east-northeast neotectonic stress regime. Three dominant orientations of lineaments were interpreted: north, northeast and northwest, and one minor east-west set of lineaments. Should the identified lineaments be reactivated under the current stress regime, the northeast oriented lineaments will likely reactivate as strike-slip faults, the northwest oriented lineaments likely as reverse dip-slip faults, and the north and east-west oriented lineaments likely as oblique-slip faults.

5.5 Relative age relationships

The structural history of the White River area, outlined in Section 2.3, provides a framework that may aid in constraining the relative age relationships of the interpreted bedrock lineaments. In brief summary, previous work in and around the White River area have identified six regionally distinguishable deformation episodes (D_1 – D_6) that are inferred to have overprinted the bedrock geological units of the area. The lineament interpretation is fairly consistent with regional observations; however the D_5 and D_6 events interpreted from the lineament analysis differ from the D_5 and D_6 events described in the literature.

Consistent with existing literature, D_1 is interpreted as compositional layering and isoclinal folds between ca. 2.719 and ca. 2.691 Ga. D_2-D_4 produced the dominant brittle-ductile structures observed within the greenstone belts, including steeply dipping foliations, isoclinal folds, and thrust faults between ca. 2.691 and ca. 2.673 Ga. Details of structural features associated with the D_5 and D_6 deformation events are limited in the literature to brittle and brittle-ductile faults of various scales and orientations (Lin 2001; Muir 2003). Within the Hemlo greenstone belt, Muir (2003) suggested that local D_5 and D_6 faults offset the Senneterre, Marathon, and Biscotasing dyke swarms (all ca. 2.2 Ga), and as such, suggested that in the Hemlo region D_5 and D_6 faults developed after 2.2 Ga. However, since there are no absolute age constraints on specific events, the entire D_5-D_6 interval of brittle deformation can only be constrained to a post-2.673 Ga timeframe that may include many periods of re-activation attributable to any of several post-Archean tectonic events.

The 2839 brittle lineaments identified in the White River area are interpreted to represent successive stages of brittle-ductile and brittle deformation. These lineaments can therefore be classified into three main stages based on relative age and in consideration of the structural history described above: 76 D_2-D_4 lineaments, 1035 D_5 lineaments, and 1728 D_6 lineaments. D_2-D_4 brittle lineaments are interpreted as Archean brittle-ductile faults. D_5 and D_6 brittle lineaments are interpreted as brittle faults. Limited information exists on the character of each interpreted fault set. At the desktop stage of preliminary assessment, it is still uncertain whether or not each interpreted lineament is in fact an actual brittle-ductile or brittle geological feature with a significant expression at depth.

Four populations of dykes have been identified in the lineament interpretation that appear to correspond to the ca. 2.473 Ga., northwest trending Matachewan dyke swarm (Buchan and Ernst 2004); the ca. 2.167 Ga., northeast trending Biscotasing dyke swarm (Hamilton et al., 2002); the ca. 2.121 Ga., north trending Marathon dyke swarm (Buchan et al., 1996; Hamilton et al., 2002); and the ca. 1.14 Ga northeast-trending Abitibi dyke swarm (Ernst and Buchan 1993). Regional geological maps also identify isolated northwest trending Sudbury dykes (ca. 1.24; Krogh et al. 1987), however the lineament analysis did not clearly identify any lineaments consistent with these dykes. The timing between D_6 faults and the Marathon dyke swarm (~2.1 Ga.) appears ambiguous. D_6 faults can be coincident with Marathon dykes, and as such earlier structures can appear offset along the trend of an individual dyke. Elsewhere, Marathon dykes are observed to crosscut D_6 faults with no observable offset. Biscotasing or Marathon dykes were not observed to be offset by D_6 faults. As such, it is thought likely that D_6 faults formed prior to emplacement of the Marathon dyke swarm and that the dykes exploited pre-existing weaknesses along the D_6 faults. However, it is also possible that some fault reactivation may have occurred coeval with, or after dyke emplacement, and this could account for the apparent offset of structures observed along dykes. Apart from these timing constraints, there are no additional absolute age constraints for these phases of deformation.

No information is available on the depth of fault penetration in the White River area; however, brittle lineament strike length may be a proxy for the depth extent. In general, D_6 faults have the longest strike length (3.9 kilometres average length, 2.6 kilometres median length), followed by D_5 faults (3.3 kilometres average length, 2.2 kilometres median length), and D_2-D_4 faults (2.4 kilometres average length, 1.7 kilometres median length).

6 Summary

This report documents the source data, workflow, and results from a lineament interpretation of publicly-available digital data sets, including geophysical (aeromagnetic with the support of electromagnetic) and surficial (satellite imagery, topography) data sets for the White River area (approximately 5,000 square kilometres), in northwestern Ontario.

The lineament analysis provides an interpretation of the location and orientation of possible individual brittle features and dykes on the basis of remotely sensed data, and helps to evaluate their relative timing relationships within the context of the regional geological setting. The three step process involved a workflow that was designed to address the issues of subjectivity and reproducibility.

The distribution of lineaments in the White River area reflects the bedrock structure, resolution of the data sets used, and surficial cover. Lineament density, as demonstrated in this study, is closely associated with the distribution and thickness of overburden cover that masks the surficial expression of bedrock structures, and with the resolution of the interpreted data sets. Due to a scarcity and uneven distribution of high resolution geophysical data, and significant overburden and lake cover, surface lineament density throughout the White River area is variable.

The greatest density of lineaments occurs in areas covered by high resolution geophysical data (e.g., the Dayohessarah greenstone belt, and small areas along the western, northwestern, and northeastern borders of the study area). Several areas not covered by high resolution geophysical data also show high lineament densities, including the northwestern portion of the Black-Pic batholith, along the eastern portion of the southern boundary of the study area, and near the northeastern boundary of the Pukaskwa batholith. These zones occasionally correlate with clusters of high density dyke lineaments.

Many areas with a low density of lineaments were identified throughout the White River area. Bedrock within the majority of these areas (in particular the northeastern quarter of the study area) is masked by significant Quaternary and lake cover. Areas of low lineament density interpreted to represent a low density of bedrock structures were restricted to select areas within the Black-Pic batholith, the Pukaskwa batholith, the Strickland pluton, the Anahareo pluton and the gneissic tonalite east of the township of White River. Within areas of exposed bedrock or thin drift, further investigations of bedrock formations and potential structures could be conducted through outcrop mapping and rock mass characterizations.

In terms of reproducibility, longer interpreted lineaments generally have higher certainty and reproducibility values. Comparison between the various data sets (RA_2) indicates that 35 percent of lineaments observed from aeromagnetic data were reproduced on at least one surficial data set and have an RA_2 value greater than 1. Of all lineaments observed on surficial data sets, 27 percent lineaments were coincident in both CDED topography and satellite imagery data, and 10 percent were observed in the geophysical data sets. The lack of reproducibility between geophysical and surficial data sets is likely a result of the poor resolution of the geophysical data sets relative to the surficial data sets. Regardless of the degree of coincidence, an observed overlap in dominant lineament orientation between all data sets suggests that all data sets are identifying the same regional sets of structures.

Azimuth data, weighted by length, for all brittle and dyke lineaments from the merged lineament data set exhibit three dominant orientations trending to the northwest, north and northeast, and one minor orientation trending east-northeast. All orientations are well defined, including the northeast trending orientation which is more diffuse in the non-merged data sets. On the basis of the structural history of the White River area, a framework was developed to constrain the relative age relationships of the interpreted lineaments.

A total of 2839 brittle lineaments were interpreted in the White River area, representing three main generations: 76 D_2-D_4 lineaments, 1035 D_5 lineaments, and 1728 D_6 lineaments. In addition, 442 dyke lineaments have been interpreted, including 286 Matachewan Suite dykes, 87 Biscotasing Suite dykes, 59 Marathon Suite dykes, and 10 Abitibi Suite dykes.

Brittle lineaments interpreted as D_2-D_4 structures follow the geometry of and occur primarily within and adjacent to the greenstone belts. D_2-D_4 lineaments are interpreted to have formed between ca. 2.719 Ga. and 2.673 Ga. Brittle lineaments representing D_5 and D_6 structures are interpreted to be younger than ca. 2.673 Ga., and represent a broad north-, northeast- and northwest-trending lineament network. Relationships between D_5 and D_6 and emplacement of the Marathon Suite dykes (ca. 2.1 Ga.) are ambiguous, therefore no absolute age constraints exist for these stages of deformation.

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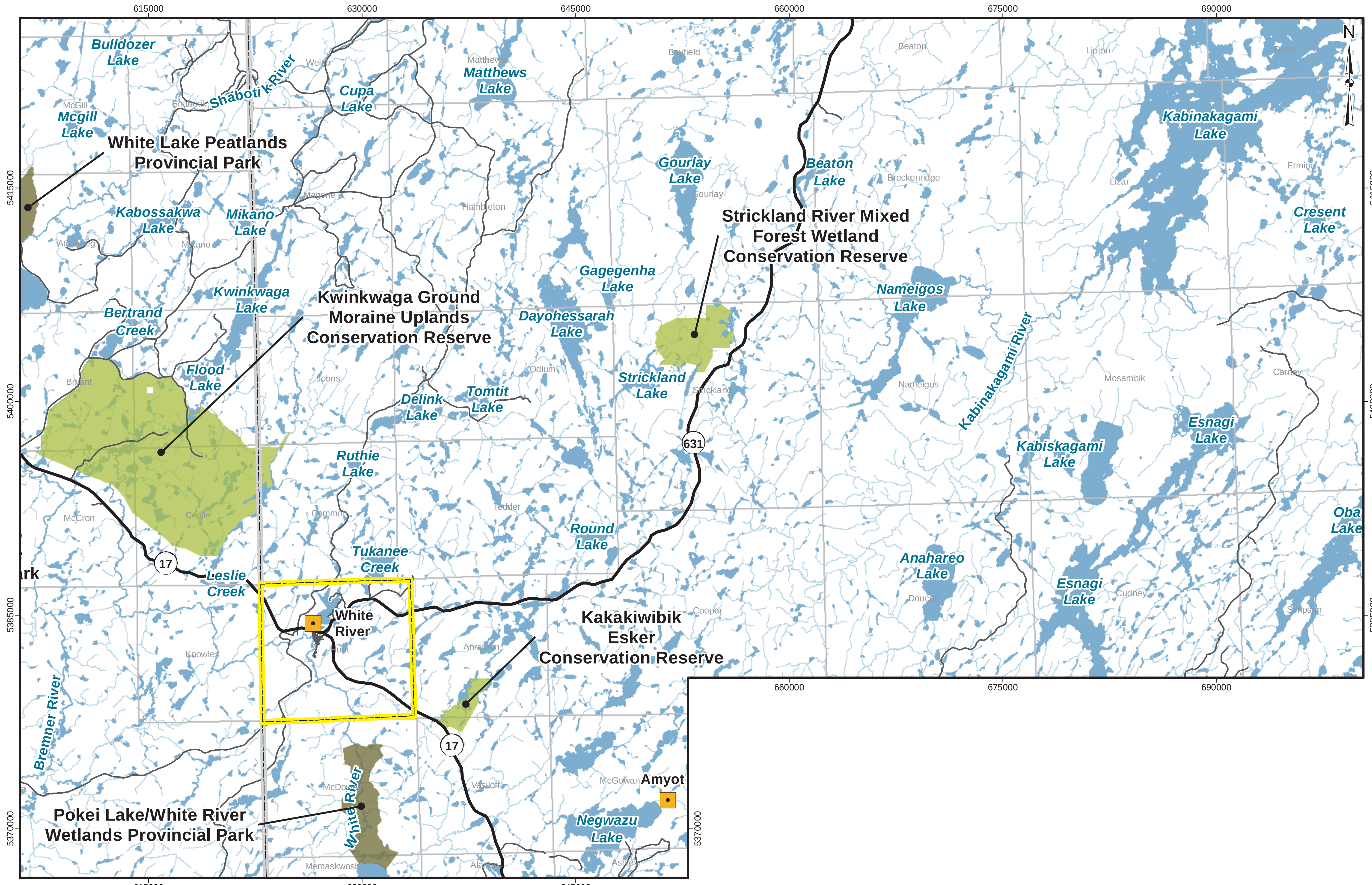
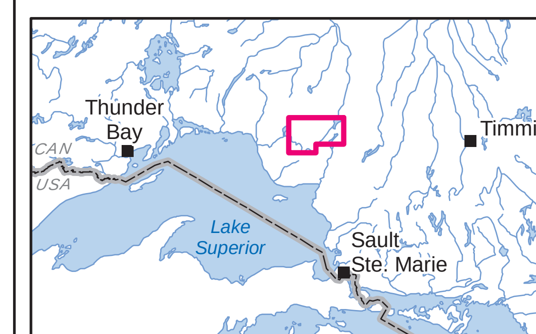


LEGEND

- Settlement
- White River Municipal Boundary
- Township Boundary
- District Boundary
- Main Road
- Local Road
- Waterbody
- Watercourse

Protected Areas

- Provincial Park
- Conservation Reserve



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
- Settlement: LIO Cities and Towns
- Road: LIO Road Segment
- Provincial Parks: LIO Provincial Parks
- Conservation Reserves: LIO Conservation Reserves
- Waterbody: LIO Waterbody
- Watercourse: LIO Watercourse
- Utility Lines: LIO Utlity Line
- Municipalities: LIO Upper, Single and Lower Tier

From Aecom (2014a)

10 km

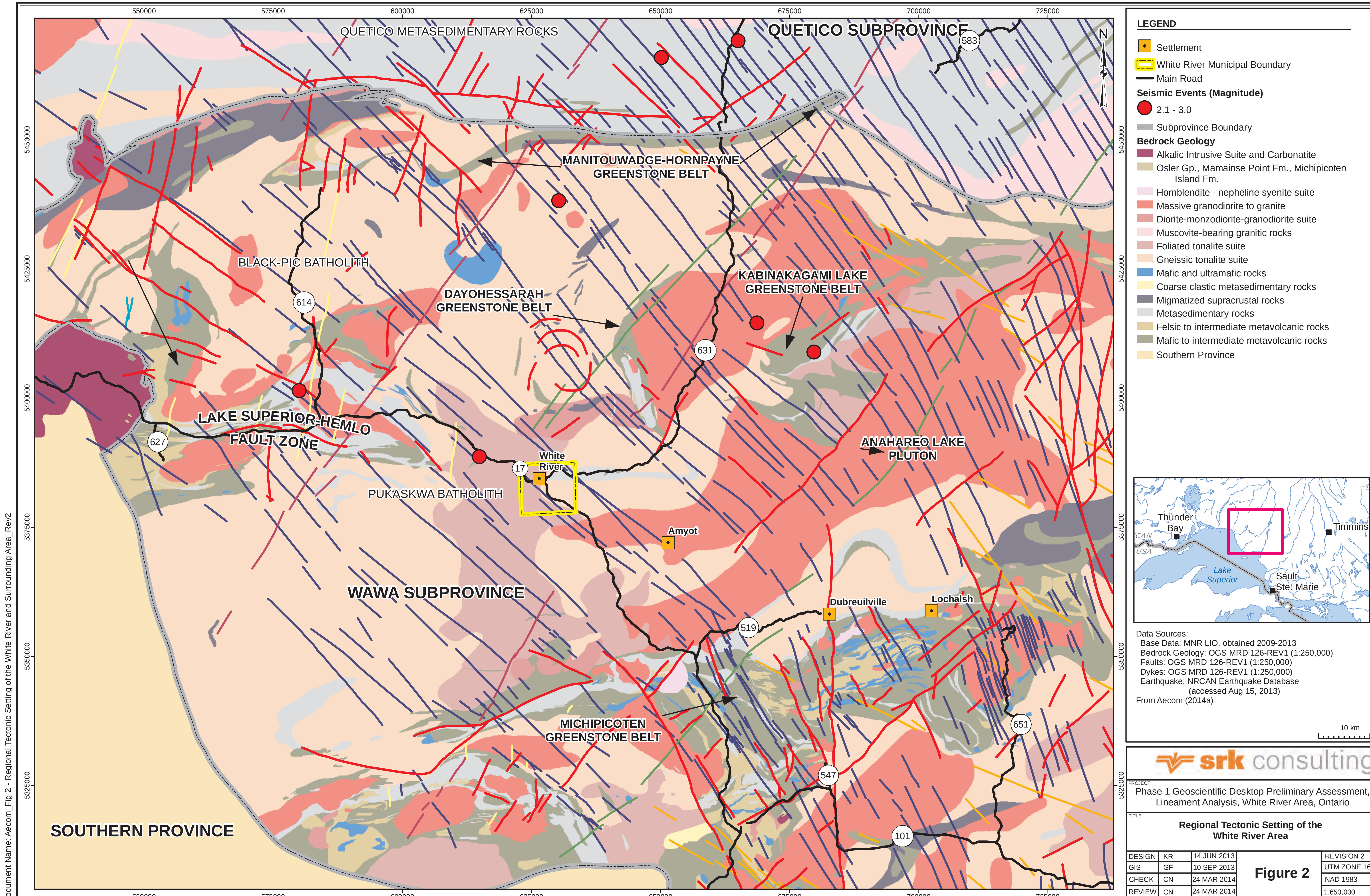
srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Location and Overview of the White River Area

DESIGN	KR	23 AUG 2013	Figure 1	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 MAR 2014		NAD 1983
REVIEW	CN	24 MAR 2014		1:300,000

Document Name: Aecom_Fig 1 - Township of White River and Surrounding Area


QUETICO METASEDIMENTARY ROCKS
QUETICO SUBPROVINCE
MANITOUWADGE-HORNPAYNE GREENSTONE BELT
BLACK-PIC BATHOLITH
DAYOHESSARAH GREENSTONE BELT
KABINAKAGAMI LAKE GREENSTONE BELT
LAKE SUPERIOR-HEMLO FAULT ZONE
ANAHAREO LAKE PLUTON
PUKASKWA BATHOLITH
White River
Amyot
WAWA SUBPROVINCE
Dubreuilville
Lochalsh
MICHIPICOTEN GREENSTONE BELT
SOUTHERN PROVINCE
583
614
631
627
17
519
651
547
101
550000
575000
600000
625000
650000
675000
700000
725000
5450000
5425000
5400000
5375000
5350000
5325000
N
LEGEND
Settlement
White River Municipal Boundary
Main Road
Seismic Events (Magnitude)
2.1 - 3.0
Subprovince Boundary
Bedrock Geology
Alkalic Intrusive Suite and Carbonatite
Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
Hornblendite - nepheline syenite suite
Massive granodiorite to granite
Diorite-monzodiorite-granodiorite suite
Muscovite-bearing granitic rocks
Foliated tonalite suite
Gneissic tonalite suite
Mafic and ultramafic rocks
Coarse clastic metasedimentary rocks
Migmatized supracrustal rocks
Metasedimentary rocks
Felsic to intermediate metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Southern Province
Thunder Bay
CAN
USA
Timmins
Lake Superior
Sault Ste. Marie
Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS MRD 126-REV1 (1:250,000)
Faults: OGS MRD 126-REV1 (1:250,000)
Dykes: OGS MRD 126-REV1 (1:250,000)
Earthquake: NRCAN Earthquake Database (accessed Aug 15, 2013)
From Aecom (2014a)
10 km
srk consulting
PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario
TITLE
Regional Tectonic Setting of the White River Area
DESIGN KR 14 JUN 2013
GIS GF 10 SEP 2013
CHECK CN 24 MAR 2014
REVIEW CN 24 MAR 2014
Figure 2
REVISION 2
UTM ZONE 16
NAD 1983
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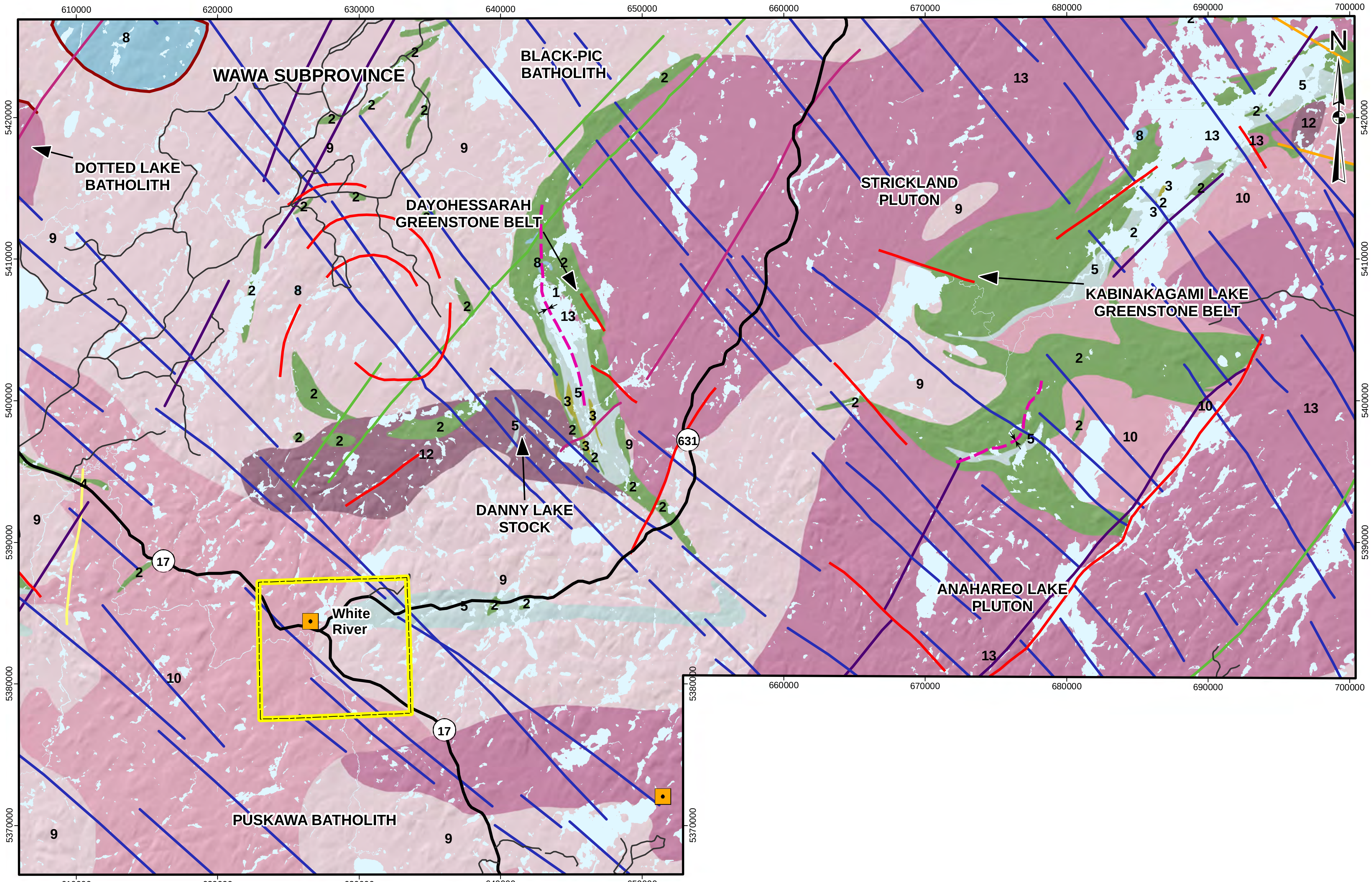
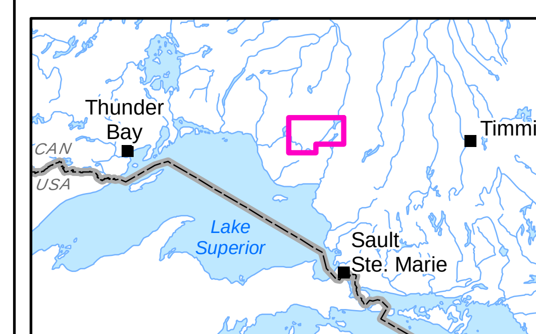
Document Name: Aecom_Fig 2 - Regional Tectonic Setting of the White River and Surrounding Area_Rev2





Legend

- White River Municipal Boundary
- Settlement
- Main Road
- Local Road
- Waterbody
- Faults
- Bedrock Geology Contact

Dykes

- Abitibi mafic dyke
- Biscotasing mafic dyke
- Marathon, Kapuskasing or Biscotasing mafic dyke
- Matachewan mafic dyke
- Sudbury mafic dyke
- unknown

Bedrock Geology

- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks

Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001; M2668, 2003 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Intrusions: Generalized from OGS M2666, 2001; M2668, 2003 (1:250,000)
Underlay: Hillshade DEM
From Aecom, 2013

10 km

srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Bedrock Geology of the White River Area

DESIGN	KR	23 APR 2013	**Figure 3**	REVISION 1
GIS	GF	29 AUG 2013		UTM ZONE 16
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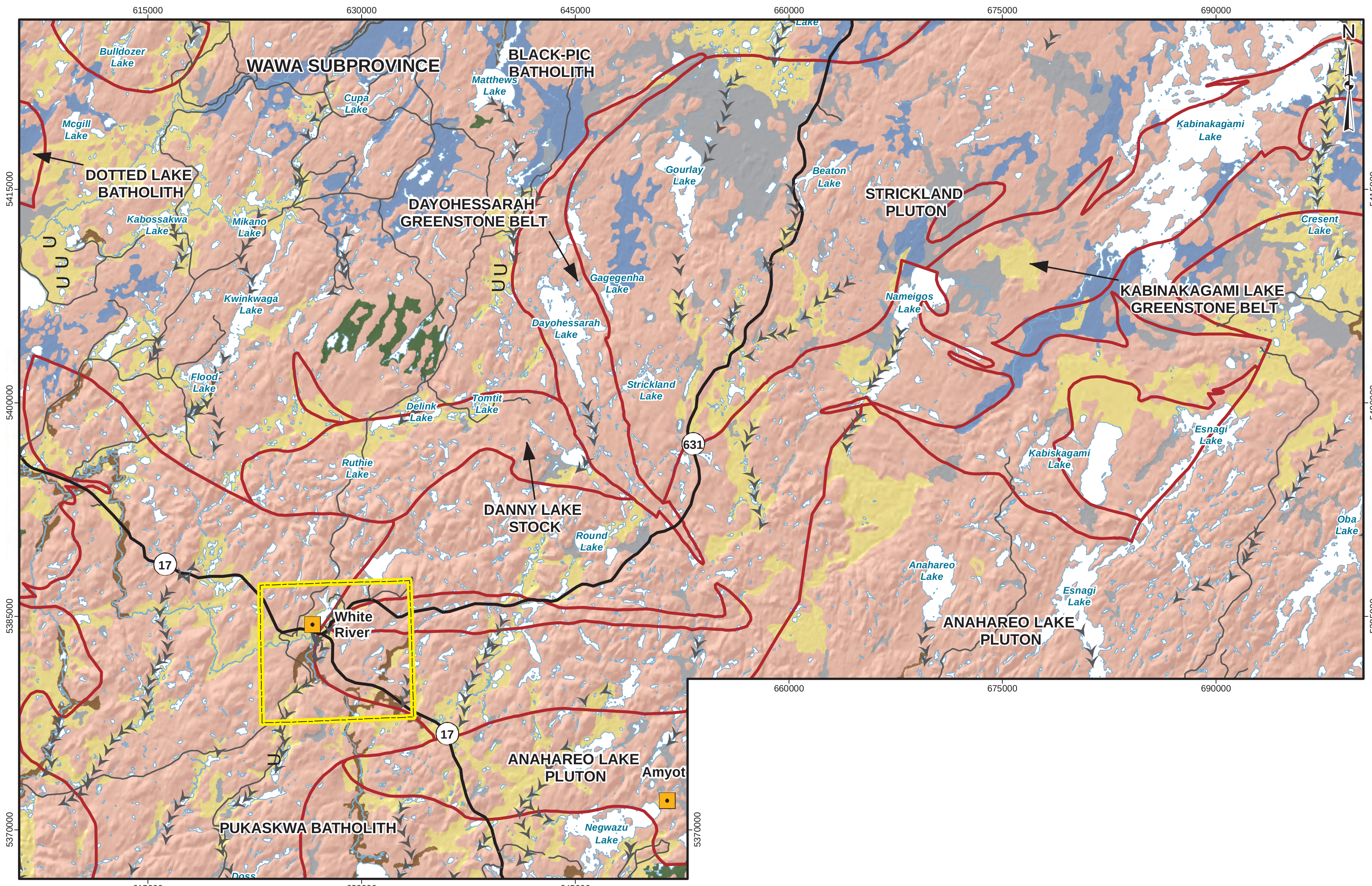
REVIEW	CN	03 OCT 2013		1:300,000

Document Name: 60297733_Fig 3 - Bedrock Geology of the White River Area



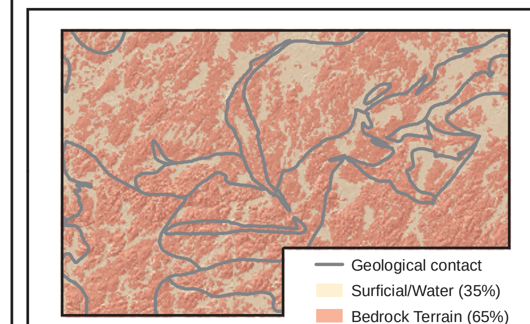
LEGEND

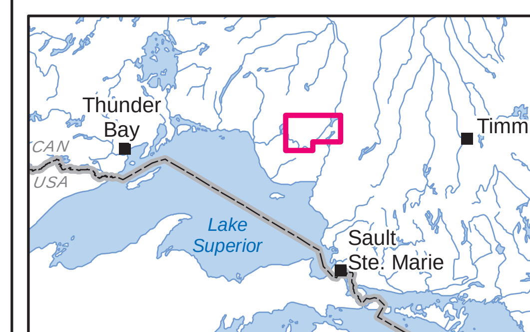
- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Waterbody
- Batholith_WR

Surficial Geology

- Morainal Terrain
- Glaciofluvial Terrain
- Glaciolacustrine Terrain
- Alluvial Terrain
- Organic Terrain
- Bedrock Terrain
- Sand Dunes
- Eskers

MAP OF SURFICIAL LANDFORMS AND WATERBODIES





Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Overburden: OGS MRD-160, NOEGTS 2006
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Underlay: Hillshade DEM, MNR Elevation and Slope
From Aecom (2014a)

10 km

srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Surficial Geology of the White River Area

DESIGN	KR	23 APR 2013	Figure 4	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
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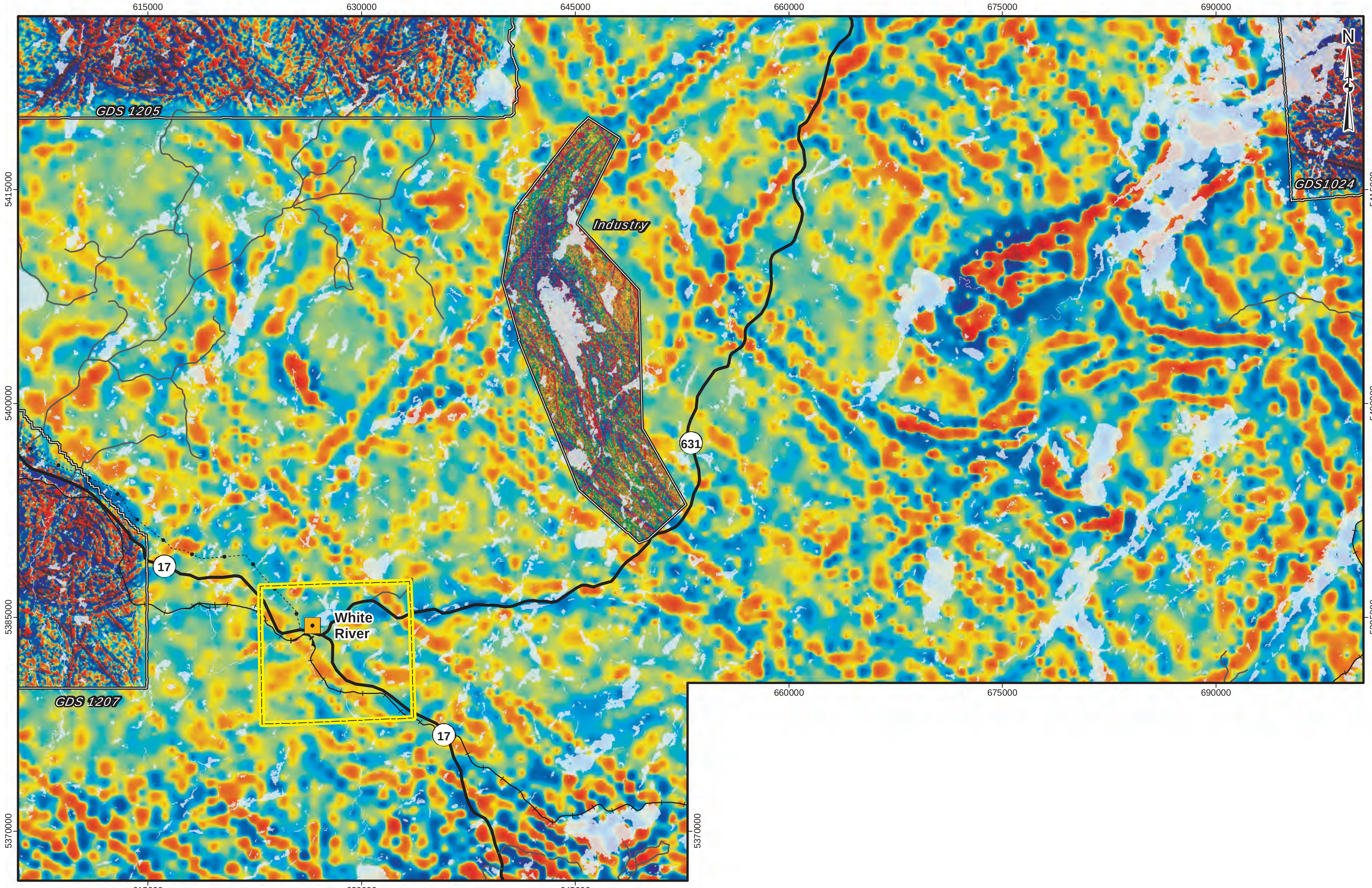
REVIEW	CN	24 MAR 2014		1:300,000

Document Name: Aecom_Fig 4 - SurficialGeology_WhiteRiver

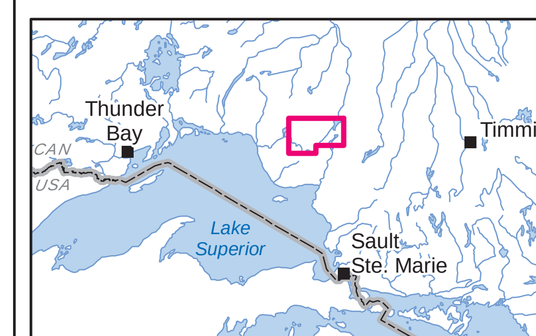


LEGEND

- White River Municipal Boundary
- Settlement
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Geophysical Survey Boundary

Residual Total Magnetic Field (nT)

2374, 148, 100, 72, 52, 38, 26, 14, 4, -4, -12, -20, -28, -36, -44, -50, -58, -68, -76, -84, -92, -102, -112, -122, -132, -146, -160, -176, -200, -370



REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Geophysics: Geological Survey of Canada - Aeromagnetic Surveys - Ontario #8, Dighem 1056
Ontario Geological Survey - Geophysical Surveys - GDS1205, GDS1207. GDS 1024

10 km

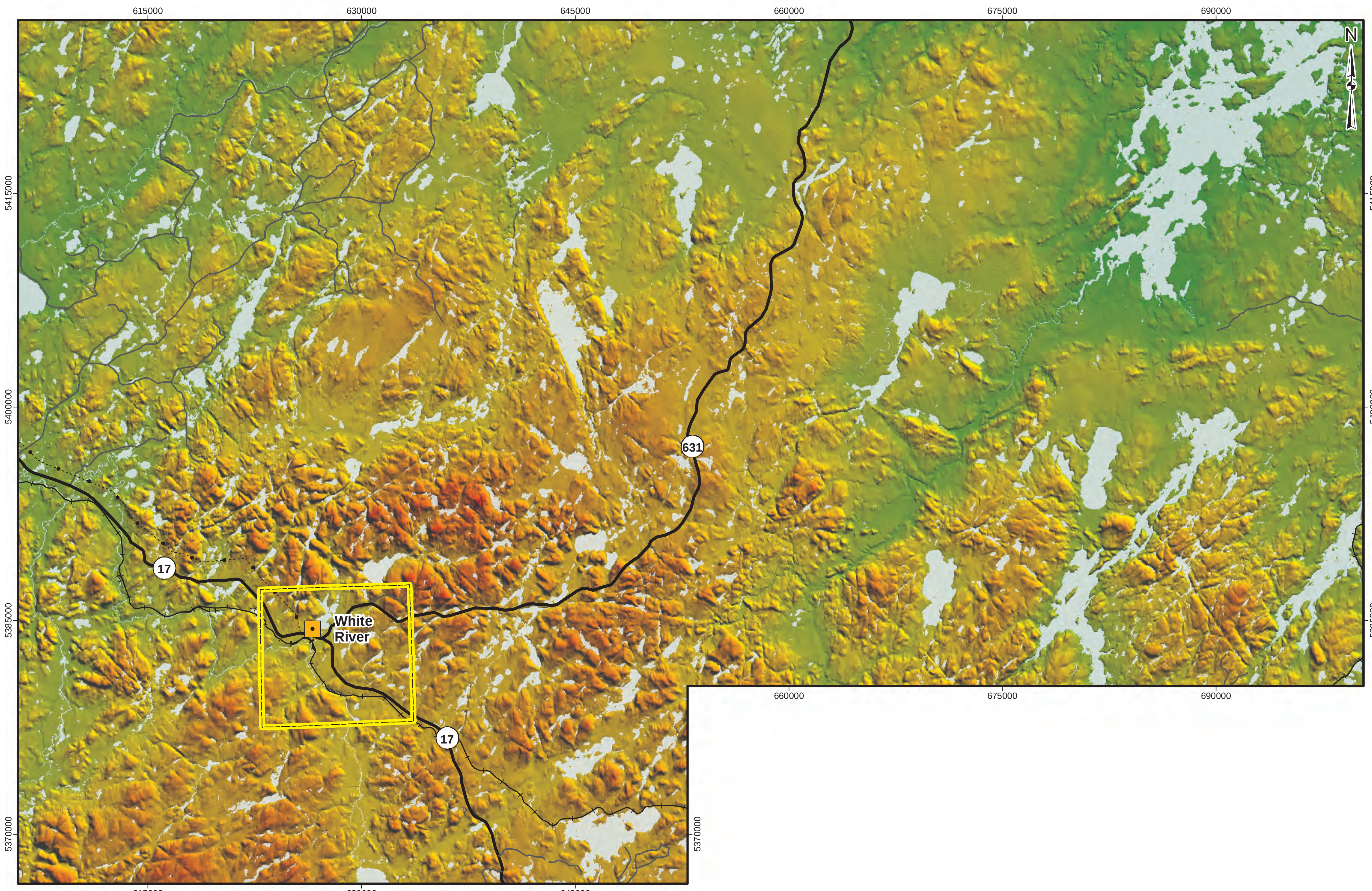
srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Pole Reduced Magnetic Data (First Vertical Derivative) of the White River Area

DESIGN	KR	23 APR 2013	**Figure 5**	REVISION 1
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

File: SRK_NWMO_WR_Fig05_MAG

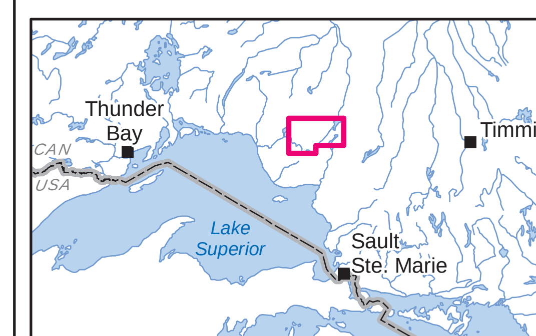


LEGEND

- White River Municipal Boundary
- Settlement
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody

Elevation (masl)

622m
600
500
400
311



REFERENCE

Base Data: MNR LIO, obtained 2009-2013
NRC CDED Topography Data

10 km

srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
CDED Digital Elevation Model of the White River Area

DESIGN	KR	23 APR 2013	**Figure 6**	REVISION 1
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

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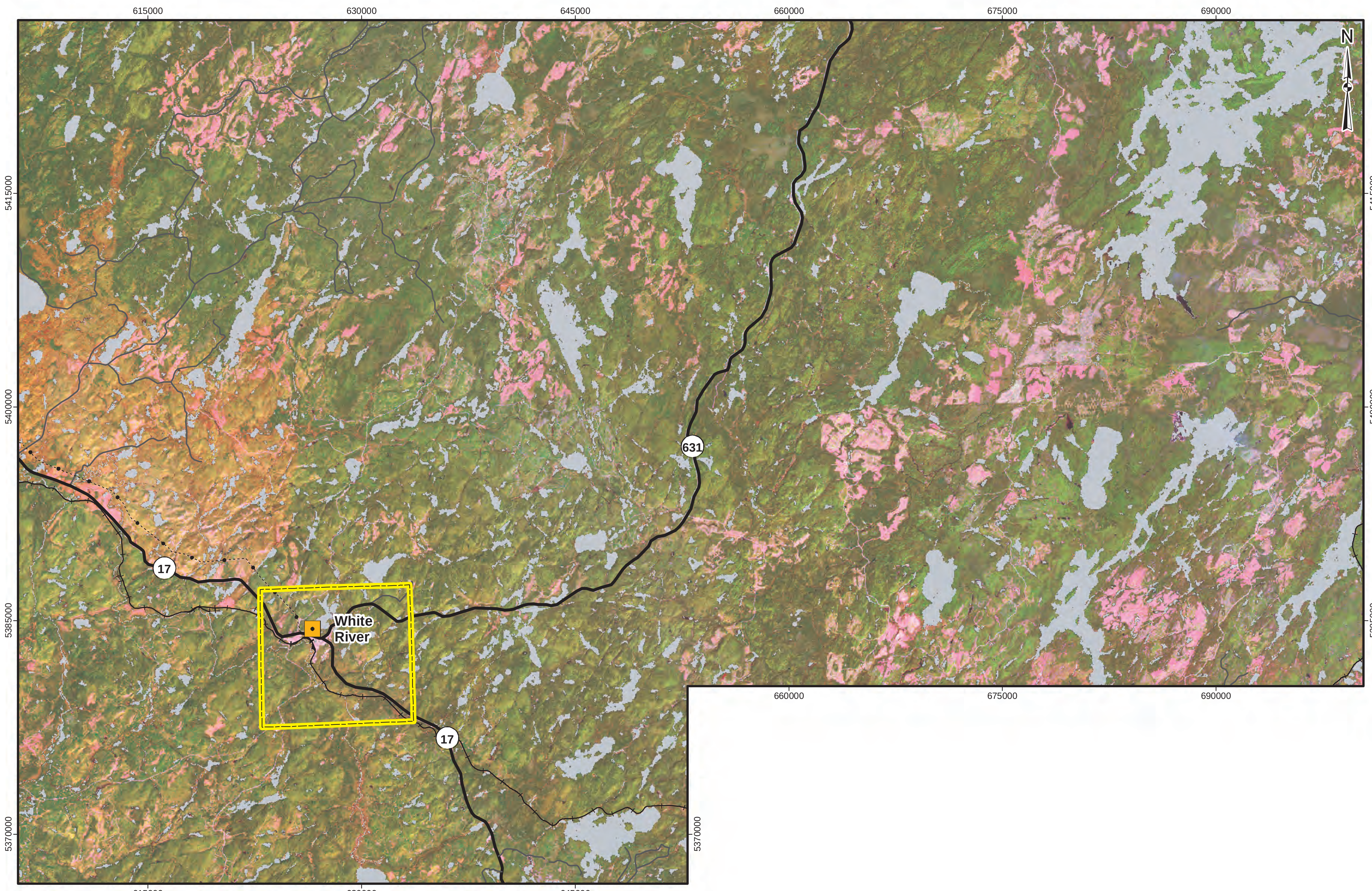
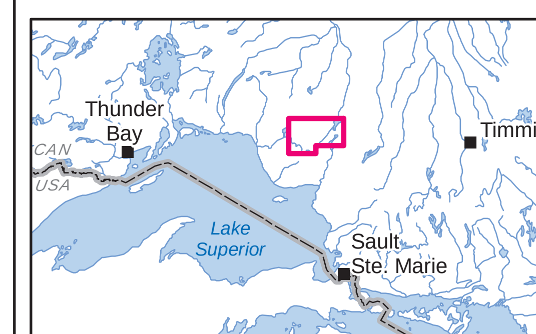


LEGEND

White River Municipal Boundary
Settlement
Main Road
Local Road
Railway
Abandoned Railway Right-of-way
Hydro Line
Waterbody



REFERENCE

Base Data: MNR LIO, obtained 2009-2013
NRC LandSAT 7 OrthoImage (CanImage)

10 km

srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Satellite Imagery Data (LandSAT 7-4-1) of the White River Area

DESIGN	KR	23 APR 2013	**Figure 7**	REVISION 1
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

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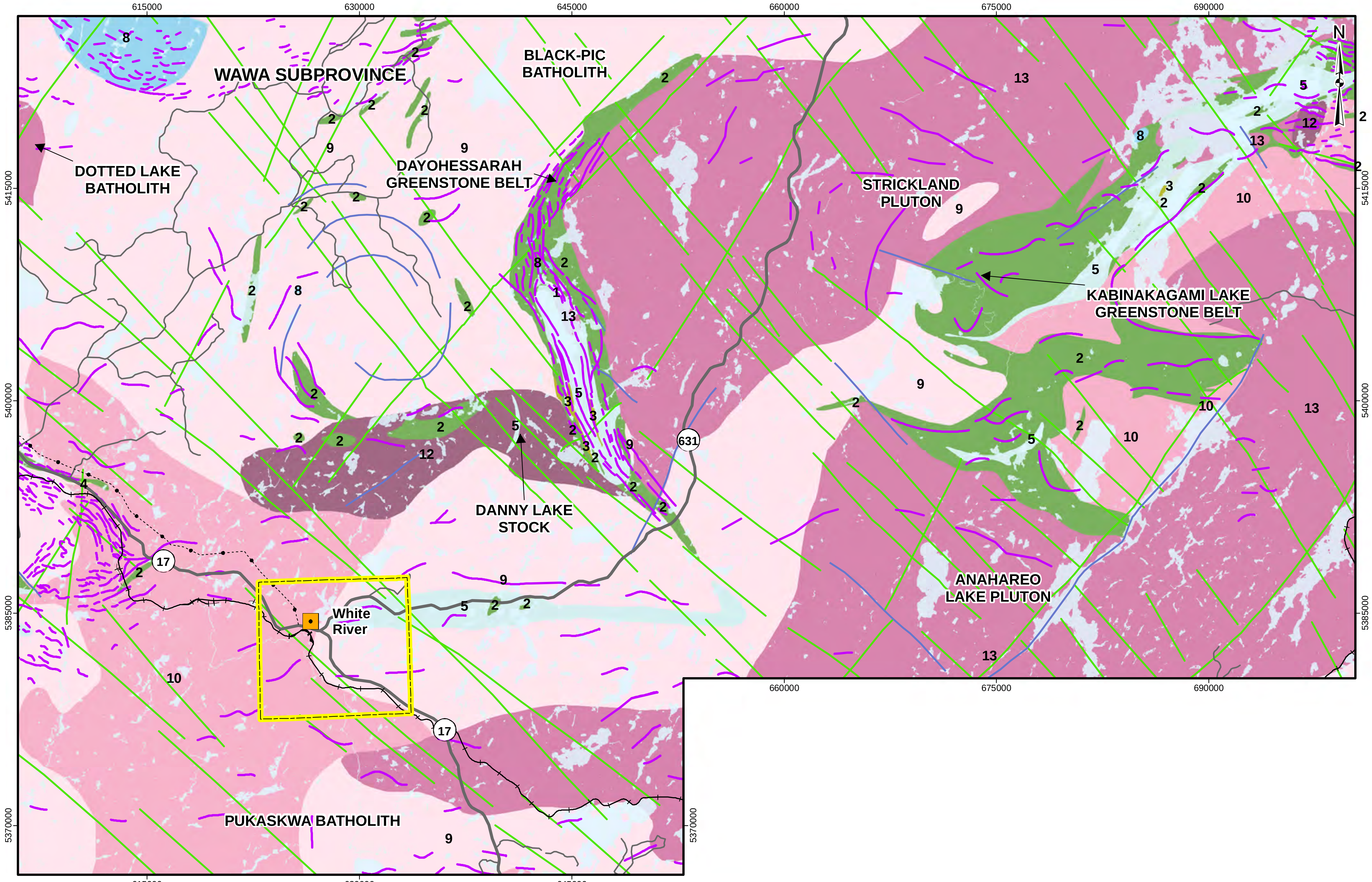
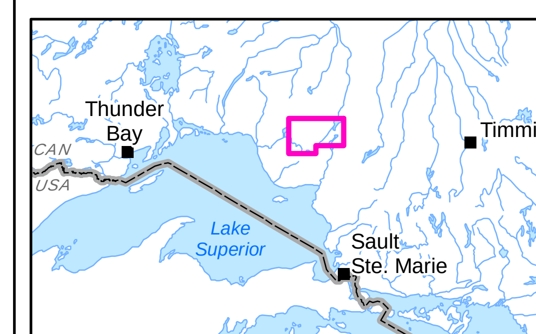


LEGEND

- White River Municipal Boundary
- Settlement
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Mapped Fault
- Mapped Dyke
- Ductile Lineament

Bedrock Geology

- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks



REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001; M2668, 2003 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)

10 km

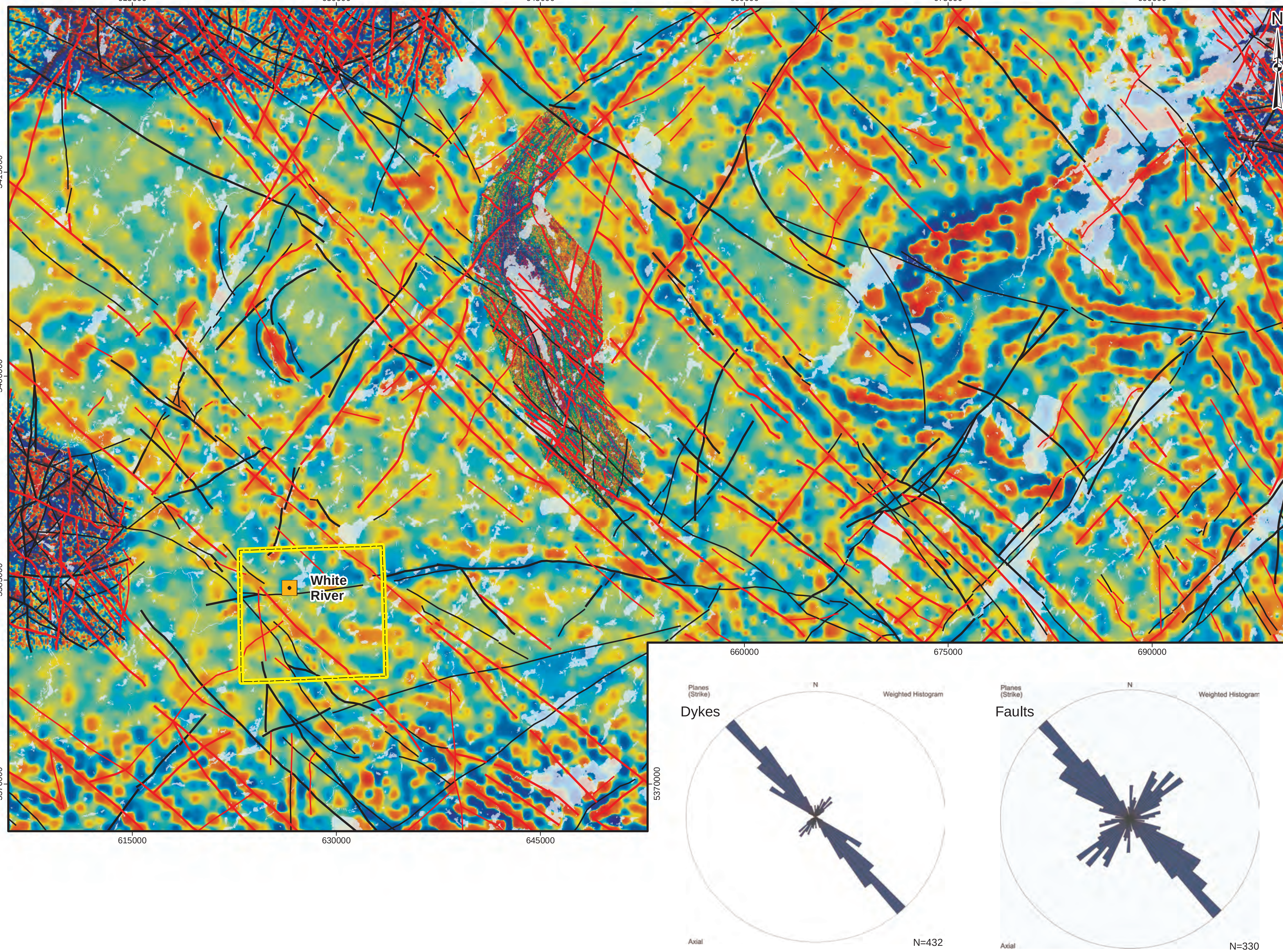
srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Ductile Lineaments for the White River Area

DESIGN	KR	23 APR 2013	Figure 8	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

File: SRK_NWMO_WR_Fig08_Ductile



LEGEND

White River Municipal Boundary

Settlement

Waterbody

Dyke (RA_1)

1

2

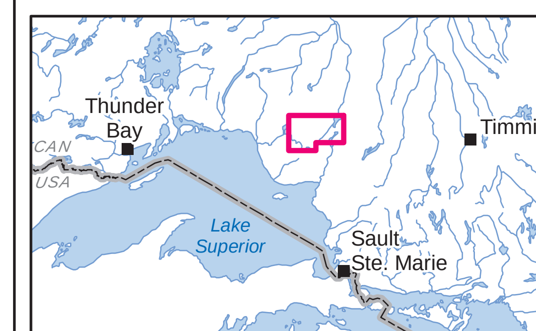
Fault (RA_1)

1

2

Residual Total Magnetic Field (nT)

2374
148
100
72
52
38
26
14
4
-4
-12
-20
-28
-36
-44
-50
-58
-68
-76
-84
-92
-102
-112
-122
-132
-146
-160
-176
-200
-370



REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Geophysics: Geological Survey of Canada - Aeromagnetic Surveys - Ontario #8, Dighem 1056
Ontario Geological Survey - Geophysical Surveys - GDS1205, GDS1207, GDS1024

10 km

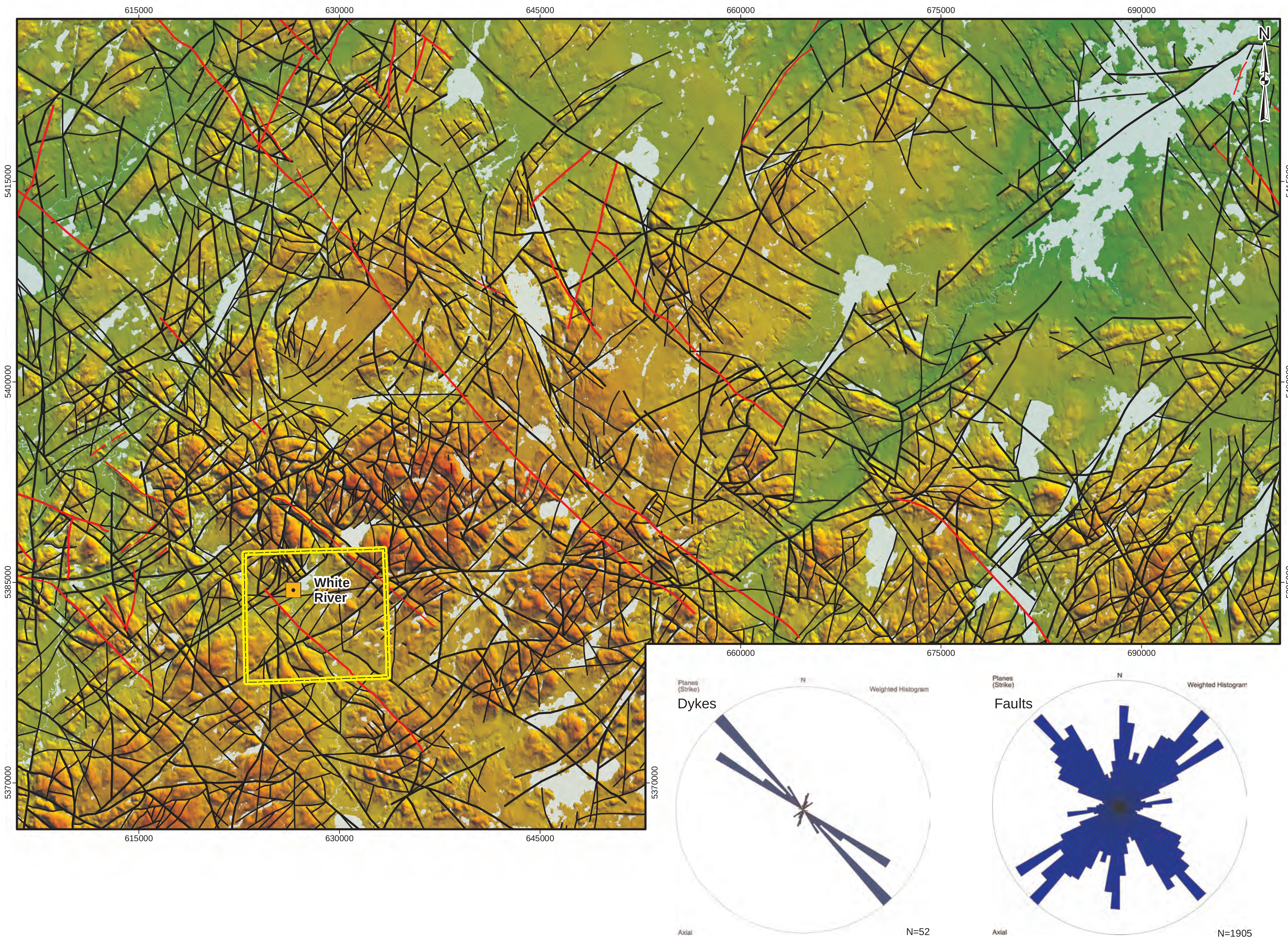
srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Aeromagnetic Data Reproducibility Assessment (RA_1) for the White River Area

DESIGN	KR	23 APR 2013	**Figure 9**	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

File: SRK_NWMO_WR_Fig09_MAGra1



LEGEND

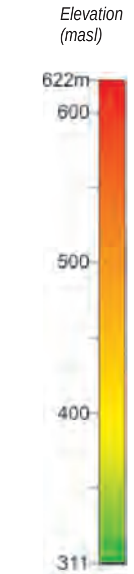
- White River Municipal Boundary
- Settlement
- Waterbody

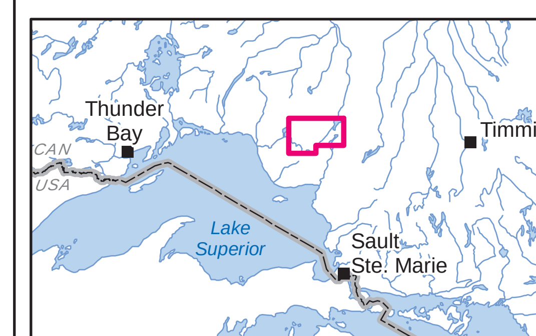
Dyke (RA_1)

- 1
- 2

Fault (RA_1)

- 1
- 2





REFERENCE

Base Data: MNR LIO, obtained 2009-2013
NRC CDED Topography Data

10 km

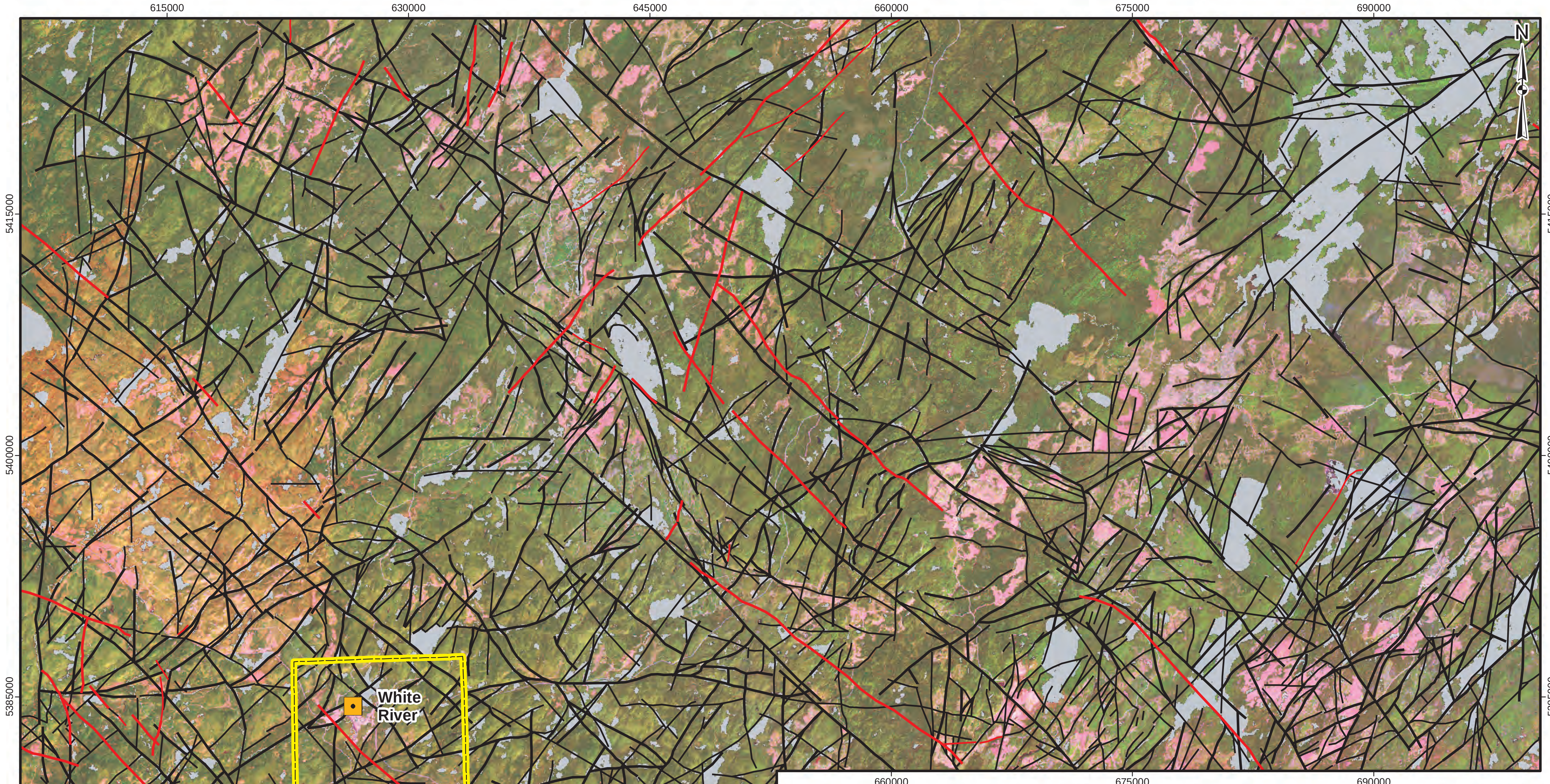
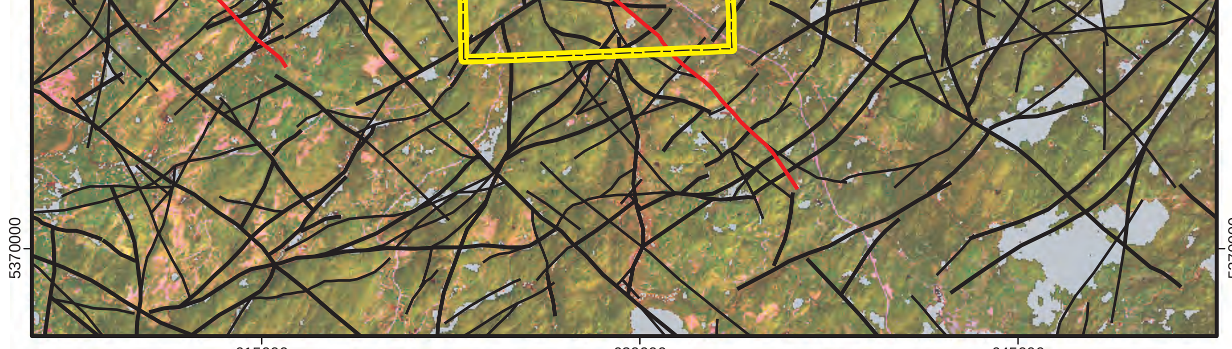
srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
CDED Topography Reproducibility Assessment (RA_1) for the White River Area

DESIGN	KR	23 APR 2013	Figure 10	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

File: SRK_NWMO_WR_Fig10_DEMra1

LEGEND

White River Municipal Boundary

Settlement

Waterbody

Dyke (RA_1)

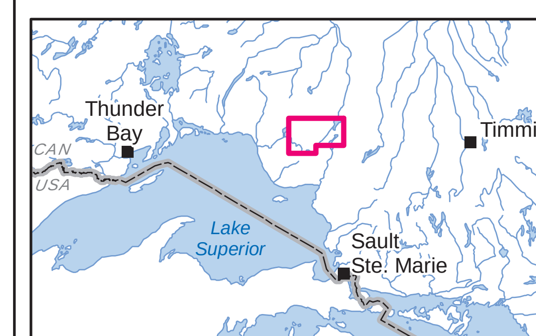
1

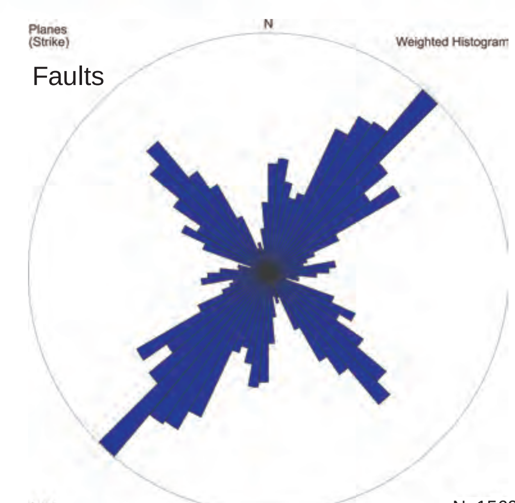
2

Fault (RA_1)

1

2





REFERENCE

Base Data: MNR LIO, obtained 2009-2013
NRC LandSAT 7 OrthoImage (CanImage)

10 km

srk consulting

PROJECT

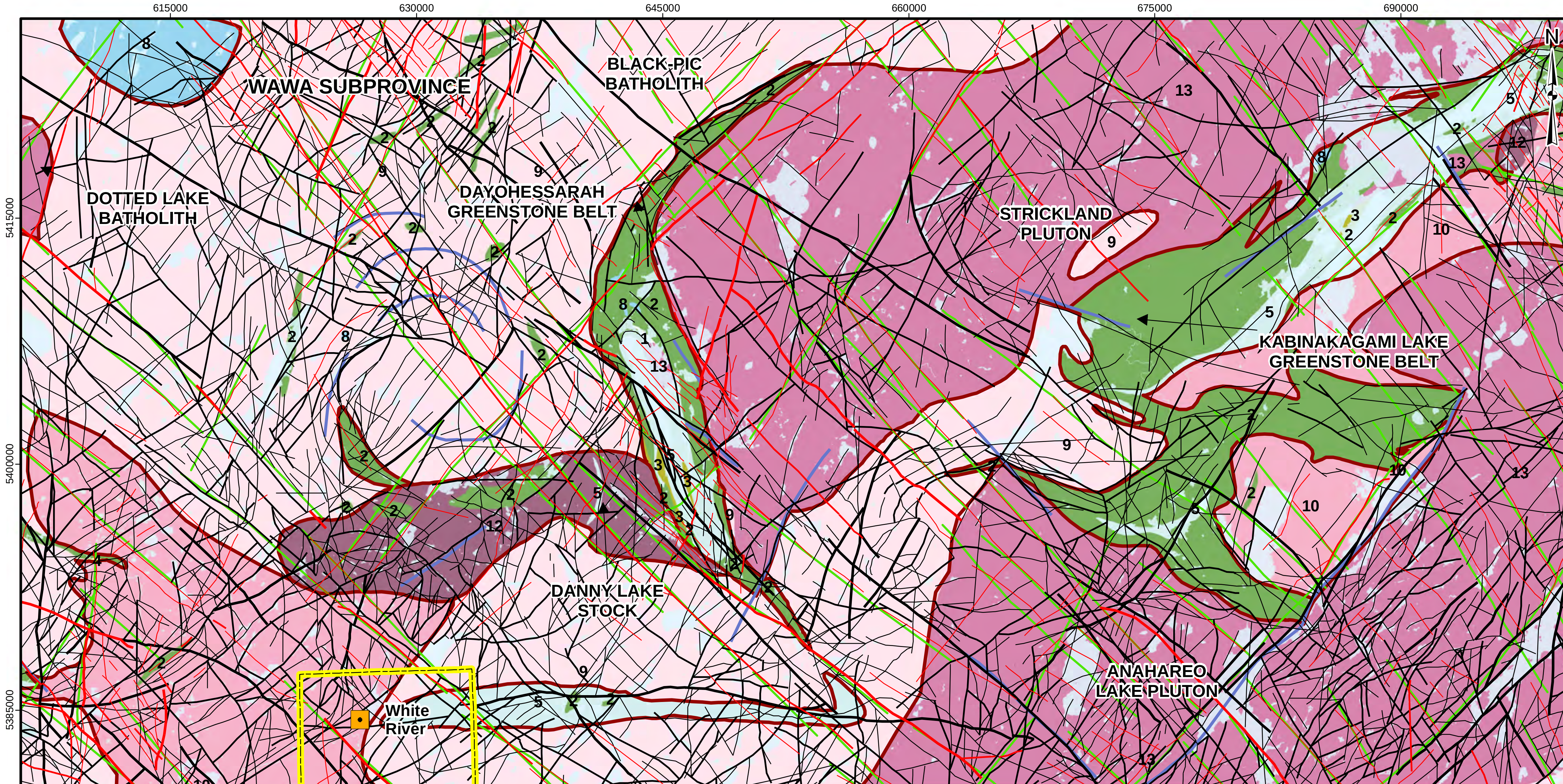
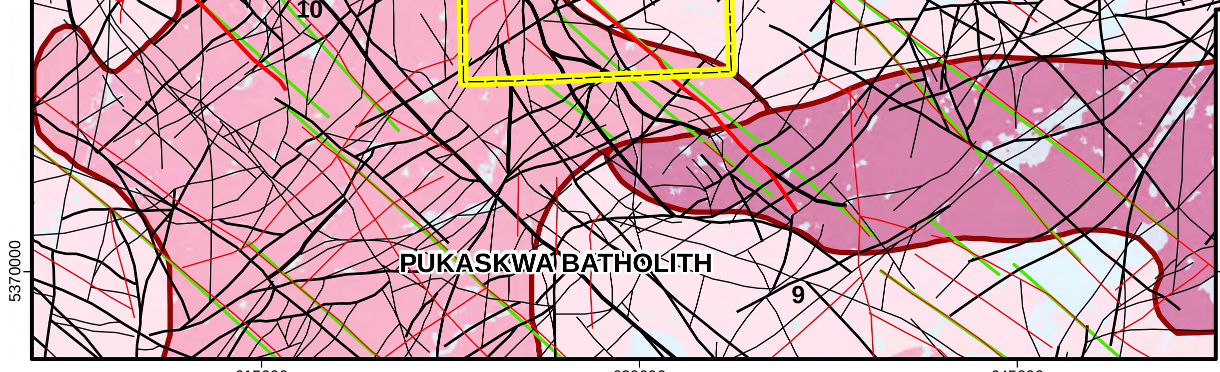
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE

Satellite Imagery (Landsat) Reproducibility Assessment (RA_1) for the White River Area

DESIGN	KR	23 APR 2013	Figure 11	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

File: SRK_NWMO_WR_Fig11_SATra1

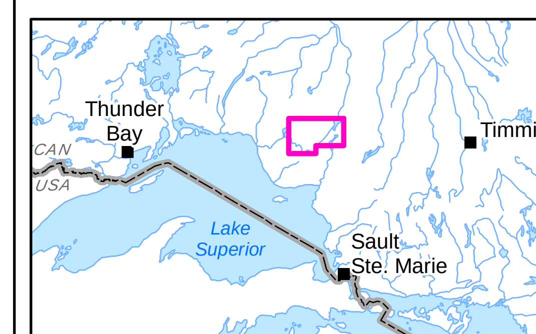
LEGEND

- White River Municipal Boundary
- Settlement
- Waterbody
- Bedrock Geology Contact
- Mapped Fault
- Mapped Dyke

Dyke (RA_2)	Fault (RA_2)
1	1
2	2
3	3

Bedrock Geology

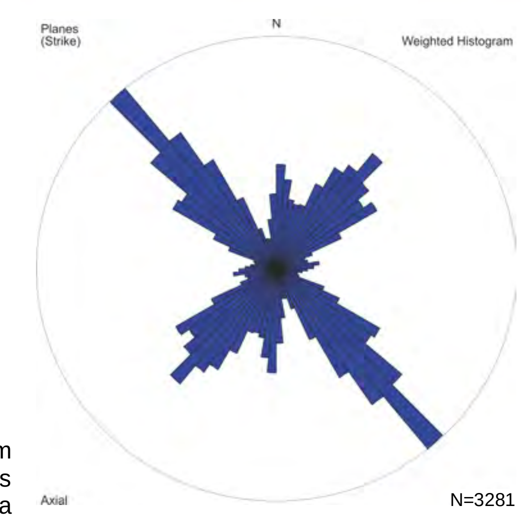
- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks



REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001; M2668, 2003 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)

10 km



Length-weighted rose diagram of interpreted lineaments in the White River area

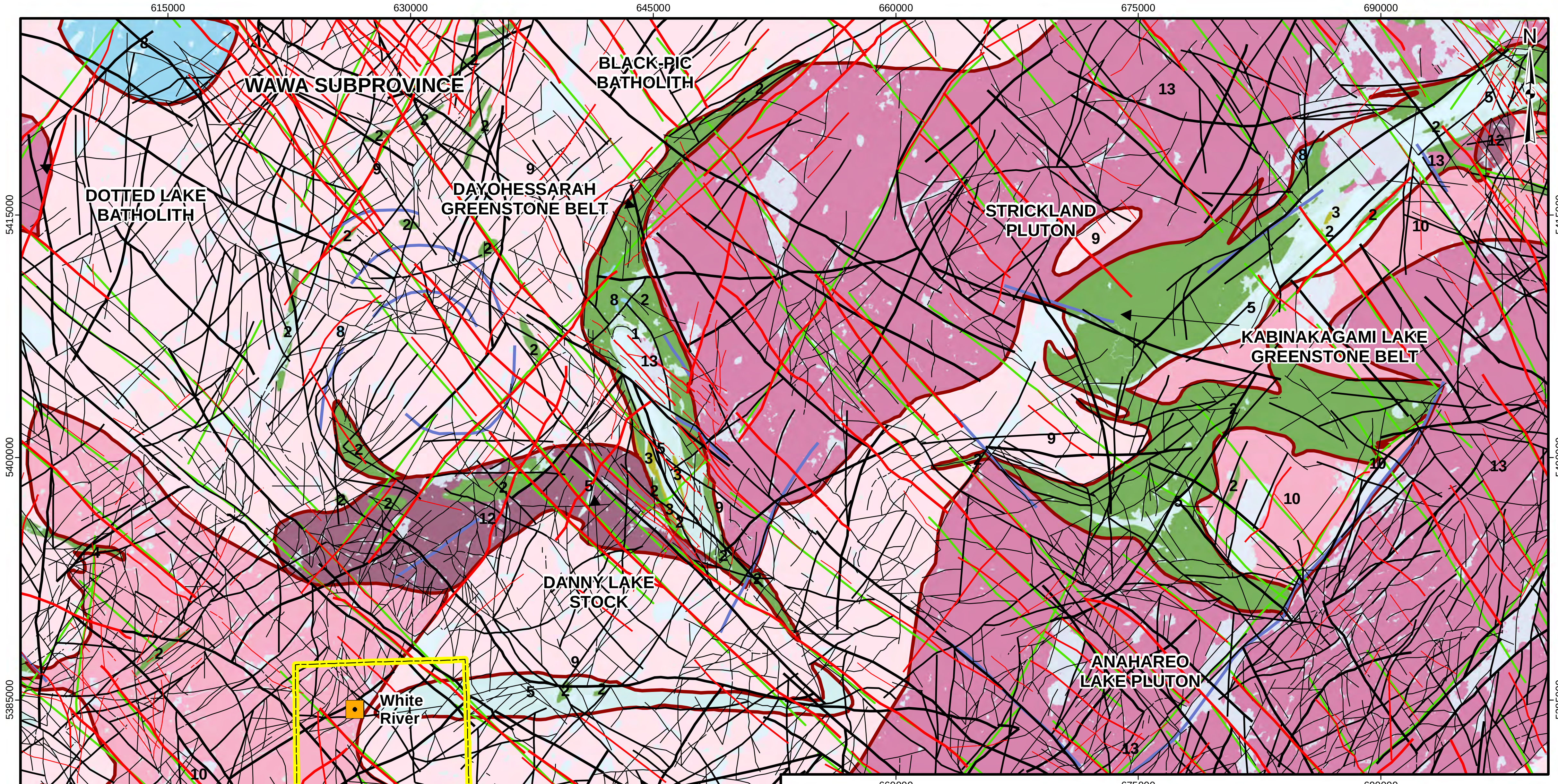
srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Lineament Classification by Reproducibility Assessment (RA_2) overlying bedrock geology of the White River Area

DESIGN	KR	23 APR 2013	**Figure 12**	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

File: SRK_NWMO_WR_Fig12_LINra2



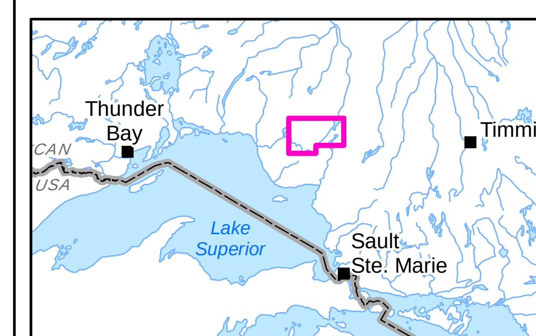

LEGEND

- White River Municipal Boundary
- Settlement
- Waterbody
- Bedrock Geology Contact
- Mapped Fault
- Mapped Dyke

Dyke (Length)	Fault (Length)
> 1 km	> 1 km
1 - 5	1 - 5
5 - 10	5 - 10
> 10 km	> 10 km

Bedrock Geology

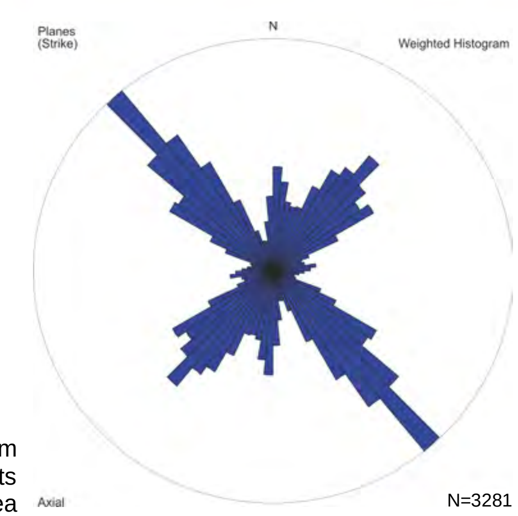
- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks



REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001; M2668, 2003 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)

10 km



Length-weighted rose diagram of interpreted lineaments in the White River area

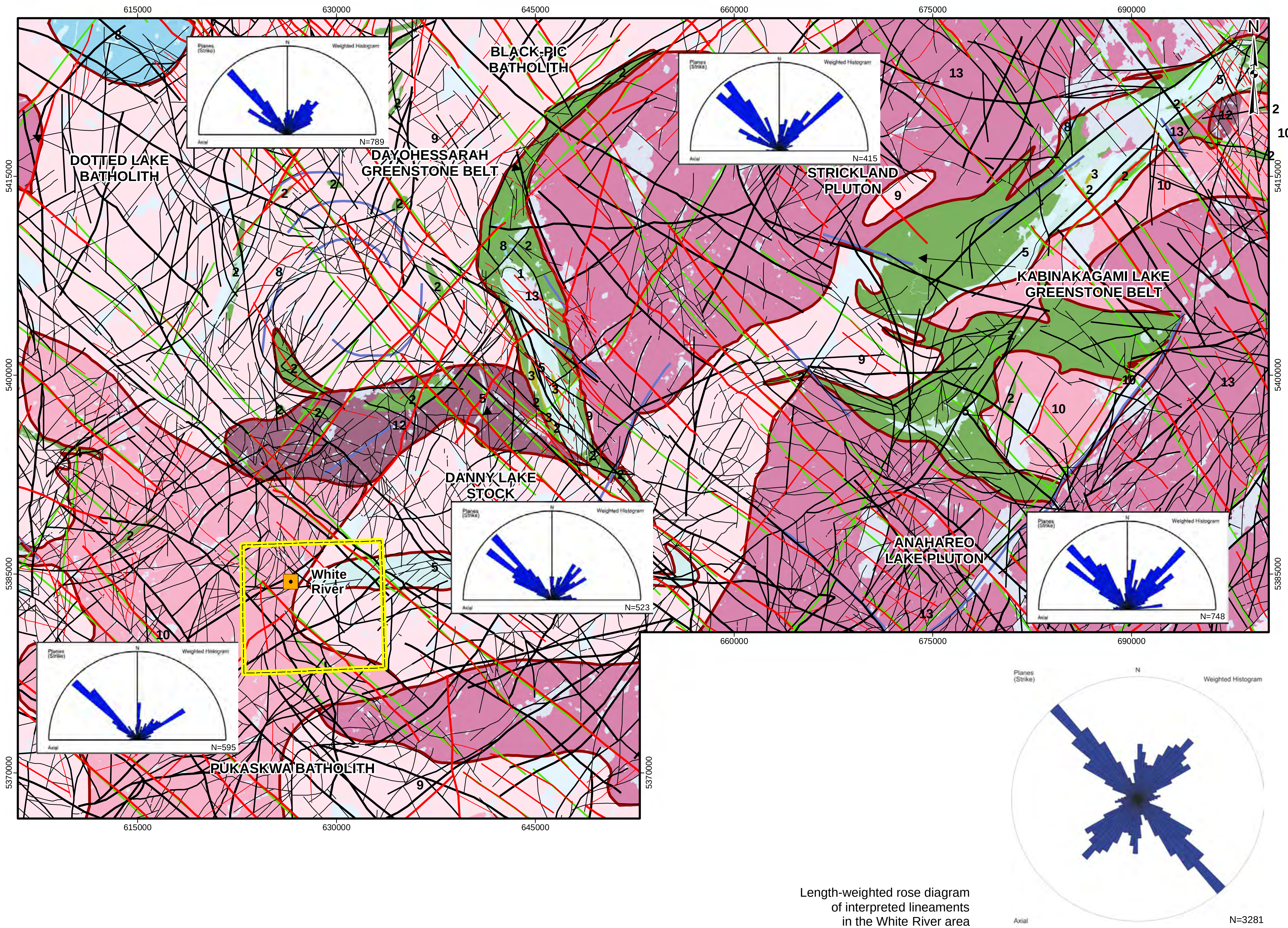
srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Lineament Classification by Length overlying bedrock geology of the White River Area

DESIGN	KR	23 APR 2013	**Figure 13**	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

File: SRK_NWMO_WR_Fig13_Length



Length-weighted rose diagram of interpreted lineaments in the White River area

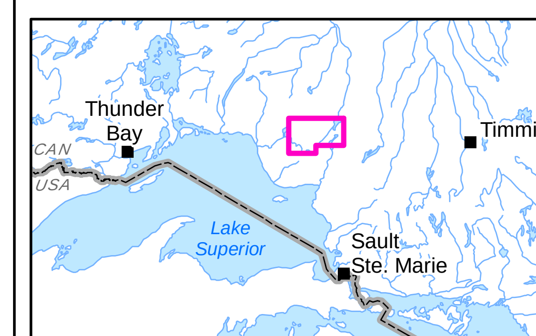
LEGEND

White River Municipal Boundary
Settlement
Waterbody
Bedrock Geology Contact
Mapped Fault
Mapped Dyke

Dyke (Length)	Fault (Length)
> 1 km	> 1 km
1 - 5	1 - 5
5 - 10	5 - 10
> 10 km	> 10 km

Bedrock Geology

13: Granite-granodiorite
12: Diorite-monzonite- granodiorite
10: Foliated tonalite suite
9: Gneissic tonalite suite
8: Gabbro
5: Metasedimentary rocks
4: Felsic volcanic rocks
3: Felsic and intermediate metavolcanic rocks
2: Mafic metavolcanic Rocks



REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001; M2668, 2003 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)

10 km

srk consulting

PROJECT
Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Analysis, White River Area, Ontario

TITLE
Lineament Distribution Relative to Lithological Units overlying bedrock geology for the White River Area

DESIGN	KR	23 APR 2013	Figure 14	REVISION 2
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	CN	24 Mar 2014		NAD 1983
REVIEW	CN	24 Mar 2014		1:300,000

File: SRK_NWMO_WR_Fig14_Orientation