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Phase 2 Geoscientific Preliminary Assessment, Lineament Interpretation

TOWN OF CREIGHTON, SASKATCHEWAN

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Phase 2 Geoscientific Preliminary Assessment,

Lineament Interpretation, The Town of Creighton, Saskatchewan

Report Prepared for

Nuclear Waste Management Organization

NUCLEAR WASTE MANAGEMENT ORGANIZATION   SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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Report Prepared by

srk consulting

Phase 2 Geoscientific Preliminary Assessment,

Lineament Interpretation, The Town of Creighton, Saskatchewan

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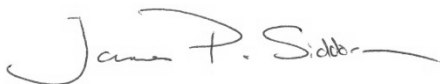**SRK Project Number: 3CN020.003**
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Executive Summary

This technical report documents the results of an updated surficial and geophysical lineament interpretation study conducted as part of the Phase 2 Geoscientific Preliminary Assessment, to further assess the suitability of the Creighton area to safely host a deep geological repository (Golder, 2015). This study followed the successful completion of a Phase 1 Geoscientific Desktop Preliminary Assessment (NWMO, 2013; Golder, 2013).

The purpose of the Phase 2 lineament interpretation was to provide an updated interpretation of the geological and structural characteristics of the bedrock units within the area identified in Phase 1 desktop assessment as warranting further studies such as high-resolution surveys and geological mapping. The assessment area considered for the lineament study includes the area covered by the newly acquired Phase 2 airborne surveys (Golder, 2015). The interpretation of lineaments was conducted using the new high-resolution airborne magnetic and topographic data, as well as high-resolution satellite data.

The lineament interpretation followed a systematic workflow involving three steps. The first step included an independent lineament interpretation by two separate interpreters for each data set and assignment of certainty level (low certainty, medium certainty, or high certainty). The second step involved the integration of interpreted lineaments for each individual data set and first determination of reproducibility. The third and final step involved the integration of lineament interpretations for the surficial data sets (topography and satellite) followed by integration of the combined surficial data set with the magnetic data set, with determination of coincidence in each integration step. Over the course of these three steps, a comprehensive list of attributes for each lineament was compiled. The four key lineament attributes and characteristics used in the assessment include certainty, length, density and orientation.

Geophysical lineaments were interpreted using the newly acquired high-resolution magnetic data (SGL 2015), which provides a significant improvement to the overall resolution and quality of magnetic data compared with the available data interpreted during the Phase 1 preliminary assessment. Lineaments interpreted using the magnetic data are typically less affected by the presence of overburden than surficial datasets, and more likely reflect potential structures at depth that may or may not have surficial expressions. The geophysical lineament density is variable throughout the Creighton Phase 2 assessment area. The highest density of geophysical lineaments is located in the eastern portion of the assessment area, and represents a zone where there is a high density of intersecting northwest and west-northwest–oriented lineaments, and a high density of lineaments defining a fold hinge within the Annabel Lake pluton. A lower lineament density zone can be observed in the western part of the assessment area. This zone is coincident with an area where fewer lineaments were present in the magnetic data. This may in part be due to a lower magnetic contrast within the core of the domal portion of the pluton, resulting in the interpretation of fewer lineaments. In addition, fewer northwest-trending lineaments were interpreted in this area.

Surficial lineaments were interpreted using the high-resolution topographic data (DEM) from the airborne surveys, and high-resolution satellite data with a cell resolution of 0.46 m. Surficial lineaments were interpreted as linear traces along topographic valleys, escarpments, and drainage patterns such as river streams and linear lakes. These linear traces may represent the expression of fractures on the ground surface. However, it is uncertain what proportion of surficial lineaments represent actual geological structures and if so, whether the structures extend to significant depth.

The observed distribution and density of surficial lineaments is highly influenced by the presence of overburden cover and water bodies, which can mask the surface expressions of potential fractures. The surficial lineament density is variable throughout the Creighton Phase 2 assessment area and is largely a reflection of the presence of large lakes and bedrock exposure (Figure 3). The highest density of lineaments is observed in the central eastern portion of the Phase 2 assessment area, where a cluster of northwest-oriented brittle lineaments intersect the west-northwest–oriented brittle-ductile structures. This zone represents an area of high bedrock exposure in the hinge of a folded portion of the Annabel Lake pluton. The high lineament density is a reflection of both the high bedrock exposure, and the pervasive brittle-ductile fabric forming the hinge zone of the fold. Lineament spacing in this area is relatively narrow due to the intersection of the two orientations of lineaments and the high degree of bedrock exposure.

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1   Introduction

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The interpretation of geophysical and surficial lineaments was conducted using newly acquired high-resolution airborne magnetic surveys (SGL, 2015). The interpretation of surficial lineaments was conducted using newly acquired topographic data (SGL, 2015) and high-resolution satellite imagery of the area (World View-2).

1.1   Scope of Work and Work Program

The scope of work for this study includes the completion of a structural lineament interpretation of remote sensing and geophysical data for the Creighton area in northeastern Saskatchewan (Figure 1).The lineament study involved the interpretation of remotely-sensed data sets, including surficial (satellite imagery, digital elevation) and geophysical (magnetic) data sets (SGL, 2015) for the Creighton area. The investigation interpreted lineament location and orientation in terms of their potential impact as bedrock structural features (e.g., individual fractures or fracture zones) and evaluated their relative timing relationships within the context of the local and regional geological setting. For the purpose of this report, a lineament was defined as, 'an extensive linear or arcuate geophysical or topographic feature'. The approach undertaken in this lineament investigation is based on the following:

- Lineaments were interpreted using newly acquired high-resolution magnetic and digital elevation data (SGL, 2015), and purchased high-resolution satellite imagery (WorldView-2);
- Lineament interpretations for each data set were made by two specialist interpreters using a standardized workflow;
- Lineaments were interpreted as having a brittle, brittle-ductile, or ductile character by each interpreter. No dykes were interpreted in the Creighton area;
- 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 interpreters; coincidence of lineaments extracted from different data sets; and comparison to literature; and
- Classification was applied to indicate the significance of lineaments based on certainty, length and reproducibility.

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

1.2   Assessment Area

The Creighton Phase 2 assessment area used for the lineament assessment and interpretation is a skewed rectangle of approximately 127 square kilometres (km^2) in area (Figure 1), and was provided by NWMO as a shape file. The approximate coordinates defining the boundaries of the Phase 2 assessment area in the Creighton area are listed in Table 1 (UTM NAD83, Zone 13N).

Table 1 : Bounding Coordinates of the Creighton Phase 2 assessment area shown in Figure 1 (UTM NAD83 Zone 13N)

X UTM	Y UTM
678,484	6,082,540
697,833	6,078,015
695,389	6,070,368
676,663	6,078,223

1.3   Qualifications of SRK and SRK Team

The SRK Group comprises 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 lineament interpretation and the compilation of this report were completed by Mr. Carl Nagy and Mr. Simon Craggs. Dr. James P. Siddorn, PGeo served as a technical advisor and reviewed lineament interpretations and drafts of this report prior to their delivery to the NWMO as per SRK internal quality management procedures.

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

Mr. Carl Nagy, MSc is a Consultant (Structural Geology) with SRK who specializes in regional bedrock mapping, structural analysis and 2D GIS compilations and interpretations. He has recently completed several regional to detailed scale lineament interpretations of remotely sensed data for projects across the Abitibi. He has also completed Phase 1 lineament interpretations for the Manitouwadge and White River areas for the NWMO. In this study, Mr. Nagy was the lead interpreter and the report author.

Mr. Simon Craggs, MSc is a Senior Consultant (Structural Geology) who specializes in regional mapping, detailed analysis of fracture/fluid flow mechanics, and the structural controls on epithermal ore deposit formation. Mr. Craggs has conducted several structural interpretations for vein-type precious metal deposits in poly-deformed terranes across Canada. He recently completed structural

Phase 1lineament interpretations for the Schreiber, Manitouwadge, and White River areas for the NWMO. In this study, Mr. Craggs was the second interpreter.

Dr. James Siddorn, PGeo is a Practice Leader (Structural Geology) and specialist in applied structural interpretation of geophysical data sets combined with the structural analysis of ore deposits. Dr. Siddorn has conducted numerous detailed interpretations of magnetic and electromagnetic data sets for gold and diamond exploration, and rock mechanics/hydrogeological engineering studies. He completed a structural lineament interpretation of the Ignace area for the NWMO. He oversaw the Phase 1 structural lineament interpretations for Schreiber and Ear Falls in 2012 and for White River and Manitouwadge in 2013 for NWMO. In this study, Dr. Siddorn was the senior reviewer.

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.

2   Summary of Geology

Details of the geology of the Creighton area were described in the Phase 1 Geoscientific Desktop
Preliminary Assessment (Golder, 2013). The following sections provide a brief description of the
geologic setting, bedrock geology, structural history and mapped structures, metamorphism and
quaternary geology, with a focus on the area identified during Phase 1 as being potentially suitable
(Annabel Lake pluton), its surrounding bedrock units and important structural features.

2.1   Geological Setting

The Creighton area is located with the Flin Flon-Glennie complex, directly north of the Phanerozoic
Western Canada Sedimentary Basin. The Flin Flon-Glennie complex is located within the Reindeer
zone in northern Saskatchewan, and represents a portion of the Paleoproterozoic Trans-Hudson
Orogen (Corrigan et al., 2007). The Western Canada Sedimentary Basin to the south of the
Creighton area dominates the southern portion of the province of Saskatchewan.

The Trans-Hudson Orogeny is one of the major orogenies that contributed to the assembly of the
Canadian Shield, and resulted from the closure of the Manikewan ocean and terminal collision of the
Rae-Hearne, Sask and Superior cratons from approximately 1.9 to 1.8 Ga (Ansdell, 2005; Corrigan
et al., 2005; Hajnal et al., 2005; Corrigan et al., 2007; Whitmeyer and Karlstrom, 2007; Corrigan et
al., 2009). The Trans-Hudson Orogen extends from South Dakota through Hudson Bay into
Greenland and Labrador. Within Canada, the Trans-Hudson Orogen is approximately 500 km wide
and is located between the Superior craton to the southeast and the Rae-Hearne craton to the north
and northwest (Ferguson et al., 1999; Corrigan et al., 2007).

The Reindeer zone represents a portion of the Trans-Hudson Orogen, and comprises a collage of
Paleoproterozoic arc and oceanic volcanic rocks, plutons, and younger molasse and turbiditic
sedimentary rocks (Corrigan et al., 2009; Morelli, 2009). Most of these rocks were formed in an
oceanic to transitional subduction-related arc setting. The Reindeer zone structurally overlies
approximately 3.2 to 2.4 Ga Archean metaplutonic and paragneissic rocks of the Sask craton, which
are exposed approximately 70 km to 80 km to the west of the Town of Creighton (Lucas et al., 1999;
Ashton et al., 2005).

The Flin Flon-Glennie complex is situated within the southeastern portion of the Reindeer zone in
Saskatchewan (Corrigan et al., 2009; Morelli, 2009), and can be divided into several lithotectonic
domains, including the Flin Flon domain. The Flin Flon domain is approximately 1.9 to 1.84 Ga and
contains a complex mixture of Paleoproterozoic volcano-plutonic rocks, representing arc, back arc,
ocean plateau and mid ocean ridge environments, and molasse-type sedimentary rocks (Ansdell and
Kyser, 1992; Corrigan et al., 2009; Morelli, 2009).

2.2   Bedrock Geology

The main geological units in the Creighton area include granitoid intrusions (Annabel Lake and
Reynard Lake plutons), supracrustal rocks of the Flin Flon greenstone belt, and metasedimentary
rocks of the Missi Group (Figure 2). A detailed description of these bedrock units can be found in
Byers and Dahlstrom (1954), Byers et al. (1965), Gendzwill (1968) and Simard et al. (2010) and is
summarized in the following subsections. The bedrock in the Creighton area is overprinted by

several orientations of brittle faults and the individual rock units have been subjected to varying amounts of metamorphism.

The Phase 2 assessment area is located within the Annabel Lake pluton, which is described in detail below. This area was identified as a general potentially suitable area in the Phase 1 Preliminary Assessment (Golder, 2013). Another general area in the south-central portion of the Reynard Lake pluton was identified as potentially suitable in the Phase 1 assessment, but was removed from further consideration as it was located on land classified as Crown Reserve (Canadian Forces Station Flin Flon). The following subsections also include a brief description of the Reynard Lake pluton, the Flin Flon greenstone belt and the Missi Group, which envelope the Annabel Lake pluton.

2.2.1 Intrusive Rocks

Annabel Lake Pluton

The Creighton Phase 2 assessment area is centered on the Annabel Lake pluton (Figure 2). This pluton is elongated parallel to the east-southeast to west-northwest oriented regional shear zones, and widens from approximately 2.5 km in the west to approximately 5 km towards the east. The pluton formed at approximately 1.86 Ga (Ansdell and Kyser, 1990), and comprises medium- to coarse-grained, foliated granodiorite with mineralogy of quartz, feldspar, biotite, and hornblende.

The magnetic response of the Annabel Lake pluton defines two distinct zones, an oval-shaped area to the west-northwest with a low homogenous magnetic response, and a higher and mixed magnetic responses area surrounding the oval shaped low magnetic zone and in the east-southeast of the pluton (Golder, 2013). No specific information is available regarding the compositional homogeneity of the pluton. However, the oval-shaped magnetically quiet area displays a distinct change in magnetic response towards the east (PGW, 2013). This change is coincident with the mapped change in bedrock units from granodiorite in the northwest to a biotite granodiorite along the eastern portion of the pluton (Byers, 1954; Byers et al., 1965). Given its proximity and similar geological history to the Reynard Lake pluton (Golder, 2013), the Annabel Lake pluton may be expected to have similar compositional zoning (see description of Reynard Lake pluton below and in Golder, 2013). Previous geophysical analyses yield a potassium-dominant radiometric response throughout the pluton, which is very similar to the northern two-thirds of the Reynard Lake pluton (PGW, 2013). The gravity response of the Annabel Lake pluton is generally low throughout most of the Creighton area. The Bouguer anomaly map reveals a >20 mGal negative anomaly across the pluton (PGW, 2013). This suggests that the Annabel Lake pluton may extend to depths in the range of 5 to 5.5 km (Hajnal et al., 1983).

Mineral foliations and lineations within the magnetically quiescent western portion of the pluton appear to define an elongated domal structure. The axial trace of this elongated dome runs through the centre of the pluton and plunges to the west-southwest, parallel to the long axis of the pluton (Byers and Dahlstrom, 1954). With the exception of the central portion of the pluton, foliations present within the pluton are approximately parallel to foliations within the adjacent metavolcanic rocks. Jointing is common at ground surface and occurs as defined sets common to both plutonic and surrounding metavolcanic rocks (Byers and Dahlstrom, 1954; Byers et al., 1965).

Reynard Lake Pluton

The northern extent of the Reynard Lake pluton straddles the southern boundary of the Phase 2 assessment area, covering only a minor portion of it (Figure 2). Additional information and references for the Reynard Lake pluton are provided in Golder (2013).

The Reynard Lake pluton is inferred to have intruded the Flin Flon greenstone belt during the Trans-Hudson Orogeny and has been dated at approximately 1.853 Ga (Ansdell and Kyser, 1990 and

1992). The pluton comprises a central core of coarse-grained porphyritic granodiorite, surrounded by a shell of discontinuous equigranular biotite granodiorite. Deep drilling indicates that the the pluton is composed of quartz diorite from 450 to 2,250 m and transitions to mafic quartz diorite at depths below this (Gendzwill, 1968; Davis and Tammemagi, 1982).

With the exception of the central portion of the pluton, foliations are prominent and generally parallel to the foliations present in adjacent metavolcanic rocks. Jointing is common at the surface and occurs as defined sets common to both plutonic and surrounding metavolcanic rocks (Byers and Dahlstrom, 1954; Byers et al., 1965).

2.2.2 Flin Flon Greenstone Belt

Within the Creighton Phase 2 assessment area, two linear elongate sequences of volcanic rocks of the Flin Flon greenstone belt trend west-northwest and bound the north and south contacts of the Annabel Lake pluton. The distribution of these volcanic rocks also straddles the Annabel Lake and West Arm shear zones (Figure 2).

The sequences of volcanic rocks within the Creighton area vary from felsic to mafic. The complete sequence of the Flin Flon greenstone belt comprises four tectonostratigraphic assemblages. These include juvenile oceanic arc (ca. 1.9 to 1.88 Ga), oceanic floor (ca. 1.9 Ga), oceanic plateau/ocean island (undated), and evolved arc (ca. 1.92 to 1.9 Ga). These rocks are the oldest in the Creighton area, and comprise volcanic flows, pyroclastic rocks, and lesser amounts of acidic to intermediate volcanic rocks and clastic rocks (Bailes and Syme, 1989; Syme et al., 1996; Lucas et al., 1999; Bailey and Gibson, 2004; Simard et al., 2010). Within this sequence, dykes, sills, and small intrusive porphyritic bodies are also present (Simard et al., 2010).

Rocks of the Flin Flon greenstone belt are heterogeneous and variable in type, and are arranged in layers of variable thickness and lithological compositions (Byers and Dahlstrom, 1954). Due to the complex structure (folding and faulting) within the Flin Flon greenstone belt, thickness of individual lithologies and stratigraphic interpretation within the assemblage can be difficult (NATMAP, 1998; Simard et al., 2010). It has been estimated that these rocks are approximately 4 to 6 km thick in the Creighton-Amisk Lake area (Byers and Dahlstrom, 1954; Byers et al., 1965). More recent estimates suggest they are in the order of 10 to 20 km thick (Lucas et al., 1994; Hajnal et al., 1996; White et al., 2005).

2.2.3 Metasedimentary Rocks of the Missi Group

Metasedimentary rocks of the Missi Group are present in the northern part of the Creighton Phase 2 assessment area (Figure 2). This sequence of metasedimentary rocks comprises dominantly sandstone, psammite, conglomerate, and metagreywacke, and trends west-northwest along the northern contact of the Annabel Lake pluton and the southern contact of the Annabel Lake shear zone.

Metasedimentary rocks of the Missi Group, including interlayered metamorphosed conglomerates, wackes and arkoses, unconformably overly the Flin Flon greenstone belt. The Missi Group represents a sequence of synorogenic fluvial molasse deposits (Byers et al., 1965; Davis and Tammemagi, 1982; Ansdell and Kyser, 1990; Simard et al., 2010). These rocks are interpreted to have been deposited during regional uplift in a collisional tectonic environment, and are approximately 1.847 to 1.842 Ga old (Fedorowich et al., 1993; Simard et al., 2010). The thickness of the rocks of the Missi Group is estimated to be approximately 1 to 2.75 km (Byers and Dahlstrom, 1954; Byers et al., 1965).

2.3   Metamorphism

Two stages of metamorphism are recorded in the Creighton area (Fedorowich et al., 1993). The earliest period of metamorphism appears to be related to the intrusion of the major felsic plutons in the area (including the Reynard Lake and Annabel Lake plutons), and consists of low metamorphic grade contact aureoles up to 1 km wide surrounding plutons (Byers et al., 1965; Fedorowich et al., 1993). Locally, a higher amphibolite grade halo has been noted around the Reynard Lake pluton (Ansdell and Kyser, 1990). This first period of metamorphism initiated during D_2 and likely continued throughout D_3 (as described in Section 2.4; Bailes and Syme, 1989).

The second stage of metamorphism is related to the collisional stage of the Trans-Hudson Orogen, and has been constrained between approximately 1.815 and 1.796 Ga (Corrigan et al., 2007). The resulting metamorphism varied from greenschist to amphibolite facies within the Creighton area (Parslow and Gaskarth, 1981; Ferguson et al., 1999). Locally, primary textures and structures are preserved (Simard and MacLachlan, 2009). This phase of metamorphism locally overprinted the earlier contact aureoles surrounding the plutons. Hydrothermal alteration within faults and shear zones in the Creighton area are also interpreted to have occurred during this period (Byers et al., 1965).

On a regional scale, metamorphic grade typically decreases from the north to the south. To the north of the Creighton area (approximately 10 km towards the Kisseynew metasedimentary gneissic belt), the metamorphic grade increases to upper amphibolite facies (Galley et al., 1991; Fedorowich et al., 1993). Within this higher grade area to the north, retrograde greenschist mineral assemblages are reported within younger faults (Byers et al., 1965). Further south, metamorphic grade decreases from mid-greenschist (biotite) in the Ross Lake and Flin Flon areas, to sub-greenschist (prehnite-pumpellite) in the White Lake area, which is approximately 8 km southeast of Town of Creighton (Bailes and Syme, 1989; Galley et al., 1991).

2.4   Structural History

The chronology of tectonic events that occurred during the Trans-Hudson Orogeny provides a framework for understanding the geological and structural history of the Creighton area. A summary of the important tectonic phases of the Trans-Hudson Orogeny is provided below (Table 2).

The summary in Table 2 is based primarily on the geological and structural history detailed in Fedorowich et al. (1995) but also includes information based on additional detailed work completed in the area (Cumming and Scott, 1976; Fedorowich et al., 1993; Stauffer and Lewry, 1993; Ansdell, 2005; Ansdell et al., 2005; Corrigan et al., 2005; Hajnal et al., 2005; Corrigan et al., 2007; Whitmeyer and Karlstrom, 2007; Corrigan et al., 2009).

The structural history of the Creighton area includes five main episodes of deformation (D_1 to D_5), and provides a relative temporal framework for the sequence of geological events described above. A later D_6 event is included herein to represent the protracted continuation of late brittle deformation until as recently as the Mesozoic Era.

D_1 deformation, attributed to north-south collision, is recognized by the development of vein arrays, thrust faulting and an early phase of folding within older sequences of volcanic rocks (ca. 1.906 to 1.886 Ga) within the Flin Flon greenstone belt, but well prior to deposition of the 1.847 to 1.842 Ga Missi Group. Kinematic and geochronological evidence constrain D_1 to have occurred between ca. 1.886 and 1.860 Ga.

Table 2: Summary of the Geological and Structural History of the Creighton Area (from Golder, 2013)

Time Period (Ga)	Geological Event
ca. 2.075	Passive margin phase associated with initiation of deposition of the Wollaston Supergroup on the eastern margin of the Hearne craton. Manikewan ocean opened at the east of Hearne craton.
1.906 to 1.886	A series of volcanic assemblages, including the La Ronge-Lynn Lake arc and a series of arc oceanic assemblages (including Amisk Group / Flin Flon greenstone belt), coexisted in the Manikewan ocean.
1.886 to 1.86	Closure of Manikewan ocean and accretion of various tectonic assemblages resulting in the formation of the Flin Flon-Glennie complex. Activation of earliest regional shear zones. [D_1]
1.86 to 1.834	Ongoing subduction and accretion during collision induced crustal thickening, thrust faulting, shear zone development, and on-going folding. [D_2] Deposition of the Missi Group between ca. 1.847 and 1.842 Ga. Emplacement of successor arc intrusions between ca. 1.86 and 1.834 Ga (including the Annabel and Reynard Lake plutons).
1.83 to 1.79	Terminal collision of Trans-Hudson Orogen and final closure of the Manikewan ocean under conditions of peak metamorphism. Transpressional deformation resulting in reactivation of regional shear zones, including Needle Falls shear zone and Tabbernor fault zone. [D_3]. Ductile shear zones form along the margins of the granitic intrusions.
1.79 to 1.76	Reactivation of regional shear zones as strike-slip fault zones and onset of retrograde metamorphic conditions. Development of northeast-trending regional folds (e.g., the Embury Lake Flexure) and reactivation of regional shear zones. [D_4]
1.725 to 1.691	Brittle faulting and brittle reactivation of regional-scale faults and shear zones. [D_5]
post-1.691	Reactivation of regional scale brittle faults; e.g., Tabbernor fault system. [D_6]

D_2 is characterized by continued movement along thrust faults and associated fold development and is considered to have been synchronous with the peak episode of crustal thickening. D_2 is constrained to have occurred between ca. 1.860 and 1.834 Ga and therefore was on-going during deposition of the Missi Group. The crustal thickening resulted in a period of syntectonic granitic activity that also continued until ca. 1.840 Ga.

D_3 produced folds and associated axial planar foliations, as well as a number of steeply dipping, north-trending sinistral-reverse oblique-slip shear zones, which likely coincided with peak metamorphic conditions. Regional relationships indicate that the D_3 event was associated with a post-thickening period of east-southeast to west-northwest–oriented transpression between ca. 1.83 and 1.79 Ga.

D_4 is characterized by the reactivation of strike-slip shear zones and the reactivation of some pre-existing faults under retrograde metamorphic conditions. D_4 deformation reoriented north-trending shear zones, under brittle- ductile conditions, into easterly trends. D_4 is constrained between ca. 1.79 and 1.76 Ga.

D_5 is characterized by late stage brittle oblique- and strike-slip movement under conditions of northwest to southeast compression between ca. 1.725 and 1.691 Ga. Resulting structures include near vertical to steeply east-dipping, north-northeast and north-northwest trending brittle faults characterized by sinistral strike-slip movement (Galley et al., 1991). A second series of resulting faults have northeast strikes and steep dips, and are characterized by dextral strike-slip movement (Galley et al., 1991). Protracted, post-1.691 Ga brittle reactivation of faults throughout the Creighton area is collectively attributed to a D_6 deformation event.

Mapped Structures and Named Faults

Several named and unnamed faults and shear zones have been mapped in the Creighton area, the most significant of which are discussed below.

The Annabel Lake shear zone dips sub-vertically to the north and strikes east along Annabel Lake and Annabel Creek on the north side of the Annabel Lake pluton (Figure 2; Byers and Dahlstrom, 1954; Simard et al., 2010). The Annabel Lake shear zone is marked by a zone of intense shearing and mylonitization (Byers et al., 1965; Parslow and Gaskarth, 1981). Sinistral strike-slip motion has been documented along this shear zone by Ashton et al. (2005); however the net slip is unknown.

The West Arm shear zone occurs between the Annabel Lake and Reynard Lake plutons, and strikes southeasterly through Wilson lake (Figure 2). The West Arm shear zone is also marked by a zone of intense shearing and mylonitization (Byers, 1962; Elliott, 1996).

The Annabel Lake and West Arm shear zones initially formed during D_2, and were likely reactivated during the peak metamorphic conditions contemporaneous with D_3 (Fedorowich et al.,1995).

Reorientation of north-trending shear zones during D_4 deformation produced the dominant map-scale fold structure in the Creighton area (Figure 2; Ansdell and Kyser, 1990; Fedorowich et al., 1993). Highly stretched cobbles of the Missi Group conglomerates are noted along the reactivated shear zones.

Numerous north-northwest trending fault splays associated with D_5 deformation extend through the greenstone belt rocks east of the Creighton Phase 2 assessment area (Byers, 1962). Similar structures extend beyond the Creighton area to the north as a complex system of interconnecting, branching and en-echelon faults displaying reverse dip-slip and strike-slip movement. These faults are also located to the east of the Annabel Lake pluton, near the Manitoba-Saskatchewan border. Towards the west, approaching the Annabel Lake pluton, several splays deflect towards the northwest. This is best observed north of Hamell Lake (adjacent to the east end of the Annabel Lake pluton) where a splay of the Ross Lake fault system bends into the Annabel Lake shear zone (Figure 2).

A second series of D_5 to D_6 faults in the Creighton area have northeast strikes and steep dips, and are characterized by dextral strike-slip movement (Galley et al., 1991). These faults have been documented in the area surrounding, but not within, the Creighton Phase 2 assessment area (Byers, 1962).

The Ross Lake fault system strikes north- to north-northwest through the area east of the Creighton Phase 2 assessment area (Figure 2), and spans a total length of over 100 km (Byers, 1962; Fedorowich et al., 1993). The Ross Lake fault system consists of several sets of inter-related faults that occur between Schist Lake to the south of the Creighton area (located within Manitoba), and Precipice Lake, to the north of the Creighton area (Byers, 1962). This fault system crosscuts the Embury Lake flexure and the Annabel Lake shear zone (Ansdell and Kyser, 1990; Fedorowich et al., 1993; NATMAP, 1998; Saskatchewan Industry and Resources, 2010) indicating a post-D_4 timing of development. Directly northeast of the Creighton area, approximately 1,250 m of sinistral-reverse oblique-slip has occurred along the Ross Lake fault system (Byers et al., 1965).

It is possible that the faults directly northeast the Creighton Phase 2 assessment area interpreted to be a part of the Ross Lake fault system are in fact related to the much larger Tabbernor fault system (Byers, 1962). The Tabbernor fault is a deep rooted, splayed fault system that extends from the Northwest Territories to the states of North and South Dakota (Giroux, 1995). In Saskatchewan, the fault has a northerly strike and displays sinistral strike-slip movement.

2.5   Quaternary Geology

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

Quaternary deposits in the Creighton area originated from the Wisconsinan glaciations and comprise glaciolacustrine and glaciofluvial sediments, till, and organic plains, with generally thin and discontinuous drift cover (Figure 3). Where glacial deposits cover topographic highs in the bedrock surface, sediments are generally thin (veneer like) and less than one metre thick (Davis and Tammemagi, 1982; Hajnal et al., 1983; Schreiner, 1984; Henderson and Campbell, 1992; Henderson, 2002). Thicker overburden deposits tend to occur in low-lying areas.

Glaciofluvial and glaciolacustrine deposits comprise the most prominent surficial sediments in the Creighton area. They are primarily ice proximal and near shore sediments of well sorted, horizontally bedded sand and gravel, as well as deep water deposits of massive to bedded fine sand, silt and clay (Henderson and Campbell, 1992).

The Quaternary deposits within the Creighton area also include two till units (Henderson and Campbell, 1992). A lower till unit comprises grayish brown sandy and silty material, which was deposited subglacially. This lower till underlies glaciolacustrine deposits. The upper till unit overlies glaciolacustrine sediments as a thin veneer in places throughout the Creighton area.

Annabel Lake pluton

Approximately 32% of the Annabel Lake pluton has been mapped as exposed bedrock, and 28% has been mapped as having a thin (<1 m) till or glaciolacustrine veneer. Exposed bedrock dominates the eastern half of the Annabel Lake pluton, over the wider portion of the pluton located near Creighton Lake (Figure 3). Within this area of exposed bedrock, patches of peat bog, fens, swamp, or marsh fill low lying areas with poor drainage. Further west, a band of thin till veneer, typically less than 1 m thick, covers the central portion of the pluton. Patches of organics, glaciolacustrine silts, and clays are associated with this band of till. Bedrock exposure improves toward the west, centred on the pluton's wider lobe in the west (Campbell and Henderson, 1997).

Thicker overburden deposits are mapped within the valleys associated with the shear zones on the north and south sides of the pluton (Campbell and Henderson, 1997). These deposits include till, silt, clay, and organic deposits. A similar narrow band of sand and gravel occurs to the northeast of the pluton near Hamell Lake (Figure 3). These deposits extend west toward Annabel Lake and may be related to a relatively large glaciofluvial deposit to the north of Annabel Lake.

3   Methodology

The structural lineament interpretation of the Creighton area was based on high-resolution remote sensing data sets, including a high-resolution airborne magnetic survey contracted by the NWMO to Sander Geophysics Limited (SGL, 2015), topographic data collected during the airborne magnetic survey (SGL, 2015), and high-resolution World View-2 satellite imagery procured from Digital Globe.

3.1   Source Data Description

All data were assessed for quality, processed, and reviewed before use in the lineament interpretation. The geophysical data were used to evaluate deeper bedrock structures and proved invaluable to identifying potential bedrock structures beneath areas of surficial cover and aiding in establishing the age relationships among the different lineament sets. Topography (DEM) and satellite imagery (World View-2) data sets were used to identify surficial lineaments expressed in the topography, drainage, and vegetation. Throughout this study, the best resolution data available was used for the lineament interpretation.

3.1.1   High-resolution Magnetic Data

Sander Geophysics Limited (SGL) completed a fixed-wing high-resolution airborne magnetic survey in the Creighton area May 4-16, 2014 (SGL, 2015; Figure 4).

The airborne survey in the Creighton area included a total of 2,402 km of flight lines covering a surface area of approximately 150 km^2. Flight operations were conducted out of the Flin Flon Airport, in Flin Flon, Manitoba, using a Britten-Norman Islander Aircraft. Data were acquired along traverse lines flown in a north-south direction spaced at 100 m, and control lines flown east-west spaced at 500 m. The survey was flown at a target altitude of 80 m above ground level, with an average ground speed of 100 knots (approximately 185 km/h). The survey acquisition parameters are listed below:

- Traverse line spacing of 100 m
- Traverse line azimuth of 000 - 180°
- Control line spacing of 500 m
- Control line azimuth of 090 - 270°
- Grid cell size of 25 m
- Targeted sensor height of 80 m
- Acquisition date of May 4 to May 16, 2014

Acquired data was processed by the Sander Geophysics Limited (SGL, 2015) and provided to SRK as GRD files. The following products of the high resolution airborne magnetic survey were available for this structural lineament interpretation:

- Total magnetic intensity
- First vertical derivative of the total magnetic intensity
- Second vertical derivative of the total magnetic intensity
- Reduction to the pole of the total magnetic intensity
- First vertical derivative of the reduction to the pole of the total magnetic intensity
- Second vertical derivative of the reduction to the pole of the total magnetic intensity

- Tilt derivative of the reduction to the pole of the total magnetic intensity
- Analytic signal of the total magnetic intensity
- Total horizontal derivative of total magnetic intensity
- Total horizontal derivative of reduction to the pole of the total magnetic intensity
- Total magnetic intensity with high-pass Butterworth filter applied
- Total magnetic intensity with low-pass Butterworth filter applied
- Reduction to pole of total magnetic intensity with high-pass Butterworth filter applied
- Reduction to pole of total magnetic intensity with low-pass Butterworth filter applied

The first and second vertical derivatives, and tilt derivative grids were converted to ERS images that had data ranges, shading, and colour ranges enhanced in ERMapper to outline the structures present. A series of compressed raster images was created in ERMapper for use in ArcGIS.

3.1.2 Digital Elevation Model

Topographic data was collected during the magnetic survey conducted by Sander Geophysics Limited (SGL, 2015). The survey acquisition parameters are identical to those described for the high-resolution magnetic data in Section 3.1.1.

Topographic data was processed by Sander Geophysics Limited and provided to SRK as GRD files. The data grid was then converted to an ERS image, and the data ranges, shading (including hill shade and shaded relief), and colour ranges of the digital elevation model (DEM) were enhanced in ERMapper to highlight the structures present (Figure 5). Compressed raster images were created in ERMapper to be brought into ArcGIS.

3.1.3 High-resolution Satellite Imagery

High-resolution World View-2 satellite imagery was procured by SRK on behalf of NWMO from Digital Globe Incorporated via ESRI Canada.

Imagery was collected by the World View-2 GeoEye sensor. The spectral ranges and spatial resolution of each band are listed in Table 3. World View-2 also collects 4 additional visible and near infrared bands not used in the construction of imagery for the Creighton area, and not listed below.

Table 3: Spectral Ranges and Spatial Resolution for the Primary World View-2 Visible Bands

Band	Range (nm)	Resolution (m)
Panchromatic	450 – 800	0.46
Blue	450 – 510	1.80
Green	510 – 580	1.80
Red	655 – 690	1.80

A natural colour composite of the World View-2 satellite imagery was provided as a georeferenced TIFF file from ESRI Canada / Digital Globe Incorporated, and utilized in this format for the lineament interpretations (Figure 6).

3.2   Lineament Interpretation Workflow

A structural lineament study of the Creighton area was conducted to identify the location and orientation of potential individual fractures or fracture zones and to evaluate their relative timing relationships within the context of the local and regional geological setting.

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 high-resolution airborne geophysical (magnetic) and high-resolution surficial (DEM and World View-2 satellite imagery) data sets described above. The interpretation guidelines involved three steps:

- Step 1: Independent lineament interpretation by two individual interpreters for each data set and assignment of certainty level (1, 2, or 3 representing low, medium and high certainty);
- Step 2: Integration of lineament interpretations for each individual data set and first determination of reproducibility; and
- Step 3: Integration of lineament interpretations for the surficial data sets (DEM and satellite imagery) followed by integration of the combined surficial data set with the geophysical data set, with determination of coincidence in each integration step.

Each identified lineament feature was classified in an attribute table in ArcGIS. The description of the attribute fields used is included in Table 4. Fields 1 to 9 are populated during Step 1. Fields 10 and 11 are populated during Step 2. Fields 12 to 20 are populated during Step 3.

The interpreted features were classified into two general categories based on a working knowledge of the structural history and bedrock geology of the Creighton area. These categories include ductile and brittle 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. See Figure A1 for example.
- **Brittle lineaments:** Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets) 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. Brittle lineaments are commonly characterized by continuous magnetic lows, offsets of magnetic highs and ductile lineaments (as described above), and breaks in topography and vegetation. At the desktop stage of the investigation, this category also includes features of unknown affinity. See Figure A2 for example.

Dykes are not a significant geological feature in the Creighton area, and were therefore not included in the classification of lineaments. A detailed description of the three workflow steps, as well as the way each associated attribute field is populated for each interpreted lineament is provided below.

Table 4: 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, DEM, 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 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 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 D. Other (if other, define in comments)
5	Name	Name of feature (if known)
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 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 (in metres)
11	RA_1	Feature value (1 or 2) based on reproducibility assessment
12	Buffer_RA_2	Buffer zone width for coincidence assessment (in metres)
13	RA_2	Feature value (1, 2 or 3) based on coincidence assessment
14	MAG	Feature identified in geophysical data set (Yes or No)
15	DEM	Feature identified in DEM data set (Yes or No)
16	SAT	Feature identified in satellite imagery data set (Yes or No)
17	F_Width	Final interpretation of the width of feature
18	Rel_age	Interpretation of relative age of feature, in accord with regional structural history
19	Comment	Comment field for additional relevant information on a feature
20	Object	Geological element identified, e.g., dyke, fault, joint, contact

*   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 judgment 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. Step 1 of

the structural lineament analysis is conducted up to a scale of 1:25,000 and follows a designated workflow.

The interpretation of magnetic data follows a two-step process. The first step involves the drawing of ductile lineaments (Figure 7), interpreted as tectono-stratigraphic form lines, using high-resolution first vertical derivative magnetic data. Additionally, the tilt angle grid was used for enhancement of areas of low magnetic contrast. The form lines trace the geometry of magnetic high lineaments and may represent the geometry of stratigraphy within metavolcanic and metasedimentary rocks or the internal fabric (foliation) within granitoid batholiths and gneissic rocks. Magnetic highs associated with dykes (i.e. linear crosscutting magnetic highs in orientations identified in the literature as dyke orientations) are not included in this process. This process highlights discontinuities between form lines, particularly in stratigraphic form lines (e.g., form lines intersecting) that represent structures (faults, folds), unconformities, or intrusive contacts. The process of drawing form lines is instrumental in highlighting lineaments in the magnetic data.

The second step involves drawing a structural base layer that represents all interpreted lineaments regardless of interpreted age, type (e.g., ductile, brittle or dyke), or kinematics. Evidence for interpreted fractures can be derived from several sources in the magnetic data, including discontinuities between form lines, offset of magnetic units, or the presence of linear magnetic lows or highs. The first vertical derivative magnetic data is used mainly with the tilt angle grid to further enhance this interpretation.

The lineament interpretation of topographic data involved tracing linear or curvi-linear features along topographic valleys, slope walls and any other structurally related features that are visible in a colour mosaic constructed from the digital elevation model (DEM) derived from the airborne geophysical survey data. Similarly, the lineament interpretation of satellite imagery involved tracing linear or curvilinear features along visible shore lines, changes in colour intensity or texture (e.g., vegetation), linear rivers and streams, and along linear chains of features associated with lakes that are visible in WorldView-2 satellite imagery.

Lineaments from each of the data sets were assigned attributes by each interpreter to characterize what type of feature the lineament was drawn along, the interpreters certainty that the lineament represents a bedrock structure, and the general width of the topographic feature.

Lineaments identified in the DEM and/or in the satellite imagery that were interpreted to be due to glacial transport were excluded from the lineament interpretation data set. The following criteria were utilized to decide whether a DEM or satellite imagery lineament should be excluded:

- The lineament coincides with a mapped ice-flow feature, moraine, or esker
- The lineament is parallel to known eskers or moraines and is marked by narrow, curving ridges
- The lineament is parallel to the local ice flow direction and is accompanies by drumlin-shaped hills in the topographic data set
- The lineament in the satellite imagery is parallel to the local ice flow direction and coincides with a lineament from the topography interpreted that has been identified as glacial
- The lineament was considered to be representative of a magmatic foliation, and not of tectonic origin

The Step 1 lineament analysis resulted in the generation of one interpretation for each data set (e.g., magnetic, DEM, satellite imagery) for each interpreter, resulting in a total of six individual GIS layer-based interpretations. Within these data sets, cross-cutting relationships between individual lineaments were assessed. Following this assessment, based on the expert judgement of each

interpreter, lineament segments were merged, resulting in lineament lengths that correspond to the sum of all parts. During Step 1, identified lineaments were attributed with fields one to nine as listed in Table 4.

3.2.2 Step 2: Lineament Reproducibility Assessment 1 (RA_1)

During Step 2, individual lineament interpretations produced by each interpreter were compared for each data set. This included a reproducibility assessment based on the coincidence, or lack thereof, of interpreted lineaments within a data set-specific buffer zone. The two individual lineament interpretations for each data set were then integrated and a single interpretation was generated for each data set (Figures 8 to 10). A discussion of the parameters used during this step follows.

Buffer Size Selection

Buffer sizes for lineaments in each data set were based on the magnetic grid resolution. 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 provided a balanced result for assessing reproducibility.

A buffer of 125 m (either side of the lineament) was generated for the magnetic data. This value is equivalent to five times the data set grid cell resolution (25 m) of the high resolution magnetic data. Given that the DEM data was extracted from the same survey, the same buffer size was applied to the DEM data.

A 125 m buffer was applied to the satellite imagery data in order to be consistent with the magnetic and DEM buffer size.

The buffer size widths were included in the attribute fields of each interpretation file (Table 4). 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.

Reproducibility Assessment

The generation of an integrated lineament interpretation for each data set, including the reproducibility assessment, followed a three-step process:

- Lineament buffers generated for the Step 1 interpretation were overlain on top of the buffers generated for the lead Step 1 interpretation for each data set. The lead interpretation Step 1 lineaments were then overlain on top of these buffers, and all lineaments that occurred within overlapping buffers were carried forward and copied into a new file for Step 2. These lineaments were attributed with a reproducibility value (RA_1; Table 4) of two in the Step 2 attribute table.
- The remaining lineaments in the lead 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. Where it was determined by the two interpreters that these features were not representative of potential bedrock structure, they were removed from the data set.
- Finally, the lineament interpretation of the second Step 1 interpretation was overlain on top of the Step 2 integrated file, and all remaining lineaments in 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. All remaining lineaments that were attributed a certainty value of one were removed, if it was determined by the two lineament interpreters that these features were not representative of potential lineaments.

As specified above, 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 followed analysis of the specified lineament with the available imagery and a discussion between the two interpreters. 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, the lineament was carried forward to the Step 2 interpretation with a RA_1 value of two.
- 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 cut, and each portion was attributed with RA_1 values accordingly.

The resulting Step 2 interpretations for each data set (e.g., 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 (RA_2)

During Step 3, the integrated lineament interpretations for each data set were amalgamated into one final interpretation. First, lineaments derived from the DEM and satellite data were merged to produce an integrated surficial lineament data set. Subsequently, the geophysical lineaments were integrated with the integrated surficial lineaments to produce a final amalgamated interpretation. A discussion of the parameters used during this step follows below.

Surficial Integration
The WorldView-2 satellite data have a resolution of 46 centimetres (cm) whilst the DEM data has a resolution of approximately 25 m. Furthermore, the orientation of minor and intermediate topographic features as identified in the DEM can be ambiguous due to the resolution of the data, while these features could be drawn with high confidence from the WorldView-2 satellite data. Therefore, lineaments derived from the satellite data were used as the lead data set, and lineaments drawn from DEM data were used as the secondary data set.

A buffer of 125 m (five times the resolution of the DEM) was generated around the DEM lineaments and the satellite lineaments were overlain on top of this buffer. Similar to the procedure in RA_1, all lineaments that occurred within overlapping buffers were carried forward and copied into a new file. These lineaments were attributed with a RA_2 reproducibility value of two (RA_2; Table 4). The remaining satellite and DEM lineaments 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. These lineaments were attributed a RA_2 value of one in the attribute table (RA_2: Table 4).

Final Integration

The geophysical data supplies important information about structures in the subsurface. Therefore, for this step of the interpretation, the lineaments derived from geophysical data were given precedence over lineaments derived from surficial data, since the latter only provide information about the surface expression of structures.

On this premise, all lineaments derived from the magnetic data were included in the final interpretation. A buffer of 125 m (five times the resolution of the geophysical data and DEM) was generated around the integrated surficial lineaments, and the geophysical lineaments were overlain on top of this buffer. This buffer size was included as an attribute field for all interpreted lineaments (Buffer RA_2; Table 4). 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. This resulted in a combined interpretation with lineaments derived from the magnetic and surficial data sets.

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

- If any coincidence of lineaments occurred between two lineament data sets, the longest lineament was carried forward 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 topographic or satellite imagery data was longer than a coincident lineament derived from geophysical 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 coincidence.
- A lineament derived from topographic and (or) satellite imagery data that would fall within the buffer of a lineament derived from geophysical 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 m) discontinuous topographic and satellite imagery data lineaments that are at low angles to geophysical data lineaments but extending outside the geophysical lineament buffer were considered to be coincident.
- Short (less than 500 m) topographic and satellite imagery data lineaments that are at high angles to geophysical data lineaments, largely overlapped with the buffer zone from the geophysical 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 fault lineament in the final interpretation based on identification in the geophysical data.

During this process, each lineament was attributed with a text field highlighting in which data sets it was identified. The final reproducibility value (RA_2; Table 4) was then calculated as the sum of the number of data sets in which each lineament was identified. (i.e., a value of 1 to 3).

The resulting lineament 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 known structural history of the Creighton region. This included defining the age relationships of the interpreted lineaments on the basis of crosscutting relationships between different generations of fault lineaments and populating the relative age

attribute field for each lineament (Rel_Age; Table 4) This incorporated a working knowledge of the structural history of the Creighton area, combined with an understanding of the fault characteristics in each lineament population (e.g., brittle versus ductile). The structural history of the area is described in Section 2.4, based on the existing literature.

The interpreted crosscutting and age relationships between different families of lineaments and within individual families of lineaments were refined using the available data. Crosscutting relationships were evaluated based on the through-going nature and termination of lineaments and evaluated against the regional structural history as described in Section 2.4.

3.2.4 Lineament Length

Lineament lengths were calculated using a simple geometrical calculation of the total length of the polyline in ArcGIS.

The length distribution of the various integrated data sets was analyzed through a comparison of summary statistics, frequency histograms, log-log plots and boxplots. Histograms and summary statistics were computed using Microsoft Excel's Data Analysis add-in. Histogram bins were computed using arbitrary 500 m bins.

There is no information available on the depth extent into the bedrock of the lineaments interpreted for the Creighton area. In the absence of available information, the interpreted length can be used as a proxy for the depth extent of the identified structures. However, this is highly dependent on the style and structural history of a given fault. A preliminary assumption may be that the longer interpreted lineaments in the Creighton area may extend to greater depths than the shorter interpreted lineaments.

3.2.5 Lineament Trends

An analysis of lineament trends is an essential part of the structural lineament interpretation, as it allows the interpreter to identify different sets of structures and to relate those sets to the known structural history of the area. Lineament orientations were assessed for each data set within the Creighton area, to determine the dominant lineament trends, and potential conjugate sets.

Lineament orientations (azimuth) were calculated using 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.

Rose diagrams are circular or semi-circular histograms that depict orientation (azimuthal) data and frequency for each data bin. The histogram peaks show the frequency of occurrence of lineament orientations within each bin. Rose diagrams were produced in Spheristat, with frequencies divided into 5° bins in order to avoid oversimplification of the lineament orientations. Lineament lengths are also used as a weight factor for computing rose diagrams that display the lineament trends.

3.2.6 Lineament Density

Analyses of lineament density were conducted for the Creighton Phase 2 assessment area. The lineament density analysis was conducted using the ArcGIS Analysis and Spatial Analyst toolsets, and included creating lineament density plots, lineament intersection points, and conducting an intersection point density analysis for the magnetic, surficial, and final integrated lineament data sets.

Lineament line density of all interpreted lineaments in the Creighton area was determined by examining the statistical density of individual lineaments using ArcGIS Spatial Analyst. A grid cell size of 50 m and a search radius of 1.25 km (equivalent to half the size of the longest boundary of the minimum area size of a potential siting area) were used. The spatial analysis used a circular search radius examining the lengths of polylines intersected within the circular search radius around each grid cell.

Lineament intersections were calculated using the ArcGIS Analysis Tools Intersect function. To improve visualization of the lineament intersection points, SRK gridded their density using the ArcGIS Spatial Analyst function. Spatial Analyst calculates point density conceptually by defining a neighbourhood around each raster cell centre, and the number of points that fall within the neighbourhood is totalled and divided by the area of the neighbourhood. A grid cell size of 50 m and a search radius of 1.25 km (equivalent to half the size of the longest boundary of the minimum area size of a potential siting area) were used.

4   Lineament Interpretation Results

The following sections describe the results of the lineament interpretation for the Creighton area based on analysis of the geophysical and surficial (DEM, Satellite) data sets. This includes discussion of the RA_1 assessment of reproducibility. In addition, the RA_2 results are discussed for the integration of the two surficial data sets and for the final integration of the geophysical data set with the surficial data sets.

4.1   Geophysical Lineaments

An interpretation of magnetic data allows for the distinction between ductile and brittle lineaments. Ductile lineaments traced from the magnetic data set are shown on Figures A1 and 7, and are interpreted as traces of the geometry of stratigraphy within the greenstone belts or the internal fabric (foliation) within plutonic and gneissic rocks. Discontinuities between ductile lineaments highlight structures (potential fractures, and fold structures), unconformities, or intrusive contacts. Therefore, they constitute an essential data component that should be used along with the first vertical derivative of the magnetic data for interpreting brittle lineaments. Ductile lineaments are included in this report to provide context to the lineament interpretation, but they were not included in the statistical analyses of the lineament data sets.

Within the Creighton Phase 2 assessment area, a total of 304 geophysical lineaments were interpreted. These data comprise lineaments that were identified and merged by the two interpreters based on interpretation from the geophysical data (Figure 8). The length of all geophysical lineaments ranges from 0.18 to 21.02 km, with a median of 1.57 km and a mean of 2.58 km. All geophysical lineaments were characterized by discrete linear magnetic lows and interpreted as brittle lineaments. No dyke lineaments were interpreted. Figure A2 shows an example of a series of northwest and west-northwest trending brittle lineaments defined by linear magnetic lows and breaks and offsets of linear magnetic highs. Azimuth data weighted by length for the interpreted geophysical lineaments display two lineament sets with one frequent orientation trending west-northwest (270-300°) and a second frequent orientation trending northwest (315-320°). The west-northwest orientation exhibits a moderately diffuse pattern, while the northwest orientation is more tightly constrained (see rose diagram inset in Figure 8).

Of the total geophysical lineaments, the reproducibility assessment identified coincidence for 117 lineaments (38%; RA_1 = 2) and a lack of coincidence for 187 lineaments (62%; RA_1 = 1). Of the 304 lineaments interpreted, 85 (28%) were assigned the highest level of certainty (three), while 153 (50%) were assigned certainty values of two, and 66 (22%) were assigned certainty values of one.

Northwest-trending lineaments crosscut west-northwest trending lineaments and locally display a sinistral strike-separation. Total strike-separation amounts along northwest lineaments are minor when present. An example of this sinistral strike-separation can be seen along the northwest-trending lineament located at approximately 678000E, 6078385N (coordinates in NAD83, UTM zone 13N; Figure 8). In many instances, northwest-trending lineaments cause breaks in west-northwest oriented magnetic fabrics but do not show a clear offset.

4.2   Surficial Lineaments

Surficial lineaments include lineaments interpreted from the DEM topography and satellite imagery data sets, and are each shown on Figures 9 and 10, respectively. An overview of the lineament interpretation based on these surface-based data sets is provided below.

4.2.1   DEM Lineaments

A total of 809 lineaments were identified by the two interpreters from the DEM topography data (Figure 9). The length of all lineaments ranges from 0.14 to 9.58 km, with a median of 0.77 km and a mean of 1.11 km. Of the 809 interpreted lineaments, 108 (13%) were assigned the highest level of certainty (three), while 233 (29%) were assigned certainty values of two, and 468 (58%) were assigned certainty values of one. The reproducibility assessment identified coincidence for 278 (34%; RA_1 = 2) and a lack of coincidence for 531 (66%; RA_1 = 1) of the total DEM lineaments. Azimuth data weighted by length for the interpreted DEM lineaments exhibit two prominent orientations, including a northwest trend (290-310°), and an east-west trend (270-280° and 90-95°). Both lineament orientations exhibit moderately diffuse patterns. Minor north (355-360°) and east-northeast trends (55-65°) are also observed (see rose diagram inset in Figure 9).

4.2.2   Satellite Imagery Lineaments

A total of 1,069 lineaments were identified by the two interpreters from the satellite data (Figure 10). The length of all lineaments ranges from 0.07 to 10.99 km, with a median of 0.71 km and a mean of 0.97 km. Of the 1,069 interpreted lineaments, 365 (34%) were assigned the highest level of certainty (three), while 417 (39%) were assigned certainty values of two, and 287 (27%) were assigned certainty values of one. The reproducibility assessment identified coincidence for 344 (32%; RA_1 = 2) and a lack of coincidence for 725 (68%; RA_1 = 1) of the total satellite imagery lineaments. Azimuth data weighted by length for the interpreted satellite imagery lineaments exhibit a prominent broad west-northwest to northwest orientation (280-315°). Additional moderate east-west (270-280° and 85-90°) and north-northwest orientations (325-340°), and minor north (355-360°) and northeast orientations (poorly defined between 20-85°) can also be observed (see rose diagram inset in Figure 10).

4.3   Integrated Surficial Lineaments (RA_2)

The lineaments interpreted based on DEM and satellite imagery data were integrated to form the surficial lineament data set. The integration resulted in a total of 1,564 surficial lineaments (Figure 11), including 319 lineaments interpreted with coincidence between both the DEM and satellite imagery data, 506 lineaments interpreted only from the DEM data, and 739 lineaments interpreted only from the satellite imagery data.

The merging of lineaments interpreted based on DEM and satellite imagery resulted in lineaments of new lengths, either shorter or longer, due to merging of original lineaments. Overall, lineaments interpreted from the satellite data are roughly equivalent in length to those interpreted from the DEM data. The length of all integrated surficial lineaments ranges from 0.08 to 12.19 km, with a median of 0.64 km and a mean of 1.03 km.

Of the 1,564 lineaments, 435 (28%) were assigned the highest level of certainty (three), while 581 (37%) were assigned certainty values of two, and 548 (35%) were assigned certainty values of one. The coincidence assessment (RA_2) identified coincidence for 319 (20%) lineaments and a lack of coincidence for 1,245 (80%) of the total integrated surficial lineaments. Azimuth data weighted by

length for the interpreted surficial lineaments exhibit two dominant orientations, including a northwest trend (280-315°), and an east-west trend (270-275° and 70-90°). Both lineament orientations exhibit moderately diffuse patterns. Three subtle and minor additional north-northwest (325-340°), north (355-360°), and northeast (30-60°) trends are also observed (see rose diagram inset in Figure 11).

4.4   Integrated Final Lineaments (RA_2)

The integrated lineament data set, classified based on certainty and produced by merging all lineaments interpreted from the surficial (DEM and satellite imagery, Figure 11) and geophysical (Figure 12) data is presented on Figure 13.

The integrated lineament data set contains a total of 1,490 lineaments (all brittle lineaments) that range in length from 0.08 to 19.64 km. The median length of these lineaments is 0.69 km and the mean length is 1.26 km. Of all integrated lineaments, 51 lineaments are greater than 5 km in length (3%), 115 lineaments are between 2.5 and 5 km in length (8%), 366 lineaments are between 1 and 2.5 km in length (25%), and 958 lineaments are less than 1 km in length (64%).

Of the 1,490 lineaments integrated from all data sets, 401 (27%) were assigned the highest level of certainty (three), while 519 (35%) were assigned certainty values of two, and 570 (38%) were assigned certainty values of one. The reproducibility assessment identified coincidence in all three data sets (RA_2 = 3) for 130 (9%) lineaments, and 403 (27%) lineaments were coincident with a lineament from one other data set (RA_2 = 2). A total of 957 (64%) lineaments were not coincident with any other data set (RA_2 = 1).

Azimuth data, weighted by length, for the merged lineament data set exhibit a dominant broad orientation ranging from west to northwest (260-320°). An additional minor north trend (350-005°) is also observed (Figure 13 inset). The broad diffuse west to northwest pattern likely contains multiple lineament generations with variable orientations. When examined together on a single rose diagram, these lineament generations form a single diffuse pattern.

5   Discussion

Lineament reproducibility, lineament trend, lineament length and the density of lineaments and their intersections are discussed below. In addition, the integration of the final lineament data set into the regional structural history and the relative age of lineament sets in the Creighton area are discussed.

5.1   Lineament Reproducibility (RA_1) and Coincidence (RA_2)

Lineament reproducibility and coincidence are assessed in several steps during the analysis. First, the two individual interpretations for each data set are integrated to produce single data set specific (RA_1) interpretations. Secondly, the individual data set interpretations are then integrated to produce the final RA_2 data set. Reproducibility and coincidence values are presented in detail in Section 4.

The RA_1 data presented in Section 4 indicate a moderate to low reproducibility between interpreters for all three data sets, with the geophysical lineaments being slightly more reproducible (38%) than the DEM lineaments (34%) and satellite lineaments (32%). Importantly, longer lineaments with higher certainty values were identified more often by both interpreters in all three data sets. Differences in the individual lineament interpretations from each interpreter for the same data set can be attributed to the judgement and subjectivity of the expert carrying out the interpretation.

Coincidence between features identified in the various data sets was evaluated for the coincidence assessment (RA_2). Reproducibility values determined by coincidence between data sets (RA_2) may provide a measure of the confidence in the interpretation and may also highlight significance bedrock structures expressed in these different data sets.

As discussed in Section 4.3, only 20% of the total surficial lineaments were coincident between the DEM and satellite imagery data. The lack of coincidence between the two surficial data sets can be attributed to structures observed in the DEM data that are obscured by vegetation and other surficial elements in the satellite 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.

Overall, coincidence between surficial and magnetic lineaments is generally low. This may be due to various factors such as deep structures that are identified in the magnetic data may not have a surface expression; surficial features may not extend to great depth; certain structural features identified in the surficial data may not possess sufficient magnetic susceptibility contrast to be recognized in the magnetic data; and surface expressions of magnetic lineaments may be masked by the presence of overburden or large water bodies (e.g. Annabel Lake in the northwest of the Creighton Phase 2 assessment area). Therefore, 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 structural feature.

Examining reproducibility values indicate that the most reproducible lineaments are typically long lineaments, occasionally extending throughout the entire Phase 2 assessment area, and typically oriented east-west to west-northwest, and northwest. In the magnetic data, these lineaments are typically characterized by continuous magnetic lows, or by multiple breaks in the magnetic grain

defining a continuous lineament. In surficial data, these lineaments are typically characterized by a combination of continuous sharp breaks in topography, vegetation and bedrock, and elongated lakes.

5.2   Lineament Trends

Length weighted lineament trends within the Creighton Phase 2 assessment area provide a strong indication of structures sets with preferred azimuths. An analysis of lineament orientations reveal an overall consistency between the orientations of lineaments identified in the various different data sets, which suggests that lineaments interpreted from all three data sets are identifying the same sets of structures. In some cases, there are differences observed between the lineament trends identified in each of the data sets. Figure A3 summarizes the orientation of lineaments for all data sets.

Lineament trends observed in the geophysical data set tend to exhibit two dominant orientations trending west to west-northwest and northwest (Figure A3 and Figure 12). West to west-northwest trending lineaments parallel the northern and southern boundaries between the Annabel lake pluton and rocks of the metasedimentary Missi Group and Flin Flon greenstone belt (Figure 12). These structures are coincident with the Annabel Lake and West Arm shear zones. Additional west-northwest to northeast trending lineaments parallel the boundaries of a strongly magnetic zone within the Annabel Lake pluton from the southern base of the western portion of the pluton towards the eastern central portion of the pluton (Figure 12). The northwest oriented lineaments, in particular, a cluster of northwest-oriented lineaments in and around the eastern part of the Annabel Lake pluton, have the same orientation and likely represent the continuation of major late brittle faults mapped throughout the Flin Flon greenstone belt to the north and southeast of the Creighton area (Figure 12). These faults, and coincident lineaments, are likely related to the north- to northwest-trending Ross Lake Fault system, which may be related to the much larger Tabbernor fault system (Section 2.4; Byers, 1962).

The surficial lineament trends exhibit a similar dominant west-northwest to northwest trend as observed in the geophysical lineaments, in addition to a moderate east-west trend, a minor north trend and a very minor northeast trend, that are not as distinct in the geophysical data (Figure A3 and Figure 11). West to west-northwest-trending lineaments seen in the surficial data parallel the approximate geometry of the Annabel Lake pluton and bounding shear zones (Figure 11). The northwest lineaments exhibit the same orientation as northwest-trending faults mapped to the north and southeast of the Creighton area (Figure 11), which as previously mentioned, may be related to the north- to northwest-trending Ross Lake Fault and Tabbernor fault systems. Rare northeast-trending lineaments are relatively short, and are not observed in the geophysical data. These lineaments exhibit the same range in orientations as unnamed mapped faults to the southeast of the Creighton area (Figure 11). Locally these lineaments are in the same orientation as the ice flow direction (shown on Figure 3), however they do not typically form topographic features distinctive of glaciation (e.g., multiple parallel lakes, drumlins, eskers, etc.), and are therefore interpreted as bedrock features. As expected, the integrated lineaments exhibit similar trends (west-northwest to northwest trend) as seen in the geophysical and surficial data sets.

The northwest-oriented lineaments may represent the most significant set of lineaments in the Creighton Phase 2 assessment area, based on their potential association with the Ross Lake Fault system and or the crustal scale Tabbernor fault system. The relationship between the through-going northwest-oriented lineaments, and the intermittent north and northeast oriented lineaments may suggest that they are parts of the same brittle fault system (discussed in Section 5.5).

5.2.1   Relationship between Lineament sets and Regional Stress Field

The principal neotectonic stress orientation in central North America is generally oriented approximately east-northeast (63 degrees ± 28 degrees; Zoback ,1992) although anomalous stress orientations have also been reported in the mid-continent that include a 90-degree 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 interpreted lineaments.

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. Roughly four orientations of lineaments were interpreted: west to west-northwest, northwest, north, and northeast. Should the identified lineaments be reactivated under the current stress regime, the northwest oriented lineaments would likely reactivate as reverse dip-slip to oblique-slip faults, the west-northwest- and north-oriented lineaments would likely reactivate as oblique-slip faults, and the northeast-oriented lineaments would likely reactivate as normal dip-slip to oblique-slip faults. This would imply that the northwest, west-northwest and north lineaments would be reactivated under shear stress and northeast lineaments would be reactivated under tensile stress. It is also possible that under the current stress regime, northwest and west-northwest oriented lineaments could simultaneous react as conjugate sets of structures.

5.3   Lineament Length

Interpreted geophysical (RA_1), surficial (RA_2) and final integrated (RA_2) lineaments classified by length are presented in Figures 14, 15 and 16. Statistical analysis of lineament lengths, including box-plots, cumulative log-log plots, and histograms graphically display the distribution of lineament length for each data set (Figures 14, 15, 16 and A4). It is important to keep in mind that the reported lengths may not necessarily reflect the full length of the lineament. Lineaments were traced within the assessment area and could extend beyond its borders.

The histograms and cumulative log-log plots for the surficial lineament data sets show that length ranges are generally similar for both DEM and satellite lineaments, while length ranges are higher for the geophysical lineaments (Figure A4). The box plot shows that the middle 50% of geophysical lineaments are significantly longer than the middle 50% of surficial lineaments. The middle 50% of satellite and DEM data lineaments are similar. This same distribution of lineament length is also observed when comparing median values of the three data sets (as presented above and in Section 4.1). The longer length of geophysical lineaments is most likely due to being defined by continuous magnetic lows, or by multiple breaks in the magnetic grain defining a continuous lineament. Conversely, surficial lineaments are typically characterized by a combination of breaks in topography, vegetation and bedrock, and elongated lakes. These surficial features are not as continuous as the magnetic features, often due to their interruption by overburden. This resulted in the interpretation of shorter surficial lineaments relative to the magnetic lineaments.

The results indicate that lineaments that are identified in all data sets (i.e. RA_2 = 3) have a median length of 2.33 km and a mean length of 3.84 km. These values are significantly greater than the mean and median lengths from each individual data set. This indicates that the most reproducible lineaments are typically longer, and commonly extend throughout large portions of the Creighton

Phase 2 assessment area. The long lineament lengths observed in the final data set is expected as this data set resulted from the integration of the geophysical and surficial data sets. During this process, the most continuous lineaments, which are typically attributed with a high certainty, were often coincident with portions of other lineaments observed in the other data sets. Integrating these lineaments resulted in longer continuous lineaments.

Examining the final integrated lineaments per bin size reveals that a smaller percentage of the lineaments have lengths greater than 2.5 km (11 %). The majority of the lineaments have lengths between 1 to 2.5 km (25 %), or less than 1 km (64 %). The longer lineaments trend predominantly northwest, west-northwest and east-west, and the shorter lineaments exhibit all dominant trends, including northwest, west-northwest, east-west, north, and northeast. This is consistent with northwest-trending lineaments defining a dominant through-going set of structures related to mapped northwest-oriented faults (most dominant in the eastern portion of the Phase 2 assessment area), and with west-northwest to east-west oriented structures defining a continuous pervasive regional ductile fabric that parallels the geometry of the Annabel lake pluton, the Missi Group metasedimentary rocks and the Flin Flon greenstone belt (most dominant in the western portion of the Phase 2 assessment area).

Although there is no information available on the depth extent of the lineaments interpreted for the Creighton Phase 2 assessment area; the length information described above can be used as a proxy for the depth extent of the identified structures. Therefore, a preliminary assumption may be that the longer interpreted lineaments may extend to greater depths than the shorter interpreted lineaments.

5.4   Density

Analyses of lineament and intersection density were conducted for the Creighton area, as described in Section 3.2.6.

5.4.1 Lineament Density

The density of interpreted lineaments is variable throughout the Creighton Phase 2 assessment area, and is largely related to bedrock structures, notably the intersection of late brittle faults with earlier brittle-ductile fabrics, and the presence of Quaternary features, in particular large lakes. In order to properly assess the surficial lineament density it is necessary to take into account the location of lakes, since the lakes lack DEM and satellite lineaments which may produce apparently lower densities. This is less of a factor for evaluating the geophysical lineament density. Lineament density is discussed for each data set below. It should also be noted that since interpreted lineaments are only traced to the margins of the Phase 2 assessment area, there will in many cases be a border of apparent low lineament density around the margin.

The geophysical lineament density is variable throughout the Creighton Phase 2 assessment area (Figure 17). The highest density of geophysical lineaments is located in the eastern portion of the assessment area, and represents a zone where there is a high density of intersecting northwest and west-northwest–oriented lineaments, and a high density of lineaments defining a fold hinge within the Annabel Lake pluton. Additional moderate density zones are present in the northwest and northeast corners of the assessment area, due to the presence of both northwest and west-northwest oriented structures. Low density zones are present around the periphery of the assessment area, likely due to lineaments terminating at the boundary of the assessment area. A lower lineament density zone can be observed in the western part of the assessment area. This zone is coincident with an area where fewer lineaments were present in the magnetic data. This may in part be due to a lower magnetic contrast within the core of the domal portion of the pluton, resulting in the interpretation of fewer lineaments. In addition, fewer northwest-trending lineaments were interpreted in this area.

The integrated surficial lineament density is variable throughout the Creighton Phase 2 assessment area (Figure 18), and is largely a reflection of the presence of large lakes and bedrock exposure (Figure 3). The highest density of lineaments is observed in the central eastern portion of the Phase 2 assessment area, where a cluster of northwest-oriented brittle lineaments intersect the west-northwest–oriented brittle-ductile structures. This zone represents an area of high bedrock exposure in the hinge of a folded portion of the Annabel Lake pluton. The high lineament density is a reflection of both the high bedrock exposure, and the pervasive brittle-ductile fabric forming the hinge zone of the fold. Lineament spacing in this area is relatively narrow due to the intersection of the two orientations of lineaments and the high degree of bedrock exposure.

Moderate lineament density is observed in certain areas of the domal portion of the Annabel Lake pluton, and likely represents a mix of zones with significant overburden, fewer structures related to bedrock, and fewer intersecting structures. The lowest lineament density zones tend to occur in the vicinity of large water bodies (including Annabel Lake, Wilson Lake, Hamell Lake and Creighton Lake) where DEM and satellite lineaments can be obscured by the water and around the periphery of the assessment area where the lower density is predominantly a result of the lineaments terminating at the boundary of the assessment area (Figure 18).

The final integrated lineament density shows a similar distribution as the geophysical and surficial data sets throughout the Creighton area (Figure 19). The highest density of final integrated lineaments is observed in the eastern portion of the Creighton area, where a cluster of northwest oriented brittle lineaments intersect the main west-northwest oriented brittle-ductile lineament, and where closely spaced lineaments define the hinge zone of a folded portion of the Annabel Lake pluton. Moderate density is observed within the domal portion of the Annabel Lake pluton, and the lowest density zones are observed around the periphery of the assessment area, for the same reasons described above.

5.4.2 Intersection Density

SRK analyzed the distribution of lineament intersections within the Creighton Phase 2 assessment area. Similar to the lineament density, the intersection density is variable, and is largely related to the intersection of late brittle faults with earlier brittle-ductile fabrics.

In general, similar distributions are observed in the geophysical lineament intersection density plots as were observed in the geophysical lineament density plots (Figure 20). These include a variable intersection density throughout the assessment area, with a markedly higher lineament intersection density in the eastern portion of the assessment area. This zone is characterized by the intersection of a series of northwest oriented lineaments (defining a late northwest-trending structural corridor of brittle lineaments) and west-northwest oriented lineaments (defining the pervasive brittle-ductile structures defining the geometry of the Annabel lake pluton). Additional moderate zones of intersection density are observed in the northwest and northeast corners of the assessment area, where cluster of northwest oriented brittle lineaments intersect west-northwest oriented brittle-ductile lineaments.

The majority of the western half of the Creighton area displays a lower geophysical lineament intersection density. This zone of lower intersection density correspond to areas of the Annabel Lake pluton and Flin Flon greenstone belts where relatively few northwest-oriented lineaments crosscut the pervasive west-northwest magnetic fabric.

Similar distributions are observed in the surficial lineament intersection density plots (Figure 21) as were observed in the surficial lineament density plots. The surficial lineament intersection density is

variable throughout the assessment area. This includes a higher density of lineament intersections in the eastern portion of the Creighton area, which occur in a zone of intersecting northwest and west-northwest structures (as described above) and in an area of high bedrock exposure in the hinge of the folded portion of the Annabel Lake pluton. A moderate density zone is observed within the domal portion of the Annabel Lake pluton, where a moderate number of northwest oriented brittle lineaments intersect the west-northwest oriented brittle-ductile lineaments. Beyond these areas, there is a lower density of surficial lineament intersections, dominantly along the periphery of the assessment area.

The final lineament intersection density shows a distribution that is predominantly similar to the surficial intersection density, and lesser so to the geophysical intersection density throughout the Creighton Phase 2 assessment area (Figure 22). This is due to the large number of surficial lineaments relative to geophysical lineaments.

5.5   Lineament Truncation and Relative Age Relationships

The structural history of the Creighton area, outlined in Section 2.4 provides a framework that may aid in constraining the relative age relationships of the interpreted bedrock lineaments. In summary, six main regionally distinguishable deformation episodes (D_1-D_6) are inferred to have overprinted the bedrock geological units of the Creighton area.

D_1 deformation is characterized by the development of vein arrays, thrust faulting and an early phase of folding due to north-south collision between ca. 1.886 and 1.860 Ga. D_2 is characterized by continued movement along thrust faults and associated fold development between ca. 1.860 and 1.834 Ga. D_3 is associated with east-southeast to west-northwest oriented transpression between ca. 1.83 and 1.790 Ga., resulting in folding and associated axial planar foliations, as well as a number of steeply dipping, north-trending oblique-slip sinistral-reverse shear zones. D_4 is characterized by the reactivation and development of strike-slip shear zones. D_4 deformation reoriented shear zones from north- to east-trending, and is constrained between ca. 1.79 and 1.76 Ga. D_5 is characterized by late stage brittle oblique-slip and strike-slip faulting under conditions of northwest to southeast compression between ca. 1.725 and 1.691 Ga. Protracted, post-1.691 Ga brittle reactivation of faults throughout the Creighton area is collectively attributed to a D_6 deformation event.

The final integrated lineaments interpreted in the Creighton area can be classified based on cross-cutting relationships into three successive stages of brittle-ductile and brittle deformation, which correlate with the regional structural history as described in Section 2.4 (Figure 23). These deformation events include (from oldest to youngest): 1020 D_2-D_4 (ductile to brittle-ductile) lineaments, 27 D_4 (ductile to brittle-ductile) lineaments, and 443 D_5-D_6 (brittle) lineaments. No dyke lineaments were identified.

The D_2-D_4 brittle-ductile lineaments trend west to west-northwest throughout the majority of the assessment area and parallel the regional geometry of all geological units (Figure 23 and A5). The geometry of these brittle-ductile lineaments within the Annabel Lake pluton outlines two distinct intrusive phases. The western portion of the pluton is characterized by dominant west-northwest trending lineaments that outline an elliptical shaped domal portion of the pluton. The D_2-D_4 brittle-ductile lineaments in the eastern portion of the pluton, where not masked by later northwest-trending D_5-D_6 brittle lineaments, define a folded portion of the pluton. The orientations of the D_2-D_4 brittle-ductile lineaments in the eastern portion of the Annabel Lake pluton vary from west-northwest to northeast. Additional short northwest- and northeast-oriented lineaments, interpreted as secondary and tertiary, linking shear zones are also present throughout the assessment area (Figure A6). The distribution of these structures is relatively uniform throughout the assessment area, with the exception of areas where large lakes are present (e.g. Annabel Lake, Figure A5), areas where these

structures are obscured by a high density of later brittle structures (dominant in the central eastern portion of the assessment area, Figure A7), and areas where these brittle-ductile structures form the hinge of folds and are more tightly spaced (Figure A8).

Along the southern and northern boundaries of the assessment area, these lineaments are typically long, continuous and parallel the west-northwest orientation of the greenstone belts (Figure 23 and A5). Lineaments in the far north and south of the assessment area correspond to the Annabel Lake and West Arm shear zones, respectively (Figure 23). These shear zones initially formed during the regional D_2 deformation event, and were likely reactivated during D_3 deformation (Fedorowich et al, 1995). In the central western portion of the assessment area, these lineaments area often oriented west-northwest, but also deviate as they define the boundaries and internal fabric of the oval-shaped domal portion of the Annabel Lake pluton (Figure A9). In the central eastern portion of the assessment area, within a separate phase of the Annabel Lake pluton, these lineaments define the nose of an isoclinal fold (presumably F_2 to F_3 in age) and a west- to northwest-oriented arcuate internal fabric (Figure A8). Lineaments interpreted as D_2-D_4 are offset and truncated by all other interpreted lineaments (Figures A7 and A10).

The D_4 brittle-ductile lineaments trend approximately west in the western portion of the assessment area. In the eastern portion of the assessment area, the D_4 lineaments fan out into orientations between northeast and southeast (Figure 23). These lineaments are typically long, continuous and characterized by consistent breaks in the magnetic fabric within the Annabel Lake pluton (Figure A11). These lineaments are interpreted as brittle-ductile, and they crosscut the D_2-D_4 lineaments (Figure A11). Therefore, these lineaments are classified as the latest stage of D_4 deformation. Their orientation is also consistent with the regional easterly trend of D_4 structures (Fedorowich et al., 1995).

The D_5-D_6 brittle lineaments exhibit a dominant northwest orientation, and minor north and northeast orientations. All D_2-D_4 lineaments, including the late D_4 lineaments, are offset and/or truncated along D_5-D_6 lineaments (Figures A7 and A10). Of the three D_5-D_6 lineament orientations, northwest-trending lineaments display minor sinistral strike-separations and are interpreted as the youngest, as they offset and or truncate north and northeast-trending D_5-D_6 lineaments (Figure A7 and A10). The relative age relationship and sense of motion along north- and northeast-trending D_5-D_6 lineaments could not be determined, however the angles between north- and northeast-oriented structures could suggest they are conjugate (Figure 23). No major offsets are observed in the Creighton area.

Northwest-oriented brittle D_5-D_6 lineaments are relatively evenly distributed in the western portion of the assessment area. In the east of the assessment area, there is an obvious cluster of closely spaced northwest-oriented brittle D_5-D_6 lineaments (Figure 23). This may represent a larger scale fault zone that appears to be the continuation of a mapped northwest brittle fault to the north and southeast of the assessment area (Figure 23 and Figure A12). The northern extent of this zone of interpreted brittle lineaments corresponds to several mapped northwest-oriented short faults bisecting the Annabel Lake shear zone (Figure 23). Northwest-oriented lineaments are also prevalent across the rest of the assessment area.

5.5.1 Mapped Fault and Lineament Relationships

Several named and unnamed faults and shear zones have been mapped in the Creighton area (discussed above in section 5.5, shown in Figure 2, and overlain with the final interpreted lineaments classified by relative age in Figure 23).

The Annabel Lake and West Arm shear zones tend to be coincident with longer lineaments that were attributed a certainty value of 3 and a reproducibility value (RA_2) of 3. This is expected as these

major structural features are clearly evident in the geophysical and surficial data sets. These large shear zones comprise multiple parallel continuous lineaments, rather than a single discrete structure.

The vast majority of the mapped faults shown on Figure 3 and 23 were interpreted, at least in part, during the lineament analysis, including several short mapped faults that bisect the Annabel Lake shear zone along the northeastern boundary of the Creighton area. The lineament study identified a northwest-oriented corridor of closely-spaced brittle lineaments continuing to the southeast of the short mapped faults, and linking up with a larger mapped fault to the southeast of the assessment area (Figures 23 and A12). These mapped faults zones and the interpreted D_5-D_6 lineaments may represent a splay of the regional scale north-northwest trending Ross Lake fault (Byers, 1962; Ansdell and Kyser, 1990; Fedorowich et al., 1993), which may be a segment of the crustal scale Tabbernor fault system (Byers, 1962), that extends from the Northwest Territories to the states of North and South Dakota (Giroux, 1995).

6   Summary of Results

This report documents the source data, workflow, and results from a lineament interpretation of geophysical (magnetic) and surficial (satellite imagery, DEM topography) data sets acquired as part of Phase 2 Preliminary Assessments for the Creighton area. The lineament analysis provides an interpretation of the location and orientation of possible individual brittle and brittle-ductile lineaments on the basis of remotely sensed data, and helps to evaluate their relative timing relationships within the context of the regional geological setting. The workflow involves a three step process that was designed to address the issues of subjectivity and reproducibility. The distribution of lineaments in the area of Creighton reflects the bedrock structure, resolution of the data sets used, and surficial cover.

Within the Creighton Phase 2 assessment area, a total of 304 geophysical lineaments, 809 DEM lineaments, and 1,069 satellite lineaments were interpreted by the two interpreters (RA_1) from their respective data sets. Merging the lineaments derived from the DEM and satellite data resulted in a total of a 1,564 surficial lineaments (RA_2). Merging the surficial lineaments with those derived from the geophysical data resulted in a total of 1,490 final integrated lineaments (RA_2).

The reproducibility assessment (RA_1) revealed a moderate coincidence between interpreters for all three data sets (i.e. 38% of the geophysical lineaments, 32 % of the satellite lineaments, and 34% of the DEM lineaments). The variability between interpreters could be attributed to the resolution of the data sets and the judgement of the expert carrying out the interpretation. In general, longer lineaments were identified more often by both interpreters.

The coincidence assessment (RA_2) revealed a moderate coincidence between lineaments interpreted from the three data sets (i.e. 36% of lineaments were coincident in at least one other data set and 64% of lineaments lacked coincidence with other data sets). The variability between lineaments derived from the different data sets could be attributed to multiple variables, including deep structures identified in the magnetic data that may not have a surface expression, surficial features that may not extend to depth, features identified in the surficial data that may not possess sufficient magnetic susceptibility contrast to be recognized in the magnetic data, and the masking of surface expressions of magnetic lineaments by the presence of overburden. Evaluating lineament lengths of the final integrated lineaments reveal that longer lineaments were identified more often in the various data sets.

An analysis of lineament orientations revealed an overall consistency between the orientations of lineaments identified in the various different data sets, which suggests that lineaments interpreted from all three data sets are identifying the same sets of structures. Examination of all data sets revealed dominant west-northwest to east-west and northwest trends, in addition to minor north and northeast trends. The west-northwest to east-west oriented lineaments define a pervasive regional brittle-ductile fabric that controls the geometry of the Annabel Lake pluton, the Missi Group metasedimentary rocks and the Flin Flon greenstone belt. The northwest-trending lineaments occur in two forms: as a tighter spaced lineament corridor in the east of the Creighton Phase 2 assessment area, and as wider spaced structures throughout the remainder of the area. The tighter spaced northwest-trending corridor of brittle lineaments in the east of the Creighton Phase 2 assessment area is interpreted to represent the northwest continuation of major late brittle faults mapped throughout the Flin Flon greenstone belt to the southeast of the Creighton area. North and northeast oriented lineaments occur more frequently near the northwest oriented lineament corridor in the west of the Creighton Phase 2 assessment area, and intermittently throughout the remainder of the area.

Evaluation of lineaments by length revealed relatively few lineaments longer than 2.5 km (i.e. 11 % of lineaments are greater than 2.5 km) and 64 % of lineaments are less than 1 km in length. The longer lineaments trend predominantly northwest, west-northwest and east-west, and the shorter lineaments exhibit all dominant trends, including northwest, west-northwest, east-west, north, and northeast.

The geophysical lineament density is variable throughout the Creighton Phase 2 assessment area (Figure 17). The highest density of geophysical lineaments is located in the eastern portion of the assessment area, and represents a zone where there is a high density of intersecting northwest and west-northwest–oriented lineaments, and a high density of lineaments defining a fold hinge within the Annabel Lake pluton. Additional moderate density zones are present in the northwest and northeast corners of the assessment area, due to the presence of both northwest and west-northwest oriented structures. Low density zones are present around the periphery of the assessment area, likely due to lineaments terminating at the boundary of the assessment area. A lower lineament density zone can be observed in the western part of the assessment area. This zone is coincident with an area where fewer lineaments were present in the magnetic data. This may in part be due to a lower magnetic contrast within the core of the domal portion of the pluton, resulting in the interpretation of fewer lineaments. In addition, fewer northwest-trending lineaments were interpreted in this area.

The integrated surficial lineament density is variable throughout the Creighton Phase 2 assessment area (Figure 18), and is largely a reflection of the presence of large lakes and bedrock exposure (Figure 3). The highest density of lineaments is observed in the central eastern portion of the Phase 2 assessment area, where a cluster of northwest-oriented brittle lineaments intersect the west-northwest–oriented brittle-ductile structures. This zone represents an area of high bedrock exposure in the hinge of a folded portion of the Annabel Lake pluton. The high lineament density is a reflection of both the high bedrock exposure, and the pervasive brittle-ductile fabric forming the hinge zone of the fold. Lineament spacing in this area is relatively narrow due to the intersection of the two orientations of lineaments and the high degree of bedrock exposure.

Moderate lineament density is observed in certain areas of the domal portion of the Annabel Lake pluton, and likely represents a mix of zones with significant overburden, fewer structures related to bedrock, and fewer intersecting structures. The lowest lineament density zones tend to occur in the vicinity of large water bodies (including Annabel Lake, Wilson Lake, Hamell Lake and Creighton Lake) where DEM and satellite lineaments can be obscured by the water and around the periphery of the assessment area where the lower density is predominantly a result of the lineaments terminating at the boundary of the assessment area (Figure 18).

Six main regionally distinguishable deformation episodes (D_1-D_6) are recognized in the Creighton area, and could be used to constrain the relative age relationships of the interpreted lineaments. The final interpreted lineaments can be classified within the structural history into three successive stages of brittle-ductile and brittle deformation, including: 1020 D_2-D_4 (ductile to brittle-ductile) lineaments; 27 D_4 (brittle-ductile) lineaments; and 443 D_5-D_6 (brittle) lineaments.

D_2-D_4 brittle-ductile lineaments trend west to west-northwest throughout the majority of the assessment area and parallel the regional geometry of all geological units. D_4 brittle-ductile lineaments trend approximately west in the western portion of the assessment area and fan out into multiple orientations in the eastern portion of the assessment area. These lineaments crosscut the D_2-D_4 lineaments.

D_5-D_6 brittle lineaments exhibit a dominant northwest orientation, and minor north and northeast orientations. All D_2-D_4 lineaments, including the late D_4 lineaments, are offset and or truncated along D_5/D_6 lineaments. In the east of the assessment area, there is an obvious cluster of closely spaced

northwest-oriented brittle D_5-D_6 lineaments, which likely represent the continuation of a mapped northwest brittle fault to the southeast of the assessment area. This lineament zone may represent a splay of the regional scale Ross Lake fault, which may be a segment of the crustal scale Tabbernor fault system.

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8   APPENDIX
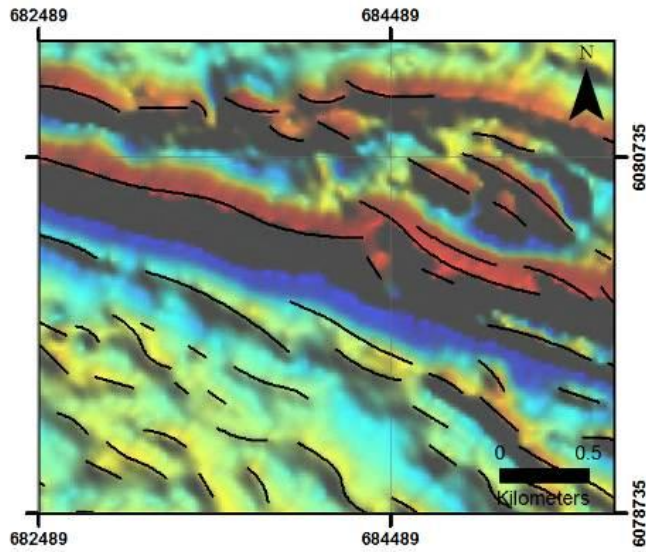
Figure A1: Example of Ductile Lineaments from the Creighton Area Defined by Curvi-linear Magnetic Highs
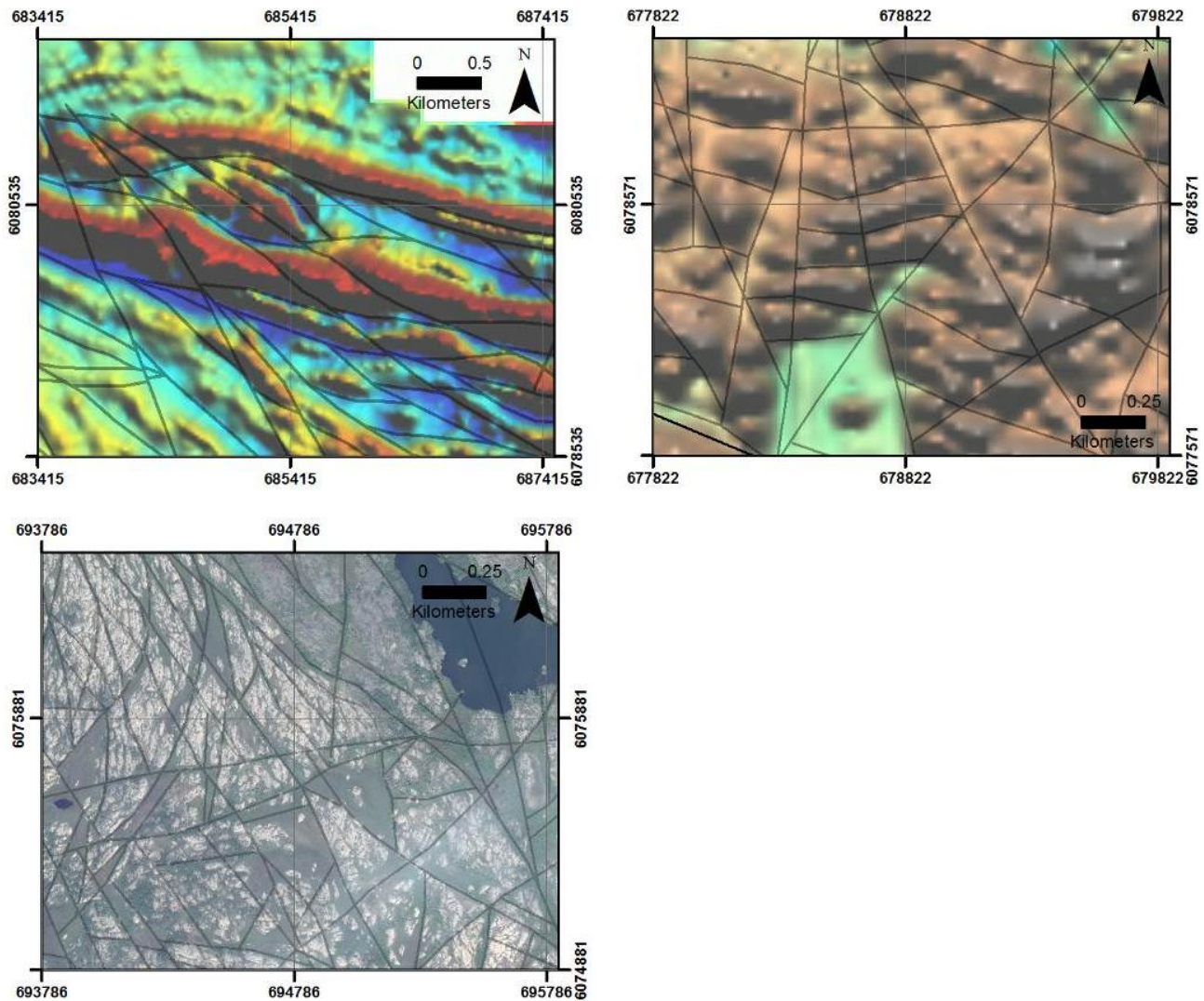
Figure A2: Example of Brittle Lineaments from the Creighton Area

Integrated magnetic lineaments defined by breaks in magnetic highs and curvi-linear magnetic lows in magnetic data (top left), integrated DEM lineaments defined by breaks in topography in DEM data (top right), and integrated satellite lineaments defined by curvi-linear breaks in exposed bedrock and vegetation in satellite data (bottom left).
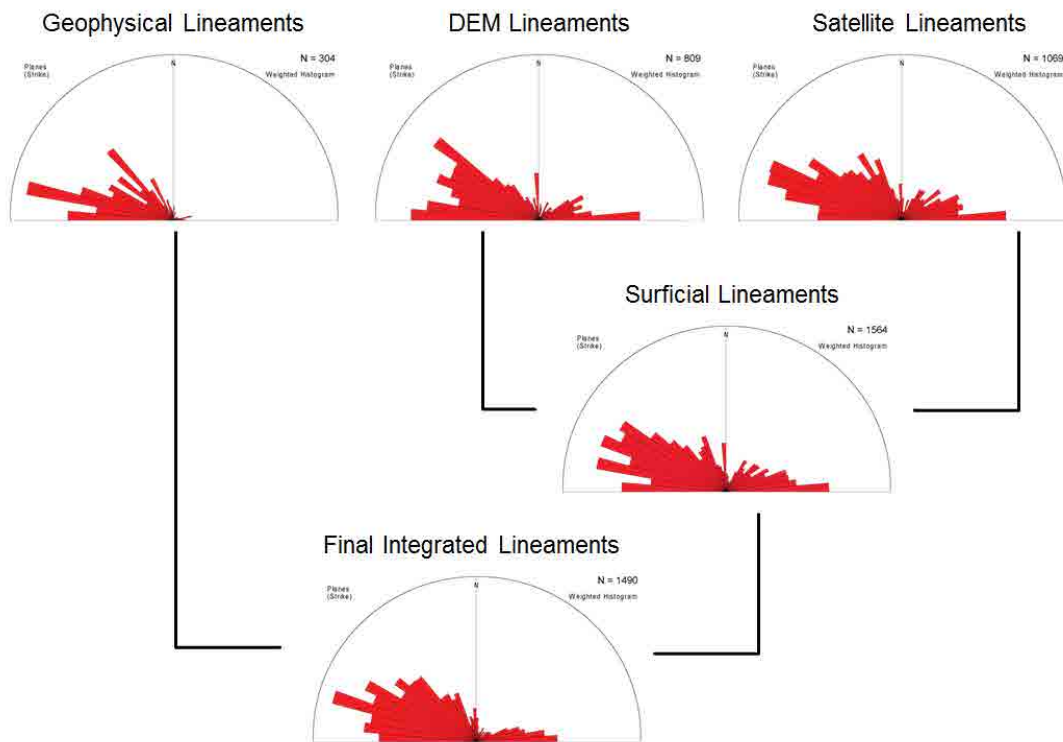
Figure A3: Summary of Lineament Orientations in the Creighton Phase 2 Assessment Area
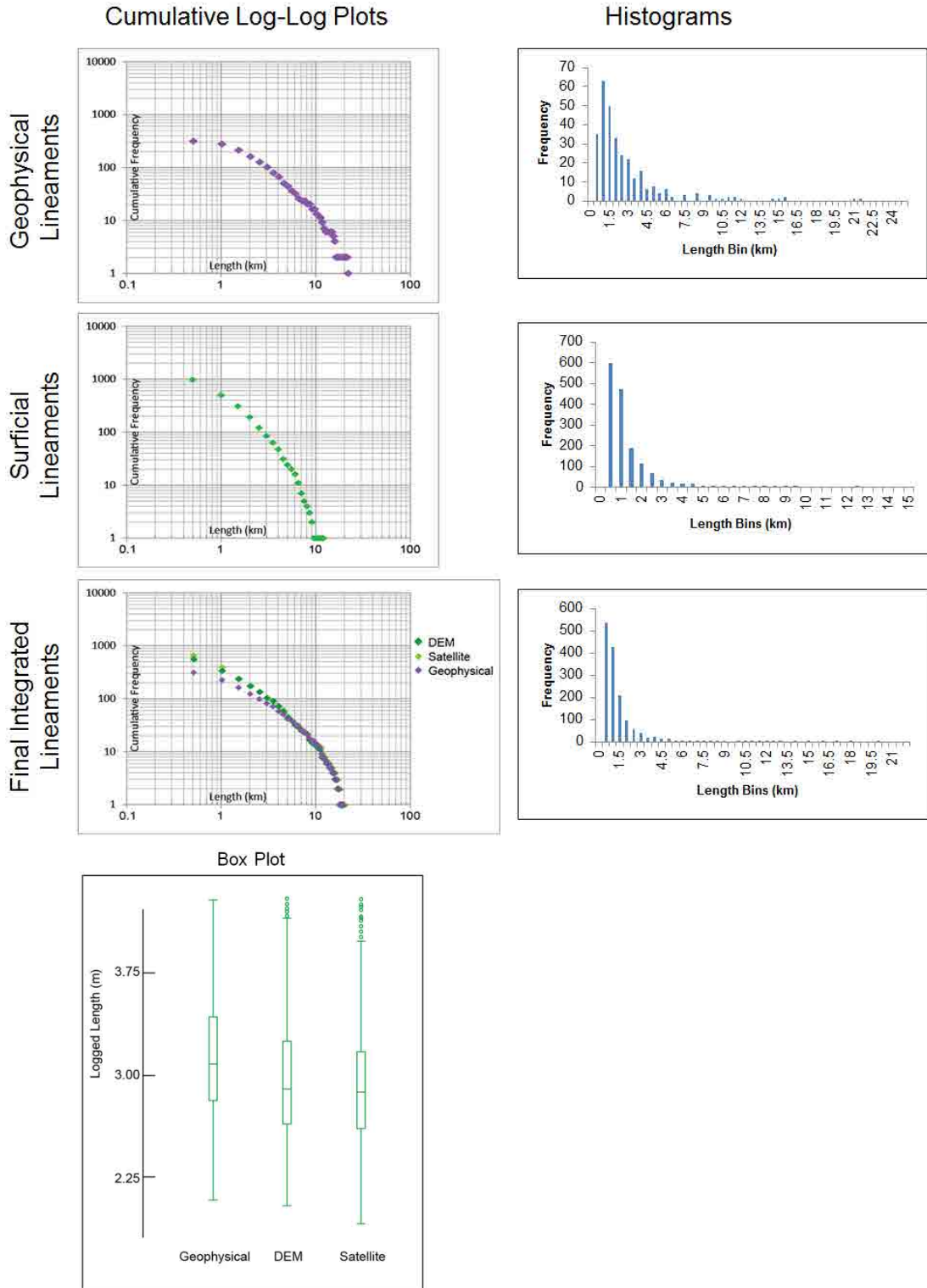
Figure A4: Summary of Length Statistics for the Creighton Phase 2 Assessment Area
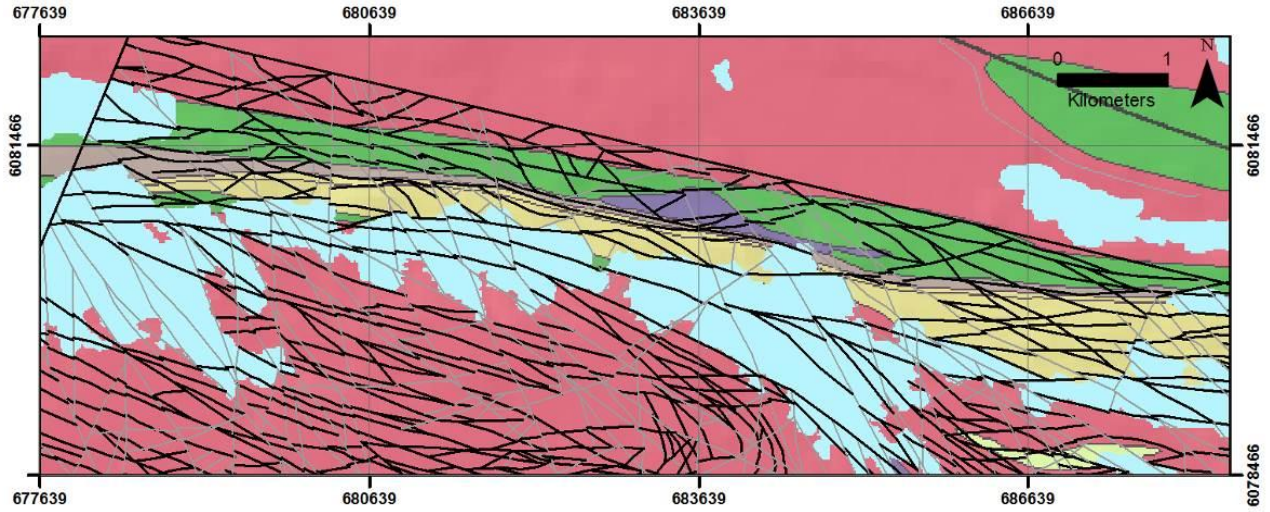
Figure A5: Final Integrated West-northwest Trending D_2-D_4 Lineaments (black) Defining Orientation of Greenstone Belt (green), Metasedimentary Rocks (yellow) and Internal Geometry of Annabel Lake Pluton (red)

Note a low number of lineaments in the areas dominated by large lakes. (Younger lineaments in grey).
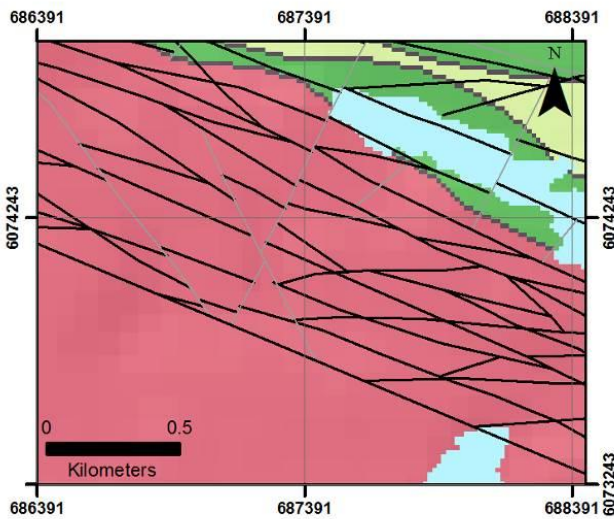
Figure A6: Final Integrated Continuous Northwest-oriented D_2-D_4 Lineaments and Short East-West to East-northeast Secondary and Tertiary Linking D_2-D_4 Shear Zones (black)
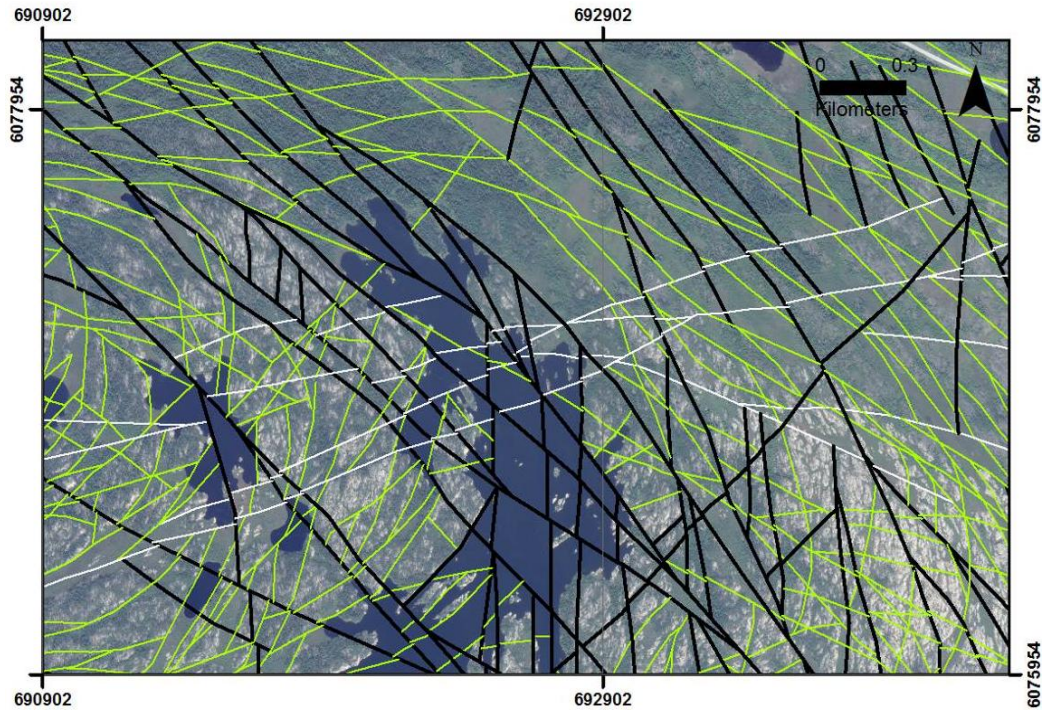
(Younger lineaments in grey).
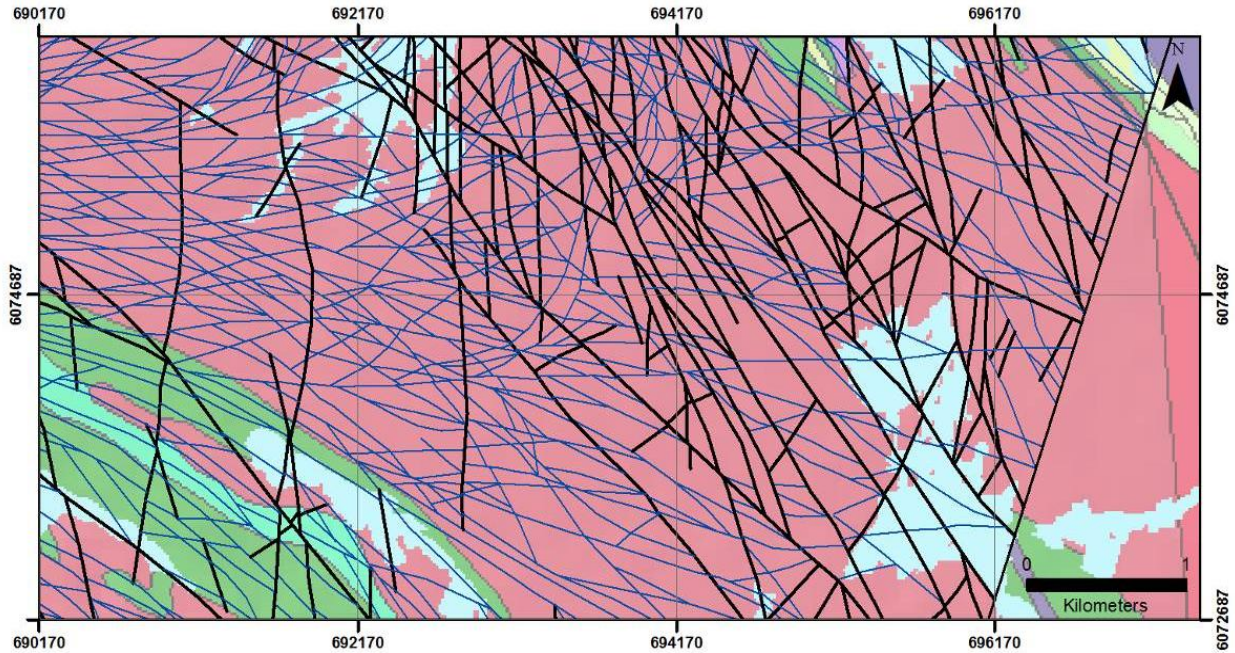
Figure A7: Within Final Integrated Lineaments, Corridor of Northwest-oriented D_5-D_6 (brittle) Lineaments (black) Truncating and Offsetting Older D_2-D_4 Brittle-ductile Lineaments (blue)

Note a lower number of D_2-D_4 brittle-ductile lineaments in the northwest-oriented D_5-D_6 lineament corridor.
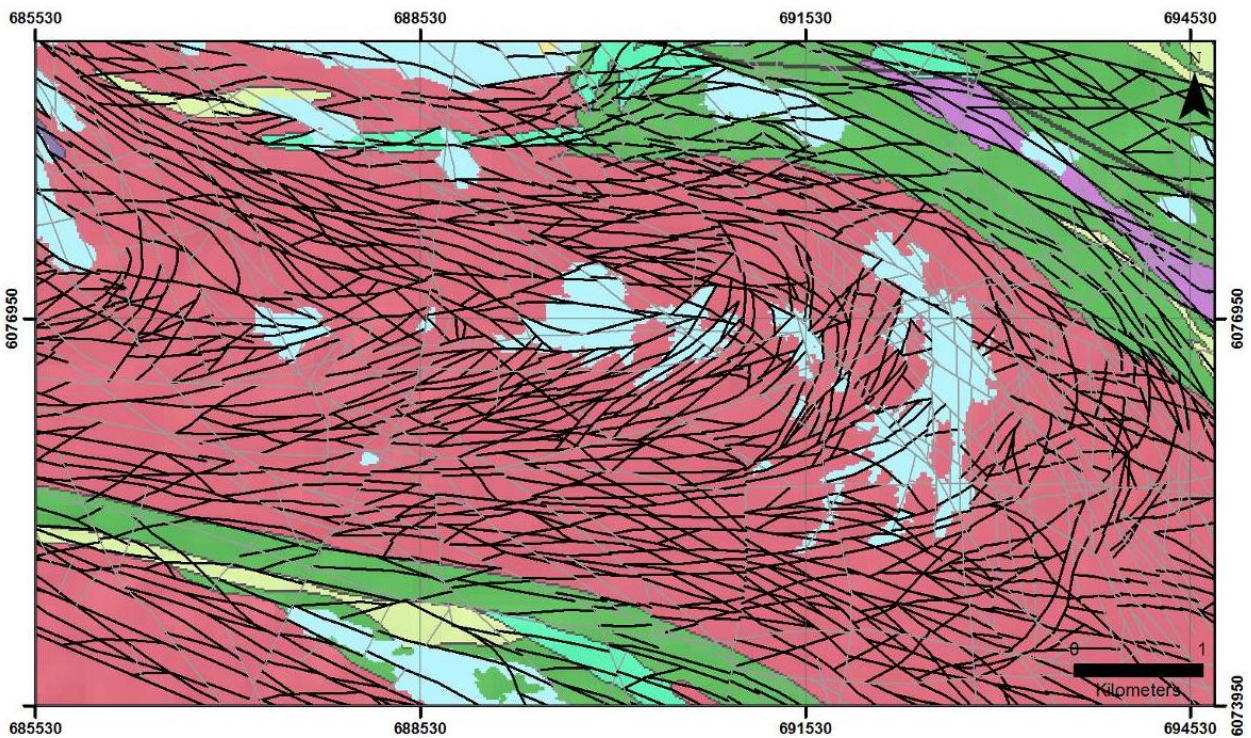
Figure A8: Within Final Integrated Lineaments, D_2-D_4 Brittle-ductile Lineaments (black) Defining Hinge of Fold within the Annabel Lake Pluton

Note tighter spacing of D_2-D_4 lineaments in hinge of fold relative to surrounding areas. (Younger lineaments in grey).
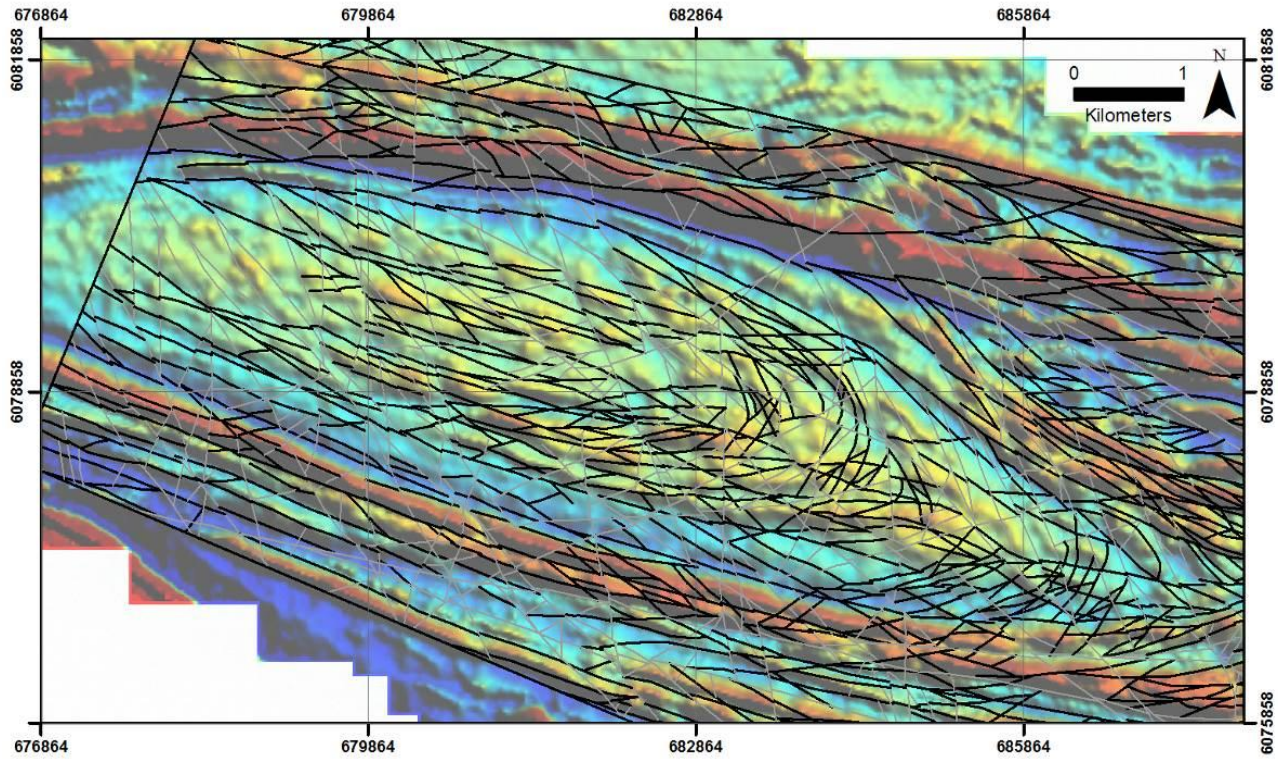
Figure A9: Within Final Integrated Lineaments, D$_2$-D$_4$ Brittle-ductile Lineaments (black) Defining Boundaries and Internal Fabric of Oval-shaped Domal Portion of Annabel Lake Pluton

(Younger lineaments in grey).

Figure A10: Within Final Integrated Lineaments, Corridor of northwest-oriented D_5-D_6 (brittle) Lineaments (black) Truncating and Offsetting Older D_4 Brittle-ductile Lineaments (white) and D_2-D_4 Brittle-ductile Lineaments (green), Overlain on Satellite Imagery
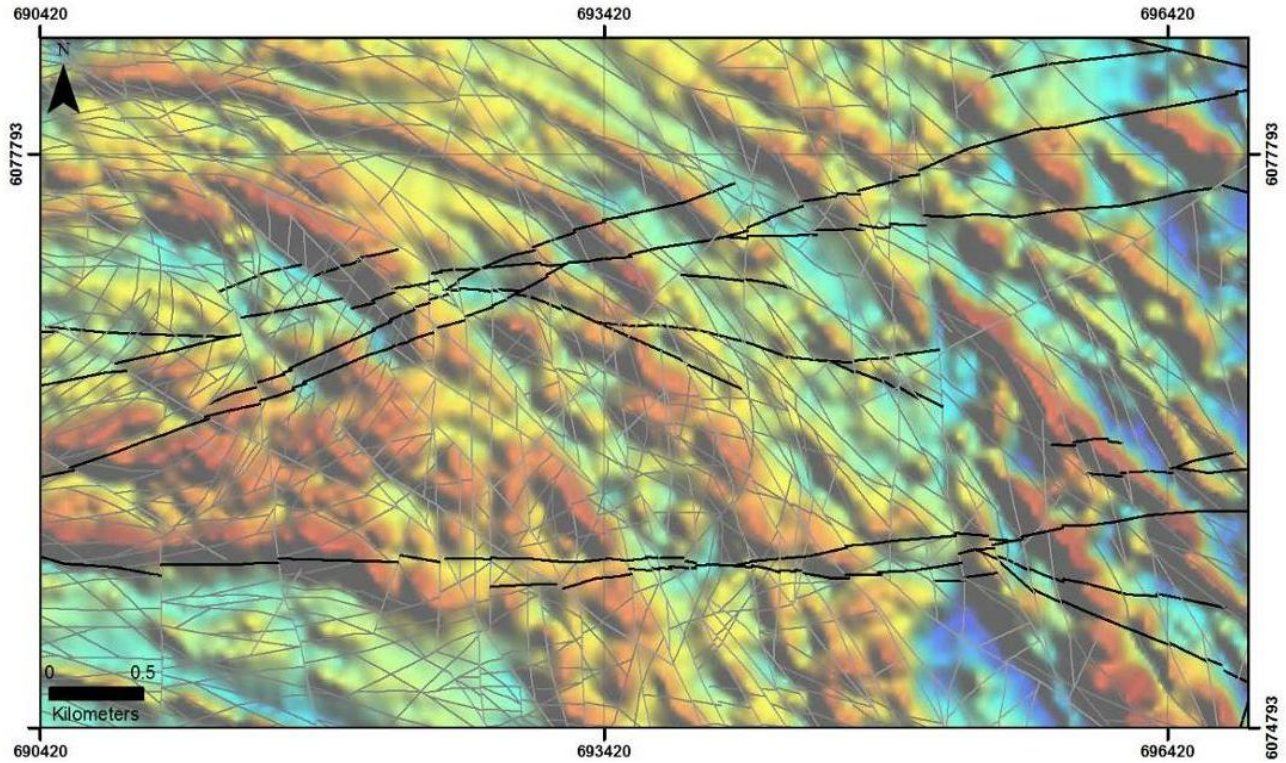
Figure A11: Within Final Integrated Lineaments, D$_4$ brittle-ductile Lineaments (black) are Defined by Consistent Breaks in the Magnetic Fabric within the Annabel Lake Pluton (Other lineaments in grey)
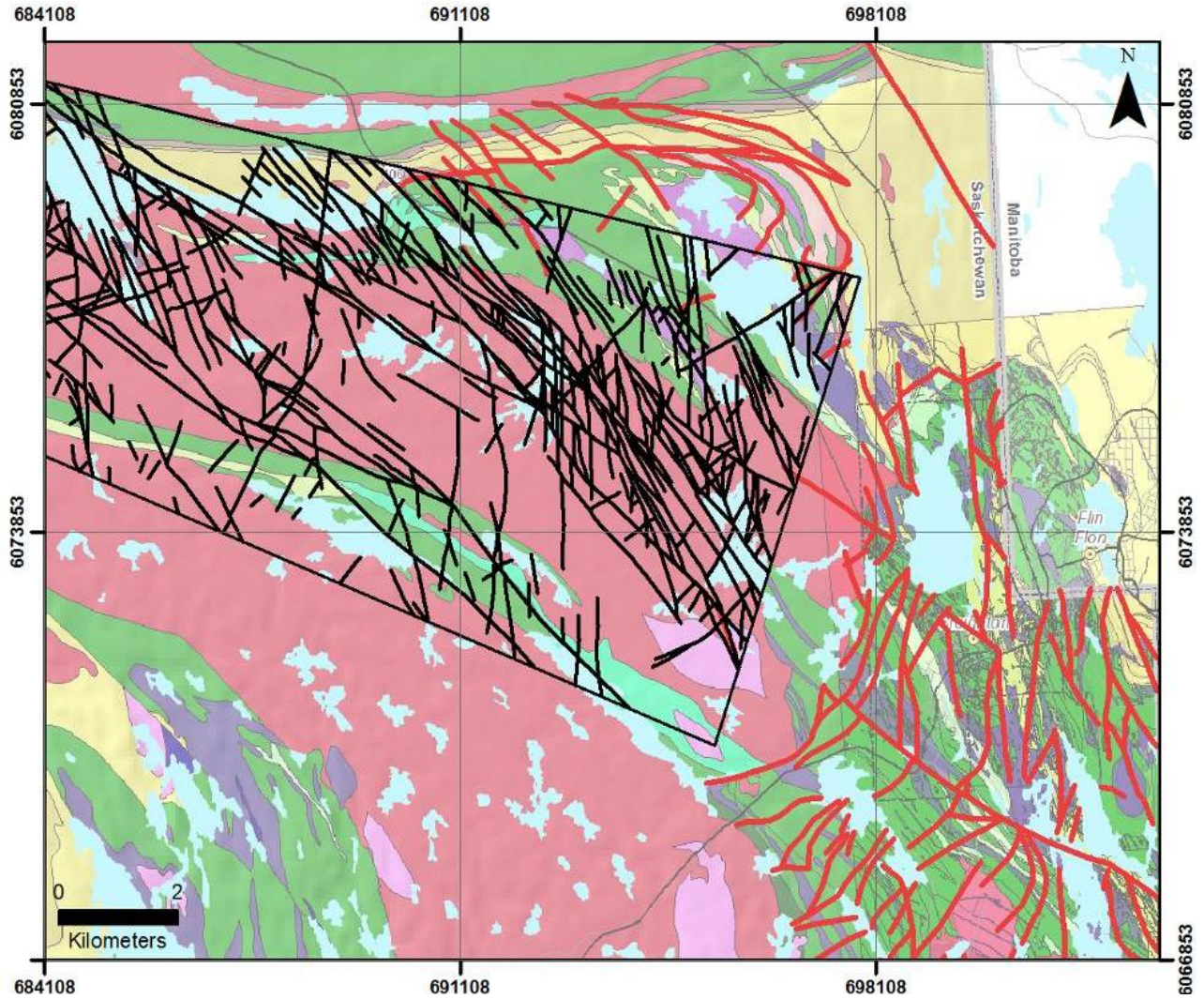
Figure A12: Northwest-oriented Final Integrated D$_5$-D$_6$ (brittle) Lineaments (black) Interpreted in the Creighton Area, and Mapped Northwest and Northeast Faults (red)

Note that the corridor of northwest-oriented lineaments in the east of the Creighton area may represent the continuation of the major northwest oriented mapped fault to the southeast of the Creighton area. (Other interpreted lineaments not displayed).
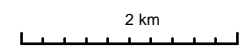
FIGURES
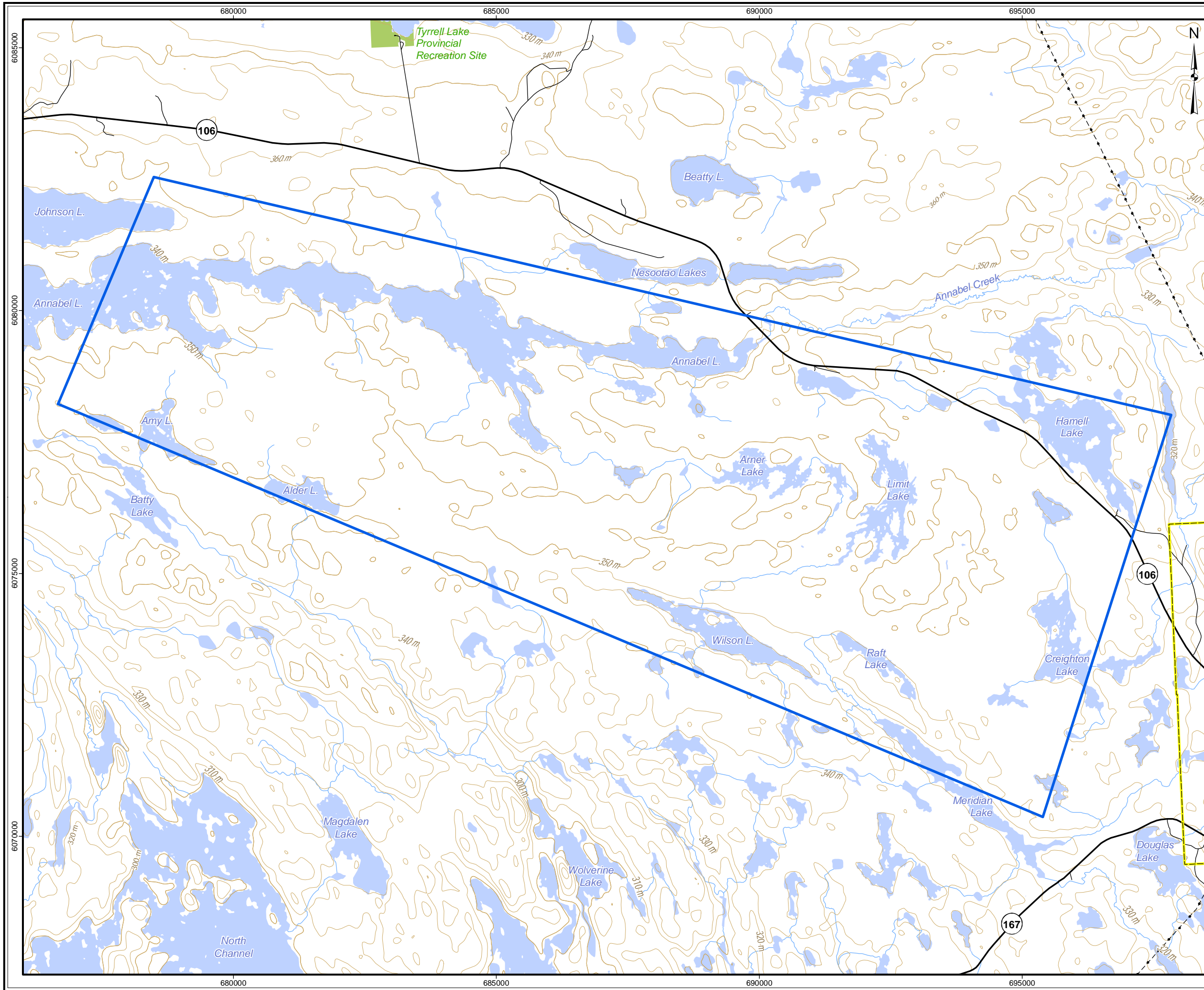
LEGEND

- — Phase 2 Assessment Area
- — Creighton Municipal Boundary
- —— Minor Road
- —— Major Road
- ·–·– Powerline
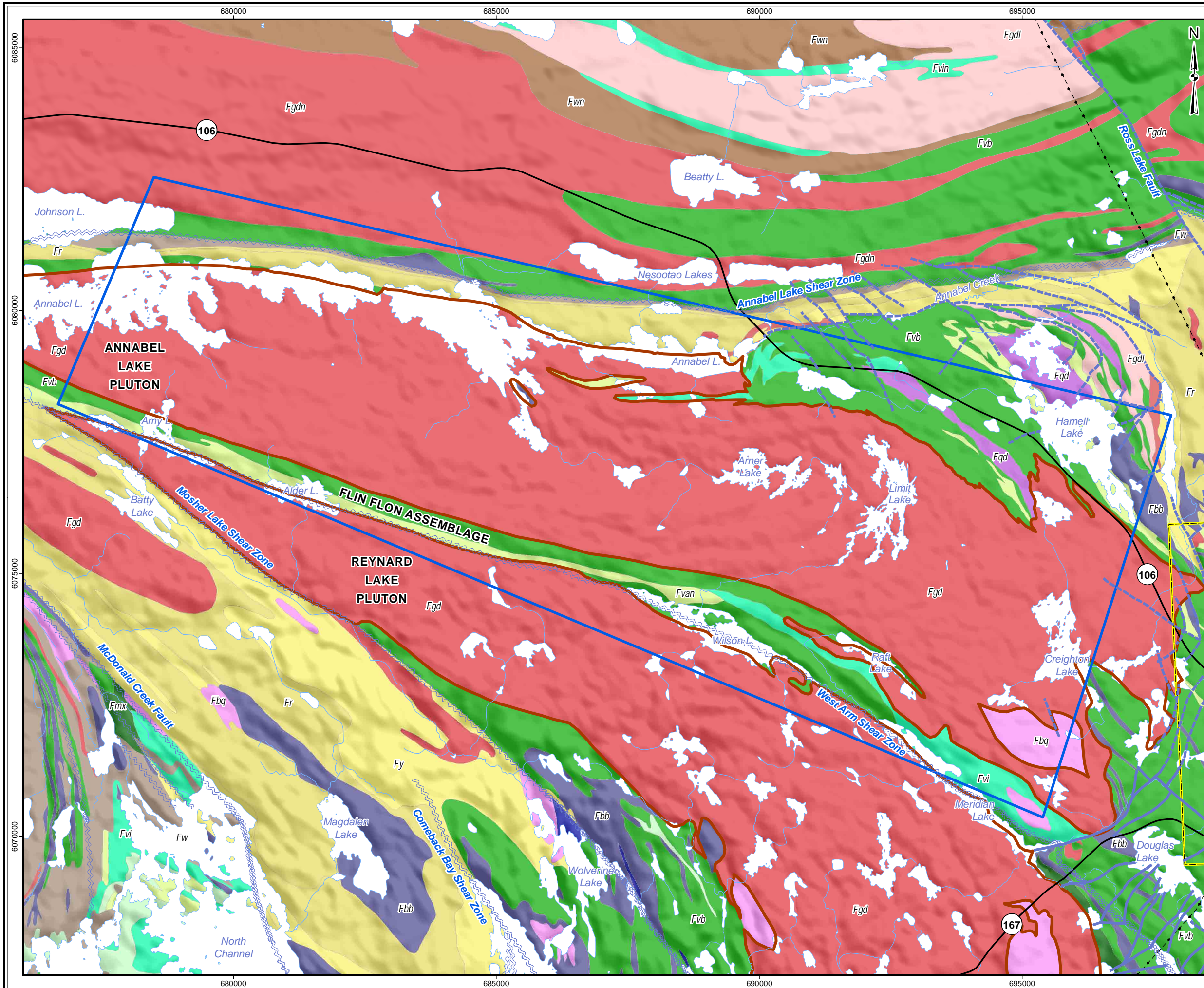- —— Contour (10m)
- —— Watercourse
- Waterbody
- Park

REFERENCE

Base Data: CanVec topography

2 km

srk consulting

PROJECT

Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE

**Location and Overview
of the Creighton Area**

DESIGN	KR	02 SEP 2014		REVISION 3
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 1**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

File: SRK_NWMO_CR_Fig01_Locality

LEGEND

- ☐ Phase 2 Assessment Area
- ☐ Creighton Municipal Boundary
- —— Major Road
- ·–·–· Powerline
- —— Watercourse
- ☐ Waterbody
- —— Batholith / Pluton contact
- – – – Mapped Faults
- 〰〰 Shear zone

- gl: Alaskite-aplogranite
- Fr: Sandstone, crossbeded sandstone
- Fry: Pebbly sandstone, pebble conglomerate, sandstone
- Fy: Polymictic conglomerate, sandstone
- Fyn: Conglomerate gneiss, local psammitic gneiss
- Fw: Metagreywacke
- Fwn: Metagreywacke gneiss
- Fgdl: Leucogranodiorite-tonalite
- Fgd: Granodiorite-tonalite
- Fgdn: Foliated to gneissic granodiorite-tonalite
- Fbq: Tonalite-quartz diorite
- Fqd: Quartz diorite-granodiorite-diorite
- Fbb: Gabbro-diorite
- Fu: Ultramafic rock
- Fmx: Mafic protomylonite to mylonite
- Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
- Fva: Acid volcanics
- Fvan: Felsic gneiss defived from felsic volcanics
- Fvi: Intermediate volcanics
- Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
- Fvb: Basic volcanics
- Fvbn: Mafic gneiss derived from basic volcanics
- Fbn: Biotite gneiss +/-hornblende +/-garnet

Missi Group
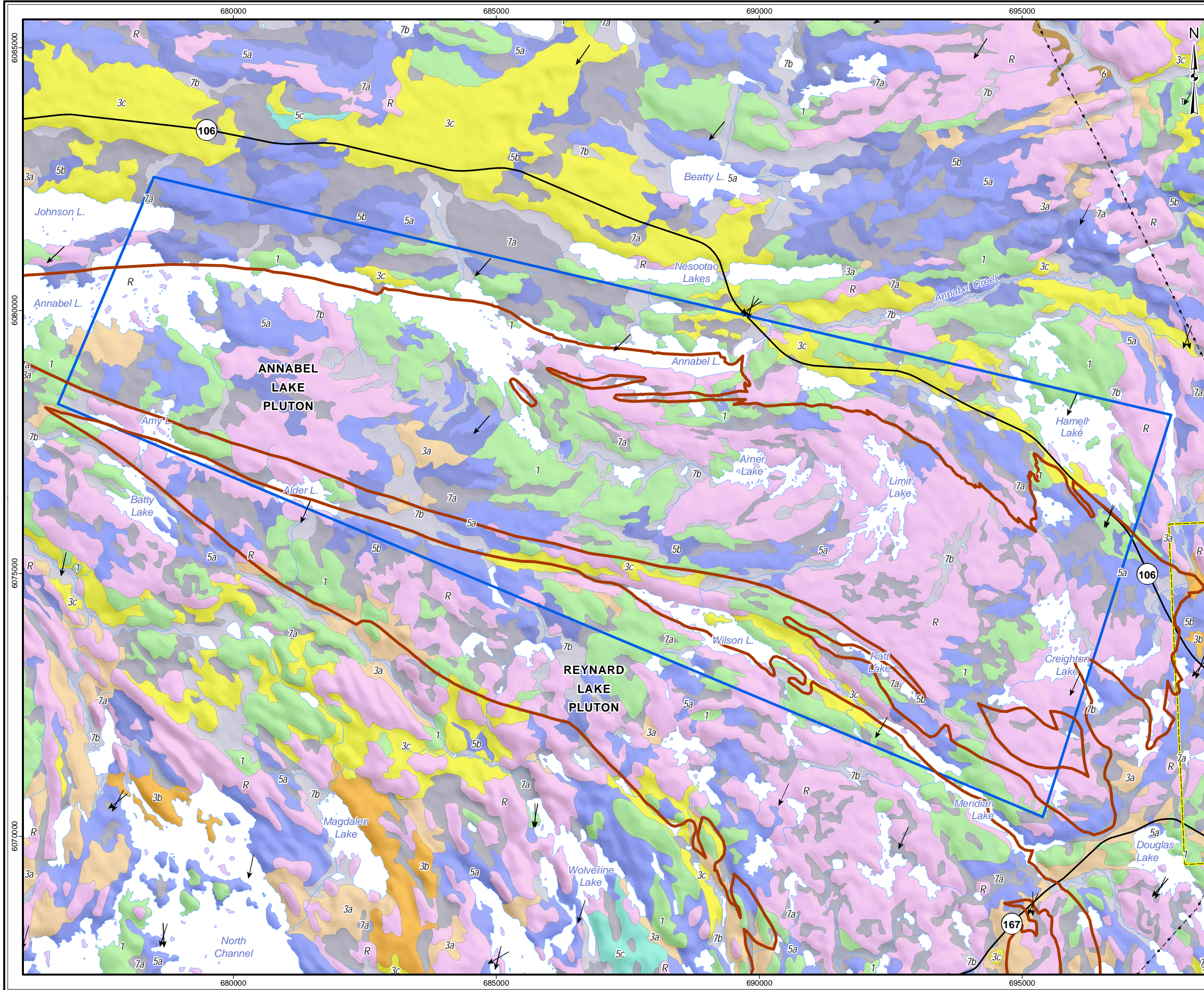
Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
NATMAP Shield Margin Project (GSC OF D3884)
Relief: Canadian Digital Surface Model (CDSM)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
**Bedrock Geology
of the Creighton Area**

DESIGN	KR	02 SEP 2014		REVISION 3
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 2**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

File: SRK_NWMO_CR_Fig02_Bedrock

Figure 3 — Terrain Features of the Creighton Area

LEGEND
- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
- Powerline
- Watercourse
- Waterbody
- Batholith / Pluton contact
- Striation

Landform
- 7b: Fen Peat
- 7a: Bog Peat
- 6: Alluvial Deposit
- 5c: Glaciolacustrine nearshore
- 5b: Glacilacustrine offshore blanket
- 5a: Glacilacustrine offshore veneer
- 3c: Glaciofluvial subaqueous outwash
- 3b: Glaciofluvial ice-contact
- 3a: Sand and gravel, undetermined origin
- 1: Till veneer
- R: Precambrian bedrock

REFERENCE
Base Data: CanVec topography
Geology: GSC Map 2010A, 1919A
GSC OF7089, TGI-3 Flin Flon Project
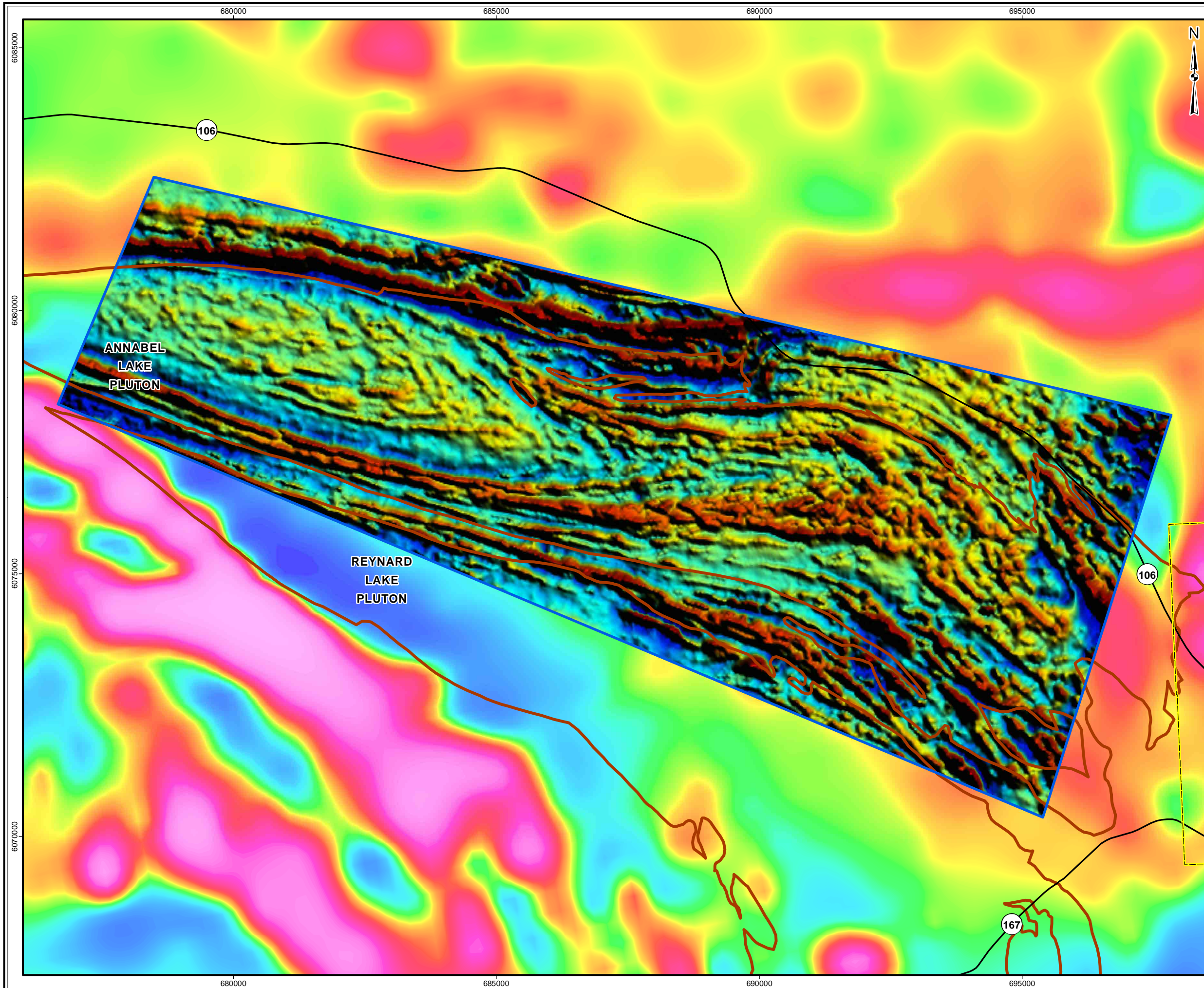Relief: Canadian Digital Surface Model (CDSM)

2 km

srk consulting

PROJECT
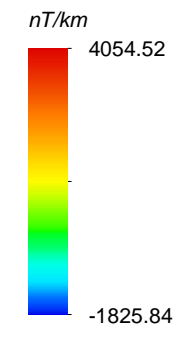Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Terrain Features
of the Creighton Area

DESIGN	KR	02 SEP 2014	REVISION 3
GIS	JA	13 FEB 2015	UTM ZONE 13N
CHECK	CN	13 FEB 2015	NAD 1983
REVIEW	AF	13 FEB 2015	1:70,000

Figure 3

File: SRK_NWMO_CR_Fig03_Surficial

LEGEND

- ▢ Phase 2 Assessment Area
- ▢ Creighton Municipal Boundary
- —— Major Road
- —— Batholith / Pluton contact

ANNABEL
LAKE
PLUTON

REYNARD
LAKE
PLUTON

106

167

nT/km

4054.52

-1825.84

REFERENCE

Base Data: CanVec topography
Geophysics: GSC Magnetic 200m Compilation
Detail: SGL 2015

2 km

srk consulting
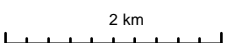
PROJECT

Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan
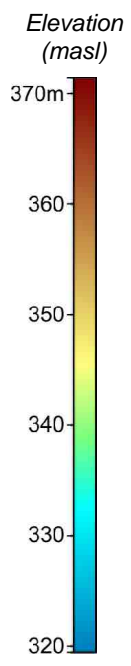
TITLE

**Pole Reduced Magnetic Data (First Vertical Derivative)
of the Creighton Area**

DESIGN	KR	02 SEP 2014		REVISION 2
GIS	JA	29 JAN 2015		UTM ZONE 13N
CHECK	CN	29 JAN 2015	**Figure 4**	NAD 1983
REVIEW	AF	29 JAN 2015		1:70,000
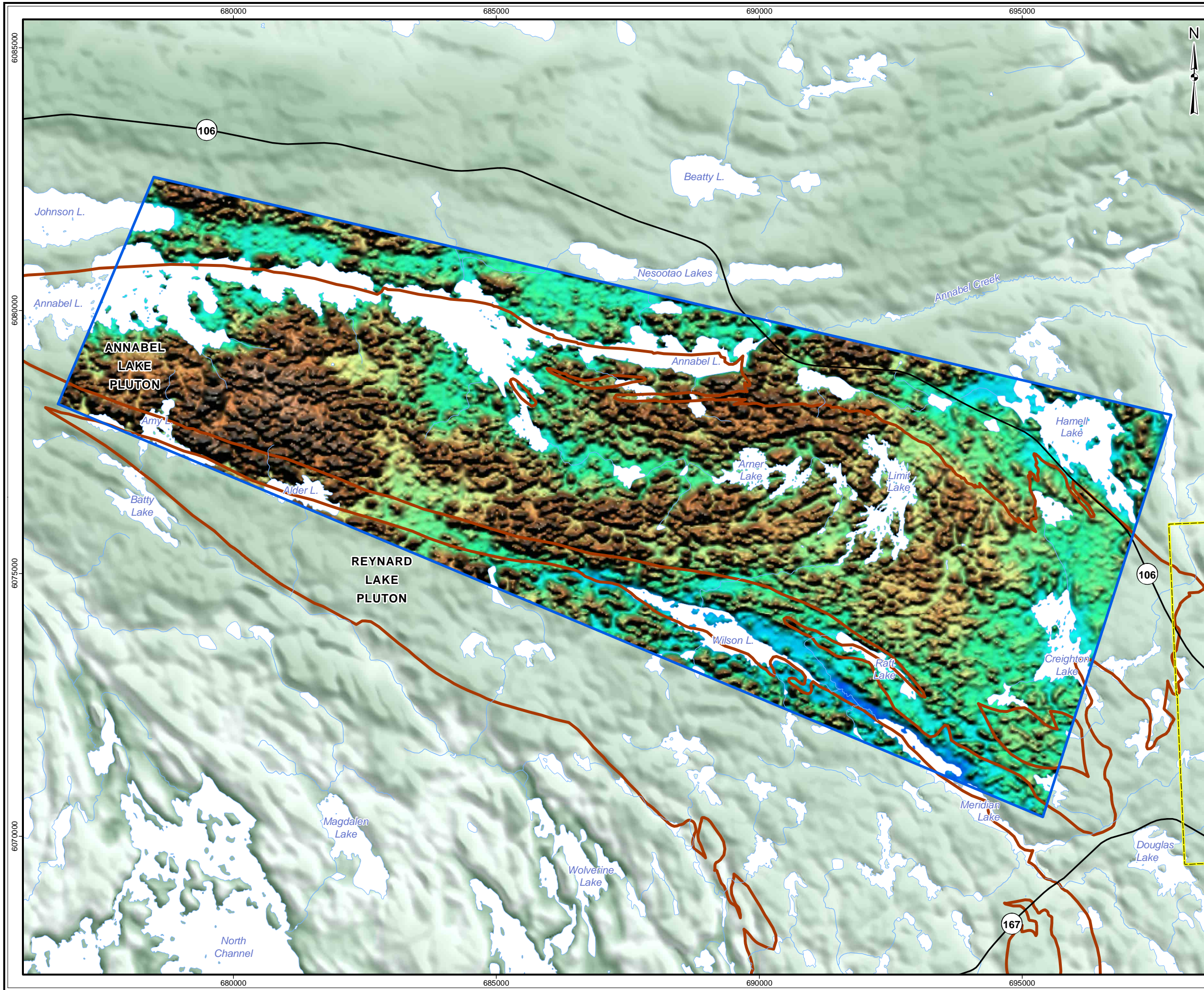
File: SRK_NWMO_CR_Fig04_MAG

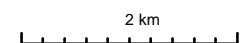**LEGEND**

- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
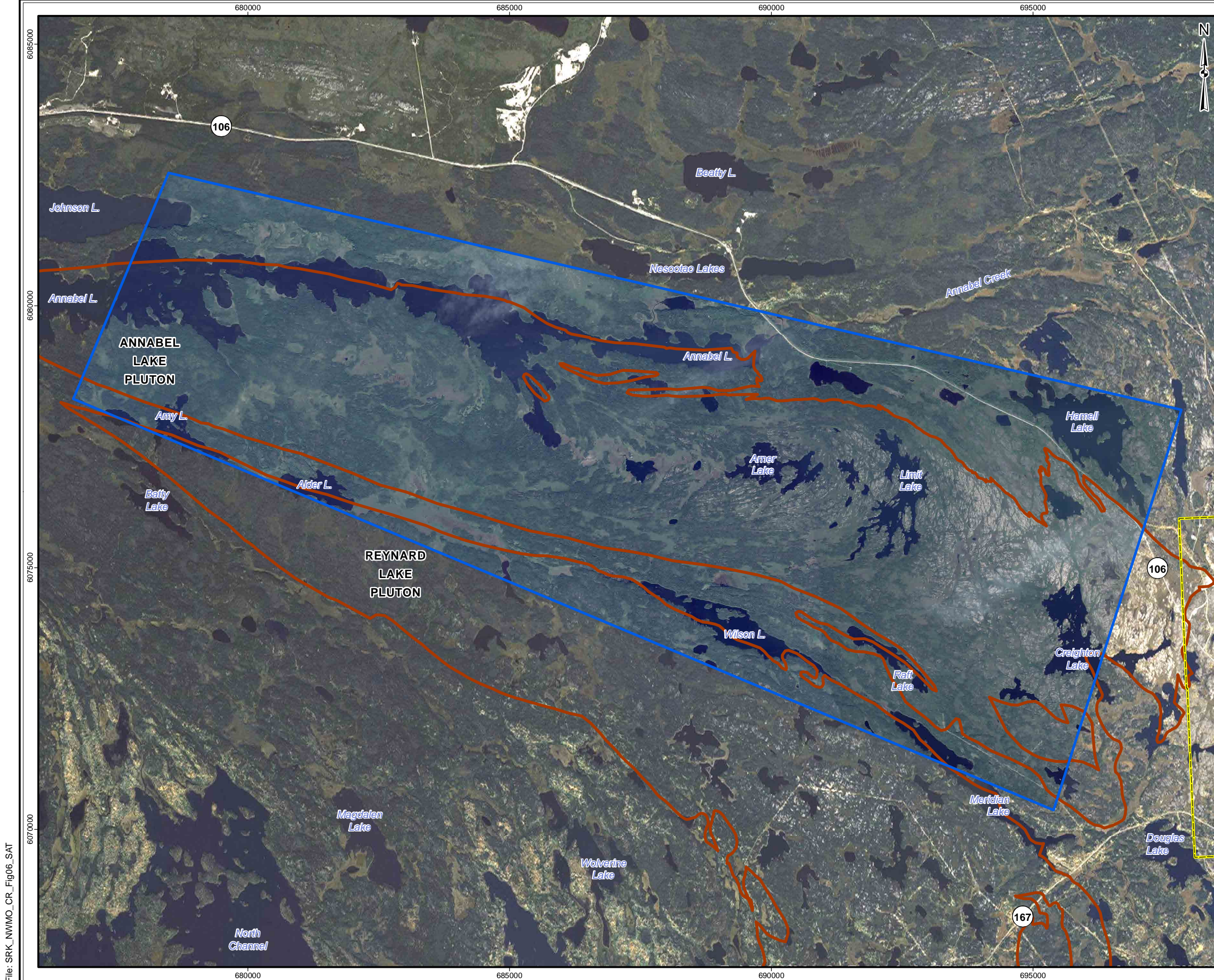- Watercourse
- Waterbody
- Batholith / Pluton contact

N

ANNABEL LAKE PLUTON

REYNARD LAKE PLUTON

Johnson L.
Beatty L.
Nesootao Lakes
Annabel Creek
Annabel L.
Annabel L.
Amy L.
Hamell Lake
Arner Lake
Limit Lake
Batty Lake
Alder L.
Wilson L.
Raft Lake
Creighton Lake
Meridian Lake
Magdalen Lake
Douglas Lake
Wolverine Lake
North Channel

106
106
167

Elevation (masl)

370m
360
350
340
330
320

SK
MB
Thompson
Flin Flon
Saskatoon

2 km

REFERENCE
Base Data: CanVec topography
Relief backdrop: CDSM (NRCAN)
DEM: SGL 2015

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
**Digital Elevation Data
of the Creighton Area**

DESIGN	KR	02 SEP 2014	REVISION 3
GIS	JA	13 FEB 2015	UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 5**	NAD 1983
REVIEW	AF	13 FEB 2015	1:70,000

File: SRK_NWMO_CR_Fig06_SAT

Figure 7. Ductile Lineaments of the Creighton Area

LEGEND

- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
- Powerline
- Watercourse
- Waterbody
- Batholith / Pluton contact
- Mapped Faults
- Shear zone

gl: Alaskite-aplogranite
Fr: Sandstone, crossbeded sandstone
Fry: Pebbly sandstone, pebble conglomerate, sandstone
Fy: Polymictic conglomerate, sandstone
Fyn: Conglomerate gneiss, local psammitic gneiss
Fw: Metagreywacke
Fwn: Metagreywacke gneiss
Missi Group
Fgdl: Leucogranodiorite-tonalite
Fgd: Granodiorite-tonalite
Fgdn: Foliated to gneissic granodiorite-tonalite
Fbq: Tonalite-quartz diorite
Fqd: Quartz diorite-granodiorite-diorite
Fbb: Gabbro-diorite
Fu: Ultramafic rock
Fmx: Mafic protomylonite to mylonite
Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
Fva: Acid volcanics
Fvan: Felsic gneiss defived from felsic volcanics
Fvi: Intermediate volcanics
Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
Fvb: Basic volcanics
Fvbn: Mafic gneiss derived from basic volcanics
Fbn: Biotite gneiss +/-hornblende +/-garnet
Flin Flon Assemblage

REFERENCE
Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
NATMAP Shield Margin Project (GSC OF D3884)
Relief: Canadian Digital Surface Model (CDSM)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Ductile Lineaments of the Creighton Area

DESIGN	KR	02 SEP 2014	REVISION 4
GIS	JA	13 FEB 2015	UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 7**	NAD 1983
REVIEW	AF	13 FEB 2015	1:70,000

File: SRK_NWMO_CR_Fig07_Ductile

Figure 8

LEGEND
- ▭ Phase 2 Assessment Area
- ▭ Creighton Municipal Boundary
- — Major Road
- — Batholith / Pluton contact

Reproducibility (RA_1)
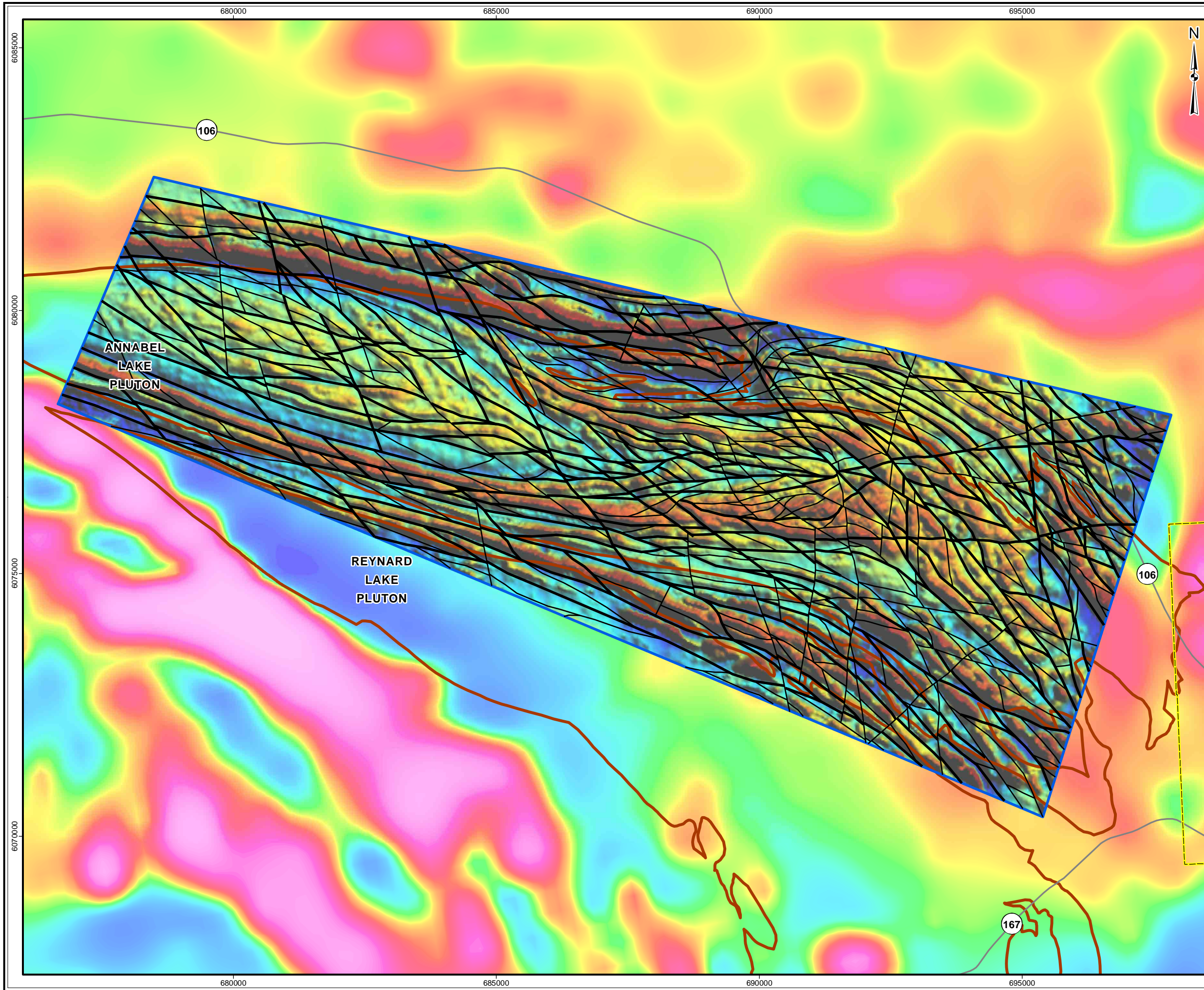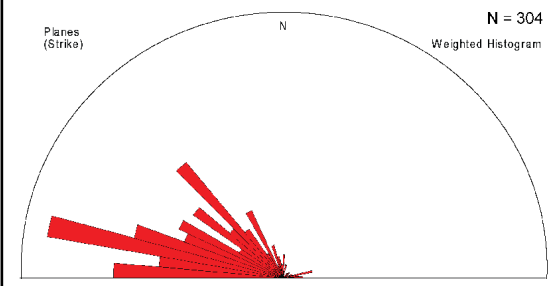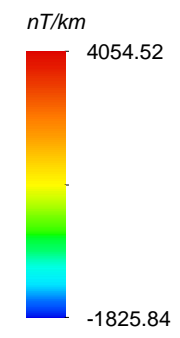- — 1
- — 2

nT/km
4054.52
−1825.84

N = 304

ANNABEL LAKE PLUTON

REYNARD LAKE PLUTON

SK | MB
Thompson
Flin Flon
Saskatoon

REFERENCE
Base Data: CanVec topography
Geophysics: GSC Magnetic 200m Compilation
Detail: SGL 2015

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
**Interpreted Lineaments
from Pole Reduced Magnetic Data (1VD)
of the Creighton Area**

DESIGN	KR	02 SEP 2014		REVISION 3
GIS	JA	29 JAN 2015		UTM ZONE 13N
CHECK	CN	29 JAN 2015	**Figure 8**	NAD 1983
REVIEW	AF	29 JAN 2015		1:70,000
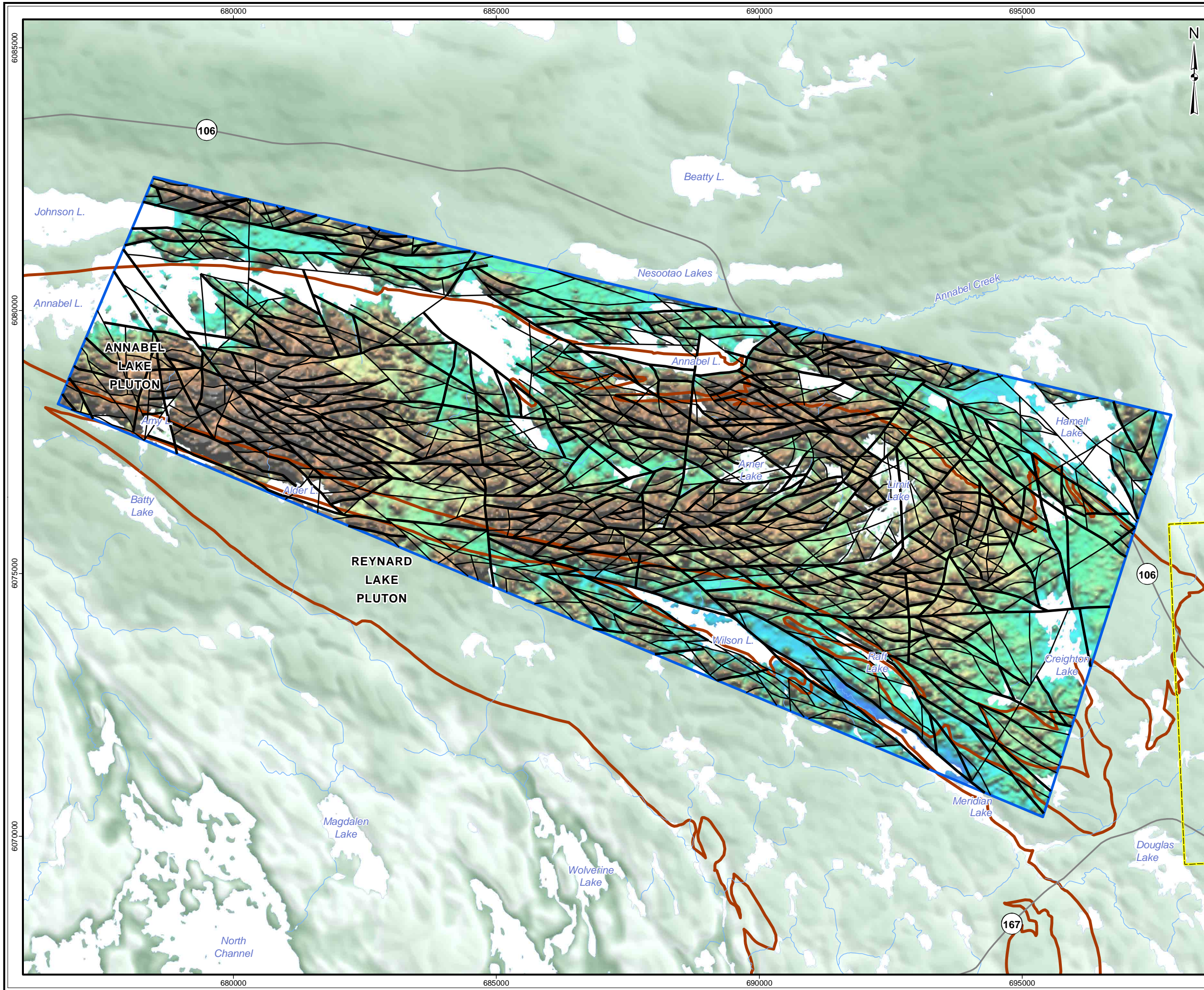
File: SRK_NWMO_CR_Fig08_MAG_ra1

LEGEND

Phase 2 Assessment Area
Creighton Municipal Boundary
Major Road
Watercourse
Waterbody
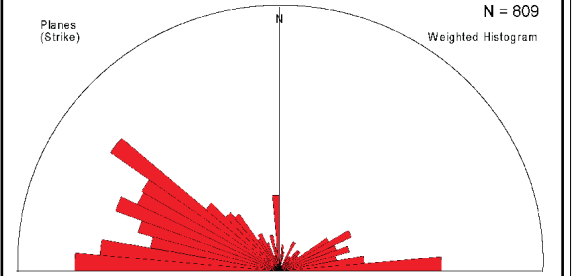Batholith / Pluton contact

Reproducibility (RA_1)
1
2

Elevation (masl)
370m
360
350
340
330
320

ANNABEL LAKE PLUTON

REYNARD LAKE PLUTON

Johnson L.
Annabel L.
Beatty L.
Nesootao Lakes
Annabel Creek
Annabel L.
Amy L.
Hamell Lake
Amer Lake
Limit Lake
Batty Lake
Alder L.
Wilson L.
Raft Lake
Creighton Lake
Meridian Lake
Magdalen Lake
Douglas Lake
Wolverine Lake
North Channel

106
167

N = 809
Weighted Histogram
Planes (Strike)

SK
MB
Thompson
Flin Flon
Saskatoon

REFERENCE
Base Data: CanVec topography
Relief backdrop: CDSM (NRCAN)
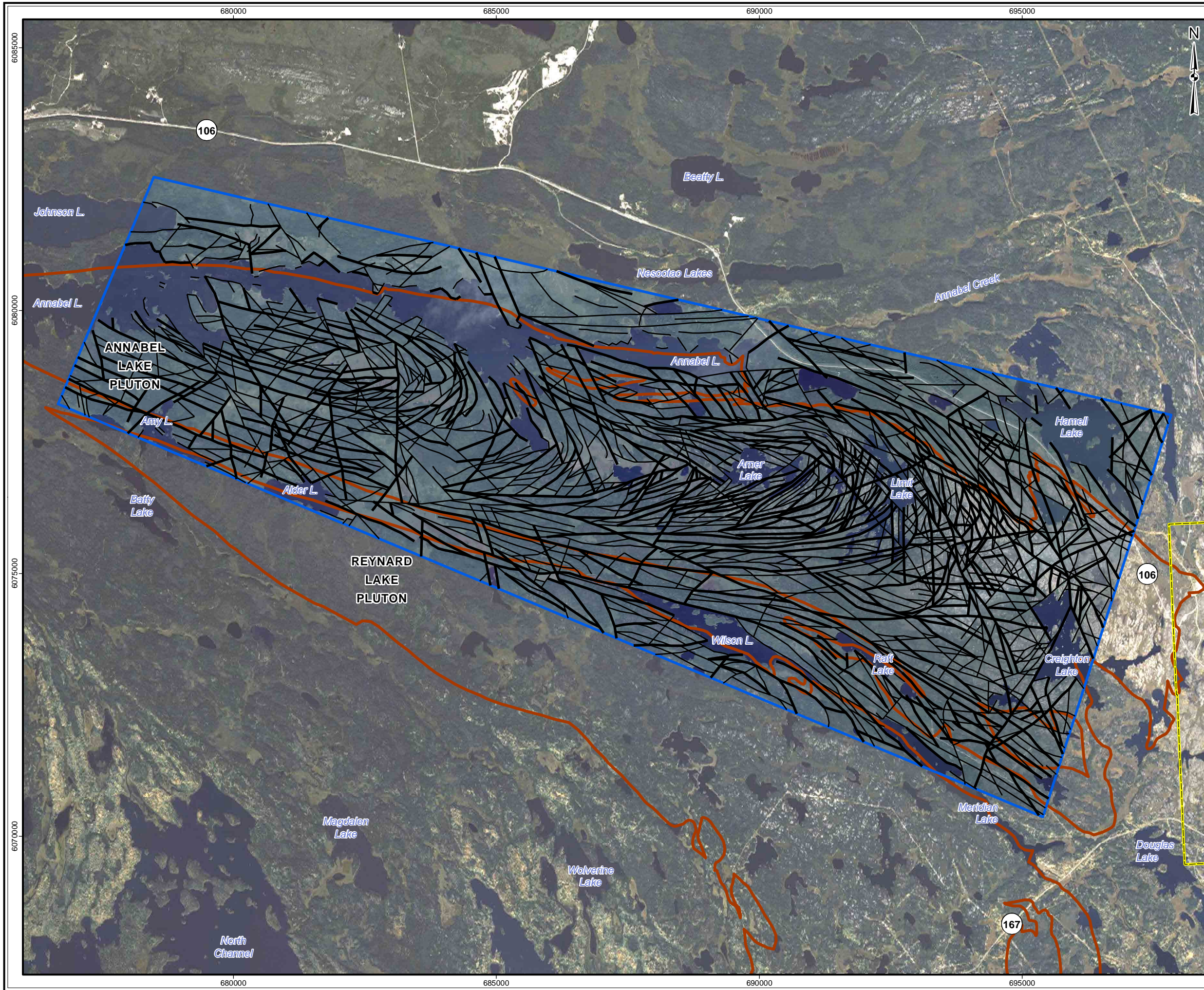DEM: SGL 2015

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
**Interpreted Lineaments
from Digital Elevation Data
of the Creighton Area**

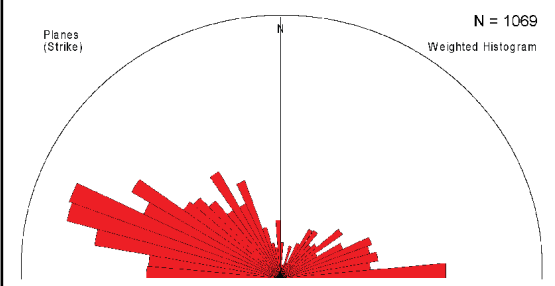| DESIGN | KR | 02 SEP 2014 | | REVISION 4 |
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 9**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

LEGEND

— Phase 2 Assessment Area
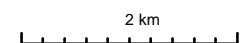— Creighton Municipal Boundary
— Batholith / Pluton contact

Reproducibility (RA_1)
— 1
— 2

N = 1069
Planes (Strike)
Weighted Histogram

REFERENCE
Base Data: CanVec topography
Image backdrop: TerraMetrics 2014
Detail: World View 2 GeoEye

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
**Interpreted Lineaments
from Satellite Imagery
of the Creighton Area**

DESIGN	KR	02 SEP 2014		REVISION 4
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 10**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

Map labels: ANNABEL LAKE PLUTON, REYNARD LAKE PLUTON, Johnson L., Annabel L., Amy L., Batty Lake, Alder L., Magdalen Lake, North Channel, Wolverine Lake, Beatty L., Nesootao Lakes, Annabel L., Amer Lake, Limit Lake, Wilson L., Raft Lake, Meridian Lake, Douglas Lake, Annabel Creek, Hamell Lake, Creighton Lake

Inset map labels: SK, MB, Thompson, Flin Flon, Saskatoon

Figure 11. Interpreted Lineaments from Surficial Data of the Creighton Area. Phase 2 Structural Lineament Interpretation, Creighton Area, Saskatchewan.

LEGEND

- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
- Powerline
- Watercourse
- Waterbody
- Batholith / Pluton contact
- Mapped Faults
- Shear zone

Certainty
- 1
- 2
- 3

- gl: Alaskite-aplogranite
- Fr: Sandstone, crossbeded sandstone
- Fry: Pebbly sandstone, pebble conglomerate, sandstone
- Fy: Polymictic conglomerate, sandstone
- Fyn: Conglomerate gneiss, local psammitic gneiss
- Fw: Metagreywacke
- Fwn: Metagreywacke gneiss
- Fgdl: Leucogranodiorite-tonalite
- Fgd: Granodiorite-tonalite
- Fgdn: Foliated to gneissic granodiorite-tonalite
- Fbq: Tonalite-quartz diorite
- Fqd: Quartz diorite-granodiorite-diorite
- Fbb: Gabbro-diorite
- Fu: Ultramafic rock
- Fmx: Mafic protomylonite to mylonite
- Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
- Fva: Acid volcanics
- Fvan: Felsic gneiss defived from felsic volcanics
- Fvi: Intermediate volcanics
- Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
- Fvb: Basic volcanics
- Fvbn: Mafic gneiss derived from basic volcanics
- Fbn: Biotite gneiss +/-hornblende +/-garnet

Missi Group

Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
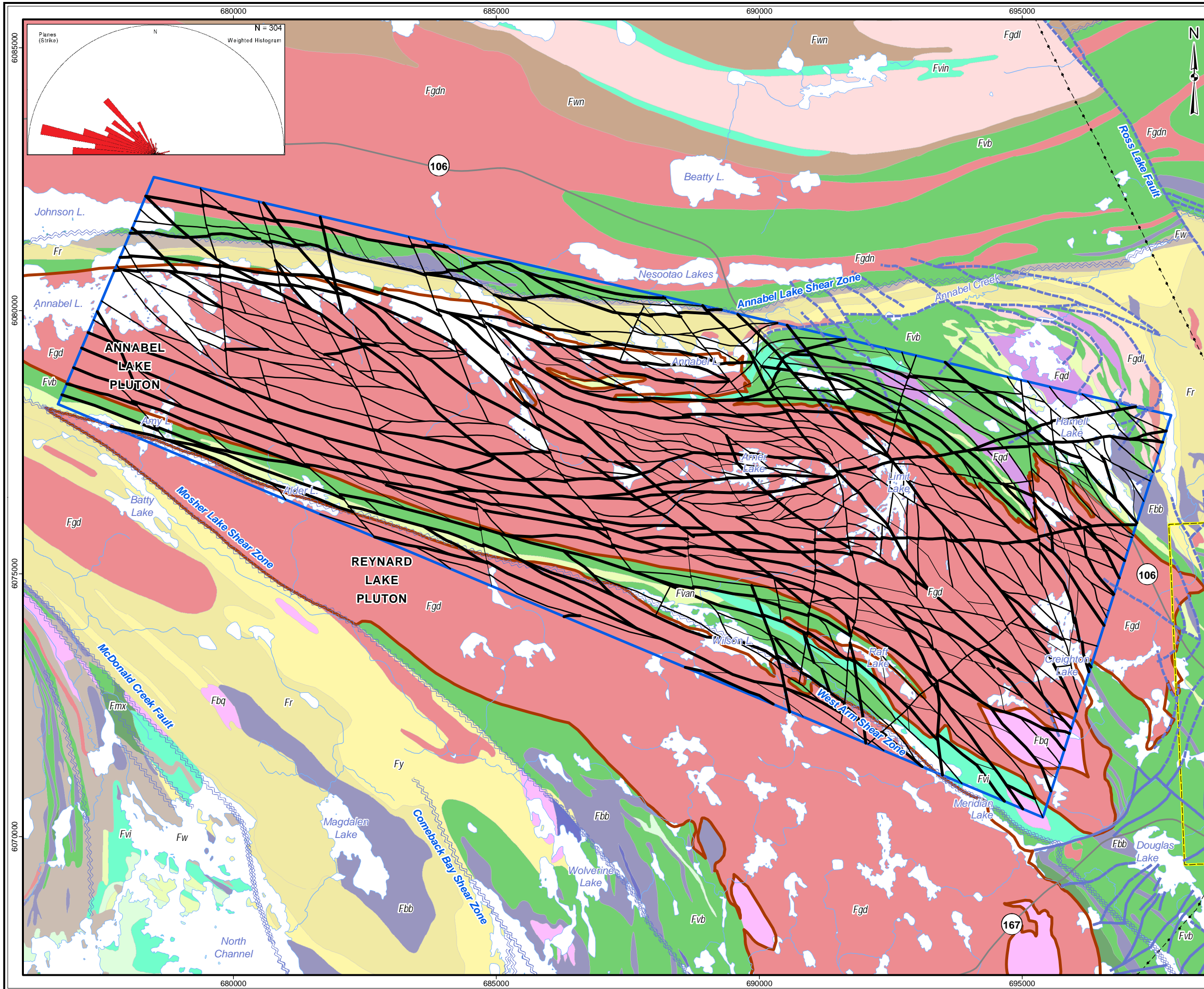NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Interpreted Lineaments
from Surficial Data
of the Creighton Area

DESIGN	KR	02 SEP 2014	REVISION 4
GIS	JA	13 FEB 2015	UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 11**	NAD 1983
REVIEW	AF	13 FEB 2015	1:70,000

File: SRK_NWMO_CR_Fig11_SurfRA1

Planes (Strike)
N = 1564
Weighted Histogram

Figure 12

LEGEND

- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
- Powerline
- Watercourse
- Waterbody
- Batholith / Pluton contact
- Mapped Faults
- Shear zone

Certainty
- 1
- 2
- 3

- gl: Alaskite-aplogranite
- Fr: Sandstone, crossbeded sandstone
- Fry: Pebbly sandstone, pebble conglomerate, sandstone
- Fy: Polymictic conglomerate, sandstone
- Fyn: Conglomerate gneiss, local psammitic gneiss
- Fw: Metagreywacke
- Fwn: Metagreywacke gneiss
- Fgdl: Leucogranodiorite-tonalite
- Fgd: Granodiorite-tonalite
- Fgdn: Foliated to gneissic granodiorite-tonalite
- Fbq: Tonalite-quartz diorite
- Fqd: Quartz diorite-granodiorite-diorite
- Fbb: Gabbro-diorite
- Fu: Ultramafic rock
- Fmx: Mafic protomylonite to mylonite
- Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
- Fva: Acid volcanics
- Fvan: Felsic gneiss defived from felsic volcanics
- Fvi: Intermediate volcanics
- Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
- Fvb: Basic volcanics
- Fvbn: Mafic gneiss derived from basic volcanics
- Fbn: Biotite gneiss +/-hornblende +/-garnet

Missi Group

Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
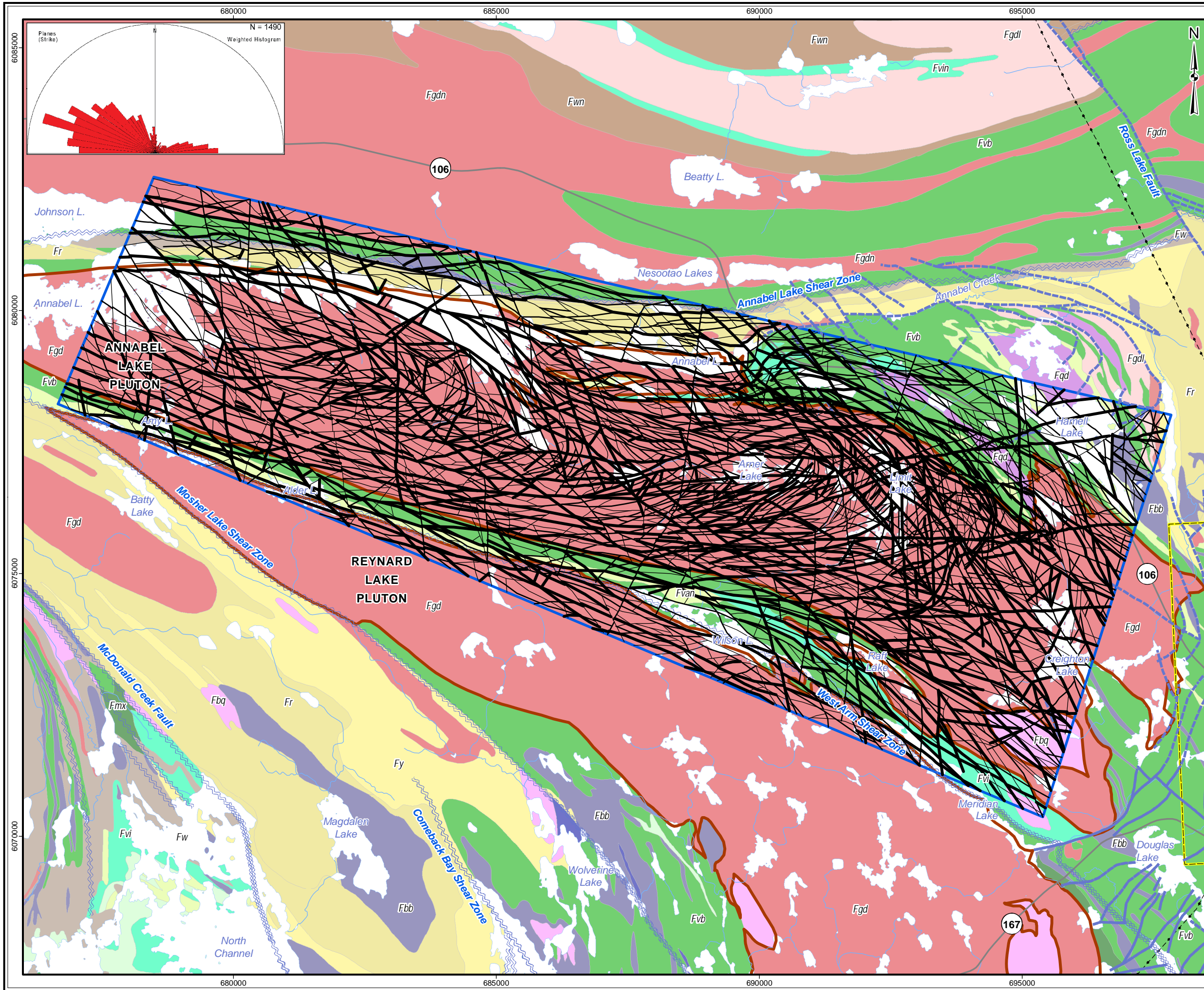NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Interpreted Lineaments
from Geophysical Data
of the Creighton Area

DESIGN	KR	02 SEP 2014	REVISION 3
GIS	JA	13 FEB 2015	UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 12**
REVIEW	AF	13 FEB 2015	NAD 1983

1:70,000

File: SRK_NWMO_CR_Fig12_GeophRA1

Figure 13. Final Integrated Interpreted Lineaments of the Creighton Area

LEGEND

- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
- Powerline
- Watercourse
- Waterbody
- Batholith / Pluton contact
- Mapped Faults
- Shear zone

Certainty
— 1
— 2
— 3

- gl: Alaskite-aplogranite
- Fr: Sandstone, crossbeded sandstone
- Fry: Pebbly sandstone, pebble conglomerate, sandstone
- Fy: Polymictic conglomerate, sandstone
- Fyn: Conglomerate gneiss, local psammitic gneiss
- Fw: Metagreywacke
- Fwn: Metagreywacke gneiss

Missi Group

- Fgdl: Leucogranodiorite-tonalite
- Fgd: Granodiorite-tonalite
- Fgdn: Foliated to gneissic granodiorite-tonalite
- Fbq: Tonalite-quartz diorite
- Fqd: Quartz diorite-granodiorite-diorite
- Fbb: Gabbro-diorite
- Fu: Ultramafic rock
- Fmx: Mafic protomylonite to mylonite
- Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
- Fva: Acid volcanics
- Fvan: Felsic gneiss defived from felsic volcanics
- Fvi: Intermediate volcanics
- Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
- Fvb: Basic volcanics
- Fvbn: Mafic gneiss derived from basic volcanics
- Fbn: Biotite gneiss +/-hornblende +/-garnet
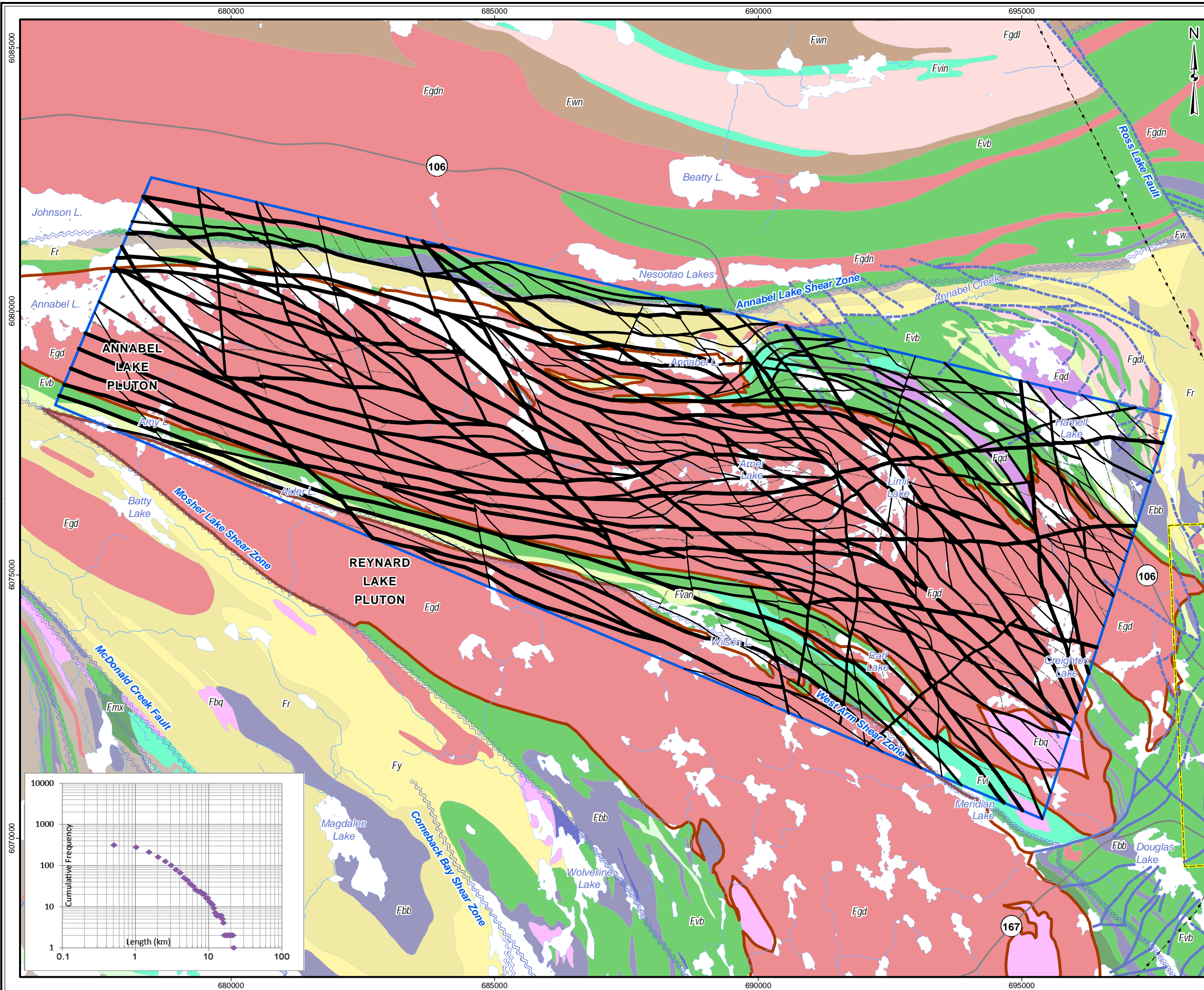
Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Final Integrated
Interpreted Lineaments
of the Creighton Area

DESIGN	KR	02 SEP 2014		REVISION 4
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	Figure 13	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

File: SRK_NWMO_CR_Fig13_FinalRA2

LEGEND

- ☐ (blue outline) Phase 2 Assessment Area
- ☐ (yellow outline) Creighton Municipal Boundary
- —— Major Road
- —•— Powerline
- —— Watercourse
- ☐ Waterbody
- —— Batholith / Pluton contact
- ─ ─ ─ Mapped Faults
- ∿∿∿ Shear zone

Length
- ─ ─ ─ <1 km
- —— 1 - 2.5
- —— 2.5 - 5
- ━━ >5 km

- gl: Alaskite-aplogranite
- Fr: Sandstone, crossbeded sandstone
- Fry: Pebbly sandstone, pebble conglomerate, sandstone
- Fy: Polymictic conglomerate, sandstone
- Fyn: Conglomerate gneiss, local psammitic gneiss
- Fw: Metagreywacke
- Fwn: Metagreywacke gneiss
- Fgdl: Leucogranodiorite-tonalite
- Fgd: Granodiorite-tonalite
- Fgdn: Foliated to gneissic granodiorite-tonalite
- Fbq: Tonalite-quartz diorite
- Fqd: Quartz diorite-granodiorite-diorite
- Fbb: Gabbro-diorite
- Fu: Ultramafic rock
- Fmx: Mafic protomylonite to mylonite
- Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
- Fva: Acid volcanics
- Fvan: Felsic gneiss defived from felsic volcanics
- Fvi: Intermediate volcanics
- Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
- Fvb: Basic volcanics
- Fvbn: Mafic gneiss derived from basic volcanics
- Fbn: Biotite gneiss +/-hornblende +/-garnet

Missi Group

Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT

Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE

Geophysical Lineaments by Length of the Creighton Area

DESIGN	KR	02 SEP 2014		REVISION 4
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 14**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

Figure 15 — Surficial Lineaments by Length of the Creighton Area

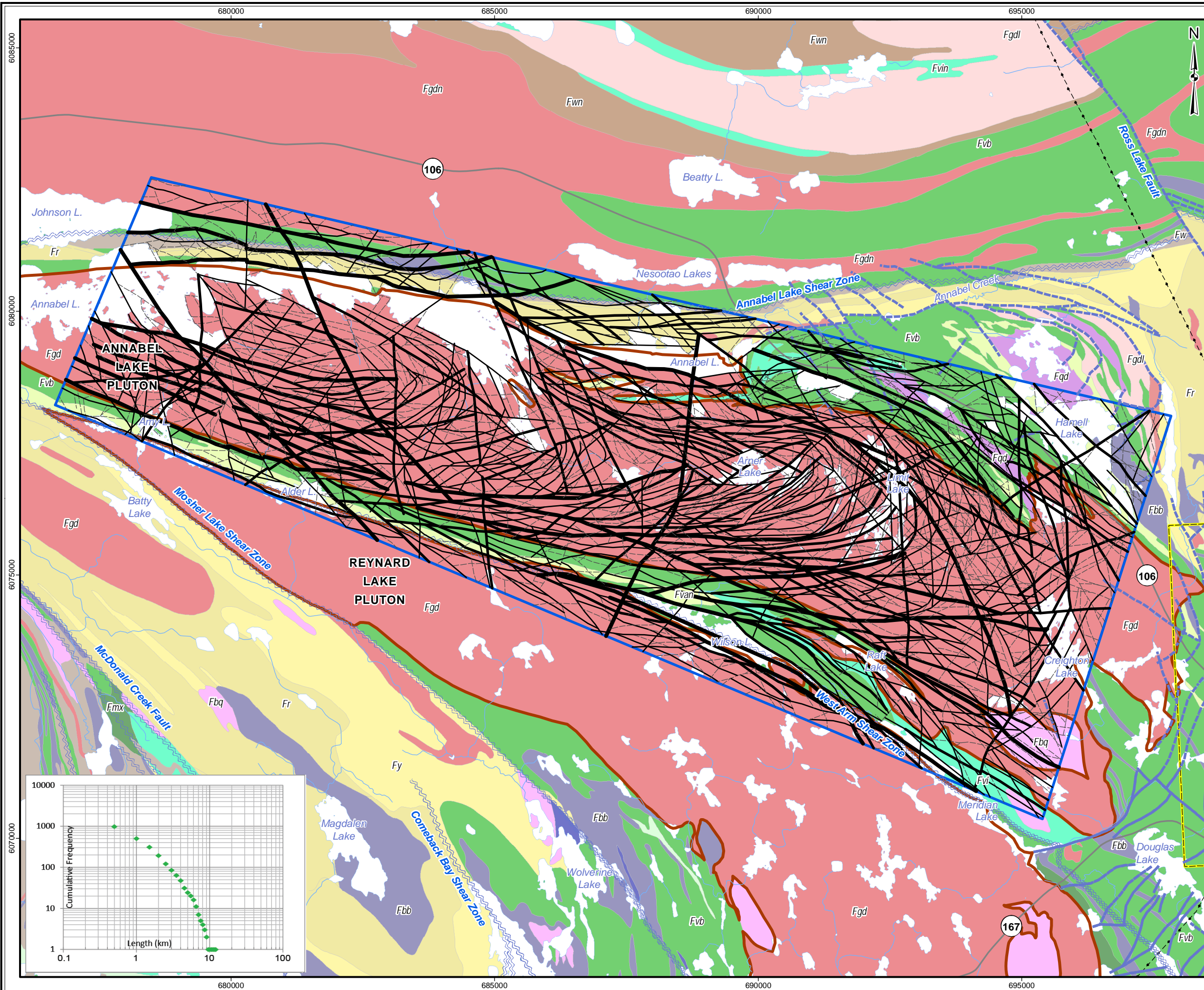Figure 16 — Final Integrated Lineaments by Length of the Creighton Area

LEGEND

Phase 2 Assessment Area
Creighton Municipal Boundary
Major Road
Powerline
Watercourse
Waterbody
Batholith / Pluton contact
Mapped Faults
Shear zone

Length
<1 km
1 - 2.5
2.5 - 5
>5 km

gl: Alaskite-aplogranite
Fr: Sandstone, crossbeded sandstone
Fry: Pebbly sandstone, pebble conglomerate, sandstone
Fy: Polymictic conglomerate, sandstone
Fyn: Conglomerate gneiss, local psammitic gneiss
Fw: Metagreywacke
Fwn: Metagreywacke gneiss
Fgdl: Leucogranodiorite-tonalite
Fgd: Granodiorite-tonalite
Fgdn: Foliated to gneissic granodiorite-tonalite
Fbq: Tonalite-quartz diorite
Fqd: Quartz diorite-granodiorite-diorite
Fbb: Gabbro-diorite
Fu: Ultramafic rock
Fmx: Mafic protomylonite to mylonite
Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
Fva: Acid volcanics
Fvan: Felsic gneiss defived from felsic volcanics
Fvi: Intermediate volcanics
Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
Fvb: Basic volcanics
Fvbn: Mafic gneiss derived from basic volcanics
Fbn: Biotite gneiss +/-hornblende +/-garnet

Missi Group
Flin Flon Assemblage

REFERENCE
Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
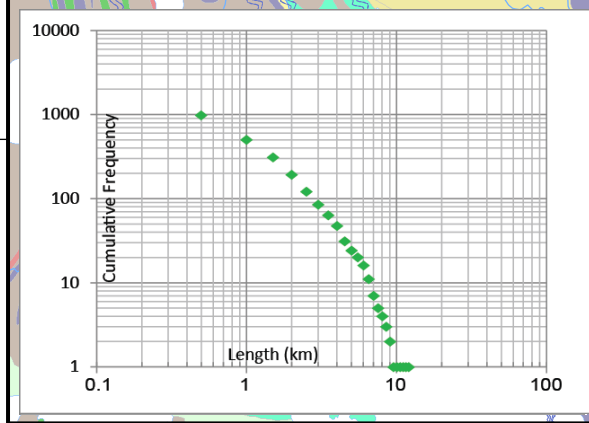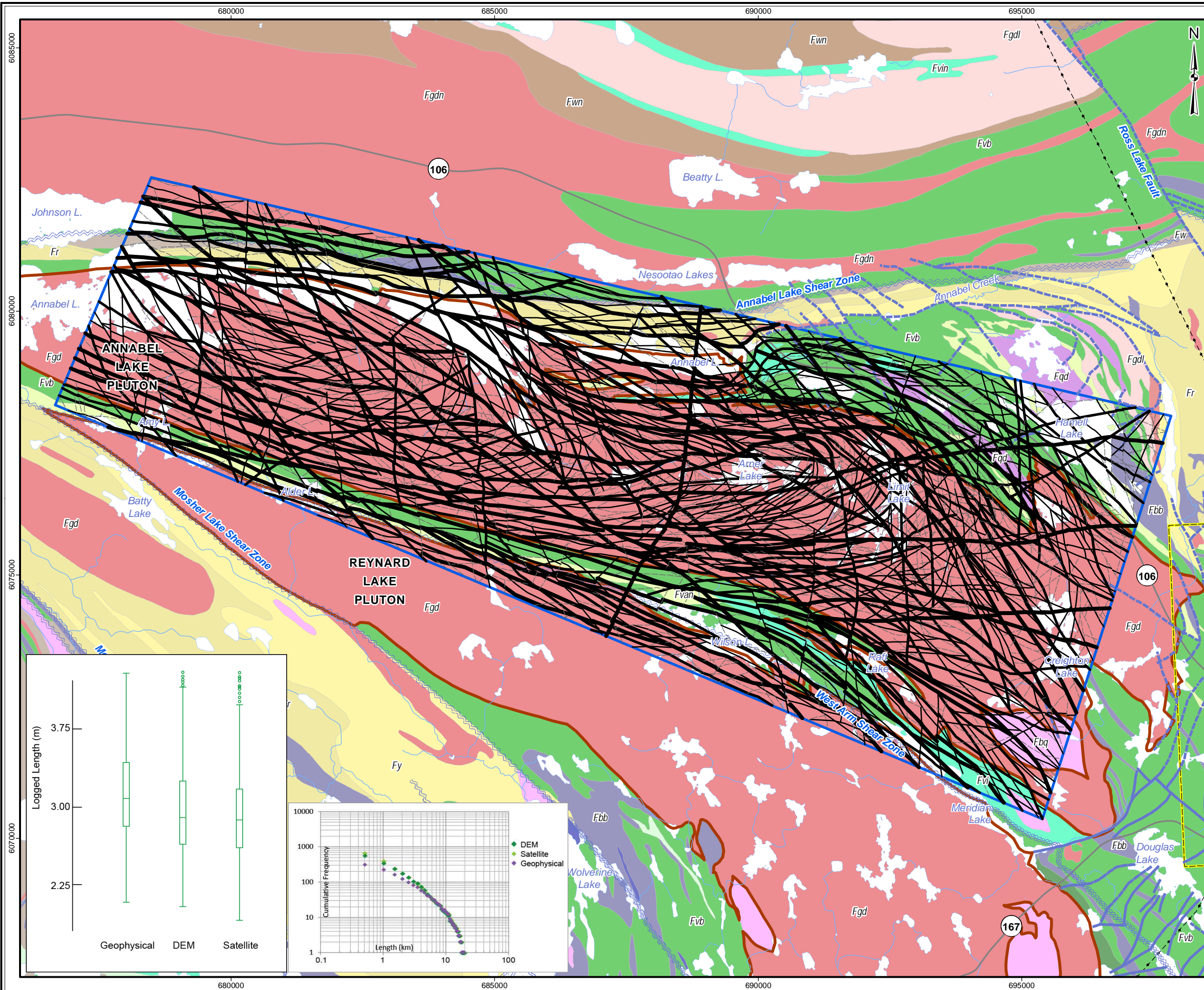NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Final Integrated Lineaments by Length of the Creighton Area

DESIGN	KR	02 SEP 2014
GIS	JA	13 FEB 2015
CHECK	CN	13 FEB 2015
REVIEW	AF	13 FEB 2015

REVISION 3
UTM ZONE 13N
NAD 1983

Figure 16

1:70,000

ANNABEL LAKE PLUTON

REYNARD LAKE PLUTON

Annabel Lake Shear Zone
Mosher Lake Shear Zone
West Arm Shear Zone
Ross Lake Fault

Johnson L.
Annabel L.
Beatty L.
Nesootao Lakes
Annabel Creek
Batty Lake
Alder L.
Amy L.
Arnel Lake
Wilson L.
Raft Lake
Hamell Lake
Creighton Lake
Meridian Lake
Douglas Lake
Wolverine Lake

SK   MB
Thompson
Flin Flon
Saskatoon

Figure 17. Geophysical Lineament Density of the Creighton Area

LEGEND

- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
- Powerline
- Watercourse
- Waterbody
- Batholith / Pluton contact
- Geophysical Lineament

Lineament Density

km/km²
High : 10.9123
Low : 0

gl: Alaskite-aplogranite
Fr: Sandstone, crossbeded sandstone
Fry: Pebbly sandstone, pebble conglomerate, sandstone
Fy: Polymictic conglomerate, sandstone — *Missi Group*
Fyn: Conglomerate gneiss, local psammitic gneiss
Fw: Metagreywacke
Fwn: Metagreywacke gneiss
Fgdl: Leucogranodiorite-tonalite
Fgd: Granodiorite-tonalite
Fgdn: Foliated to gneissic granodiorite-tonalite
Fbq: Tonalite-quartz diorite
Fqd: Quartz diorite-granodiorite-diorite
Fbb: Gabbro-diorite
Fu: Ultramafic rock
Fmx: Mafic protomylonite to mylonite
Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry — *Flin Flon Assemblage*
Fva: Acid volcanics
Fvan: Felsic gneiss defived from felsic volcanics
Fvi: Intermediate volcanics
Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
Fvb: Basic volcanics
Fvbn: Mafic gneiss derived from basic volcanics
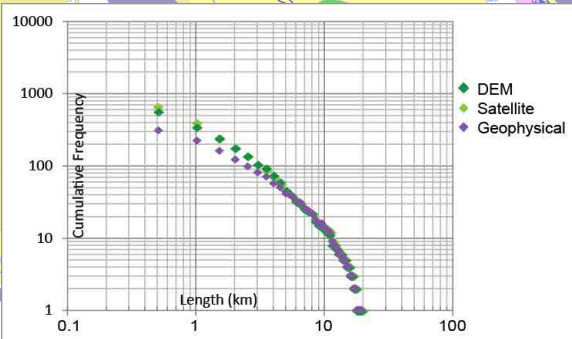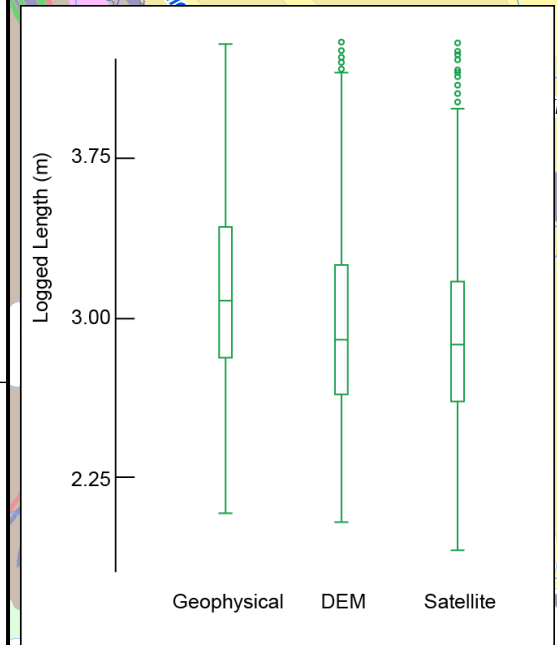Fbn: Biotite gneiss +/-hornblende +/-garnet

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
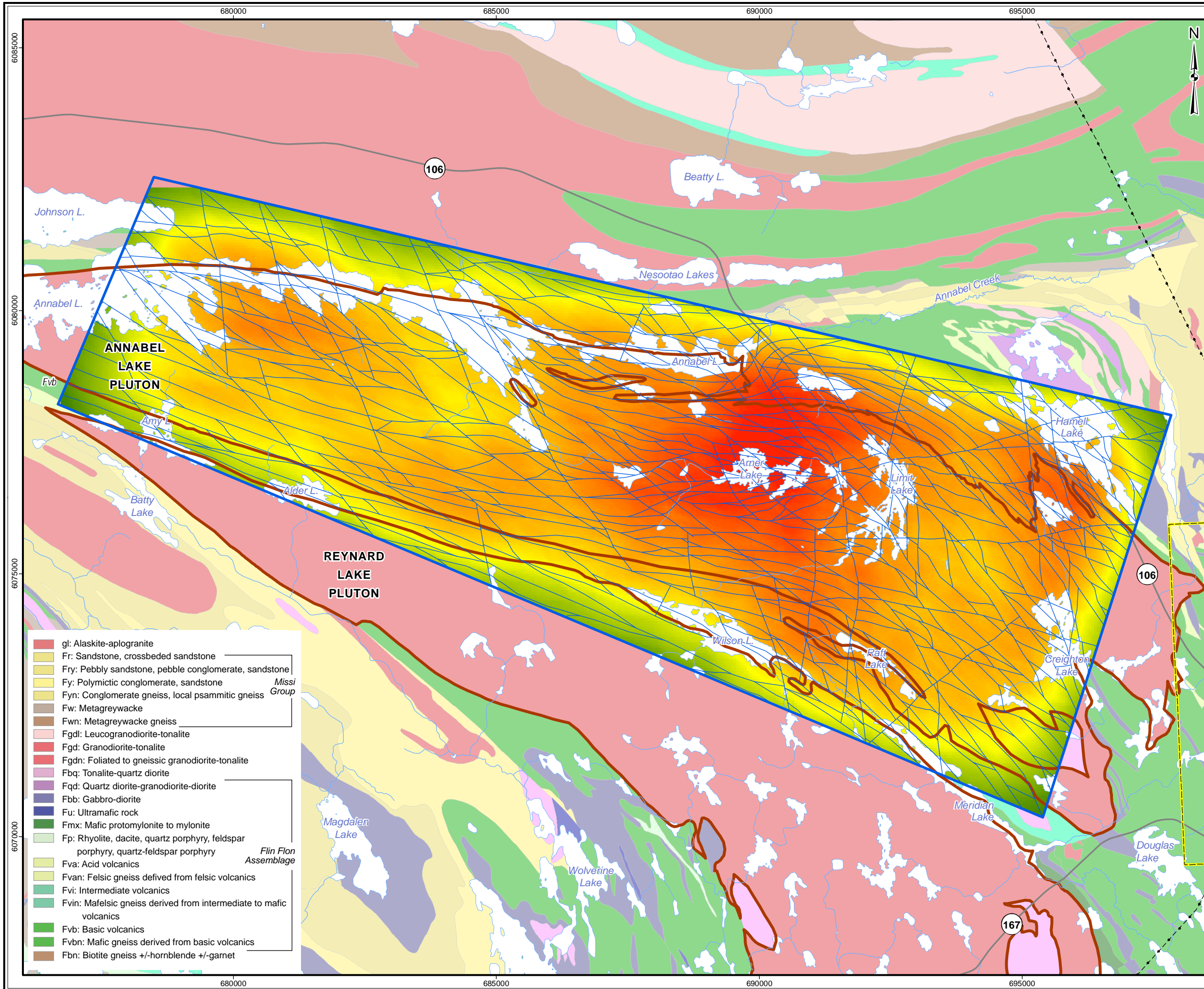NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Geophysical Lineament Density of the Creighton Area

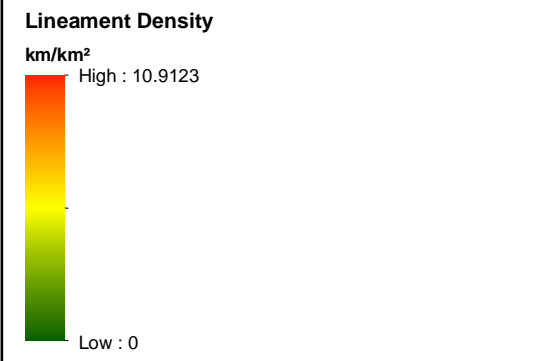|			
DESIGN	KR	02 SEP 2014	REVISION 3
GIS	JA	13 FEB 2015	UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 17** NAD 1983
REVIEW	AF	13 FEB 2015	1:70,000

File: SRK_NWMO_CR_Fig17_GeophDENSL

LEGEND

- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
- Powerline
- Watercourse
- Waterbody
- Batholith / Pluton contact
- Surficial Lineament

Lineament Density

km/km²

High : 19.8997

Low : 0

gl: Alaskite-aplogranite
Fr: Sandstone, crossbeded sandstone
Fry: Pebbly sandstone, pebble conglomerate, sandstone
Fy: Polymictic conglomerate, sandstone
Fyn: Conglomerate gneiss, local psammitic gneiss
Fw: Metagreywacke
Fwn: Metagreywacke gneiss
Fgdl: Leucogranodiorite-tonalite
Fgd: Granodiorite-tonalite
Fgdn: Foliated to gneissic granodiorite-tonalite
Fbq: Tonalite-quartz diorite
Fqd: Quartz diorite-granodiorite-diorite
Fbb: Gabbro-diorite
Fu: Ultramafic rock
Fmx: Mafic protomylonite to mylonite
Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
Fva: Acid volcanics
Fvan: Felsic gneiss defived from felsic volcanics
Fvi: Intermediate volcanics
Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
Fvb: Basic volcanics
Fvbn: Mafic gneiss derived from basic volcanics
Fbn: Biotite gneiss +/-hornblende +/-garnet

Missi Group

Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Surficial Lineament Density of the Creighton Area

DESIGN	KR	02 SEP 2014		REVISION 3
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 18**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

File: SRK_NWMO_CR_Fig18_SurfDENSL

LEGEND

- ▭ Phase 2 Assessment Area
- ▭ Creighton Municipal Boundary
- — Major Road
- –·– Powerline
- — Watercourse
- ▭ Waterbody
- — Batholith / Pluton contact
- — Final Integrated Lineament

Lineament Density

km/km²

High : 21.7917

Low : 0

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
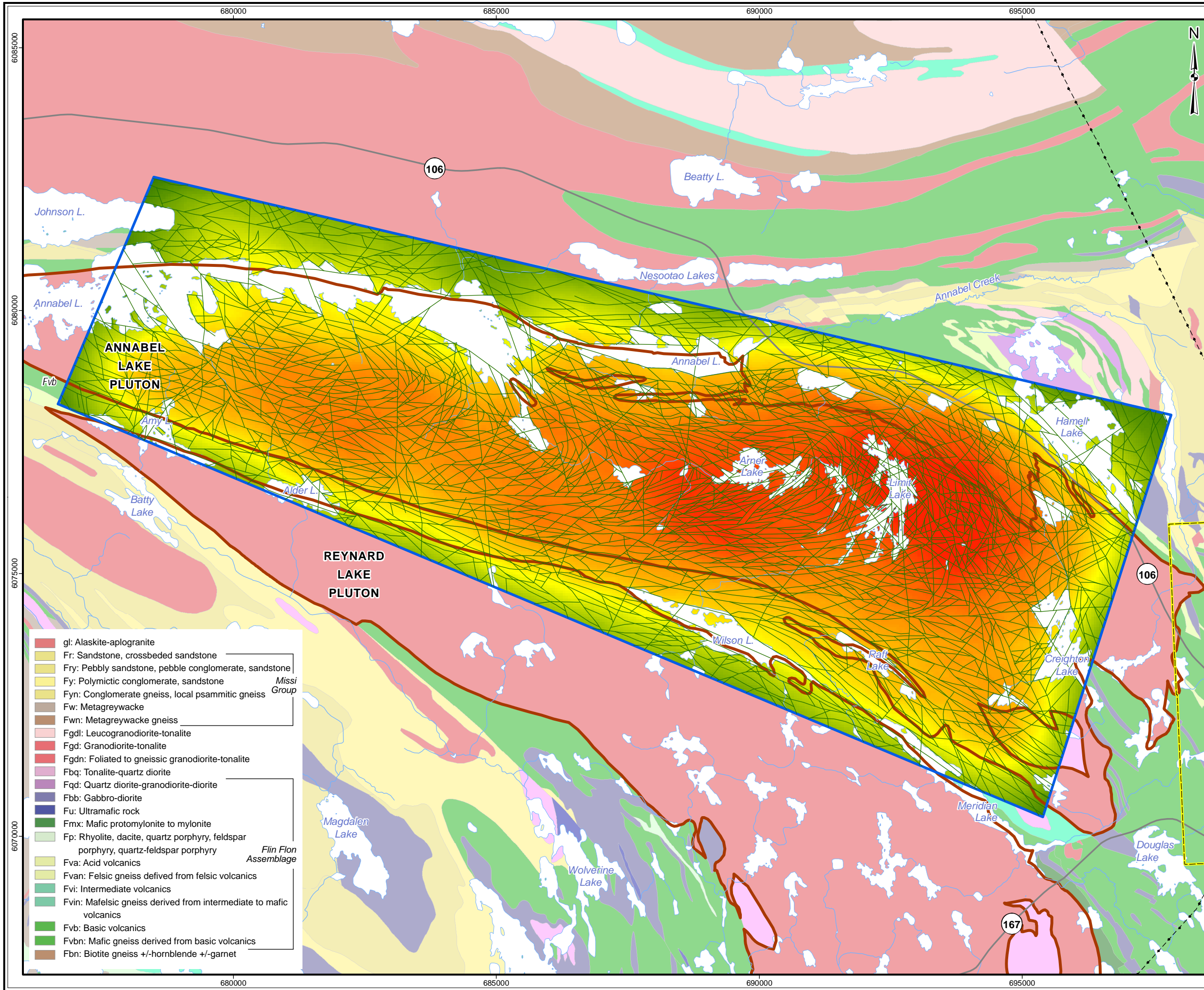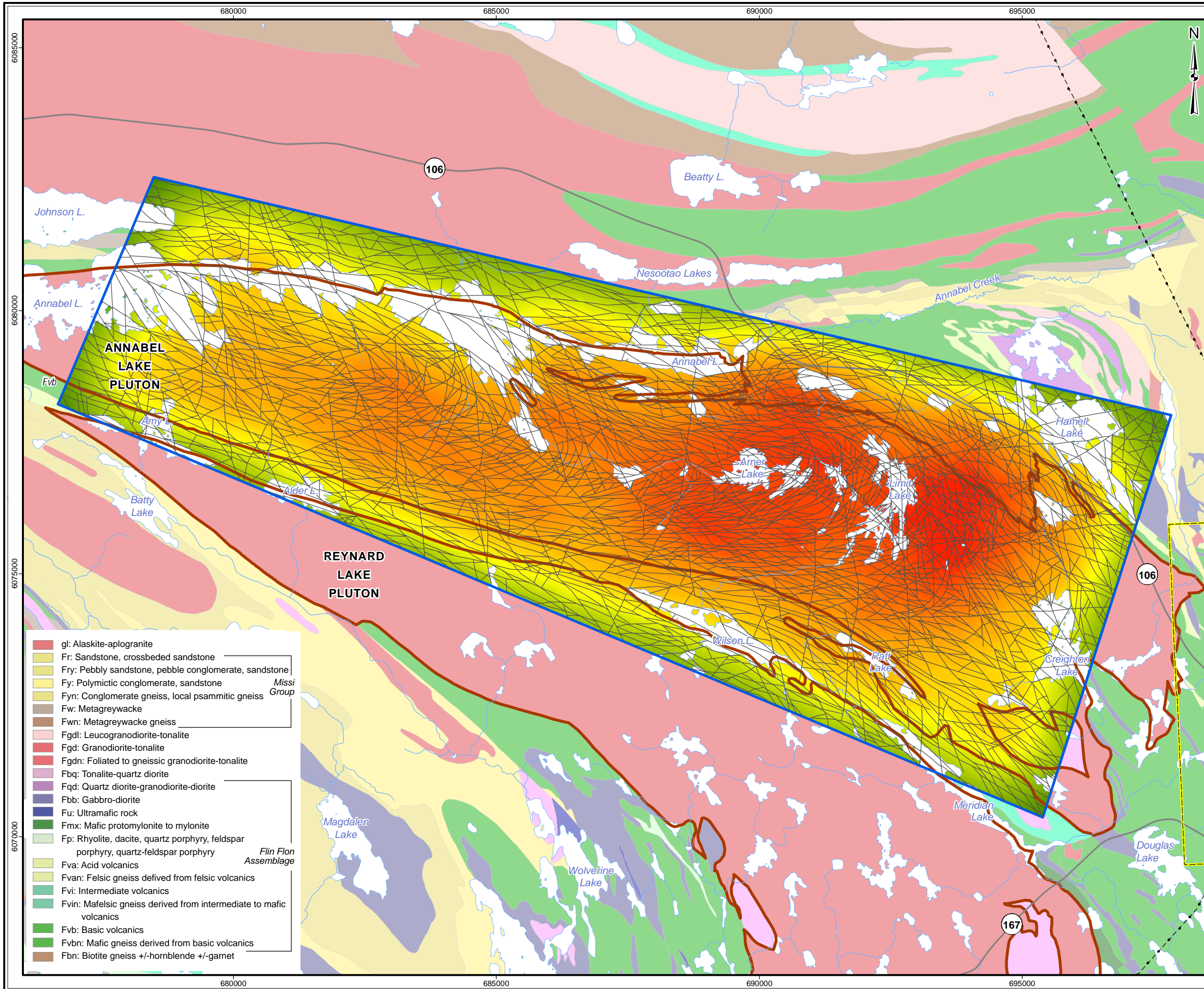NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
**Final Integrated Lineament Density
of the Creighton Area**

DESIGN	KR	02 SEP 2014		REVISION 3
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 19**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

gl: Alaskite-aplogranite
Fr: Sandstone, crossbeded sandstone
Fry: Pebbly sandstone, pebble conglomerate, sandstone
Fy: Polymictic conglomerate, sandstone
Fyn: Conglomerate gneiss, local psammitic gneiss
Fw: Metagreywacke
Fwn: Metagreywacke gneiss
Fgdl: Leucogranodiorite-tonalite
Fgd: Granodiorite-tonalite
Fgdn: Foliated to gneissic granodiorite-tonalite
Fbq: Tonalite-quartz diorite
Fqd: Quartz diorite-granodiorite-diorite
Fbb: Gabbro-diorite
Fu: Ultramafic rock
Fmx: Mafic protomylonite to mylonite
Fp: Rhyolite, dacite, quartz porphyry, feldspar
   porphyry, quartz-feldspar porphyry
Fva: Acid volcanics
Fvan: Felsic gneiss defived from felsic volcanics
Fvi: Intermediate volcanics
Fvin: Mafelsic gneiss derived from intermediate to mafic
   volcanics
Fvb: Basic volcanics
Fvbn: Mafic gneiss derived from basic volcanics
Fbn: Biotite gneiss +/-hornblende +/-garnet

Missi Group

Flin Flon Assemblage

File: SRK_NWMO_CR_Fig19_FinalDENSL

LEGEND

- ▭ Phase 2 Assessment Area
- ▭ Creighton Municipal Boundary
- — Major Road
- -·-· Powerline
- — Watercourse
- ▭ Waterbody
- — Batholith / Pluton contact
- — Geophysical Lineament
- ▲ Geophysical Lineament Intersection

Lineament Intersection Density

Intersections/km²

High : 22.0016

Low : 0

Legend (geology units)

- gl: Alaskite-aplogranite
- Fr: Sandstone, crossbeded sandstone
- Fry: Pebbly sandstone, pebble conglomerate, sandstone
- Fy: Polymictic conglomerate, sandstone
- Fyn: Conglomerate gneiss, local psammitic gneiss
- Fw: Metagreywacke
- Fwn: Metagreywacke gneiss

Missi Group

- Fgdl: Leucogranodiorite-tonalite
- Fgd: Granodiorite-tonalite
- Fgdn: Foliated to gneissic granodiorite-tonalite
- Fbq: Tonalite-quartz diorite
- Fqd: Quartz diorite-granodiorite-diorite
- Fbb: Gabbro-diorite
- Fu: Ultramafic rock
- Fmx: Mafic protomylonite to mylonite
- Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
- Fva: Acid volcanics
- Fvan: Felsic gneiss defived from felsic volcanics
- Fvi: Intermediate volcanics
- Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
- Fvb: Basic volcanics
- Fvbn: Mafic gneiss derived from basic volcanics
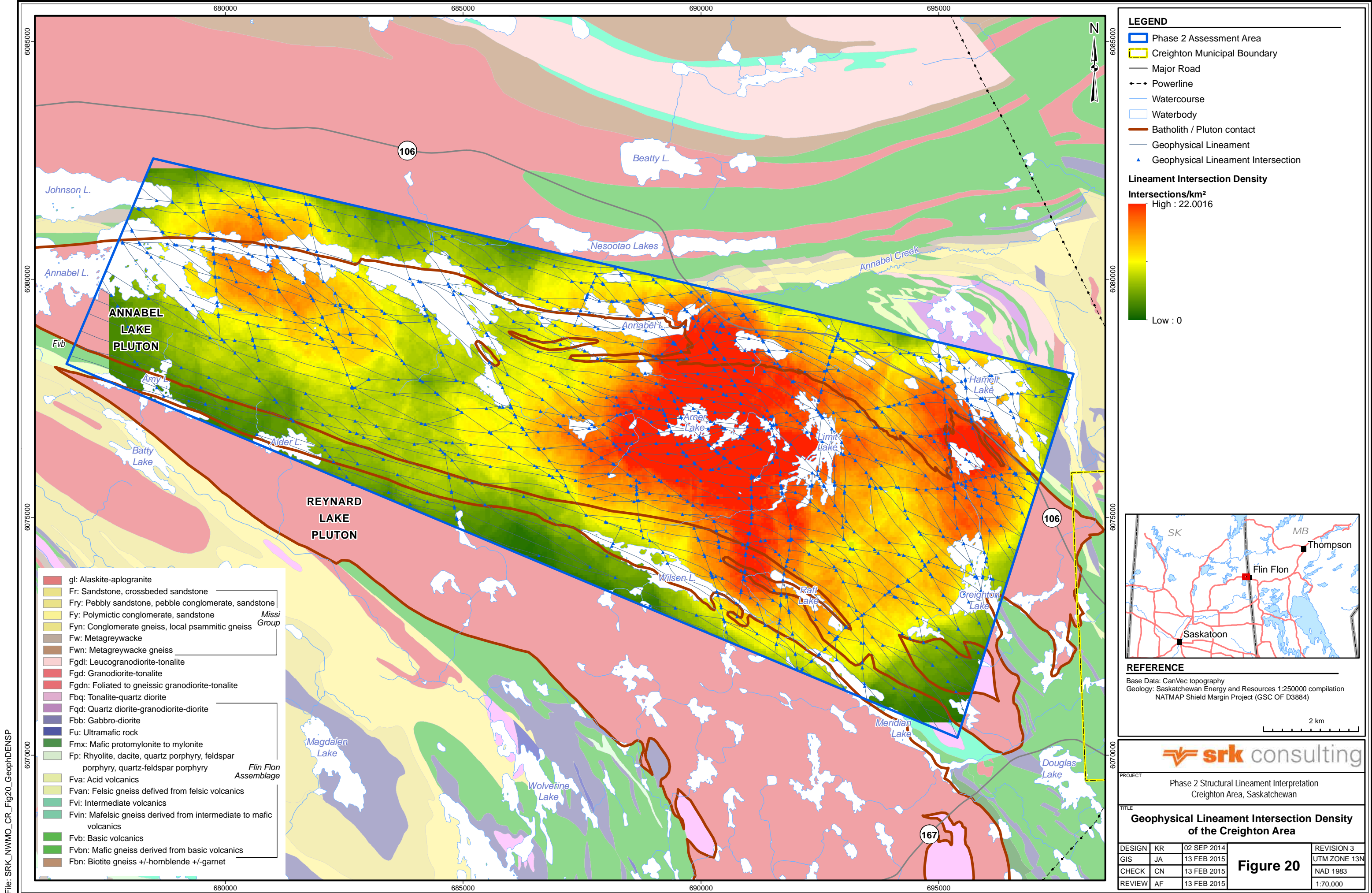- Fbn: Biotite gneiss +/-hornblende +/-garnet

Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
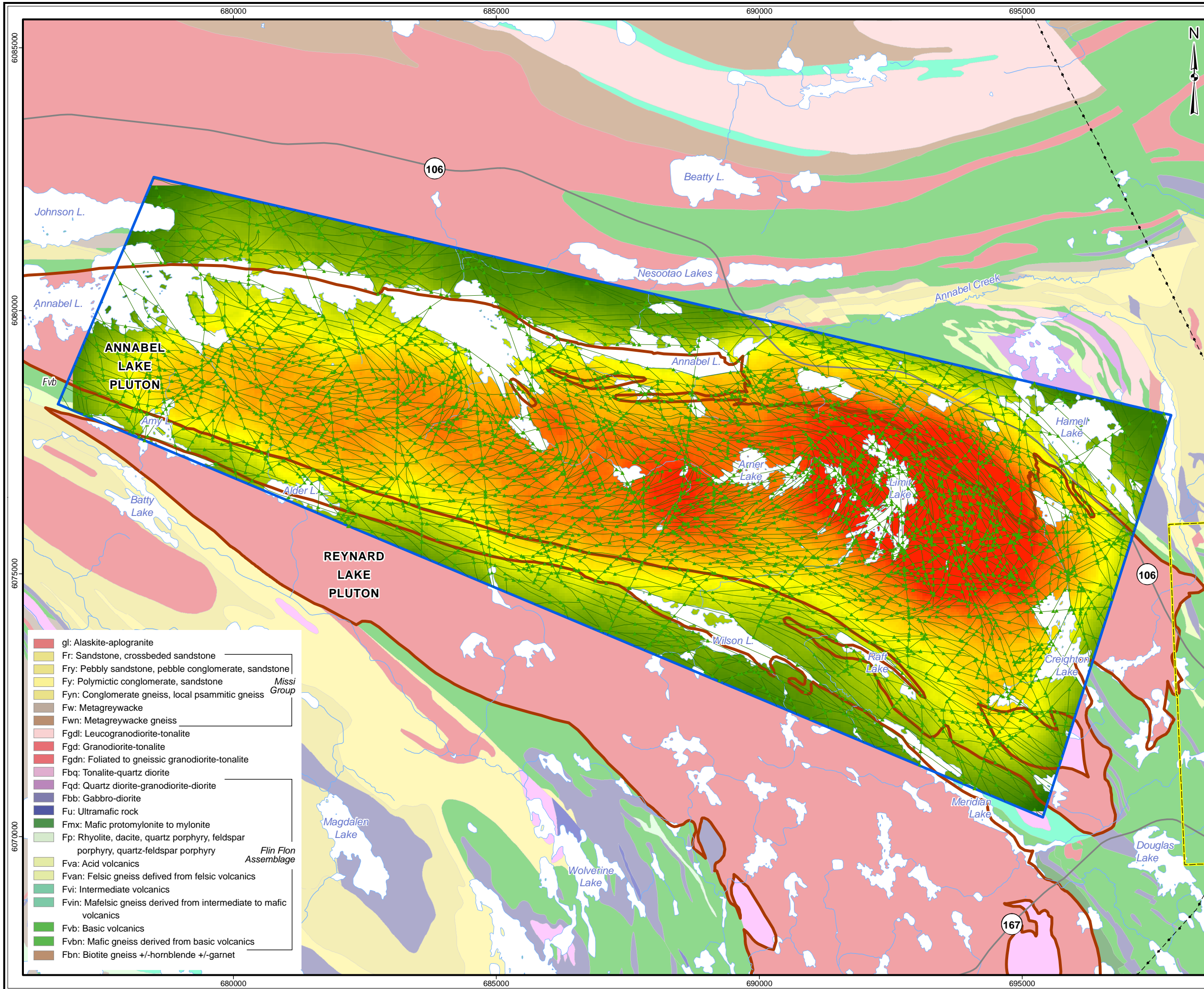NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Geophysical Lineament Intersection Density of the Creighton Area

					REVISION 3
DESIGN	KR	02 SEP 2014			UTM ZONE 13N
GIS	JA	13 FEB 2015		**Figure 20**	NAD 1983
CHECK	CN	13 FEB 2015			
REVIEW	AF	13 FEB 2015			1:70,000

File: SRK_NWMO_CR_Fig20_GeophDENSP

Figure 21

LEGEND

	Phase 2 Assessment Area
	Creighton Municipal Boundary
	Major Road
	Powerline
	Watercourse
	Waterbody
	Batholith / Pluton contact
	Surficial Lineament
▲	Surficial Lineament Intersection

Lineament Intersection Density

Intersections/km²
High : 100.637

Low : 0

gl: Alaskite-aplogranite
Fr: Sandstone, crossbeded sandstone
Fry: Pebbly sandstone, pebble conglomerate, sandstone
Fy: Polymictic conglomerate, sandstone   *Missi Group*
Fyn: Conglomerate gneiss, local psammitic gneiss
Fw: Metagreywacke
Fwn: Metagreywacke gneiss
Fgdl: Leucogranodiorite-tonalite
Fgd: Granodiorite-tonalite
Fgdn: Foliated to gneissic granodiorite-tonalite
Fbq: Tonalite-quartz diorite
Fqd: Quartz diorite-granodiorite-diorite
Fbb: Gabbro-diorite
Fu: Ultramafic rock
Fmx: Mafic protomylonite to mylonite
Fp: Rhyolite, dacite, quartz porphyry, feldspar
    porphyry, quartz-feldspar porphyry   *Flin Flon Assemblage*
Fva: Acid volcanics
Fvan: Felsic gneiss derived from felsic volcanics
Fvi: Intermediate volcanics
Fvin: Mafelsic gneiss derived from intermediate to mafic
    volcanics
Fvb: Basic volcanics
Fvbn: Mafic gneiss derived from basic volcanics
Fbn: Biotite gneiss +/-hornblende +/-garnet

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
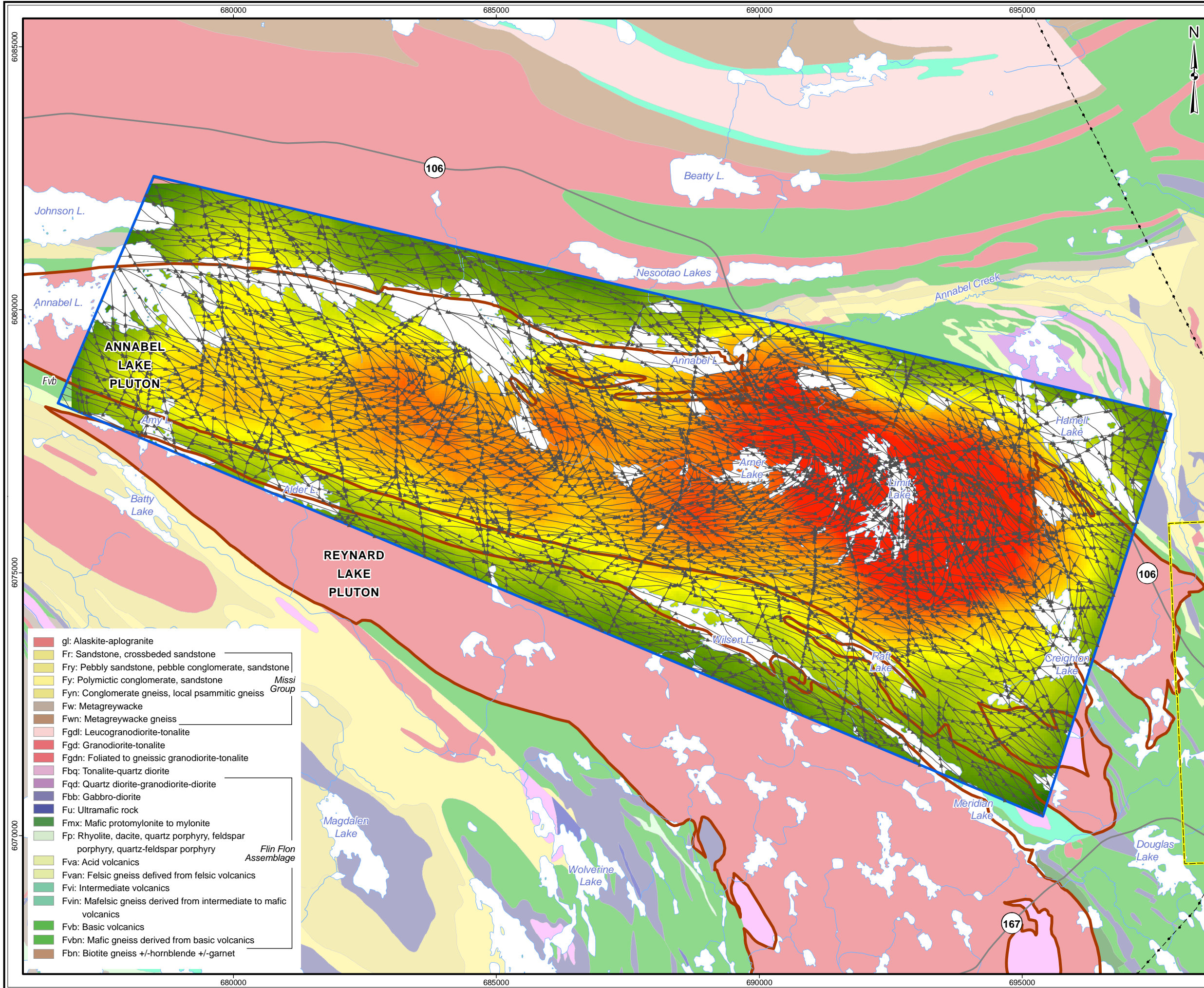   NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
**Surficial Lineament Intersection Density
of the Creighton Area**

DESIGN	KR	02 SEP 2014		REVISION 3
GIS	JA	13 FEB 2015		UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 21**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

File: SRK_NWMO_CR_Fig21_SurfDENSP

LEGEND

- ☐ Phase 2 Assessment Area
- ☐ Creighton Municipal Boundary
- —— Major Road
- -●-●- Powerline
- —— Watercourse
- ☐ Waterbody
- —— Batholith / Pluton contact
- —— Final Integrated Lineament
- ▲ Final Integrated Lineament Intersection

Lineament Intersection Density

Intersections/km²

High : 161.141

Low : 0

gl: Alaskite-aplogranite
Fr: Sandstone, crossbeded sandstone
Fry: Pebbly sandstone, pebble conglomerate, sandstone
Fy: Polymictic conglomerate, sandstone
Fyn: Conglomerate gneiss, local psammitic gneiss
Fw: Metagreywacke
Fwn: Metagreywacke gneiss
Fgdl: Leucogranodiorite-tonalite
Fgd: Granodiorite-tonalite
Fgdn: Foliated to gneissic granodiorite-tonalite
Fbq: Tonalite-quartz diorite
Fqd: Quartz diorite-granodiorite-diorite
Fbb: Gabbro-diorite
Fu: Ultramafic rock
Fmx: Mafic protomylonite to mylonite
Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
Fva: Acid volcanics
Fvan: Felsic gneiss defived from felsic volcanics
Fvi: Intermediate volcanics
Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
Fvb: Basic volcanics
Fvbn: Mafic gneiss derived from basic volcanics
Fbn: Biotite gneiss +/-hornblende +/-garnet

Missi Group

Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
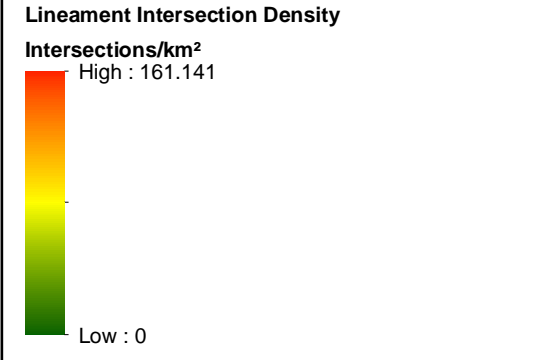Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Final Integrated Lineament Intersection Density of the Creighton Area

DESIGN	KR	02 SEP 2014	REVISION 3
GIS	JA	13 FEB 2015	UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 22**	NAD 1983
REVIEW	AF	13 FEB 2015		1:70,000

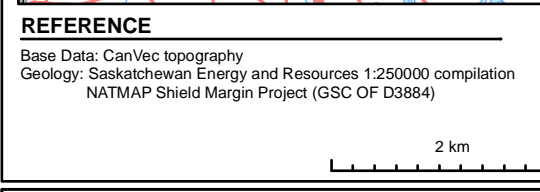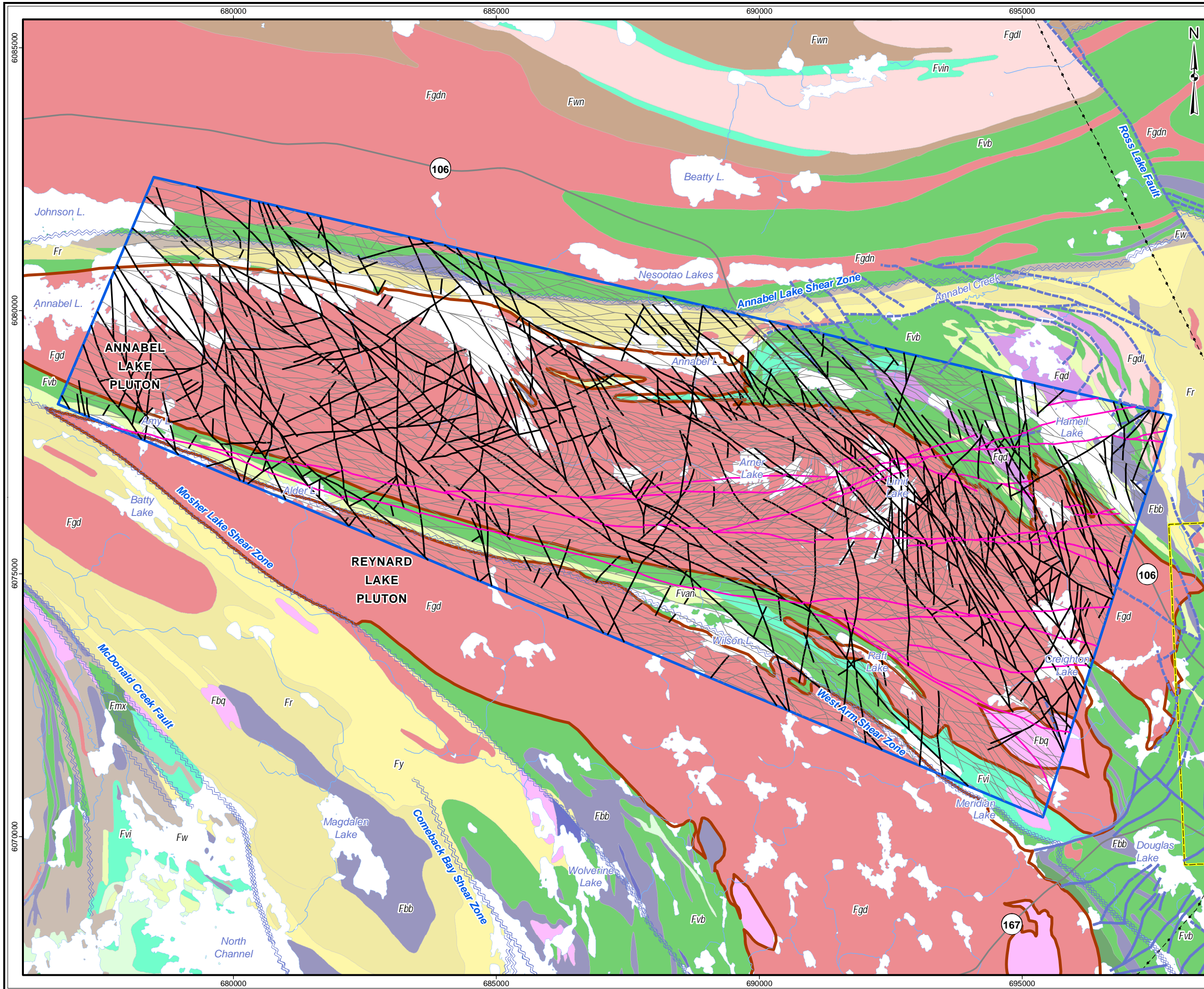Figure 23. Lineament Truncation and Relative Age Relationships of the Creighton Area

LEGEND

- Phase 2 Assessment Area
- Creighton Municipal Boundary
- Major Road
- Powerline
- Watercourse
- Waterbody
- Batholith / Pluton contact
- Mapped Faults
- Shear zone

Relative Age
- D2-D4
- D4
- D5/D6

- gl: Alaskite-aplogranite
- Fr: Sandstone, crossbeded sandstone
- Fry: Pebbly sandstone, pebble conglomerate, sandstone
- Fy: Polymictic conglomerate, sandstone
- Fyn: Conglomerate gneiss, local psammitic gneiss — *Missi Group*
- Fw: Metagreywacke
- Fwn: Metagreywacke gneiss
- Fgdl: Leucogranodiorite-tonalite
- Fgd: Granodiorite-tonalite
- Fgdn: Foliated to gneissic granodiorite-tonalite
- Fbq: Tonalite-quartz diorite
- Fqd: Quartz diorite-granodiorite-diorite
- Fbb: Gabbro-diorite
- Fu: Ultramafic rock
- Fmx: Mafic protomylonite to mylonite
- Fp: Rhyolite, dacite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry
- Fva: Acid volcanics
- Fvan: Felsic gneiss defived from felsic volcanics
- Fvi: Intermediate volcanics
- Fvin: Mafelsic gneiss derived from intermediate to mafic volcanics
- Fvb: Basic volcanics
- Fvbn: Mafic gneiss derived from basic volcanics
- Fbn: Biotite gneiss +/-hornblende +/-garnet

Flin Flon Assemblage

REFERENCE

Base Data: CanVec topography
Geology: Saskatchewan Energy and Resources 1:250000 compilation
NATMAP Shield Margin Project (GSC OF D3884)

2 km

srk consulting

PROJECT
Phase 2 Structural Lineament Interpretation
Creighton Area, Saskatchewan

TITLE
Lineament Truncation and Relative Age Relationships of the Creighton Area

DESIGN	KR	02 SEP 2014	REVISION 3
GIS	JA	13 FEB 2015	UTM ZONE 13N
CHECK	CN	13 FEB 2015	**Figure 23** NAD 1983
REVIEW	AF	13 FEB 2015	1:70,000

File: SRK_NWMO_CR_Fig23_FinalRELAGE