GS-2 Geology and geochemistry of the Schist Lake mine area, Flin Flon, Manitoba (part of NTS 63K12)

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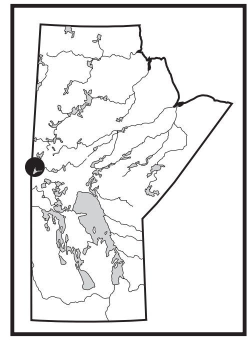

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Summary

The goal of this two-year research project is to characterize and describe the Schist Lake and Mandy volcanogenic massive sulphide (VMS) deposits and their hostrocks, and to determine if these VMS deposits are time-stratigraphic equivalent to those occurring in the main Flin Flon camp. The first year of this project focused on the area around the Schist Lake mine, where detailed lithofacies and alteration facies maps were completed, along with detailed field descriptions of each lithofacies. The mine is hosted by a succession of mafic and felsic volcaniclastic rocks that were deposited in a basin environment. Geochemical study of these rocks has shown that all lithofacies share common interelement ratios and can be divided into three or possibly four populations, including a mafic population, a felsic population, a bedded tuff facies, and a couple of 'odd' samples making up a possible fourth, felsic population. A preliminary alteration study illustrates that most of the samples have undergone extensive chlorite (and minor pyrite) alteration that is typical of VMS deposits. A thorough geochemical analysis of the hostrocks and alteration will be undertaken pending geochemical results from the systematic drillcore samples collected during the summer of 2008.

Introduction

The Flin Flon district of the Paleoproterozoic Flin Flon Belt is one of the most productive base-metal districts in Canada, hosting numerous world-class volcanogenic massive sulphide (VMS) deposits. Three current (Callinan, Triple 7 and Trout Lake) and three past-producing (Flin Flon, Mandy and Schist Lake) VMS deposits occur in the immediate vicinity of the town of Flin Flon. Extensive mapping and research have been undertaken in the area in the 1980s and 1990s as part of various Manitoba Geological Survey (MGS) and Geological Survey of Canada (GSC) initiatives (e.g., Syme and Bailes, 1993; Lucas et al., 1996) and more recently as projects funded by the Natural Sciences and Engineering Council of Canada (NSERC; Devine et al., 2002; DeWolfe and Gibson, 2006) and as part of the Targeted Geoscience Initiative (TGI3; MacLachlan, 2006; MacLachlan and Devine, 2007; Simard, 2006, 2007; Cole et al., 2007; Lewis et al., 2007). Despite this history and volume of work, there are fundamental uncertainties regarding the stratigraphic and temporal relationship between the main deposits — Callinan, Triple 7 and Flin Flon — and the Schist Lake–Mandy deposits located just a few kilometres to the south of the main camp. The objective of this research is to document the volcanic and structural setting of the Schist Lake and Mandy deposits, document the alteration types associated with these deposits, and ultimately compare the Schist Lake and Mandy deposits with the aforementioned current VMS deposits of the main Flin Flon camp.

As part of the detailed lithofacies mapping conducted in the 2007 field season, an extensive geochemical study was undertaken to 1) determine if the mapped lithofacies are compositionally uniform and unique, 2) define contacts that are otherwise difficult to determine due to the amount of alteration present, 3) determine the composition of the different lithofacies, and 4) determine the alteration types. The geochemical, lithofacies analytical and lithofacies geochronological results of these studies will provide a basis for comparing the strata of the area around the Schist Lake mine to that of the main Flin Flon camp. This report presents an up-to-date summary of the geochemical results of the study.

Work completed in the 2008 field season included mapping at a 1:1000 scale and logging of representative drillcore. Mapping and sampling was directed at completing coverage of the Schist Lake–Mandy area in order to 1) define strata hosting the Schist Lake–Mandy VMS deposits, 2) resolve structural complexities near the former mines, and 3) determine the structural and stratigraphic relationships between the Schist Lake–Mandy strata and a succession of basalt to the west that have been correlated with those of the Hidden formation (Simard, 2007). Determining if this contact is structural (fault) or stratigraphic is key to resolving if the Schist Lake–Mandy strata occur within the Flin Flon Block, as proposed by Bailes and Syme (1989), or in the Hook Lake Block, as recently proposed by Simard (2007). Drillcore from five drillholes (SCH-7 – 977 m, SCH-10 – 1065 m, SCH-3 – 1403 m, SCH-9 – 494 m and SCH-15 – 584 m) that intersect and crosscut strata hosting and along strike of the Schist Lake and Mandy VMS deposits was logged and sampled in order to 1) establish

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the stratigraphy hosting the Schist Lake–Mandy VMS deposits, 2) determine alteration types associated with the deposits, and 3) refine structural interpretations. The drillcore was systematically sampled for geochemical analysis and thin sections at 30 m intervals and/or at a change in lithofacies. Two samples were taken from drillcore for geochronology, one from a coherent rhyolite hosting the Schist Lake VMS deposit in drillhole SCH-10 and one from an interbedded argillite-siltstone unit in drillhole SCH-3. Analytical results from 2008 fieldwork are pending and will be reported in a future MGS publication.

Regional geology

The Paleoproterozoic Trans-Hudson Orogen (THO) is a collisional belt that extends from South Dakota through Saskatchewan, Manitoba and northern Quebec into Greenland (Figure GS-2-1). It formed during a ca. 1850–1780 Ma collision of at least two Archean cratons: the Superior craton to the east and the Rae-Hearne craton to the west (Hoffman, 1988; Lewry and Collerson, 1990; Lewry et al., 1994; Corrigan et al., 2005, 2007).

The Flin Flon Belt has been subdivided into four main tectonostratigraphic assemblages that formed at ca. 1.90–1.85 Ga: isotopically juvenile oceanic arc, ocean floor, oceanic plateau–ocean island and isotopically evolved oceanic arc rocks (Syme, 1990; Syme and Bailes, 1993; Stern et al., 1995). Volcanic rocks in the Flin Flon area are part of a ca. 1903–1890 Ma juvenile arc assemblage (Syme et al., 1999), consisting mostly of subaqueous mafic rocks with associated volcaniclastic deposits, minor felsic flows and volcaniclastic rocks (Bailes and Syme, 1989). Juvenile arc assemblages host all 27 known VMS deposits in the Flin Flon greenstone belt, including the Mandy and Schist Lake deposits (Syme et al., 1999).

Geology and lithofacies of the Schist Lake–Mandy area

Volcanic strata hosting the Schist Lake and Mandy deposits were interpreted by Bailes and Syme (1989) as belonging to the Flin Flon Block, which also hosts the Flin Flon, Callinan and 777 VMS deposits, thus the Schist Lake–Mandy stratigraphy was interpreted to be correlative to the main ore-hosting stratigraphy in Flin Flon (Figure GS-2-2). Following recent mapping in the area (Simard, 2006; Simard and Creaser, 2007), Kremer and Simard (2007) suggested that the strata hosting the Schist Lake and Mandy deposits could also be part of the western sequence of the Hook Lake Block (Figure GS-2-2), which questions the inferred time-stratigraphic relationship between the Schist Lake and Mandy VMS deposits to those within the Flin Flon Block.

Strata of the Schist Lake–Mandy area are generally well exposed along the west shore of Schist Lake with fewer outcrops located in adjacent forested areas. The volcanic strata in the study area strike approximately north and appear to young uniformly to the west (towards the north-northwest–striking Mandy Fault, which dissects the area; Figure GS-2-2). The relationship of the strata to the Mandy Road anticline to the west is uncertain as it appears to be cut to the south by the Mandy Fault (Figure GS-2-2). Strata hosting the Schist Lake–Mandy deposits have undergone significant deformation and are strongly foliated (Cole et al., 2007). Two foliations are recognized as trending at 340°–360° and 310°–330°; the former foliation is most likely axial planar to the Mandy Road anticline, as defined by Simard (2006, 2007).

Cole et al. (2007) divided the lithofacies in the immediate vicinity of the Schist Lake orebody into three facies, two of which are breccias and the third is a fine-grained bedded tuff unit (Figure GS-2-3). The first lithofacies is a mafic-dominated volcaniclastic facies, characterized by mafic clasts in either a felsic or mafic matrix. The second felsic volcaniclastic facies is characterized by felsic clasts in a mafic or felsic matrix, and the third lithofacies is a bedded tuff facies characterized by fine laminations of fine-grained and slightly coarser grained tuff, which is intercalated with the other two much coarser volcaniclastic units. The volcanic strata are metamorphosed to lower-greenschist facies and the dominantly mafic lithofacies contain a mineral assemblage dominated by chlorite, actinolite and albite with localized epidote patches. Cole et al. (2007) documented four types of alteration, including chlorite, sericite, iron staining and quartz veining. Chlorite alteration is particularly dominant on the western shore of Schist Lake, where it is found in the form of a dark green–black vein stockwork, which covers an area of ~20 m^2 and progressively decreases in intensity inland. Sericite alteration is pervasive over the entire peninsula. It is found along foliation planes and imparts a chalky white appearance to the rocks when scraped. Iron staining is a common occurrence, particularly in the eastern portion of the Schist Lake mine peninsula. The stained zones are parallel to the main foliation and tend to be linear in appearance. Quartz veins are observed throughout the area, but are most abundant on the eastern portion of the peninsula, where they tend to be associated with iron-stained areas.

Lithogeochemistry

To determine the composition of the different lithofacies and alteration types in the area, a total of 79 samples were collected in 2007 following a 10 m sampling grid in areas of high outcrop exposure around the Schist Lake mine (Figure GS-2-3). Of these 79 samples, 30 were from the mafic volcaniclastic facies, 32 were from the felsic volcaniclastic facies, and the remaining 17 samples were from the bedded tuff facies. These samples were analyzed at Acme Laboratories Ltd. in Vancouver, British Columbia, for major, minor, trace and rare-earth elements.

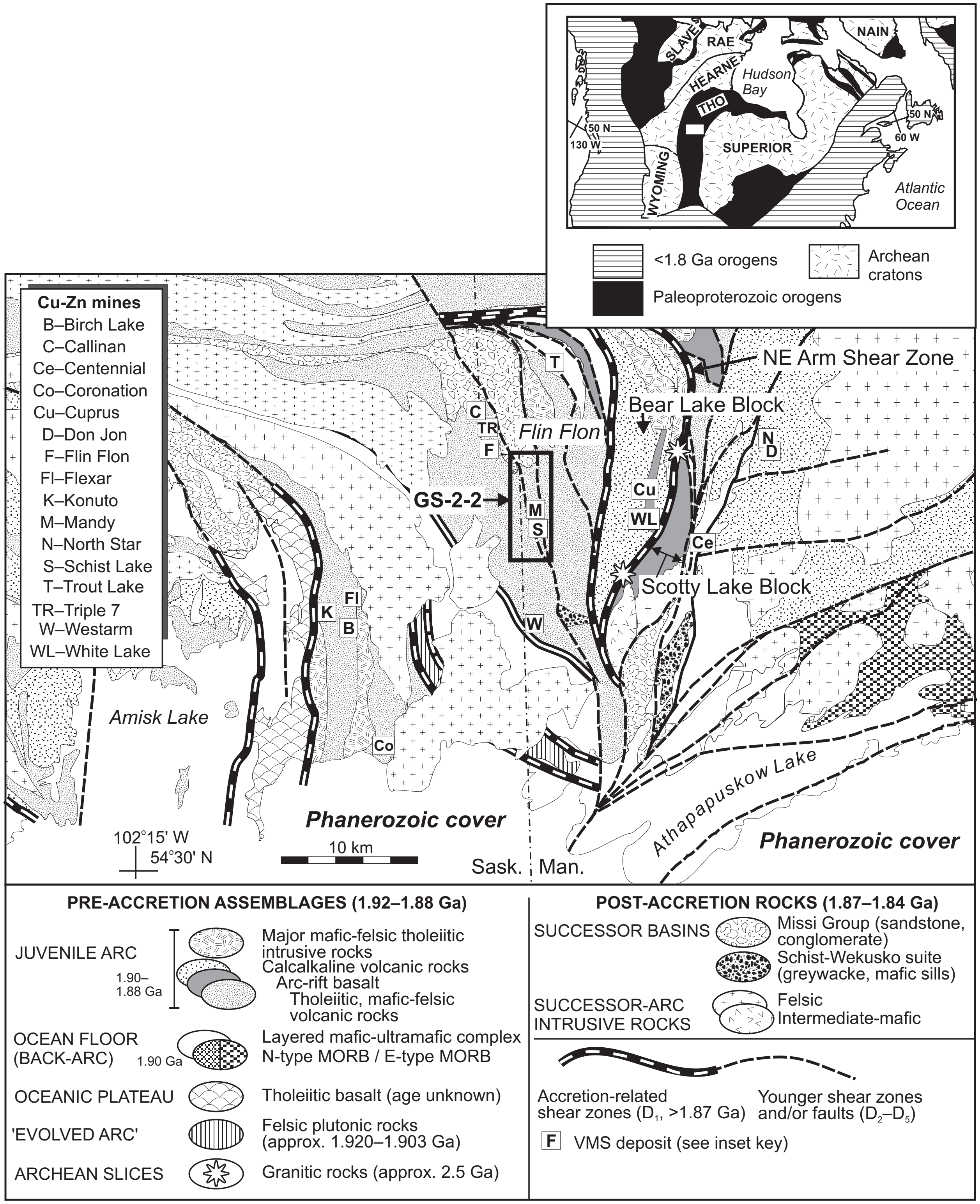

Figure GS-2-1: *Geology of the Flin Flon Belt, showing locations of known volcanogenic massive sulphide (VMS) deposits (*modified from *Syme et al., 1999); the box indicates the area covered by Figure GS-2-2; the inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO). The white box in the inset refers to the area covered by this figure.*

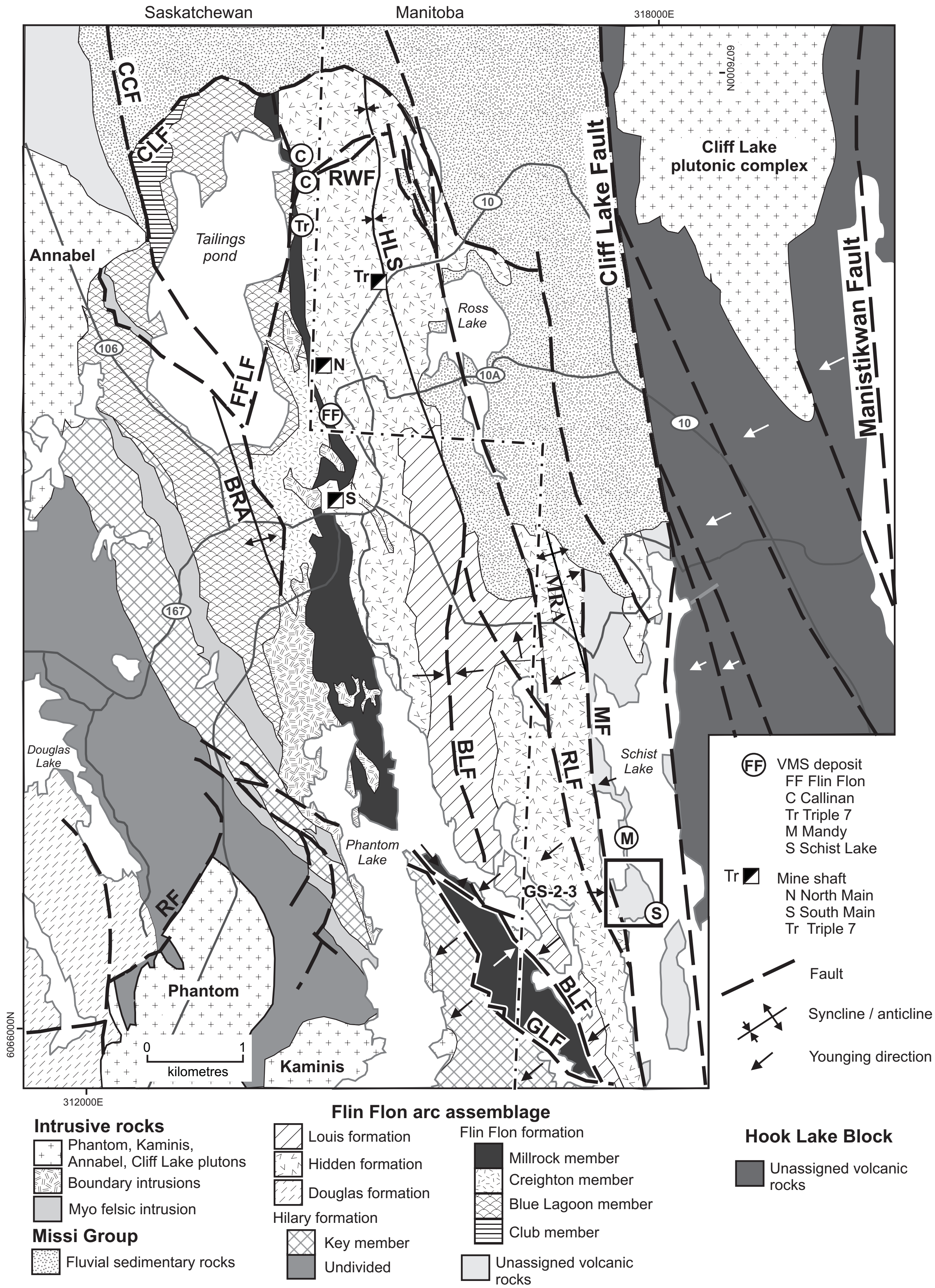

***Figure GS-2-2:** Simplified geology of the Flin Flon area, showing the major structures (*modified from *Simard, 2006); box indicates the location of the Schist Lake–Mandy mines area. Abbreviations: BLF, Burley Lake Fault; BLS, Burley Lake syncline; BRA, Beaver Road anticline; CCF, Creighton Creek Fault; CLF, Cliff Lake Fault; FFLF, Flin Flon Lake Fault; GLF, Green Lake Fault; HLS, Hidden Lake syncline; MF, Mandy Road Fault; MRA, Mandy Road anticline; RF, Rio Fault; RLF, Ross Lake Fault; RWF, Railway Fault.*

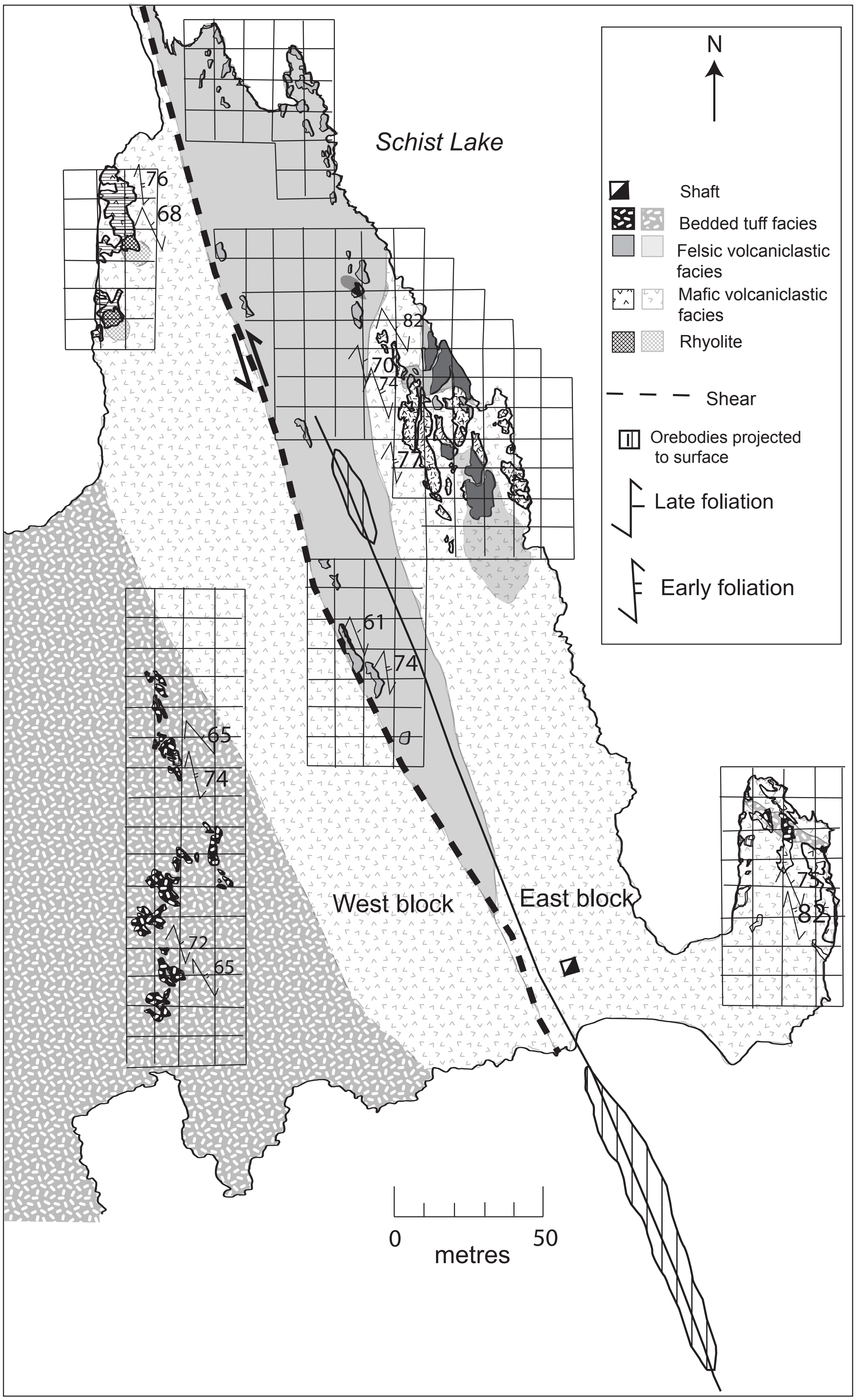

Figure GS-2-3: *Geology of the Schist Lake mine peninsula, including the surface projection of the Schist Lake orebody and the location of the shaft. The grid indicates the locations of the lithogeochemical samples taken. The bold patterns indicate known rock types and the faint patterns indicate inferred rock types.*

Major elements were analyzed by inductively coupled plasma–emission spectrometry (ICP-ES) following a lithium metaborate/tetraborate fusion and dilute nitric digestion. In addition, total trace, rare-earth and refractory elements were determined by inductively coupled plasma–mass spectrometry (ICP-MS) following a lithium metaborate/tetraborate fusion and nitric acid digestion of a 0.1 g sample. A separate 0.5 g split digested in aqua regia was analyzed by ICP-MS for precious and base metals.

Given the degree of alteration, deformation and metamorphism within the Schist Lake and Mandy mines area, much of the original mobile-element attributes commonly used to identify and define rock type (e.g., SiO_2, Na_2O, K_2O) have been mobilized; hence, immobile elements are favourable to determining the primary petrological and lithogeochemical attributes of the 'felsic' and 'mafic' lithofacies within the Schist Lake and Mandy volcaniclastic rocks. In this report, immobile-element attributes of the Schist Lake and Mandy rocks are concentrated upon, with the exception of the alteration geochemical attributes at the end of this section.

Binary plots were constructed using samples of different lithofacies to determine immobile elements (e.g., MacLean and Barrett, 1993) that could be used for classification and to assess alteration. Data for all lithofacies define a straight line through the origin for Nb, Zr, Y, Hf, Nd, Sm, Tb and Ho, indicating that these elements were immobile during alteration (e.g., MacLean and Barrett, 1993) and that all mapped lithofacies have common interelement ratios regardless of their composition (Figure GS-2-4; only variations for Zr, Y and Nb are illustrated).

Figure GS-2-5 shows the overall 'mafic' and subalkaline composition of the three volcaniclastic lithofacies. Most samples of the mafic volcaniclastic and tuff lithofacies have a low Zr/TiO_2 ratio and plot in the basaltic field, whereas samples of the 'felsic' volcaniclastic lithofacies display a higher Zr/TiO_2 ratio and plot more towards the andesite–basalt field. A further test of the compatible-incompatible element characteristics of the Schist Lake and Mandy rocks is shown on Figure GS-2-6, where the incompatible elements Zr, Nb and Y are plotted against the compatible element TiO_2. Notably, the samples group into two clusters that correspond, in part, to the lithofacies: the mafic volcaniclastic lithofacies define a cluster characterized by high compatible-element contents and low incompatible-element contents and the felsic volcaniclastic lithofacies define a cluster characterized by low compatible-element contents and high incompatible-element contents (Figure GS-2-6). Samples of the bedded tuff lithofacies overlap with samples of the mafic volcaniclastic lithofacies, suggesting that the bedded tuff lithofacies has a provenance that is likely dominated by mafic detritus (Figure GS-2-6). Given the volcaniclastic nature of the three lithofacies, the variance in lithogeochemical characteristics of each lithofacies may be due to mixing between mafic and felsic source rocks and/or alteration. To further examine the mixing hypothesis, samples from the Hidden Lake basalt and Millrock Hill rhyolite are plotted on the diagrams in Figure GS-2-6. The Hidden Lake basalt was selected as the mafic end member because the mafic volcaniclastic rocks may be related to this formation. The Millrock Hill rhyolite is the felsic end member as it may represent a dominant detrital source to the felsic volcaniclastic rocks and because the geochemical data for the Schist Lake rhyolite sampled in drillcore during the summer of 2008 are not yet available. In Figure GS-2-6, it is apparent that all samples of the three volcaniclastic lithofacies fall between the hypothetical mafic and felsic end-member samples, consistent with but not he unequivocal of a mixing process. However, there is no diagnostic mixing line that fits all the data. Further mixing tests with the entire lithogeochemical dataset will be undertaken at a later date.

The plot of Sc versus La in Figure GS-2-7 indicates that the mafic volcaniclastic facies has low La values with moderate to high Sc values relative to samples of the felsic volcaniclastic lithofacies, which have higher La values and lower Sc values. Data for the bedded tuff lithofacies (grey field in Figure GS-2-7), in comparison, have high Sc and moderate to high La concentrations, indicating an intermediate composition between the mafic and felsic volcaniclastic lithofacies.

To test the degree of alteration of the different volcaniclastic lithofacies in the Schist Lake area, the Ishikawa alteration index and chlorite-carbonate-pyrite index (CCPI) were calculated for all data and plotted on an alteration box plot (Large et al., 2001; Figure GS-2-8). Notably, only few samples lie within the least-altered boxes on this diagram and most samples fall in the field of strong hydrothermal alteration. The pronounced shift of data towards the chlorite-pyrite end of the box reflects pronounced chlorite alteration, as is readily observable in the field.

Interpretations

Binary plots of immobile elements (Figure GS-2-4) indicate that the three volcaniclastic lithofacies mapped in the area around the Schist Lake mine have the same interelement ratios for the immobile elements Nb, Zr, Y, Hf, Yb, Sm, To and Ho, suggesting that they have a common source and/or provenance. The incompatible–compatible element relationships are consistent with a felsic volcaniclastic lithofacies characterized by low compatible-element contents (e.g., TiO_2, Sc) and high incompatible-element contents (e.g., Zr, Nb, Y), and a mafic volcaniclastic lithofacies with the opposite characteristics (Figures GS-2-6 and -7). Although samples of the bedded tuff lithofacies appear to be similar to the mafic volcaniclastic lithofacies when plotted against TiO_2, on a Sc versus La plot (Figure GS-2-7), the data lie between the mafic and felsic volcaniclastic lithofacies, perhaps

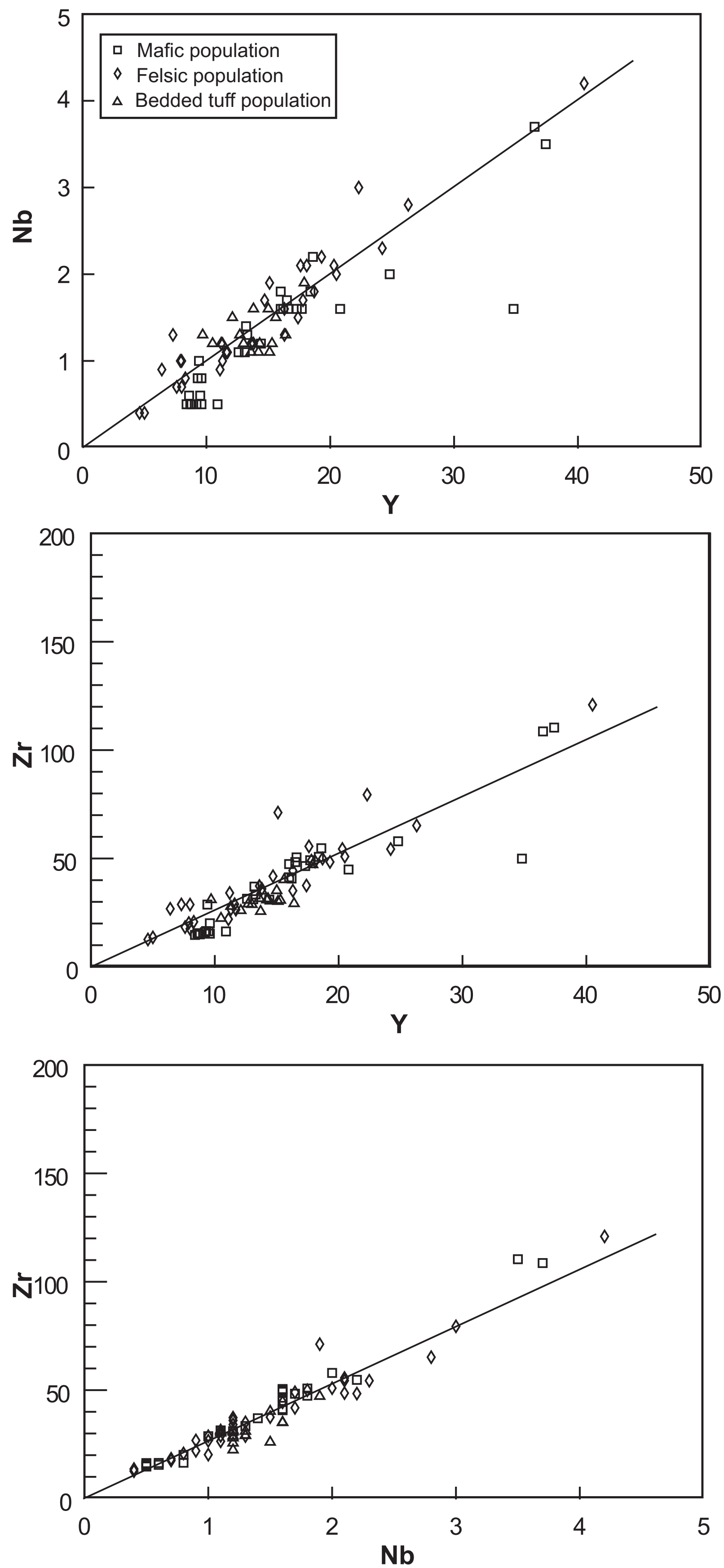

Figure GS-2-4: *Samples of the three volcaniclastic lithofacies display constant interelement ratios for Nb, Y and Zr.*

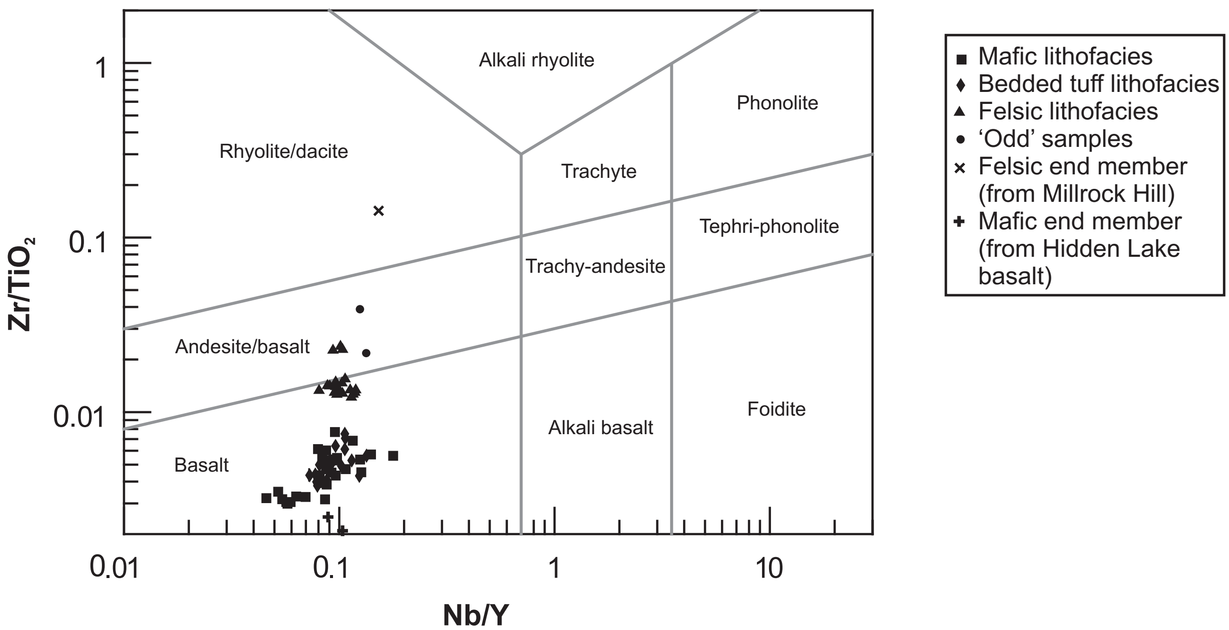

Figure GS-2-5: *Zr/TiO$_2$ versus Nb/Y discrimination diagram* (modified from *Winchester and Floyd, 1977), showing the 'mafic' and subalkaline composition of all lithofacies.*

suggesting a more intermediate composition. Previous studies have suggested that the Schist Lake and Mandy mines areas are dominated by felsic volcaniclastic rocks (Bailes and Syme, 1989); however, immobile-element systematics suggest that they are predominantly basaltic and basalt-andesite in composition. It should also be noted that a coherent, autobrecciated, mineralized and altered rhyolite was encountered in drillholes (SCH-7 and SCH-10), but the geochemical data for this lithofacies is not yet available.

The compositional characteristics described above correspond well with the mapped lithofacies, except in the most altered area of the Schist Lake mine peninsula, where some of the mafic volcaniclastic samples have geochemical attributes that correspond with the felsic volcaniclastic lithofacies and vice versa. The misidentification of mafic versus felsic volcaniclastic lithofacies during mapping may reflect the higher degree of chlorite alteration in this area.

Due to the high degree of alteration of all lithofacies mapped on the Schist Lake mine peninsula, it is difficult to establish a precursor, which is necessary to quantify alteration. From the alteration box plot, however, it is apparent that most of the volcaniclastic rocks on the Schist Lake mine peninsula have undergone significant hydrothermal alteration. In particular, the volcaniclastic lithofacies display lithogeochemical signatures consistent with strong chlorite-pyrite alteration typical to that associated with VMS deposits. Further work will include a more quantitative assessment of the alteration, variations in alteration intensity and its spatial distribution.

Conclusions and economic considerations

The mapped lithofacies in the Schist Lake and Mandy mines area appear to be compositionally uniform and unique, and are divisible into a mafic volcaniclastic, a felsic volcaniclastic and a bedded tuff lithofacies. The lithogeochemical study has shown that the three volcaniclastic lithofacies are more mafic than previously described. Previous workers suggested that the Schist Lake and Mandy mines area was dominated by felsic volcaniclastic rocks; the geochemical data presented herein, however, suggest that what has been described as felsic in the past is mafic in composition. It is anticipated that a more extensive alteration study including samples from drillholes logged this past summer may aid exploration for an extension of the Schist Lake and Mandy deposits.

The Schist Lake and Mandy mines area has previously been correlated with the Flin Flon Block, but more recently has been correlated with the Hook Lake Block. Alternatively, the Schist Lake and Mandy mines rocks may not be related to either of these blocks. The results of the summer 2008 fieldwork and ongoing studies will take these issues into account more fully.

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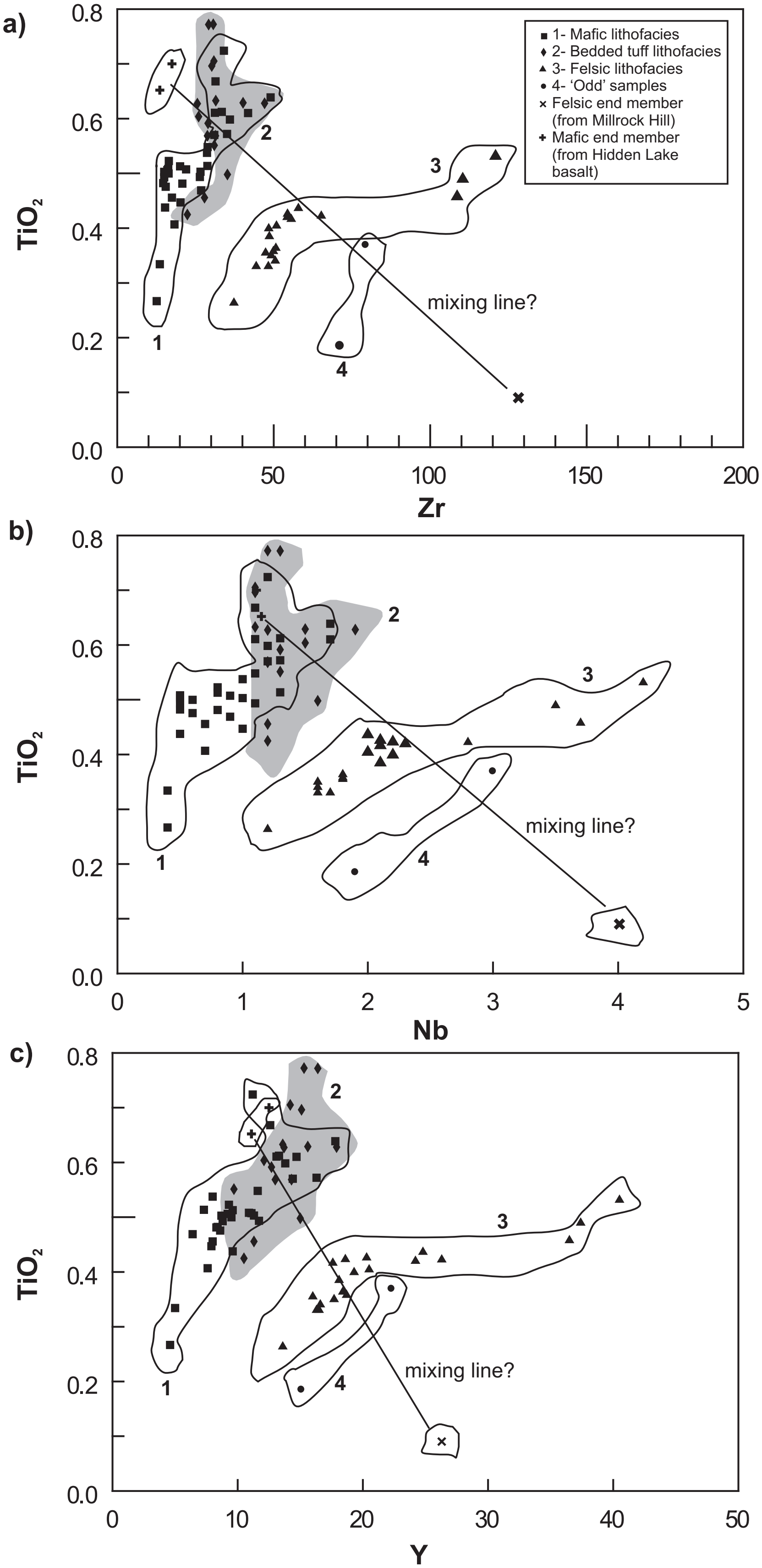

Figure GS-2-6: *Binary plots of TiO_2 versus* ***a)*** *Zr,* ***b)*** *Nb and* ***c)*** *Y for the three lithofacies, showing potential diagnostic mixing lines.*

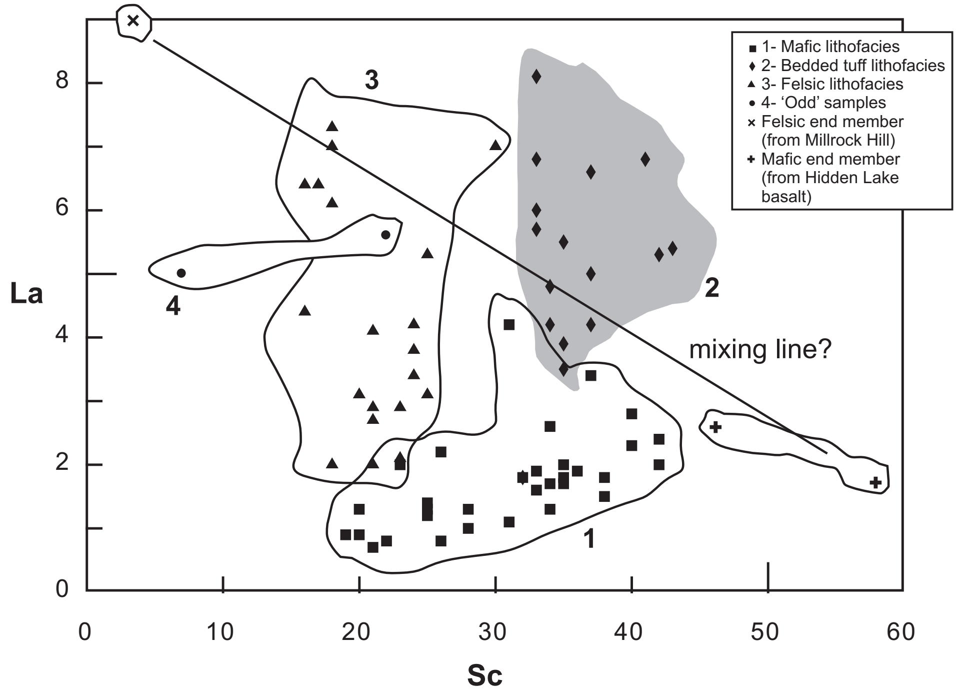

Figure GS-2-7: Sc versus La plot for the three lithofacies, showing an intermediate composition for samples of the bedded tuff lithofacies.

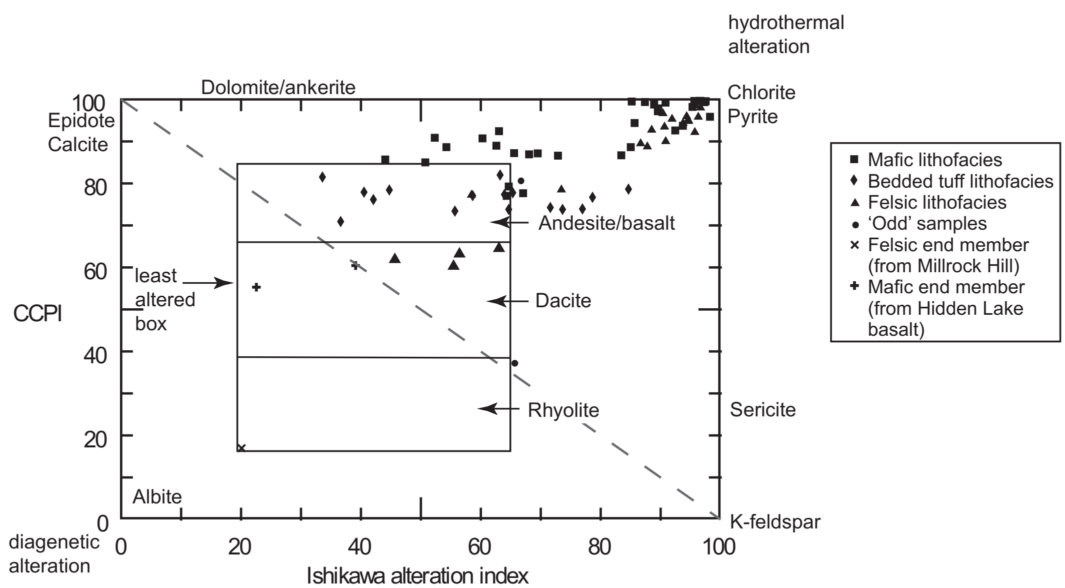

*Figure GS-2-8: Box plot used to illustrate the dominantly chlorite (pyrite) alteration associated with the Schist Lake samples (*from *Large et al., 2001).*

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