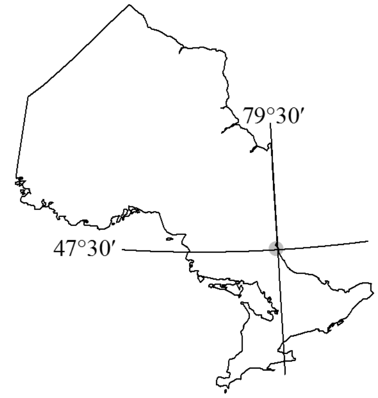
38. Structure and Stratigraphy of Archean Volcanic Units and the Paleoproterozoic Cobalt Group Near Cobalt, Ontario



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INTRODUCTION

The work presented in this summary is a portion of the larger Metal Earth project carried out by the Mineral Exploration Research Centre (MERC, Laurentian University, Sudbury), a multi-year, multi-disciplinary collaboration focussed on the factors that control metal endowment within Archean greenstone belts. As part of this larger initiative, this project is focussed on determining the structural and stratigraphic framework and controls on silver-cobalt (Ag-Co) arsenide veins hosted in Archean volcanic and Paleoproterozoic sedimentary units in the Cobalt region (Figure 38.1).

Mineral exploration and mining has played a significant role in Cobalt's history since the early 1900s. Historically, arsenide veins were targeted for silver, although cobalt, nickel and copper were also recovered from the ore. With the world's growing demand for cobalt in technologies, such as lithium-ion batteries and high-performance alloys, interest and exploration in the region has been revitalized.

Two main areas were chosen as the focus for geologic mapping during 2018, based on lithologies exposed, economic potential, and proximity to two-dimensional (2-D) seismic reflection surveys carried out by Metal Earth in 2017. Both locations—the "Cobalt silver area" (as designated by Knight 1924) and South Lorrain Township (*see* Figure 38.1)—have produced economically significant quantities of silver from silver-cobalt arsenide veins. Although the veins in both regions are similar in terms of mineralogy (Andrews et al. 1986), their structural and stratigraphic settings are different. In the Cobalt silver area, more than 90% of the veins are hosted in sedimentary rocks of the Huronian Supergroup, and are found near the base of a Nipissing diabase sill. In South Lorrain Township, Archean volcanic units host the veins, which are found near the upper contact of a Nipissing diabase sill. The goal of this study is to resolve these differences by determining the structural and stratigraphic controls on mineralization.

REGIONAL GEOLOGY

The current understanding of the regional geology in the Cobalt silver area and South Lorrain Township is largely based on mapping by Thomson (1964a, 1964b, 1964c) and McIlwaine (1970) and reports referenced therein. The region is largely underlain by Precambrian rocks, the oldest of which are Archean basement rocks consisting of volcanic and interbedded sedimentary units (*see* Figure 38.1) of the "Keewatin" assemblage (e.g., Thurston 2002), which make up the southernmost portion of the western Abitibi Subprovince within the Superior Province (*see* Figure 38.1, inset A). This succession, herein referred to as "the volcanic succession", was intruded by Archean mafic and ultramafic dikes and granitic batholiths. Sedimentary rocks of the Paleoproterozoic Huronian Supergroup (e.g., Sims, Card and

Summary of Field Work and Other Activities, 2018,
Ontario Geological Survey, Open File Report 6350, p.38-1 to 38-8.

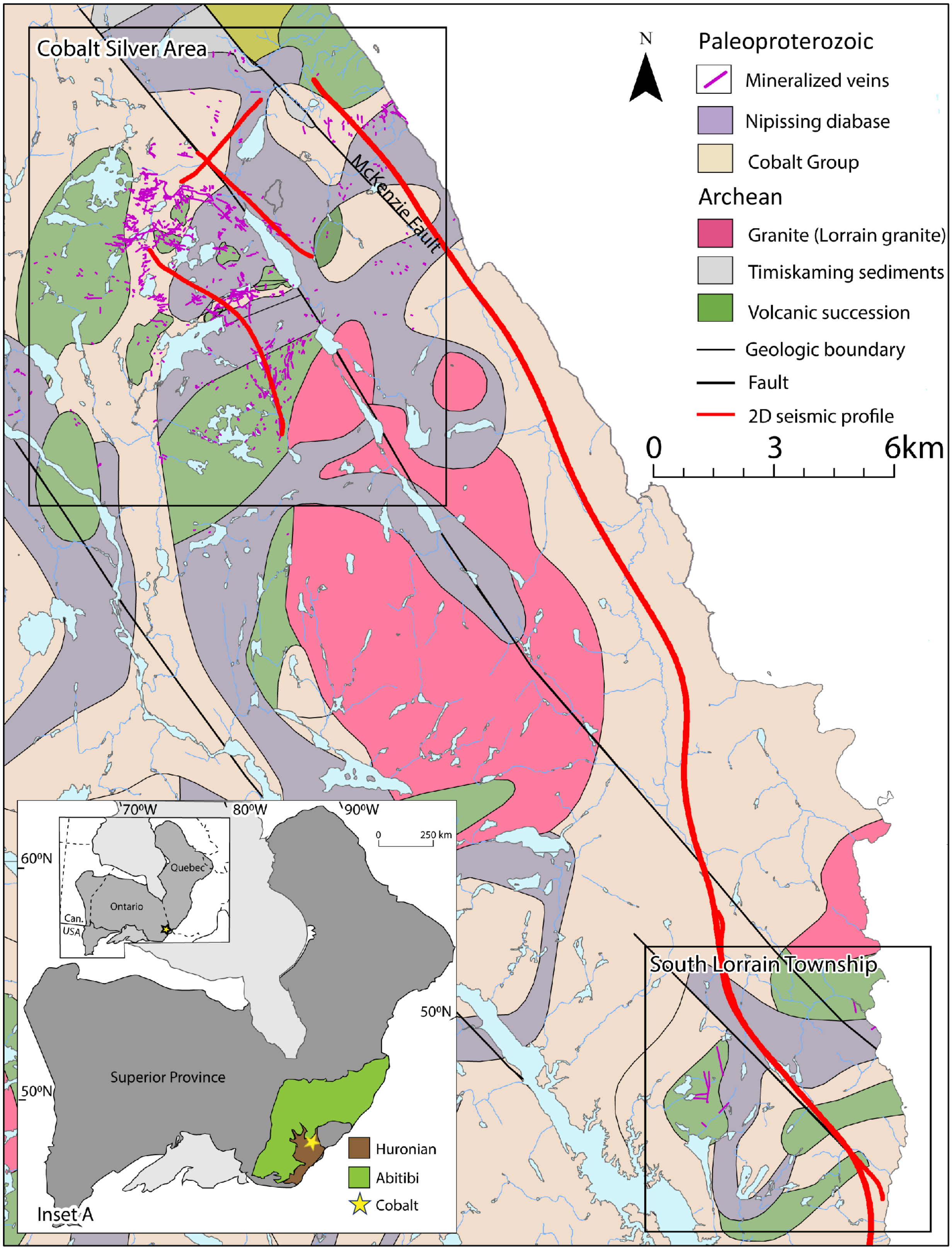

Figure 38.1. Regional geology map of the Cobalt area, showing study locations (*modified from* maps of Thomson 1964a, 1964b, 1964c; McIlwaine 1970). **Inset A** shows the position of the town of Cobalt (yellow star) relative to the Abitibi Subprovince and Superior Province.

Lumbers 1981) unconformably overlie the Archean basement, which is only exposed as inliers in the region (*see* Figure 38.1). Only the Gowganda and Lorrain formations of the upper Huronian Supergroup are exposed in the Cobalt area. The Nipissing diabase (2.2 Ga; Corfu and Andrews 1986), a suite of gabbroic dikes and sills (e.g., Lightfoot, de Souza and Doherty 1993), intrudes both Archean basement and Paleoproterozoic cover.

The Archean units have been regionally metamorphosed to greenschist facies, with typical mineral assemblages of actinolite, chlorite, epidote and albite observed (Smyk and Watkinson 1990). Archean volcanic and sedimentary rocks have steep dips (Thomson 1964a, 1964b, 1964c) as a result of steeply plunging, tight to isoclinal folding. The overlying sediments of the Cobalt Group are relatively flat lying, although moderate to steep dips are observed, which have traditionally been attributed to faulting (Mcllwaine 1970) or compaction on basement highs (Legun 1986).

STRATIGRAPHY: FIELD OBSERVATIONS

The following section describes stratified rocks in the Cobalt region in terms of observations made during the 2018 field season.

Archean Volcanic Succession

The dominant lithologies in the Archean volcanic succession are mafic to intermediate volcanic flows. Flows vary from massive to pillowed (Photo 38.1A) to brecciated. Massive flows are typically fine grained to aphanitic, and pillowed flows are usually feldspar-porphyritic. A distinct glomeroporphyritic texture (Photo 38.1B) is observed in basalts at a few locations, and may represent a marker horizon in an otherwise monotonous succession of mafic flows. Felsic volcanic and volcaniclastic rocks are observed at several localities and consist of i) coherent rhyolite flows, with varying quartz crystal content; ii) massive felsic tuffs with feldspar and quartz crystal fragments; and iii) monomictic volcanic breccia with quartz-porphyritic fragments (Photo 38.1C).

Sedimentary units are interbedded within the volcanic rocks, and thicker intervals of these sedimentary units are commonly observed at the transition from mafic to felsic lithologies. Sedimentary rocks range from massive to well bedded, with ripples and cross-laminations rarely observed. Ball-and-flame structures (Photo 38.1D), although not common, are the most convincing way-up indicators in these successions. Interflow sedimentary deposits are dominated by mudstone, laminated mudstone, and siltstone. Thin to medium beds of fine- to medium-grained quartz arenite, and conglomerate, also occur within some interflow successions.

Timiskaming Group

Archean sandstone and conglomerate units unconformably overlie units of the Archean volcanic succession. Units of thick, massive polymictic conglomerate (Photo 38.1F) and coarse-grained, cross-bedded sandstone (Photo 38.1E) allow for easy distinction between these younger strata and the muddy interflow sediments of the volcanic succession. The unconformity between the Timiskaming Group sediments and volcanic succession was not observed in the mapping area. The only exposures recognized by previous workers (Thomson 1964a, 1964b, 1964c; Mcllwaine 1970) are northwest of the town of North Cobalt, immediately west of the McKenzie fault (*see* Figure 38.1). However, during the 2018 field mapping, previously unrecognized outcrops of Timiskaming Group conglomerate and sandstone were observed immediately west of the McKenzie fault, approximately 1 km south of previously discovered exposures (*see* Figure 38.1).

Photo 38.1. Field photos of geologic units mapped during the 2018 field season. **A**) Pillow basalt (arrow indicates way up). **B**) Glomeroporphyritic texture of feldspar in massive basalt flow. **C**) Felsic volcanic breccia. **D**) Ball-and-flame structure in interflow sediments (arrow indicates way up). **E**) Cross-bedded Timiskaming Group sediments (arrow indicates way up). **F**) Polymictic conglomerate of the Timiskaming Group succession. **G**) Coleman Member diamictite. **H**) Dropstone in diamictite. **I**) Laminated mudstone of Firstbrook Member.

Paleoproterozoic Cobalt Group

The Cobalt Group is the only unit of the Huronian Supergroup exposed in the Cobalt region. The group is further subdivided into the Gowganda and Lorrain formations, whereas major lithological differences have led to even further subdivision of the Gowganda Formation into a lower Coleman Member and upper Firstbrook Member (Thomson 1957). The Coleman Member consists of diamictite (Photo 38.1G), polymictic conglomerate, coarse-grained sandstone, and laminated mudstone and siltstone.

Poorly sorted diamictites have been interpreted to have a glacial origin (e.g., clasts are dropstones) and field observations of laminations wrapping around the base of cobble- to boulder-sized clasts (Photo 38.1H) support these interpretations. Clasts are predominantly granitic, although volcanic, metamorphic and sedimentary clasts are also observed. Clast-supported conglomerate beds often have well-rounded clasts and demonstrate grading, indicating not all "conglomeratic units" within the Gowganda Formation have a glacial origin. The Firstbrook Member is predominantly a well-laminated mudstone (Photo 38.1I), and no dropstones or large clasts are observed.

The Lorrain Formation conformably overlies the Gowganda Formation and consists of quartz arenite, arkosic sandstone and pebble conglomerate. The unit is easily distinguishable from the mudstone-rich lithologies of the Gowganda Formation.

The Huronian Unconformity

The Cobalt Formation unconformably overlies the Archean basement. Paleoproterozoic sediments were observed to lie both parallel and at a high angle to basement, indicating an irregular paleotopography during deposition. The Gowganda Formation usually directly overlies basement; however, the Lorrain Formation is also observed to directly overlie basement units where Gowganda Formation units are missing.

STRUCTURE: FIELD OBSERVATIONS

Archean Volcanic Succession

Changes in pillow facing indicate folding of primary layering. Although the fold type is difficult to observe in volcanic units, sedimentary interbeds are observed to be folded into tight isoclinal folds, with steep subvertical limbs. Primary fabrics (i.e., bedding) in the Archean volcanic (AV) succession are herein termed $S0_{AV}$. Currently, these isoclinal folds are considered F_1 folds, based on local genetic relationships of structure; however, it is unlikely that isoclinal folding is a function of a D_1 episode, and further work will help decipher these events with more certainty.

A penetrative secondary foliation (S_1) is oriented subparallel to $S0_{AV}$ ($S0_{AV}$ is transposed into the plane of S_1). The S_1 foliation is axial planar to F_1 isoclinal folds and, although S_1 is present in most localities, the defining fabric elements vary with lithology, and intensity of metamorphism and deformation. In the Cobalt silver area (*see* Figure 38.1), the degree of deformation and metamorphism is conspicuously higher than in South Lorrain Township. Felsic volcanic units have a cleaved to schistose fabric (Photos 38.2D and 38.2F) and metasedimentary rocks develop a strong phyllitic foliation (defined by chlorite). Intensity of deformation varies in the intermediate to mafic igneous units in South Lorrain Township. Massive porphyries and pillowed flows are preserved and appear relatively unstrained, whereas a strong flattening of the pillows (Photos 38.2A and 38.2B) and compositional banding (Photo 38.2C) define S_1 foliations in mafic volcanic units south of Maidens Lake and Oxbow Lake. Units in the Cobalt silver area are relatively less deformed, and interflow sediments are mildly to moderately cleaved. Coherent rhyolite flows are generally massive, whereas felsic volcaniclastic units are mildly to moderately cleaved. Mafic volcanic units are relatively unstrained.

Where S_1 is defined by a schistose or phyllitic foliation, crenulations (L_2?) are observed parallel to the plane of S_1 foliation. These crenulations plunge moderately towards the northwest. The S_1 foliation is also observed to be regionally folded about an axis that plunges steeply towards the northwest.

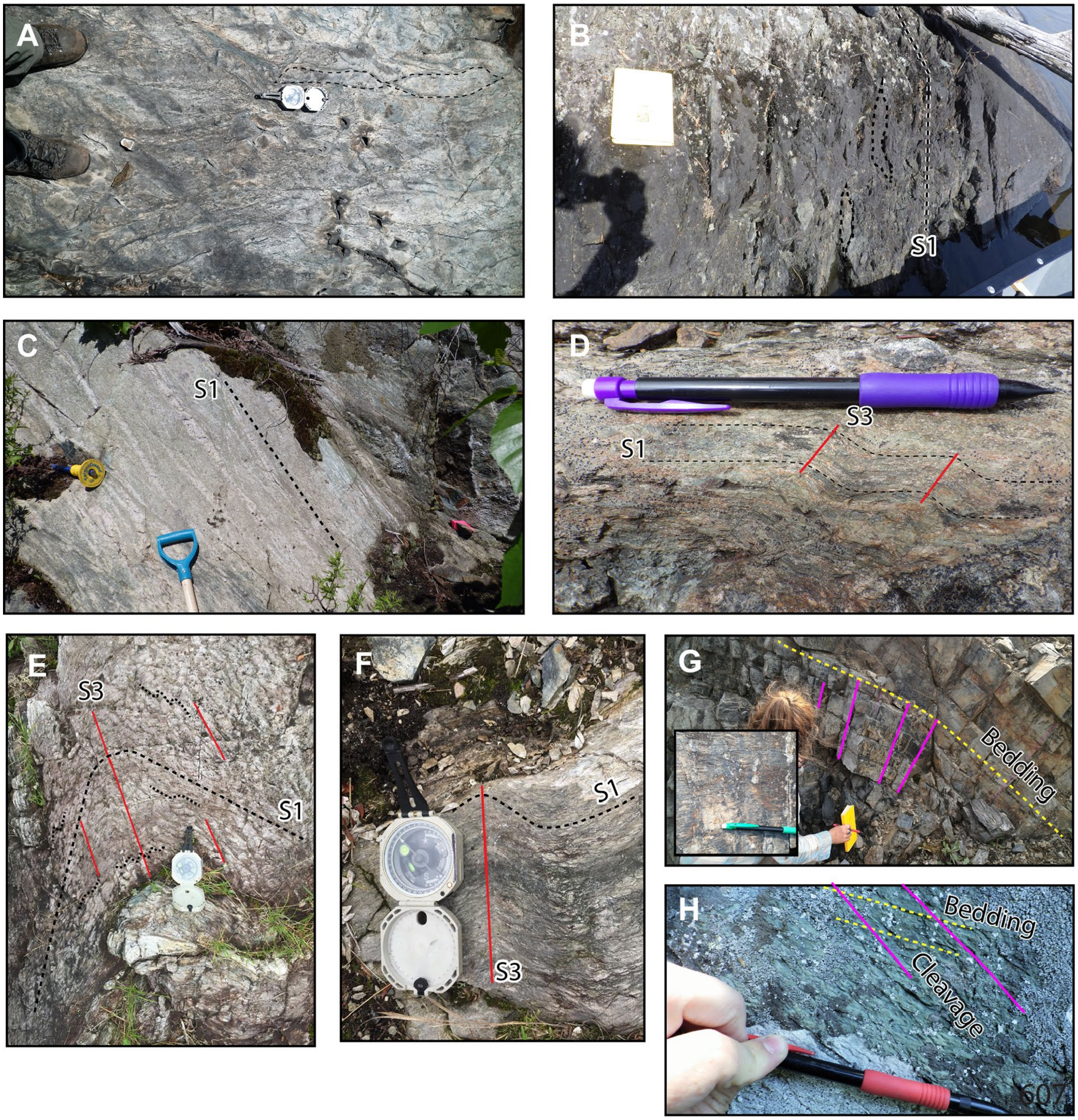

Photo 38.2. Field photos of structural fabrics documented during the 2018 field mapping. **A**) Flattened pillows (outlined). **B**) Flattened pillows (outlined) defining regional S_1 foliation. **C**) S_1 foliation in Archean gabbro. **D**) S_1 schistosity in felsic volcanic crenulated by S_3 crenulation cleavage. **E**) S_1 foliation folded by S_3 folds. Parasitic folds forming on either limb have axial planes also parallel to S_3. **F**) Spaced crenulation cleavage. **G**) Folded Paleoproterozoic sediments with spaced axial planar fabric. Inset shows slickenlines along bedding planes. **H**) Strong, penetrative cleavage formed in Cobalt Group sediments.

A spaced crenulation cleavage (S_3) is observed where units are schistose or phyllitic (e.g. Photos 38.2D, 38.2E and 38.2F). This foliation refolds S_1 (along with L_2 crenulations). The fabric strikes southwest and northeast, with steep dips. The L_3 crenulation hinges associated with S_3 cleavage plunge moderately to the northeast and folds are asymmetric (Z shaped) when viewed in the down-plunge direction.

Timiskaming Group

Bedding ($S0_{AT}$) (AT: Archean Timiskaming) is easily recognizable in the Timiskaming Group sediments. Dips are steep to subvertical and strike is variable. The $S0_{AT}$ bedding has been folded about a southeast-trending, steeply plunging axis. An west-striking, subvertical cleavage is formed in newly recognized exposures of Timiskaming Group sedimentary rocks south of North Cobalt. This cleavage is axial planar to both folded $S0_{AT}$ bedding and F_2 folds. These F_2 folds (which fold S_1) formed in the volcanic succession, and the cleavage (S_2) likely represents an S_2 foliation that was difficult to discern in the more highly deformed volcanic succession.

Paleoproterozoic

Bedding ($S0_P$) (P: Proterozoic) in the Cobalt Group is generally subhorizontal to shallowly dipping, although locally $S0_P$ can dip moderately to steeply. The change in bedding orientation suggests regional folding (Photo 38.2G) about a subhorizontal fold axis trending towards 246°. A cleavage is formed locally within the Proterozoic strata (Photo 38.2H). Near Kerr Lake, the measured cleavage is 060/80 and is axial planar to the large-scale regional folding. The associated intersection lineation at 242-02° is parallel to the regional fold axis. Folded beds often display slickenlines, consistent with folding resulting from flexural slip parallel to bedding (inset in Photo 38.2G). Other cleavage orientations measured in the Paleoproterozoic sediments vary and could result from a later refolding episode.

SAMPLING FOR DETRITAL ZIRCON GEOCHRONOLOGY

A total of 7 samples were collected to perform U/Pb analysis of zircon using laser ablation inductively coupled mass spectrometry (LA-ICP–MS). Five samples were collected from the Archean interflow sediments. These samples were collected from silt and sandstone beds, the coarsest material available, to increase the likelihood of obtaining a significant amount of zircon. Two samples were collected from quartzite beds (~1 m thick) that were closely associated with felsic volcanic units of the Archean volcanic succession. Zircon ages from these sediments will give a maximum age of deposition of these units, which is currently unknown.

Three samples were also collected from the Cobalt Group: 2 samples from the Gowganda Formation and 1 sample from the Lorrain Formation. Two samples were collected near the boundary between the Gowganda and Lorrain formations, from the units on either side. The goal of this sampling is to test whether there is a provenance shift across the boundary, which will help constrain depositional models and identify regions undergoing uplift and erosion during development of the Paleoproterozoic basin.

SAMPLING FOR THERMAL IONIZATION MASS SPECTROMETRY

Six samples in total were collected for U/Pb analyses of zircon using thermal ionization mass spectrometry (TIMS). Four samples were from felsic volcanic and volcaniclastic units of the Archean volcanic succession, and 1 sample was from a rhyolite near the contact of the Archean succession and overlying Paleoproterozoic strata. The samples from the Archean volcanic succession should provide igneous ages, which will be used to test the hypothesis that the volcanic succession in the Cobalt region generally youngs to the north. One sample was collected from a granitic dike (~5 m wide) crosscutting the Nipissing diabase. A U/Pb zircon age from this sample will indicate whether the granite is a late phase of a Nipissing intrusive event or a later magmatic episode altogether.

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