Canadian Journal of Earth Sciences
Revue canadienne des sciences de la Terre

**The Geology, Petrology and Geochronology of the Archean
Côté Gold Large-Tonnage, Low-Grade Intrusion-Related
Au(-Cu) Deposit, Swayze Greenstone Belt, Ontario, Canada**

Journal:	<i>Canadian Journal of Earth Sciences</i>
Manuscript ID	cjes-2016-0007.R2
Manuscript Type:	Article
Date Submitted by the Author:	16-Jun-2016
Complete List of Authors:	Katz, Laura; Laurentian University, Earth Science Kontak, Dan; Department of Earth Sciences Dubé , Benoît; Commission géologique du Canada Québec McNicoll, Vicki; Natural Resources Canada Earth Sciences
Keyword:	Chester intrusive complex, Low-Al tonalite, Composite synvolcanic intrusion, Swayze greenstone belt, Intrusion-related

SCHOLARONE™
Manuscripts

The Geology, Petrology and Geochronology of the Archean Côté Gold Large-Tonnage, Low-Grade Intrusion-Related Au(-Cu) Deposit, Swayze Greenstone Belt, Ontario, Canada

Laura R. Katz. Mineral Exploration Research Centre, Department of Earth Science, Goodman School of Mines, Laurentian University, 935 Ramsey Lake Road, Sudbury, Ontario, P3E 2C6, Canada. (e-mail: lkatz@laurentian.ca; phone number: (705) 920-3717)

Daniel J. Kontak. Mineral Exploration Research Centre, Department of Earth Science, Goodman School of Mines, Laurentian University, 935 Ramsey Lake Road, Sudbury, Ontario, P3E 2C6, Canada. (e-mail: dkontak@laurentian.ca)

Benoît Dubé. Geological Survey of Canada, 490 rue de la Couronne, Québec, G1K 9A9, Canada. (e-mail: benoit.dube@canada.ca)

Vicki McNicoll. Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8, Canada. (e-mail: vicki.mcnicoll@canada.ca)

Corresponding author: Laura R. Katz

Draft

The Geology, Petrology and Geochronology of the Archean Côté Gold Large-Tonnage, Low-Grade Intrusion-Related Au(-Cu) Deposit, Swayze Greenstone Belt, Ontario, Canada

Laura R. Katz, Daniel J. Kontak, Benoît Dubé and Vicki McNicoll

Abstract

The Archean Côté Gold Au(-Cu) deposit is the first large gold deposit discovered in the Swayze greenstone belt of the Abitibi Subprovince. The deposit is a low-grade, large-tonnage type with a combined indicated and inferred resource of 8.65 M oz Au. The deposit is hosted by the Chester intrusive complex (CIC), a multi-phase, subvolcanic intrusion comprised of low-Al tonalite, diorite and quartz diorite, plus magmatic and hydrothermal breccia bodies. The age of the tonalite and dioritic phases is constrained at 2741 to 2739 ± 1 Ma using high-precision ID-TIMS U-Pb zircon geochronology. Although these phases are co-temporal and co-spatial, they appear to be petrogenetically unrelated. The CIC was emplaced into mafic metavolcanic rocks of the Arbutus Formation whose geochemistry reflects a back-arc environment. The tonalite of the CIC is coeval and co-genetic with the felsic to intermediate metavolcanic rocks of the Yeo Formation. Emplacement of the CIC into a shallow crustal level is inferred based on the incorporation of screens and inclusions of the Yeo Formation and is supported by the presence of textures in tonalite and dioritic rocks (e.g., granophyres, miarolitic cavities and pegmatites), as well as Al-in-hornblende geobarometry results of $\leq 1.3 \pm 0.6$ kbars. The CIC is petrologically similar to other subvolcanic, low-Al tonalite-trondhjemite-diorite intrusions that underlie VMS-type deposits and which themselves may contain syn-intrusion mineralization. Several geochemically unrelated dykes and deformation events crosscut and postdate the CIC.

Key words: Composite synvolcanic intrusion, Swayze greenstone belt, Chester intrusive complex, Côte Gold deposit

Introduction

The Côte Gold Au(-Cu) deposit, located in the Swayze greenstone belt (SGB) of the Archean Abitibi Subprovince, is a low-grade (<1 g/t Au), large-tonnage deposit (indicated: 296 Mt @ 0.88 g/t Au (7.61 M oz) and inferred: 44 Mt @ 0.74 g/t Au (1.04 M oz); IAMGOLD Corporation 2013). The deposit is hosted by a ca. 2741 to 2739 Ma subvolcanic tonalite-diorite-quartz diorite intrusive complex, known as the Chester intrusive complex (CIC). Tonalite-trondhjemite plutonic suites, which may also contain granodiorite and diorite rocks, are voluminous in the Archean and for this reason have attracted much research attention (Barker and Arth 1976; Barker 1979; Martin and Moyen 2002; Condie 2005; Martin et al. 2005; Bédard 2006). These suites are subdivided into high-Al (>15 wt. %) and low-Al (<15 wt. %) types based on their Al_2O_3 content at 70% SiO_2 , in addition to other geochemical criteria (Barker 1979). Most of these Archean plutonic rocks belong to the high-Al tonalite-trondhjemite-granodiorite (TTG) suite, whereas the low-Al tonalite-trondhjemite-diorite (TTD) suites are subordinate (Martin et al. 2005). Low-Al TTD suites have been documented to form small, composite synvolcanic intrusions in rift environments that underlie and are considered the heat and/or metal source for spatially related VMS mineralization (Campbell et al. 1981; Cathles 1981; Franklin 1996; Barrie et al. 1999; Galley et al. 2000; Galley 2003; Yergeau et al. 2015). The low-Al composite intrusions are compositionally equivalent to FII and FIII-type rhyolites, and as such, are prospective for base metal mineralization (Leshner et al. 1986). Some of these intrusions have been documented to host Cu-Mo(-Au) mineralization with a porphyry-type affinity (Friske 1974;

Trowell 1974; Goldie 1979; Poulsen and Franklin 1981; Kennedy 1985; Galley and van Breemen 2002; Galley 2003; Galley and Lafrance 2014).

The Côté Gold deposit represents a significant new discovery (2009/2010; Rogers et al. 2013) for several reasons: (1) it is the first large gold deposit (i.e., >1 M oz Au) of any type discovered in the SGB, compared to the gold-rich Abitibi greenstone belt (AGB); (2) the deposit defines a new gold environment in that the mineralization (disseminations, veins and breccias) is hosted by a ca. 2741 to 2939 Ma, high-level, subvolcanic tonalite-diorite-quartz diorite intrusive complex which is atypical in the AGB (Robert et al. 2005); and (3) based on Re-Os dating of molybdenite that is co-genetic with gold mineralization, the deposit defines a new gold metallogenic event at ca. 2740 Ma (Kontak et al. 2013a, 2013b; Katz 2016). Based on the overlap of magmatic and hydrothermal events, the nature of mineralization (e.g., breccias, stockwork, disseminations) and the alteration types (e.g., amphibole-, biotite-, muscovite- and albite-rich assemblages), previous studies have suggested an intrusion-related origin for the deposit with an affinity to porphyry-type deposits (Kontak et al. 2013a; Katz et al. 2015; Katz 2016).

This article constitutes the first detailed description of the geology of the Côté Gold deposit and defines: (1) the relative timing of the intrusive phases through crosscutting relationships; (2) the absolute ages of intrusive units using high precision ID-TIMS U-Pb zircon geochronology; (3) the lithogeochemistry of the igneous rocks and the tectonic setting of the CIC; and (4) a model for the origin of the CIC. This work builds on the preliminary findings of the nature of the deposit presented by Kontak et al. (2013a) and Rogers et al. (2013). Details of the alteration and mineralization types, geochronological constraints on the timing of

mineralization, geochemical fingerprinting of the alteration and mineralization and a detailed discussion of a deposit model and its classification are presented in Katz (2016).

Regional geological setting

The Côté Gold deposit is located in the southeastern part of the SGB, which is part of the Abitibi Subprovince (Fig. 1). The volcano-sedimentary rocks in the SGB are inferred to be contiguous with the southern extension of the AGB. The SGB was once considered to be separate from the AGB but based on lithological and geochronological data the SGB is now considered to contain equivalent stratigraphic assemblages and structural features typical of the southern part of the AGB (Fig. 2; Ayer et al. 2002; van Breemen et al. 2006). The rocks in SGB are diverse and include volcanic and intrusive rock types that range from ultramafic to felsic in composition, as well chemical and clastic sedimentary rock types (Ayer et al. 2002). These rock types range in age from 2750 to 2670 Ma (Thurston et al. 2008). In the SGB, six supracrustal groups are recognized, which from oldest to youngest are the Chester, Marion, Biscotasing, Trailbreaker, Swayze and Ridout (Heather 2001; van Breemen et al. 2006), and correlate to the assemblages in the AGB (Fig. 2; Ayer et al. 2002).

The SGB has a complex structural history which includes polyphase folding with the development of multiple foliations, ductile high-strain zones and late brittle faulting (Heather 2001). The observed map pattern within the SGB mainly reflects D₂ deformation, an orogen-wide shortening event (van Breemen et al. 2006). Several, regionally extensive, east-west trending D₂ high-strain zones transect the SGB.

The Ridout deformation zone (RDZ), which represents one such D₂ high-strain zone, is up to 2 km wide and transects the length of the southern SGB (Heather 2001; van Breemen et al. 2006). The RDZ, which occurs approximately 3 km north of the deposit, has a complex history

of ductile shearing with later brittle faulting (Heather 2001; van Breemen et al. 2006; Berger 2011). Previous studies suggested the RDZ is the western extension of the gold-rich Larder Lake-Cadillac deformation zone (Heather 2001; van Breemen et al. 2006). It has been argued that although of similar age, it is unlikely that these two deformation zones are correlative based on different kinematic histories and their location along different parts of the regional stratigraphy (Berger 2011).

Metamorphic grade ranges from sub-greenschist to greenschist grade but locally higher amphibolite grade conditions were attained next to large synvolcanic and syntectonic intrusions (Heather 2001; van Breemen et al. 2006). The peak of metamorphism in the southern AGB is estimated to have occurred from 2677 to 2643 Ma (Powell et al. 1995).

Local geological setting

The following description, particularly the volcanic rocks, is largely taken from Heather (2001). The Arbutus Formation is traceable throughout much of the southern SGB and it forms the lowest formation in the Chester Group and consequently in the SGB (Fig. 3). The formation has not been dated directly but is inferred to be ca. 2750 to 2735 Ma. The unit contains pillow basalts, mafic flows and massive, medium-grained amphibolite interpreted to be either coarser-grained flows or intrusive sills. This formation is overlain conformably by the Yeo Formation (Heather 2001).

The Yeo Formation, which forms the upper formation in the Chester Group, consists of intercalated felsic and intermediate volcanic rocks, clastic sedimentary and volcanoclastic rocks, iron formation and Fe-rich sedimentary rocks (Heather 2001). Two U-Pb zircon ages for the felsic lapilli tuff constrain this formation at 2739 ± 1 Ma (van Breemen et al. 2006) and 2734 ± 2 Ma (Heather and Shore 1999a, 1999b; see locations in Fig. 3).

The Côte Gold deposit is hosted by a multi-phase, subvolcanic intrusion known as the CIC and is located along the southern margin of the Ridout syncline in the southeastern part of the SGB (Figs. 1 and 3). The CIC has an overall laccolithic shape with dimensions approximately 35 km (east-west) by <10 km (north-south). Based on the current understanding of the study area, the CIC has been tilted moderately to steeply north from its original orientation. The CIC contains numerous rafts, screens and inclusions of the Arbutus (Heather 2001) and Yeo Formations (Berger 2012; Fig. 3).

The intrusive phases of the CIC have complex crosscutting relationships that are considered to reflect their coeval emplacement and possible co-mingling between the tonalitic and dioritic magmas (Heather 1993; Heather and Shore 1999a; Heather 2001; Berger 2011). Evidence supporting this interpretation includes: (1) abundant diorite, quartz diorite and tonalite inclusions of variable size (<1 cm to >1 m) and texture (i.e. fine- to coarse-grained) within the tonalite and tonalite bodies or veins intruding diorite; (2) fragments of tonalite within a dioritic matrix; (3) cusped or lobate contacts between tonalite and diorite; and (4) a frothy or pitted net-texture in some mafic inclusions. Importantly, these field relationships suggest that the various phases are approximately contemporaneous.

Previous U-Pb zircon studies have constrained the age of the tonalite phase of the CIC to 2740 ± 2 Ma (Heather and van Breemen 1994) and more recently to 2741.1 ± 0.9 and 2738.7 ± 0.8 Ma (Kontak et al. 2013a; see Fig. 3 for sample locations). The older age for the Yeo Formation is coeval with the CIC and Berger (2012) suggested that it may include eruptive equivalents of tonalite in the CIC.

The CIC and surrounding host volcano-sedimentary strata are cut by a series of dykes. Many of these dykes are in turn overprinted by several deformation events.

Geology of the Côté Gold deposit

The deposit, located in the northwestern part of the CIC (Fig. 3), is hosted by both tonalite and dioritic phases. A surface map showing the geology of the deposit area is presented in Figure 4 and a cross section through the deposit is presented in Figure 5. The deposit geology, as described below, is based on the observations from detailed logging of 157 diamond drill holes by the senior author and mapping of a few select, but critical outcrops (Fig. 6).

In general, the deposit area is dominated by tonalite with lesser amounts of diorite bodies and various intrusive and hydrothermal breccia bodies. The distribution of the intrusive phases is shown in the plan map and cross section in Figures 4 and 5, respectively. There is little manifestation of the breccia bodies on surface, whereas the cross section in Figure 5 shows the extent of the magmatic breccias at depth.

Kontak et al. (2013a), Katz et al. (2015) and Katz (2016) described the mineralization and alteration types and noted that several styles of gold mineralization are present (e.g., disseminations, sheeted veins, stockworks, breccias) and they are co-spatial with hydrothermal alteration (e.g., amphibole, biotite, muscovite, albite). Gold mineralization is centred on breccia bodies of magmatic and hydrothermal origin (Fig. 5) but also occurs in the tonalite and diorite shouldering such bodies. The best estimate of the age of mineralization is based on four Re-Os molybdenite ages, two each from Kontak et al. (2013a) and Katz (2016). These data constrain the mineralizing event to 2740.2 ± 5.6 Ma (MSWD = 0.73), which suggests a syn-intrusion timing for the formation of the deposit.

Several deformation events are recognized in the deposit area (Smith et al. 2014). Small (<3 m wide), east-west trending deformation zones thought to be related to the RDZ overprint the major rock types, alteration and mineralization in the deposit (Smith et al. 2014). A west-

striking, moderate to steeply dipping brittle fault zone cuts through the centre of the deposit (Fig. 4). The fault has an apparent dextral offset which has been recognized based on offsets in the breccia bodies, albite alteration zone and diabase dykes (Fig. 4). Therefore, the last movement on the fault is late with respect to deposit formation.

Intrusive phases and hydrothermal breccias of the Chester intrusive complex

The deposit is hosted by several tonalite (Fig. 7) and dioritic (Fig. 8) phases that are intruded by both magmatic and hydrothermal breccia bodies. The principal characteristics of each intrusive phase are summarized in Table 1 and each phase is distinguished by their relative crosscutting relationships, textural features and chemistry (see below).

Tonalite

Tonalite occurs as the earliest phase in the deposit into which dioritic phases intrude but also occurs as a later more voluminous phase that intrudes dioritic phases (Fig. 6a, b). Tonalite is a leucocratic rock composed principally of plagioclase (An_{15-40}) and quartz (Fig. 7a) but with rare phenocrystic phases of each. The leucocratic phases of the intrusive complex comprise both tonalite and trondhjemite based on the normative An-Ab-Or diagram (O'Connor 1965; Barker 1979; see geochemistry section below) but are referred to here as tonalite for simplicity. The tonalite contains granophyric texture (Fig. 7b) and plagioclase has polysynthetic twinning and is both zoned (Fig. 7c, d) and unzoned. Small miarolitic cavities (≤ 1 cm) with spherical shape are present and are lined by plagioclase and filled with quartz $\pm$ carbonate (Fig. 7d). Rare, 5 cm to >1 m sized, elliptical to angular cavities resembling miaroles are also present and are lined by plagioclase and filled with quartz (Fig. 7e).

Tonalite breccia

This unit is a magmatic breccia and formed as a result of tonalite brecciating diorite and rarely tonalite along its intrusive margins (Fig. 7f-h). Therefore, the tonalite matrix is mineralogically and texturally identical to the tonalite described above. Two types of contacts are observed: (1) angular to rounded diorite fragments with sharp to diffuse contacts against tonalite (Fig. 7f); and (2) rare lobate contacts between the tonalite and diorite (Fig. 7g, h). Textures along the lobate contacts include the grain-size reduction of fragments (i.e., quenching; Fig. 7g, h, i) and granophyre and rare miarolitic cavities along the host rock contact (Fig. 7g). In addition, titanite and/or amphibole are present along the interface between the two phases (Fig. 7i).

Diorite phases

In the deposit several co-temporal dioritic phases occur and include diorite (Fig. 8a, b), quartz diorite (Fig. 8c) and hornblende-plagioclase $\pm$ quartz pegmatite (Fig. 6c). The diorite and quartz diorite intrude tonalite and commonly exhibits chilled or brecciated margins. Both melanocratic amphibole-rich diorite/quartz diorite (Fig. 8a, c) and leucocratic plagioclase-rich diorite/quartz diorite are present. The crosscutting relationships between dioritic phases are complex but typically the more melanocratic phases are intruded by the leucocratic phases (Fig. 8d), although the reverse is also observed. The hornblende-plagioclase $\pm$ quartz pegmatite can form either as pegmatitic segregations in diorite and quartz diorite or as distinct bodies that intrude diorite, quartz diorite and more rarely tonalite with sharp to diffuse contacts (Fig. 6c). The dioritic phases are mineralogically and texturally similar and contain variable amounts of plagioclase (An₁₀₋₅₀), amphibole, quartz, titanite, ilmenite, magnetite and apatite. In thin section, the dioritic phases may have granophyric texture and plagioclase shows primary oscillatory zoning and polysynthetic twinning. In addition, rare acicular amphibole grains (<1 cm) are present in the pegmatite (Fig. 8e).

Diorite breccia

A second type of magmatic breccia is present and formed as a result of dioritic magma brecciating tonalite and dioritic rocks. This breccia type occurs in the southern and central parts of the deposit; these bodies dip moderately to steeply to the north (Fig. 5). This breccia contains several different crystalline dioritic matrices based on mineralogy and texture (Table 1; Fig. 8f, g). The breccia is heterolithic with abundant tonalite fragments and smaller amounts of dioritic fragments (Fig. 8f). Diorite fragments are generally more melanocratic than the matrix but the reverse also occurs. The fragments rarely exhibit exfoliation textures (Fig. 8h), a feature suggestive of collapse or decompression (Sillitoe 1985). In-situ brecciation is not commonly observed and is characterized by tabular tonalite fragments; this texture occurs along the margins of the breccia bodies. This unit is often overprinted by hydrothermal alteration (e.g., biotite, chlorite; Fig. 8g) and gold mineralization is erratic.

Hydrothermal amphibole breccia

This breccia is the least abundant of the breccia types and appears to be restricted to the southern and central parts of the deposit area. This unit contains tonalite fragments and rare dioritic fragments in a fine-grained, amphibole-rich matrix (Table 1; Fig. 9a-c). Amphibole-bearing veins, which are associated with the amphibole breccia, overprint the diorite breccia (Fig. 9d). Thus, the hydrothermal amphibole event postdates at least some of the magmatic activity. This unit is gold-bearing (Fig. 9b), but it does not contain significant sulphide mineralization.

Hydrothermal biotite breccia

The hydrothermal biotite breccia (Fig. 10a) is present predominantly in the central and northern parts of the deposit. Several different biotite-rich matrices occur based on mineralogy

(Table 1): (1) a biotite-rich matrix (Fig. 10b, c); (2) a sulphide- and/or magnetite-rich matrix (Fig. 10d, e); and (3) a carbonate-rich matrix (Fig. 10f, g). The breccia is monolithic and contains tonalite fragments which may have chlorite rims (Fig. 10f). This breccia type has textures indicative of in-situ brecciation (i.e., mosaic; Fig. 10h) which suggests formation by hydrofracturing (Ross et al. 2002). This unit is consistently mineralized and has the highest average grades of Au (avg. 0.67 g/t) and Cu (avg. 1000 g/t), along with an association of elevated Mo and Ag.

Post-Chester intrusive complex dykes

The dykes, all of which are barren, have sharp contacts with units of the CIC, vary in their width (cm to several m), and are distinguished on macroscopic, petrographic (Table 2) and geochemical bases. The dykes include (1) feldspar $\pm$ quartz porphyries of dacitic to andesitic to trachyandesitic composition; (2) lamprophyre; (3) diorite; (4) gabbro; and (5) diabase. In addition, a non-mineralized tectonic breccia and heterolithic quartz $\pm$ carbonate breccia are associated with the west-striking brittle fault that cuts the CIC.

Analytical methods

Electron microprobe analysis

Amphibole grains from quartz diorite were analyzed by electron microprobe analysis (EMPA) to assess the mineral chemistry and use the data for geobarometry (Table 3). The amphiboles were analyzed by wavelength dispersive spectrometry using a Cameca SX 100 electron probe micro-analyzer at the Ontario Geological Survey Geoscience Laboratories (Geo Labs) in Sudbury, Ontario. The accelerating potential was 20 kV, the beam current was 20 nA and the beam size was 15 μm . Standards used for calibration include diopAST and pyrxBRN.

Whole-rock geochemistry

A total of 455 samples were taken from the deposit area as part of an overall deposit-scale study and includes all of the main intrusive units, dyke rocks, part of the volcanic sequence, as well as all alteration types and mineralization styles. The entire geochemical data set, along with detection limits and precision of the data, is available as a supplementary file (Katz et al. 2016).

The results reported in this study focus on the least-altered rocks in and outside the deposit area. A total of 55 samples are reported on below and in Table 4 the average compositions for all the rock units are presented. The samples include tonalite, diorite and quartz diorite, Arbutus Formation and Yeo Formation metavolcanic rocks and a variety of dyke rocks (e.g., feldspar $\pm$ quartz porphyry, lamprophyre, dioritic, gabbroic and diabase dykes). These samples were selected based on visual criteria (i.e., preservation of primary texture) and geochemical criteria. Tonalite samples with LOI <1.5 wt. %, $\text{CO}_2 \leq 0.61$ wt. %, $\text{K}_2\text{O} \leq 0.52$ wt. % and $\text{F} \leq 0.01$ wt. % and dioritic samples with LOI <2.5 wt. % and $\text{CO}_2 \leq 1$ wt. % were selected as least-altered. Samples from both the Arbutus and Yeo Formations are relatively fresh and only contain minor alteration which is considered insignificant in terms of the overall chemistry. Dykes with $\text{CO}_2 < 3.5$ wt. % were chosen as least-altered to avoid carbonate alteration.

The whole-rock geochemical data were obtained at Activation Laboratories, Ancaster, Ontario. Major elements were determined by lithium metaborate-tetraborate fusion inductively coupled plasma (ICP) whole-rock method. The FeO concentration was determined by titration and combined with total iron to determine FeO/Fe₂O₃ ratio in all the samples. The trace and rare earth elements (REE) were determined by a combination of fusion ICP, fusion inductively coupled plasma mass spectrometry (ICP-MS) and total digestion ICP-MS. The abundances of the

metalloids - As, Sb, Bi Se and Te - were determined by a combination of aqua regia ICP-MS and nitric peroxide fusion ICP-MS, whereas Au, Pd and Pt were measured by fire assay. All of the anion and volatiles were also determined: (1) Cl by instrumental neutron activation analysis; (2) B by prompt gamma neutron activation analysis; (3) F by ion selective method; and (4) S and CO₂ by infrared analysis. Mercury was determined by the cold vapor flow injection mercury technique.

U-Pb zircon and titanite geochronology

Seven samples were selected for U-Pb zircon and titanite dating based on field relationships. Heavy minerals were concentrated from the samples selected for geochronology using standard crushing and grinding followed by separation on a Wilfley table and by heavy liquid techniques. The mineral separates were sorted by magnetic susceptibility using a FrantzTM isodynamic separator followed by hand-picking using a binocular microscope. Analyses were done on zircon and titanite grains that were chemically abraded following the techniques of Mattinson (2005), including annealing for 48 hours at 1000°C prior to leaching with HF at 180°C for varying lengths of time. Details of zircon morphology, quality, and HF leaching times are summarized in Table 5. The U-Pb isotope dilution thermal ionization mass spectrometry (ID-TIMS) techniques utilized in this study are modified after Parrish et al. (1987) with treatment of analytical errors after Roddick (1987). Procedural blank levels were generally on the order of 0.5-1.0 pg for Pb. Age uncertainties are presented at the 2 σ level. Analytical results are presented in Table 5 and displayed in concordia plots (see below).

Amphibole chemistry and barometry

The results of mineral chemical analyses for amphibole are discussed below and the data is used to estimate the pressure of quartz diorite emplacement. Table 3 presents the mineral chemistry of samples used for geobarometry calculations. All of the probe analyses presented in Figure 11 can be found in Katz (2016).

All the amphiboles analyzed are calcic and plot in the tschermakite-actinolite diagram (Fig. 11a) and the pargasite-edenite diagram (Fig. 11b). The majority of the amphiboles plot in the magnesiohornblende fields, whereas a few samples plot in the ferrotschermakite and ferropargasite fields. In thin section, magnesiohornblende samples are brown, green or green-blue in plane polarized light (Fig. 12a) and correspond to medium- to dark-grey amphiboles in back-scattered electron (BSE) images (Fig. 12b), whereas the tschermakite and ferropargasite amphiboles are often vibrant blue in plane polarized light in thin section and correspond to the light-grey areas in BSE images (Fig. 12b). These differences correspond to changes in chemistry with the former containing lower Al concentrations and the latter containing higher Al concentrations. Previous studies have indicated that igneous hornblendes have lower Al^{iv} contents than metamorphic hornblendes (Leake 1971; Hammarstrom and Zen 1986). In this study, magnesiohornblende amphiboles are considered to be chemically and texturally primary, whereas ferrotschermakite and ferropargasite amphiboles are considered to be chemically and texturally secondary. The formation of the latter is likely the result of re-crystallization of primary amphibole during metamorphism.

Due to the calcic nature of the amphiboles in this study, it is possible to use Al-in-hornblende barometry to estimate the depth of emplacement of the CIC phases (Hammarstrom and Zen 1986). Crystallization pressures of the amphibole have been calculated using the Al-in-hornblende barometer of Anderson and Smith (1995) and Anderson et al. (2008). The use of this

barometer is recommended for samples which contain a quartz-potassium feldspar-plagioclase-hornblende-biotite-iron titanium oxide-titanite mineral assemblage. It is noted that potassium feldspar and biotite are not part of the quartz diorite assemblage, but the absence of the former does not appear to significantly affect pressure determinations (Anderson and Smith 1995). The effect of the absence of biotite on the pressure calculations is not known and therefore, the pressures obtained in this study may not be valid and should be tested against the results of other barometers. The results are presented in Table 3 and only samples with the appropriate limiting $\text{Fe}^{3+}/(\text{Fe}^{3+} + \text{Fe}^{2+})$ ratio of ~ 0.2 (Schmidt 1992) and $\text{Fe}_{\text{tot}}/(\text{Fe}_{\text{tot}} + \text{Mg})$ ratios with a range of 0.4 to 0.6 were used. The calculated pressures range from 0.3 to 1.3 ± 0.6 kbars at 750 °C and 0.2 to 0.4 ± 0.6 kbars at 800 °C.

Whole-rock geochemistry

Geochemistry of the Chester intrusive complex

The intrusive rocks from the CIC are classified on the basis of where they plot in the Zr/TiO₂ vs. Nb/Y (Fig. 13a) and normative An-Ab-Or classification diagrams (Fig. 13b). Thus, the tonalite suite plots in the tonalite and trondhjemite fields (Fig. 13b). However, these rocks are collectively referred to here as tonalites for simplicity. In the Zr/TiO₂ vs. Nb/Y diagram the samples plot in the rhyodacite/dacite field (Fig. 13a). In terms of the alkalis, the tonalites have between 4.0 and 6.0 wt. % Na₂O with K₂O/Na₂O ratios < 0.5 (Fig. 13c). The tonalites equate to the low-Al type (<15 wt. % Al₂O₃) based on their Al₂O₃ contents at 70 wt. % SiO₂ (Fig. 13d; Barker and Arth 1976; Barker 1979). Importantly, all the tonalite samples overlap compositionally in terms of their major element chemistry regardless of their relative timing. Furthermore, based on their Zr/Y ratios, all of the tonalites have a calc-alkaline to transitional affinity (Fig. 13e) and using the Zr/Y ratios and absolute Y contents they equate to the fields for

FII or FIIIa rhyolites but trend towards the FI rhyolite field (Fig. 13f). The major and trace element chemistry of the tonalite samples from the study area overlap with the tonalite samples obtained by Berger (2012; Fig. 13a, c-f) to the east of the study area.

The diorite and quartz diorite phases plot in the basalt to andesite fields in the Zr/TiO₂ vs. Nb/Y diagram (Fig. 13a). In terms of their normative mineralogy, the quartz diorite rarely extends into the tonalite field as hornblende tonalites. Both phases are tholeiitic to transitional in nature, which differs from the calc-alkaline to transitional nature of the tonalites (Fig. 13e). The diorite samples collected regionally by Berger (2012) overlap geochemically with the diorite and quartz diorite samples from this study (Fig. 13a, c-e).

In both the Sr/Y vs. Y (Fig. 14a) and La/Yb vs. Yb diagrams (Fig. 14b) the tonalite and diorite of the CIC plot in the arc-related rock field rather than the fields for TTGs and adakites. These diagrams further emphasize that the tonalite and dioritic phases are atypical in the Archean where high-Al TTG suites are dominant but not atypical of other recorded TTD subvolcanic suites in the AGB VMS camps (Leshner et al. 1986).

The least-altered tonalites are characterized by relatively flat REE patterns with La/Yb_N values of 0.48 to 2.36 (Fig. 15a). The tonalites are also characterized by moderate negative Eu anomalies (Eu_N/Eu*) of 0.30 to 0.81 and Gd/Y ratios of 0.14 to 0.15. These geochemical features, along with other trace element criteria (e.g., Sr and Zr/Y), are most consistent with FII rhyolites (Leshner et al. 1986). All the tonalite samples display similar primitive mantle-normalized spider patterns with negative Ti, P, Nb, Ba, Sr and Eu anomalies and positive Zr, Pb, Th and U anomalies (Fig. 15b). The negative Eu and Ba anomalies along with the low Sr contents in these rocks are indicative of plagioclase-dominated fractionation. In this case, the REE and primitive mantle-normalized patterns contrast with the regional tonalite samples from

Berger (2012). The only difference appears to be the relatively flat light REE (LREE) pattern of the tonalite samples in the deposit area compared to elevated LREE pattern in the regional samples (Fig. 15a, b).

The least-altered diorite and quartz diorite have slightly elevated and concave LREE profiles with La/Yb_N values of 2.65 to 4.85 and display weak negative Eu anomalies ($\text{Eu}_N/\text{Eu}^* = 0.43$ to 0.85 ; Fig. 15c). In addition, the middle REE (MREE) have a slightly sloped pattern (Fig. 15c) and Gd/Y ratios of 0.16 to 0.23. Hence, the signatures for these rocks contrast with the REE patterns for the tonalite samples. Although most field evidence suggests fractionation of diorite to quartz diorite over time, the REE data show that some of the diorite samples are more fractionated than quartz diorite samples (Fig. 15c). As expected, the primitive mantle-normalized spider diagram patterns for diorite and quartz diorite rocks are similar and confirm they are geochemically related. Diorite and quartz diorite show weak negative Ti, Zr, Sr, P and Rb, moderate Ba, Nb and Ta anomalies and weak positive Pb anomalies (Fig. 15d). The slightly negative Eu anomalies along with the negative Sr and Ba anomalies in the diorites are consistent with plagioclase fractionation. These patterns are similar to those of the diorite samples collected in the eastern part of the CIC by Berger (2012), suggesting a genetic relationship.

Geochemistry of the Arbutus and Yeo Formations

The geochemistry of the Arbutus Formation samples is used here to help infer a tectonic setting for the CIC. Three samples of the Arbutus Formation were collected and include one pillow basalt and two massive aphanitic basaltic flows or sills. The samples correspond to low-K tholeiitic basalts (Fig. 16a, b) and are characterized by low ΣREE and flat unfractionated patterns with the absence of an Eu anomaly (Fig. 16c). The primitive mantle-normalized spider diagram shows depletions in Th, Nb, Ta, and Cs and consistent enrichments in Ti but variable

weak enrichments in K, P and Ba relative to the overall flat profile. The pattern is most similar to those of modern back-arc basin basalts (Fig. 16d; e.g., Ewart et al. 1994; Hergt and Farley 1994).

Seven samples collected from the Yeo Formation are used to compare to the tonalite of the CIC and include feldspar crystal ash-sized tuffs and heterolithic lapilli tuffs. They are rhyodacitic/dacitic in composition (Fig. 16a) and have a calc-alkaline affinity (Fig. 16b). These samples do not typically plot in the low-Al field (Fig. 16e) due to SiO_2 contents <70 wt. %. The samples have Zr/Y vs. Y values which correspond to FII or FIIIa rhyolites (Fig. 16f) but are more consistent with FII rhyolites (Leshner et al. 1986). The Yeo Formation samples are enriched in the LREE with a moderately fractionated pattern ($\text{La/Yb}_N = 5.74$ to 7.46) and weak negative Eu anomaly ($\text{Eu}_N/\text{Eu}^* = 0.54$ to 0.78 ; Fig. 16g). The REE patterns contrast with the tonalite from the study area but overlap with the tonalite collected regionally within the CIC (Fig. 16g; Berger 2012). The primitive mantle-normalized spider diagram shows moderately to strongly negative Nb, Ta, Sr, P and Ti anomalies and weak positive Pb and K anomalies (Fig. 16h) and this pattern is similar to the regional tonalites.

Geochemistry of dyke rocks

The geochemistry of the dyke rocks is presented to determine if they are related to the CIC. The classification of the different dyke rocks has been done with the use of a Zr/TiO₂ vs. Nb/Y plot (Fig. 17a), chondrite-normalized REE diagrams and primitive mantle-normalized spider diagrams. The dyke rocks contain fractionation trends that differ from the CIC, as illustrated by the La/Yb_N vs. Yb_N plot (Fig. 17b).

Feldspar ± quartz porphyry dykes are subalkaline and equate to both andesitic to dacitic compositions, with one sample plotting in the trachyandesitic field (Fig. 17a). These dykes have variable chemistry, which is reflected in their REE (Fig. 17c) and spider diagram patterns (Fig.

17d). The REE patterns indicate five distinct feldspar $\pm$ quartz porphyry dykes (Fig. 17c). The spider diagram patterns for the dacitic samples also reflect an overall variable chemistry but all samples contain negative Nb, Ta, P and Ti and positive Pb anomalies, whereas the andesitic dykes display negative Ba, Nb, Ta, Sr, P, Eu and Ti anomalies and weakly positive Pb and U anomalies (Fig. 17d).

The lamprophyre dykes, which include both biotite-phyric and amphibole- and biotite-phyric varieties, equate to medium- to high-K subalkaline to alkaline suites and plot in the basalt and andesite fields (Fig. 17a). These rocks have fractionated patterns ($\text{La/Yb}_N = 6.55$ to 12.52) with little to no Eu anomalies ($\text{Eu}_N/\text{Eu}^* = 0.79$ to 0.94 ; Fig. 17e) and have well-developed negative Nb, Ta and Ti anomalies and positive K, Pb and Sr anomalies (Fig. 17f). These dykes have a very uniform REE, HFSE (e.g., Zr, Nb, Ta), Th and U chemistries. The LILE are slightly variable though, which may reflect alteration.

The dioritic dyke is subalkaline to rarely alkaline in nature and plots in the basalt and andesite fields (Fig. 17a). This dyke has a moderately fractionated REE pattern ($\text{La/Yb}_N = 3.83$ to 12.83) and lacks a significant Eu anomaly ($\text{Eu}_N/\text{Eu}^* = 0.76$ to 0.95 ; Fig. 17g). In the spider diagram, there are variable enrichments in the LILE, Pb, K and Sr and negative Nb, Ta and Ti anomalies (Fig. 17h).

The gabbroic dyke is subalkaline in nature and plots in the basalt field (Fig. 17a). This dyke is distinguished from the other dykes by having an overall flat REE pattern ($\text{La/Yb}_N = 0.92$ to 2.44) and either a very weak negative Eu anomaly ($\text{Eu}_N/\text{Eu}^* = 0.84$ to 1.06) or none (Fig. 17i). In the spider diagram, this dyke has low overall elemental abundances, as compared to the other dyke rocks, and typically has negative Nb, Ta and P anomalies, positive Sr and Pb anomalies and variability in K and the LILE (Fig. 17j).

The diabase dyke is subalkaline in nature and plots in the basalt field (Fig. 17a). This dyke has a slightly fractionated REE pattern ($\text{La/Yb}_N = 2.48$ to 2.69) with a weak negative Eu anomaly ($\text{Eu}_N/\text{Eu}^* = 0.78$ to 0.85 ; Fig. 17k). In the spider diagram, the data show a distinct enrichment in the LILE, positive Pb and K anomalies and negative Sr, P, Nb and Ta anomalies (Fig. 17l).

U-Pb Geochronology

Summary of U-Pb geochronology data

U-Pb geochronology was conducted on host rock samples to establish the absolute chronology of magmatic events in the deposit area and detailed mapping of the North Breccia Outcrop (Fig. 6) provided the framework for selecting these samples. In addition, dyke rock samples were selected in an attempt to constrain the minimum age of the deposit. Samples selected included five from the North Breccia Outcrop (see Fig. 6a for sample locations) and two feldspar-quartz porphyry dyke samples from drill core; all samples are located in the deposit area. The concordia diagrams are found in Figure 18 and a paragenesis is presented in Figure 19. The sample descriptions and age interpretations are found in Appendix 1 and the analytical data are presented in Table 5.

The new ages from the North Breccia Outcrop include 2741.5 ± 0.7 Ma for the diorite (Sample A; NBxDRLK12; Fig. 18a) and 2741.4 ± 0.9 Ma and 2741.7 ± 0.7 Ma for the tonalites (Sample B; NBxTonaLk12; Fig. 18b and Sample C; NBxTonbLK12; Fig. 18c, respectively). All of these ages are within analytical error. The age of 2741.0 ± 0.6 Ma for the North Breccia pegmatite (Sample D; NBxPegLK12; Fig. 18d) is slightly younger but within analytical error of the other ages obtained. The new ages for the diorite, tonalite and pegmatite, along with previously obtained tonalite ages of 2740 ± 2 Ma (Heather and van Breemen 1994) and $2741.1 \pm$

0.9 Ma and 2738.7 ± 0.8 Ma (Kontak et al. 2013a), demonstrate that the phases of the CIC are coeval. These data are consistent with the crosscutting relationships described in this study.

The age obtained from the lamprophyre dyke at 2742.2 ± 0.8 Ma (Sample E; Nbxlamp02; Fig. 18e) is coeval with the intrusive phases of the CIC and is within error. Conversely, unaltered lamprophyre dykes intrude altered tonalite and diorite phases, suggesting that this dyke postdates the CIC. Furthermore, in the AGB lamprophyre dykes are documented to be contemporaneous with late- to post-tectonic alkaline magmatism (2680 to 2674 Ma; Wyman and Kerrich 1993). Although the crosscutting relationships suggest the zircon represents an inherited age, additional data is needed to definitively determine if this is the case.

Two feldspar-quartz porphyry dyke samples, one that crosscuts altered tonalite and one that crosscuts a breccia body, were sampled to provide a minimum age for deposit formation. The first sample, which comprises an unaltered feldspar-quartz porphyry dyke, yielded an age of 2696.0 ± 0.9 Ma (Sample F; E11-119-240m; Fig. 18f). The second sample, which comprises a muscovite altered feldspar-quartz porphyry dyke, yielded a similar age of 2697.1 ± 0.8 Ma (Sample G; E12-370-215m; Fig. 18g). The muscovite alteration associated with the dyke may be related to the D₂ deformation that affects the sample. These ages indicate that the porphyry dykes are feeders to the Brett Lake Formation, which forms part of the Swayze Group (Heather 2001). Therefore, these samples provide an age for some of the youngest magmatic activity in the SGB. Given the ages, these samples do not constrain well the minimum age for deposit formation.

Discussion

The study of the CIC highlights its features as a subvolcanic, low-Al composite intrusion. Such intrusions are characterized by a complex intrusive history, high-level textures, FII or FIII chemical affinity and coeval and co-genetic volcanic rocks (Galley 2003). These intrusions can

host Cu-Au-Mo mineralization, such as the Flavrian-Powell intrusive complex (Goldie 1979; Galley and van Breemen 2002) and the Mooshla intrusive complex (Galley and Lafrance 2014). Geochronological evidence comparing the ages of the CIC with the contained gold mineralization indicates that the latter is synchronous with magmatism at 2740.2 ± 5.6 Ma (Katz 2016). It is important, therefore, to understand how the CIC formed to put the deposit into a geological context. The following discussion addresses the tectonic setting, relationship between the tonalite and diorite and investigates the petrogenetic relationship of the Yeo Formation with the tonalite of the CIC. The dyke rocks are discussed with regards to their dissimilar geochemistry with the CIC. Finally, the history and magmatic evolution of the CIC is discussed.

Tectonic setting of the Chester intrusive complex

Archean TTG/D suites represent the largest portion of preserved Archean continental crust and understanding their origin is important in terms of Archean geodynamic processes, which in turn is relevant to the formation of Au(-Cu) deposits such as Côté Gold. Two types of Archean TTG/D suites can be distinguished geochemically, the voluminous high-Al type (>15 wt. % Al_2O_3) and the rarer low-Al type (<15 wt. % Al_2O_3 ; Barker 1979). The high-Al TTG suite equates chemically to FI-type felsic volcanic rocks and are produced by high-pressure melting of hydrated basalt within the garnet stability field (Condie 2005). In contrast, the low-Al TTD suite equates chemically to FII- and FIII-type felsic volcanic rocks and are products of partial melting of a low-pressure source area within the plagioclase stability field (Condie 2005; Martin et al. 2005; Beakhouse 2011). Geochemically, this is reflected by relatively unfractionated REE distribution patterns, negative Eu anomalies, low Sr values (<300 ppm) and lower Sr/Y ratios. The lower pressure conditions of melt generation for the low-Al TTD suite implies that they are generated by a different mechanism than high-Al TTG suites. This is illustrated by the Sr/Y vs.

Y and La/Yb vs. Yb diagrams (Fig. 14) in which tonalite and diorite plot in the post-Archean normal arc-related field rather than the Archean adakite and high-Al TTG field. The low-Al TTD suites are interpreted to form in rift-related extensional settings within oceanic-arc environments (Barrie et al. 1993; Galley 2003; Hart et al. 2004).

The tectonic setting of the Arbutus Formation, into which the CIC intrudes, is important to understand in the context of the deposit setting. The use of its trace element geochemistry can be used to infer the tectonic setting for the formation and by extension the deposit. The Arbutus Formation samples from this study display similar enrichments (e.g., Ba, K, P, Ti) and depletions (e.g., Th, Nb, Ta) to those of modern back-arc basin basalts and to a lesser extent island arc tholeiites (Fig. 16d). Therefore, this formation is suggested to have formed from an undepleted mantle source in a possible back-arc environment, consistent with the inferred tectonic setting of low-Al composite intrusions.

Petrogenetic relationship between phases of the Chester intrusive complex

In the deposit area, the CIC consists of two geochemically discrete intrusive phases, tonalite and diorite. Crosscutting relationships suggest that diorite differentiates to quartz diorite but not the more voluminous tonalite. Mutually crosscutting relationships between tonalite and dioritic phases suggest they are coeval and geochronological results from this study confirm their temporal relationship. Of relevance here is the petrogenetic relationship among these spatially and temporally related phases.

This study demonstrates that all tonalite samples in the deposit area are geochemically related, based on their low-Al nature, transitional to calc-alkaline affinity, chemical signature equating to FII-type rhyolites, unfractionated REE patterns, weak to moderate negative Eu anomalies and similar primitive mantle-normalized profiles (Figs. 15d-f and 17a, b). Therefore,

any differences noted in their texture (i.e., presence of diorite fragments) is a reflection of the relative timing of emplacement. The only major geochemical difference between least-altered tonalite samples from the deposit area and regional tonalite samples is the lower LREE concentrations (i.e., La, Ce, Pr and Nd) in the former compared to the elevated LREE concentrations in the latter (Fig. 15a, b). This geochemical difference either reflects that the two tonalites are unrelated or that the LREE in the deposit have been mobile. Although the REE are typically immobile in most systems, even when subjected to intense hydrothermal alteration, exceptions to this occur (Fryer 1980; Schneider et al. 1988; Lottermoser 1992). In the deposit, the LREE have been demonstrated to be mobile under hydrothermal alteration (Katz 2016). Therefore, the second explanation for the difference in LREE concentration is preferred and the tonalite in the deposit is interpreted to be geochemically related to the regional tonalite.

The geochemical data presented in this study suggest tonalite and dioritic phases of the CIC are not genetically related. The slight difference in the MREE slope between tonalite and diorite rocks (Fig. 15a, c), which corresponds to differences in Gd/Y ratios, suggests that they were derived from different source areas; the former from a plagioclase stable source and the latter from a source area where plagioclase and amphibole were stable. Based on Zr/Y ratios, the dioritic phases are tholeiitic to transitional in nature, whereas the tonalitic phases have a calc-alkaline to transitional affinity (Fig. 13e). These variable chemical affinities, and hence petrogenetic associations, have been previously documented in TTD suites and may indicate that these intrusive suites consist of a composite of differentiated lithospheric mantle and lower-crust partial melts (Galley and Lafrance 2014).

Previous studies recorded mingling textures between tonalite and dioritic phases in the CIC (Heather 1993; Heather and Shore 1999a; Heather 2001; Berger 2011) and these textures

must be addressed to better understand tonalite and diorite petrogenesis. Magma mingling is a term used to describe magmas that are mixed physically although heterogeneities exist such that banding or enclaves are formed due to a lack of chemical exchange (Vernon 1984; Sparks and Marshall 1986; Wilcox 1999; Kuşcu and Floyd 2001). Magma mixing refers to a homogeneous product or composition resulting from chemical exchange (Sparks and Marshall 1986; Neves and Vauchez 1995; Kuşcu and Floyd 2001). In magma mixing or mingling, certain textures are often observed, such as mafic ‘pillows’ enclosed in felsic rocks (Snyder et al. 1997; Wilcox 1999), irregular shaped mafic enclaves (Vernon 1984; Vernon et al. 1988), rapakivi feldspars, acicular grains, ocelli (Baxter and Feely 2002), normal and reverse zoning in crystals from the same sample (Luhr and Carmichael 1980) and disequilibrium textures (i.e., sieve texture, rounded and embayed crystals, reaction rims on minerals; Stimac and Pearce 1992; Kuşcu and Floyd 2001). The lack of mingling textures and no documented intermediate composition between tonalite and diorite suggest magma mingling did not occur in the deposit area. Instead, the rare lobate contacts observed between diorite fragments and tonalite matrix suggest quenching (Vernon 1984) along the intrusive margin of tonalite. Lobate contacts are typical of boundaries between two liquids with different viscosities (Sklyarov and Fedorovskii 2006) and its presence suggests that diorite was still hot when tonalite intruded (Vernon 1984). The chilled diorite fragments against tonalite (Fig. 7g, h), acicular amphibole and miarolitic cavities near the contacts (Fig. 7g) support quenching and undercooling of the fragments and breccia matrix.

Petrogenetic relationship between the Yeo Formation and the Chester intrusive complex

The petrogenetic relationship of subvolcanic intrusions and temporally related volcanic rocks has been demonstrated in several low-Al composite intrusions (Davis et al. 1985; Bailes and Galley 1996; Barrett and MacLean 1999). Previous studies have shown the Yeo Formation

to be geochemically related to the tonalite of the CIC based on similar REE patterns (Heather et al. 1996; Berger 2012). The REE patterns of the Yeo Formation samples collected in this study overlap with the tonalite samples collected regionally by Berger (2012; Fig. 16g, h). Thus, the results are consistent with previous data and demonstrate that the Yeo Formation represents the eruptive equivalent of the tonalite in the CIC.

Geochemistry of the dyke rocks

Based on geochemical evidence, such as their steeper, fractionated REE patterns (i.e., FI-type rhyolites; Leshner et al. 1986; Fig. 17c), the feldspar $\pm$ porphyry dykes are not petrogenetically related to the CIC. The geochemistry of these dykes, particularly the dacitic samples, resemble the metavolcanic rocks from younger formations in the SGB (Heather et al. 1996). These samples are interpreted to be feeder dykes to several metavolcanic formations in the SGB (2739 to 2695 Ma; van Breemen et al. 2006). Geochronology results from this study support this interpretation with two porphyry dyke samples dated at ca. 2696 Ma.

Although mineralogically and texturally different, both the lamprophyre and dioritic dykes have strongly fractionated REE patterns and weakly negative to no Eu anomalies. Thus, a deep, garnet-bearing source area is inferred for these melts based on their depleted HREE profiles (Fig. 17e, g). Their similar La/Yb_N values (Fig. 17b), Eu anomalies and primitive mantle-normalized spider profiles (Fig. 17f, h) suggest they were derived from a similar source.

The gabbroic dyke has a flat REE pattern and lacks an Eu anomaly. The flat pattern reflects that it has undergone little fractionation. Notably, the REE pattern of this dyke is similar to the Arbutus Formation. These rocks are not known to be temporally related, but we note that there is no absolute age for the dyke rock.

The diabase dyke has relatively flat REE patterns with slightly elevated LREE ($\text{La/Yb}_N = 2.48$ to 2.69). This dyke is likely equivalent to the ca. 2450 Ma Matachewan dykes (Heaman 1997) in the AGB.

The dyke rocks in the deposit area postdate the formation of the CIC based on their crosscutting relationships and it is demonstrated here that they have no petrological relationship with the CIC. This study also reveals that the CIC magmatism is geochemically unique to this part of the SGB. This latter point is significant given the suggested magmatic origin for the mineralization (Kontak et al. 2013a; Katz et al. 2015; Katz 2016).

Formation of the Côté Gold deposit

The following discussion addresses the setting of this deposit but not its genesis per se, this being addressed in future papers. Instead, this section discusses aspects of the CIC in the context of its emplacement history, level of emplacement and magmatic evolution that pertains to the origin of the deposit. A paragenesis is presented in Figure 19 and a schematic model for the formation of the CIC and deposit is shown in Figure 20.

The CIC was emplaced at ca. 2741 to 2739 Ma into the volcanic-sedimentary packages of Arbutus and Yeo Formations based on the incorporation of screens and inclusions these volcanic rocks (Fig. 20a; Heather 2001; Berger 2012). Although the CIC contains screens and inclusions of the Yeo Formation (Berger 2012), which suggests the CIC intruded into its own volcanic pile, the 2739 ± 1 Ma (van Breemen et al. 2006) and 2734 ± 2 Ma (Heather and Shore 1999a) ages obtained from the Yeo Formation suggest volcanism also occurred syn- to post-magmatism (Fig. 19).

The CIC is inferred to have been emplaced into a high-crustal level based on the incorporation of screens and inclusions of the coeval and co-genetic Yeo Formation.

Emplacement of a magma into shallower levels can result in undercooling of the magma and this is accompanied by a variety of textures (e.g., miarolitic cavities, granophyric texture, pegmatites and acicular crystals; Candela 1997). Therefore, the textures present in the tonalite and diorite phases are consistent with a high-level of emplacement. In addition, the Al-in-hornblende geobarometry results of ≤ 1.3 kbars are in agreement with the above interpretation.

The emplacement history of the CIC is complex and in the deposit area can be broadly simplified into five stages (Fig. 20): (1) emplacement at ca. 2741 Ma of multi-phase tonalite and diorite of variable thickness probably along primary stratigraphic contacts as sill-like bodies; (2) the diorite evolved at depth to more leucocratic phases; this process may have repeated several times during the history of the intrusive complex. The forceful emplacement of diorite and quartz diorite resulted in brecciation of tonalite and earlier dioritic phases; (3) emplacement of coeval, small hornblende-plagioclase $\pm$ quartz pegmatite units within dioritic phases indicates the diorite approached volatile saturation during its fractionation; (4) the continued or renewed injection of tonalite and hence its contemporaneity with emplacement of dioritic phases, as indicated from the lobate contacts between these units; and (5) emplacement of several hydrothermal stages (e.g., hydrothermal amphibole and biotite breccias) accompanied by Au-Cu mineralization which are constrained to 2740.2 ± 5.6 Ma based on four Re-Os molybdenite ages (Kontak et al. 2013a; Katz 2016).

Conclusions

The complex intrusive history of the CIC is the result of multi-phase, high-level injections of tonalite and diorite that intruded into a subaqueous back-arc environment. The CIC has been constrained at ca. 2741 to 2739 Ma based on high-precision U-Pb ID-TIMS geochronology and is both coeval and co-genetic with the felsic to intermediate rocks of the Yeo

Formation. Although tonalite and dioritic rocks are co-temporal and co-spatial, they appear to be petrogenetically unrelated with one representing a mantle differentiate and the other a lower-crust partial melt. The results from this study indicate that the CIC is similar to other low-Al, subvolcanic intrusions that underlie VMS-type mineralization and have been noted to contain porphyry-style Cu-Mo-Au mineralization.

Acknowledgments

This paper was completed in partial fulfillment of a Ph.D. degree at Laurentian University. The initial funding and contributions for this project by Trelawney Mining and Exploration Inc. and David Beilhartz are recognized and thanked. The IAMGOLD Corporation is thanked for their considerable funding of this project. Jamie Rogers is thanked for his involvement and support of this research project. The entire geology team at Côté Gold project is thanked, in particular Marie-France Bugnon, Alan Smith and Brian Tomzcuk. Funding and support was also provided by the Geological Survey of Canada under the Natural Resources Canada Targeted Geoscience Initiative 4 (TGI-4 Lode Gold project). Dave Crabtree is thanked for his capable assistance with the microprobe analyses. We also thank the journal reviewers for their comments that resulted in substantial improvement to the manuscript. Special thanks to Steve Scott whose time and patience are greatly appreciated.

References

- Anderson, J.L., and Smith, D.R. 1995. The effects of temperature and f_{O_2} on the Al-in-hornblende barometer. *American Mineralogist*, **80**: 549-559.
- Anderson, J.L., Barth, A.P., Wooden, J.L., and Mazdab, F. 2008. Thermometers and thermobarometers in granitic systems. *Reviews in Mineralogy and Geochemistry*, **69**: 121-142.
- Ayer, J., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J., Kwok, K., and Trowell, N. 2002.

- Evolution of the southern Abitibi greenstone belt based on U-Pb geochronology: autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation. *Precambrian Research*, **115**: 63-95.
- Ayer, J.A., and Chartrand, J.E. 2011. Geological compilation of the Abitibi greenstone belt. Ontario Geological Survey, Miscellaneous Release Data 282.
- Bailes, A.H., and Galley, A.G. 1996. Setting of Paleoproterozoic volcanic-hosted massive base metal sulphide deposits, Snow Lake. In *EXTECH 1: A multidisciplinary to massive sulphide research in the Rusty Lake-Snow Lake greenstone belts, Manitoba. Edited by G.F. Bonham-Carter, A.G. Galley and G.E.M. Hall. Geological Survey of Canada, Bulletin 426*, pp. 105-138.
- Barker, F. 1979. *Trondhjemites, dacites and related rocks*. Elsevier, New York, 659 p.
- Barker, F., and Arth, J.A. 1976. Generation of trondhjemitic-tonalitic liquids and Archean bimodal trondhjemite-basalt suites. *Geology*, **4**: 596-600.
- Barrett, T.J., and MacLean, W.H. 1999. Volcanic sequences, lithogeochemistry, and hydrothermal alteration in some bimodal volcanic-associated massive sulfide systems. *Reviews in Economic Geology*, **8**: 101-133.
- Barrie, C.T., Ludden, J.N., and Green, T.H. 1993. Geochemistry of volcanic rocks associated with Cu-Zn and Ni-Cu deposits in the Abitibi Subprovince. *Economic Geology*, **88**: 1341-1358.
- Barrie, C.T., Cathles, L.M., and Erendi, A. 1999. Finite element heat and fluid flow computer simulations of a deep ultramafic sill model for the giant Kidd Creek volcanic-associated massive sulfide deposit, Abitibi Subprovince, Canada. *Economic Geology Monograph*, **10**: 529-540.
- Baxter, S., and Feely, M. 2002. Magma mixing and mingling textures in granitoids: examples from the Galway granite, Connemara, Ireland. *Mineralogy and Petrology*, **76**: 63-74.
- Beakhouse, G.P. 2011. The Abitibi Subprovince plutonic record: Tectonic and metallogenic implications. Ontario Geological Survey, Open File 6268, pp. 1-161.
- Bédard, J.H. 2006. A catalytic delamination-driven model for coupled genesis of Archean crust and sub-continental lithospheric mantle. *Geochimica et Cosmochimica Acta*, **70**: 1188-1214.

- Berger, B.R. 2011. Geological Investigations South of Gogama. *In* Summary of Field Work and Other Activities 2011. Ontario Geological Survey, Open File 6270, pp. 1-7.
- Berger, B.R. 2012. Interpretation of Geochemistry in the South of Gogama Area. *In* Summary of Field Work and Other Activities 2012. Ontario Geological Survey, Open File 6280, pp. 1-14.
- Campbell, I.H., Franklin, J.M., Gorton, M.P., Hart, T.R., and Scott, S.D. 1981. The role of subvolcanic sills in the generation of massive sulfide deposits. *Economic Geology*, **76**: 2248-2253.
- Candela, P. A. 1997. A review of shallow, ore-related granites: Textures, volatiles, and ore metals. *Journal of Petrology*, **38**: 1619-1633.
- Castillo, P.R., Janney, P.E., and Solidum, R.U. 1999. Petrology and geochemistry of Camiguin Island, southern Philippines: insights to the source of adakites and other lavas in a complex arc setting. *Contributions to Mineralogy and Petrology*, **134**: 33-51.
- Cathles, L.M. 1981. Fluid flow and the genesis of hydrothermal ore deposits. *Economic Geology*, 75th anniversary volume, pp. 424-457.
- Condie, K.C. 2005. TTGs and adakites: are they both slab melts? *Lithos*, **80**: 33-44.
- Davis, D.W., Krogh, T.E., Hinzer, J., and Nakamura, E. 1985. Zircon dating of polycyclic volcanism at Sturgeon Lake and implications for base metal mineralization. *Economic Geology*, **80**: 1942-1952.
- Defant, M.J., and Drummond, M.S. 1993. Mount St. Helens: Potential example of the partial melting of the subducted lithosphere in a volcanic arc. *Geology*, **21**: 547-550.
- Dubé, B., and Gosselin, P. 2007. Greenstone-hosted quartz-carbonate vein deposits. *In* Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods. *Edited by* W.D. Goodfellow. Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, pp. 49-73.
- Ewart, A., Bryan, W.B., Chappell, B.W., and Rudnick, R.L. 1994. 24. Regional geochemistry of the Lau-Tonga arc and backarc systems. *Proceedings of the Ocean Drilling Program, Scientific Results*, **135**: 385-425.

- Franklin, J.M., 1996, Volcanic-associated massive sulphide base metals. *In* *Geology of Canadian Mineral Deposit Types*. Edited by O.R. Eckstrand, W.D. Sinclair and R.I. Thorpe. Geological Survey of Canada, Geology of Canada Series, No. 8, p. 158-183.
- Friske, P. 1974. The Beidelman Bay copper porphyry deposit. Unpublished B.Sc. thesis, Lakehead University, Thunder Bay, Ontario, 109 p.
- Galley A.G. 2003. Composite synvolcanic intrusions associated with Precambrian VMS-related hydrothermal systems. *Mineralium Deposita*, **38**: 443-473.
- Galley, A.G., and Lafrance, B. 2014. Setting and evolution of the Archean synvolcanic Mooshla intrusive complex, Doyon-Bousquet-LaRonde mining camp, Abitibi greenstone belt: emplacement history, petrogenesis, and implications for Au metallogensis. *Economic Geology*, **109**: 205-229.
- Galley, A.G., and van Breemen, O. 2002. Timing of synvolcanic magmatism in relation to base-metal mineralization, Rouyn-Noranda, Abitibi volcanic belt, Quebec. Geological Survey of Canada, Current Research 2002-F8, pp. 1-9.
- Galley, A.G., van Breemen O., and Franklin, J.M. 2000. The relationship between intrusion-hosted Cu-Mo mineralization and the VMS deposits of the Archean Sturgeon Lake mining camp, northwestern Ontario. *Economic Geology*, **95**: 1542-1550.
- Goldie, R. Kotila, B., and Seward, D. 1979. The Don Rouyn Mine: an Archean porphyry copper deposit near Noranda, Quebec. *Economic Geology*, **74**: 1680-1684.
- Hammarstrom, J.M., and Zen, E. 1986. Aluminum in hornblende: An empirical igneous geobarometer. *American Mineralogist*, **71**: 1297-1313.
- Hart, T.R., Gibson, H.L., and Leshner, C.M. 2004. Trace element geochemistry and petrogenesis of felsic volcanic rocks associated with volcanogenic massive Cu-Zn-Pb sulfide deposits. *Economic Geology*, **99**: 1003-1013.
- Hawthorne, F.C., and Oberti, R. 2007. Classification of the amphiboles. *Reviews in Mineralogy and Geochemistry*, **67**: 55-88.
- Heaman, L.M. 1997. Global mafic magmatism at 2.45 Ga: Remnants of an ancient large igneous province? *Geology*, **25**: 229-302.

- Heather, K.B. 1993. Regional geology, structure, and mineral deposits of the Archean Swayze greenstone belt, southern Superior Province, Ontario. Geological Survey of Canada, Current Research 93-1C, pp. 295-305.
- Heather, K.B. 2001. The geological evolution of the Archean Swayze greenstone belt, Superior Province, Canada. Unpublished Ph.D. thesis, Keele University, Keele, England, 370 p.
- Heather, K.B. and Shore, G.T. 1999a. Geology, Swayze Greenstone Belt, Ontario. Geological Survey of Canada, Open File 3384a, sheet 2, scale 1:50 000.
- Heather, K.B. and Shore, G.T. 1999b. Geology, Gogama, Swayze greenstone belt, Ontario. Geological Survey of Canada, Open File 3384g, scale 1:50 000.
- Heather, K.B., and van Breemen, O. 1994. An interim report on geological, structural, and geochronological investigations of granitoid rocks in the vicinity of the Swayze greenstone belt, southern Superior Province, Ontario. Geological Survey of Canada, Current Research 1994-C, pp. 259-268.
- Heather, K.B., Shore, G.T., and van Breemen, O. 1996. Geological investigations in the Swayze greenstone belt, southern Superior Province, Ontario: A final update. Geological Survey of Canada, Current Research 1996-C, pp. 125-136
- Hergt, J.M., and Farley, K.N. 1994. 26. Major element, trace element and isotope (Pb, Sr, and Nd) variations in site 834 basalts: Implications for the initiation of backarc opening. *Proceedings of the Ocean Drilling Program, Scientific Results*, 135: 471-485.
- IAMGOLD Corporation. 2013. IAMGOLD provides mineral resource update for Côté Gold and reports strongest quarter for production in 2012 with confirmed production guidance for 2013 [online, cited 22 January 2013].
- Katz, L.R. 2016. Geology of the Archean Côté Gold Au(-Cu) intrusion-related deposit, Swayze greenstone belt, Ontario. Unpublished Ph.D. thesis, Laurentian University, Sudbury, Ontario, 328 p.
- Katz, L.R., Kontak, D.J., Dubé, B., and McNicoll, V. 2015. The Archean Côté Gold intrusion-related Au(-Cu) deposit, Ontario: A large-tonnage, low-grade deposit centred on a magmatic-hydrothermal breccia. *In Targeted Geoscience Initiative 4: Contributions to the Understanding of Precambrian Lode Gold Deposits and Implications for Exploration. Edited by B. Dubé and P. Mercier-Langevin*. Geological Survey of Canada, Open File 7852, pp. 139-155.

- Katz, L.R., Kontak, D.J., Dubé, B., Mercier-Langevin, P., Bécu, V., Lauzière, K. 2016. Whole-rock lithogeochemistry of the Archean intrusion-related Côté Gold Au(-Cu) deposit, Ontario, Canada. Geological Survey of Canada, Open File 8040, 1 .zip file.
- Kennedy, L.P. 1985. The geology and geochemistry of the Archean Flavrian pluton, Noranda, Quebec. Unpublished Ph.D. thesis, University of Western Ontario, London, Ontario, 460 p.
- Kontak, D.J., Creaser, R.A., and Hamilton, M. 2013a. Geological and geochemical studies of the Côté Lake Au(-Cu) deposit Area, Chester Township, northern Ontario. *In* Results from the Shining Tree, Chester Township and Matachewan Gold Projects and the Northern Cobalt Embayment Polymetallic Vein Project. *Edited by* J.A. Ayer, D.J. Kontak, R.L Linnen and S. Lin. Ontario Geological Survey, Miscellaneous Release Data 294.
- Kontak, D.J., Katz, L., Creaser, R.A., and Hamilton, M. 2013b. The Archean Côté Gold Au(-Cu) deposit, northern Ontario, Canada: A large tonnage, low-grade Au deposit centred on a 2740 Ma magmatic-hydrothermal diorite complex. *In* Geological Association of Canada-Mineralogical Association of Canada, Annual Meeting, Winnipeg, Manitoba, Abstracts.
- Kuşcu, G.G., and Floyd, P.A. 2001. Mineral compositional and textural evidence for magma mingling in the Saraykent volcanics. *Lithos*, **56**: 207-230.
- Leake, B.E. 1971. On aluminous and edenitic hornblendes. *Mineralogical Magazine*, **38**: 389-407.
- Le Bas, M.J., Le Maitre, R.W., Streckeisen, A.L., and Zanettin, B. 1986. A chemical classification of volcanic rocks based on the total alkali-silica diagram. *Journal of Petrology*, **27**: 745-750.
- Le Maitre, R.W., Streckeisen, A., Zanettin, B., Le Bas, M.J., Bonin, B., Bateman, P., Bellieni, G., Dudek, A., Efremova, S., Keller, J., Lameyre, J., Sabine, P.A., Schmid, R., Sørensen, H., and Woolley, A.R. 2002. *Igneous rocks: A classification and Glossary of Terms*, 2nd edition. Cambridge University Press, Cambridge, 236 p.
- Lentz, D.R. 1998. Petrogenetic evolution of felsic volcanic sequences associated with Phanerozoic volcanic-hosted massive sulphide systems: the role of extensional geodynamics. *Ore Geology Reviews*, **12**: 289-327.

- Leshner, C.M., Goodwin, A.M., Campbell, I.H., and Gorton, M.P. 1986. Trace-element geochemistry of ore-associated and barren, felsic metavolcanic rocks in the Superior Province, Canada. *Canadian Journal of Earth Sciences*, **23**: 222-237.
- Lottermoser, B.G. 1992. Rare earth elements and hydrothermal ore formation processes. *Ore Geology Reviews*, **7**: 25-41.
- Luhr, J.F., and Carmichael, I.S.E. 1980. The Colima volcanic complex, Mexico: I. Post-caldera andesites from volcán Colima. *Contributions to Mineralogy and Petrology*, **71**: 343-372.
- Martin, H., and Moyen, J.F. 2002. Secular changes in tonalite-trondhjemite-granodiorite composition as markers of the progressive cooling of Earth. *Geology*, **30**: 319-322.
- Martin, H., Smithies, R.H., Rapp, R., Moyen, J.-F., and Champion, D. 2005. An overview of adakite, tonalite-trondhjemite-granodiorite (TTG), and sanukitoid: Relationships and some implications for crustal evolution. *Lithos*, **79**: 1-24.
- Mattinson, J.M. 2005. Zircon U-Pb chemical abrasion ("CA-TIMS") method: Combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages. *Chemical Geology*, **220**: 47-66.
- Neves, S.P., and Vauchez, A. 1995. Successive mixing and mingling of magmas in a plutonic complex of Northeast Brazil. *Lithos*, **34**: 275-299.
- O'Connor, J.T. 1965. A classification for quartz-rich igneous rocks based on feldspar ratios. U.S. Geological Survey, Professional Paper 525B, pp. 79-84.
- Parrish, R.R., Roddick, J.C., Loveridge, W.D., and Sullivan, R.W. 1987. Uranium-lead analytical techniques at the Geochronology Laboratory. Geological Survey of Canada Paper 87-2, pp. 3-7.
- Poulsen, K.H. and Franklin, J.M. 1981. Copper and gold mineralization in an Archean trondhjemitic intrusions, Sturgeon Lake, Ontario. Geological Survey of Canada, Paper 81-1a, pp. 9-14.
- Powell, W.G., Carmichael, D.M., and Hodgson, C.J. 1995. Conditions and timing of metamorphism in the southern Abitibi greenstone belt, Québec. *Canadian Journal of Earth Sciences*, **32**: 787-805.
- Richard, J.P., and Kerrich, R. 2007. Special Paper: Adakite-like rocks: Their diverse origins

- and questionable role in metallogenesis. *Economic Geology*, **102**: 537-576.
- Robert, F., Poulsen, K.H., Cassidy, K.F., and Hodgson, C.J. 2005. Gold metallogeny of the Yilgarn and Superior cratons. *Economic Geology*, 100th anniversary volume, pp. 1001-1033.
- Roddick, J.C. 1987. Generalized numerical error analysis with applications to geochronology and thermodynamics. *Geochimica et Cosmochimica Acta*, **51**: 2129-2135.
- Rogers, J.R., Beilhartz, D., Kontak, D.J., Katz, L., Dubé, B., and McNicoll, V. 2013. The Côté Gold deposit: discovery of a new generation low-grade, multi-million ounce gold resource in the Archean Superior Province of Canada. *In* NewGenGold Conference, Perth, Australia, Extended Abstracts, pp. 159-174.
- Ross, P.S., Jebrak, M., and Walker, B.M. 2002. Discharge of hydrothermal fluids from a magma chamber and concomitant formation of a stratified breccia zone at the Questa porphyry molybdenum deposit, New Mexico. *Economic Geology*, **97**: 1679-1699.
- Schmidt, M.W. 1992. Amphibole composition in tonalite as a function of pressure: An experimental calibration of the Al-in-hornblende barometer. *Contributions to Mineralogy and Petrology*, **110**: 304-310.
- Schneider, H.-J., Özgür, N., and Palacios, C.M. 1988. Relationship between alteration, rare earth element distribution, and mineralization of the Murgul copper deposit, Northeastern Turkey. *Economic Geology*, **83**: 1238-1246.
- Sillitoe, R.H. 1985. Ore-related breccias in volcanoplutonic arcs. *Economic Geology*, **80**: 1467-1514.
- Sklyarov, E.V., and Fedorovskii, V.S. 2006. Magma mingling: Tectonic and geodynamic implications. *Geotectonics*, **40**: 120-134.
- Smith, J., Lafrance, B., and Kontak, D. 2014. A comparative study of the deformation history of auriferous quartz veins in the Archean Côté Gold deposit and the structural evolution of the spatially-related Ridout deformation zone, Swayze greenstone belt, northern Ontario. *In* Geological Association of Canada-Mineralogical Association of Canada, Annual Meeting, Fredricton, New Brunswick, Abstracts.
- Snyder, D., Crambes, C., Tait, S., and Wiebe, R.A. 1997. Magma mingling in dikes and sills. *The Journal of Geology*, **105**: 75-86.

- Sparks, R.S.J., and Marshall, L.A. 1986. Thermal and mechanical constraints on mixing between mafic and silicic magmas. *Journal of Volcanology and Geothermal Research*, **29**: 99-124.
- Stacey, J.S., and Kramers, J.D. 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. *Earth and Planetary Science Letters*, **26**: 207-221.
- Stimac, J.A., and Pearce, T.H. 1992. Textural evidence of mafic-felsic magma interaction in dacite lavas, Clear Lake, California. *American Mineralogist*, **77**: 795-809.
- Stolz, A.J., Varne, R., Davies, G.R., Wheller, G.E., and Foden, J.D. 1990. Magma source components in arc-continent collision zone: the Flores-Lembata sector, Sunda arc, Indonesia. *Contributions to Mineralogy and Petrology*, **105**: 585-601.
- Sun, S.S., and McDonough, W.F. 1989. Chemical and isotopic systematics of ocean basalts: Implications for mantle composition and process. *In* *Magmatism and ocean basins*. Edited by A.D. Saunders and M.J. Norry. Geological Society Special Publication No. 42, pp. 313-345.
- Taylor, R.P., and Fryer, B.J. 1980. Multiple-stage hydrothermal alteration in porphyry copper systems in northern Turkey: The temporal interplay of potassic, propylitic, and phyllic fluids. *Canadian Journal of Earth Sciences*, **17**: 901-926.
- Thurston, P.C., Ayer, J.A., Goutier, J., and Hamilton, M.A. 2008. Depositional gaps in the Abitibi greenstone belt stratigraphy: A key to exploration for syngenetic mineralization. *Economic Geology*, **103**: 1097-1134.
- Trowell, N.F. 1974. Geology of the Bell Lake-Sturgeon Lake area, districts of Thunder Bay and Kenora. Ontario Geological Survey, Geological Report 114, pp. 1-67.
- Turner, S., Hawkesworth, C., Rogers, N., Bartlett, J., Worthington, T., Hergt, J., Pearce, J., and Smith, I. 1997. ^{238}U - ^{320}Th disequilibria, magma petrogenesis, and flux rates beneath the depleted Tonga-Kermadec island arc. *Geochimica et Cosmochimica Acta*, **61**: 4855-4884.
- Van Breemen, O., Heather, K.B., and Ayer, J.A. 2006. U-Pb geochronology of the Neoarchean Swayze sector of the southern Abitibi greenstone belt. Geological Survey of Canada, Current Research 2006-F1, pp. 1-32.
- Vernon, R.H. 1984. Microgranitoid enclaves in granites—globules of hybrid magma quenched in a plutonic environment. *Nature*, **309**: 438-439.

- Vernon, R.H., Etheridge, M.A., and Wall, V.J. 1988. Shape and microstructure of microgranitoid enclaves: Indicators of magma mingling and flow. *Lithos*, **22**: 1-11.
- Wilcox, R.E. 1999. The idea of magma mixing: History of a struggle for acceptance. *The Journal of Geology*, **107**: 421-432.
- Winchester, J.A., and Floyd, P.A. 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chemical Geology*, **20**: 325-343.
- Wyman, D.A., and Kerrich, R. 1993. Archean shoshonitic lamprophyres of the Abitibi Subprovince, Canada: Petrogenesis, age, and tectonic setting. *Journal of Petrology*, **34**: 1067-1109.
- Yergeau, D., Mercier-Langevin, P., Dubé, B., Malo, M., McNicoll, V.J., Jackson, S.E., Savoie, A., and La Rochelle, F. 2015. The Archean Westwood Au deposit, southern Abitibi: Telescoped Au-rich VMS and intrusion-related Au systems. *In Targeted Geoscience Initiative 4: Contributions to the Understanding of Precambrian Lode Gold Deposits and Implications for Exploration. Edited by B.Dubé and P. Mercier-Langevin. Geological Survey of Canada, Open File 7852, pp. 177–191.*

Fig. 1. Regional geological map of the Abitibi Subprovince showing the distribution of major gold deposits and main structural features, in particular the Porcupine-Destor and Larder Lake-Cadillac faults zones (modified after Dubé and Gosselin 2007). The black dashed line outlines the Swayze greenstone belt area. The yellow star shows the location of the Côté Gold deposit, which is located near the Ridout deformation zone (RDZ).

Fig. 2. Schematic stratigraphic type section from the central Swayze greenstone belt (SGB), modified after Ayer et al. (2002), which correlates the supracrustal groups of the SGB with the Abitibi greenstone belt (AGB). The ages for the AGB are from Thurston et al. (2008).

Fig. 3. Simplified district-scale geological map of the Chester intrusive complex (CIC) and the southeastern arm of the Swayze greenstone belt compiled from Ayer and Chartrand (2011) and Berger (2011), as shown by the inset. Note the Ridout deformation zone extends west through the map area past the more detailed map by Berger (2011). The location of previous U-Pb geochronology ages from the CIC and Yeo Formation are shown by white stars and are discussed in the text.

Fig. 4. Simplified geological map of the Côté Gold deposit. The deposit outline corresponds to the open pit shell outline as of October 2012 and the geology from within this shell was created by using the first bedrock collared in 373 diamond drill holes along with mapping of several outcrops. The inset shows the distribution of drill holes used to construct the map. The geology from outside the deposit shell is taken from Ayer and Chartrand (2011). The vertical cross section (A-A') is found in Figure 5 and the yellow star shows the location of the North Breccia Outcrop (Fig. 6).

Fig. 5. Vertical geological cross section of grid line 87+00 (A-A') from the Côté Gold deposit with the geological interpretation based on drill hole data. The gold grades are included to show the spatial distribution of gold with rock type.

Fig. 6. (a) Geological map of the North Breccia Outcrop (1:300 scale) which contains important crosscutting relationships. The yellow stars show the locations of U-Pb geochronology samples (A-E) and the ages are found in Figure 19. (b) A tonalite body that sharply intrudes into a diorite. (c) A hornblende-plagioclase pegmatite dyke that intrudes sharply along the margin of tonalite and diorite. The yellow book for scale is 19 by 12 cm.

Fig. 7. Outcrop, drill core (4.5 cm in width) and thin section photographs of least-altered tonalite and tonalite breccias. (a) Photo of a least-altered leucocratic tonalite. (b) Thin section photo in crossed polarized light of granophyric texture between quartz and plagioclase in tonalite. (c) Thin section photo in plane polarized light of zoned plagioclase in tonalite. Plagioclase grains are inundated with very fine-grained epidote. (d) Thin section photo in plane polarized light of a miarolitic cavity in tonalite with inwards pointing euhedral, zoned plagioclase crystals; the cavity is now filled with secondary carbonate and quartz. (e) Outcrop photo of a quartz-plagioclase miarolitic-like cavity outlined by the red dashed lines. (f) Outcrop photo of a tonalite breccia; diorite fragments are outlined in red dashed lines. The yellow book for scale is 19 by 12 cm. (g) Photo of lobate contacts between tonalite and diorite with a miarolitic cavity near the contact. (h) Photo showing lobate contacts between tonalite and diorite. (i) Thin section photo in plane polarized light of diorite fragments in tonalite; diorite fragments are outlined in red dashed lines. Abbreviations: Albite = Ab, Carbonate = Cb, Hornblende = Hbl, Plagioclase = Pl, Quartz = Qz.

Fig. 8. Drill core (4.5 cm in width) and thin section photographs of least-altered dioritic phases and diorite breccias. (a) An example of an equigranular, melanocratic diorite. (b) Thin section photo in plane polarized light of diorite that contains amphibole, epidote altered plagioclase, ilmenite and apatite. (c) A melanocratic quartz diorite with quartz phenocrysts. (d) An example of a brecciated contact between melanocratic quartz diorite and leucocratic diorite. Note along the contact the diorite fragments are quenched. (e) An example of a hornblende-plagioclase-quartz pegmatite with acicular amphibole. (f) An example of the diorite breccia with a melanocratic diorite matrix surrounding variably sized angular to sub-rounded tonalite and subordinate diorite fragments. (g) Close-up photo of a diorite breccia showing the diorite texture in the matrix. Note the finer-grained nature of the diorite matrix closer to the tonalite fragment is due to disseminated fine-grained biotite alteration that alters primary amphibole and plagioclase.

(h) An example of exfoliation texture of a tonalite fragment. Abbreviations: Apatite = Ap, Hornblende = Hbl, Ilmenite = Ilm, Plagioclase = Pl.

Fig. 9. Drill core (4.5 cm in width) and thin section photographs of the hydrothermal amphibole breccia. (a) Hydrothermal amphibole breccia with a fine-grained, black amphibole-rich matrix and disseminated amphibole altered tonalite fragments. (b) A gold-bearing hydrothermal amphibole breccia with a fine-grained amphibole-rich matrix with tonalite and diorite fragments. (c) A thin section photo in plane polarized light of an amphibole-, quartz- and biotite-bearing breccia matrix. Chlorite partially replaces both hornblende and biotite and is not considered part of the hydrothermal assemblage. (d) A hydrothermal hornblende-quartz-carbonate vein cutting a diorite breccia with tonalite fragments. Abbreviations: Biotite = Bt, Carbonate = Cb, Chlorite = Chl, Hornblende = Hbl, Quartz = Qz.

Fig. 10. Drill core (4.5 cm in width) and thin section photographs of the hydrothermal biotite breccia. (a) Photo of a mineralized hydrothermal biotite breccia with sericite altered tonalite fragments. (b) An example of a mineralized breccia with a biotite-quartz-carbonate-epidote $\pm$ sulphide matrix (assemblage 1). Note the green colour of the matrix is due to partial chloritization of biotite. (c) Thin section photo in plane polarized light of an assemblage 1 matrix containing biotite-quartz-epidote-pyrite. (d) A mineralized breccia which is characterized by abundant sulphides and contains a biotite-quartz-magnetite-chalcopryrite-pyrite matrix (assemblage 2). (e) Thin section photo in reflected light of an assemblage 2 matrix with abundant magnetite, pyrite and chalcopryrite. (f) An example of a mineralized breccia with a biotite-quartz-carbonate-pyrite matrix (assemblage 3). (g) Thin section photo in plane polarized light of an assemblage 3 matrix with coarse-grained orange-brown biotite set in a finer-grained quartz-carbonate-biotite-pyrite matrix. (h) An example of in-situ brecciation texture. Abbreviations: Biotite = Bt, Carbonate = Cb, Chalcopryrite = Ccp, Epidote = Ep, Magnetite = Mag, Plagioclase = Pl, Pyrite = Py, Quartz = Qz.

Fig. 11. Amphibole classification diagrams for calcic amphiboles following Hawthorne and Oberti (2007) for quartz diorite samples.

Fig. 12. Images of quartz diorite sample used for mineral chemistry. (a) Thin section photo in plane polarized light of brown to green-blue magnesiohornblende grains. (b) A backscatter electron image of magnesiohornblende grains in (a) that have been partially replaced by ferropargasite and ferrotschermakite in cores and along rims. Abbreviations: Hornblende = Hbl, Ilmenite = Ilm, Ferropargasite = Prg, Plagioclase = Pl, Quartz = Qz, Ferrotschermakite = Ts.

Fig. 13. Whole-rock geochemistry of least-altered tonalite ($n = 6$) and dioritic phases ($n = 9$) from the Chester intrusive complex. Least-altered averages of tonalite ($n = 10$) and diorite ($n = 3$) from Berger (2012) are plotted for comparison. (a) A Zr/TiO_2 vs. Nb/Y plot (Winchester and Floyd 1977) of least-altered samples. (b) Normative feldspar differentiation diagram plotting tonalite and dioritic phases from Barker (1979) modified after O'Connor (1965). (c) Total alkalis vs. silica diagram (Le Bas et al. 1986) of tonalite and dioritic rocks. (d) An Al_2O_3 vs. SiO_2 plot showing tonalite is low-Al based on Barker (1979). (e) Samples of tonalite and diorite plotted in the Zr vs. Y diagram; the fields for different magma associations is from Galley and Lafrance (2014). (f) A Zr/Y vs. Y plot which shows the FII affinity of tonalite from Lentz (1998), modified after Leshner et al. (1986).

Fig. 14. (a) A Sr/Y vs. Y diagram that shows the distribution of least-altered tonalite and diorite phases in comparison to the fields for adakites/high-Al TTGs and normal island arc andesite-dacite-rhyolite suites from Defant and Drummond (1993) and Richards and Kerrich (2007). (b) A La/Yb vs. Yb diagram that shows the distribution of least-altered tonalite and diorite phases in comparison with adakites/high-Al TTGs fields and typical arc rocks from Castillo et al. (1999) and Richards and Kerrich (2007). The legend from Figure 13 is used here.

Fig. 15. Comparison of REE and spider diagrams between least-altered tonalite and dioritic samples from this study and average tonalite ($n = 10$) and diorite ($n = 3$) samples from Berger (2012). (a) Chondrite-normalized REE diagram of least-altered tonalite. (b) Primitive mantle-normalized spider diagram of least-altered tonalite. (c) Chondrite-normalized REE plot of least-altered diorite and quartz diorite. (d) Primitive mantle-normalized spider diagram of least-altered diorite and quartz diorite. The chondrite and primitive mantle values are from Sun and McDonough (1989).

Fig. 16. Geochemistry of metavolcanic rocks of the Arbutus and Yeo Formations. The average tonalite from Berger (2012) is plotted for comparative purposes. (a) A Zr/TiO_2 vs. Nb/Y plot (Winchester and Floyd 1977) of the Arbutus and Yeo Formation samples. (b) A Zr vs. Y diagram for Arbutus and Yeo Formation samples; the fields for different magma associations is from Galley and Lafrance (2014). (c) A chondrite-normalized REE diagram of Arbutus Formation samples. (d) A primitive mantle-normalized spider diagram of Arbutus Formation samples with modern arc basalts plotted for comparison: BABB = back-arc basin basalt (avg. of sites 834B to 839B in the Lau-Tonga arc and back-arc system (Ewart et al. 1994)); IAT = island arc tholeiite (avg. of samples 482-8-11, 482-8-12, 482-8-1, 482-8-8 and 482-8-3 from the Tonga arc (Turner et al. 1997)); and Med-K CAB = medium-K calc-alkaline basalt (avg. of samples 67150, 67154, B2 and B5 from Flores in the Sunda arc (Stolz et al. 1990)). (e) An Al_2O_3 vs. SiO_2 plot showing the Yeo Formation is not typically low-Al (Barker 1979). (f) A Zr/Y vs. Y plot which shows the FII affinity of tonalite from Lentz (1998), modified after Leshner et al. (1986). (g) A chondrite-normalized REE diagram of Yeo Formation samples. (h) A primitive mantle-normalized spider diagram of Yeo Formation samples. The chondrite and primitive mantle values are from Sun and McDonough (1989).

Fig. 17. Whole-rock geochemistry of least-altered dyke rocks. (a) A Zr/TiO_2 vs. Nb/Y diagram plotting all of the dykes. (b) A La/Yb_N vs. Yb_N plot that shows the dyke rocks contain a different fractionation trend compared to tonalite and diorite samples of the CIC. (c) A chondrite-normalized REE plot of the feldspar $\pm$ quartz porphyry dykes. (d) A primitive mantle-normalized spider diagram of the feldspar $\pm$ quartz porphyry dykes. (e) A chondrite-normalized REE plot of the lamprophyre dyke. (f) A primitive mantle-normalized spider diagram of the lamprophyre dyke. (g) A chondrite-normalized REE plot of the dioritic dyke. (h) A primitive mantle-normalized spider diagram of the dioritic dyke. (i) A chondrite-normalized REE plot of the gabbroic dyke. (j) A primitive mantle-normalized spider diagram of the gabbroic dyke. (k) A chondrite-normalized REE plot of the diabase dyke. (l) A primitive mantle-normalized spider diagram of the diabase dyke. The chondrite and primitive mantle values are from Sun and McDonough (1989).

Fig. 18. Concordia diagrams for samples (a) North Breccia diorite (NBxDRLK12), (b) North Breccia tonalite (NBxTonaLK12), (c) North Breccia tonalite (NBxTonbLK12), (d) North Breccia pegmatite (NBxPegLK12), (e) North Breccia lamprophyre dyke (NBxlamp02), (f) feldspar-quartz porphyry dyke (E11-119-240m) and, (g) feldspar-quartz porphyry dyke (E12-370-215m). The pencil for scale is 15 cm long and drill core samples are 4.5 cm in width.

Fig. 19. Paragenesis of the host rocks, Yeo Formation and dyke rocks. The open circles and bars show the U-Pb zircon ages from this study, as well as previous tonalite and Yeo Formation ages. Dotted lines represent relative ages based on crosscutting relationships.

Fig. 20. Simplified schematic model of the Chester intrusive complex that is largely based on crosscutting relationships in the deposit area. Note that each injection depicted in the diagram represents multi-phase intrusions.

Table 1. Petrographic characteristics, crosscutting relationships and U-Pb geochronology of major rock types at the Côté Gold deposit.

Rock type	Size, distribution and texture	Mineralogy	Crosscutting relationships	Age
Tonalite	Few cm to >100 m in apparent width intrusions; fine- to medium-grained, massive, equigranular, with rare quartz and plagioclase phenocrysts; granophyric texture and mariolitic cavities (≤ 1 cm, spherical-shaped, lined by Pl and filled by Qz $\pm$ Cb); majority of tonalite postdates diorite	Pl (50-60%) and Qz (40-50%) with accessory titanite, zircon, apatite, rutile, ilmenite, tourmaline, monazite and xenotime	Early tonalite intruded by all dioritic phases; later tonalite intrudes diorite, quartz diorite and rarely tonalite	2740 $\pm$ 2 Ma (Heather and van Breemen 1994); 2741.1 $\pm$ 0.9 Ma (Kontak et al. 2013a); 2741.7 $\pm$ 0.7 Ma and 2741.4 $\pm$ 0.9 Ma (this study)
Tonalite breccia	Typically restricted to intrusive margins; two types of cm- to m-sized fragments occur: (1) angular to rounded fragments of medium-grained, homogeneous diorite with sharp to diffuse contacts; or (2) rare medium-grained or chilled diorite fragments with lobate contacts; in the latter type of contact granophyric texture and rare mariolitic cavities occur; rare angular cm-sized tonalite fragments occur	Fine- to medium-grained, rare quartz and/or plagioclase porphyritic tonalite matrix; mineralogically same as tonalite described above	Brecciates diorite and quartz diorite; rarely brecciates tonalite	2738.7 $\pm$ 0.8 Ma (Kontak et al. 2013a)
Diorite	Few m to <150 m in apparent width intrusions; appears to dominate in the south of the deposit; medium- to coarse-grained, massive to rarely foliated, equigranular to inequigranular; rare layering, rare granophyric texture; chilled margins against tonalite	Pl (35-70%), Hbl (35-60%), Qz (0-5%), Ttn (<4%), Ilm and Mag (<2%) with accessory apatite, zircon and rare tourmaline	Co-temporal with quartz diorite and cut by pegmatite	2741.5 $\pm$ 0.7 Ma (this study)
Quartz diorite	Few m to <150 m in apparent width intrusions; appears to dominate in the north part of the deposit; medium- to coarse-grained, massive, equigranular to inequigranular and often contains quartz and/or plagioclase phenocrysts; granophyric texture	Pl (55-60%), Hbl (30-35%), Qz (5-15%), Ttn (<3%), Ilm and Mag (<2%) with accessory apatite, zircon and rare tourmaline	Co-temporal with diorite and cut by pegmatite	No ages
Hornblende-plagioclase $\pm$ quartz pegmatite	Typically <1 m dykes; very coarse-grained, (>2 mm to ≤ 2.5 cm); spatially associated with diorite and quartz diorite phases; massive, inequigranular; granophyric texture, rare acicular hornblende	Pl (60-65%), Hbl (20-30%), Qz (0-10%), Ttn (<5%), Ilm and Mag (<2%) with accessory apatite and zircon	Cuts tonalite, diorite and quartz diorite	2741.0 $\pm$ 0.6 Ma (this study)
Diorite breccia (Au $\pm$ Cu)	Few cm to >100 m in apparent width intrusions; occurs in the southern and central parts of the deposit; rounded to angular tonalite fragments (<1 mm to rarely > 1 m) and diorite, quartz diorite and pegmatite fragments (<50 cm) with sharp contacts; rare exfoliation textures and tabular tonalite fragments	Medium to coarse-grained melanocratic diorite or fine- to medium-grained melanocratic quartz diorite (typically quartz porphyritic) matrices; same as dioritic phases in terms of mineralogy	Brecciates tonalite, tonalite breccia and all dioritic phases	No ages
Hydrothermal Amphibole breccia (Au)	Spatially restricted to southern and central parts of the deposit; fine- to coarse-grained matrix; rounded to angular tonalite and rare diorite fragments (cm-sized); primary zoned amphibole, mariolitic cavities	Hbl (55-95%), Qz (5-45%), Bt (0-7%), Cb (0-3%), Py (<1%) and Ccp (<1%)	Brecciates tonalite and rarely diorite; overprints magmatic breccia	No ages
Hydrothermal biotite breccia (Au $\pm$ Cu)	Few cm sized to <200 m in apparent width; occurs in central and northern parts of the deposit; fine- to coarse-grained matrix; angular to sub-rounded tonalite fragments (cm-sized); chlorite rims, in situ, (i.e., mosaic) textures, rare mariolitic cavities (<5 cm)	<i>Assemblage 1:</i> Bt-Qz $\pm$ Ep $\pm$ Cal $\pm$ Py $\pm$ Ccp $\pm$ Mag $\pm$ Aln $\pm$ Ttn $\pm$ Fl <i>Assemblage 2:</i> Bt-Mag-Qz-Ank-Ccp-Py $\pm$ Sp $\pm$ Aln $\pm$ Bst $\pm$ Ap $\pm$ Ttn <i>Assemblage 3:</i> Bt-Ank-Cal-Qz-Py $\pm$ Aln $\pm$ Ap $\pm$ Mag $\pm$ Ccp $\pm$ Po	Brecciates tonalite; <i>assemblage 3</i> rarely contains fragments of <i>assemblage 2</i>	No ages

Note: Mineral content is estimated from the least-altered samples.

Abbreviations: Aln = allanite, Ank = ankerite, Ap = Apatite, Bst = bastnaesite, Bt = biotite, Cal = Calcite, Cb = carbonate, Ccp = chalcopryite, Ep = epidote, Fl = fluorite, Hbl = hornblende, Ilm = ilmenite, Mag = magnetite, Pl = plagioclase, Po = pyrrhotite, Py = pyrite, Qz = quartz, Sp = Sphalerite, Ttn = titanite.

Table 2. Petrographic characteristics and crosscutting relationships of post-CIC dyke and breccia rocks at the Côté Gold deposit.

Rock type	Subtype	Textures, deformation, relative timing and comments	Mineralogy
Feldspar ± quartz porphyry dykes	Dacitic to andesitic to trachyandesitic	Fine- to medium-grained, light-grey to dark-grey, foliated and 10 cm to <30 m in apparent width; moderately to strongly epidote, hematite altered and rarely muscovite altered; cut by the lamprophyre dyke and represent feeder dykes to the overlying volcanic rocks of the SGB	<i>Phenocrysts:</i> < 1 cm Pl (5-20%), <3 mm Qz (1%) <i>Groundmass:</i> variable proportions of Pl, Qz, Ttn, Mag, Py
Lamprophyre dyke (or kersantite; Le Maitre et al. 2002)	Biotite-phyric	Fine- to medium-grained black, glomeroporphyritic, dark green or dark-red, foliated and <1 to rarely >50 m in apparent width; N-NW striking; unaltered dyke intrudes altered phases of the CIC; the unit can be silicified and/or muscovite altered and cut by epidote veins; typically unmineralized, however, one sample contained VG	<i>Phenocrysts:</i> Bt (up to 7%) <i>Groundmass:</i> Pl (40-70%), Bt (20-30%), Cal (0-10%), Ep (0-5%), Mag (<1%), Py (0-3%)
	Amphibole ± biotite phyrice	Fine- to medium-grained black, dark-green or dark-red, foliated and <1 m in apparent width; strikes N-NW; the unit is characterized by coarse-grained (<2 cm) phenocrysts and contains rare myrmekitic texture; the dyke can be silicified and/or muscovite altered	<i>Phenocrysts:</i> Amp (15%), Bt (0-5%) <i>Groundmass:</i> Pl (40-60%), Amp (30-35%), Bt (1-30%), Cal (0-5%), Ep (0-3%), Mag (<1%), Py (<1%)
Dioritic dyke		Fine- to medium-grained, typically plagioclase porphyritic, black to dark-grey, massive, and 0.1 to rarely 100 m in apparent width; saussuritization of plagioclase is common; this unit contains chill margins against diorite of CIC	Pl (45-60%), Amp (40-45%), Qz (0-3%), Mag (<1%), Py (<1%)
Gabbroic dyke		Fine- to medium-grained, black to dark-green/grey, massive and 0.1 to rarely 100 m in apparent width; saussuritization of plagioclase is common; the unit contains chill margins against diorite of CIC	Amp (60-90%), Pl (5-40%), Qz (0-3%), Mag (<1%), Py (<1%)
Diabase dyke		Aphanitic, often plagioclase glomeroporphyritic (<2 cm) fine-grained or medium-grained, black, massive and magnetic; <0.1 m to 100 m in apparent width; N-NW striking and is offset by the brittle fault; rarely epidote altered and localized brecciation by epidote-quartz veins	<i>Phenocrysts:</i> Plagioclase (0-5%) <i>Groundmass:</i> Pl (60-70%), Cpx (30-40%), Mag (5%), Ilm (<1%), Py (<1%)
Tectonic breccia		Fine-grained with an incoherent, black to dark-brown matrix and angular to sub-rounded fragments (<10 cm); typically <10 m in apparent width; spatially associated with the west striking brittle fault; the unit postdates muscovite alteration	<i>Matrix:</i> rock flour (chloritized and unmineralized) <i>Fragments:</i> altered tonalite, altered diorite, veins, xenoliths
Heterolithic quartz ± carbonate breccia		Fine-grained with a light-green to grey matrix and angular to sub-rounded fragments (<1 mm to <5 cm); typically <15 m in apparent width; the unit is characterized by quartz-carbonate flooding that contains Ccp; spatially associated with brittle fault; the unit postdates gold mineralization as VG was found in a quartz vein fragment	<i>Matrix:</i> Cal and Qz with up to 4% Ccp <i>Fragments:</i> altered tonalite, veins, mafic dykes

Note: Mineral content is estimated from the least-altered samples. Thickness of dyke rocks are apparent thickness.
Abbreviations: Amp = amphibole, Bt = biotite, Cal = calcite, Ccp = chalcopyrite, Chl = chlorite, Cpx = clinopyroxene, Ep = epidote, Ilm = ilmenite, Mag = magnetite, Pl = plagioclase, Py = pyrite, Qz = quartz, Ttn = titanite.

Table 3. Microprobe analyses for calcic amphiboles.

Sample number	QDR1-3	QDR2-2	QDR3-1
SiO ₂	48.586	46.829	47.011
TiO ₂	0.974	1.48	1.462
Al ₂ O ₃	4.862	6.192	6.036
FeO	18.967	19.362	19.695
Cr ₂ O ₃	0.018	0	0.014
MnO	0.342	0.346	0.343
MgO	11.882	10.922	10.796
CaO	10.484	10.408	10.2
Na ₂ O	0.751	0.943	0.908
K ₂ O	0.561	0.403	0.372
F	0.32	0.173	0.17
Cl	0.368	0.233	0.248
Subtotal	98.1	97.29	97.24
O = Cl, F	0.22	0.13	0.13
Total	97.88	97.16	97.11
Si p.f.u.	7.19	7.001	7.03
Al	0.78	0.996	0.964
Fe ³⁺	0.03	0.003	0.006
Ti	0	0	0
T sites	8	8	8
Al	0.067	0.094	0.099
Cr	0.002	0	0.002
Fe ³⁺	0.561	0.575	0.593
Ti	0.108	0.166	0.164
Mg	2.621	2.434	2.407
Fe ²⁺	1.619	1.709	1.713
Mn	0.021	0.022	0.021
Ca	0	0	0
C sites	5	5	5
Mg	0	0	0
Fe ²⁺	0.137	0.134	0.150
Mn	0.022	0.022	0.022
Ca	1.662	1.667	1.634
Na	0.106	0.135	0.130
B sites	1.928	1.959	1.936
Ca	0	0	0
Na	0.109	0.138	0.133
K	0.106	0.077	0.071
A sites	0.215	0.215	0.204
cations	15.142	15.174	15.141
Cl	0.092	0.059	0.063
F	0.150	0.082	0.080
Cl/(Cl + F)	0.380	0.418	0.44
Fe ³⁺ /Fe ²⁺	0.347	0.336	0.346
Pressure (750 °C)	0.28	1.32	1.2
Pressure (800 °C)	-	0.36	0.2

Note: Oxides are presented in wt. %.

Cations calculated on the basis of 23 (O, F, Cl) p.f.u. and the average ferric iron constraint (values obtained from the average 15eNK and 13 eCNK).

Pressures in kbars with an error of ± 0.6 kbars.

Table 4. Average compositions of least-altered major, regional metavolcanic and dyke rocks from the Côte Gold deposit.

Rock Type	Tonalite			Diorite			Yeo Formation			Arbutus Formation			Dacitic porphyry dyke		
	Average	STD	No.	Average	STD	No.	Average	STD	No.	Average	STD	No.	Average	STD	No.
SiO ₂	76.40	2.39	6	56.16	5.04	9	68.82	3.28	7	50.41	1.41	3	67.11	2.3	5
Al ₂ O ₃	12.41	0.70	6	14.93	1.33	9	13.17	1.71	7	14.42	0.94	3	15.26	0.76	5
FeO	1.1	0.9	6	6.5	1.8	9	2.8	0.7	7	9.6	0.3	3	2.9	1.0	5
FeO _T	1.53	0.95	6	9.42	2.28	9	4.64	0.88	7	14.05	0.80	3	4.14	1.25	5
MnO	0.02	0.01	6	0.14	0.04	9	0.09	0.98	7	0.21	0.04	3	0.04	0.01	5
MgO	0.40	0.25	6	3.69	1.24	9	1.55	0.59	7	5.37	0.82	3	1.61	0.5	5
CaO	1.69	0.65	6	7.75	1.22	9	2.16	0.70	7	8.47	1.20	3	4.33	0.93	5
Na ₂ O	5.36	0.50	6	3.91	0.40	9	2.28	0.74	7	2.79	0.55	3	4.65	0.78	5
K ₂ O	0.53	0.14	6	0.75	0.54	9	2.27	0.46	7	0.20	0.07	3	1	0.75	5
TiO ₂	0.331	0.040	6	1.623	0.473	9	0.460	0.077	7	1.141	0.249	3	0.446	0.071	5
P ₂ O ₅	0.06	0.01	4	0.30	0.11	8	0.08	0.01	7	0.09	0.03	3	0.11	0.01	5
LOI	1.01	0.16	6	1.69	0.37	9	4.44	1.21	7	3.55	2.59	3	1.54	0.61	5
Total	99.7	0.5	6	100.3	0.3	9	99.9	0.7	7	100.7	0.4	3	100.3	0.4911	5
Total S	0.09	0.06	6	0.10	0.12	8	0.07	0.09	4	0.16	0.03	3	0.09	0.12	4
CO ₂	0.39	0.22	6	0.42	0.21	9	2.52	1.20	7	1.79	2.25	3	0.5	0.39	5
Cs	0.2	0.0	4	0.8	1.1	7	1.0	0.4	7	<0.1	0	3	1.0	1.1	4
Rb	14	5	6	26	29	9	62	13	7	3	1	3	35	31	5
Ba	128	67	6	137	95	9	494	151	7	53	21	3	345	308	5
Th	8.11	1.44	6	2.53	1.06	9	5.37	0.52	7	0.38	0.05	3	3.47	0.85	5
U	1.65	0.35	6	0.89	0.62	9	1.42	0.17	7	0.14	0.01	3	1.22	0.42	5
Nb	6.9	2.3	6	9.5	4.5	9	10.8	1.8	7	2.4	0.6	3	5.4	2.1	5
Ta	0.82	0.17	6	0.88	0.90	9	0.80	0.11	7	0.18	0.04	3	0.51	0.09	5
Pb	4	2	3	3	2	6	5	1	7	<2	0	3	4	0	5
Sr	124	55	6	271	86	9	123	32	7	110	18	3	397	180	5
Zr	272	36	6	151	61	9	236	35	7	70	15	3	151	36	5
Y	28.6	6.0	6	40.2	12.7	9	29.5	5.4	7	23.1	4.4	3	17.5	12.3	5
La	6.00	3.06	6	19.82	7.50	9	30.45	4.08	7	4.37	0.55	3	19.63	7.17	5
Ce	15.98	7.01	6	56.18	22.24	9	63.22	7.1197	7	11.04	1.7	3	41.04	14.03	5
Pr	2.41	0.88	6	8.15	3.09	9	7.72	1	7	1.67	0.29	3	5.02	1.76	5
Nd	10.97	3.53	6	35.20	12.45	9	29.38	4.37	7	8.1	1.68	3	19.48	7.43	5
Sm	3.40	0.91	6	7.99	2.55	9	6.03	0.92	7	2.61	0.54	3	4.01	1.83	5
Eu	0.74	0.36	6	1.80	0.60	9	1.18	0.23	7	0.98	0.1	3	0.84	0.10	5
Gd	4.15	0.87	6	7.78	2.47	9	5.73	1.07	7	3.61	0.66	3	3.48	1.81	5
Tb	0.77	0.16	6	1.25	0.38	9	0.93	0.17	7	0.67	0.12	3	0.54	0.32	5
Dy	4.98	1.13	6	7.48	2.19	9	5.43	1.05	7	4.35	0.84	3	3.14	2.01	5
Ho	1.04	0.21	6	1.47	0.44	9	1.08	0.21	7	0.91	0.17	3	0.62	0.42	5
Er	3.20	0.68	6	4.25	1.17	9	3.28	0.67	7	2.75	0.49	3	1.77	1.21	5
Tm	0.51	0.10	6	0.65	0.17	9	0.5	0.1	7	0.41	0.08	3	0.27	0.18	5
Yb	3.21	0.54	6	4.13	1.11	9	3.29	0.6703	7	2.81	0.57	3	1.84	1.34	5
Lu	0.449	0.069	6	0.601	0.160	9	0.473	0.0816	7	0.42	0.08161	3	0.268	0.1885	5

Table 4 (concluded).

Rock Type	Andesitic porphyry dyke			Lamprophyre dyke			Dioritic dyke			Gabbroic dyke			Diabase dyke		
	Average	STD	No.	Average	STD	No.	Average	STD	No.	Average	STD	No.	Average	STD	No.
SiO ₂	55.94	1.35	2	53.53	2.36	8	52.11	2.92	5	48.37	1.87	7	49.62	0.95	3
Al ₂ O ₃	15.18	0.29	2	11.98	1.54	8	12.84	2.15	5	13.99	1.27	7	12.88	0.25	3
FeO	5.50	0.7	2	5.8	0.9	8	6.26	1.08	5	8.2	1.0	7	10.5	0.4	3
Fe ₂ O ₃	8.15	0.16	2	8.77	1.32	8	9.45	1.15	5	12.63	0.96	7	16.78	0.12	3
MnO	0.09	0.01	2	0.15	0.02	8	0.14	0.05	5	0.17	0.03	7	0.26	0.03	3
MgO	4.61	0.18	2	7.99	1.48	8	7.98	1.76	5	8.35	2.28	7	4.89	0.12	3
CaO	8.28	0.99	2	8.65	1.09	8	8.15	3.27	5	8.46	2.42	7	7.39	0.18	3
Na ₂ O	2.77	0.08	2	2.76	0.44	8	3.35	1.14	5	1.82	1.14	7	2.52	0.15	3
K ₂ O	0.93	0.13	2	2.37	0.74	8	0.86	0.57	5	0.23	0.12	7	1.60	0.18	3
TiO ₂	0.823	0.033	2	0.760	0.124	8	0.859	0.269	5	0.861	0.215	7	1.752	0.014	3
P ₂ O ₅	0.14	0.014	2	0.37	0.09	8	0.33	0.15	5	0.08	0.03	7	0.22	0.00	3
LOI	3.78	1.8	2	3.10	1.68	8	3.92	1.38	5	5.06	1.88	7	2.18	0.11	3
Total	100.8	0.25	2	100.4	0.73	8	100.0	0.57	5	100.0	0.67	7	100.1	0.7	3
Total S	0.02	0	2	0.10	0.05	8	0.14	0.14	5	0.10	0.04	6	0.16	0.01	3
CO ₂	1.39	1.32	2	1.39	1.29	8	1.50	1.19	5	1.45	1.13	7	0.99	0.07	3
Cs	1.6	1.1	2	2.0	1.5	8	1.2	1.0	4	0.5	0.4	3	1.3	0.4	3
Rb	54	20	2	85	41	8	25	19	5	6	3	7	73	16	3
Ba	101	1	2	656	329	8	227	113	5	57	41	7	324	57	3
Th	2.58	0.03	2	2.84	0.51	8	2.55	0.70	5	0.46	0.30	7	2.22	0.05	3
U	1.53	0.37	2	1.06	0.20	8	0.85	0.20	5	0.12	0.07	7	0.56	0.01	3
Nb	4.9	0.8	2	3.1	1.0	8	3.5	2.0	5	3.0	2.9	7	6.9	1.1	3
Ta	0.35	0.02	2	0.26	0.08	8	0.26	0.08	5	0.40	0.46	7	0.49	0.04	3
Pb	2	0	2	8	3	8	6	2	4	5	1	2	3	0	3
Sr	242	11	2	607	150	8	472	205	5	182	91	7	176	14	3
Zr	112	5	2	103	15	8	104	44	5	52	9	7	158	5.0	3
Y	33.9	2.7	2	16.4	2.3	8	17.4	4.0	5	17.9	2.6	7	37.5	1.1	3
La	7.48	0.09	2	18.16	2.87	8	18.10	10.23	5	4.22	2.18	7	14.63	0.53	3
Ce	26.70	2.30	2	39.65	5.93	8	41.02	23.57	5	10.16	4.84	7	31.57	1.03	3
Pr	4.48	0.49	2	5.26	0.73	8	5.47	3.05	5	1.47	0.56	7	4.29	0.17	3
Nd	21.65	1.65	2	22.34	2.97	8	22.90	12.29	5	6.90	2.31	7	19.17	0.54	3
Sm	6.04	0.43	2	4.87	0.60	8	5.08	2.08	5	2.10	0.47	7	5.02	0.17	3
Eu	0.88	0.22	2	1.33	0.15	8	1.37	0.38	5	0.76	0.16	7	1.47	0.04	3
Gd	6.03	0.43	2	4.20	0.45	8	4.43	1.40	5	2.73	0.46	7	5.94	0.29	3
Tb	1.06	0.06	2	0.59	0.06	8	0.65	0.18	5	0.51	0.08	7	1.04	0.04	3
Dy	6.16	0.42	2	3.17	0.40	8	3.48	0.91	5	3.23	0.51	7	6.58	0.07	3
Ho	1.25	0.08	2	0.58	0.09	8	0.64	0.18	5	0.68	0.09	7	1.35	0.02	3
Er	3.68	0.23	2	1.63	0.26	8	1.79	0.44	5	2.09	0.31	7	3.95	0.15	3
Tm	0.58	0.03	2	0.24	0.05	8	0.26	0.05	5	0.32	0.05	7	0.63	0.01	3
Yb	3.75	0.22	2	1.52	0.28	8	1.62	0.39	5	2.09	0.32	7	4.08	0.12	3
Lu	0.568	0.037	2	0.229	0.04695	8	0.238	0.051	5	0.305	0.032	7	0.610	0.013	3

Note: Major elements, S and CO₂ in wt. % and trace elements in ppm.

Table 5. U-Pb zircon ID-TIMS analytical data.

Fraction ¹	Description ²	Wt. ug	U ppm	Pb ³ ppm	²⁰⁶ Pb/ ²⁰⁴ Pb	Pb ⁵ pg	Isotopic Ratios ⁶								Ages (Ma) ⁸						% Disc
							²⁰⁸ Pb/ ²⁰⁶ Pb	²⁰⁷ Pb/ ²³⁵ U	±1SE Abs	²⁰⁶ Pb/ ²³⁸ U	±1SE Abs	Corr. ⁷ Coeff.	²⁰⁷ Pb/ ²⁰⁶ Pb	±1SE Abs	²⁰⁶ Pb/ ²³⁸ U	±2SE	²⁰⁷ Pb/ ²³⁵ U	±2SE	²⁰⁷ Pb/ ²⁰⁶ Pb	±2SE	
(A) North Breccia diorite - NBxDRLK12 (Z10896): UTM NAD83, zone 17, 429713E-5266923N																					
A10-1 (1;Z)	Co,Clr,Tip,Fr,CA10	3.4	56	37	6086	1.0	0.25	13.838	0.016	0.528	0.001	0.939	0.190	0.0001	2735.0	4.2	2738.7	2.2	2741.4	1.4	0.3
A16-1 (1;Z)	Co,Clr,Tip,rIn,rFr,CA10	1.7	73	46	4648	0.9	0.19	13.852	0.017	0.529	0.001	0.944	0.190	0.0001	2736.3	4.6	2739.6	2.4	2742.0	1.5	0.3
B10-1 (1;Z)	Co,Clr,Eu,St,Fr,CA10	5.0	166	108	8718	3.0	0.24	13.822	0.016	0.528	0.000	0.946	0.190	0.0001	2733.1	4.1	2737.6	2.2	2740.9	1.4	0.4
B16-1 (1;Z)	Co,Clr,Eu,Pr,Fr,CA10	1.1	94	62	3702	0.9	0.26	13.884	0.018	0.530	0.001	0.923	0.190	0.0001	2741.6	4.7	2741.8	2.4	2742.0	1.6	0.0
(B) North Breccia tonalite - NBxTonaLK12 (Z10976): UTM NAD83, zone 17, 429711E-5266917N																					
A16-1 (2;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA16	1.3	68	42	781	3.8	0.16	13.964	0.022	0.533	0.001	0.819	0.190	0.0002	2755.6	5.1	2747.3	3.0	2741.2	3.0	-0.7
A16-2 (1;Z)	Co,Clr,Eu,Pr,Fr,CA16	0.7	106	69	862	2.9	0.26	13.761	0.021	0.526	0.001	0.848	0.190	0.0002	2725.6	5.3	2733.4	2.9	2739.2	2.7	0.6
A20-1 (1;Z)	Co,Clr,Eu,Pr,Fr,CA20	1.2	70	44	863	3.3	0.19	13.877	0.023	0.530	0.001	0.855	0.190	0.0002	2742.2	6.0	2741.4	3.2	2740.8	2.8	-0.1
A20-2 (2;Z)	Co,Clr,Eu,Pr,Fr,CA20	1.8	122	76	2858	2.5	0.18	13.864	0.018	0.529	0.001	0.925	0.190	0.0001	2739.0	4.6	2740.5	2.4	2741.5	1.7	0.1
A20-3 (1;Z)	Co,Clr,Eu,Pr,rFr,rIn,CA20	1.1	76	48	584	4.8	0.19	13.934	0.030	0.531	0.001	0.881	0.190	0.0002	2747.4	9.0	2745.2	4.0	2743.6	3.3	-0.2
A20-4 (1;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA20	1.0	93	59	1241	2.0	0.20	13.906	0.020	0.531	0.001	0.885	0.190	0.0001	2745.5	5.5	2743.3	2.8	2741.7	2.2	-0.2
A20-5 (1;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA20	1.0	78	49	1514	1.7	0.19	13.876	0.020	0.530	0.001	0.911	0.190	0.0001	2740.2	5.4	2741.3	2.7	2742.0	1.9	0.1
(C) North Breccia tonalite - NBxTonbLK12 (Z10993): NAD83, zone 17, 429717E-5266928N																					
A16-1 (1;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA16	2.7	77	48	2766	2.5	0.18	13.899	0.017	0.530	0.001	0.913	0.190	0.0001	2743.2	4.3	2742.8	2.3	2742.5	1.7	0.0
A16-2 (1;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA16	3.1	91	57	7814	1.2	0.17	13.885	0.017	0.530	0.001	0.943	0.190	0.0001	2741.6	4.3	2741.9	2.3	2742.1	1.4	0.0
A16-3 (1;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA16	1.0	75	45	1635	1.5	0.14	13.888	0.020	0.530	0.001	0.914	0.190	0.0001	2742.6	5.5	2742.1	2.7	2741.7	1.9	0.0
A20-1 (1;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA20	3.9	123	77	6586	2.4	0.18	13.765	0.016	0.526	0.000	0.936	0.190	0.0001	2724.3	4.0	2733.7	2.2	2740.6	1.4	0.7
A20-2 (1;Z)	Co,Clr,Eu,St,Fr,CA20	2.0	78	49	2800	1.9	0.18	13.896	0.017	0.530	0.001	0.927	0.190	0.0001	2743.3	4.5	2742.6	2.4	2742.1	1.6	-0.1
(D) North Breccia hornblende-plagioclase pegmatite - NBxPegLK12 (Z10992): NAD83, zone 17, 429709E-5266922N																					
A10-1 (1;Z)	pBr,Clr,Eu,Pr,Fr,rIn,CA10	3.0	115	84	778.2	16.0	0.4	13.988	0.023	0.534	0.001	0.810	0.190	0.0002	2756.3	4.5	2748.9	3.1	2743.5	3.3	-0.6
A10-2 (1;Z)	pBr,Clr,Eu,Pr,Fr,rIn,CA10	5.3	160	118	7323	3.8	0.43	13.863	0.016	0.529	0.000	0.941	0.190	0.0001	2738.6	4.0	2740.4	2.2	2741.8	1.4	0.2
A16-1 (1;Z)	pBr,Clr,Eu,Pr,Fr,CA16	4.1	231	170	4307	7.2	0.43	13.838	0.016	0.529	0.000	0.937	0.190	0.0001	2736.0	4.0	2738.7	2.2	2740.7	1.5	0.2
A16-2 (1;Z)	pBr,Clr,Eu,Pr,Fr,CA16	3.3	190	134	3231	6.1	0.42	13.268	0.016	0.507	0.000	0.933	0.190	0.0001	2643.1	3.9	2698.9	2.2	2740.9	1.6	4.3
A16-4 (1;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA16	2.0	204	147	8545	1.6	0.38	13.892	0.016	0.530	0.000	0.940	0.190	0.0001	2743.5	4.1	2742.3	2.2	2741.5	1.4	-0.1
TA (25;T)	Br,Clr,An,Frag	100.0	103	80	2368	142.0	0.54	13.582	0.016	0.520	0.000	0.916	0.190	0.0001	2697.8	3.9	2721.0	2.3	2738.3	1.7	1.8
TB (20;T)	pBr,Clr,An,Frag	60.0	38	29	4123	18.0	0.51	13.806	0.016	0.527	0.000	0.936	0.190	0.0001	2730.8	3.9	2736.5	2.2	2740.7	1.5	0.4
TC (20;T)	Br,Clr,An,Frag	60.0	99	82	6184	32.0	0.64	13.783	0.016	0.527	0.000	0.937	0.190	0.0001	2727.9	4.0	2734.9	2.2	2740.1	1.5	0.5
(E) North Breccia Lamprophyre dyke - NBxlamp02 (Z11150): NAD83, zone 17, 429719E-5266932N																					
A10-1 (1;Z)	Co,Clr,Eu,St,fln,rFr,CA10	1.1	82	52	1903	1.6	0.19	13.922	0.020	0.531	0.001	0.932	0.190	0.0001	2746.6	5.7	2744.4	2.8	2742.7	1.8	-0.2
A12-2 (1;Z)	Co,Clr,Eu,Pr,rFr,CA12	1.8	127	77	7556	1.0	0.13	13.846	0.017	0.529	0.001	0.938	0.190	0.0001	2735.4	4.6	2739.2	2.3	2742.0	1.5	0.3
A16-1 (1;Z)	Co,Clr,Eu,Pr,CA16	1.2	43	27	6362	0.5	0.16	13.873	0.018	0.529	0.001	0.925	0.190	0.0001	2738.9	5.0	2741.1	2.5	2742.6	1.6	0.2
A16-3 (1;Z)	Co,Clr,Eu,Pr,fln,CA16	4.3	78	50	12355	0.9	0.23	13.883	0.016	0.530	0.001	0.941	0.190	0.0001	2741.5	4.3	2741.7	2.2	2741.9	1.4	0.0

Table 5 (concluded).

Fraction ¹	Description ²	Wt. ug	U ppm	Pb ³ ppm	²⁰⁶ Pb ⁴ ²⁰⁴ Pb	Pb ⁵ pg	Isotopic Ratios ⁶								Ages (Ma) ⁸						% Disc
							²⁰⁸ Pb ²⁰⁶ Pb	²⁰⁷ Pb ²³⁵ U	±1SE Abs	²⁰⁶ Pb ²³⁸ U	±1SE Abs	Corr. ⁷ Coeff.	²⁰⁷ Pb ²⁰⁶ Pb	±1SE Abs	²⁰⁶ Pb ²³⁸ U	±2SE	²⁰⁷ Pb ²³⁵ U	±2SE	²⁰⁷ Pb ²⁰⁶ Pb	±2SE	
(F) Brett Lake feldspar-quartz porphyry dyke - E11-119-240m (Z10881)																					
A16-1 (1;Z)	Co,Clr,Eu,Pr,Fr,rIn,CA16	1.3	89	53	613	2.3	0.15	13.274	0.026	0.521	0.001	0.841	0.185	0.0002	2701.9	6.6	2699.4	3.7	2697.5	3.5	-0.2
A16-2 (1;Z)	Co,Clr,Eu,Pr,Fr,CA16	2.1	54	34	992	13.1	0.23	13.269	0.021	0.520	0.001	0.893	0.185	0.0001	2699.2	5.9	2699.0	3.0	2698.8	2.4	0.0
A16-3 (1;Z)	Co,Clr,Eu,Pr,Fr,In,CA16	1.4	221	146	1160	7.6	0.30	13.224	0.019	0.519	0.001	0.858	0.185	0.0001	2695.3	4.2	2695.8	2.6	2696.1	2.5	0.0
A16-4 (1;Z)	Co,Clr,Eu,Pr,Fr,CA16	0.6	122	75	750	1.2	0.20	13.252	0.025	0.520	0.001	0.875	0.185	0.0002	2697.7	7.9	2697.8	3.5	2697.8	3.0	0.0
B10-1 (1;Z)	Co,Clr,Eu,Pr,rFr,In,CA10	2.0	147	92	2421	0.9	0.22	13.233	0.018	0.519	0.001	0.932	0.185	0.0001	2695.1	5.2	2696.4	2.6	2697.4	1.7	0.1
B16-1 (1;Z)	Co,Clr,Eu,Pr,Fr,CA16	0.7	83	51	5396	0.3	0.18	13.234	0.016	0.520	0.001	0.925	0.185	0.0001	2697.6	4.5	2696.5	2.3	2695.6	1.6	-0.1
(G) Brett Lake feldspar-quartz porphyry dyke - E12-370-215m (Z11113)																					
A16-1 (1;Z)	Co,Clr,Eu,Pr,Fr,In,CA16	0.8	76	44	3069	0.6	0.10	13.250	0.019	0.520	0.001	0.948	0.185	0.0001	2697.2	5.6	2697.6	2.7	2697.9	1.5	0.0
A16-2 (1;Z)	Co,Clr,Eu,Pr,In,Fr,CA16	2.1	142	86	3621	2.7	0.18	13.240	0.016	0.519	0.000	0.929	0.185	0.0001	2696.4	4.2	2696.9	2.3	2697.4	1.6	0.1
A16-3 (1;Z)	Co,Clr,Eu,Pr,Fr,In,CA16	2.1	63	38	2241	1.9	0.17	13.284	0.018	0.521	0.001	0.854	0.185	0.0001	2705.4	5.6	2700.0	2.6	2696.1	2.4	-0.4
A20-1 (1;Z)	Co,Clr,Eu,Pr,Fr,In,CA20	1.6	68	41	1918	1.8	0.16	13.241	0.019	0.520	0.001	0.916	0.185	0.0001	2698.3	5.3	2697.0	2.6	2696.0	1.9	-0.1
A20-2 (1;Z)	Co,Clr,Eu Pr,In,Fr,CA20	0.9	91	54	3266	0.8	0.13	13.233	0.018	0.519	0.001	0.920	0.185	0.0001	2695.4	5.0	2696.4	2.5	2697.1	1.7	0.1

Notes:

¹Number in bracket refers to the number of grains in the analysis. Z=zircon; T=titanite; CA = chemically abraded.

²Fraction descriptions: Co = Colourless, pBr = pale brown, Br = brown, Clr = Clear, Eu = Euhedral, An = Anhedral, Pr = Prismatic, St= Stubby Prism, El = Elongate, Tip = Tip, Frag = Fragment, rFr = Rare Fractures, fFr = Few Fractures, Fr = Fractures, rIn = Rare Inclusions, fIn = Few Inclusions, In = Inclusions, CA10 = Chemically Abraded for 10 hours.

³Radiogenic Pb.

⁴Measured ratio, corrected for spike and fractionation.

⁵Total common Pb in analysis corrected for fractionation and spike.

⁶Corrected for blank Pb and U and common Pb, errors quoted are 1 sigma absolute; procedural blank values for this study ranged from <0.1- 0.1 pg for U and 0.5-2 pg for Pb; Pb blank isotopic composition is based on the analysis of procedural blanks; corrections for common Pb were made using Stacey and Kramers (1975) compositions.

⁷Correlation Coefficient.

⁸Corrected for blank and common Pb, errors quoted are 2 sigma in Ma.

Draft

Geology of the North Breccia Outcrop

Draft

Appendix A

U-Pb geochronology sample descriptions

Sample A North Breccia diorite (NBxDRLK12; z10896)

This sample is a massive, melanocratic, medium-grained, equigranular diorite composed of amphibole, plagioclase and minor titanite. Based on crosscutting relationships, the diorite is interpreted to be the oldest unit in the outcrop. The zircons from this sample are well faceted, clear, colourless, fractured prismatic crystals and prism tips, ranging in length from ~100 to 250 μm in the longest dimension. Analysis of four single-grain zircon fractions yielded a cluster of concordant and near-concordant data (Fig. 18a, Table 5). A weighted mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of all of the analyses is calculated at 2741.5 ± 0.7 Ma (MSWD = 0.53; probability of fit (pof) = 0.66), which is interpreted as the crystallization age of the diorite.

Sample B North Breccia tonalite (NBxTonaLk12; z10976)

The sample is massive, fine-grained, equigranular and composed of plagioclase and quartz. The sample has secondary disseminated biotite alteration (<3%), chlorite alteration after biotite and weak muscovite alteration. This tonalite sharply intrudes the diorite (Sample A; Fig. 6b). The zircons from this sample are well faceted, euhedral, fractured prismatic zircon grains ranging from ~50 to 125 μm in size. Analysis of two fractions comprised of two grains and five single-grain zircon fractions yielded a cluster of concordant to slightly discordant data (Fig. 18b, Table 5). The weighted mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of all of the analyses is calculated to be 2741.4 ± 0.9 Ma (MSWD = 0.40; pof = 0.53), which is interpreted as the crystallization age of the tonalite.

Sample C North Breccia tonalite (NBxTonbLK12; z10993)

The sample is a massive, medium-grained, inequigranular tonalite composed of plagioclase and quartz with <1% coarse-grained plagioclase phenocrysts. Minor alteration occurs as disseminated fine-grained clusters of biotite (~5%), chlorite after biotite and weak fracture-controlled muscovite alteration. Based on crosscutting relationship, this sample postdates diorite (Sample A). The zircons from this sample are 100 to 250 μm in size, clear, colourless, euhedral prisms with numerous fine fractures and inclusions. Five single-grain zircon fractions yielded a cluster of four overlapping concordant analyses and one slightly discordant analysis (A20-1, 0.7% discordant; Fig. 18c, Table 5). A weighted mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of all of the analyses is calculated at 2741.7 ± 0.7 Ma (MSWD = 0.98, pof = 0.42) and is interpreted as the crystallization age of the tonalite.

Sample D North Breccia hornblende-plagioclase pegmatite (NBxPegLK12; z10992)

This is a massive, very coarse-grained, inequigranular pegmatite composed of plagioclase, amphibole and minor quartz and titanite. The pegmatite intrudes along the contact of diorite (Sample A) and tonalite (Sample C; Fig. 6c) and therefore postdates both phases. The zircons from this sample are clear, pale brown to colourless, euhedral prisms that contain numerous inclusions and are highly fractured. Analysis of five single-grain zircon fractions yields a cluster of concordant to near-concordant data and two discordant analyses (Fig. 18d, Table 5). The pegmatite also contains abundant anhedral brown titanite fragments. Analysis of three multigrain titanite fractions results in two near-concordant (TB, TC) analyses and one discordant analysis (TA). The weighted mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of the most concordant zircon and titanite analyses is calculated to be 2741.0 ± 0.6 Ma (MSWD = 0.89, pof = 0.47). This date is interpreted to be the crystallization age of the pegmatite.

Sample E North Breccia lamprophyre dyke (Nbxlamp02; z11150)

This is a lamprophyre dyke from the North Breccia Outcrop. The groundmass is dark-green to black, medium-grained and composed of plagioclase, quartz and chlorite after amphibole, with abundance secondary carbonate. This dyke crosscuts a mineralized breccia unit and is deformed with a weakly developed crenulation cleavage defined by chlorite. Zircon grains from this sample are clear, colourless, euhedral, stubby prismatic to prismatic crystals that ranged from 75 to 250 μm in size and most grains have few, if any, fractures and inclusions. Analyses of four single-grain zircon fractions yielded a cluster of concordant to slightly discordant data (Fig. 18e, Table 5). A weighted mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of the analyses is calculated at $2742.2 \pm 0.8\text{Ma}$ (MSWD = 0.27; pof = 0.85), which is interpreted to be the crystallization age of the zircons and by inference the lamprophyre dyke, but we note that inheritance may be an issue for this sample.

Sample F Brett Lake feldspar-quartz porphyry dyke (E11-119-240m; z10881)

This is a dyke rock from drill core that has 15% phenocrysts of rounded to elongated zoned plagioclase (<6 mm) and rounded quartz (<4 mm) in a grey, fine- to medium-grained groundmass composed of plagioclase, quartz and biotite. The plagioclase phenocrysts are dusted by hematite and epidote alteration. This dyke intrudes biotite altered tonalite and therefore postdates alteration. The zircons from this sample are clear, colourless, euhedral, stubby to elongate prisms that range between 100 to 200 μm in size and have few, if any, fractures and inclusions. Analyses of six single-grain zircon fractions yielded a cluster of concordant data (Fig. 18f, Table 5). A weighted mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of the analyses is calculated at $2696.9 \pm 0.9\text{ Ma}$ (MSWD = 1.28; pof = 0.27), which is interpreted to be the age of crystallization of the porphyry dyke.

Sample G Brett Lake feldspar-quartz porphyry dyke (E12-370-215m; z11113)

This is a feldspar-quartz porphyry dyke rock from drill core that has ~5% quartz phenocrysts that have been elongated due to deformation. The groundmass is grey, fine-grained and composed of plagioclase and quartz. This dyke crosscuts a mineralized breccia unit and both the dyke and breccia unit show pervasive muscovite alteration. A late-stage sulphide-bearing vein that cuts the porphyry is not gold-bearing (assays results = 0.01 ppm Au). The zircons from this sample are clear, colourless and prismatic that range in size from 100 to 250 μm and many contain inclusions and some degree of fracturing. Analyses of five single-grain zircon fractions yielded a cluster of concordant to near-concordant data (Fig. 18g, Table 5). A weighted mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of these analyses is calculated to be 2697.1 ± 0.8 Ma (MSWD = 0.83, pof = 0.51), which is interpreted as the age of crystallization of this sample.

Draft