

Geological setting and gold mineralization associated with the Sunday Lake and Lower Detour deformation zones, northwestern Abitibi greenstone belt, Ontario and Quebec

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ABSTRACT

The Detour Lake gold mine (~25 Moz or 775 t Au) and Lower Detour zones (e.g. Zone 58N; 0.53 Moz or 16.6 t Au) are located in the northwestern part of the Abitibi greenstone belt in Ontario. They are spatially associated with the Sunday Lake and Lower Detour deformation zones, which extend eastward into Quebec where they host other auriferous zones (e.g. Vortex and Martiniere-Bug Lake deposits). Gold is associated with quartz-carbonate-pyrite-pyrrhotite±tourmaline veins and/or disseminated to very locally semi-massive sulphides in hydrothermally altered wall rocks. These structurally controlled auriferous zones are hosted in tholeiitic and calc-alkaline volcanic rocks of the 2734 to 2724 Ma Deloro assemblage and in ca. 2694 Ma subalkaline to locally alkaline porphyritic intrusive rocks near faulted contacts with the <2.70 Ga Caopatina clastic sedimentary assemblage. Panels or fault-bounded basin remnants of strained Timiskaming-like polymictic conglomerate locally delineate the regional-scale deformation zones and yield maximum depositional ages of between 2706 and 2692 Ma. These relationships are reminiscent of the prolific southern Abitibi greenstone belt in the Timmins-Porcupine and Val-d'Or gold districts. The revised regional geological setting, coupled with documentation of the key characteristics of gold deposits and their hydrothermally altered host rocks, provide a geological framework for improved mineral exploration strategies in a poorly exposed, but prospective region that includes the giant Detour Lake gold mine.

INTRODUCTION

The principal characteristics of orogenic gold deposits, such as the association with major fault zones, panels of polymictic conglomerate, felsic and locally alkaline intrusions, and various types of hydrothermal alteration (carbonate, biotite, sericite, albite) of tholeiitic and komatiitic basalt are present in the poorly exposed but prospective northwestern Abitibi greenstone belt (e.g. Ayer et al., 2009; Faure, 2015). In Ontario, the Detour Lake mine (~25 Moz or 775 tonnes Au) and Zone 58N (~534,000 oz or 16.6 t Au; Detour Gold Corporation, 2019) are spatially associated with the Sunday Lake and Lower Detour deformation zones, respectively (Fig. 1; Oliver et al., 2012; Castonguay et al., 2019). The latter deformation zones extend into Quebec and control the distribution of syndeformation auriferous zones comprising quartz-carbonate±tourmaline veins, silicified zones, and sulphides in hydrothermally altered wall rocks. This research aims to improve the knowledge of the geological setting, styles of gold mineralization, metallotects, and relative timing of events in the northwestern Abitibi region and draw analogies with that of mineralized corridors in the southern Abitibi greenstone belt. The present paper,

which builds on previous reports (e.g. Castonguay et al., 2019), is a synthesis of observations of several gold deposits made through the examination of outcrops and drill core from numerous diamond drillholes and the analysis of new geochemical and geochronological data.

REGIONAL GEOLOGICAL SETTING

The northwestern portions of the Abitibi greenstone belt mostly comprise 2734 to 2724 Ma volcanic rocks of the Deloro assemblage (Fig. 1; Thurston et al., 2008; Ayer et al., 2009; Oliver et al., 2012). The <2707 to 2695 Ma Caopatina assemblage of turbiditic, volcanoclastic, and locally conglomeratic rocks unconformably overlies, or is in tectonic contact with the Deloro assemblage, forming an east-trending elongated sedimentary belt that is similar to those comprising the Porcupine/Cadillac assemblages in the southern Abitibi. To the east in Quebec, these assemblages correlate with the volcanic Manthet and Brouillan groups and the sedimentary Rivière Turgeon Formation, respectively (Lacroix, 1994; Faure, 2015). Synvolcanic (e.g. Brouillan pluton) and pre- to syntectonic (i.e. the main phase of shortening) tonalitic to granodioritic intrusions (e.g. Turgeon and Jeremie plutons) surround

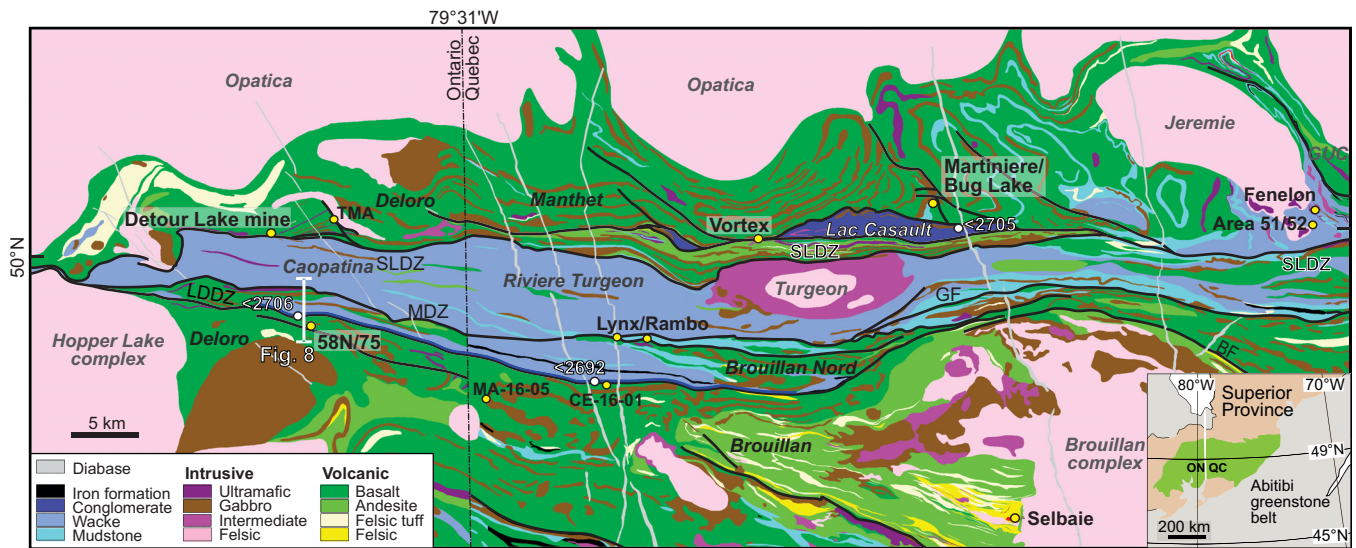


Figure 1. Simplified regional geological map of the northwestern Abitibi belt in the Sunday Lake and Lower Detour 'gold trends' area (*modified from Faure, 2015*) with identification of the main lithological assemblages and deformation/fault zones and the location of gold mines, mineralized zones, and cited exploration drillholes and preliminary U-Pb zircon geochronological data of polymictic conglomerate (maximum age in Ma). Abbreviations: BF = Bapst fault zone, GF = Grasset fault zone, GUC = Grasset ultramafic complex, LDDZ = Lower Detour deformation zone, MDZ = Massicotte deformation zone, SLDZ = Sunday Lake deformation zone.

and cut the volcanic and sedimentary assemblages. The Sunday Lake deformation zone (SLDZ) delineates the northern margin of the Caopatina assemblage, whereas the Lower Detour deformation zone (LDDZ) and its subsidiary Massicotte deformation zones (MDZ) mark its southern contact (Fig. 1). These deformation zones

represent the main, first-order controlling structures for gold mineralization in the study area.

Rock units of the study area have been affected by polyphase deformation and greenschist to lower amphibolite facies metamorphism. In the Detour Lake mine area (Fig. 2), Oliver et al. (2012) recognized four

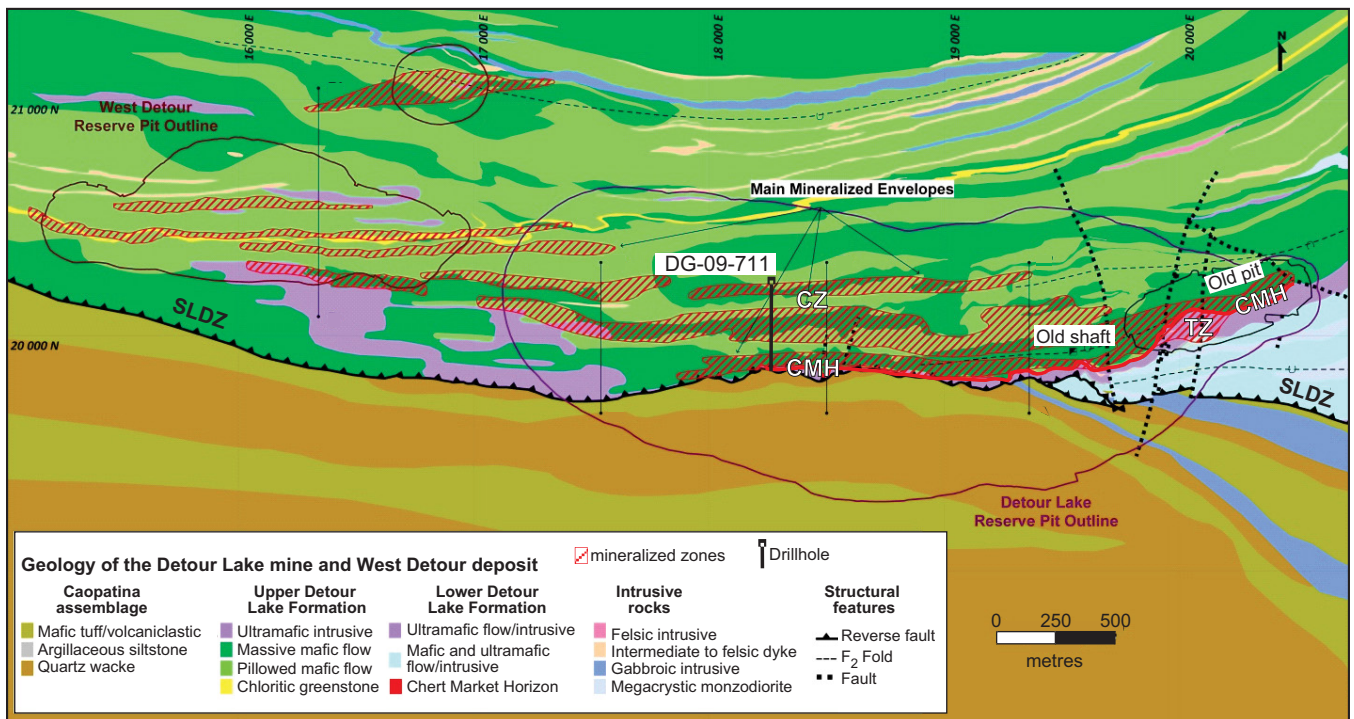


Figure 2. Simplified geological map of the Detour Lake deposit area, with the location of the main mineralized zones and historical and future pit locations outlined (*modified from Oliver et al. (2012) and Detour Gold Corporation (2018)*). Abbreviations: CMH = chert marker horizon, CZ = Calcite Zone, SLDZ = Sunday Lake deformation zone, TZ = Talc zone.

phases of deformation. The earliest phase, related to basin formation and deposition of the Caopatina sedimentary rocks, is not associated with any regional fabric. The main regional foliation (S_2) is generally steeply dipping and axial planar to west-trending tight to isoclinal F_2 folds. S_2 foliation varies from a spaced cleavage to a penetrative schistosity near high-strain or mylonitic zones, such as within the SLDZ (Fig. 1). Oliver et al. (2012) interpret the SLDZ as a south-directed D_2 reverse fault with late sinistral and dextral transpressive components. The steeply dipping S_2 foliation also affects units present within the southern part of the studied area where it is spatially associated with high-strain zones and L-tectonites within the LDDZ and its subsidiary splays. D_3 deformation is defined by broad, open, and southeast-trending F_3 folds that mostly occur north of the SLDZ (Fig. 1). The fourth phase of deformation, D_4 , is characterized by a series of southeast-trending late faults that are locally intruded by Proterozoic diabase dykes.

In general, the regional metamorphic grade increases northward, reaching amphibolite facies toward the contact with the Opatika subprovince (Fig. 1). Mafic host rocks at the Detour Lake mine are metamorphosed to amphibolite facies, comprising biotite, actinolite, albite, and almandine garnet (Marmont, 1986; Oliver et al., 2012; Dubosq et al., 2019). Further south and eastward into Quebec, greenschist-facies assemblages predominate.

LITHOSTRATIGRAPHIC FRAMEWORK OF THE SUNDAY LAKE DEFORMATION ZONE

The lithostratigraphic framework of the SLDZ is best documented in the Detour Lake mine area (Fig. 2). Here, the Deloro assemblage has been assigned by Oliver et al. (2012) to the Detour Lake Formation, which these authors further subdivide into upper and lower subunits. The lower Detour Lake Formation comprises ultramafic-dominated flows, mostly komatiitic basalt, and sills or dykes that are intercalated with mafic flows of tholeiitic affinity (Fig. 3a) and gabbroic intrusions. The upper Detour Lake Formation mainly consists of massive to pillowed mafic volcanic flows of tholeiitic affinity and volcanoclastic rocks (Fig. 3a), with some interlayered subalkaline feldspar porphyritic units. The lower and upper members of the Detour Lake Formation are locally separated by the 2725.1 ± 1.4 Ma “chert marker horizon” (CMH; Oliver et al., 2012). The CMH is not a primary chert, but a fine-grained sulphidized and silicified band (2 m thick on average) of mafic volcanic or volcanoclastic rocks, intruded by sub-alkaline to locally alkaline (e.g. albitite) intermediate to felsic sills and/or dykes (Fig. 3b). In the eastern part of the Detour Lake mine area, felsic to intermediate calc-alkaline volcanoclastic rocks also occur along strike of

the CMH. Massive to porphyritic, felsic, and gabbroic plutons and dykes (ca. 2722–2700 Ma) intrude the Detour Lake Formation (Marmont and Corfu, 1988; Oliver et al., 2012). South of the SLDZ, the Caopatina assemblage consists of younger than ca. 2697 Ma turbidite, volcanoclastic units, and local polymictic conglomerate (Oliver et al., 2012).

Eastward in Quebec, rocks of the Deloro assemblage north of the SLDZ are correlative with similar tholeiitic to calc-alkaline volcanic and volcanoclastic rocks, lesser ultramafic volcanic rocks, and carbonaceous mudstone, known locally as the Manthet Group (Fig. 1, 3a; Lacroix, 1994; Faure, 2015). Lesser gabbro-pyroxenite sills and intrusions, such as the Grasset ultramafic complex, intrude this sequence. Intermediate to felsic, subalkaline to alkaline, and porphyritic dykes (Fig. 3b) that also intrude the volcanic rocks are locally spatially related to gold mineralization (*see below*). The SLDZ becomes wider (up to 4 km) and splits into several splays that bound clastic, conglomerate-filled basins, such as the Lac Casault basin (Fig. 1; Faure, 2015). Sensitive high-resolution ion microprobe (SHRIMP) U-Pb analyses of detrital zircon from a polymictic conglomerate sample collected from the eastern part of the Lac Casault basin yielded a preliminary age of <2705 Ma (this study), which represents the best estimate for the maximum deposition age of the unit. South of the SLDZ, the Rivière Turgeon Formation (Lacroix, 1994) represents the eastern continuation of the Caopatina assemblage. The syntectonic Turgeon pluton, composed of quartz diorite with a core of quartz monzodiorite, intrudes the Rivière Turgeon Formation south of the SLDZ (Fig. 1; Lacroix, 1994). North of the SLDZ, the Jeremie pluton has a granitic to granodioritic composition and is interpreted as syntectonic, although its southern part may comprise an early synvolcanic phase (Lacroix, 1994; Faure, 2015).

SUNDAY LAKE ‘GOLD TREND’

Gold deposits and mineralized zones occurring within the SLDZ and along second-order structures informally define the Sunday Lake ‘gold trend’. The Detour Lake mine in Ontario and the Vortex Zone and the Martiniere-Bug Lake deposits in Quebec are three of the largest deposits within this trend (Fig. 1). Other gold deposits and occurrences, such as the Fenelon deposit and the recently discovered Area 51 (Wallbridge Mining Company, 2019) and Area 52 (Balmoral Resources, 2019) zones, also occur eastward along the Sunday Lake gold trend outside of the study area.

Detour Lake Gold Mine

Auriferous zones of the Detour Lake mine are commonly subvertical and oriented subparallel to a series

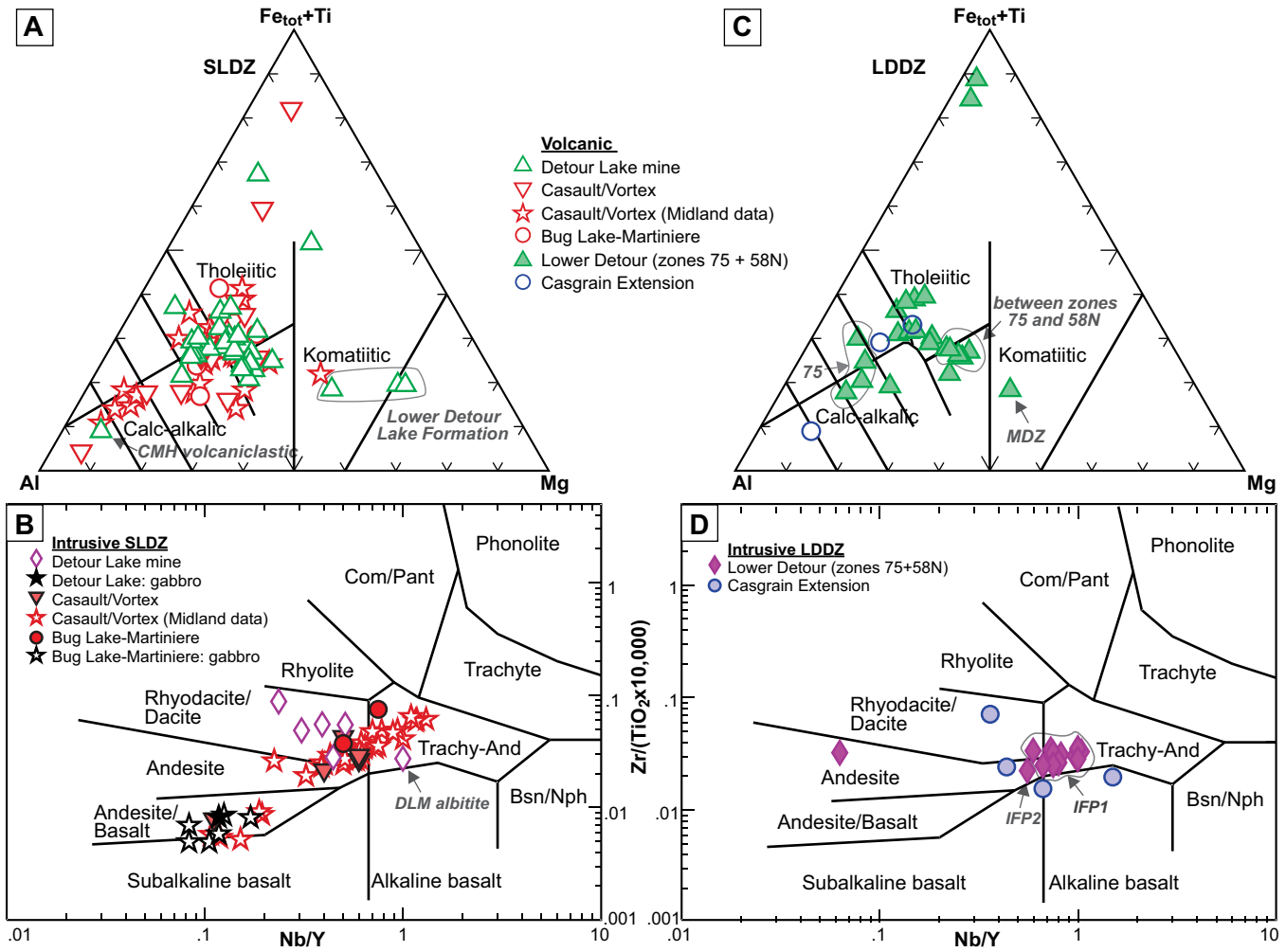


Figure 3. Geochemical classification diagrams of volcanic (a and c) and intrusive (b and d) rock samples taken from drill core collected at sites along the Sunday Lake (a and b) and Lower Detour deformation zones (c and d). **a, c)** $Fe_{total}+Ti$ -Al-Mg ternary diagram of Jensen and Pyke (1982) for volcanic rocks. **b, d)** $Zr/(TiO_2 \times 10,000)$ versus Nb/Y diagram of Winchester and Floyd (1997) used here for intrusive rocks to minimize the effects of hydrothermal alteration. Abbreviations: Bsn/Nph = basanite nephelinite; CMH = chert marker horizon; Com/Pant = comendite pantellerite; DLM = Detour Lake mine; IFP = intermediate feldspar porphyry; LDDZ = Lower Detour deformation zone; MDZ = Massicotte deformation zone; Trachy-And = Trachyte-andesite.

of high-strain zones within the SLDZ (Fig. 2; Marmont, 1986; Oliver et al., 2012; Dubosq et al., 2018, 2019). Previously mined high-grade zones (i.e. the Main Zone) focused on the CMH and also included the hanging wall ‘Q-Veins’ and footwall ‘Talc Zone’, which preferentially occur at a structural bend in the orientation and dip of the SLDZ (historically called the “hanging-wall roll”). From 1987 to 1999, the total production (open pit and underground) of the Detour Lake mine is estimated to have been 1.76 Moz of gold from the milling of just over 14.3 Mt of rock at an average head grade of 3.8 g/t Au (Detour Gold Corporation, 2018). Open-pit production, between 2013 and 2019, has been approximately 2.36 Moz Au, leaving roughly 14.8 Moz Au of reserves at 2019 year-end (Detour Gold Corporation, 2019, 2020).

The mineralization associated with the CMH consists of 0.5 to 4 m zones with abundant quartz veins and

stockwork veinlets, restricted zones of silicification (as replacement), and 3 to 7 vol.% pyrrhotite-pyrite (Fig. 4a,b; e.g. 15.8 g/t Au over 2.5 m: Oliver et al., 2012). It is hosted in altered volcanic or volcanoclastic units, which are intruded by altered subalkaline to locally alkaline, fine-grained intermediate intrusive rocks. Mineralization hosted within the “Q-Veins” (e.g. 8.6 g/t Au over 5.4 m: Oliver et al., 2012) consists of strongly deformed, centimetre-scale quartz±carbonate fault-fill and extensional veins and pyrrhotite-pyrite ±chalcopyrite stringers that cut biotite-rich, mafic volcanic rocks. Gold associated with pyrrhotite and pyrite also occurs in the Talc Zone (e.g. 9.4 g/t Au over 3.2 m: Oliver et al., 2012), which is located in the footwall of the CMH and is characterized by strongly foliated, serpentine-talc-chlorite-amphibole-altered ultramafic rocks adjacent to an intermediate intrusive body (Oliver et al., 2012; Detour Gold Corporation, 2018).

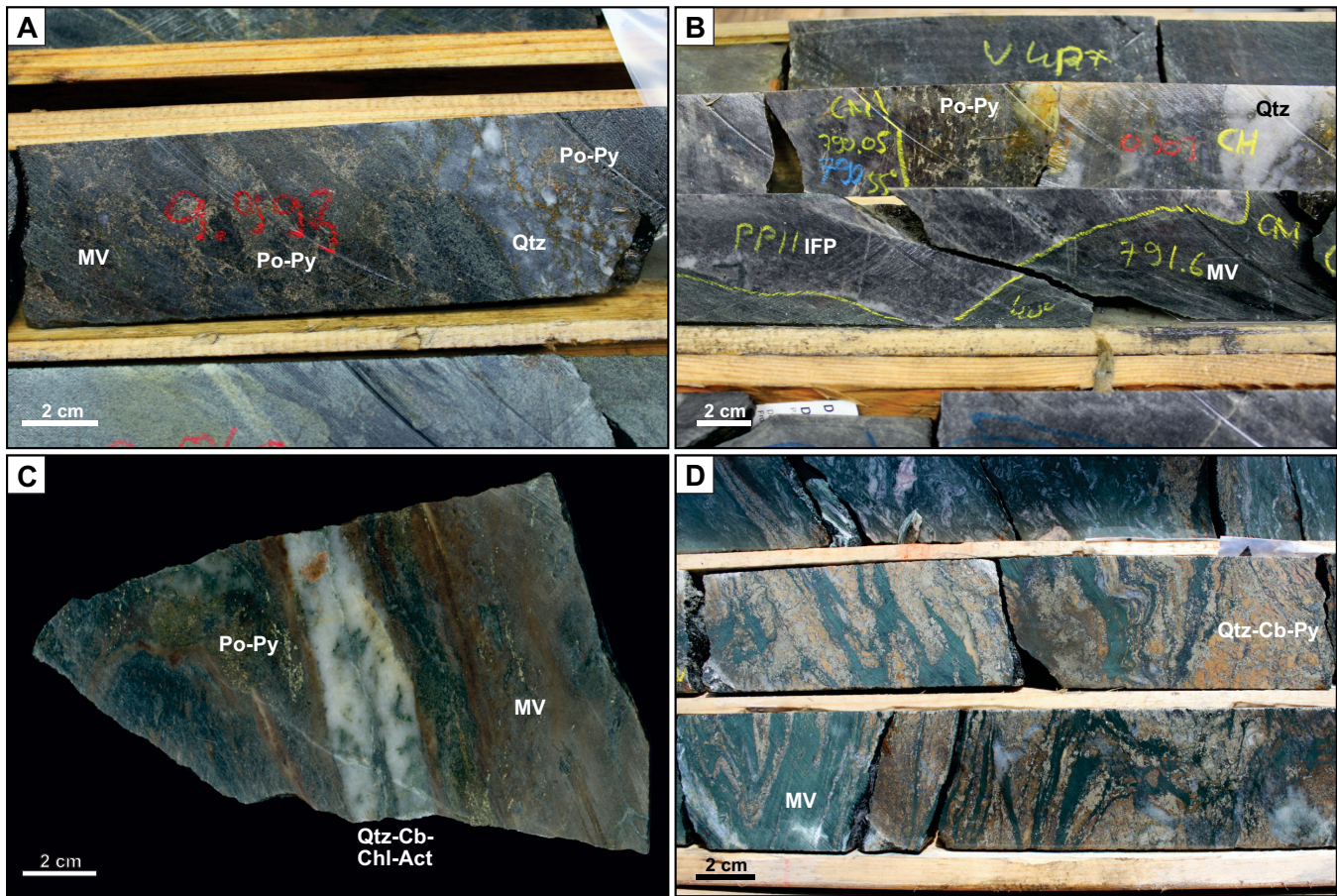


Figure 4. Photographs of representative mineralized zones along the Sunday Lake deformation zone. NQ core diameter is 47.6 mm. **a)** Detour Lake mine, chert marker horizon: quartz-biotite-chlorite-carbonate-altered basalt with 10 to 20 vol.% pyrrhotite-pyrite (interval is 9.9 g/t Au over 1.0 m). **b)** Detour Lake mine, chert marker horizon: albite±sericite±quartz-altered intermediate feldspar porphyry with 2 vol.% pyrrhotite-pyrite intruding a mafic volcanic unit with the contact marked by quartz veins and 5 vol.% pyrrhotite stringers (interval is 0.9 g/t Au over 0.5 m). **c)** Detour Lake mine, Calcite Zone ore: quartz-carbonate-chlorite-actinolite veins and disseminated pyrrhotite-pyrite (or as stringers) in biotite-altered mafic volcanic rocks. **d)** Vortex Zone 475: deformed quartz-carbonate-sulphide veins and stringers in sheared mafic blocky tuff, locally with 5 to 20 vol.% pyrite (2.7 g/t Au over 0.5 m). Abbreviations: Act = actinolite, Cb = carbonate, Chl = chlorite, IFP = intermediate feldspar porphyry, MV = mafic volcanic/volcaniclastic rock, Po = pyrrhotite, Py = pyrite, Qtz = quartz.

Since late 2012, open-pit mining has been concentrated in the low-grade (approximately 1 to 2 g/t Au average), high-tonnage Calcite Zone, which consists of steep, west-trending, and frequently boudinaged and folded, quartz-calcite veins with disseminated or stringers of pyrrhotite-pyrite hosted in biotite-altered massive and pillowed mafic volcanic rocks (Fig. 4c). Several veins types (early-, syn-, and post-D₂; Dubosq et al, 2018) occur in these hydrothermally altered domains, including sulphide-rich brecciated veins. Dubosq et al. (2018) interpret the latter vein-type to be associated with late brittle-ductile strain and gold remobilization.

Core from drillhole DG-09-711, which transects most of the ore zones at the Detour Lake mine including the Calcite Zone and the western extension of the Main Zone (Fig. 2; CMH and hanging-wall veins) was studied in detail and systematically sampled for whole-rock lithogeochemical analysis (Fig. 5a). Along this drillhole, the Calcite Zone comprises quartz-calcite

veins, 1 to 8 vol.% pyrrhotite-pyrite within a biotite-quartz-actinolite-chlorite-albite±calcite and/or Fe-carbonate alteration envelope at the contact zone between massive and pillowed basalt. Mineralization within the Calcite Zone is relatively wide but low-grade (1.8 g/t Au over 82 m). Total sulphur and CO₂ contents and the K₂O/(K₂O+Na₂O) ratios across the Calcite Zone are consistent with sulphide-carbonate-biotite alteration of the host rocks. The Main Zone (CMH and hanging-wall veins; 4.0 g/t Au over 46 m) lies roughly 200 m down this same drillhole below the Calcite Zone. In the hanging-wall of the CMH, mineralization is made up of strongly deformed quartz±carbonate veins with 2 to 5 vol.% pyrrhotite-pyrite±chalcopyrite stringers that cut altered massive mafic volcanic rocks. The mineralization associated with the CMH, which forms the southern part of the orebody, consists of quartz-sulphide veins (1–8 cm) and locally visible gold hosted in biotite-quartz-albite-carbonate-altered mafic volcanic

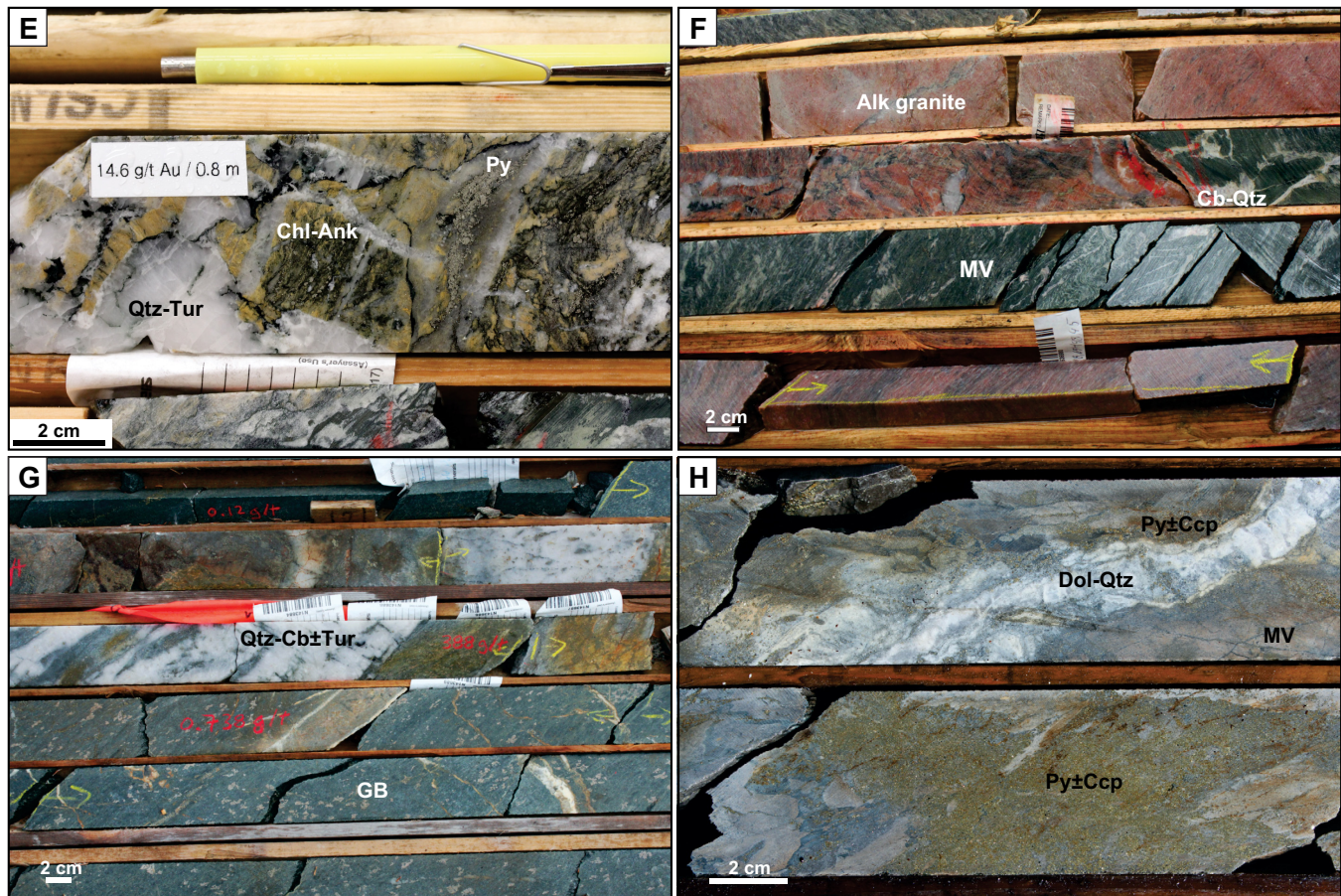


Figure 4 continued. Photographs of representative mineralized zones along the Sunday Lake deformation zone. NQ core diameter is 47.6 mm. **e)** Vortex Zone 450: quartz-carbonate-tourmaline veins, chlorite veinlets, and disseminated pyrite developed at the contact between an albite-ankerite-altered alkaline granitic dyke and mafic volcanoclastic rocks (14.6 g/t Au over 0.8 m; drillhole CAS-17-96). **f)** Reddish alkaline granitic dyke intruding mafic volcanic rocks in the footwall of Zone 450. Contacts are strongly foliated, brecciated, and marked by quartz-carbonate veins. **g)** Martiniere West: quartz-dolomite/ankerite-pyrite-tourmaline veins in a carbonate-quartz-sericite-altered, leucogabbro. **h)** Upper zone of Bug South: dolomite-quartz-pyrite veins and 5 to 10 vol.% pyrite±chalcocopyrite stringer (5.8 g/t Au over 1.7 m) in sericitized pillowed basalt. Abbreviations: Alk = alkaline; Ank = ankerite, Cb = carbonate, Ccp = chalcocopyrite, Chl = chlorite, Dol = dolomite, GB = gabbro, MV = mafic volcanic/volcanoclastic rock, Py = pyrite, Qtz = quartz, Tur = tourmaline.

rocks, talc-chlorite schist, and subalkaline intermediate albite-quartz-altered intrusive rocks. The CO_2 content and $\text{K}_2\text{O}/(\text{K}_2\text{O}+\text{Na}_2\text{O})$ ratios (biotite alteration) are anomalous but significantly lower than in the Calcite zone.

Vortex Zone

The Vortex Zone, part of the Casault property (Midland Exploration, 2018) is located at the western tip of the Lac Casault conglomerate basin along a fault splay of the SLDZ, about 40 km east of the Detour Lake mine (Fig. 1). The auriferous, west-trending, high-strain Vortex Zone occurs at the contact between tholeiitic and calc-alkaline volcanic and volcanoclastic units of the Manthet Group (Fig. 3a, 6). Mineralized intervals within this zone are spatially associated with subalkaline to reddish albite-sericite-hematite-altered alkaline porphyritic dykes (Fig. 3b). Auriferous quartz veins are transposed, boudinaged, and folded, but some are

locally oblique and cut the main foliation (likely the S_2 of Oliver et al., 2012), suggesting that the veins overlapped the main foliation forming event. Vein stockwork and hydrothermal breccia occur in the high-strain zones and locally comprise rotated foliated clasts, indicating that brecciation is syn- to late-main phase deformation. These hydrothermal breccia zones are spatially associated with a locally strongly developed crenulation cleavage that overprints the main deformation fabric near the mineralized zones. Mafic to intermediate volcanoclastic rocks of calc-alkaline affinity are likely correlative with the hydrothermally altered CMH, which occurs along strike of the SLDZ at the Detour Lake deposit (Faure, 2015).

The schematic and geochemical profile of drillhole CAS-17-094 (Fig. 5b, 6) illustrates the setting, distribution, and characteristics of the mineralized intervals and lithogeochemical signature of the Vortex Zone. Strain increases from north to south (i.e. down the drill-

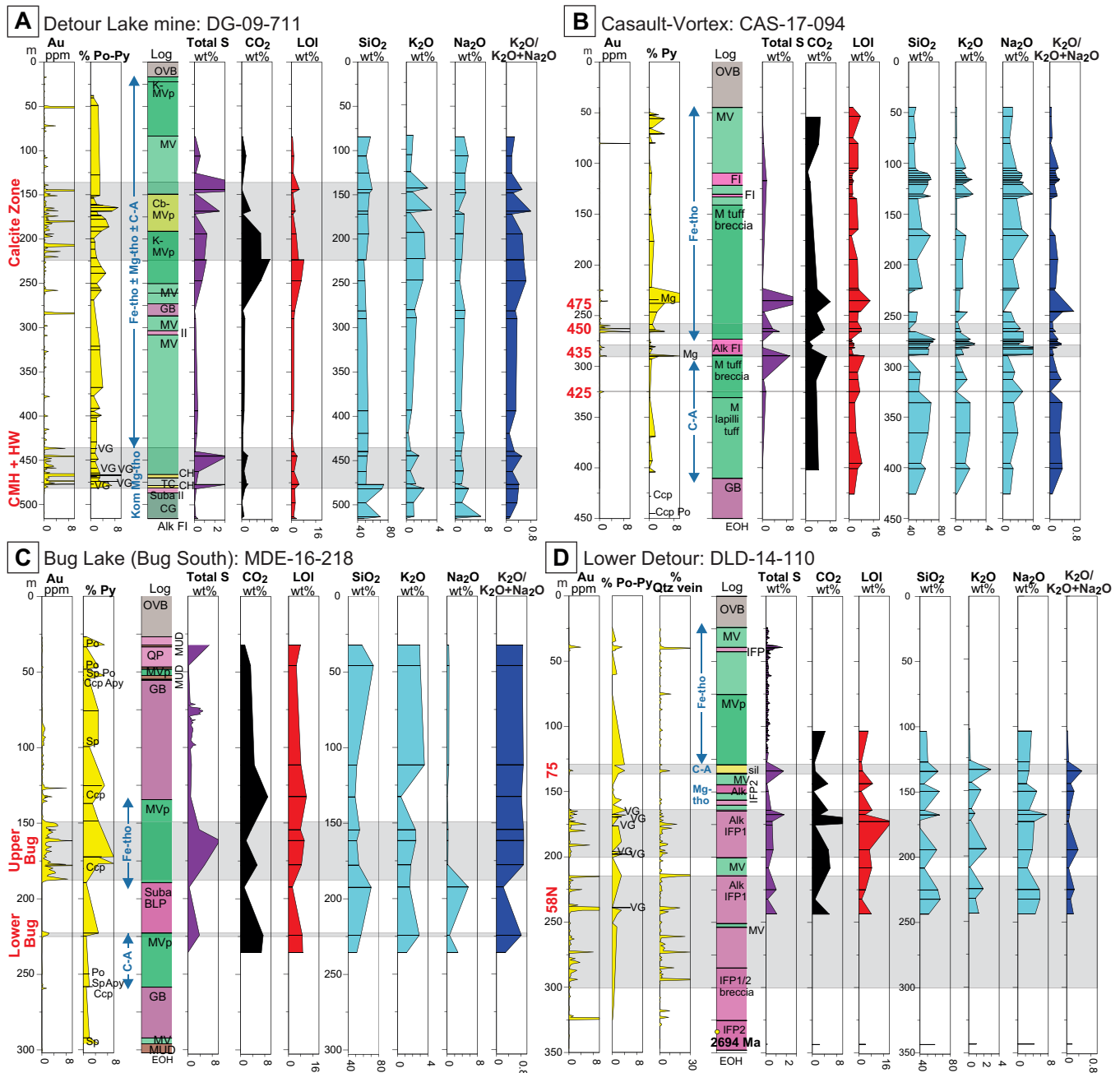


Figure 5. Drillhole profiles across the main mineralized zones showing the relationships between gold and vol.% of pyrite plus pyrrhotite (also showing number of specks of visible gold (VG) with other minerals (Apy = arsenopyrite, Ccp = chalcopyrite, Mg = magnetite, Po = pyrrhotite, Sp = sphalerite), other elements, and oxides (LOI= loss on ignition) in the logged rock types and their main geochemical affinities). The $K_2O/(K_2O+Na_2O)$ ratio outlines the sericite and potassic alteration. **a)** Detour Lake mine, drillhole DG-09-711 with the chert marker horizon (CMH), hanging-wall zone, and the Calcite Zone labelled. **b)** Casault-Vortex Zone, drillhole CAS-17-094 with zones 425, 435, 450, and 475 labelled. **c)** Bug Lake-Bug South zone, drillhole MDE-16-218 with Upper and Lower Bug zones labelled. **d)** Lower Detour, drillhole DLD-14-110 with zones 75 and 58N labelled. Abbreviations for the log profile: Alk = alkaline, BLP = Bug Lake porphyry, C-A = calc-alkaline, Cb = carbonate-altered, CG = chloritic greenstone, CH and SIL = silicified zone, EOH = end of hole, Fe-tho = high-Fe tholeiite, FI = felsic intrusive, GB = gabbro, IFP = intermediate feldspar porphyry, II = intermediate intrusive, K = potassic-altered, Kom = komatiite, Mg-tho = high-Mg tholeiite, MUD = mudstone, MV = mafic volcanic, MVp = pillowed mafic volcanic, OVB = overburden, QP = quartz porphyry, Sil = silicified zone, Suba = subalkaline, TC = talc-chlorite schist.

hole), and several steeply north-dipping mineralized intervals were identified. Zone 475 consists of deformed quartz-carbonate-sulphide veins in sheared carbonate-chlorite-sericite-altered andesitic blocky tuff

with 5 to 20 vol.% pyrite (locally semi-massive) and 3 to 5 vol.% magnetite (e.g. 0.4 g/t Au over 8 m, including 2.7 g/t Au over 0.5 m; Fig. 4d). Zone 450 comprises deformed quartz-carbonate (ankerite)±tourmaline veins

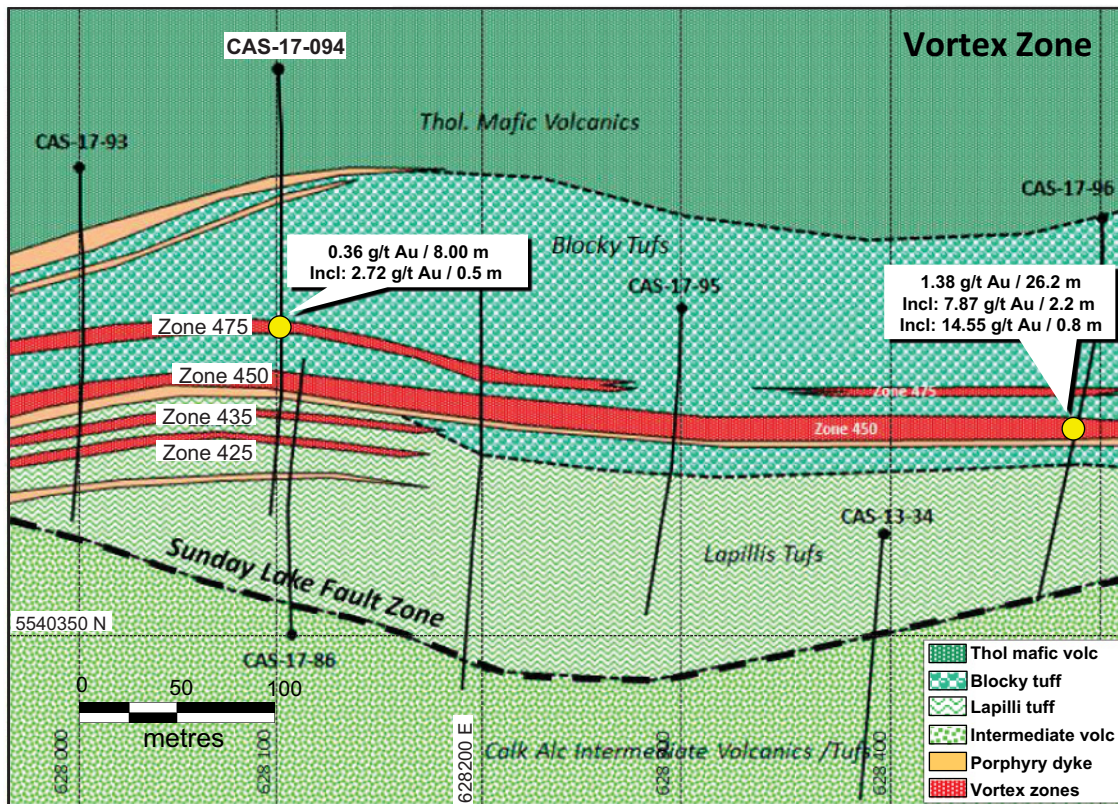


Figure 6. Simplified geological map of a part of the Vortex Zone (modified from Midland Exploration, 2018). Abbreviations: Calk Alc = calc-alkaline, Incl = including, Thol = tholeiitic, volc = volcanic rocks.

and disseminated pyrite (2–5 vol.%) associated with high-strain zones and hydrothermal breccia (e.g. 14.6 g/t Au over 0.8 m in drillhole CAS-17-096; Fig. 4e, 6) at the contact between strongly deformed carbonate-chlorite-altered basaltic volcanoclastic rocks and a more competent, albite-hematite-altered alkaline granitic dyke (Fig. 4f). At greater depths, secondary zones, such as zone 435, consist of quartz-carbonate veins and disseminated pyrite (3–10 vol.%, with ≤ 8 vol.% magnetite) in strongly deformed, hematite-sericite-altered andesitic lapilli tuff (e.g. Zone 435: 0.5 g/t Au over 4.6 m) in the footwall of the alkaline granite dyke. The higher Na₂O and K₂O/(K₂O+Na₂O) index values of the dyke samples (Fig. 5b) is likely due to the original alkaline composition of the unit and/or overprinting albite-sericite alteration. In general, geochemical analyses within the mineralized zones yield anomalous S and CO₂ concentrations, which is consistent with the carbonate-pyrite alteration related to auriferous veins.

Martiniere West and Bug Lake Deposits

The Martiniere West and Bug Lake deposits (Fig. 7; Martiniere property; Voordouw and Jutras, 2018) are located about 50 km east of the Detour Lake mine, 12 km east of the Vortex Zone, and approximately 2 km from the interpreted northern splay of the SLDZ (Fig. 1).

The Martiniere West deposit comprises two north-east-trending mineralized brittle-ductile high-strain zones, which are approximately 10 to 20 m wide. Each zone is characterized by multiple generations of quartz-carbonate (dolomite/ankerite)-tourmaline veins and 1 to 5 vol.% pyrite±arsenopyrite±chalcopyrite (Fig. 4g). Intervals (10–40 cm wide) of breccia vein locally occur near the contact with carbonate-quartz-sericite±albite-altered wall rocks. The 400 m long West Main Zone (e.g. 10.6 g/t Au over 21.4 m: drillhole MDW13-88) is hosted in moderately foliated (likely S₂ foliation), leucoxene-bearing tholeiitic quartz gabbro (Fig. 3b), near and subparallel to the contact with mafic volcanic and sedimentary units. Away from mineralized high-strain zones, the host gabbro is massive to weakly foliated and contains chlorite and titanomagnetite.

The Bug Lake deposit consists of moderately to steeply eastward-dipping brittle-ductile high-strain zones with an en echelon (right-stepping) apparent geometry, delineating the North and South zones (Fig. 7). Both zones are hosted by mafic volcanic rocks and gabbro along both the upper and lower contacts (e.g. ‘Upper Bug’ and ‘Lower Bug’ subzones) of the north-northwest-trending Bug Lake porphyry, which lies almost perpendicular to the layering of host rocks. The dyke is a lenticular 10 to 30 m thick, massive to weakly foliated, fine-grained sericitized subalkaline quartz

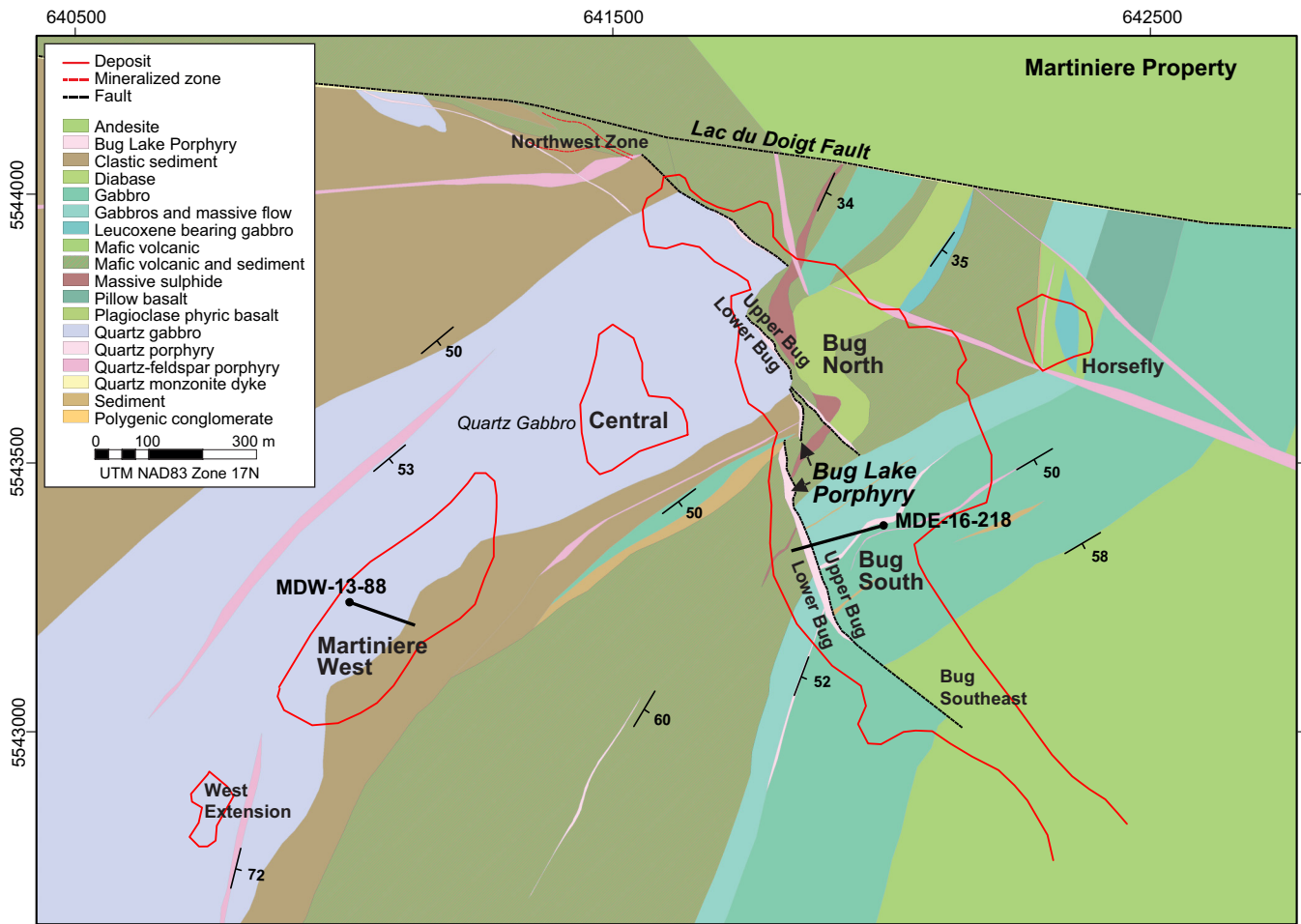


Figure 7. Geological map of the Martiniere West and Bug Lake deposits, Martiniere property (modified from Voordouw and Jutras, 2018).

porphyry (quartz diorite to granodiorite; rhyodacite/dacite field in Fig. 3b) with 1 to 2 vol.% disseminated pyrite, but with no significant (i.e. <25 ppb) gold values. The profile of drillhole MDE-16-218 (Fig. 5c, 7) shows that the auriferous intervals of Bug South occur as several discrete high-strain and hydrothermally altered (carbonate-sericite-quartz) zones overprinting pillow basalt and andesitic basalt of tholeiitic (Upper Bug) to calc-alkaline (Lower Bug) affinities (Fig. 3a). The Upper Bug subzone (e.g. 2.8 g/t Au over 40.3 m; Fig. 5c) is characterized by quartz-sericite veins, abundant crosscutting dolomite/ankerite-quartz±tourmaline veins (Fig. 4h) and breccia vein, locally showing a crustiform texture. Auriferous zones are associated with 5 to 10 vol.% pyrite±chalcopyrite, disseminated and within veinlets. Thin (2–3 m), secondary breccia zones with dolomite/ankerite-quartz-pyrite±chalcopyrite veins (0.5 to locally 8 g/t) occur in a ~50 m low-grade envelope (0.2–0.5 g/t Au) within massive basalt and leucoxene-bearing gabbro above the Upper Bug zone. The lower subzone at Bug South is a much thinner (~3 m) and lower grade (e.g. 2.2 g/t Au over 2.3 m) interval characterized by 2 to 5 vol.% pyrite stringers,

with disseminated pyrrhotite, chalcopyrite, and arsenopyrite within the contact zone between the porphyry and sericite-altered pillow basalt (Fig. 5c).

LITHOSTRATIGRAPHIC FRAMEWORK OF THE LOWER DETOUR DEFORMATION ZONE

In Ontario, the LDDZ lies roughly 7 km south of the SLDZ, across the Caopatina assemblage (Fig. 1). Its geological setting is less defined than that of the SLDZ. However, active exploration by Detour Gold since 2011, including a fence of 28 diamond drillholes along a north-south cross-section (Detour Gold, 2018, unpub. data; Fig. 8), provides critical insights into the lithostratigraphic and structural settings of the Lower Detour mineralized zones. The section lies approximately 1.3 km west of the 58N and 75 zones (*see below*). Lithogeochemical data from Detour Gold and the present study are summarized here to better characterize the main host rocks.

The LDDZ juxtaposes volcanic units correlated with the Detour Lake Formation of the Deloro assemblage

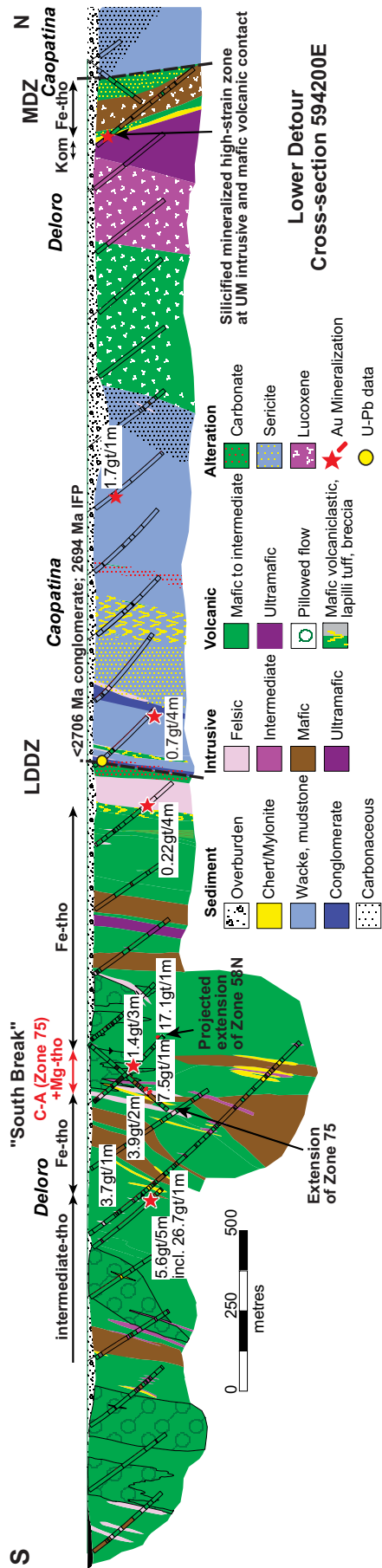


Figure 8. Simplified section across the Lower Detour area (see Fig. 1 for location; modified from "stratigraphic section 594200E": Detour Gold Corporation, 2018, unpub. data). Note: the limits and extent of the lithochemical affinities are approximate. Abbreviations: C-A = calc-alkaline, Fe-tho = high-Fe tholeiite, IFP = intermediate feldspar porphyry, Kom = komatiitic, LDDZ = Lower Detour deformation zone, MDZ = Massicotte deformation zone, Mg-tho = high Mg-tholeiite.

against sedimentary rocks of the Caopatina assemblage to the north (Fig. 1, 8). This inferred structural contact is repeated 2 km northward along the MDZ, where a locally mineralized silicified contact zone between ultramafic intrusive and mafic volcanic rocks, locally of calc-alkaline affinity, is similar to the CMH at the Detour Lake mine along the SLDZ. A strongly sheared and silicified deformation zone (informally termed the "South Break") occurring roughly 1 km south of the LDDZ is spatially associated with auriferous zones 75 and 58N and likely represents a second-order structure to the LDDZ.

The mafic to intermediate volcanic (pillow and massive) and volcanoclastic rocks occurring within and south of the LDDZ mostly have a Fe-rich tholeiitic affinity (Fig. 3c, 8). However, the thin panel of silicified intermediate volcanic rocks hosting Zone 75 within the South Break and the mafic units between zones 75 and 58N locally have distinctive calc-alkaline and high-Mg tholeiitic signatures, respectively. Again, this contact is similar to the CMH and the contact with the upper Detour Lake Formation at the Detour Lake mine.

The Caopatina sedimentary rocks located between the LDDZ and MDZ consist of interlayered polymictic conglomerate, wacke, mafic volcanoclastic and carbonaceous mudstone (Fig. 1, 8). The polymictic conglomerate along the LDDZ is frequently iron carbonate-altered, strongly deformed, and locally lineated, evolving into an L>S tectonite. U-Pb SHRIMP and thermal ionization mass spectrometry (TIMS) analyses of detrital zircon from a polymictic conglomerate sample from the immediate footwall of the LDDZ yielded a preliminary age of ≤ 2706 Ma (this study), which represents the maximum age for the deposition of the unit.

A swarm of feldspar porphyry dykes intrude the volcanic and sedimentary rocks within and south of the LDDZ. Two intrusive phases are interpreted (Malcolm et al., 2015): 1) intermediate feldspar porphyry 1 (IFP1) is leucocratic, plagioclase phenocryst-rich (30–50 vol.%) quartz monzonite, mainly of alkaline affinity (Fig. 3d); and 2) intermediate feldspar porphyry 2 (IFP2) is a melanocratic subalkaline quartz diorite consisting of less than 20 vol.% phenocrysts, which locally appear to intrude and brecciate IFP1, especially in Zone 58N where both phases occur in the hanging wall of an intermediate intrusion. U-Pb SHRIMP and TIMS zircon analyses from samples of IFP1 and IFP2 yielded identical (within error) preliminary crystallization ages of ca. 2694 Ma (this study).

The LDDZ, the MDZ, and the main lithological assemblages extend eastward into an extensively overburden-covered area of Quebec for which geological information is limited (Fig. 1; Faure, 2012, 2015). The

Rivière Turgeon Formation, which is the eastern continuation of the Caopatina assemblage, consists of turbiditic siltstone, sandstone, and locally mudstone (Lacroix, 1994). Layers of magnetite-bearing iron formation and polymictic conglomerate occur in the southern part of the sedimentary belt, in the immediate structural footwall (north) of the LDDZ. The volcanic rocks occurring south of the MDZ and LDDZ comprise the Brouillan Nord assemblage and the Brouillan Group (or volcanic complex; Lacroix, 1994; Faure, 2012), respectively. The Brouillan Group principally consists of calc-alkaline andesitic basalt and volcanoclastic rocks with lesser rhyolitic layers, which are surrounded by tholeiitic basalt, including that of the Brouillan Nord assemblage. The Brouillan Group extends southeastward in the Selbaie past-producing mine and B26 deposit area, where ca. 2729–2728 Ma felsic volcanic rocks (Barrie and Krogh, 1996; Fayard et al., 2020) are broadly coeval with the Deloro assemblage.

LOWER DETOUR ‘GOLD TREND’

The Lower Detour gold trend comprises gold mineralization spatially associated with the Massicotte and Lower Detour deformation zones, including zones 58N and 75 (Zone 58N: 534,000 oz or 16.6 t Au; Detour Gold Corp., 2019) and lesser studied gold occurrences in Quebec. The MDZ and LDDZ correlate eastward with the Grasset fault zone (Fig. 1; Faure, 2015).

Zones 58N and 75

The steeply south-dipping zones 58N and 75 occur along an anticlockwise bend of the magnetic lineaments and structural grain within the South Break (Fig. 1, 5; Malcolm et al., 2015; Detour Gold Corporation, 2018). The profile of drillhole DLD-14-110 (Fig. 5d) illustrates that Zone 75 (1.4 g/t Au over 1.0 m) is hosted in silicified, sericite-biotite-altered tholeiitic andesite, calc-alkaline andesite, and dacite (Fig. 9a,b), and locally in a feldspar porphyry dyke. Zone 75 mineralization comprises 5 to 20 vol.% sulphide (i.e. mainly pyrite, chalcopyrite, sphalerite, and lesser pyrrhotite). Higher gold concentrations (e.g. 8.0 g/t Au over 6 m: drillhole DLD-16-203) generally correlates with increasing strain intensity and sulphide content. Below Zone 75, the much wider Zone 58N consists of discrete laminated quartz-tourmaline-carbonate \pm visible gold veins and stockwork (e.g. 55.8 g/t Au over 6 m, including 308 g/t Au over 1 m; Fig. 5d, 9c) hosted in a swarm of leucocratic feldspar porphyry dykes, mostly of the IFP1 phase (Fig. 9d). The IFP2 is locally gold-bearing in high-strain zones. The highest gold grades within these zones are spatially associated with veining (Fig. 5d). The auriferous veins are associated with a decimetre-wide albite-sericite-quartz-car-

bonate (\pm hematite) alteration zone (Fig. 9c). Between 0.5 and 5 vol.% disseminated pyrite occurs within the veins or their immediate selvages, along with trace amounts of sphalerite and chalcopyrite. Based on the age of the host porphyry, the bulk of the mineralization is interpreted to be younger than 2694 Ma.

Lower Detour ‘Gold Trend’ in Quebec

Auriferous zones of the Lower Detour trend in Quebec include the Lynx and Rambo zones (Balmoral Resources) and those of Probe Metals-SOQUEM ‘Detour Quebec’ project. The Lynx (7.8 g/t Au over 7.2 m) and Rambo (6.3 g/t Au over 2.7 m) zones are east-trending, 0.4 to 13.4 m thick, and are characterized by quartz-carbonate-pyrite veins at the contact between andesitic and basaltic volcanic rocks within the MDZ (Fig. 1; Balmoral Resources, 2018). The Massicotte and Casgrain Extension properties cover a 74 km long corridor along the eastward extension of the LDDZ (Probe Metals, 2018). Sparse diamond drilling has intersected auriferous zones (e.g. 2.8 g/t Au over 0.7 m: drillhole CE-16-01; Fig. 1) along the LDDZ and second-order splays to the south. At Massicotte, a mineralized zone comprises pyrite \pm galena \pm sphalerite veins in a sericite schist (e.g. 5.3 g/t Au over 3.4 m, including 17.5 g/t Au over 1 m: drillhole MA-16-05; Fig. 1; Probe Metals, 2016). Mineralization at the Casgrain Extension comprises quartz-carbonate-tourmaline-pyrite veins at sheared contacts between chlorite-epidote-altered calc-alkaline andesitic basalt (Fig. 3c) and hematite-leucoxene-sericite-altered quartz-eye porphyry or rhyodacite (Fig. 3d, 9e), which are intruded by albite-hematite-sericite-altered alkaline porphyritic monzonite (alkaline basalt field in Fig. 3d).

Exploration drilling in the Casgrain Extension property has intersected several intervals of polymictic conglomerate. One, thick (~260 m) polymictic conglomerate interval occurs just north of the LDDZ, at the same structural position as that of the Lower Detour area to the west (blue line along LDDZ in Fig. 1). It consists of flattened subrounded to subangular clasts, principally of mafic volcanic origin with lesser felsic volcanic, porphyritic, and quartz vein clasts. The strongly deformed conglomerate is intruded by buff-coloured subalkaline to alkaline, porphyritic quartz diorite dykes (andesite to subalkaline basalt fields in Fig. 3d), at the contact of which occur strong albite, sericite and carbonate alteration, disseminated pyrite, and a thin (10 cm thick) quartz-tourmaline breccia vein (e.g. 1.3 g/t Au over 1.0 m; Fig. 9f). U-Pb SHRIMP detrital zircon analyses of this conglomeratic unit yielded a preliminary age of <2692 Ma (this study; Fig. 1), which represents a maximum deposition age that is significantly younger than the other age data for polygenic conglomerate obtained in this study.

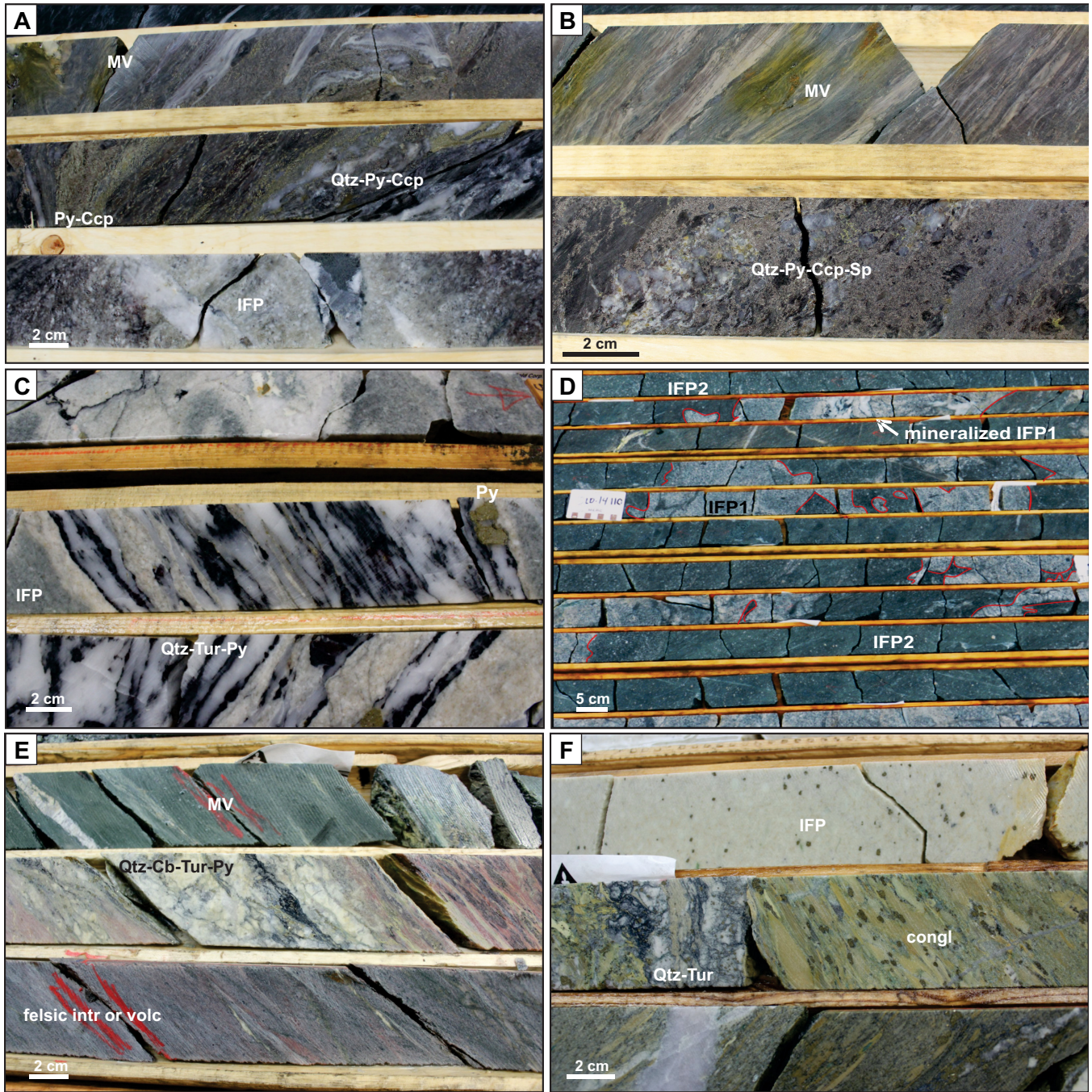


Figure 9. Photographs of representative mineralized zones related to the Lower Detour deformation zone. NQ core diameter is 47.6 mm. **a)** Zone 75: silicified, sulphidized, and biotite-sericite-albite-altered mafic volcanic units and feldspar-quartz porphyry. **b)** Zone 75: sulphide-rich zone (mainly pyrite with lesser pyrrhotite, chalcopyrite, and sphalerite) in highly strained and altered mafic volcanic rocks. **c)** Typical Zone 58N: laminated quartz-tourmaline veins in albite-sericite-quartz-altered feldspar porphyry with trace to 2 vol.% coarse pyrite along vein contacts with the feldspar porphyry (interval is 34.9 g/t Au over 1 m). **d)** Ore-hosting leucocratic porphyry (IFP1) brecciated by a melanocratic intermediate porphyry (IFP2; *modified from Malcolm et al., 2015*). Both units have the same preliminary crystallization age of ca. 2694 Ma. **e)** Casgrain Extension: quartz-tourmaline-pyrite vein (anomalous in gold) at sheared contact between hematite-sericite-altered felsic intrusive and chloritized mafic volcanic units. **f)** Casgrain Extension: contact marked by a quartz-tourmaline vein breccia between albite-sericite-pyrite-altered intermediate feldspar porphyry and sericitized polymictic conglomerate (1.27 g/t Au over 1 m interval). Abbreviations: Cb = carbonate, Ccp = chalcopyrite, congl = conglomerate, IFP = intermediate feldspar porphyry, intr = intrusive rock, MV = mafic volcanic, Po = pyrrhotite, Py = pyrite, Qtz = quartz, Sp = sphalerite, Tur = tourmaline, volc = volcanic rock.

DISCUSSION

The present study refines the geological setting of what we informally refer to as the Sunday Lake and Lower Detour gold trends. These gold trends follow regional deformation zones mainly affecting volcanic units of the Deloro assemblage and small fault-bounded basins of polymictic conglomerate. The most prolific deformation zones border the turbidite deposit of the Caopatina assemblage, which shares similarities with the deformed Porcupine/Cadillac basins of the southern Abitibi (Fig. 1). Preliminary dating of the polymictic conglomerate units yielded maximum detrital zircon ages of ≤ 2706 to ≤ 2692 Ma. Further work will determine if these conglomerate units are temporally distinct from the Caopatina assemblage. The somewhat older conglomerate (≤ 2706 Ma) may be part of the Caopatina assemblage and correlative to the < 2703 Ma Stella Formation, such as in the Chapais-Chibougamau camp (e.g. Leclerc et al., 2012). However, the potentially younger conglomerate (≤ 2692 Ma) from the Casgrain Extension property may represent a different unit that unconformably or structurally overlies the Caopatina basin. If correct, some conglomerate horizons may be correlative with the Timiskaming-like Haüy Formation (< 2691 Ma; David et al., 2007; Leclerc et al., 2012). Intermediate to felsic, typically reddish, subalkaline to alkaline porphyritic dykes (preliminary ages suggest that some of these dykes are ca. 2694 Ma) are also spatially related to the SLDZ and LDDZ. The preliminary dyke ages are similar to, but slightly older than, the ca. 2692 Ma alkaline syenitic intrusions occurring in the Chibougamau area (Leclerc et al., 2012).

The geological setting of the study area, including the lithostratigraphic characteristics and age relationships of the units, are reminiscent of the prolific gold camps of the southern Abitibi greenstone belt, such as the Timmins district (e.g. Robert et al., 2005; Dubé and Gosselin, 2007; Bleeker, 2015; Dubé et al., 2017). In these areas, major deformation zones (e.g. Destor-Porcupine fault zone) are thought to be inherited from extensional faults that delimit panels of “synorogenic” Timiskaming clastic rocks. These crustal-scale structures are interpreted to have facilitated mantle-derived alkaline magmatism and migration of gold-bearing fluids during later thrust inversion and regional tectonometamorphism (Cameron, 1993; Bleeker, 2015; Dubé et al., 2017).

The present study also outlines the main characteristics of the various deposits and prospects along the SLDZ and LDDZ, as summarized in Table 1. Gold along these major deformation zones is structurally controlled by second-order faults or high-strain zones that commonly coincide with structural flexures or bends. Auriferous zones occur along contact zones

between Deloro volcanic units (and equivalent Manthet and Brouillan groups) of different compositions or signatures and intermediate porphyritic dykes or gabbroic intrusive rocks. Gold is associated with quartz-carbonate±tourmaline or sulphide-rich veins, stockwork, and breccia zones in hydrothermally altered (carbonate, sericite, biotite) wall rocks.

Along the SLDZ, a thin discontinuous band of volcanoclastic rocks occurs between the lower part of the Deloro assemblage (i.e. ultramafic komatiitic volcanic and intrusive units comprising the Lower Detour Lake Formation; Oliver et al., 2012) and the dominantly tholeiitic mafic volcanic rocks of the Upper Detour Lake Formation. Along strike, this thin band of volcanoclastic rocks is interpreted to correlate with the prolific CMH that hosts part of the higher grade mineralization at the Detour Lake mine (Fig. 1, 5a; Oliver et al., 2012). There, the strained horizon consists of a 0.5 to 2.0 m thick intermediate to felsic, calc-alkaline volcanoclastic unit, interlayered with silicified mafic volcanic rocks and albitite dykes. A similar lithological assemblage extends eastward in Quebec, such as across the Vortex Zone (Fig. 1). Here, the mineralization is subparallel to the SLDZ and likewise is located at the contact between tholeiitic mafic and calc-alkaline intermediate volcanoclastic units, adjacent to an alkaline granite or albitite dyke (Fig. 5b). Although the dyke is locally mineralized, most of the gold is hosted by the strongly deformed volcanoclastic units.

The settings of the Massicotte and Lower Detour deformation zones are also analogous to the CMH along the SLDZ (Fig. 1, 5, 8). A similar silicified and sulphidized (cherty) mineralized zone is present at the contact between komatiitic and tholeiitic volcanic and intrusive rocks just south of the MDZ. Further south, in the structural hanging wall of the LDDZ, the silicified and sulphidized rocks of Zone 75 locally have a calc-alkaline affinity and occur along a second-order deformation zone that juxtaposes Fe-rich with Mg-rich tholeiitic sequences. Gold in Zone 58N is almost exclusively hosted by the leucocratic alkaline intermediate feldspar porphyry (IPF1), which acted as a competent unit during deformation and formation of the gold-bearing quartz-carbonate-tourmaline vein network. The ca. 2694 Ma age of the dyke represents the maximum age of the mineralization. Some thin, higher grade zones occur near contacts with highly strained mafic volcanic rocks, which are mostly barren of gold.

The Bug Lake deposit may represent a different gold mineralization style. The auriferous, steeply dipping, high-strain zones are northwest- to north-northwest-trending and occur at the contacts of a porphyry dyke, most probably due to a strong competency contrast with the enveloping mafic volcanic rocks. These high-strain zones are subparallel to the Martiniere fault to

Table 1. Main characteristics of some of the gold mineralized deposits/zones associated with the Sunday Lake and Lower Detour deformation zones.

Locality	Geological setting	Main characteristics	Associated alteration	Timing versus main stage of deformation-metamorphism	Similar style
Detour Lake mine: Main Zone	Local bend/ramp in SLDZ: Contact between Deloro >2725 Ma komatiitic and <2725 Ma tholeiitic volcanic units, intruded by subalkaline to locally alkaline intermediate dykes/sills	Silicified/sulphidized zone (CMH) and hanging-wall fault-fill=extensional quartz-carbonate veins (Q veins) and late sulphide-rich breccia	Biotite-quartz-albite-carbonate; talc-chlorite in komatiitic basalt	Syn to late	
Detour Lake mine: Calcite Zone	Hanging wall of SLDZ: contacts between Deloro tholeiitic ±calc-alkaline massive and pillow basalt	High-strain zones with deformed quartz-calcite-sulphide veins, stockwork, and stringer	Biotite-quartz-actinolite-chlorite-albite±carbonate	Syn to late	
Vortex Zone 475	SLDZ: contacts between Manthet (Deloro) tholeiitic and calc-alkaline mafic=intermediate volcanic and volcanoclastic units (similar horizon as CMH)	High-strain zones with deformed quartz-carbonate-pyrite veins, locally with semi-massive pyrite	Carbonate-chlorite-sericite	Syn to late	Lower Detour Zone 75
Vortex Zone 450	SLDZ: contacts between Manthet tholeiitic and calc-alkaline volcanic and volcanoclastic units (similar horizon as CMH) in the hanging wall of alkaline granite dyke	High-strain zones with quartz-carbonate±tourmaline veins and disseminated pyrite-associated late breccia zones	Carbonate-chlorite-sericite in volcanic; albite-sericite-carbonate-hematite in dyke	Syn to late	CMH; Bug Lake
Martiniere West	Hanging wall of SLDZ: high-strain zones in tholeiitic leucoxene-bearing quartz gabbro	Silicified high-strain and breccia zones with quartz-(dolomite/ankerite)-tourmaline veins and 1 to 5 vol.% pyrite±arsenopyrite±chalcoppyrite	Carbonate-quartz-sericite	Syn to late	
Bug Lake	Hanging wall north of SLDZ: NW-trending high-strain zones in Manthet Fe-tholeiitic to calc-alkaline pillow basalt and gabbro along both contacts of a feldspar porphyry dyke	5 to 10 vol.% disseminated (±stringer) pyrite ±chalcoppyrite with dolomite/ankerite-quartz ±tourmaline veins and breccia	Carbonate-sericite-quartz	Syn to late	Vortex 450; CMH
Lower Detour: Zone 75	Hanging-wall splay of the LDDZ (South Break): high-strain zone juxtaposing Deloro Fe-tholeiitic basalt against calc-alkaline and high-Mg tholeiitic intermediate volcanic units	Silicified high-strain zone with 5 to 20 vol.% sulphides as mainly pyrite±pyrrhotite-chalcoppyrite-sphalerite	Quartz-sericite-biotite	Syn	Vortex zone 475
Lower Detour: Zone 58N	Footwall of SouthBreak: in ca. 2694 Ma alkaline plagioclase-phryic quartz monzonite to tonalite	Discrete laminated quartz-tourmaline-carbonate±visible gold veins, stockwork, and pseudo-breccia; 0.5 to 5 vol.% sulphides	Albite-sericite-quartz-carbonate±hematite	Syn	Goldex
Lower Detour "trend" in Quebec	MDZ and LDDZ: high-strain zones at contacts between calc-alkaline andesite and tholeiitic basalt or at margins of sub-alkaline to alkaline, intermediate to felsic porphyritic intrusions	Quartz-carbonate±tourmaline veins with pyrite ±galena±sphalerite	Chlorite-epidote-carbonate in volcanic; albite (hematite)-sericite-chlorite in porphyry	Syn to late	Lower Detour zones

Abbreviations: CMH = chert marker horizon, LDDZ = Lower Detour deformation zone, MDZ = Massicotite deformation zone, SLDZ = Sunday Lake deformation zone.

the northeast (e.g. Faure, 2015) and may represent subsidiary structures of this fault. All structures related to this fault system extend southeastward where they are interpreted to merge into the SLDZ. At first glance, such overall lithological and structural settings are comparable to those of the Fenelon deposit (Wallbridge Mining Company, 2019), as well as the recently discovered auriferous high-strain zones at Area 51 (Wallbridge Mining Company, 2019), Area 52 (Balmoral Resources, 2019), and at the TMA area (Detour Gold Corporation, 2018), west of the Detour Lake mine (Fig. 1).

IMPLICATIONS FOR EXPLORATION

The geological setting and characteristics of gold mineralization along the SLDZ and LDDZ outline and refine the main critical metallotects for orogenic gold exploration in the northwestern Abitibi greenstone belt, which include (1) major long-lived deformation zones and second-order structures; (2) tholeiitic and komatiitic volcanic assemblages, locally separated by calc-alkaline volcanoclastic rocks; (3) Porcupine/Cadillac-like basins with turbidite deposits known locally as the Caopatina assemblage and deformed and altered Timiskaming-like polymictic conglomerate potentially correlative to the Haüy Formation; (4) intermediate to felsic, typically subalkaline to alkaline reddish-coloured dykes and small intrusions; (5) quartz-carbonate±tourmaline veins, stockwork and breccia zones, with varying amounts of sulphides and silicification; and (6) carbonate-sericite/biotite-albite-altered wall rocks. These key elements are analogous to parts of the prolific southern Abitibi gold belt, such as the Timmins-Porcupine and Val-d'Or gold districts. The revised geological and geochronological model for the SLDZ and LDDZ provides a framework to improve exploration strategies in a poorly exposed, but fertile region that includes the giant Detour Lake gold mine.

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REFERENCES

- Ayer, J.A., Chartrand, J.E., Duguet, M., Rainsford, D.R.B., and Trowell, N.F., 2009. Geological compilation of the Burntush-Detour lakes area, Abitibi greenstone belt; Ontario Geological Survey, preliminary maps P3609, scale 1:100 000.
- Balmoral Resources, 2018. The Detour East Property; Balmoral Resources <<http://www.balmoralresources.com/projects/detour-east/mineralization>> [accessed November 14, 2019]
- Balmoral Resources, 2019. Balmoral intersects 14.03 g/t gold over 3.29 metres in shallow, high-grade gold discovery, area 52, Detour gold trend project, Quebec <<http://www.balmoralresources.com/assets/docs/nr/NR19-17-16-09-2019-BAR-Discoveries-New-High-Grade-on-SLD.pdf>> [accessed November 14, 2019]
- Barrie, C.T. and Krogh, T.E., 1996. U-Pb zircon geochronology of the Selbaie Cu-Zn-Ag-Au Mine, Abitibi subprovince, Canada; *Economic Geology*, v. 91, p. 563–575.
- Bleeker, W., 2015. Synorogenic gold mineralization in granite-greenstone terranes: The deep connection between extension, major faults, synorogenic clastic basins, magmatism, thrust inversion, and long-term preservation; *in* Targeted Geoscience Initiative 4: Contributions to the understanding of Precambrian lode gold deposits and implications for exploration, (ed.) B. Dubé and P. Mercier-Langevin; Geological Survey of Canada, Open File 7852, p. 25–47.
- Cameron, E.M., 1993. Precambrian gold: Perspectives from the top and bottom of shear zones; *The Canadian Mineralogist*, v. 31, p. 917–944.
- Castonguay, S., Dubé, B., Mercier-Langevin, P., and Wodicka, N., 2019. Geological setting and mineralization styles of the Sunday Lake and Lower Detour 'gold trends', northwestern Abitibi greenstone belt, Ontario and Quebec; *in* Targeted Geoscience Initiative: 2018 report of activities, (ed.) N. Rogers; Geological Survey of Canada, Open File 8549, p. 9–22.
- David, J., Davis, D.W., Dion, C., Gautier, J., Legault, M., and Roy, P., 2007. Datations U-Pb effectuées dans la Sous-province de l'Abitibi en 2005–2006; Ministère des Ressources naturelles et de la Faune du Québec, RP 2007-01, 17 p.
- Detour Gold Corporation, 2018. Detour Lake operation Ontario, Canada: NI 43-101 technical report; Detour Gold Corporation, 354 p. <<https://www.detourgold.com/investors/news/press-release-details/2018/Detour-Gold-Files-Technical-Report-for-Detour-Lake/>> [accessed November 14, 2019]
- Detour Gold Corporation, 2019. Detour Gold Reports Fourth Quarter and Year-End 2018 Financial Results <<https://www.detourgold.com/investors/news/press-release-details/2019/Detour-Gold-Reports-Fourth-Quarter-and-Year-End-2018-Financial-Results/>> [accessed November 14, 2019]
- Detour Gold Corporation, 2020. Detour Gold Reports Q4 and FY 2019 Production Results <<https://www.detourgold.com/investors/news/press-release-details/2020/Detour-Gold-Reports-Q4-and-FY-2019-Production-Results/>> [accessed January 30, 2020]
- 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, (ed.) W.D. Goodfellow; Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 49–73.
- Dubé, B., Mercier-Langevin, P., Ayer, J., Atkinson, B., and Monecke, T., 2017. Orogenic greenstone-hosted quartz-carbonate gold deposits of the Timmins-Porcupine camp; *in* Archean

- Base and Precious Metal Deposits, southern Abitibi Greenstone Belt, Canada, (ed.) T. Monecke, P. Mercier-Langevin, and B. Dubé; Society of Economic Geologists, Reviews in Economic Geology, v. 19, p. 51–79.
- Dubosq, R., Lawley, C.J.M., Rogowitz, A., Schneider, D., and Jackson, S.E., 2018. Pyrite deformation and connections to gold mobility: Insight from micro-structural analysis and trace element mapping; *Lithos*, v. 310–311, p. 86–104.
- Dubosq, R., Schneider, D., Camacho, A., and Lawley, C.J.M., 2019. Geochemical and geochronological discrimination of biotite types at the Detour Lake gold deposit, Canada; *Minerals*, v. 9, 22 p.
- Faure, S., 2012. Réévaluation paléo-environnementale du complexe volcanique de Selbaie et de son potentiel métallogénique; CONSOREM Project Report 2011-08, 26 p. <http://www.consorem.ca/production_scientifique/2011_08/Rapport%202011-08%20Selbaie.pdf> [accessed November 15, 2019]
- Faure, S., 2015. Prolongement de la faille Sunday Lake (mine Detour Gold, Ont.) au Québec et son potentiel pour les minéralisations aurifères et en métaux de base; CONSOREM Project Report 2013-02, 41 p. <http://www.consorem.ca/production_scientifique/2013_02/Rapport%202013-02%20DETOUR_VF_20160401.pdf> [accessed November 15, 2019]
- Fayard, Q., Mercier-Langevin, P., Wodicka, N., Daigneault, R., and Perreault, S., 2020. The B26 Cu-Zn-Ag-Au project, Brouillon volcanic complex, Abitibi greenstone belt, part 1: Geological setting and geochronology; in Targeted Geoscience Initiative 5: Contributions to the Understanding of Gold Deposit, (ed.) P. Mercier-Langevin, C.J.M. Lawley, and S. Castonguay; Geological Survey of Canada, Open File 8712, p. 98–107. doi:10.4095.323668
- Jensen, L.S. and Pyke, D.R., 1982. Komatiites in the Ontario portion of the Abitibi belt; in Komatiites, (ed.) N.T. Arndt and E.G. Nisbet; George Allen and Unwin, London, p.147–157.
- Lacroix, S., 1994. Géologie de la partie ouest du sillon Harricana-Turgeon, Abitibi; Ministère des Ressources naturelles du Québec, MB 94-54, 26 p.
- Leclerc, F., Harris, L.B., Bédard, J.H., van Breemen, O., and Goulet, N., 2012. Structural and stratigraphic controls on magmatic, volcanogenic, and shear zone-hosted mineralization in the Chapais-Chibougamau mining camp, northeastern Abitibi, Canada; *Economic Geology*, v. 107, p. 963–989.
- Malcolm, K.J., Kontak, D.J., Tinkham, D.K., Ayer, J.A., and MacGillivray, G., 2015. The Lower Detour Lake Au discovery, Ontario, Canada: A high-grade oxidized intrusion-related Au deposit; American Geophysical Union-Geological Association of Canada-Mineralogical Association of Canada-Canadian Geophysical Union Joint Assembly, Abstracts and Proceedings, p. 302–303.
- Marmont, S., 1986. The geological setting of the Detour Lake gold mine, Ontario, Canada; in Gold '86: An International Symposium on the Geology of Gold Deposits, (ed.) A.J. Macdonald; Toronto, p. 3–22.
- Marmont, S. and Corfu, F., 1988. Timing of gold introduction in the late Archean framework of the Canadian Shield: Evidence from U-Pb zircon geochronology of the Abitibi Subprovince; in The Geology of Gold Deposits: The perspective in 1988, (ed.) R.R. Keays, W.R.H., Ramsay, and D.I. Groves; Society of Economic Geologists, Monograph 6, p. 101–111.
- Midland Exploration, 2018. Midland et SOQUEM découvrent un important système aurifère (zone Vortex) de type "syenite-associated" à l'est de Detour Lake; Midland Exploration <<https://www.midlandexploration.com/fr/2018/01/17/midland-et-soquem-decouvrent-un-important-systeme-aurifere-zone-vortex-de-type-syenite-associated-a-lest-de-detour-lake/>> [accessed November 14, 2019]
- Oliver, J., Ayer, J., Dubé, B., Aubertin, R., Burson, M., Panneton, G., Friedman, R., and Hamilton, M., 2012. Structure, stratigraphy, U-Pb geochronology, and alteration characteristics of gold mineralization at the Detour Lake gold deposit, Ontario, Canada; *Exploration and Mining Geology*, v. 20, p. 1–30.
- Probe Metals, 2016. Probe Metals and SOQUEM drill 17.5 g/t Au over 1 metre along the Lower Detour gold trend and commence drilling on phase II program; Probe Metals <https://www.probemetals.com/site/assets/files/1069/2016-08-24_nr.pdf> [accessed November 14, 2019]
- Probe Metals, 2018. Detour Quebec project overview Probe Metals <<https://www.probemetals.com/projects/detour-quebec/overview/>> [accessed November 14, 2019]
- Robert, F., Poulsen, K.H., Cassidy, K.F., and Hodgson, C.J., 2005. Gold metallogeny of the Superior and Yilgarn Cratons; in Economic Geology 100th Anniversary Volume, (ed.) J.W. Hedenquist, J.F.H. Thompson, R.J. Goldfarb, and J.P. Richards; Society of Economic Geologists, p. 1001–1033.
- Thurston, P.C., Ayer, J.A., Goutier, J., and Hamilton, M.A., 2008. Depositional gaps in Abitibi greenstone belt stratigraphy: A key to exploration for syngenetic mineralization; *Economic Geology*, v. 103, p. 1097–1134.
- Voordouw, R. and Jutras, M., 2018. Technical (N.I. 43-101) Report on the Martinier Property, March 27, 2018; Balmoral Resources, 113 p. <<http://www.balmoralresources.com/assets/docs/Martinier%202018%20NI%2043-101%20report%20redsize-20180329174245.pdf>> [accessed November 14, 2019]
- Wallbridge Mining Company, 2019. Fenelon Project <<https://www.wallbridgemin.com/s/fenelon.asp>> [accessed November 14, 2019]
- Winchester, J.A. and Floyd, P.A., 1997. Geochemical discrimination of different magma series and their differentiation products using immobile elements; *Chemical Geology*, v. 20, p. 325–343.