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Structure, Stratigraphy, U-Pb Geochronology and Alteration Characteristics of Gold Mineralization at the Detour Lake Gold Deposit, Ontario, Canada

J. Oliver[1,†], J. Ayer[2], B. Dubé[3], R. Aubertin[4], M. Burson[4], G. Panneton[4], R. Friedman[5], and M. Hamilton[6]

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Abstract — The Detour Lake gold deposit is located within the northwestern limit of the Archean Abitibi Subprovince of the Superior Province. Mineralized zones are hosted by a sequence of pillowed and massive flows, hyaloclastite units, and altered ultramafic rocks, and are commonly oriented parallel to a series of high-strain zones that are co-planar to the regional-scale Sunday Lake Deformation Zone. Early in its kinematic history, the Sunday Lake Deformation Zone placed older (2.72 Ga) volcanic rocks of the Detour Lake Formation over younger (2.70 Ga) sedimentary rocks of the Caopatina assemblage. Gold mineralization is also parallel to the position of a laterally persistent siliceous rock unit, the 2.725 Ga 'Chert Marker Horizon.' The Chert Marker Horizon coincides with the boundary between the mafic-dominated upper Detour Lake Formation and the ultramafic-dominated lower Detour Lake Formation. Stratigraphic and geochronological data suggest that the Chert Marker Horizon is a deformed felsic volcaniclastic unit.

At a cut-off of 0.6 g/t Au, the Detour Lake deposit contains 17.26 million ounces of Au within 445.9 million tonnes of rock grading 1.20 g/t Au. Gold occurs in shear-hosted and extensional vein arrays within rocks of the upper and lower Detour Lake Formation and within the Chert Marker Horizon. The Detour Lake deposit has many of the characteristics of a greenstone-hosted, quartz-carbonate vein deposit; its very large size may be attributed to large-scale rheological controls resulting in the formation of dilatant sites in permissive rock units. **© 2012 Canadian Institute of Mining, Metallurgy and Petroleum. All rights reserved.**

Key Words: Detour Lake, Detour Lake Formation, Gold mineralization, Northern Abitibi Greenstone Belt Structural controls, U-Pb geochronology

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Sommaire — Le gîte d'or de Detour Lake est situé à la limite nord-ouest de la Sous-province archéenne de l'Abitibi dans la Province du Supérieur. Les zones minéralisées sont contenues dans une séquence de laves massives et coussinées, des unités d'hyaloclastites ainsi que des roches ultramafiques altérées et sont le plus souvent orientées parallèlement à une série de zones fortement déformées coplanaires avec la zone de déformation régionale de Sunday Lake. Tôt dans son évolution cinématique, la zone de déformation de Sunday Lake a placé les roches volcaniques plus anciennes (2.70 Ga) de la Formation de Detour Lake par-dessus les roches sédimentaires plus jeunes (2,70 Ga) de l'assemblage de Caopatina. La minéralisation aurifère est également parallèle à une unité de roche siliceuse montrant une bonne continuité latérale, «l'Horizon repère de chert » âgé de 2,725 Ga. L'Horizon repère de chert est situé à la limite entre la partie supérieure de la Formation de Detour Lake, laquelle consiste principalement en roches mafiques, et la partie inférieure de la Formation de Detour Lake principalement constituée de roches ultramafiques. Les données stratigraphiques et géochronologiques suggèrent que l'Horizon repère de chert est en fait une unité de roches volcaniclastiques felsiques déformées.

À une teneur de coupure de 0,6 g / t Au, le gîte de Detour Lake contient une ressource de 17.26 millions d'onces d'Au distribuée dans 445,9 millions de tonnes de roche à une teneur moyenne de 1,20 g / t Au. L'or se trouve dans des réseaux de veines d'extension et de cisaillement mises en place dans les roches des unités supérieure et inférieure de la Formation de Detour Lake ainsi que dans l'Horizon repère de chert. Le dépôt de Detour Lake présente beaucoup des caractéristiques des gîtes d'or filoniens à veines de quartz-carbonate développés dans les ceintures de roches vertes; sa très grande taille peut être attribuée à des contraintes rhéologiques à grande échelle menant à la formation de zones dilatantes dans des unités rocheuses propices. **© 2012 Canadian Institute of Mining, Metallurgy and Petroleum. All rights reserved.**

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[1] HDI Mining Inc., 15th Floor, 1040 W. Georgia Street, Vancouver, BC, Canada, V6E 4H8
[2] Ontario Geological Survey, 933 Ramsey Lake Road, Sudbury, ON, Canada, P3E 6B5
[3] Geological Survey of Canada, 490 rue de la Courrone, Québec, QC, Canada, G1K 9A9
[4] Detour Gold Corporation, 200 Bay Street, Suite 2040, Box 23, Toronto, ON, Canada, M5J 2J1
[5] Pacific Centre for Isotopic and Geochemical Research, Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, 6339 Stores Road, Vancouver, BC, Canada, V6T 1Z4
[6] Jack Satterly Geochronology Laboratory, Dept. of Geology, University of Toronto, 22 Russell Street, Toronto, ON, Canada, M5S 3B1
† Corresponding author: e-mail – olivergeoscience@gmail.com

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Introduction

The Detour Lake property is located in northeastern Ontario, Canada, 195 km northeast of Timmins (Fig. 1). The deposit is situated close to the northeastern limit of the Archean Abitibi Subprovince of the Superior Province. Bedrock in the region is poorly exposed due to extensive till and clay cover, and consequently the area has undergone relatively limited mineral exploration.

At the Detour Lake deposit, auriferous zones tend to be localized at lithological boundaries, including lava flow and dike contacts. Many of the vein systems at Detour Lake have a spatial relationship to east–west-trending, subvertically dipping, brittle–ductile deformation zones. These are located within a few tens to hundreds of meters of a regional-scale structural zone, the Sunday Lake Deformation Zone. All supracrustal units are mineralized at Detour Lake, including the youngest supracrustal sedimentary rocks, the ca. 2700 Ma Caopatina assemblage.

The Detour Lake deposit was actively explored and developed between 1979 and 1999. Between 1983 and 1999, 1,764,986 ounces of gold were produced from 14.3 million tonnes of rock at an average grade of 3.82 g/t Au (Kallio, 2006) from both underground and open-pit operations. Production ceased in 1999, and until 2007 the property was largely dormant. Since 2007, an aggressive exploration and development drill program has increased the currently known Measured and Indicated (NI 43-101 compliant) resources at the deposit to 335 tonnes (17.26 million ounces) Au in 445.9 million tonnes of rock grading 1.20 g/t, at a cut-off grade of 0.6 g/t and using a value of $775.00 per ounce Au (Table 1; Houde et al., 2009). With more than 17 million ounces of Measured and Indicated gold resources, the deposit clearly represents a world-class (≥250 tonnes Au) deposit (Laznicka, 1999; Poulsen et al., 2000).

Geological studies of the Detour Lake gold belt and Detour Lake deposit were conducted by Johns (1982), Marmont (1986, 1987), and Marmont and Corfu (1988). Marmont (1986) documented the principal alteration styles, stratigraphic relationships, regional metamorphic history, and generalized structural relationships of the deposit. In addition, Marmont and Corfu (1988) published the first U-Pb zircon age (2722 +3/-2 Ma) on dike rocks proximal to mineralized zones. Based on this age and on the field relations of dikes to mineralized zones, Marmont and Corfu (1988) concluded that gold mineralization in the Detour Camp occurred early in the evolution of this belt and significantly pre-dated the timing of gold mineralization in the southern Abitibi Subprovince.

In this paper, we document the geological setting and principal characteristics of gold mineralization at Detour Lake, the nature of related hydrothermal alteration, and the structural style of gold-mineralized zones. Many of the observations and conclusions are based on the senior author's stratigraphic and structural logging of >40,000 m of drill core, and on the mapping and examination of all available outcrops. We present new U-Pb ages that provide the stratigraphic framework for the Detour Lake gold deposit and constrain the timing of gold mineralization. As well, we outline similarities and differences between the Detour Lake gold deposit and other Archean deposits in the Abitibi Subprovince and elsewhere.

Table 1. Global mineral resource estimate. [1,2,3]

Category	Tonnes (millions)	Grade (g/t Au)	Contained Au (000s oz)
Measured	102.1	1.48	4,846
Indicated	343.8	1.12	12,417
Measured + Indicated	445.9	1.20	17,263
Inferred	151.4	1.07	5,189

Notes:
[1] Mineral reserves are included within the mineral resources reported.
[2] Capping grade estimated by domains and ranges from 20 g/t to 50 g/t.
[3] Based on a gold price of $775/oz and a cut-off grade of 0.60 g/t Au.

Regional Geology

The Abitibi Subprovince has long been central to the understanding of greenstone belt-hosted mineral deposits (e.g., Goodwin, 1979). The greenstone belts of the Abitibi have had a total mineral production valued at approximately $120 billion as of 2005. The production was derived from volcanogenic massive sulfide (VMS) deposits of the Rouyn-Noranda region (Gibson and Watkinson, 1990) and at Kidd Creek (Bleeker et al., 1999); gold-rich VMS deposits such as Laronde Penna (Dubé et al., 2007; Mercier-Langevin et al., 2007a, 2007b); and epigenetic gold deposits such as the Hollinger-McIntyre and Dome mines (Bateman et al., 2008), the Kirkland Lake 'main break' deposits (Ispolatov et al., 2008), and the Sigma-Lamaque complex (Robert and Brown, 1986a, 1986b). This mineral wealth led to considerable mapping and research, making the Abitibi Subprovince an important area for models of development and evolution of greenstone belts (Goodwin, 1979; Dimroth et al., 1982, 1983; Jensen and Langford, 1985; Jackson et al., 1994; Ayer et al., 2002, 2005).

The Abitibi is composed of east–west-trending synclines of largely volcanic rocks (felsic to ultramafic in composition) and intervening domes cored by syn-volcanic plutonic rocks (tonalite and gabbro-diorite) with alternating, east–west-trending bands of late tectonic turbiditic and conglomeratic sedimentary rocks (Ayer et al., 2002; Daigneault et al., 2004; Goutier and Melançon, 2007). Most of the volcanic and sedimentary strata dip vertically and are commonly bound by abrupt, east–west-trending faults with varied dips. Some of these faults, such as the Porcupine–Destor Fault, display evidence of overprinting deformation events, including early thrusting with later strike-slip and extension events (Goutier, 1997; Benn and Peschler, 2005; Bateman et al., 2008).

Field mapping and more than 500 U-Pb zircon ages provide widespread evidence of isotopic inheritance, indicating that the Abitibi Subprovince developed autochthonously (Ayer et al., 2002, 2005; Thurston et al., 2008). The stratigraphy of the Abitibi (Fig. 1) is subdivided into earlier volcanic-dominated episodes that include the Pacaud assemblage (2770–2736 Ma), the Deloro assemblage (2730–

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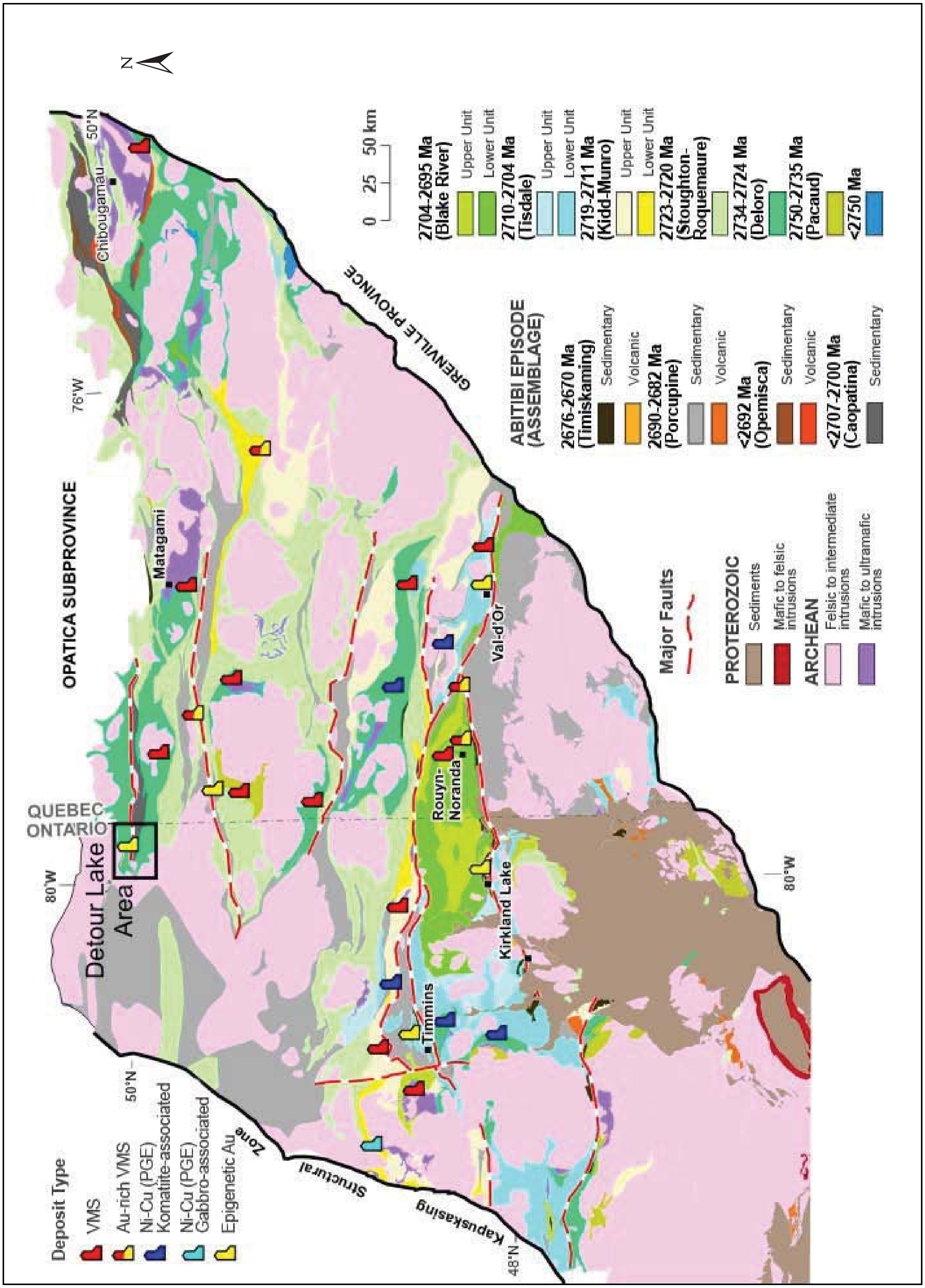

Figure 1. Geological map of the Abitibi Subprovince (greenstone belt) and location of the Detour Lake deposit (modified after Thurston et al., 2008). Abbreviations: PGE = platinum group elements; VMS = volcanogenic massive sulfide deposit.

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2724 Ma), the Stoughton–Roquemaure assemblage (2723–2720 Ma), the Kidd–Munro assemblage (2719–2711 Ma), the Tisdale assemblage (2710–2704 Ma), and the Blake River assemblage (2704–2695 Ma). These sequences are unconformably overlain by turbidites and calc-alkaline volcanic rocks of the Caopatina assemblage (ca. 2700 Ma) in the north and the Porcupine assemblage (2690–2685 Ma) in the south. These units in turn are unconformably overlain by coarse clastic and alkaline volcanic rocks of the Opemisca assemblage (ca. 2692 Ma) in the north and the Timiskaming assemblage (2676–2670 Ma) in the south (Ayer et al., 2002, 2005, 2010; Goutier and Melançon, 2007; this study).

A considerable amount of structural analysis and geochronological data on the Timmins–Kirkland Lake region has helped to elucidate the timing relationships between emplacement of felsic intrusions and deformation events (Ayer et al., 2005). This work indicates that early syn-tectonic intrusions (2695–2685 Ma) may be related to compressive stresses that induced early folding and faulting related to the onset of collision between the Abitibi and older subprovinces to the north. These intrusions occur in both the plutonic belts and the intervening greenstone belts (supracrustal rocks). Several episodes of regional deformation have been identified on the basis of the overprinting relationships of folds and faults, with D_1 constrained by the cessation of volcanism at 2696 Ma in the Blake River assemblage, and the onset of the deposition at 2690 Ma in the Porcupine assemblage. D_1 folds are commonly refolded and transposed by later deformation; it thus is difficult to determine the original orientation of D_1 structures.

In the Timmins area, the base of the Porcupine assemblage is interpreted to be a low-angle unconformity that cuts progressively downward into Tisdale strata eastward along the north limb of the Porcupine Syncline (Bateman et al., 2008). This is likely the result of uplift and erosion and suggests that the unconformity was caused by east–west-oriented compression and/or extension related to D_1 folding (F_1) and the emplacement of syn-tectonic intrusions (Ames et al., 1997). A series of stacked, south-over-north, D_2 thrust faults with hanging-wall folds is located north of the Porcupine–Destor Deformation Zone (Bateman et al., 2008). The D_2 phase of deformation is post-Porcupine assemblage in timing (i.e., <2685 Ma) because the assemblage is folded and faulted by D_2 deformation; however, it is pre-Timiskaming (i.e., >2676 Ma) because the Timiskaming unconformity truncates the D_2 folds and thrust faults (Bateman et al., 2008). A post-Porcupine age for early thrusting coincides with age data from the Duparquet Basin associated with the Porcupine–Destor Deformation Zone in Québec (Mueller et al., 1996).

Syn-tectonic intrusions consisting of syenite, albitite, feldspar-quartz porphyry, and lamprophyre are broadly coeval with the Timiskaming assemblage (2676–2670 Ma) and are spatially associated with the Porcupine–Destor Deformation Zone and Larder Lake–Cadillac Deformation Zone. The opening of the Timiskaming basin in a dilatational jog was more or less synchronous with this magmatic event and was followed by foliation and folding in the Timmins area, only the late stages of which affected the Timiskaming sedimentary rocks (Bateman et al., 2008).

Geology of the Detour Lake Area

Figure 2 illustrates the distribution of rock units on a shaded aeromagnetic map of the Detour Lake area. It shows that the greenstone–granite architecture is partially aligned and disrupted along a linear east–west-trending belt defined by the juxtaposition of rock units with low and high magnetic signatures. This belt defines the position of the Sunday Lake Deformation Zone. Similar truncations of magnetic features that define deformation zones have been documented in the southern Abitibi Subprovince (Robert and Poulsen, 1997; Whitaker, 2004).

The rock units (Fig. 3) include volcanic rocks of the upper and lower Deloro assemblage, sedimentary rocks of the Caopatina assemblage, and intrusive rocks that are predominantly tonalites and granodiorites. Volcanic rocks north of the clastic sedimentary unit (Fig. 2) were previously assigned to the 'Upper Detour assemblage,' and the clastic sedimentary rocks, to the 'Lower Detour assemblage,' whereas the southern volcanic package was called the 'Vandette assemblage' (Jackson and Fyon, 1991). Both volcanic assemblages (Detour and Vandette) are characterized by abundant iron-rich tholeiitic basalts with minor intercalated chemical sedimentary rocks and felsic tuffs (Pressaco, 1999).

On the basis of new geochronological data, discussed below, we propose that rocks formerly assigned to the Detour and Vandette assemblages be named the Detour Lake Formation, which is part of the 2730–2724 Ma Deloro volcanic assemblage (Ayer et al., 2002, 2005). Farther to the south, the volcanic sequences have generally lower magnetic signatures and a younger age of 2721 Ma (Fig. 2), indicating they are part of the 2724–2720 Ma Stoughton–Roquemaure assemblage (Ayer et al., 2002, 2005).

The felsic and mafic intrusive rocks in the Detour Lake area (Fig. 2) locally intrude sedimentary units of the Caopatina assemblage. Thus, they are part of the younger monzodiorite-granodiorite-tonalite-diorite suite, rather than older gneissic suites of the Opatica Subprovince or older, syn-volcanic tonalitic suites that core many of the regional anticlines of the Abitibi Subprovince (Sawyer and Benn, 1993; Chown et al., 1992).

Johns (1982) developed the earliest interpretations of the geology and structural relationships of the Detour Lake area and was followed by Marmont (1986, 1987). The Caopatina sedimentary rocks were interpreted to form the core of a regional east–west-trending synform, with older volcanic rocks symmetrically distributed in the northern and southern limbs. Mineralized deformation zones (Sunday Lake and Lower Detour Lake; Fig. 2) were identified along, and approximately parallel to, both the northern and southern sedimentary–volcanic rock contacts.

However, our work shows that the northern and southern contacts differ in style. The southern contact is irregular and is characterized by volcanic rocks with a very high magnetic signature typical of the lower Detour Lake Formation,

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which in turn is characterized by abundant ultramafic and lesser mafic volcanic rocks. This scalloped southern contact is considered to be a low-angle unconformity similar to the one found at the base of the Porcupine assemblage in the Timmins Camp (Bateman et al., 2008). In contrast, the northern contact is curvilinear, except where it is breached by an intrusive complex in the west (Fig. 2). This contact is coincident with the position of the Sunday Lake Deformation Zone. Volcanic units north of this deformation zone are dominated by pillowed and massive flows of the upper Detour Lake Formation.

Geology of the Detour Lake Deposit

The detailed geological map of the Detour Lake gold deposit (Fig. 3) is based on a compilation of all available surface and subsurface data, including observations from more than 1000 surface boreholes over a strike length of 15 km. Supracrustal rocks are divided into two principal units: the younger Caopatina assemblage, which is composed of clastic sedimentary and volcaniclastic rocks; and the older Deloro assemblage or Detour Lake Formation, which comprises an upper part characterized by a thick sequence of tholeiitic basaltic rocks and a lower part dominated by ultramafic flows, dikes, and sills.

Lower Detour Lake Formation (>2725 Ma)

The lower Detour Lake Formation includes the following units.

Ultramafic Flows, Sills, and Dikes: Much of the lower Detour Lake Formation comprises a thick sequence of ultramafic flows, with locally preserved spinifix textures, coarse-grained pyroxenites, and fine-grained ultramafic sills. These bodies generally have conformable contact relations with the overlying rock units.

Mafic Flows, Sills, and Dikes: Thick sequences of mafic flows and gabbroic intrusions are interlayed with the ultramafic rocks. Textural distinctions between flow and intrusive units are commonly difficult to discern because pillow lavas are rare. Mafic intrusions contain 10–15% disseminated magnetite grains, are strongly magnetic, and have well-defined airborne magnetic signatures. This sequence also contains thin (3–5 m thick) layers of clastic sedimentary rocks.

Mafic Flow Contact Unit: This thin, 5–20 m thick flow unit commonly overlies ultramafic rocks. It is fine grained, dense, green-black, and lacks significant matrix feldspar. Underground plans clearly demonstrate that this rock unit is present on both the footwall and hanging-wall sides of the Chert Marker Horizon.

Chert Marker Horizon: After several decades of exploration and development, the term 'Chert Marker Horizon' is ingrained in the literature and mine terminology of the district. Historically, this highly strained unit has been interpreted as either a mylonitized intrusion or a chert horizon (Marmont, 1986; Pressacco, 1999), but here it is interpreted as a volcaniclastic unit (see below). It consists of a thin (0.5–2.0 m thick), pale cream to buff, aphanitic, locally laminated, and commonly strongly sulfidized felsic rock. Rocks of the Chert Marker Horizon have felsic to intermediate calc-alkaline affinity and fractionated REE patterns (Ayer et al., 2009b). Thin sections from least altered and deformed parts of the unit show relict clastic texture defined by fine-grained subangular quartz grains in a recrystallized matrix of chlorite and amphibole. Collectively, the calc-alkaline chemical signature, relict clastic texture, and lack of inheritance in contained zircons (see **Geochronology**) suggest that this unit represents deformed tuffacous or volcaniclastic rocks, which mark the transition from ultramafic- to mafic-dominated volcanism in the Detour Lake Formation.

Felsic Volcaniclastic Rocks: These unusual rocks have been intersected only in drill core and are of uncertain stratigraphic position. They are highly foliated, are pale yellowish cream in color, and locally contain subangular lithic clasts. They are present near the southern contact of the mafic–ultramafic complex, close to its interpreted stratigraphic top. This would be at approximately the same stratigraphic position as the Chert Marker Horizon in the Detour Lake gold deposit, and the units may be correlative. Felsic volcaniclastic rocks have also been cored deep within the mafic–ultramafic complex, well below the contact between the upper and lower parts of the Detour Lake Formation. In at least one instance, this unit has significant gold mineralization.

Upper Detour Lake Formation (<2725 Ma)

Rocks of the upper Detour Lake Formation have been mapped in hundreds of diamond drill holes collared in the vicinity of the gold deposits and include the following units.

Mafic Tuffs: These rocks are characterized by thin, centimeter-scale, highly planar compositional layers with minor cherty layers. Compositional layers are defined by variations in the abundance of plagioclase, quartz, and mafic minerals. Locally, these layers, and the changes in their composition, are well defined by the appearance of amphibole porphyroblasts. Graded beds have not been identified in this unit.

Mafic Flows: Several massive tholeiitic flows are present in the hanging wall of the Detour Lake gold deposit: that is, structurally above the Chert Marker Horizon. They typically contain 12–15% matrix plagioclase with 85% recrystallized mafic minerals (actinolite or hornblende), commonly occurring as 2–4 mm elongate, interlocking, recrystallized laths. Thicker flows are coarser grained toward their base.

Mafic Hyaloclastites: Mafic hyaloclastites are present in the North Walter Lake area and the Calcite Zone (Fig. 3), where they commonly host gold mineralization. The rock

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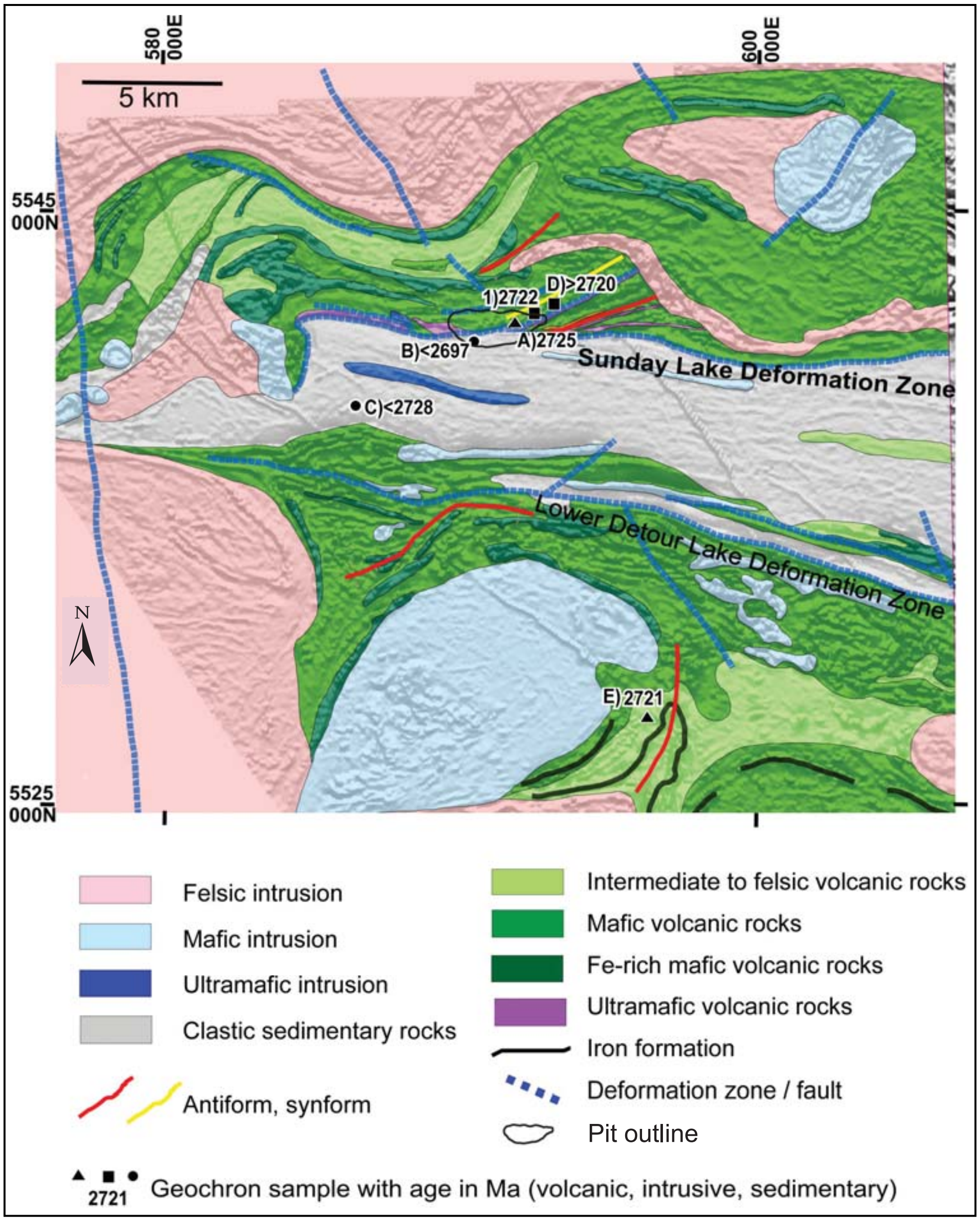

Figure 2. Regional-scale bedrock geology of the Detour Lake gold belt (after Ayer et al., 2009a), overlain on a shaded magnetic map (magnetic data from OGS Geophysical Data Set 1062). The locations of geochronological samples are shown, with ages in millions of years. UTM grid NAD 83.

contains abundant, shard-like, centimeter-scale fragments that commonly contain calcite in a matrix that is less carbonate-rich. Locally, these rocks are weakly stratified.

Pillowed Flows: Pillow lavas are common throughout the area but are difficult to recognize in high-strain zones. Pillow cusps and margins are preferentially altered by secondary biotite, albite, and pyrite-pyrrhotite-chalcopyrite, with increasing intensity proximal to mineralized zones.

Caopatina Assemblage (ca. 2700 Ma)

The Caopatina assemblage consists of interbedded argillaceous siltstones, quartz wackes, banded amphibolites, and lesser mafic volcaniclastic rocks. Compositionally well-laminated volcaniclastic rocks commonly feature centimeter-scale felsic bands containing >40% quartz, separated by centimeter-scale biotite-actinolite-hornblende-rich bands containing <10% quartz. Biotite within these bands is coarse grained and defines the main foliation (S_2); scattered garnet grains are common. Pyrite and pyrrhotite average 1–2% with a few narrow pyrite and chalcopyrite bands. Conglomerates are rare, although narrow (0.5–1.0 m), coarse-grained epiclastic interbeds are present.

Basin-wide variations have been noted. The western part of the basin (syncline) contains a higher percentage of reworked mafic volcaniclastic rocks than does the eastern part, which is dominated by well-bedded quartz wackes, lithic wackes, and argillaceous siltstones.

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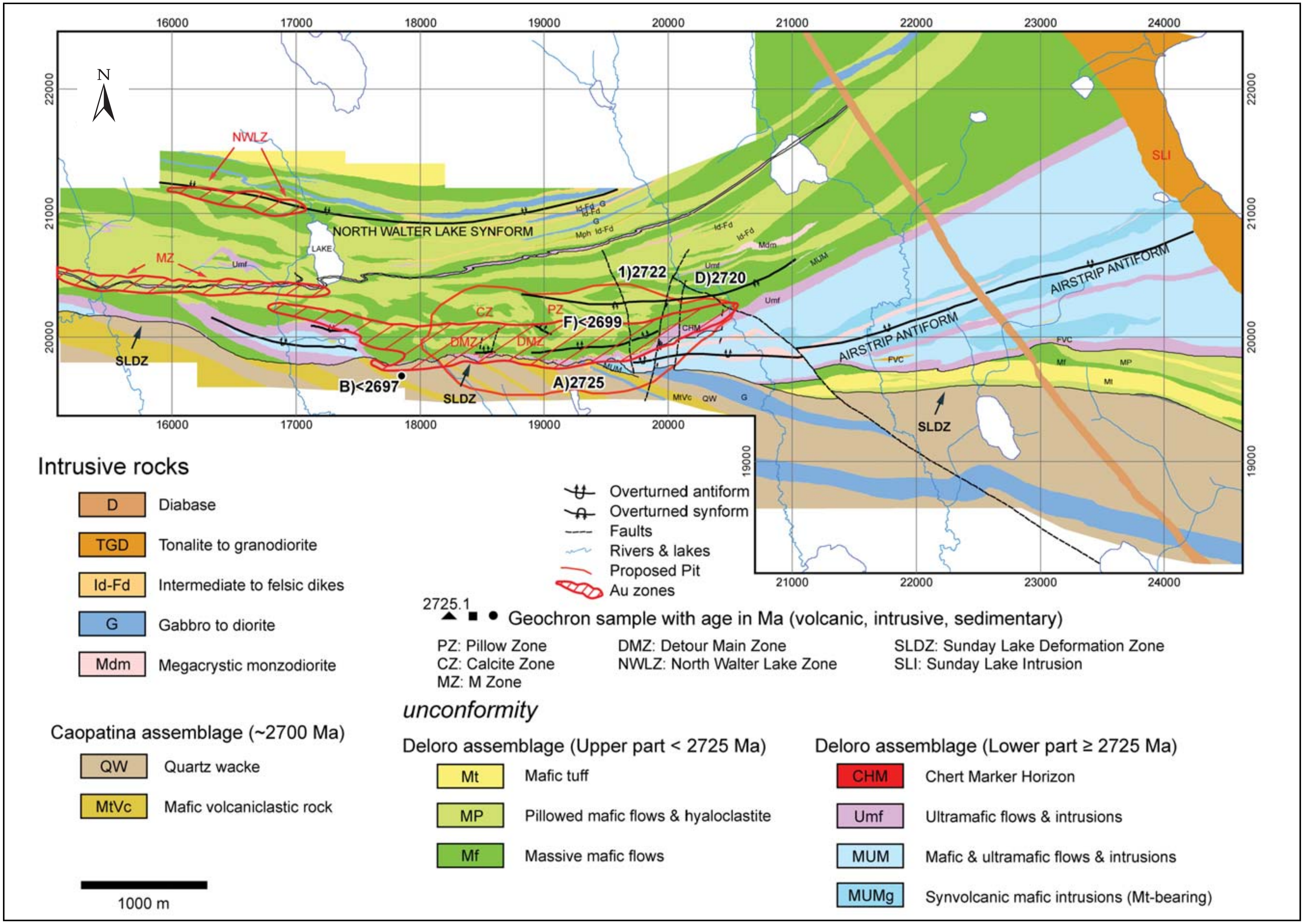

Figure 3. Geological setting of the Detour Lake gold deposit, showing distribution of the gold mineralization, the Sunday Lake Deformation Zone, and the regional-scale antiforms. Four main gold trends–the Detour Zone, QK Zone, M Zone, and North Walter Lake Zone–form a nearly continuous belt of gold mineralization with a strike length that exceeds 9 km. All grid coordinates are metric and are referenced to the local mine grid.

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Intrusive Rocks

Gabbro to Diorite: Gabbroic to dioritic intrusions range from 1–40 m in thickness and commonly form sill-like bodies that closely track major volcanic contacts. The rocks contain an abundance of porphyritic plagioclase clots that form 2–5 cm aggregates (glomerocrysts) in a dark green, fine-grained matrix. These intrusions are typically non-magnetic and were historically interpreted as porphyritic flows. However, they locally cut across volcanic strata and are younger than volcanic rocks of the Detour Lake Formation (see **Geochronology**). Therefore, they are considered to be related to magmatism that produced volcanic rocks of the 2723–2720 Ma Stoughton–Roquemaure assemblage (Ayer et al., 2002, 2005).

Felsic to Intermediate Dikes: Tan to light green, locally plagioclase-phyric dikes occur throughout the area, where they intrude rocks of the Detour Lake Formation and the Caopatina assemblage. Sheeted dike swarms, with individual dikes ranging from 0.5 m to 10 m thick, are developed locally. The dikes have a fine-grained matrix composed of felted, interlocking plagioclase and K-feldspar ± quartz, which accounts for 75–85% of the rock; distinct laths of hornblende ± biotite comprise 10–15% of the rock. In places, small (sub-millimeter) red-brown garnets are present, and in others, millimeter-size quartz grains constitute 3–5% of the dikes. These intrusions locally have a purple-maroon coloration due to the development of strong secondary biotite.

Tonalite to Granodiorite Intrusion: A large tonalitic to granodioritic body, the Sunday Lake intrusion, occurs near the eastern end of the Detour Lake gold belt (Fig. 3). It strikes at ~140° and cuts rocks of both the upper and lower Detour Lake Formation. The body is weakly foliated and has a marginal phase that contains ~10% quartz, 30% plagioclase, and 45–50% (by volume) mafic minerals (biotite, hornblende). The percentages of mafic minerals decrease inward toward the center, such that the composition is more granodioritic 300 m from its outer contact. An epidote-albite-garnet-pyrite-pyrrhotite contact aureole is locally well developed where this intrusion cuts sedimentary rocks of the Caopatina assemblage, and it extends for ~200 m into the host rocks. Irregular copper- and gold-mineralized zones occur within the contact aureole and are distinctly different in form and style from the main gold-mineralized zones at the Detour Lake deposit. These irregular zones comprise disseminated pyrrhotite, pyrite, and lesser chalcopyrite in a calc-silicate gangue.

Mafic Dikes: Khaki green to dark greenish black, fine-grained mafic dikes commonly intrude north-northwest-trending faults and post-date all forms of gold mineralization in the Detour Camp. They cut all supracrustal rock units, including the Caopatina assemblage.

Late Diabasic and Gabbroic Dikes: The youngest intrusive rocks in the Detour Lake area are a series of north-northwest-trending, reddish brown-weathering, highly magnetic gabbroic dikes that are strongly discordant to the regional structural grain. Diabasic and gabbroic dikes can be discriminated from other mafic dikes by their high magnetic susceptibilities and ophitic textures. The dikes have a maximum width of ~100 m and strike lengths that may exceed 5 km. Their general north-northwest orientation, ophitic textures, and high magnetic susceptibilities suggest that these rocks are part of the Matachewan swarm and thus are Proterozoic.

Geochronology of the Detour Lake Area

Six samples were collected from the Detour Lake area for U-Pb zircon isotopic analysis. Age-dating was done to better understand stratigraphic and structural relationships in the vicinity of the Detour Lake gold deposit, as only one U-Pb zircon age of 2722 +3/-2 Ma (locality 1 on Fig. 2, 3) had previously been determined for a felsic dike associated with gold mineralization (Marmont and Corfu, 1988). These samples are shown on Figures 2 and/or 3, and their Concordia plots, on Figure 4. The full data appear in Table 2 (p. 24–25), and geochronological methods are reported in Appendix 1. The following rocks or units were sampled.

Chert Marker Horizon

Approximately 2 m of diamond drill core (sample 08JAA-011) was collected from Detour Gold Corporation's hole D6-08-464 (locality A on Fig. 2, 3) at a depth of 367–371 m (excluding an albitite dike at 369.65–371.05 m). The sample was collected in chloritized and amphibolitized felsic schist of the Chert Marker Horizon, part of the lower Detour Lake Formation. The sample contains some sulfide-rich zones and numerous highly deformed and brecciated quartz veins. Five zircons were chemically abraded and analyzed. They yielded an average U-Pb age of 2725.1 ± 1.4 Ma, with <0.2% discordance, which indicates virtually no inheritance (Fig. 4a, Table 2).

Metawacke

Exactly 1.5 m of diamond drill core (sample 06JAA-057) was collected from Pelangeo- Larder Mines Ltd.'s hole PM-118 (locality B on Fig. 2, 3) at a depth of 324.5–326.0 m in metasedimentary rocks of the Caopatina assemblage. In thin section, these rocks display relict bedding defined by varied amounts of biotite, chlorite, and garnet crystals, which are intergrown with fine-grained subangular to subrounded quartz grains. The sample yielded detrital zircons with individual $^{207}Pb/^{206}Pb$ ages ranging from 2696.9 ± 6.6 Ma to 2821 ± 2.3 Ma, with the youngest age being the maximum depositional age (Fig. 4b, Table 2).

A second sample of metawacke (sample 06JAA-014) was collected for geochronological analysis from archived diamond drill core at the Ontario Geological Survey storage facility, located in Timmins. The sample was taken from 705–740 ft in hole Ti1659 (company drill hole # T-83-3), which is located approximately 5 km southwest of the deposit (locality C on Fig. 2). This sample yielded individual detrital zircon $^{207}Pb/^{206}Pb$ ages that ranged from 2728.9 ± 2.4 Ma to 2891.6 ± 1.1 Ma (Fig. 4c, Table 2).

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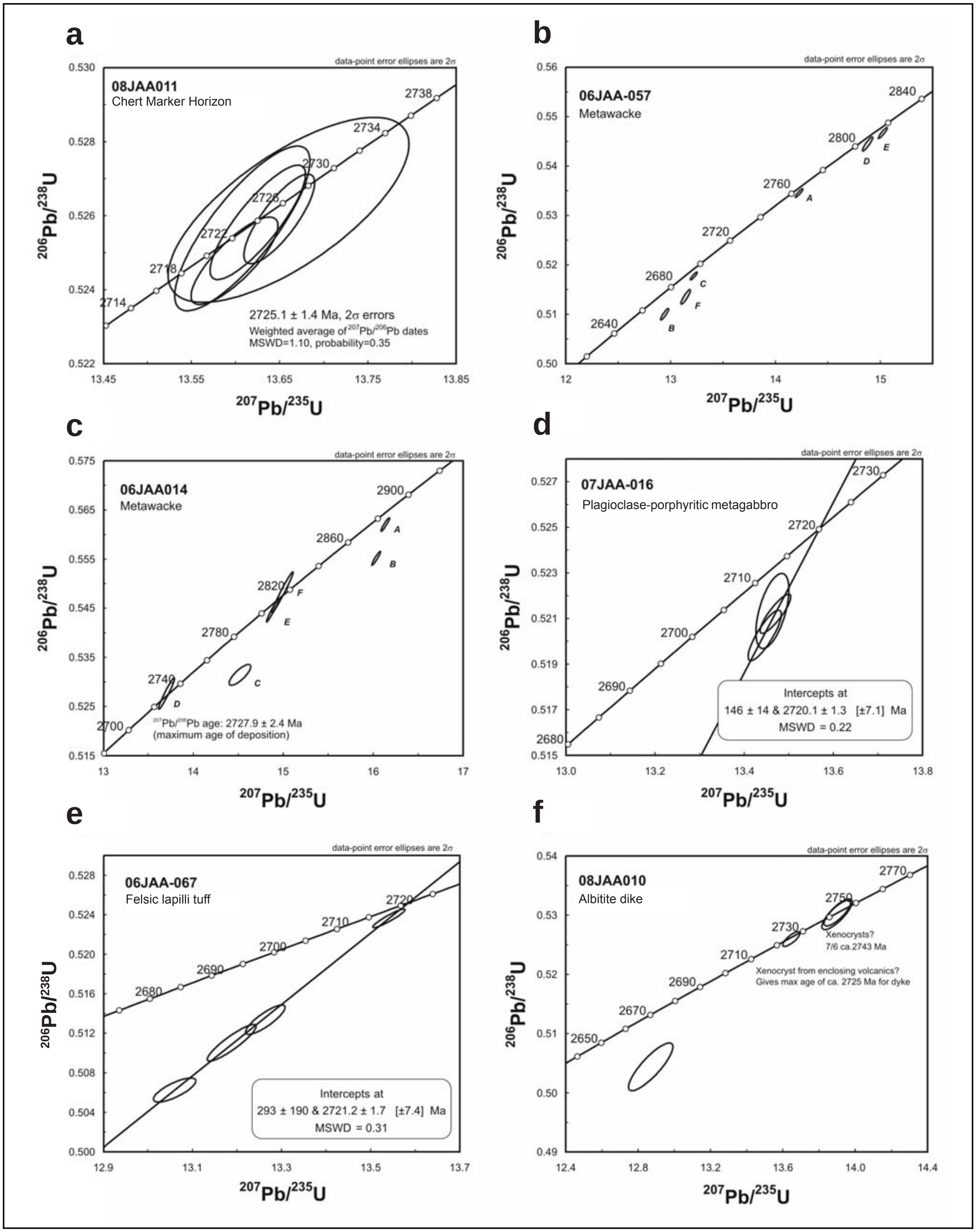

Figure 4. Geochronological sample results from the Detour Lake area. Figures 2 and 3 show the sample locations, and text provides the sample descriptions. Table 2 lists the U-Pb data and exact sample coordinates, and Appendix 1 describes the analytical methods used.

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Collectively, the ages of detrital zircons in these two samples indicate a maximum depositional age of 2697 ± 6.6 Ma, with sedimentary detritus supplied from local volcanic sources and from older terrain, most likely the >2800 Ma Opatica Subprovince to the north. These data thus support the interpretation that the sedimentary unit south of the Detour Lake deposit is part of the Caopatina assemblage (ca. 2700 Ma), a laterally extensive turbidite-dominated sequence that extends across the northern part of the Abitibi Subprovince (Goutier and Melançon, 2007; Ayer et al., 2010).

Metagabbro

Approximately 2 m of diamond drill core (sample 07JAA-016) from Detour Gold Corporation's hole 464-106A (locality D on Fig. 2, 3), at 596–598 m downhole, was collected from plagioclase porphyritic metagabbro for geochronology. The metagabbro intrudes the upper Detour Lake Formation and yielded zircons that gave a U-Pb age of 2720.1 ± 1.3 Ma (Fig. 4d, Table 2). This is younger than the 2725.1 ± 1.4 Ma age of the Chert Marker Horizon in the Detour Lake Formation and is thus considered to be related to younger magmatism of the 2723–2720 Ma Stoughton–Roquemaure assemblage (Ayer et al., 2002, 2005). This age is also similar to the 2722 +3/-2 Ma age of the mineralized felsic dike at the Detour Lake deposit (locality 1 on Fig. 2, 3), as reported by Marmont and Corfu (1988).

Felsic Lapilli Tuff

Approximately 2 m of diamond drill core (sample 06JAA-067) was collected from Better Resources Ltd.'s hole 96-02 (locality E on Fig. 2), at a depth of 119–121 m, in felsic lapilli tuff of the lower Detour Lake Formation. This felsic unit has an age of 2721.2 ± 1.7 Ma (Fig. 4e, Table 2), indicating that volcanic rocks of the Stoughton–Roquemaure assemblage crop out in the southern part of the Detour Lake area, and raising the possibility that synvolcanic intrusions of this age could exist in the northern part of the Detour Lake area.

Albitite Dike

Approximately 1.4 m of diamond drill core (sample 08JAA-010) was collected from Detour Gold Corporation's hole D6-08-464 (locality F on Fig. 3), at a depth of 369.65–371.05 m, in a relatively undeformed albitite dike that cuts the mineralized and deformed Chert Marker Horizon. Contained zircons yielded U-Pb ages ranging from 2698.8 ± 6.9 Ma to 2743.1 ± 4.3 Ma (Fig. 4f, Table 2). Most likely, these zircons were inherited from the surrounding rock units. The similarity of the youngest zircon age to that of the wacke sample from the Caopatina assemblage (see above) suggests that the wackes were a potential source of at least some of the inherited zircons in this dike.

Structural Setting of Detour Lake Gold Deposit

Four phases of deformation, labeled D_1 to D_4, are recognized in the Detour Lake area (Fig. 3). The first phase is represented by the regional unconformity at the southern volcanic–sedimentary contact (Fig. 2) described previously. No penetrative fabric is associated with the D_1 event.

The second phase of deformation produced folds that affect the unconformity. Shallow, west-plunging, upright to southerly overturned antiform–synform couples with east–west-trending axial surfaces formed during D_2. Most of the penetrative fabrics are interpreted as S_2 fabrics associated with the D_2 deformation event and are axial planar to D_2 folds. Two major synform–antiform couples—the North Walter Lake Synform and the Airstrip Antiform—have maximum interlimb distances exceeding 1000 m and can be traced along strike for greater than 10 km. Although plunges of D_2 folds are varied, shallow, west-directed plunges (10° → 270°) are the most common. (All linear fabrics reported in this paper use a plunge–azimuth convention.)

The Sunday Lake Deformation Zone (Fig. 2) is a high-strain zone tens of kilometers in length and several hundred meters in width. Vesicles within pillow lavas provide a measure of strain intensity in this deformation zone, where aspect ratios of vesicle cross-sections range from 1:1 in low-strain zones to greater than 24:1 in high-strain zones (Zhang, 1997).

The age relationships between the volcanic and sedimentary sequences require that the Sunday Lake Deformation Zone was a south-verging, north-dipping thrust fault early in its kinematic history, which is also consistent with southerly overturned D_2 folds. Both are compatible with roughly north–south-directed compression. However, the Sunday Lake Deformation Zone had a protracted deformational history, and both sinistral and dextral reverse movements occurred after thrusting. The variations in kinematics and related auriferous high-strain zones are discussed further below.

The third deformation event is represented by broad, open folds with axial traces that strike at ~145° and plunge shallowly 10°–35° toward 335°; these folds can be clearly seen on Figure 2. The interlimb distances of these folds are approximately 8–12 km, and the folds lack a penetrative, axial-plane cleavage.

The fourth phase of deformation is represented by a series of faults that trend 120°–145° and are locally intruded by Proterozoic diabase dikes. Maximum offsets across these structures are typically on the order of a few tens of meters. These structures are not mineralized, and they postdate the gold mineralization at Detour Lake. In contrast to much of the southern part of the Abitibi Subprovince, the volume of Proterozoic dikes in the Detour Lake gold belt is very minor (Prevec and Morris, 2001).

Regional Metamorphism

At Detour Lake, primary mineralogy in mafic volcanic rocks is poorly preserved. Corroded primary pyroxenes and amphiboles are preserved locally in a groundmass of fine-grained metamorphic minerals, consisting mainly of biotite, actinolite, epidote, albite, and almandine. Calcite and quartz are always present, and chlorite occurs as a minor retrograde mineral. Field and petrographic observations (Fig. 5a, 5b) suggest the prograde metamorphic mineral assemblage is actinolite-biotite-plagioclase-epidote-

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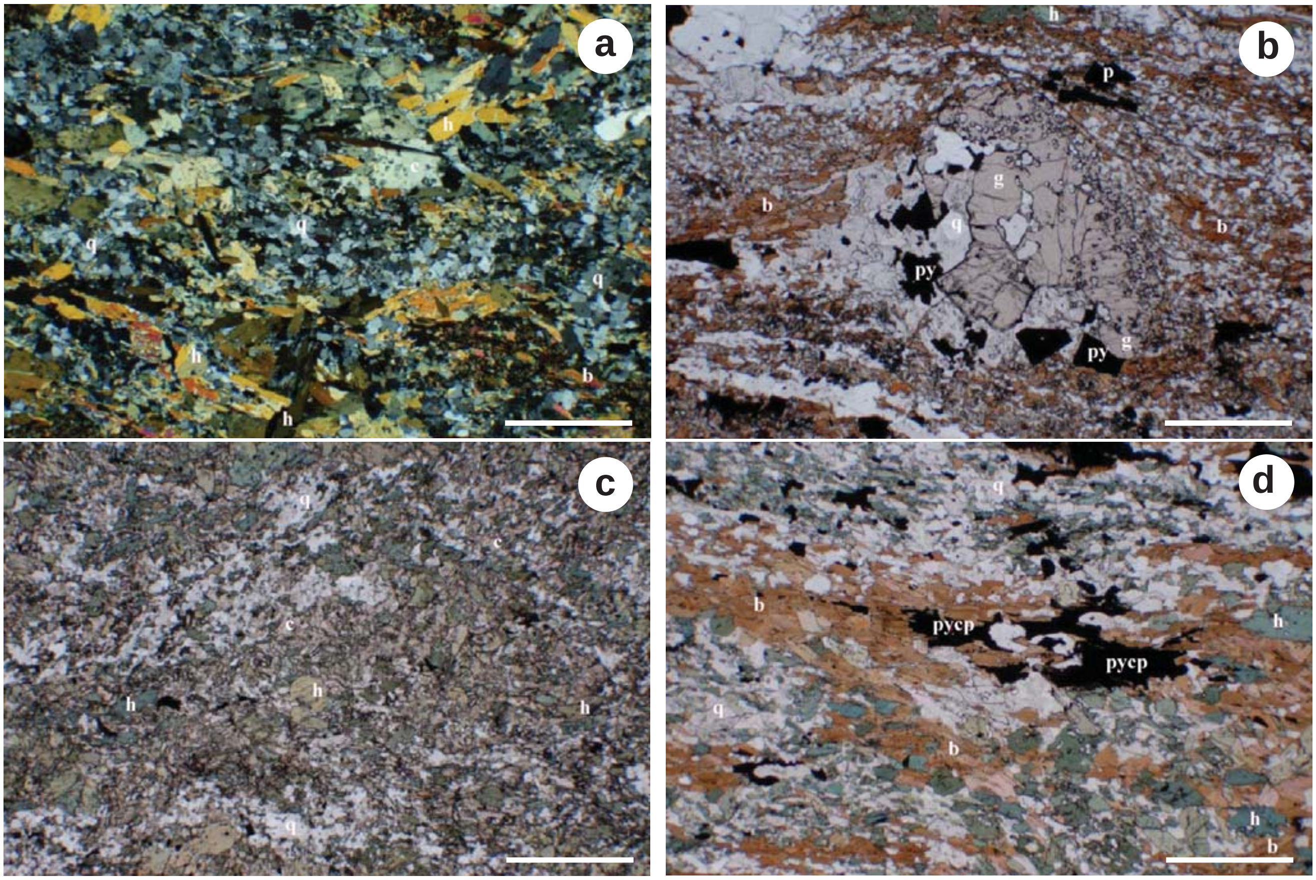

Figure 5. ***a)*** Prograde lower amphibolite facies metamorphic assemblage (sample 464-46 at 79 m). The protolith is a massive, non-hydrothermally altered mafic lava flow. Primary mafic minerals have been replaced by abundant amphibole laths in a matrix of albite-quartz ± epidote exhibiting trigonal grain boundaries. Chlorite is replaced by hornblende and biotite. ***b)*** Prograde metamorphic mineral assemblage of actinolite-plagioclase ± epidote ± sericite has modified and replaced most of the primary minerals in this massive tholeiitic flow (sample 464-46 at 16 m). ***c)*** Retrograde, hydrothermal biotite replacing early actinolitic amphibole and breakdown of metamorphic garnets (sample D23 at 42.5 m). ***d)*** Abundant brown secondary biotite laths replace early amphiboles. Black minerals in the center of the field of view are pyrrhotite-chalcopyrite aggregates (sample 464-46 at 150 m). Bar scale in all photographs = 1 mm. All photographs are in plane-polarized light except for Figure 5a (cross-polarized light). DDH 464-46 collared at mine grid coordinates 20501W, 20459N and DDH D23, at 18561W, 20060N. Sample numbers refer to drill-hole name and downhole distance in meters. Abbreviations: b = biotite; c = chlorite; h = hornblende; py = pyrite; q = quartz, po = pyrrhotite.

almandine ± calcite ± quartz ± ilmenite, reflecting lower amphibolite grade.

The transition from greenschist to amphibolite facies metamorphism is reflected by an increase in the Ca content of plagioclase. Marmont (1986) reported that Detour Lake plagioclase has a compositional range of An_{28-58}, which lies well above the peristerite gap that characterizes the greenschist to amphibolite facies transition (Spear, 1993). Furthermore, the assemblage epidote-actinolite-almandine, although partially controlled by f_{O2}, suggests that the maximum pressure–temperature conditions would have been ~33,000 kPa and 550°C (using the data of Spear, 1993): that is, within the lower amphibolite facies range.

In the Detour Lake area, the youngest rocks affected by regional metamorphism are those of the ca. 2700 Ma Caopatina assemblage. In the southern Abitibi Subprovince, Powell et al. (1995a, 1995b) have bracketed the timing of regional metamorphism between 2.67 Ga and 2.64 Ga, which is consistent with the timing of metamorphism at Detour Lake.

Hydrothermal Alteration

The regional metamorphic assemblages have been extensively modified and re-equilibrated by hydrothermal processes related to the gold mineralization at Detour Lake. Characteristics of hydrothermal wall-rock alteration have been documented by Marmont (1986), Thomas (1994), Wells (1997), and Pressacco (1999), who recognized the importance of host-rock chemistry in controlling the alteration mineral assemblages. In the tholeiitic volcanic rocks of the hanging wall, Marmont (1986) observed that secondary biotite was the dominant alteration mineral, with sericite occurring proximal to gold-mineralized zones and veins. Marmont (1986) also noted the alteration assemblage of K-feldspar-quartz-chlorite directly adjacent to gold-mineralized veins. These alteration minerals appear to increase in intensity toward the Chert Marker Horizon and proximal to felsic dikes. In ultramafic rocks, chlorite-talc-calcite-tremolite-actinolite-bearing assemblages constitute the dominant alteration type.

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The breakdown and replacement of early metamorphic mineral assemblages (amphibole-garnet) by secondary biotite (Fig. 5c, 5d) is common near the Detour Lake gold deposit. Secondary biotite and actinolite may be co-planar with the principal metamorphic fabric, or randomly oriented with respect to it. This suggests that the minerals formed either synchronously with, or slightly after, the formation of regional metamorphic assemblages.

Secondary biotite forms a broad halo, up to hundreds of meters in width, into the hanging wall of major gold-mineralized zones. The biotite alteration is typically best developed in pillow lavas and hyaloclastites but also occurs in massive flow sequences. In the Pillow Zone, which extends several tens of meters into the hanging wall above the Chert Marker Horizon (Fig. 3), qualitative observations suggest that carbonate and iron carbonate alteration are enhanced. Carbonate-rich mafic hyaloclastites are also more common in the Pillow Zone than elsewhere. To the west, the QK Zone (20200N, 16600E) exhibits K-feldspar alteration, fracture-controlled sulfides, and quartz-veining (Pressacco, 1999).The distribution of secondary biotite commonly overlaps areas where the main sulfide phase in the rock mass is pyrrhotite, not pyrite, which results in subtly elevated magnetic signatures.

On the basis of earlier work by Marmont (1986), Thomas (1994), Wells (1997), and Pressacco (1999), and the information in this study, gold-related hydrothermal alteration assemblages may be summarized as follows.

Alteration in Mafic Rocks

The idealized hydrothermal alteration assemblage is biotite-quartz-actinolite-chlorite-pyrrhotite ± albite ± calcite ± ankerite. Within hyaloclastites and locally in pillow lavas with interstitial hyaloclastite, the proportions of calcite-ankerite-albite are higher than the other alteration minerals, whereas in pillow lavas with poorly developed hyaloclastite zones, the most common alteration assemblage is calcite-ankerite-biotite-albite-pyrrhotite-quartz-chlorite. In massive tholeiitic flows, alteration minerals are poorly developed.

Alteration in Ultramafic Rocks

In ultramafic rocks, the principal alteration assemblage is actinolite-tremolite-chlorite-magnetite. Such a hydrothermal assemblage is broadly equivalent to the 'amphibole-class' alteration, which characterizes a series of vein-type gold deposits in the Archean Yilgarn Craton of Western Australia (Ridley et al., 2000).

Alteration Associated with Sunday Lake Tonalite Intrusion

A distinct alteration assemblage occurs in the extreme eastern part of the Detour Lake property, adjacent to the Sunday Lake intrusion (Fig. 3), where calc-silicate-albite-sulfide (pyrite-pyrrhotite-chalcopyrite) mineral assemblages occur in mafic volcanic rocks. The contact alteration front extends for several tens of meters to a few hundred meters from the Sunday Lake intrusion into the enclosing volcanic rocks. Elevated gold values, in the low ppm range, have been obtained from the calc-silicate alteration zones.

Characteristics of Gold Mineralization

At Detour Lake, gold resides within discrete, structurally controlled quartz ± carbonate veins and in preferred rock units. The three zones described below are referred to here as the 'Detour Main Zone' (which includes the Pillow Zone and Calcite Zone), the 'M Zone,' and the 'North Walter Lake Zone' (Fig. 3). However, the names of historical gold zones are also retained in the following descriptions to maintain continuity with previous work.

Detour Main Zone (Q Veins and Chert Marker Horizon)

The Detour Main Zone is within the Sunday Lake Deformation Zone (Fig. 2), an area of high strain. Contoured poles of shear foliations and deformation bands from 89 individual high-strain zones (Fig. 6a) clearly show that nearly all of the zones have east–west strikes and subvertical dips (079°/86°S, defined by maximum pole density). Shallowly dipping high-strain zones are virtually absent.

Veins exposed along the north wall of the Campbell Pit (20100N, 20100E) likely belong to a series of four 'Q vein' systems (the Q50, Q70, Q100, and Q120 zones in mine terminology) that splay from the main deformation zone and form part of the Detour Main Zone. These Q veins have mostly steep to subvertical northward dips and, in the Campbell Pit area, are typically <1 m wide and <100 m in strike length. Sheeted veins commonly occur with a frequency of greater than one per meter. In plan view, the veins are commonly observed as a series of sheeted subparallel veins that meet the Chert Marker Horizon at angles of 30°–35° (Barclay, 1993). These quartz veins are typically boudinaged and locally post-date and cut folded foliation surfaces near the Chert Marker Horizon (Pressacco, 1999). Textural features suggest that the Q veins evolved late in the deformational history of the Detour Camp. The Q vein zones and the mineralized Chert Marker Horizon were the dominant hosts of the high-grade gold resource (14.3 million tonnes of rock at an average grade of 3.82 g/t Au) that was exploited between 1983 and 1999 during early exploitation of the Detour Lake Mine (Kallio, 2006).

The orientations of 242 quartz veins, which were obtained from oriented drill cores in the Detour Main Zone, show three main vein sets ('a', 'b', and 'c' on Fig. 6b). The first set has an average orientation of 093°/84°N and mainly represents the dominant, steeply dipping shear or fault-fill veins. The second set has an average orientation of 102°/8°N. The third set has an average orientation of 077°/50°N and is related to a series of extensional veins that may have formed contemporaneously with the main shear-hosted veins. The orientations of the steeply dipping shear veins and the much flatter extensional veins are compatible with a reverse sense of motion on the deformation zone. The extensional veins typically occur as small, centimeter-scale veins that are discordant to the fabric and have very weak alteration halos.

The high-grade mineralization in the Detour Main Zone was associated with a structural feature, historically called the 'Hanging Wall Roll' in mine terminology. The Hanging Wall Roll is characterized by a 'left step' or north-directed

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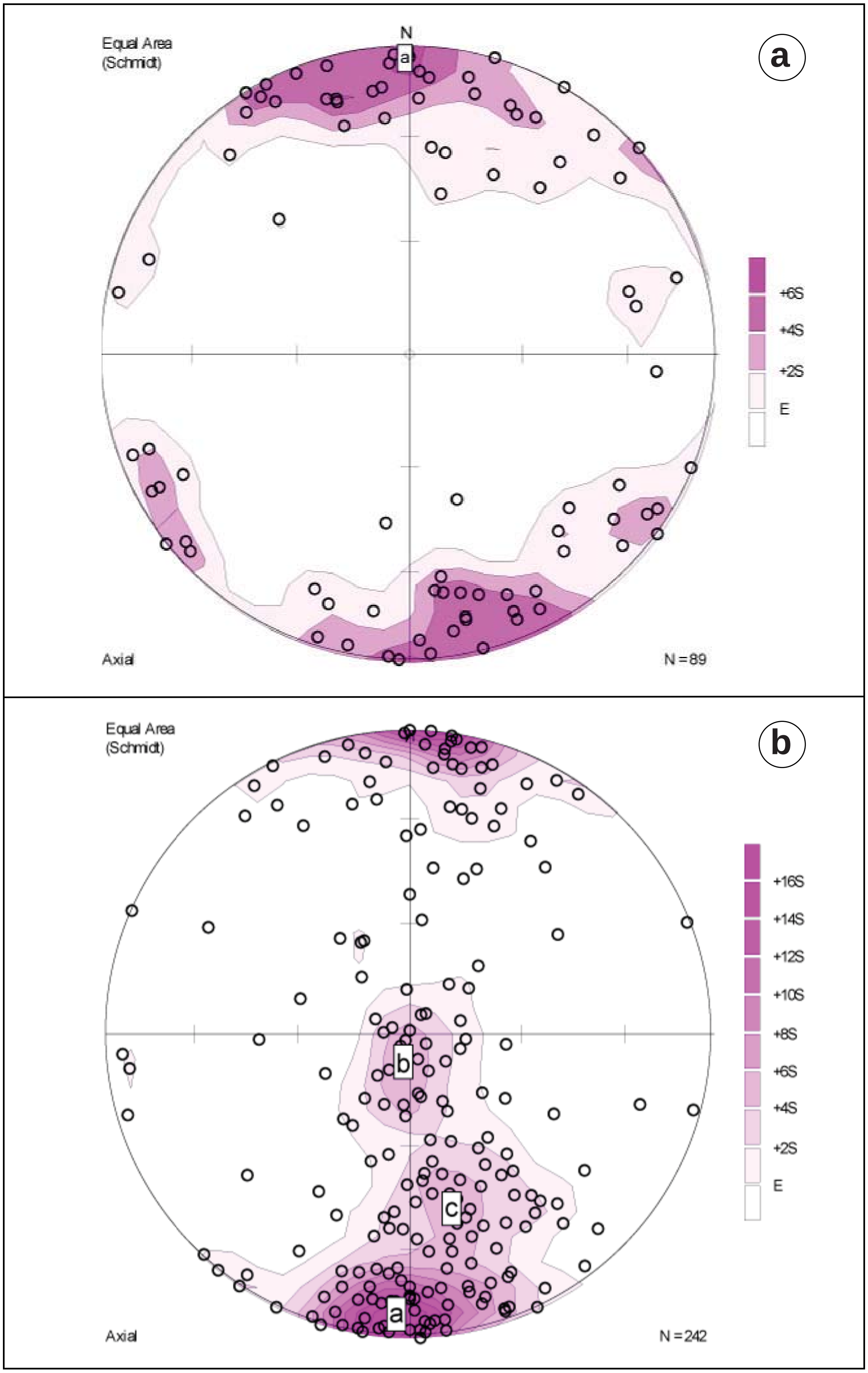

Figure 6. Contoured poles ***a)*** to fabrics in high-strain zones, showing that most are subvertical, and ***b)*** to quartz veins in oriented drill core, demonstrating that they are both subvertical (shear-hosted veins) and, less commonly, flat (extensional veins). Data are derived mainly from vein orientations in the Detour Main Zone.

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bend in the Chert Marker Horizon and by an overall flattening of its dip. On the detailed plan of the 360 Level (Fig. 7), the Chert Marker Horizon strikes at ~030°, which contrasts with the general east–west strike of this unit at the property scale, and it defines the locus of a dilational jog in the Sunday Lake Deformation Zone. The enhanced development of shear-hosted quartz veins within this dilatational jog is compatible with sinistral movement along the deformation zone at the time of mineralization. Geometries of veins proximal to the Hanging Wall Roll indicate that both sinistral and reverse movement occurred on the deformation zone at the time of mineralization.

The direction of extension in the high-strain zones may be determined from intersection lineations (1) between shear and extensional veins (Fig. 8a), and (2) between mineral stretching and elongation directions, or from quartz mullions within mineralized quartz veins (Fig. 8b). D_2 extensional lineations correspond to the overall plunge of ore shoots at the Detour Lake gold deposit, but they have varied orientations across the 9 km strike length of the known gold zones. Plunge directions of mineralized zones generally shallow to the west, doing so over strike distances in excess of 1500 m. On section 19725E, the mineralized zones rake at 55° → 270°; at 19250E, they rake at 16° → 257°; and at 18125E, the mineralized zone rakes at 3° → 259° (Zhang, 1997). Farther to the west, however, plunges in the North Walter Lake Zone steepen to 30° → 270° (Fig. 9).

Geometry and Kinematics of the M Zone

The M Zone is approximately 5–6 km west of the Campbell Pit (Fig. 3). The M Zone trend merges with the Detour Main Zone, giving a strike length that exceeds 9 km. In part, the M Zone appears to be localized near an 80°N-dipping contact between talc-chlorite-altered rock ('the chloritic greenstone unit' in mine terminology) and massive flows and pillow lavas. The protolith of this chloritic greenstone unit may have been an ultramafic flow or sill.

Much of the mineralization in the talc-chlorite unit occurs in a series of subvertical quartz-sulfide shears on the hanging-wall contact to the talc-chlorite unit. On surface, intense strain fabrics are observed in outcrops over widths of ~30–50 m. Kinematic indicators in these outcrops strongly suggest a sinistral shear sense (Fig. 10) at the M Zone, similar to what is observed at the Detour Main Zone.

Geometry and Kinematics of the North Walter Lake Zone

The North Walter Lake Zone is 600–1000 m north of the M Zone and is oriented at 110°/75°S. It is localized at or near the contact between massive, strongly sulfidized pillow lavas and massive flows with talc-chlorite-altered (komatiitic basalt) rock, as at the M and Detour Main zones. This mineralized deformation zone lies in the southern limb of the regional-scale North Walter Lake Synform, and it displays the clearest kinematic indicators of the three gold-bearing zones. In contrast to the M Zone and most of the Detour Main Zone, the North Walter Lake Zone has a dextral shear sense, as shown by S/C fabrics in a series of boudinaged quartz veins (Fig. 11a, 11b).

Gold Mineralization

Miller (2006) proposed two distinct paragenetic stages of mineralization at Detour Lake: a pre-ore stage characterized by colloform-banded pyrrhotite, and an ore stage comprising Au-pyrite-chalcopyrite-bismuthinite-tetradymite-Bi-tellurobismuthite. The grain size of ore-stage gold particles is highly varied, ranging from 1 µm to 200 µm (Fig. 12a). All gold is free-milling and occurs in quartz-calcite vein selvedges (Fig. 12b, 12c) within the interstices of biotite-altered and sulfidized pillow margins, and in the pressure shadows to recrystallized actinolite-talc laths in talc-chlorite alteration units. Bismuth tellurides have also been identified in numerous samples from the West Pit area, where the most common metal association is Au + Bi + Te + Cu.

Much of the gold at Detour Lake is contained in discrete fault-fill and extensional quartz vein networks. Most of these veins are quartz-dominant, with ankerite-quartz veins being poorly represented. Late-stage, sulfide-rich and very high-grade gold-bearing breccia veins cut the earlier shear and extensional vein networks (Oliveira, 1997). The Chert Marker Horizon appears to have acted as a competent unit that was cut by fault-fill quartz veins and stockwork quartz veinlets. Subvertical Q veins merge with the Chert Marker Horizon trend and are particularly well developed at the flexure or offset of the main Chert Marker Horizon. Q veins that parallel the Chert Marker Horizon are mostly parallel to foliation and are generally interpreted as conjugate, fault-fill or shear-hosted veins. In general, the grade–thickness of gold mineralization increases as the Chert Marker Horizon is approached.

Gold mineralization also occurs on both the hanging wall and footwall contacts of intermediate to felsic intrusions where they cut talc-chlorite-altered ultramafic rocks (Fig. 7). Grade–thickness data clearly demonstrate that gold mineralization is best developed near the contacts but not within the dikes themselves. This relationship is relatively common at Detour Lake and has also been well documented in the Timmins Camp, where strong gold mineralization is developed at or near the contacts of the more competent Paymaster and Pearl Lake porphyries (Longley and Lazier, 1948).

Broad, lithologically controlled areas of gold mineralization include the Calcite, Talc, and Pillow zones (Fig. 3, 7), where gold occurs over significant widths with few if any veins. Dilatant sites at pillow lava–massive flow contacts, hyaloclastite units, and strongly altered ultramafic rocks are commonly gold-mineralized. Examples of lithologically controlled gold are illustrated by graphic logs of three diamond drill holes, labeled PM-113, 464-047, and DG 07-117 (Fig. 13). In these graphic logs, gold assay histograms are plotted beside the main lithological units.

Hole PM-113 was cored in the central part of the Calcite Zone (mine grid coordinates: 18560.00E, 20135.00N). The strongest gold mineralization is associated with a vein-deficient, ~100 m mineralized interval in the center of a hyaloclastite sequence. All volcanic rocks in this drill hole are assigned to the upper Detour Lake Formation.

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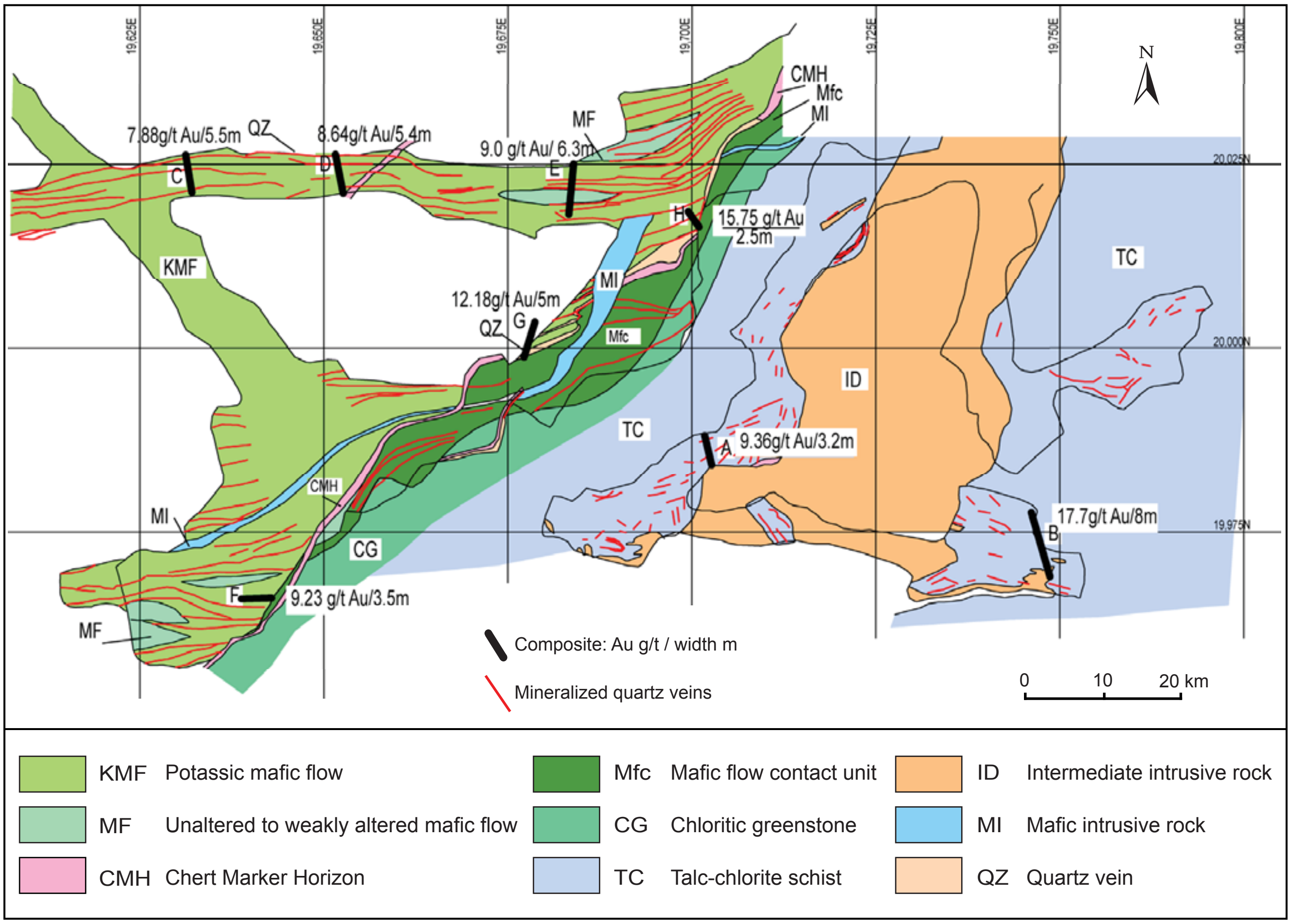

Figure 7. Spatial relationships of the Chert Marker Horizon, the Q vein zones, and footwall-talc gold-mineralized zones, as illustrated on the underground 360-Level plan of the Detour Lake Mine. The Chert Marker Horizon forms an approximately semi-conformable body between ultramafic rocks in the footwall and highly strained, altered, gold-mineralized tholeiitic volcanic rocks in the hanging wall. This map is excerpted and modified from Barclay (1993); the grid is referenced to the local mine grid.

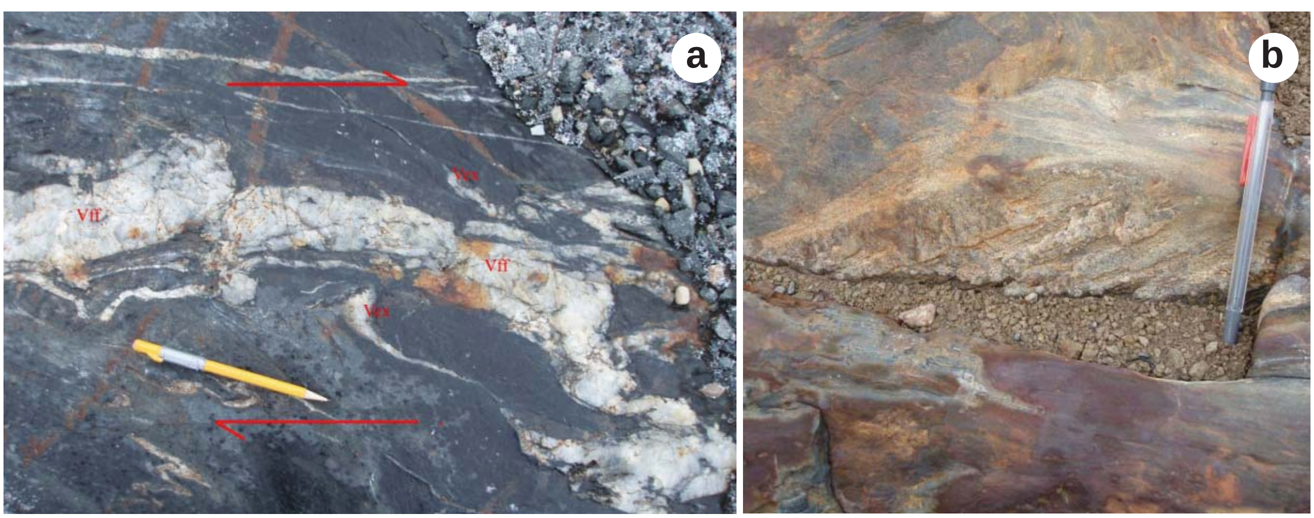

Figure 8. ***a)*** Photograph showing the relationship between the Q Zone fault-fill veins (Vff) and extensional veins (Vex) in the Campbell Pit. The central fault-fill vein has an orientation of 102º/85ºS, and the extensional veins are oriented at 128º/87ºS. The main fault-fill vein has been folded after vein formation (lower right-hand field of view). The host lithology is a massive mafic flow. ***b)*** Linear D_2 shape fabrics in the North Walter Lake area within a mineralized quartz selvedge, which is oriented at 36º → 274º. This small-scale extensional feature also closely correlates with the direction and plunge of large-scale, regional D_2 folds such as the Airstrip Antiform.

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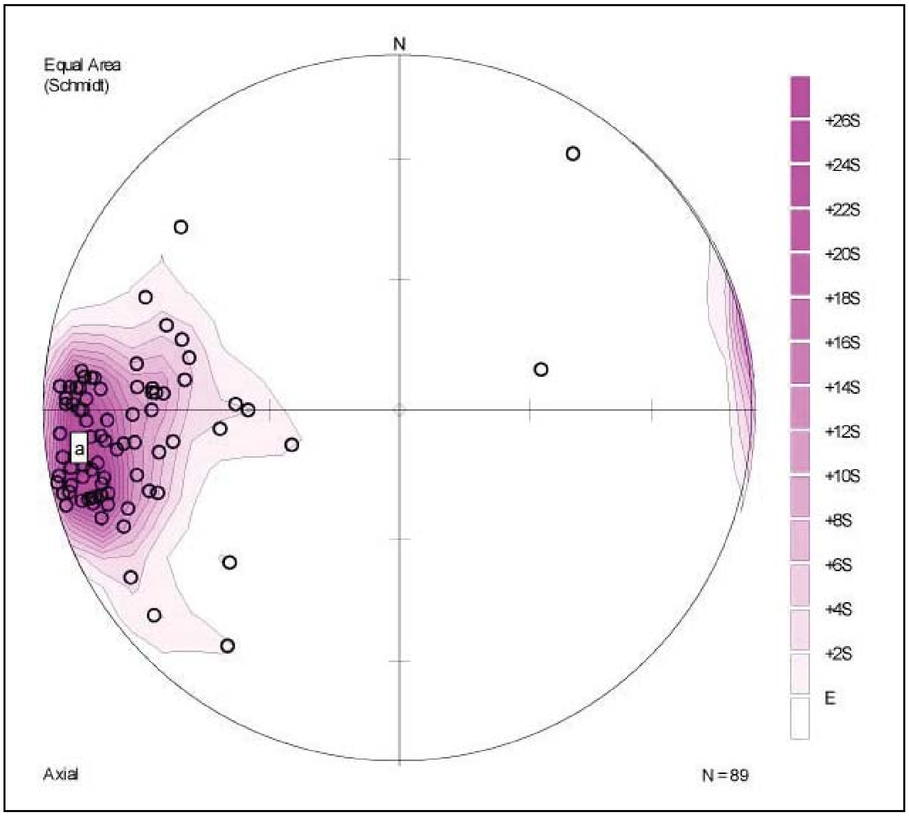

Figure 9. Regional plunges and extensional direction of mineralized zones in the North Walter Lake area.

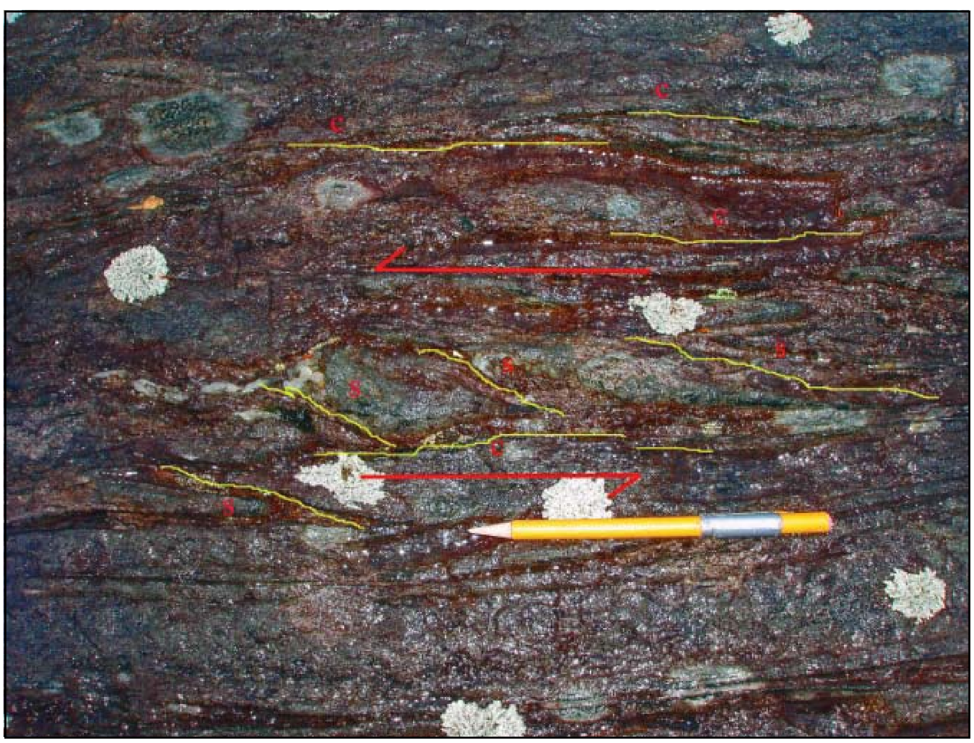

Figure 10. S/C fabrics in the M Zone. The C, or shear, planes, are the reddish brown surfaces parallel to the long axis of the pencil. S planes are oriented at ~30° to the C planes, which is consistent with sinistral shear. Red arrows indicate shear direction.

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Figure 11a *(above)*. Boudinaged quartz vein fragments in the North Walter Lake Zone. The quartz vein fragments display preserved internal S fabric, with the C fabric parallel to the long axis of the quartz fragments. The asymmetrical shape of the quartz boudins, and the orientation of S/C fabric, are compatible with dextral shear. Red arrows indicate shear direction.

Figure 11b *(above)*. Boudinaged quartz vein fragments in a strongly sulfidized pillow lava sequence, North Walter Lake Zone. The boudinaged veins are parallel to the dominant strain fabric that postdates the main stage of vein formation.

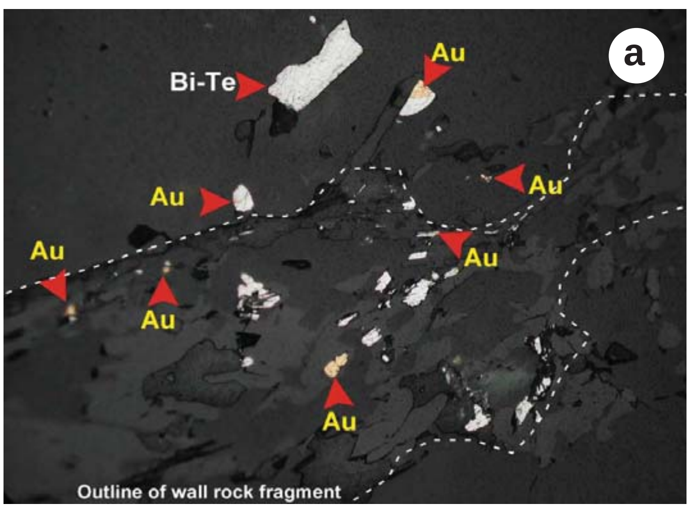
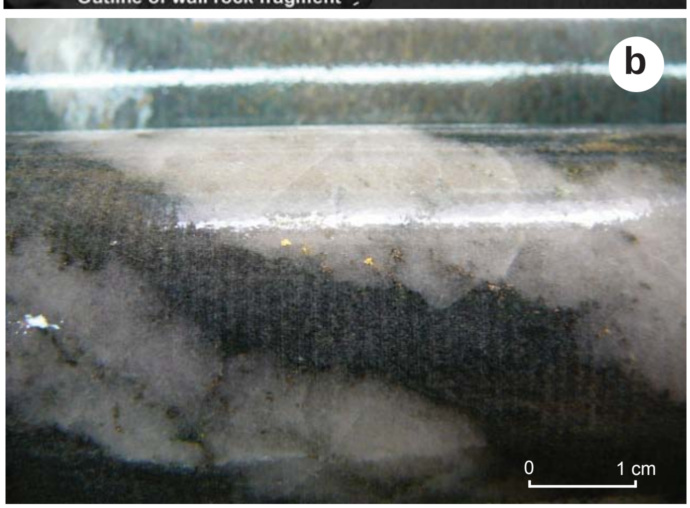


Figure 12a *(to left)*. Discrete grains of native gold and bismuth tellurides in a quartz-carbonate vein, and associated wall-rock fragment within the vein. Reflected light photomicrograph; field of view = 1.35 mm (photograph is excerpted from Miller, 2005).

Figures 12b and 12c *(below)*. Visible gold in Detour Lake quartz-carbonate veins, which occurs as small grains flanking foliation-parallel quartz veins.



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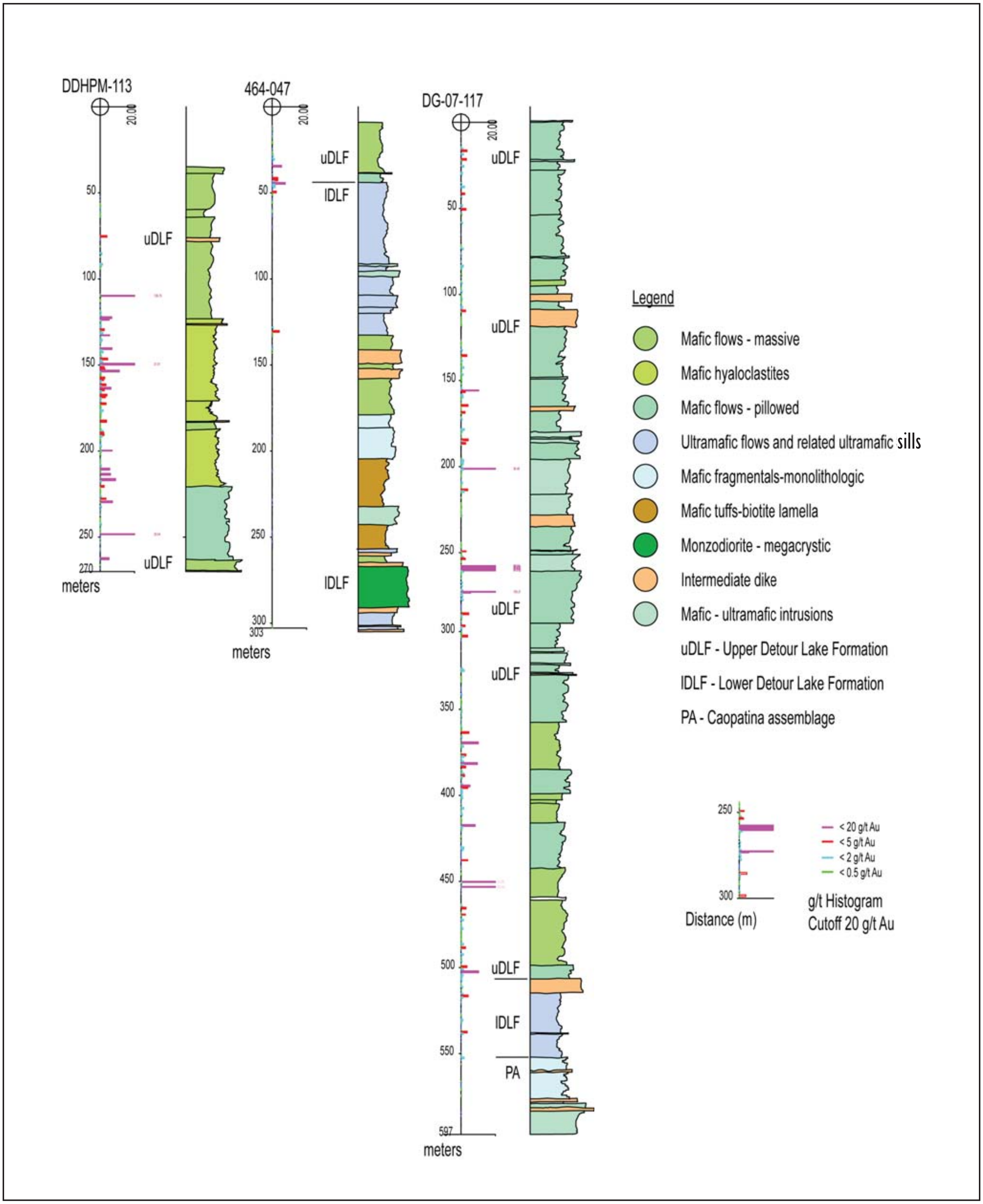

Figure 13. Graphic logs of three drill holes at Detour Lake, which show the distribution of gold assays with respect to rock type. The Chert Marker Horizon was not intersected in these three holes, but when present elsewhere, it is located at or near the contact between the upper mafic and lower ultramafic parts of the Detour Lake Formation. Note that gold assay data are truncated to a maximum grade of 20 g/t Au. See Figure 3 for hole locations: all holes are oriented approximately orthogonal, grid south, to the east–west strike of the stratigraphy.

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Hole 464-047 (Fig. 13) was cored near the eastern limit of the currently known gold resource at Detour Lake (mine grid coordinates: 17798.95E, 19700.40N). In contrast to PM-113, gold mineralization in this hole is constrained to structurally controlled fault-fill and extensional quartz veins that are developed at or near the contact between the mafic upper and ultramafic lower parts of the Detour Lake Formation. Although gold grades commonly exceed 30 g/t Au at this contact, these high grades are generally developed only over narrow widths, typically <5 m.

Hole DG 07-117 (Fig. 13) was collared at 19419.76E, 20213.79N (mine grid). It cuts all styles of gold mineralization, both major volcanic units, felsic to intermediate dikes, and sedimentary rocks of the Caopatina assemblage. The grade-interval histograms indicate that the most enriched gold zones are developed at or near the contacts between pillow lavas and massive flow units (e.g., at depths of ~260 m and 272 m). Gold mineralization within massive flows is commonly associated with abundant, small (centimeter-wide) auriferous quartz veins. Most of the felsic to intermediate dikes contains little or no gold, except for those in highly strained zones proximal to the Sunday Lake Deformation Zone. High-grade zones are present near the contact between the upper and lower parts of the Detour Lake Formation, between 502 m and 506 m. Gold is also present in talc-chlorite-altered ultramafic rocks at depths between 516 m and 552 m. The strongest gold mineralization in talc-chlorite-altered ultramafic units occurs in dilatant zones at or near the contacts between incompetent ultramafic units and competent intermediate to felsic dikes.

The principal gold-mineralized zones at Detour Lake are illustrated on two geological cross-sections (19820E and 18560E), which are separated by a distance of 1260 m. Section 19820E (Fig. 14) shows three gold-mineralized zones: the Talc Zone, which is hosted by strongly talc-altered ultramafic rocks; the Footwall Zone, which includes mineralization in the footwall volcanic and volcaniclastic rocks; and the Q vein zones. In this section, 10–20 m wide slivers of volcaniclastic rocks, possibly lower Detour Lake Formation or Caopatina assemblage, are present >250 m north of where they should be based on the mine geology. Therefore, the gold-mineralized high-strain zones in this area are interpreted as secondary splays from the main Sunday Lake Deformation Zone, which lies 250 m to the south of this section. Gold mineralization is most concentrated at inflection points or changes in orientation, from steep (75°) to shallow (45°) and north-dipping, of structural zones that follow the contact with ultramafic units. The gold-mineralized Q vein zones comprise sets of sheeted, subvertical, low-sulfide quartz veins, which may reflect dilatent loci in a reverse fault system.

In Section 18560E (Fig. 15), a clear relationship is evident between lithology and gold-mineralized zones. The Detour Main Zone closely follows a high-strain zone at or near the contact between mafic rocks of the upper Detour Lake Formation and ultramafic rocks of the lower Detour Lake Formation but is mostly in strongly carbonatized mafic hyaloclastic rocks rather than the planar high-strain zones. Strong gold mineralization in hyaloclastite and pillow lavas occurs over widths of >110 m and over vertical distances of >700 m. Bulk rock composition and the partitioning of strain into preferred lithological units may explain the development of gold mineralization in these sites.

The size and strength of the mineralizing system at Detour Lake are illustrated on a deposit-scale, east–west longitudinal section (Fig. 16). Contoured gold grades show the westerly rake of the mineralized zones and the shallowing of these ore shoots to the west. The section also demonstrates that gold mineralization occurs over a nearly continuous strike distance of at least 4 km. The deepest gold intersection was cored at depths of >891 m, which is well below the limits of the proposed open pit.

Discussion

Recent mapping, structural studies, and geochronological work demonstrate that tectonic events were diachronous across the Abitibi Subprovince, where sedimentation, deformation, and syn-tectonic plutonism are approximately 10 million years older in the north than in the south (Ayer et al., 2010). The age of porphyry dikes associated with mineralization at the Barry deposit in the northeastern part of the Abitibi precisely constrains epigenetic gold mineralization and D_1 deformation to 2697 ± 1 Ma (Kitney et al., 2009).

Our new geochronological results from Detour Lake indicate that D_2 resulted in thrusting of the 2720 Ma Detour Lake Formation over the ca. 2700 Ma Caopatina assemblage. However, our structural analysis indicates that gold at Detour Lake is related to deformational events that post-date D_2, similar to what has been interpreted for many of the large gold deposits in the southern Abitibi (Bateman et al., 2008; Ispolatov et al., 2008).

The timing (minimum age) of gold mineralization at Detour Lake is also constrained by the presence of gold-bearing veins in the ca. 2700 Ma Caopatina assemblage and by the 2699 ± 7 Ma maximum age of a barren, post-ore albitite dike that cuts deformed auriferous veins in the 2725 ± 1 Ma Chert Marker Horizon. Chemically similar albitite dikes at the McIntyre Mine in Timmins have yielded a magmatic zircon age of 2672 ± 1 Ma, but these dikes are cut by main-stage auriferous quartz-carbonate veins (Bateman et al., 2008, and references therein). This suggests that gold mineralization at Detour Lake is older than the main-stage gold event in the Timmins Camp.

Structural Controls on Au Mineralization

The gold mineralization was formed in dilatant structural zones proximal to the Sunday Lake Deformation Zone, the earliest history of which suggests that it was a south-verging, regional-scale thrust fault that emplaced 2720 Ma volcanic rocks of the Detour Lake Formation above ca. 2700 Ma sedimentary rocks of the Caopatina assemblage. A series of south-verging, synform–antiform couples, which formed coevally with thrusting, are present in hanging-wall volcanic rocks of the Sunday Lake Deformation Zone. A south-verging, regional-scale antiform (the Airstrip Antiform) that is cored by ultramafic rocks of the lower Detour

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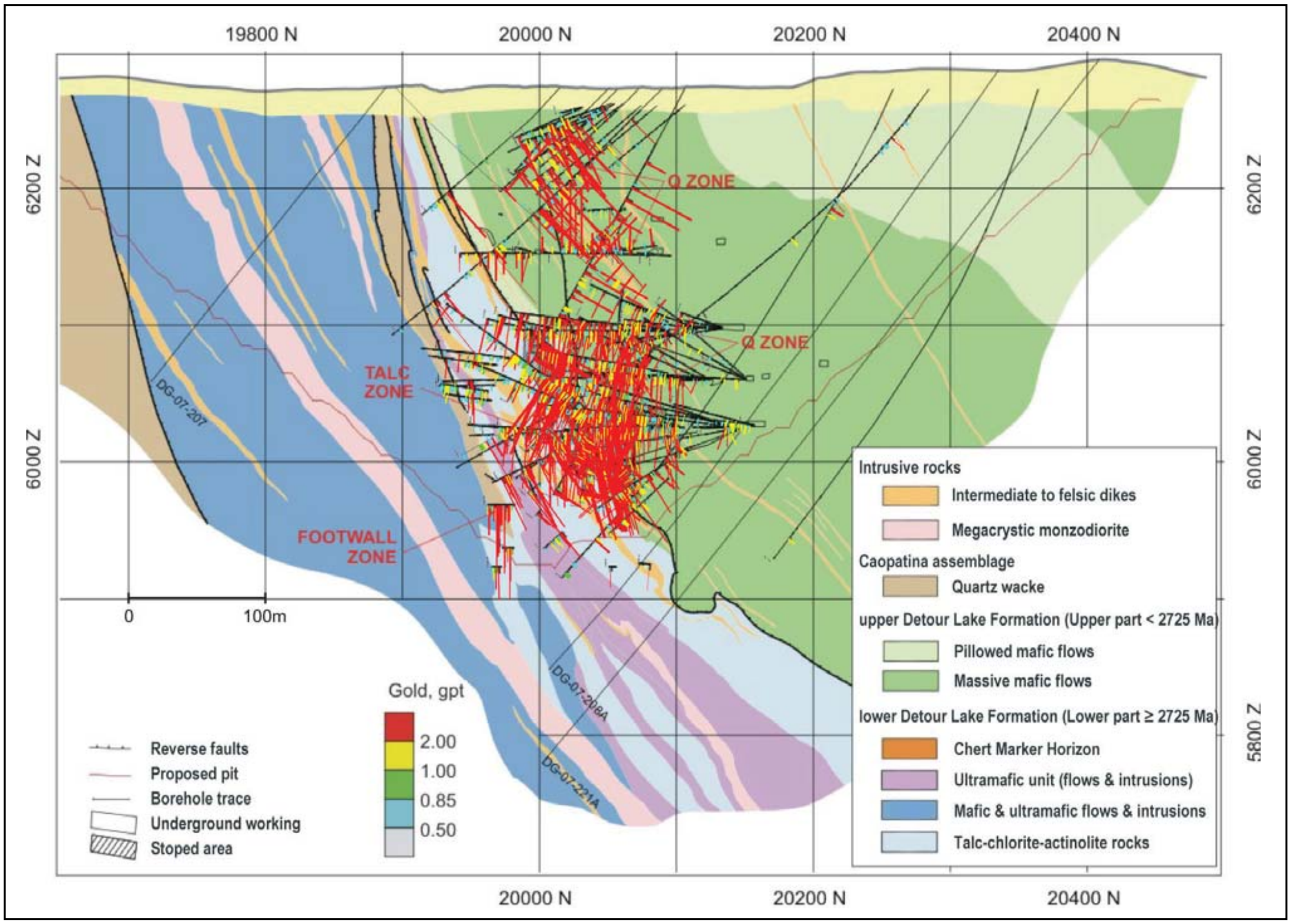

Figure 14. Section 19820E at the Detour Lake deposit. See Figure 3 for location in terms of mine grid coordinates; no vertical exaggeration. Gold mineralization occurs (1) within the Chert Marker Horizon, (2) as subvertical Q zones in the hanging wall volcanic rocks, and (3) on the footwall side of the Chert Marker Horizon within talc-altered ultramafic units, and within sedimentary rocks of the Caopatina assemblage.

Lake Formation (Fig. 3) is closest to the gold zones. Commonly, the rocks within high-strain zones along the north limb of this antiform are intensely gold-mineralized.

The early fold and fault relationships preserved at Detour Lake are consistent with the structural architecture of other Archean fold-and-thrust belts in the Abitibi Subprovince (e.g., Lacroix and Sawyer, 1995; Benn and Peschler, 2005; Peschler et al., 2006; Bateman et al., 2008). Large-scale anticlinoria are spatially associated with major gold deposits of the Wiluna–Kalgoorlie region in the Yilgarn block of Australia; the identification of these domal features is currently being used as an indicator of prospectivity for mineral exploration (Henson and Blewett, 2006).

Juxtaposition of the west-plunging Airstrip Antiform and the Sunday Lake Deformation Zone placed rock units of differing competency and chemistry in contact with one another and created a structurally favorable site for gold mineralization. This also caused the trend of the Detour Lake high-strain zones to be deflected away from the regional structural grain, which assisted in the development of large-scale dilatant sites that enhanced fluid flow and increased the complexity of shear structures at deposit scale. Similar relationships have been described and quantified using fractal analysis of structural patterns at Golden Mile in Kalgoorlie and in the Ora Banada district of Australia (Tripp, 2003; Weinburg et al., 2004).

In the Timmins Camp of the southern Abitibi Subprovince, the Porcupine–Destor Fault was previously interpreted as a large-scale, terrane-bounding fault, with gold deposits in the camp having formed as the end result of crustal-scale collisional processes (Hodgson and Hamilton, 1988; Mueller et al., 1996). However, more recent work has shown that the stratigraphy is more or less continuous across the Porcupine–Destor Fault, indicating that the fault is an internal structure and not a terrane-bounding suture (Ayer et al., 2002, 2005; Bateman et al., 2008). Similarly, the Sunday Lake Deformation Zone is not a terrane-bounding fault, because the Detour Lake Formation is continuous across it. Internal faults are also recognized in the Narryer, Kalgoorlie, and Murchison terranes within the Yilgarn Craton (Myers, 1992).

The proximity of gold mineralization to, and the presence of gold mineralization within, the Sunday Lake Deformation Zone is unusual. In many Archean orogenic gold systems (e.g., the Timmins Camp), mineralization is best developed in splays and second-order structural sites dis-

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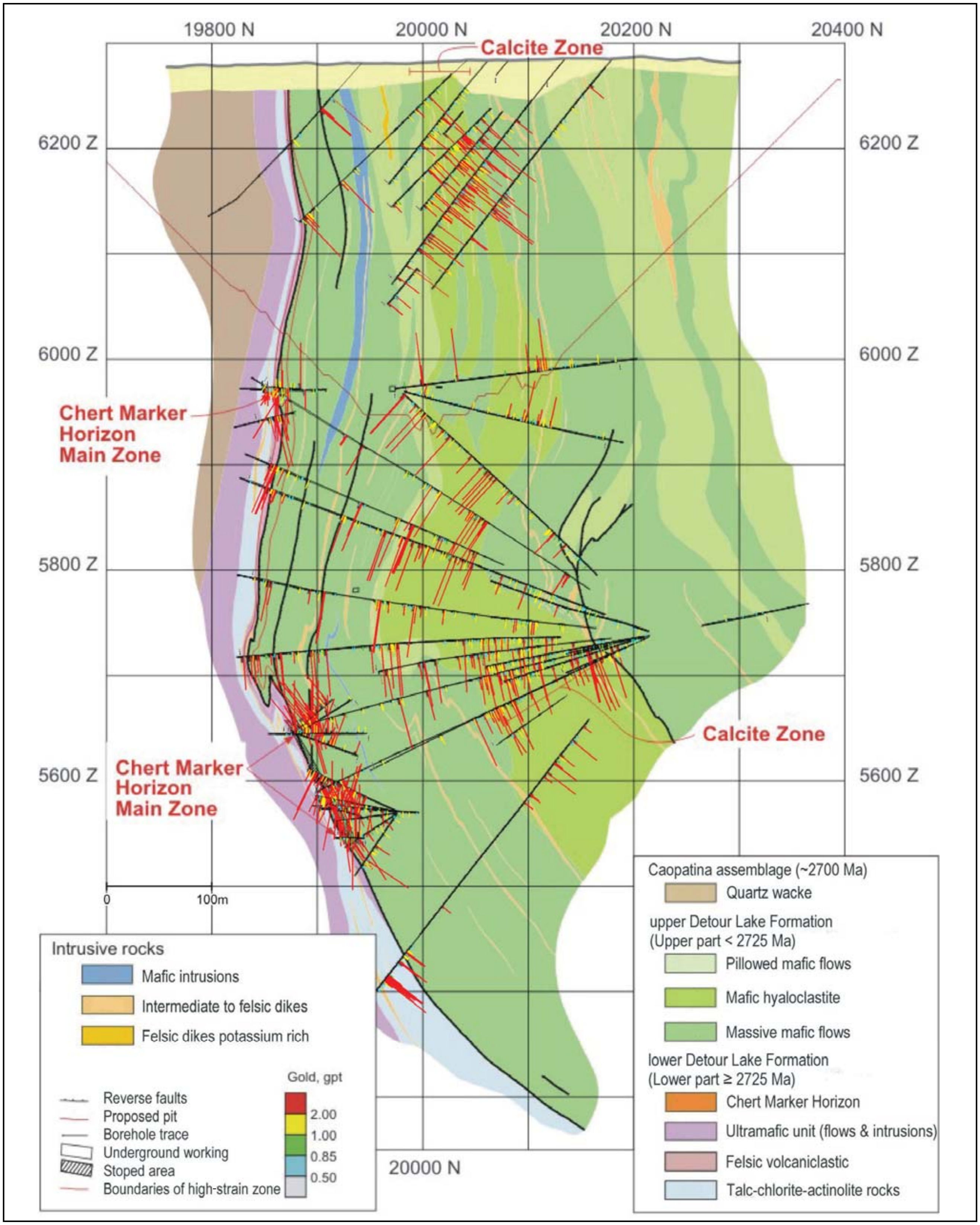

Figure 15. Section 18560E at the Detour Lake deposit. See Figure 3 for location in terms of mine grid coordinates; no vertical exaggeration. The section illustrates the nature of gold mineralization associated with the Chert Marker Horizon. It also shows a broad mineralized zone, the Calcite Zone, that follows the contacts of a hyaloclastite unit that is ~100 m thick.

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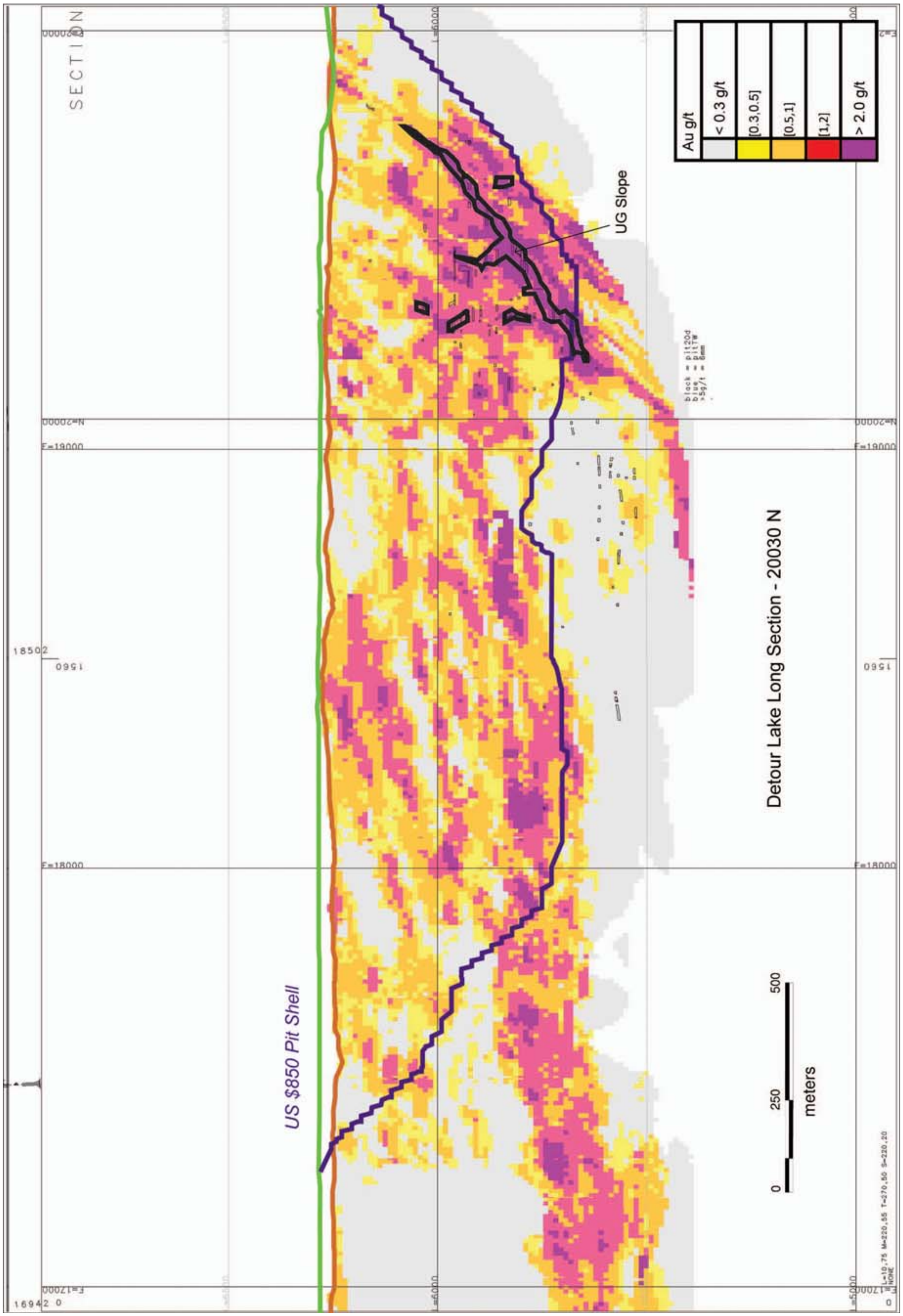

Figure 16. Longitudinal grade-thickness plot of the Detour Lake gold deposit (mine grid, no vertical exaggeration). Gray dots indicate drill-hole pierce points.

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tal to the main structural break (Robert and Poulsen, 1997; Robert et al., 1997; Bateman et al., 2008; Ispolatov et al., 2008). At Detour Lake, much of the gold mineralization is concentrated in structural features that formed less than a few hundreds of meters into the hanging wall of the Sunday Lake Deformation Zone and even within the Sunday Lake Deformation Zone itself. The extensive and protracted history of rock strain along the zone and in structures parallel to it is demonstrated by the imbrication and boudinage of early planar vein systems. The orientation of these veins relative to the Sunday Lake Deformation Zone also suggests a complex kinematic history.

The camp-scale rock relations require that the older Detour Lake Formation was thrust over the younger Caopatina assemblage. In this kinematic regime, flat or shallow-dipping extensional veins and subvertical fault-fill veins should be evident. However, flat extensional veins are poorly developed at Detour Lake. This implies that the south-verging thrusts, which are the product of the earliest motion on the Sunday Lake Deformation Zone, may in part pre-date the main gold-mineralizing event at Detour Lake.

In contrast, gold-bearing veins measured in drill core from Detour Lake, and the extensive modeling studies of the orientation of the high-grade gold shoots (Risto et al., 2008), indicate that most vein types are subvertical in orientation. These subvertical veins would have formed under a transpressional strike-slip kinematic regime. Depending on which structural strand is examined (Detour Main Zone–sinistral; M Zone–sinistral; North Walter Lake Zone–dextral), the gold mineralization may have resulted from both dextral and sinistral displacements possibly linked to, or superimposed on, reverse movements (i.e., dextral-reverse; sinistral-reverse).

The Sunday Lake Deformation Zone extends for many tens of kilometers, but it is gold-mineralized at mineable grades and widths only in the Detour Lake area. Morey et al. (2007) suggested that gold endowment in shear-hosted gold deposits is higher in those deposits with complex versus simple deformational histories and in those that occur in well-focused or concentrated structural corridors. The diverse structural styles, coincidence of regional antiforms with the Sunday Lake Deformation Zone, and tight spatial relationships between second-order structures and the Sunday Lake Deformation Zone may be the fundamental reasons for the major gold endowment of this district.

Deposit Model for Detour Lake

Robert and Poulsen (1997) divided world-class Archean gold deposits in Canada into three broad categories: precious metal-rich, syn-volcanic sulfide deposits; intrusion-related deposits; and syn-tectonic mesothermal or orogenic vein deposits.

The Detour Lake gold deposit has characteristics of orogenic vein deposits as set out by Robert and Poulsen (1997). Such deposits are also known as greenstone-hosted quartz-carbonate vein deposits. In general, these deposits are associated with crustal-scale faults, have vertical continuity in excess of 2 km, and demonstrate no significant metal zonation (Hagemann and Cassidy, 2000; Groves et al., 2003; Dubé and Gosselin, 2007).

Even though the Detour Lake gold deposit has many characteristics of orogenic vein deposits, it differs from them in some respects. For example, the overall plunge of linear structural elements and the gold zones is shallow westerly, and the gold zones bottom out at a depth of approximately 1 km. This differs from many gold deposits of the southern Abitibi Subprovince, where linear rock fabrics are steeply plunging, and auriferous vein networks extend to depths of several kilometers.

Alteration assemblages (actinolite-tremolite-magnetite-biotite-ankerite-albite-quartz-pyrrhotite) associated with gold mineralization at Detour Lake formed either synchronous with, or slightly after, peak regional metamorphism. Many gold deposits formed under greenschist facies conditions clearly post-date peak metamorphism (Marmont and Corfu, 1988; Powell et al., 1995a, 1995b). In contrast, deposits formed under amphibolite facies conditions are contemporaneous with peak metamorphism (Clarke et al., 1986; Hamilton and Hodgson, 1986; Blenkinsop and Frei, 1996; Hagemann and Cassidy, 2000).

The Detour Lake gold deposit also differs from other Archean orogenic vein deposits of the southern Abitibi Subprovince in terms of grade–tonnage relationships. Most gold deposits in the southern Abitibi have average gold grades in the 5–15 g/t range; the majority of these deposits have sizes of <60 million tonnes, with most <5 million tonnes (Poulsen et al., 2000; Dubé and Gosselin, 2007). In contrast, the current Measured and Indicated gold resource at Detour Lake is contained within 445.9 million tonnes of rock grading 1.20 g/t Au (at a cut-off grade of 0.6 g/t Au) for a total resource of 17.26 million ounces Au (Table 1; Houde et al., 2009). By comparison, Goldcorp's Porcupine Mine in the Timmins area contains Proven and Probable reserves, and Measured and Indicated resources of 166.4 million tonnes of rock grading 1.37 g/t and containing 7.35 million ounces Au (Belanger, 2011). The economics of these large-tonnage and relatively low-grade gold deposits has also been profoundly influenced by changes in commodity prices, especially of gold.

The very large size of the Detour Lake gold deposit may be related to the fact that gold mineralization occurs in two significantly different sites: dilatent sites within high-strain zones, and lithologically controlled low-strain sites. The highest grade zones are related to dilatant sites within high-strain zones, where classic shear (fault-fill) and extensional veins developed, even within the Chert Marker Horizon. Historically, these structural zones hosted 9.1 million tonnes of ore grading 4.98 g/t Au (Kallio, 2006). The development of fault-fill and oblique extensional vein sets and the distribution of gold in these vein systems may be explained by 2-D Anderson or Riedel strain models (Anderson, 1951). In these models, the assumption is made that all strain is planar and that no changes occur in the orientation of the intermediate strain axis. However, a 2-D strain model does not fully explain the distribution of gold in the larger bulk tonnage targets, which are the principal host to most gold mineralization at Detour Lake.

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Table 2. U-Pb TIMS analytical data for zircon from the Detour Lake area. Notes for this table appear on the facing page.

Grain[1]	Wt[2]	U[3]	Pb*[4]	^{206}Pb[5]	Pb*[6]	Pb[7]	Th/U[8]	Isotopic ratios ±1σ,% [9]			corr.	% [10]	Apparent ages ±2σ,Ma[11]		
	(μg)	(ppm)	(ppm)	^{204}Pb	Pbc	(pg)		^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	coef.	discordant	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb
Sample A: 08JAA011 felsic tuff; UTM NAD 83; E591825, N5540775															
A	1.0	89.1	53.0	2624	51.6	2.3	0.452	0.52591 ± 0.09	13.6496 ± 0.12	0.18824 ± 0.07	0.807	0.1	2724.2 ±4.2	2725.7 ± 2.3	2726.8 ± 2.3/2.3
B	1.5	127.7	73.9	999	19.1	3.8	0.332	0.52582 ± 0.12	13.6253 ± 0.16	0.18794 ± 0.09	0.841	0.0	2723.8 ±5.3	2724.0 ± 3.1	2724.2 ± 2.9/2.9
C	1.0	24.7	14.6	556	10.3	1.5	0.421	0.52566 ± 0.17	13.6078 ± 0.23	0.18775 ± 0.13	0.815	0.0	2723.1 ±7.7	2722.8 ± 4.4	2722.6 ± 4.4/4.4
D	1.0	155.3	91.0	981	19.7	7.8	0.399	0.52478 ± 0.09	13.5988 ± 0.15	0.18794 ± 0.09	0.807	0.2	2719.4 ±4.1	2722.2 ± 2.8	2724.2 ± 3.0/3.0
E	1.5	29.4	17.3	640	11.8	2.1	0.412	0.52616 ± 0.19	13.6601 ± 0.41	0.18829 ± 0.30	0.710	0.1	2725.2 ±8.6	2726.4 ± 7.7	2727.3 ± 10/10
Sample B: 06JAA057; wacke; UTM NAD 83; E590081, N5540500															
A	5	110.7	70.8	7306	141.1	2.5	0.696	0.53456 ±0.07	14.2274 ±0.11	0.193032 ± 0.05	0.92694	0.3	2760.6 ±3.1	2765.0 ± 2.0	2768.2 ± 1.6/1.6
B	5	68.7	41.6	6672	128.4	1.6	0.691	0.51000 ±0.10	12.9433 ±0.13	0.184067 ± 0.05	0.91778	1.5	2656.6 ±4.2	2675.5 ± 2.4	2689.9 ± 1.8/1.8
C	5	64.1	39.3	6795	130.2	1.5	0.678	0.51775 ±0.07	13.2218 ±0.11	0.185211 ± 0.05	0.91474	0.5	2689.7 ±2.9	2695.6 ± 2.0	2700.1 ± 1.8/1.8
D	5	51.9	34.6	7250	144.0	1.2	0.806	0.54447 ±0.11	14.880 ±0.14	0.198207 ± 0.06	0.92043	0.4	2802.1 ±5.0	2807.6 ± 2.6	2811.5 ± 1.8/1.8
E	4	64.0	39.5	12550	229.3	0.7	0.402	0.54673 ±0.09	15.0262 ±0.12	0.199332 ± 0.05	0.92668	0.4	2811.5 ±3.9	2816.9 ± 2.2	2820.7 ± 1.6/1.6
F	3	110.1	68.9	5478	107.6	1.9	0.810	0.51351 ±0.12	13.1441 ±0.15	0.185646 ± 0.06	0.90598	1.5	2671.6 ±5.2	2690.1 ± 2.7	2704.0 ± 2.1/2.1
Sample C: 06JAA014; wacke; UTM NAD 83; E586617, N5538119															
A	1.0	105.6	66.9	6782	117.9	0.6	0.374	0.56203 ± 0.10	16.1342 ± 0.12	0.20820 ± 0.04	0.947	0.7	2875.0 ±4.8	2884.8 ± 2.4	2891.6 ± 1.4/1.4
B	0.9	163.1	107.1	15496	284.2	0.3	0.601	0.55513 ± 0.10	16.0330 ± 0.12	0.20922 ± 0.04	0.941	2.3	2846.5 ±4.7	2878.8 ± 2.3	2901.4 ± 1.4/1.4
C	0.4	117.5	72.9	551	8.7	3.1	0.580	0.53144 ± 0.16	14.5200 ± 0.34	0.19816 ± 0.23	0.792	2.8	2747.5 ±7.3	2784.3 ± 6.4	2811.1 ± 7.6/7.6
D	0.4	59.3	35.6	2337	40.1	0.3	0.484	0.52764 ± 0.25	13.7036 ± 0.27	0.18836 ± 0.07	0.964	-0.2	2731.5 ±11	2729.4 ± 5.1	2727.9 ± 2.4/2.4
E	0.8	50.2	32.2	6819	123.9	0.2	0.624	0.54457 ± 0.18	14.8840 ± 0.20	0.19823 ± 0.05	0.975	0.4	2802.6 ±8.3	2807.8 ± 3.7	2811.6 ± 1.5/1.5
F	0.5	39.3	25.4	2818	50.5	0.2	0.628	0.54823 ± 0.31	14.9922 ± 0.32	0.19834 ± 0.06	0.980	-0.2	2817.8 ±14.3	2814.7 ± 6.2	2812.5 ± 2.1/2.1
Sample D: 07JAA016; gabbro; UTM NAD 83; E592772, N5541429															
A	3.3	60.2	36.2	7135	141.5	0.9	0.553	0.52133 ± 0.13	13.4632 ± 0.11	0.18730 ± 0.11	0.566	0.6	2704.8 ±5.7	2712.7 ± 2.1	2718.6 ± 3.7/3.7
B	2.0	330.2	269.1	4841	135.6	4.4	2.263	0.52121 ± 0.07	13.4701 ± 0.1	0.18744 ± 0.06	0.864	0.7	2704.3 ±3.0	2713.2 ± 2.0	2719.8 ± 1.9/1.9
C	3.0	99.7	64.8	1964	61.5	3.5	3.132	0.36694 ± 0.12	9.3477 ± 0.15	0.18476 ± 0.06	0.919	29.3	2015.0 ±4.0	2372.7 ± 2.7	2696.1 ± 2.0/2.0
E	1.6	132.8	147.0	6385	221.2	1.1	4.616	0.52026 ± 0.09	13.4460 ± 0.11	0.18744 ± 0.06	0.837	0.9	2700.3 ±3.8	2711.5 ± 2.1	2719.9 ± 2.1/2.1
Sample E: 06JAA067; felsic lapilli tuff; UTM NAD 83; E592772, N5541429															
A	8	84.7	50.4	10930	204.8	2.0	0.57	0.51337 ±0.12	13.2637 ±0.14	0.187384 ± 0.07	0.84226	2.2	2671.0 ±5.1	2698.6 ± 2.6	2719.3 ± 2.4/2.4
B	7	64.1	38.8	11030	205.7	1.3	0.559	0.52364 ±0.07	13.5412 ±0.11	0.187554 ± 0.05	0.93327	0.3	2714.6 ±3.3	2718.2 ± 2.1	2720.8 ± 1.6/1.6
C	6	73.5	44.3	4935	93.9	2.8	0.629	0.51104 ±0.15	13.1884 ±0.17	0.187171 ± 0.07	0.90082	2.5	2661.1 ±6.5	2693.2 ± 3.2	2717.5 ± 2.4/2.4
D	6	75.6	45.0	2583	48.8	5.5	0.632	0.50625 ±0.10	13.0602 ±0.15	0.187103 ± 0.1	0.7608	3.4	2640.6 ±4.3	2684.0 ± 2.8	2716.9 ± 3.2/3.2
Sample F: 08JAA010; albitite dike; UTM NAD 83; E591825, N5540775															
A	1.0	323.9	192.7	1018	20.6	10.5	0.457	0.52597 ± 0.10	13.6475 ± 0.14	0.18819 ± 0.09	0.791	0.1	2724.4 ±4.3	2725.6 ± 2.7	2726.4 ± 2.9/2.9
B	2.8	41.4	24.0	569	10.1	6.9	0.285	0.53034 ± 0.17	13.9014 ± 0.22	0.19011 ± 0.13	0.801	0.0	2742.9 ±7.5	2743.0 ± 4.1	2743.1 ± 4.3/4.3
D	1.8	16.4	8.4	342	5.6	2.8	0.002	0.50438 ± 0.33	12.8702 ± 0.39	0.18507 ± 0.21	0.844	3.0	2632.6 ±14	2670.2 ± 7.3	2698.8 ± 6.9/6.9
E	3.0	26.5	15.8	496	9.2	5.4	0.439	0.53015 ± 0.20	13.8994 ± 0.25	0.19015 ± 0.15	0.807	0.1	2742.1 ±8.9	2742.9 ± 4.6	2743.5 ± 4.7/4.8

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The bulk of the contained gold at Detour Lake is hosted by thick mineralized panels of rock, which developed at broad changes in rock ductility such as pillow flow–massive flow contacts, hyaloclastite–massive flow contacts, and ultramafic dike–structural zone contacts. In contrast to the Q vein zones and gold zones in the high-strain Chert Marker Horizon, the lithologically controlled gold zones, such as the Pillow Zone, are sites of relatively low strain. Much more complex fracture patterns and inconsistent directions of extensional lineations are the hallmark of fault and fracture systems, whose dilatant sites are best modeled by 3-D strain fields. Under such conditions, the orientation of large-scale layer ductility contrasts, or the 3-D bulk modulus of the rock, is related to (and controls development of) subtle dilatant zones in a low-strain environment.

The spatial relationship of gold mineralization to lithological contacts at Detour Lake is clearly illustrated on Figure 7 and Figures 13–15. Gold mineralization of this type (i.e., in dilatational low-strain zones controlled by large ductility contrasts in the rocks) has also been documented at the San Antonio Mine, Manitoba (Poulsen et al., 2000); in the Golden Mile Dolerite, Western Australia (Boulter et al., 1987); and at the Norbeau Mine, Québec (Dubé et al., 1989). Roughly stratabound, structurally controlled gold mineralized zones are noted at the Hallnor Mine, Ontario, where gold is hosted in hyaloclastites, and at the Dome Mine, Ontario, where gold is hosted in flow-contact subparallel veins (Brisbin and Pressacco, 1999).

The distribution of gold in the layered rocks of highly contrasting ductility, as exemplified at Detour Lake, is perhaps better explained by the application of 3-D strain models. Such models deal effectively with fracture propagation through layered media, with the interaction of pre-existing faults and rotational strain also being accounted for. The models generally produce much more complex, mesh-style fracture patterns. They also suggest that multiple orientations of fault-slip planes, extensional lineations, and subsequently variations in the orientation of gold-mineralized dilatant sites may occur (Nieto-Samaniego and Alaniz-Alvarez, 1997). Gold mineralization at the Detour Lake deposit does not rely on the presence and mineralization of a single preferred site; instead, the massive size of the deposit chiefly reflects the diverse array of lithological and structural environments that are gold-mineralized.

Conclusions

The Detour Lake gold deposit is an excellent example of how several key parameters culminate in the formation of an exceptionally large gold deposit. The deposit is located at or near a regional-scale antiformal closure, which places ultramafic rocks of the 2720 Ma lower Detour Lake Formation against sedimentary rocks of the ca. 2700 Ma Caopatina assemblage. The high-strain zones that host gold mineralization were formed originally as part of a south-verging thrust fault, the central part of which is known as the Sunday Lake Deformation Zone. Although the earliest movements across this deformation zone appear to be thrust-related, much of the gold mineralization is associated with vein systems that

Notes:

1 All zircons except for those from samples 08JAA011 and 08JAA010 have been air-abraded (Krogh, 1982). Those from the latter samples underwent chemical abrasion pretreatment (Scoates and Friedman, 2008); all zircons were processed and run as single grains.

2 Grain mass determined on Sartorious SE2 ultra-microbalance to ± 0.1 microgram, except for sample 06JAA014, with masses estimated based on grain volumes.

3 U concentration corrected for spike, blank 0.2 pg ± 50% at 2 sigma, and mass fractionation, which is directly determined with ^{233}U-^{235}U double spike.

4 Radiogenic Pb; corrected for spike, fractionation, blank and initial common Pb. Mass fractionation correction of 0.23% /amu ± 40% (2 sigma) is based on analysis of NBS-982 Pb reference material throughout course of study. Blank Pb of 0.5-2 pg ± 40% (2 sigma) with composition of $^{206}Pb/^{204}Pb$ = 18.50 ± 2%; $^{207}Pb/^{204}Pb$ = 15.50 ± 2%; $^{208}Pb/^{204}Pb$ = 36.40 ± 2%, all at 2 sigma. Initial common Pb compositions based on Cummings and Richards (1975) model Pb at $^{207}Pb/^{206}Pb$ age of grain or interpreted age of rock.

5 Measured ratio corrected for spike and fractionation.

6 Ratio of radiogenic to common Pb.

7 Total weight of common Pb calculated assuming blank isotopic composition.

8 Model Th/U ratio calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{206}Pb$ age.

9 Corrected for spike, fractionation, blank and initial common Pb.

10 % discordance to origin.

11 Age calculations are based on U decay constants of Jaffey et al., 1971.

Notes for JSGL analyses:

a) Laboratory blank Pb for the JSGL analyses assumes a composition of 206/204 - 18.221; 207/204 - 15.612; 208/204 - 39.360 (errors of 2%).

b) Where applicable, initial common Pb in excess of blank assumes the compositions based on Stacey and Kramers (1975) model Pb.

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most likely formed later under a transpressional, kinematic regime that was superimposed on early reverse movements.

All rocks in the Detour Lake Camp have experienced significantly higher metamorphic grades (lower amphibolite facies) than the lower greenschist facies grades found in gold deposits of the southern Abitibi Subprovince. The Detour Lake gold deposit has only a weak expression of the iron-carbonate-sericite-pyrite alteration assemblage that is characteristic of gold lodes hosted in lower greenschist facies rocks. Conversely, the Detour Lake deposit is characterized by biotite-actinolite-albite-pyrrhotite alteration assemblages that are more typical of amphibolite facies gold deposits (Phillips et al., 1998; Eilu et al., 1999; Hagemann and Cassidy, 2000). Generally, the strongest gold-mineralized zones are enveloped by a broad halo of secondary biotite that can extend more than 100 m into the hanging wall. Vein textures and petrographic fabrics suggest that the timing of gold mineralization at Detour Lake is syn-metamorphic to slightly post-metamorphic.

The major structural zones at Detour Lake appear to have had varied and protracted kinematic histories. The North Walter Lake Zone most likely was associated with a dextral–reverse high-strain zone that occupied the core of a regional-scale synform. Other major mineralized corridors (the Detour Main Zone or Chert Marker Horizon, and the M Zone) formed in high-strain zones that at the time of mineralization were predominantly sinistral and reverse in nature.

The many quartz veins that flank the Detour Main Zone are mainly steeply dipping, oblique fault-fill or shear veins. They formed subparallel to penetrative strain fabrics and are likely conjugate to the main structural zones, and have an opposing shear sense. Most of these veins do not have the overall geometries, alteration, and kinematic signatures of extensional gold veins. All vein systems at Detour Lake (both fault-fill and extensional) have been highly deformed by later processes that obscured and complicated kinematic interpretations of pre-deformation vein geometries.

The bulk of the gold mineralization at Detour Lake is contained within broad, low-strain, rheologically controlled mineralized zones. Most of these well-developed, large-volume mineralized zones are confined to pillow flow–massive flow contacts, hyaloclastite–massive flow contacts, and talc-chlorite-altered ultramafic rock–felsic dike contacts, with much weaker linkages to discrete vein systems than is typical of most gold deposits of the Archean Abitibi Subprovince.

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Appendix 1: Geochronological Methods

Sample preparation, geochemical separations, and mass spectrometry were done at the Pacific Centre for Isotopic and Geochemical Research in the Department of Earth and Ocean Sciences, University of British Columbia, on samples 08JAA-011, 06JAA-057, 07JAA-016, and 08JAA-010.

Zircon was separated from samples using conventional crushing, grinding, and Wilfley table techniques, followed by final concentration using heavy liquids and magnetic separation. Mineral fractions for analysis were selected on the basis of grain quality, size, magnetic susceptibility, and morphology. All zircon was pretreated (chemical abrasion) employing the technique outlined in Scoates and Friedman (2008). Single zircon grains were then dissolved in sub-boiled 48% HF and 14 M HNO_3 (ratio of ~10:1, respectively, ~75 µL total) in the presence of a mixed $^{233\text{-}235}U$-^{205}Pb tracer for 40 hours at 240°C in 300 µL PFA or PTFE Teflon microcapsules contained in high-pressure vessels (Parr™ acid digestion vessels with 125 mL PTFE liners). Sample

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solutions were then dried to salts at ~130°C. Zircon residues were re-dissolved in ~50 µL of subboiled 6.2 M HCl for 12 hours at 210°C in high pressure vessels. These solutions were transferred to 7 mL PFA beakers, and dried to a small droplet after addition of 2 µL of 0.5 N H_3PO_4.

Samples were then loaded on single, degassed, zone-refined Re filaments in 5 µL of a silicic acid–phosphoric acid emitter (Gerstenberger and Haase, 1997). Isotopic ratios were measured using a modified single collector VG-54R thermal ionization mass spectrometer equipped with an analogue Daly photomultiplier. Measurements were done in peak-switching mode on the Daly detector. Analytical blanks during the course of this study were 0.2 pg for U and 1.0 pg for Pb. Uranium fractionation was determined directly on individual runs using the $^{233-235}$U tracer, and Pb isotopic ratios were corrected for fractionation of 0.23%/amu, based on replicate analyses of the NBS-982 Pb standard and the values recommended by Thirlwall (2000).

Reported precisions for Pb/U and Pb/Pb dates were determined by numerically propagating all analytical uncertainties through the entire age calculation using the technique of Roddick (1987). Standard Concordia diagrams were constructed and regression intercepts calculated with Isoplot 3.00 (Ludwig, 2003). Unless otherwise noted, all errors are quoted at the 2σ level. Isotopic dates are calculated using the decay constants λ_{238}=1.55125E-10 and λ_{235}=9.8485E-10 (Jaffey et al. 1971).

Samples 06JAA-014 and 06JAA-067 were analyzed for U-Pb geochronology at the Jack Satterly Geochronology Laboratory (JSGL) at the University of Toronto. Weathered surfaces were removed, and each piece was subsequently washed and dried in the laboratory before further processing. Rocks were initially reduced in size using a jaw crusher, and then were reduced to sand-size particles using a disk mill. Wilfley table, heavy liquid, and magnetic separation techniques were then employed to obtain an initial concentration of zircon and other accessory minerals of high density.

From the least paramagnetic groups, highest quality zircon grains were handpicked under alcohol using a binocular microscope, with preferential individual grain selection made on the basis of clarity, as well as the absence of cores, cracks, alteration, and (Pb-bearing) inclusions. All zircon fractions were subjected to an air abrasion treatment in order to remove exterior portions of grains that may have experienced post-crystallization Pb-loss. Prior to dissolution, weights of abraded zircons were estimated by use of a scaled digital photographic measurement of the length and breadth of each grain and an estimate of the maximum thickness, together with the known density.

Following abrasion, selected zircons were washed briefly in warm 4N HNO_3, given a brief second cleaning in 7N HNO_3, and then transferred in a single drop of 7N HNO_3 into clean Teflon dissolution vessels together with concentrated hydrofluoric acid and a measured quantity of mixed ^{205}Pb-^{235}U isotopic tracer solution. Complete sample dissolution was accomplished over a period of approximately four days at a temperature of 195ºC. In all cases, zircon grain sizes were sufficiently small such that no ion exchange column chemical isolation and purification of Pb and U was necessary. Instead, fractions were dried down, re-dissolved in 3N HCl, dried down again with phosphoric acid and loaded directly with silica gel onto outgassed single Re filaments.

All of the isotopic compositions of Pb and U were determined on a VG354 mass spectrometer using a single Daly detector equipped with a digital ion counting system. System dead time corrections during the analytical period were 20 ns for both Pb and U. Corrections for Daly mass discrimination were 0.07% per a.m.u., while that for thermal mass discrimination was estimated at 0.1% per a.m.u. for both Pb and U. Isotopic compositions of Pb standard SRM982 were monitored throughout the course of this work. Laboratory procedural blanks at the JSGL are routinely at the 0.5 pg and 0.1 pg levels or less for Pb and U, respectively. In most cases, the measured total common Pb in the samples was low and was assigned the isotopic composition of the laboratory blank; in a few cases, however, higher common Pb contents could be correlated with the presence of inclusions or minor cracks in zircons and can be interpreted to represent initial common Pb, estimated here after Stacey and Kramers (1975).

Comprehensive error estimation was made by propagating all known sources of analytical error, including internal (within-run) ratio variability, uncertainty in the fractionation corrections for Pb and U (based on long-term monitoring of standards), and uncertainties in the quantities and isotopic compositions of the laboratory blank and initial common Pb. The decay constants used for the U-Pb system are those outlined in Jaffey et al. (1971). In most cases, ages and errors were calculated using the algorithms of either Davis (1982) or Ludwig (2003) and are equivalent. U-Pb Concordia diagrams were generated using the Microsoft Excel Add-in IsoPlot/Ex v.3.0 (Ludwig, 2003).