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GEOLOGY AND GOLD MINERALIZATION OF THE DUDER LAKE GOLD SHOWINGS, EASTERN NOTRE DAME BAY, NEWFOUNDLAND

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ABSTRACT

Structurally controlled, gabbro-hosted gold mineralization occurs at Duder Lake, northeastern Newfoundland. Discovered in 1988 by Noranda Exploration Company Limited, it is one of several recent gold finds in rocks of the eastern Dunnage Zone.

The mineralization is confined to wall-rock alteration adjacent to brittle low-angle Riedel shears. The gold occurs as fine intergrowths with pyrite, arsenopyrite, and minor sulphosalts, which formed contemporaneously with titaniferous, siliceous, and carbonate alteration. Mineralization style is manifested as disseminated, semi-massive, and stringer sulphides.

The Corvette and Goldstash prospects, as well as the Flirt showing, delineate a 4-km-long shear zone that hosts significant concentrations of gold. A third prospect, Stinger, was inferred to be related to a splay originating from the main structure.

The Duder Lake gold showings are hosted by late gabbroic dykes and sills that intrude rocks of the Davidsville and Botwood groups. This mineralization style is similar to other gabbro-hosted gold showings in the eastern Dunnage Zone.

INTRODUCTION

A study of the gold occurrences hosted by Siluro-Ordovician sedimentary and gabbroic rocks at Duder Lake was initiated in the summer of 1991, in conjunction with a regional gold-metallogeny project carried out by the Newfoundland Department of Mines and Energy (see Evans, *this volume*). This study, which forms the basis of a M.Sc. thesis by the first author, will focus on structural controls of mineralization and alteration, details of the alteration associated with gold mineralization, possible mineralizing fluid sources based on geochemical and isotopic studies, and affinity of the gabbroic bodies closely associated with mineralization at Duder Lake. This work will include grid and trench mapping, diamond-drill-core logging, and rock sampling for geochemical and isotopic analyses.

Duder Lake (Figure 1) is located approximately 3 km east of Birchy Bay, Notre Dame Bay. The area is readily accessible by logging roads from Birchy Bay that lead west and south of Duder Lake, and from Loon Bay that lead to the eastern and northern parts of the study area.

The gold showings at Duder Lake are located on a 9-km-long north-trending peninsula, which separates Duder Lake from Rocky Pond to the east and from Ten Mile Lake to the south. The peninsula is characterized by low relief, and elongate ridges that appear to be controlled by the geological structures that transect the peninsula. The southern part of the peninsula is heavily forested and contains numerous small bogs and dense alder beds; the northern areas have been cut over by recent logging.

The morphology south of Duder Lake, Rocky Pond, and Ten Mile Lake reflects regional northeast structural controls and bedrock grain. The region is covered by a thin till veneer and locally thick glaciofluvial deposits.

REVIEW AND REGIONAL SETTING

Duder Lake is located in the eastern Dunnage Zone of the Newfoundland Appalachians (Williams, 1979). The Dunnage Zone records the evolution, and subsequent destruction, of the Paleozoic Iapetus Ocean. The geological history of the Dunnage Zone is subdivided into two stages: pre-accretion and post-accretion.

Pre-accretion events include the development of island arcs and back-arc basins during the Cambrian to Middle Ordovician. These systems recorded both pre- and syn-accretion sedimentation, which is manifested as distal turbiditic sedimentation. Cessation of volcanism during the

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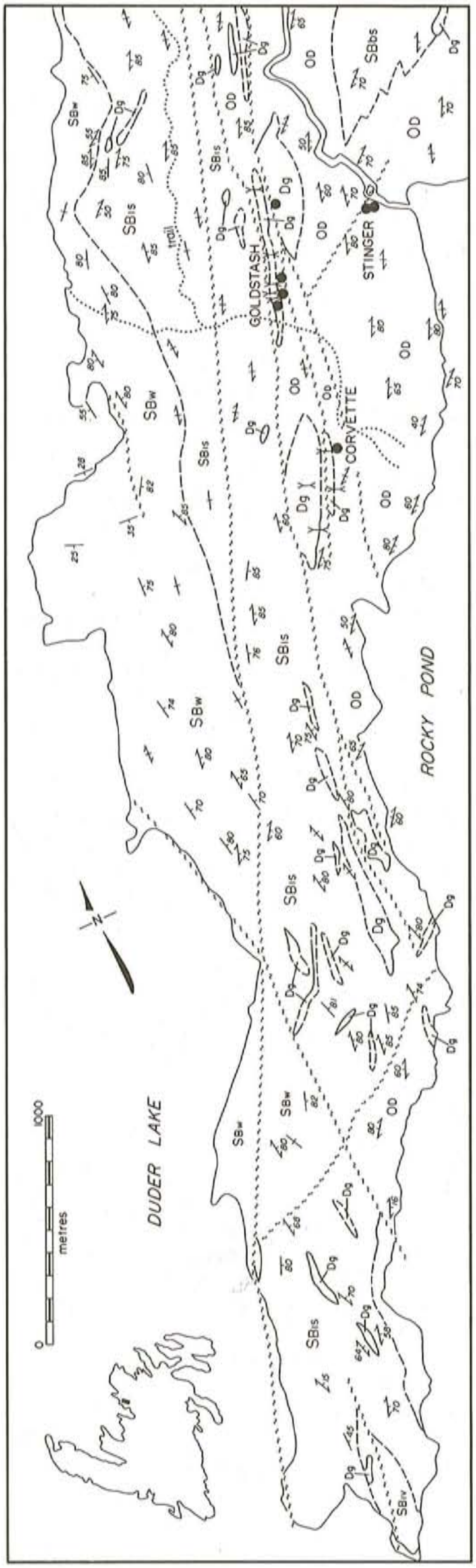

LEGEND

DEVONIAN

Dg — *Medium- to coarse-grained gabbro, diorite, and diabase, locally leucoxene rich. Primarily igneous layering sometimes present as well as pegmatitic textures in larger bodies. Usually dark-green but when altered, exhibits a distinct reddish-brown oxidation surface*

SILURIAN

Botwood Group

Wigwam Formation

SBw — *Red and green sandstone, and minor siltstone. Massive to locally laminated with crossbedding, and graded bedding. Siliceous and micaceous moderate cleavage developed locally*

Lower Unit

SBIv — *Pillowed basaltic flows and breccias; vesicular*

SBIs — *Undivided olive-green, green and red, and red siltstone, minor sandstone, and slate. Thinly interbedded with local massive units up to 25 m in thickness. Moderate to strong penetrative cleavage developed*

ORDOVICIAN

Davidsville Group

OD — *Dark-grey, green, and black slate with minor siltstone and fine-grained sandstone. Thinly interbedded and exhibiting a strong penetrative slaty cleavage*

Contact (defined, approximate)

Faults

Strike and Dip (dipping, vertical)

S_1 Schistosity (dipping, vertical)

Drill Road

Trench

Diamond Drill Hole

Figure 1. *Geology and location of gold prospects in the Duder Lake area, showing location of drillholes and trenches.*

Middle Ordovician corresponded with the emplacement of the Taconic allochthons. Continued closure of Iapetus resulted in flyschoid-sediment deposition in fault-bound basins of the east-central Dunnage Zone.

The Davidsville Group (cf. Kennedy and McGonigal, 1972) is a thick sequence of distal back-arc turbidites, which were fed from the older island-arc systems to the west, and were deposited on allochthonous oceanic basement delineated by rocks of the Gander River Ultrabasic Belt (Blackwood, 1982). This distinct belt of northeast-trending ultramafic rocks have been formally termed the Gander River Complex by O'Neill (1991).

Shelf-facies rocks of the Gander Zone pass conformably westward into rocks of the Dunnage Zone in north-central Newfoundland. The Dunnage Zone is interpreted to be regionally allochthonous upon rocks of the Gander Zone (Colman-Sadd and Swinden, 1984).

Post-accretionary events include deposition of the Silurian Botwood and Indian Island groups. During the Late Ordovician to Middle Silurian, regional-scale transcurrent discontinuities were either activated or reactivated causing the development of pull-apart basins (Szybinski *et al.*, 1990) and crustal anatexis resulting in widespread epicontinental-style volcanism (Coyle and Strong, 1987). Basin infilling was characterized by the deposition of fluviatile- to shallow-marine facies accompanied by subaerial volcanism forming the Botwood and Indian Island groups.

The Botwood Group comprises grey to red micaceous sandstone and siltstone, minor fossiliferous calcareous beds, and conglomerate (Williams, 1964). The Indian Islands Group consists of phyllitic slates, quartzitic and calcareous sandstone, thin limestone lenses, and conglomerate (Baird, 1958). Patrick (1956) also identified minor felsic volcanic rocks intercalated with this unit.

The intense deformation and plutonism prevalent in the eastern Dunnage Zone, originally thought to be related to Acadian deformation, is now considered to have resulted from a Silurian orogenic event (Dunning *et al.*, 1990).

Rocks of both the Botwood and Davidsville groups record the deformation as a regional, northeast-trending penetrative cleavage (S_1), which is axial planar to isoclinal folds. Cleavage in the Davidsville Group is slaty and relatively well developed; in contrast, the Botwood Group does not exhibit this slaty characteristic and cleavages are only well developed, in local instances, where cleavage is strongly developed by regional shearing. Second-phase deformation (S_2) is typified as small conjugate kink bands and minor open to moderately tight southward-plunging folds that fold the F_1 axial-planar cleavage (Blackwood, 1982). Metamorphism is confined to lower-greenschist facies.

Intruding both the Davidsville and Botwood groups are small, fine- to coarse-grained gabbroic sills and dykes, which appear to be most prevalent at, or near, the contact between the two groups. These gabbroic bodies are generally undeformed except where they have been sheared by movement along north- to northeast-trending brittle shear zones. These gabbroic rocks are observed elsewhere in the eastern Dunnage Zone. Mafic plutonic rocks were observed to intrude both Davidsville and Botwood groups in the Gander River area and form part of the Mount Peyton Intrusive Suite (Blackwood, 1982).

PREVIOUS WORK

The first recorded geological survey of north-central Newfoundland was done by Murray and Howley in 1881. This was a regional mapping investigation, in which the geology was examined in eastern Notre Dame Bay, the Gander River, and Gander Lake areas. Several regional studies have encompassed the study area.

A geological survey of the Notre Dame Bay area was undertaken by Kranck (1952). Part of the study focussed on the geology in the vicinity of Loon Bay. Kranck (1952) noted six different units comprising the stratigraphy of this area as well as the strong deformation present. Patrick (1956) examined the geology in the Comfort Cove map area (NTS 2E/7) and assigned rocks in the Duder Lake area to the Springdale Group. He defined two sedimentary units in the vicinity of Duder Lake. The westernmost unit was described as red, brown, grey, and green quartzite and quartzitic sandstones. The unit to the east was described as red, brown, grey, and green slates, argillites and shales. In addition, small gabbroic dykes and sills of Devonian age were recorded outcropping along the southeast shore of Duder Lake. Williams (1964) undertook a study to compile the geology, complete initial geological mapping, and to investigate the mineral deposits in northeast Newfoundland. In the Duder Lake area, he identified two different units: a Silurian-aged unit composed of red and grey micaceous sandstone and siltstone, conglomerate, shale, coralline shale, and limestone; and an Ordovician-aged unit consisting of grey to black slate and siltstone, greywacke and minor volcanic rocks. The Silurian-aged unit was mapped as part of the Botwood Group whereas the Ordovician-aged unit was determined to be part of the Gander Lake Group.

Several regional stratigraphic, tectonic, and structural studies have focussed on the Silurian and Ordovician stratigraphy of north-central Newfoundland. Most notable is the work of Twenhofel and Shrock (1937); Heyl (1937); Williams (1967); Kay (1967); Horne and Helwig (1967); Dean (1977, 1978); Nelson and Casey (1978); Arnott *et al.* (1985) and Goodwin and O'Neill (1991).

Since 1980, the eastern Dunnage Zone has become the focus of extensive gold exploration after the discovery of quartz-vein-hosted gold mineralization in the Jonathan's Pond area (Blackwood, 1982).

The Newfoundland Department of Mines and Energy, in 1988, released the results of a regional lake-sediment geochemical survey, which yielded anomalous Au, Sb, and As over a wide area in the eastern Dunnage Zone (NTS 2E, Davenport and Nolan, 1988). The highest concentrations of As and Sb were located at Duder Lake, Rocky Pond, and Ten Mile Lake. This prompted exploration companies, such as Noranda Exploration Company Limited, to stake ground in the immediate area since the Au–As–Sb association usually accompanies Au mineralization.

As a result of prospecting and soil geochemical surveys, several significant gold discoveries were made in rocks of the Davidsville and Botwood groups (Green, 1989; Tallman, 1990).

LOCAL GEOLOGY

The Duder Lake area encompasses the contact between the Botwood and Davidsville groups. Mapping by Noranda geologists in 1988 and 1989, and by the authors in 1991, have identified outcrops of both the Botwood and Davidsville groups. These units are present as north-trending belts, which divide the area separating Duder Lake from Rocky Pond (Figure 1). The Botwood Group is subdivided into two units: the Wigwam Formation (Dean, 1977), and a sequence of undivided olive-green, greenish-red sandstones and siltstones informally named the 'lower unit'.

Intruding these sedimentary units are gabbroic dykes and sills, which are important to mineralization.

Deformation within the Duder Lake area is recognized as a well-developed, penetrative cleavage (S_1), which parallels the regional fabric (Plate 1) and is axial planar to F_1 folds produced during the regional deformation. Lower hemisphere projections of the structural data (Figure 2) indicate that cleavage orientation is northeast trending and has variable inclinations from shallow dipping to vertical (Figure 2a). The bedding plane data (S_0) is observed to be quite varied in orientation and dip. However, a π-girdle can be constructed through the data points, which infers that the fold-axis trends in a northerly direction (Figure 2b).

Comparing the two plots, it is apparent that the cleavage is axial planar to the folding, which reaffirms the regional structural relationships.

BOTWOOD GROUP

Wigwam Formation

This unit is exposed along the western and eastern shorelines of Duder Lake. It is characterized by massive and locally laminated, maroon micaceous sandstone and siltstone containing minor conglomeratic lenses and beds. These rocks contain abundant shallow-water sedimentary structures such as convoluted bedding, dessication cracks, crossbedding and ripple marks. Bedding planes dipping steeply toward the east and south and the variations in attitudes can be attributed to broad open-folding.

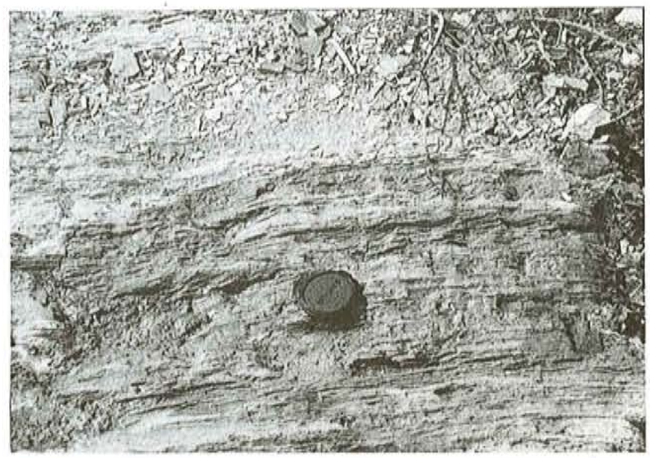

Plate 1. *Penetrative axial-planar cleavage representative of the S_1 deformational fabric at Duder Lake.*

Deformational fabrics are not well developed, but intense S_1 cleavage is developed and locally parallels the regional fabric.

Lower Unit

This informally termed sedimentary unit forms a second north-trending belt to the east of the Wigwam Formation, separating the Wigwam Formation and the Davidsville Group. The contact with the Wigwam Formation appears to be fault-modified but conformable. Although classified as part of the Botwood Group, the sedimentary rocks of this unit also have features similar to those of the Davidsville Group.

This unit is divided into two subunits–one sedimentary and the other dominated by mafic vesicular pillow basalts, flows, and breccias. Williams (1964) observed that the Botwood Group contained red, green, and purple amygdaloidal lavas, agglomerates, siliceous tuff, and minor sandstone, which may be intercalated with terrestrial micaceous sandstones and siltstones of typical Botwood Group affinity.

The sedimentary unit comprises locally micaceous, olive green, greenish-red, and red siltstone, minor sandstone, and slate. These rocks are thinly interbedded but contain local massive units of undivided sandstone and siltstone up to 25 m in thickness. Detrital mica content is observed to decrease eastward toward the Davidsville Group. This unit exhibits a moderate to strongly developed cleavage, which becomes slatey toward the contact with the Davidsville Group. The contact between this unit and the Davidsville Group is inferred to be a fault-modified gradational contact.

To summarize, it would appear that the lower unit records a transition between the Wigwam Formation and the Davidsville Group, which has been observed elsewhere in the eastern Dunnage Zone (Blackwood, 1982). The variable detrital mica contents observed in rocks of the Davidsville and Botwood groups reflect the different provenance of both

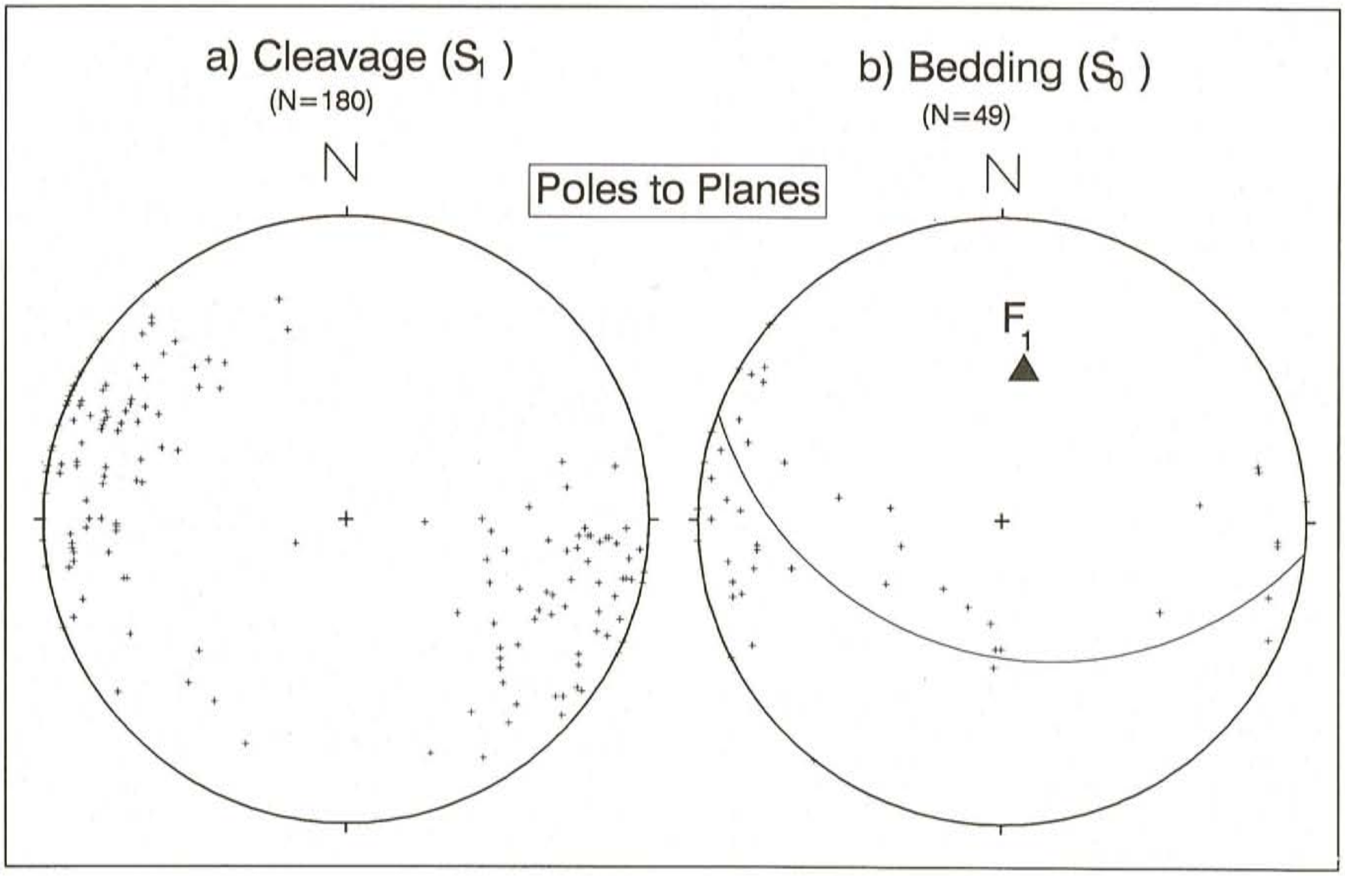

Figure 2. *Lower hemisphere projections for structural data collected from Duder Lake. (a) cleavage, (b) bedding. Data is presented as poles to planes (refer to text for discussion).*

groups. Sedimentary rocks of the Davidsville Group were derived from the island-arc systems to north and west. Evolution of the basin infilling denoted a shift in provenance during earliest Silurian times. An easterly mica-rich source region supplied the material that formed the Botwood Group. Blackwood (1982) suggests that this source was the high-grade metamorphic terrane of the Gander Zone lying to the east.

DAVIDSVILLE GROUP

The Davidsville Group in the Duder Lake area comprises a monotonous sequence of dark-grey, green, and black slate, associated with minor siltstone, fine-grained sandstone, and minor carbonaceous sandstone and siltstone. These rocks are thinly interbedded and exhibit strong penetrative slaty cleavage, which is axial planar to the F_1 folds. This fabric is locally crenulated.

GABBROIC DYKES AND SILLS

Numerous small gabbroic bodies intrude all units in the Duder Lake area. The bodies are typified by dykes and sills—some of which still possess primary igneous layering.

The gabbroic rocks have varied mineralogical compositions and two distinct gabbro types can be delineated: melanocratic and leucocratic. Melanocratic gabbros appear to be more refractory and have an abundance of Fe- and Ti-rich minerals. The leucocratic gabbros contain less of these minerals, thus yielding a lower colour index (Plate 2).

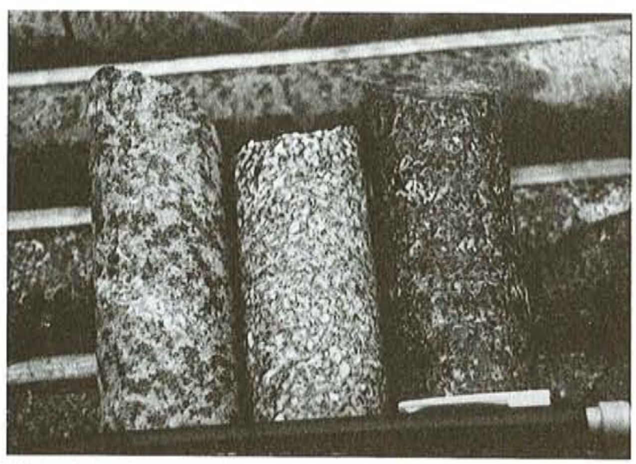

Plate 2. *Compositional and textural variety observed in the gabbro from drill core.*

Preliminary results indicate that only the melanocratic gabbros that intrude the Davidsville Group, host significant mineralization.

The textures of the gabbroic intrusions are variable ranging from extremely coarse grained in the sills to fine grained (almost aphanitic) in the dykes. Coarse pegmatitic pods of gabbroic material occur in some of the coarser grained gabbros. The gabbros are typically undeformed except when found proximal to the north-trending shears. In such cases, the gabbros exhibit well-developed schistosity. The gabbros appear to be related to the lineaments transecting the area and are shown in Figure 1. A two-stage model is derived for their emplacement and subsequent deformation: 1) Activation of the north-trending structures may have supplied enough frictional heating at depth to allow for small-scale crustal melting giving rise to the gabbroic rocks; and 2) subsequent movement of the structures, either during activation or later reactivation, caused the deformation observed in these rocks.

GOLD MINERALIZATION

In the Duder Lake area, exploration programs were carried out by Noranda Exploration Company Limited and their joint-venture partner Noront Resources, during 1988 and 1989. As a result of prospecting and regional till- and soil-geochemical surveys, three gold prospects (Figure 2) and one gold showing were outlined in the Duder Lake area—Goldstash, Corvette, Stinger, and Flirt (not shown on figure), respectively. All four mineralized zones are spatially related to a south-trending, 4-km-long shear zone. Assays from the Goldstash Showing drill-core yielded 4.2 g/t over 7.8 m, of which 2.8 m of this interval ran 6.4 g/t. Trench sampling from the same showing yielded an average grade of 12.8 g/t over a 2.6 m interval.

Evans (1991, *this volume*) defined several styles of gold mineralization after documenting gold showings in the eastern Dunnage Zone. This classification nomenclature will be utilized in the discussion on the gold mineralization at Duder Lake.

Goldstash, Corvette, and Flirt (Type 1)

The Goldstash and Corvette showings at Duder Lake are both hosted by gabbros that intrude rocks of the Davidsville Group. The style of mineralization at these showings is structurally controlled and is termed Type-1 Disseminated Mesothermal Mineralization (gabbro-hosted).

Gold mineralization is largely confined to the wall rock and is controlled by brittle structures, which appear to be low-angle Riedel shears that trend 000 to 010° (Green, 1989) and originate from the regional shears. The highest gold grades are found in wall-rock mineralization.

Alteration assemblages adjacent to the shears delineate an alteration halo, which decreases in intensity away from the shear. This halo is comprised of three zones:

1) Alteration within the shear is intense Fe-oxidation with accompanying Fe-carbonate—carbonate—quartz-alteration phases. In addition, small shear-parallel, barren, quartz—carbonate veins are present, locally. Extensive weathering of this lateration style combined with the jointing pattern, produces a 'blocky' alteration pattern similar to that described by Evans (1991) from Clutha (Plate 3). Mineralization is confined to the sheared gabbroic rock and comprises finely disseminated pyrite and arsenopyrite.

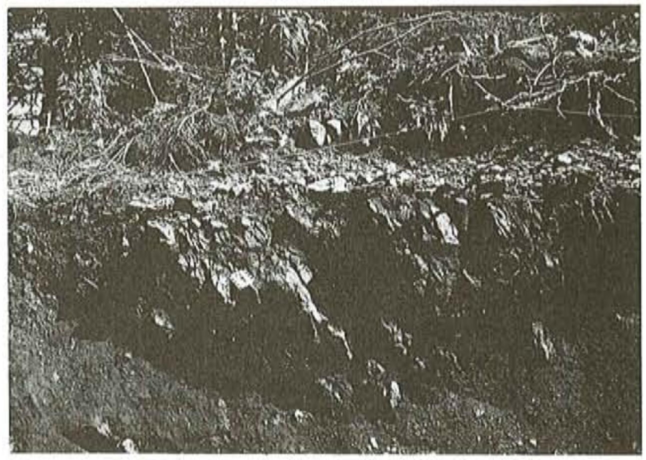

Plate 3. *Recessive weathering and accompanying 'blocky' alteration pattern of mineralized shear structure as observed in trench wall.*

2) The next alteration assemblage found immediately adjacent to the shear is delineated by intense wall-rock alteration, where the gabbroic host is almost completely replaced by silica and carbonate. Such alteration attests to the volume of silica- and carbonate-rich fluid that must have been localized and transported by the shear. This is the zone that contains the most significant economic concentrations of gold, pyrite, and arsenopyrite mineralization.

3) The third alteration assemblage is characterized by quartz—sericite—leucoxene. This zone passes gradationally into relatively fresh gabbro. Mineralization in this zone occurs as very fine disseminations of pyrite and arsenopyrite in low concentrations.

Leucoxene is a common mineral phase present in all the showings. At present, its relationship with unaltered gabbro undergoing hydrothermal alteration is undetermined. However, intense leucoxene alteration (almost 90 percent) can be observed in drill core and in the trench at the Corvette Showing. Such abundance of a TiO_2-rich amorphous mineral phase would imply that the gabbro was initially rich in ilmenite or rutile.

The size of the alteration haloes are proportional to the size of the shear that produces them. The zonation depicted in Figure 3 was the result of the development of a 0.75-m-

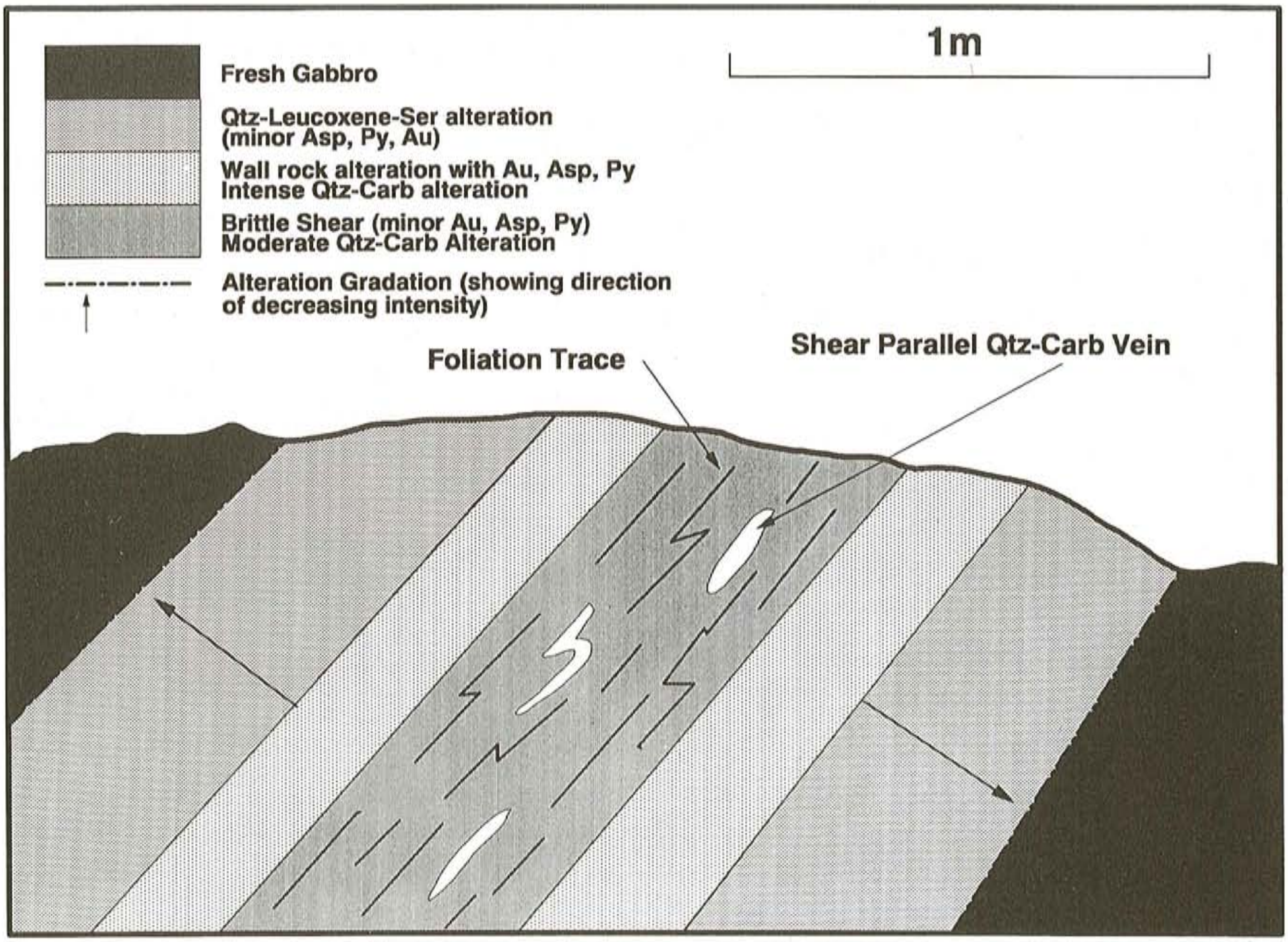

Figure 3. *Schematic diagram showing the features observed in trench from the Goldstash Showing. Note the alteration halo and accompanying mineralization surrounding the brittle shear.*

wide shear. In this instance, the entire zonation spanned a distance of approximately 1 to 1.5 m on either side of the shear.

Stinger Prospect (Type 2)

Evans (1991) stated that the Stinger Prospect comprises sediment-hosted auriferous quartz–carbonate veins with accompanying carbonatization and silicification developed in carbonaceous fine-grained slates and siltstones. Further work is required on this showing since it was not accessible during the time spent at Duder Lake (high water levels did not allow the first author to investigate the mineralized zones that outcrop in Rocky Pond River).

GEOCHEMISTRY

Preliminary data, shown in Figure 4, illustrate some of the bulk chemical characteristics of the fresh, altered, and mineralized gabbros. The distinction between these three gabbro types are based on their field appearance. Fresh gabbros contain no appreciable alteration or mineralization. Altered gabbros are representative of the alteration zonations observed at sites of mineralization and possess little or no pyrite–arsenopyrite mineralization. The mineralized gabbros are typically intensely silicified and carbonatized and contain appreciable concentrations of sulphides. The plot of Log Cr versus Log Ni (Figure 4a) does not discriminate between any of the three gabbro types, implying no appreciable Cr or Ni was exchanged with the mineralizing fluids. As a result, the Cr and Ni concentrations probably reflect pre-alteration concentrations.

Ternary plots of Cu–As–Zn and Cu–Pb–Zn (Figure 4b) characterize bulk chemical changes that occurred during alteration and mineralization. The mineralized gabbros show a bimodal distribution of arsenic from values, which correspond to original fresh gabbro to concentrations in excess of 40,000 ppm. This would suggest that As was being brought into the system from an exterior source, and its concentration does not reflect original compositions.

Further geochemical work will better characterize the geochemical changes observed in the system and should lead to some inference of fluid composition and/or source.

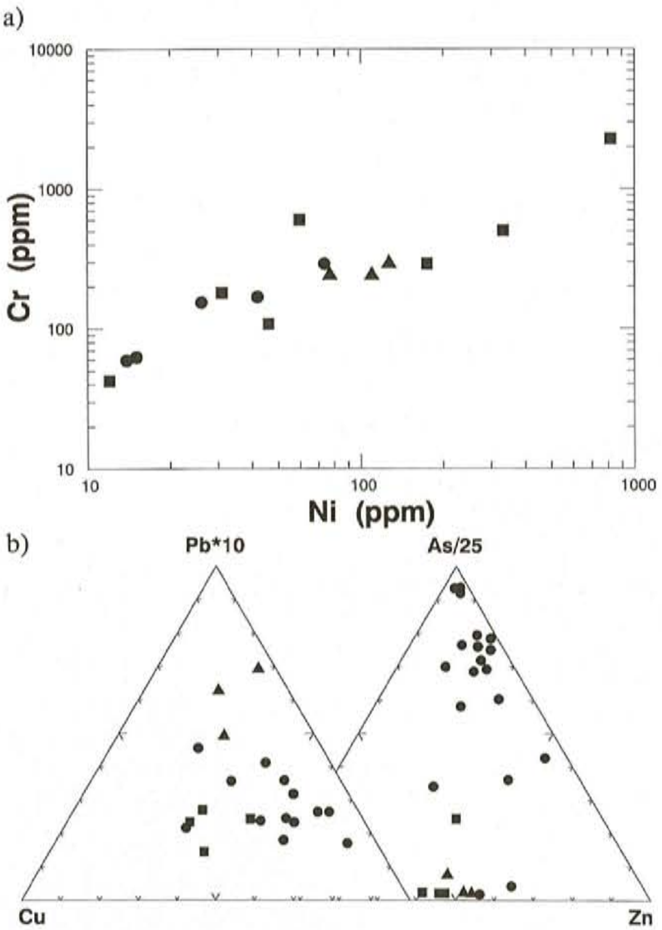

Figure 4. *Geochemical plots of fresh gabbros (squares), altered gabbros (triangles), and mineralized gabbros (circles). a) Plot of Log Cr versus Log Ni. b) Ternary plots of Cu–Pb–Zn and Cu–As–Zn.*

DISCUSSION

The styles of mineralization observed at Duder Lake are comparable to similar gold mineralization found elsewhere in the eastern Dunnage Zone. The preliminary investigation at Duder Lake implies that alteration and mineralization is strongly controlled by structure. Evans (*this volume*) suggests that the style of mineralization observed at Duder Lake is reminiscent of mesothermal-style mineralization. Although valid for the structural controls on mineralization, lode-gold mineralization has not been observed in the vein networks at the Goldstash Showing. It appears that mineralization is best developed in wall-rock alteration, which is accompanied by intense silicification and carbonatization.

Since mineralization is confined to gabbros, which have been sheared by second- and third-order structures, it would imply that they must be rheologically suitable as a site for mineralization. Compared to the surrounding rocks, the gabbros would be enriched with respect to Mg and Fe. This mechanism is not suitable to explain mineralization at the Stinger Prospect, which is sediment-hosted. The carbonaceous nature of the sandstones and siltstones at the Stinger Prospect may control fluid precipitation.

Barley and Groves (1990) state that a degree of disequilibrium is produced when auriferous fluids rich in silica and carbonate interact with rocks having a high Fe/(Fe+Mg) ratio. As a result of disequilibrium, the system becomes unstable and precipitates pyrite, arsenopyrite, and gold. A similar situation can be ascribed for the Stinger Showing, as the organic carbon found in the rocks would lead to chemical reduction if the fluid was originally oxidized (Stokes *et al.*, 1990).

The silicification and carbonatization observed accompanying deformation can be likened to the brittle-ductile transition zone of mesothermal deposits, which possess a vertical gold zonation (Colvine *et al.*, 1988).

Presently, drill-core and trench observations infer that, if the model is valid, only the uppermost part of the vein systems are being seen (i.e., the uppermost part of the brittle-ductile transitionary zone).

The sedimentary packages of the eastern Dunnage Zone have been affected by the Silurian orogenic event resulting in high-heat flow, intense brittle and even ductile transpressive structure development, which may reach deep-crustal levels, and an abundant supply of H_2O- and CO_2-rich fluids, which would be focussed up along these major crustal discontinuities ultimately culminating in gold mineralization at upper crustal levels (Kerrich, 1989; Sibson *et al.*, 1988).

Future investigations in the Duder Lake area will concentrate on the structural constraints placed on mineralization and alteration, the affinity of the gabbroic bodies, better constraint on the Davidsville–Botwood contact, and geochemical and isotopic evidence to deduce a genetic model for these showings. The completion of these tasks will hopefully give insight into the regional significance of the Duder Lake showings and analogous gold and base-metal showings elsewhere in the eastern Dunnage Zone in an effort to develop a regional exploration model for this region.

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