

# Preliminary Results of Geological and Geochemical Studies at the Stirling Deposit with Emphasis on Quartz-talc-carbonate (QTC) Rock Associated with Massive Sulphide Ore

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## Introduction

The Stirling massive sulphide deposit, located in southeast Cape Breton Island (NTS 11F/09; Fig. 1), was initially discovered as a copper prospect in the 1890s, but over the next few decades the zinc-rich nature of the deposit was realized (up to 30 wt. % Zn over several feet; Cairnes, 1917). The deposit was developed in the 1930s and 1950s as an underground massive sulphide mine with production of about 1.2 million tonnes of ore with 6.4% Zn, 1.5% Pb, 0.74% Cu, 2.2 oz./ton Ag and 0.03 oz./ton Au (Miller, 1979). Underground mining was initially carried out using a single shaft, but in the 1950s a second, deeper shaft was developed that accessed ore to the 850 ft. level. Exploration on the property and adjoining areas has continued intermittently over the past 40 years.

Because of the lateral continuity of the deposit, its location within a shear zone, and the appearance of replacement textures, the deposit was originally considered to have formed as a result of magmatic-related solutions ascending a shear or fault zone and replacing the host felsic volcanic rocks (Alcock, 1930; Weeks, 1924, 1954; Watson, 1954, 1957, 1959). However, as a result of new theories on the origins of volcanogenic-hosted massive sulphide deposits in the 1970s, the Stirling deposit was re-interpreted as being of exhalative origin (Poole, 1974; Miller, 1979), based on analogies with younger, less deformed massive sulphide deposits such as those found in Japan.

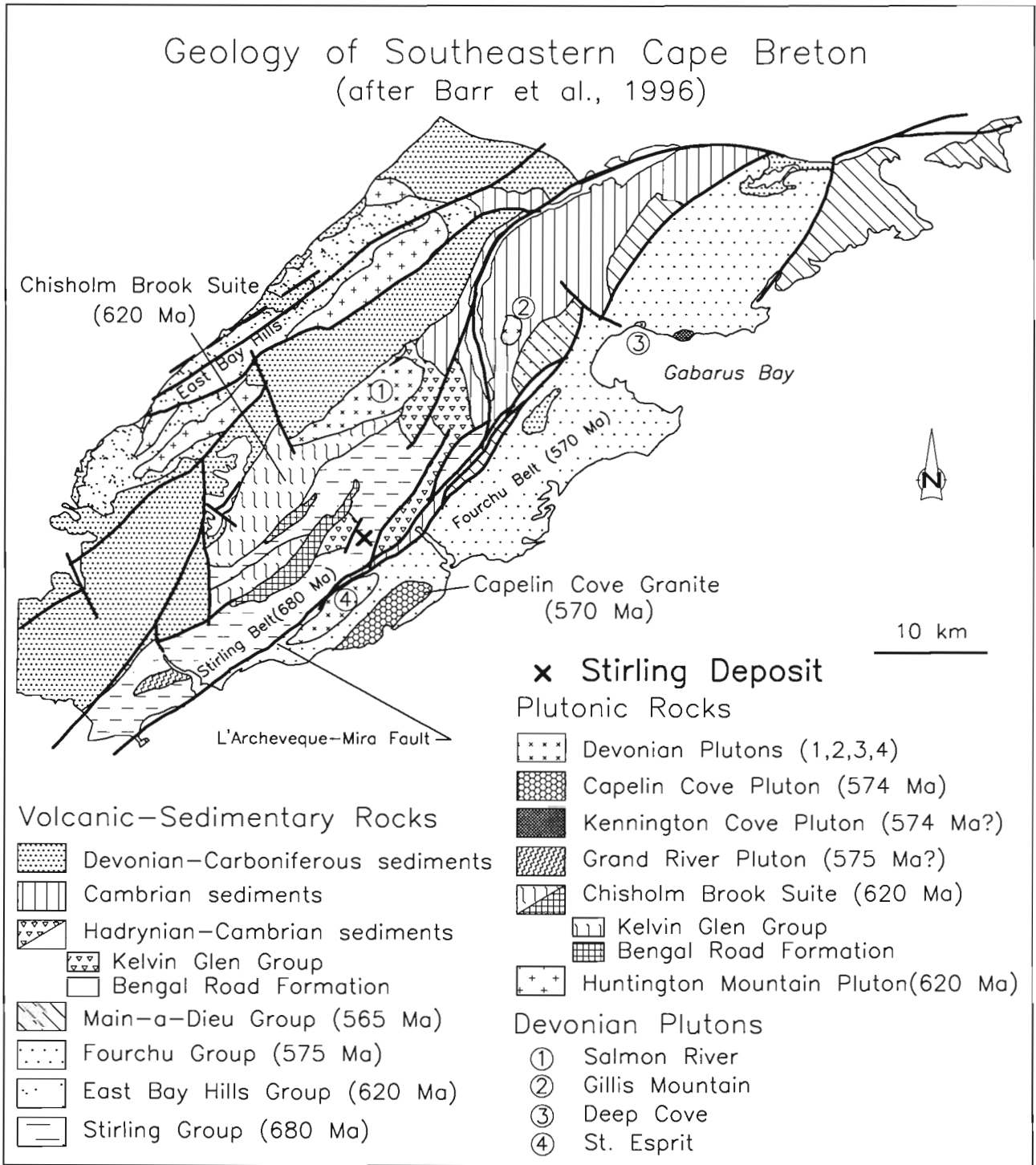
This paper summarizes the initial results of field work conducted at the Stirling deposit during the 1997 field season, along with follow-up petrological work and compilation of data in assessment reports. Field work was restricted to the mine dumps, the area around the Glory Hole, and river traverses northeast of the deposit. Conclusions are preliminary in nature, as more work is planned for the forthcoming field season, including logging of drill core.

## Regional Geology

The geology of southeast Cape Breton Island has recently been summarized by Barr *et al.* (1996) and is shown in Figure 1. The Mira terrane is dominated by four Late Hadrynian volcanic-plutonic belts separated, from east to west, into the Fourchu (ca. 570 Ma), Main-a-Dieu (ca. 70 Ma), Stirling (ca. 680 Ma) and East Bay Hills (ca. 620 Ma) groups. These rocks have been intruded by Late Hadrynian (ca. 620 Ma, ca. 570 Ma) and Devonian-Carboniferous plutonic suites of mafic to felsic composition. The Fourchu and Stirling groups are separated by the Mira-L'Archeveque Fault and the East Bay Hills Group is surrounded by Carboniferous rocks. The Main-a-Dieu Group, probably a lateral equivalent of the Fourchu Group, is fault bounded against the Fourchu Group. Late Hadrynian to Cambrian sedimentary rocks infilled fault-bounded basins developed within the volcanic-plutonic belts.

The Stirling deposit is located within the ca. 680 Ma Stirling Group. This group consists of mafic and felsic volcanic and volcanoclastic rocks of epiclastic origin interbedded with lenses of fine- to coarse-grained clastics composed of detritus from the volcanic rocks. The Stirling Group was interpreted by Macdonald and Barr (1993) to have been deposited within and around a trough flanked by volcanic centres in an intra-arc setting. Relevant with respect to massive sulphide mineralization are observations that sedimentary structures (rip-up clasts, graded bedding, basal scours) in litharenites (unit Hsla of Barr *et al.*, 1996) indicate subaqueous mass transport with deposition below wave base (Macdonald and Barr, 1993; observations of DJK). Thus, even though the felsic and mafic volcanic rocks show little evidence of subaqueous deposition, the intermixed sedimentary rocks provide clear evidence of such a setting.

Structurally, the Stirling Group is variably deformed, with northwest-southeast directed compression and



**Figure 1.** Regional geological map of southeast Cape Breton Island showing the distribution of Late Hadrynian volcanic-sedimentary packages and intrusive rocks with younger overlapping sequences and plutonic rocks. Location of the Stirling Zn-Pb-Cu-Ag-Au deposit is indicated within the 680 Ma Stirling Group rocks.

northeast strike-slip movement, such that highly strained, mylonitic zones grade into less deformed areas over distances of tens of metres. The most intense deformation

on a regional scale occurs proximal to the Mira-L'Archeveque Fault (Fig. 1).

## Deposit Geology

### General Setting

The geology of the Stirling deposit and surrounding area (Fig. 2) consists of a variety of sedimentary rocks, mafic and intermediate flows, and felsic units, both extrusive and intrusive (i.e. domes or subvolcanic intrusions), that are intruded by mafic sheets and dykes (Cormier, 1951; Roscoe, 1975; Mosher, 1979; Hunter and Anderson, 1975; Miller, 1979; Macdonald, 1989). Many of these previous workers have noted that the stratigraphy youngs to the northwest and that the rocks beneath the deposit area are dominantly felsic, whereas along strike and stratigraphically overlying the deposit intermediate volcanics and sediments dominate with rare occurrences of felsic rocks. In addition, the stratigraphy thickens to the northeast and down-dip of the deposit, which suggests

that basin-like conditions existed. Complicating interpretation of the geology are the following: (1) lateral facies changes, (2) uncertainty of whether felsic and volcanic units are flows, sills or subvolcanic plugs, (3) presence of a variety of alteration types (carbonate, silica, sericite, epidote), and (4) overprinting of the rocks by intense deformation. In the following section these aspects of the geology are addressed with the intent of emphasizing the difficulty in determining the stratigraphy, which is critical in evaluating the nature and origin of mineralization, as well as its economic potential.

### Mine Stratigraphy

The general stratigraphy in the deposit area is given below, from oldest to youngest, based on the detailed work of Hunter (1989) and modified from observations made during the field season. Note that the stratigraphy

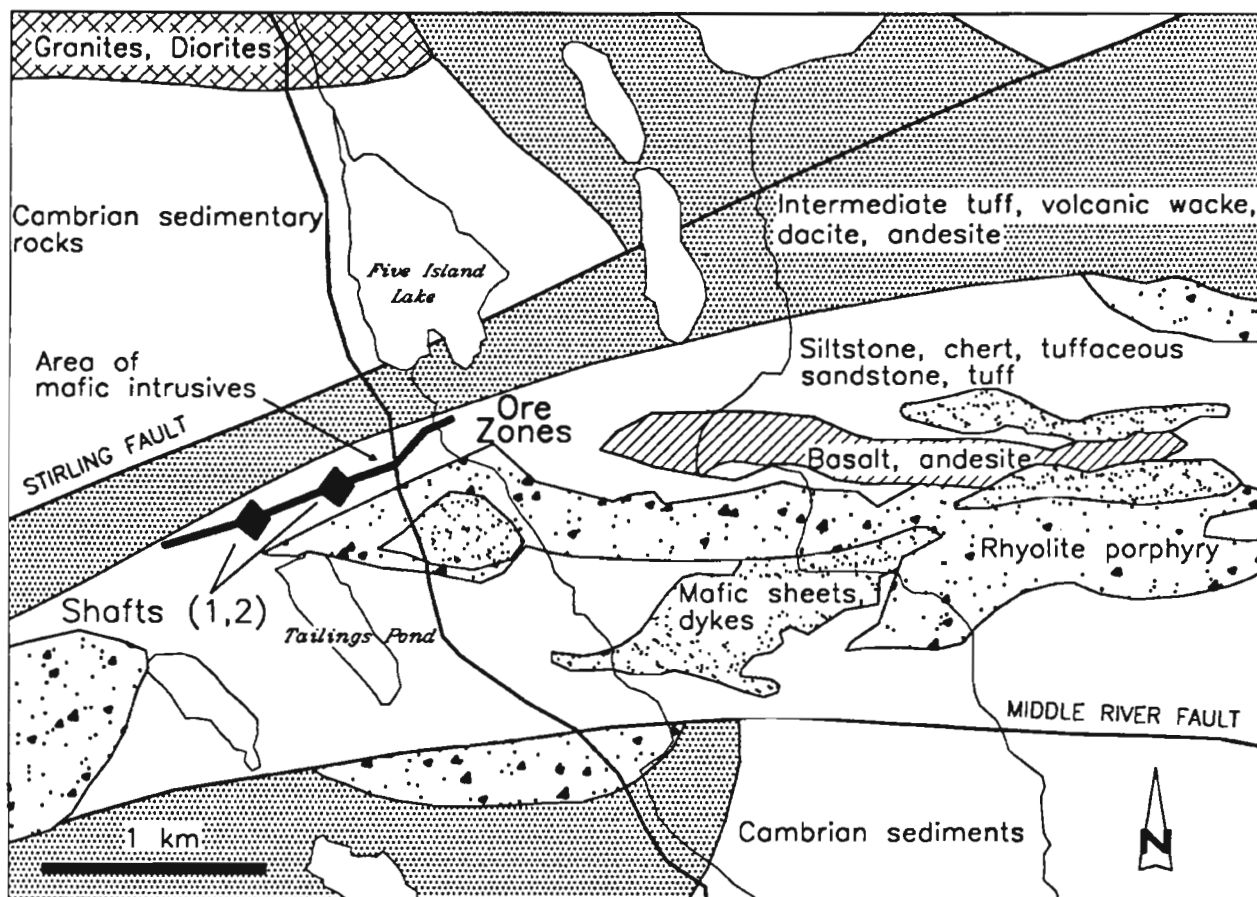


Figure 2. Geological map of the Stirling area (modified after Macdonald, 1989) showing distribution of the main rock types, projection of the ore zones, locations of the two shafts that accessed the deposit (#1 and #2), and the tailings pond.

given in Figure 3 (after Hunter, 1989) does not include the oldest unit in the following discussion.

(1) A package of mixed volcanic and sedimentary rocks consisting of intermediate-mafic flows and tuffs, laminated siliceous siltstone and chert, and tuffaceous siltstone, greywacke and crystal tuffs. These rocks appear on all the maps as a mixed package with no subdivisions made, presumably because of limited outcrop. It is possible that the massive mafic rocks may represent sills.

(2) Variably coloured (grey, buff, purple, green) felsic-rhyolitic rocks that include: (a) coarse quartz-feldspar porphyries, (b) massive aphyric units, (c) tuffaceous rocks and (d) agglomerates. This unit forms an elongate, northeast-trending body with a distinct convex-up shape interpreted to be a volcanic or subvolcanic centre. Within these rocks there are zones of intense alteration, also illustrated by chemical analysis (e.g. Miller, 1979), and locally they are highly strained with mylonitic zones present. These rocks are well exposed along river sections (e.g. Framboise River, Middle Framboise River, Copper Brook). In thin section the rocks contain spherulitic textures (Fig. 4a) and rare granophyric-textured fragments (Fig. 4b). Earlier work by Cormier (1951) suggests both intrusive and extrusive components to the unit.

(3) The ore zone includes: (a) massive sulphide ore, and (b) quartz-talc-carbonate (QTC) rock with variable amounts of sulphide minerals. This unit is referred to by Hunter (1989) and Miller (1979) as being of exhalative origin, hence the term sinter deposits in the stratigraphic column of Figure 3. The QTC rock is characterized by a well-laminated texture and in thin section both this and colloform textures are seen to coexist (Fig. 4d), which Watson (1954) was first to discuss in detail (see below). From underground plans it is also apparent that felsic volcanic rocks occur in this zone, but their stratigraphic position may have resulted from subsequent structural modification rather than being original, as discussed below.

(4) A volcanic-sedimentary unit which includes a sequence of variably coloured pyritic mudstone-siltstone and chemical sediments of both cherty and calcareous nature. Boulders of this unit are abundant near shaft #2, but also occur throughout the deposit area. A slab of this rock is shown in Figure 5a with a matching photomicrograph (Fig. 5b). The rock is well laminated with both planar and graded bedding present. In addition, abundant fine-grained carbonate cement and euhedral pyrite occur in the coarser parts of the sample.

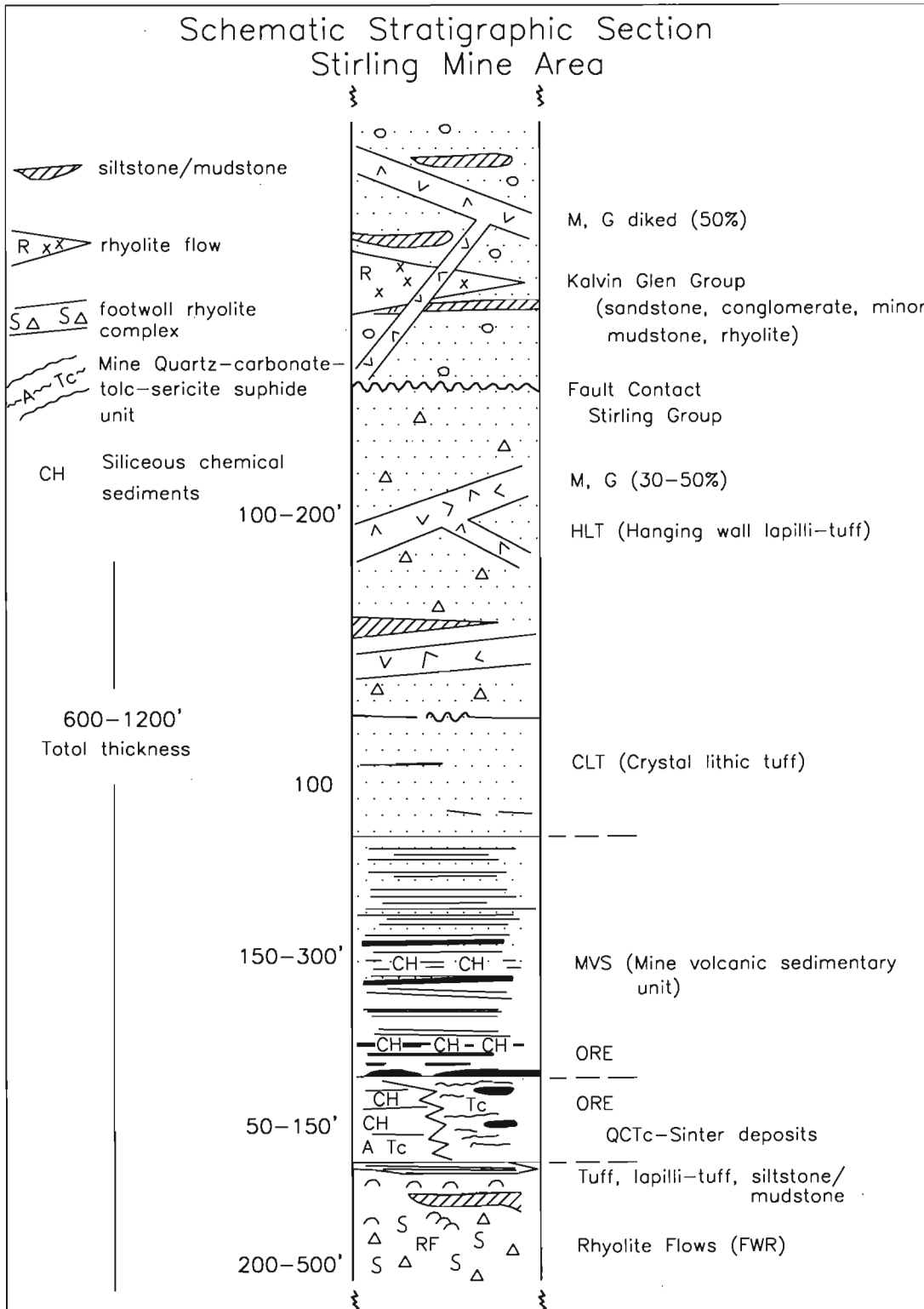
(5) Crystal lithic tuff (hanging wall tuff of Miller, 1979) which is a fine- to coarse-grained, green to grey granular rock with good fabric and abundant quartz grains (2-3 mm). Hunter (1989) notes a distinct coarsening of the unit from top to bottom (or fining upwards - author's interpretation). The rock may contain yellow, sericite-rich flattened fragments that may have been original pumice. Thin section examination shows that this rock is composed dominantly of chlorite and carbonate (Fig. 4c) and has a well developed flattening fabric.

(6) A hanging-wall lapilli tuff unit of pale to medium green with abundant white pumice fragments which are seen to be almost pure carbonate in thin section. The matrix contains dark green, wispy to cusped chloritic fragments. Felsic volcanic fragments are less common.

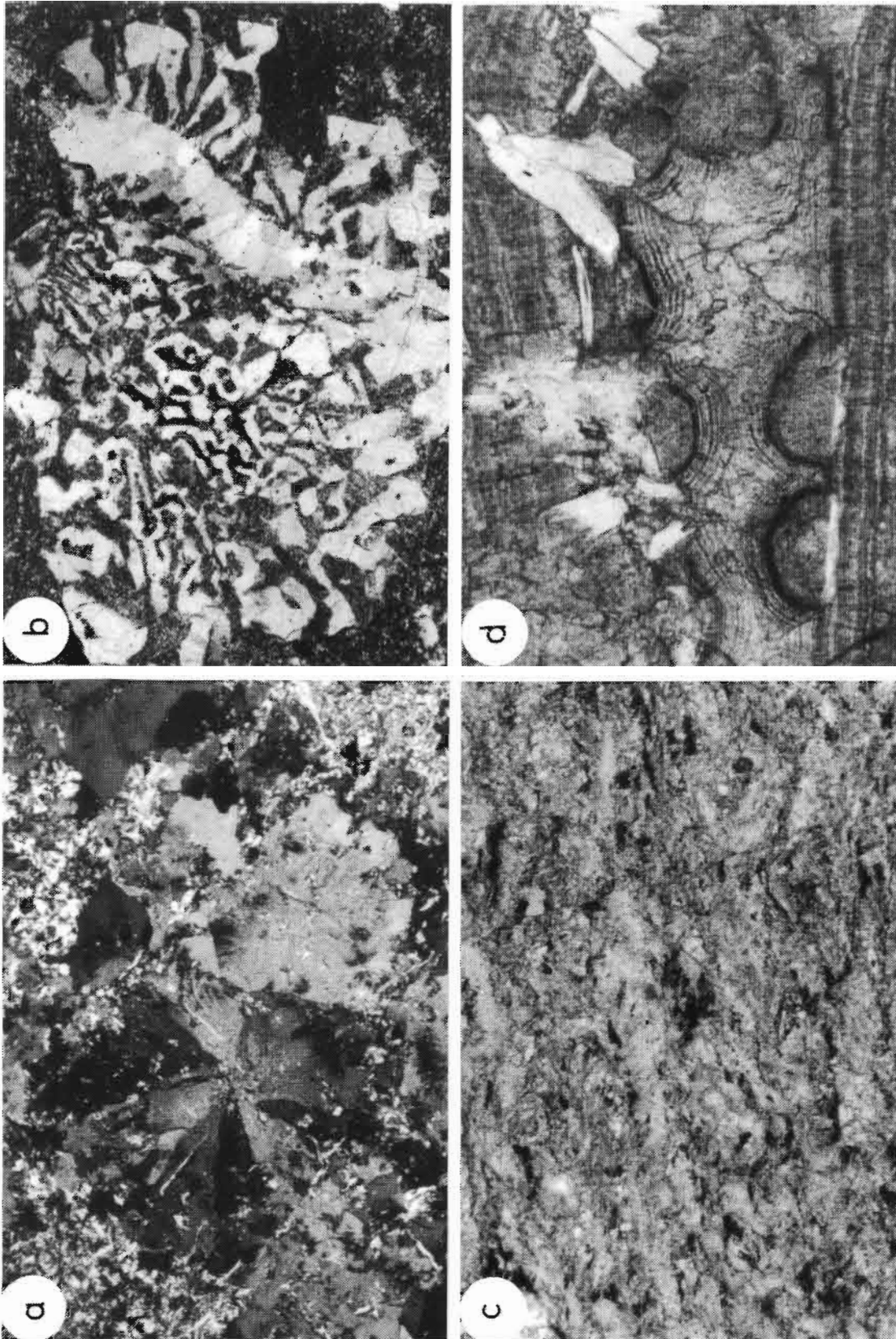
## Geology of the Glory Hole

The best exposure of the deposit geology on the Stirling property is around what is known as the Glory Hole (Fig. 6), located immediately northwest of shaft #2, where the ore zone, foot wall (FW) and hanging wall (HW) rocks are exposed. The stratigraphic foot wall consists of buff talc-carbonate schist with pods (10s of cm) of QTC rock and disseminated sulphides. Toward the ore zone the amounts of sulphide and carbonate increase and the rock is referred to as QTC. At the northeast end of the hole, the QTC rock is intensely sheared and in fault contact with a strongly deformed, green chloritic rock with a distinct granular texture; this rock may correspond to the crystal lithic tuff of Hunter (1989). In contrast, there is a ca. 2 m thick section of banded pyrite, sphalerite and chalcopyrite rock (i.e. massive sulphide) at the west end of the hole. The lack of outcrop does not permit observing the hanging wall contact relationships and the foot wall here is QTC rock. The final unit observed in this area is a massive, medium-grained mafic dyke in the northeast part of the hole.

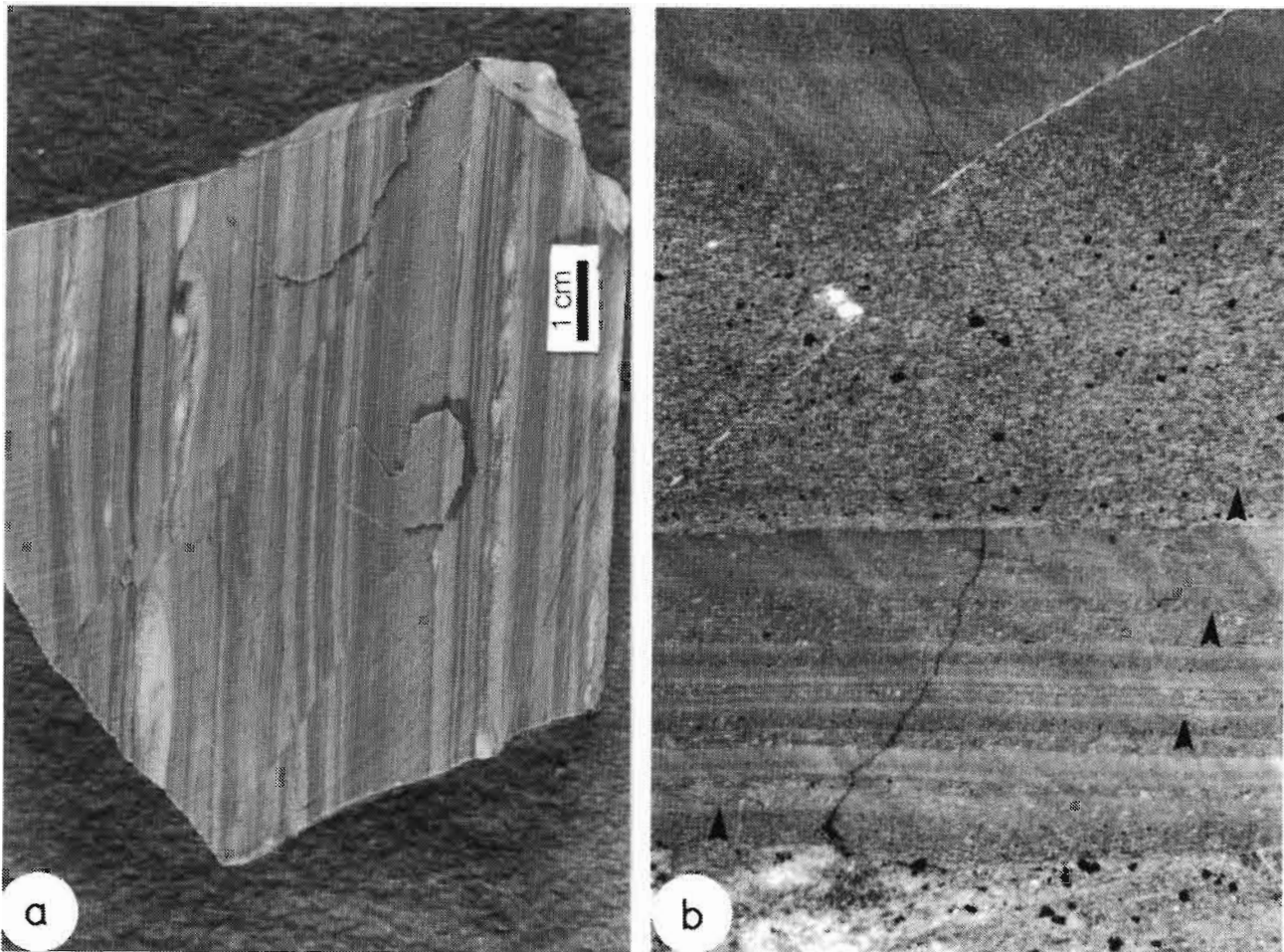
The following important points are noted in terms of the geology of the Glory Hole. (1) The thickness of the QTC rock is less than the 10s of metres seen in underground plan maps. (2) There is no sedimentary unit (the cherty to calcareous siltstone/mudstone unit of Hunter, 1989) forming the stratigraphic hanging wall. (3) The rocks are highly strained and overturned. These features of the Glory Hole geology may be resolved if one assumes structural complexity (see below) such that original stratigraphic relationships have been greatly modified.



**Figure 3.** Stratigraphic column for the Stirling deposit area (after Hunter, 1989). Note that the Bourinot and Middle River groups have been replaced by the Stirling and Calvin Glen groups, respectively, to be consistent with more recent geological terms (Barr *et al.*, 1996). The siliceous chemical sediment (QCTc-sinter deposits) refers to the quartz-talc-carbonate (QTC) rock discussed in the text.



**Figure 4.** Photomicrographs of different rock types at the Stirling deposit (a, b in crossed-nicols and c, d in plane transmitted light). (a) Spherulitic textured matrix of felsic rock. Note the abundance of talc in the matrix (see chemistry section). Width of photo 1.3 mm. (b) Quartz-feldspar fragment with granophyric texture in matrix of very fine-grained intergrowth of quartz-albite-carbonate-mica. Width of photo 2.6 mm. (c) Photo of a green laminated tuff (?) rock that consists mainly of chlorite and carbonate with minor titanite and pyrite. Rock is strongly deformed and layering is mainly of tectonic origin. Width of photo 2.6 mm. (d) QTC rock with parallel laminated texture giving way in centre to isopachous layering of magnesite and dolomite. Note the large flakes of talc that overgrow the carbonate fabric and indicate a late-stage growth. Width of photo 2.6 mm.



**Figure 5.** Photos of the finely laminated siltstone collected from a dump near Shaft #2 at the deposit. The rock is reddish in hand sample from oxidation of disseminated sulphides. This rock is probably part of the hanging wall stratigraphy (see Fig. 3). (a) Cut slab of finely laminated siltstone unit. Note the following details: (1) small offsets along brittle faults with normal displacement, as indicated from the tops to the left; (2) graded bedding in the coarser units with darker, shaly tops; and (3) light coloured beds that record internal folding (soft sediment deformation or tectonic?). (b) Photomicrograph (plane polarized light, ca. 2 cm long) of siltstone showing the following features: (1) graded bedding (arrow indicates tops); (2) disseminated pyrite euhedra in the coarser, silty units; and (3) carbonate occurs in the silty units and renders them a white colour.

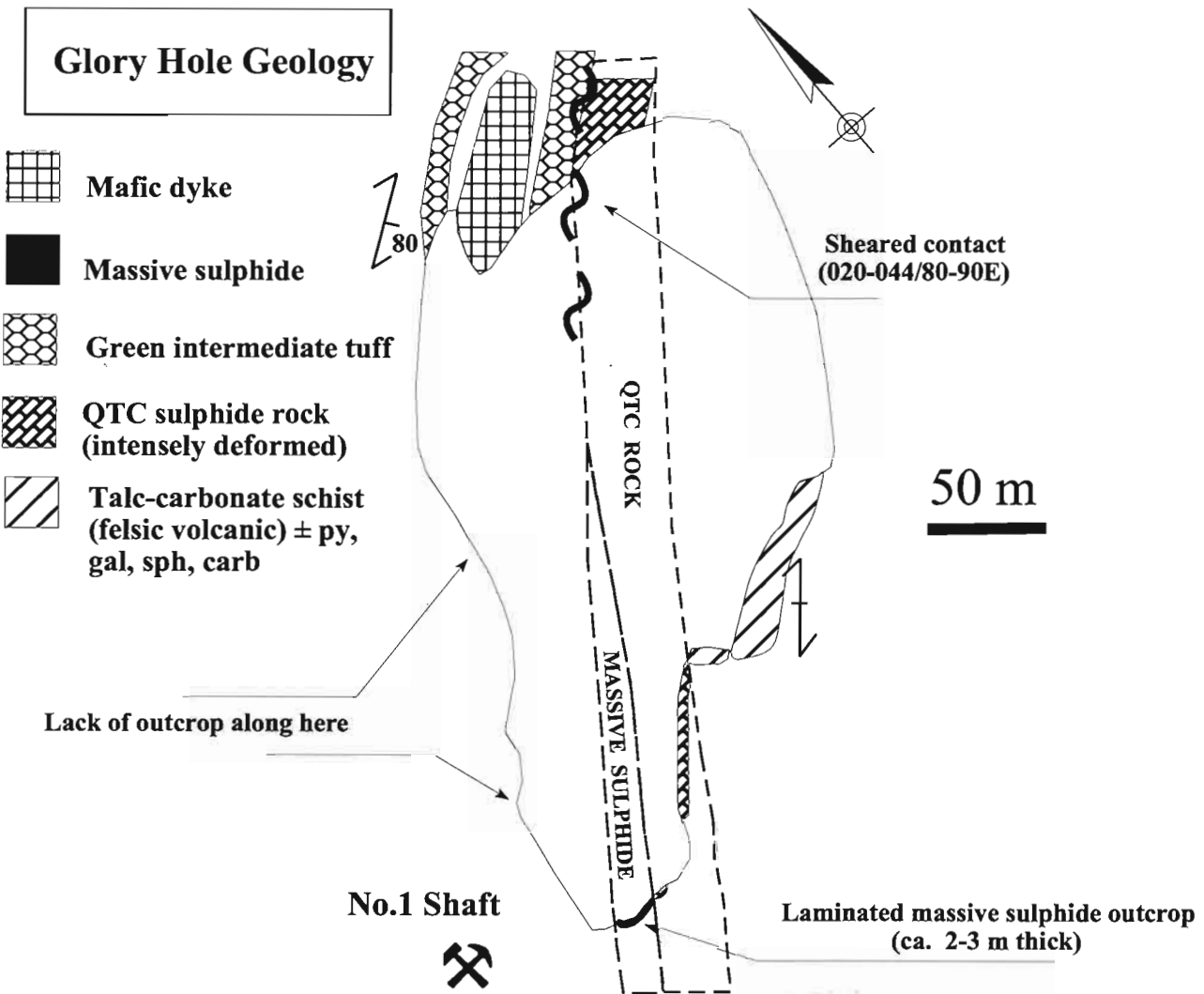
## Ore Zone

The ore zone consists of two mixed rock types, the massive sulphide mined for its metallic minerals, and the QTC which forms a gangue. However, as already noted, lenses of felsic volcanic rock occur within this zone (Fig. 7). The ore zone has a strike length of ca. 1.1 km and actually consists of two main ore zones, the Main or Central Zone and the North Zone, which come within 60 m and 151 m, respectively, of surface (Hunter, 1989; Fig. 8). The ore, mined to the 260 m level with two access shafts, occurs in 10 discrete lens and was always within the QTC rock. The maximum thickness of the ore zone is 75 m. At depth the massive sulphide rock contains

increasing amounts of QTC, such that up to 50-75% of the ore zone is talc. This factor contributed significantly to mine closure.

## Structure

The main structural features of the deposit area are the prominent northeast orientations of the lithological boundaries, including the ore zone, and a well developed planar fabric (schistosity) found in many of the rocks. However, in some rocks delicate features such as bedding and igneous textures (e.g. spherulites) are preserved, indicating that the deformation was heterogeneous with windows of low strain. The Mine Shear, which hosts the

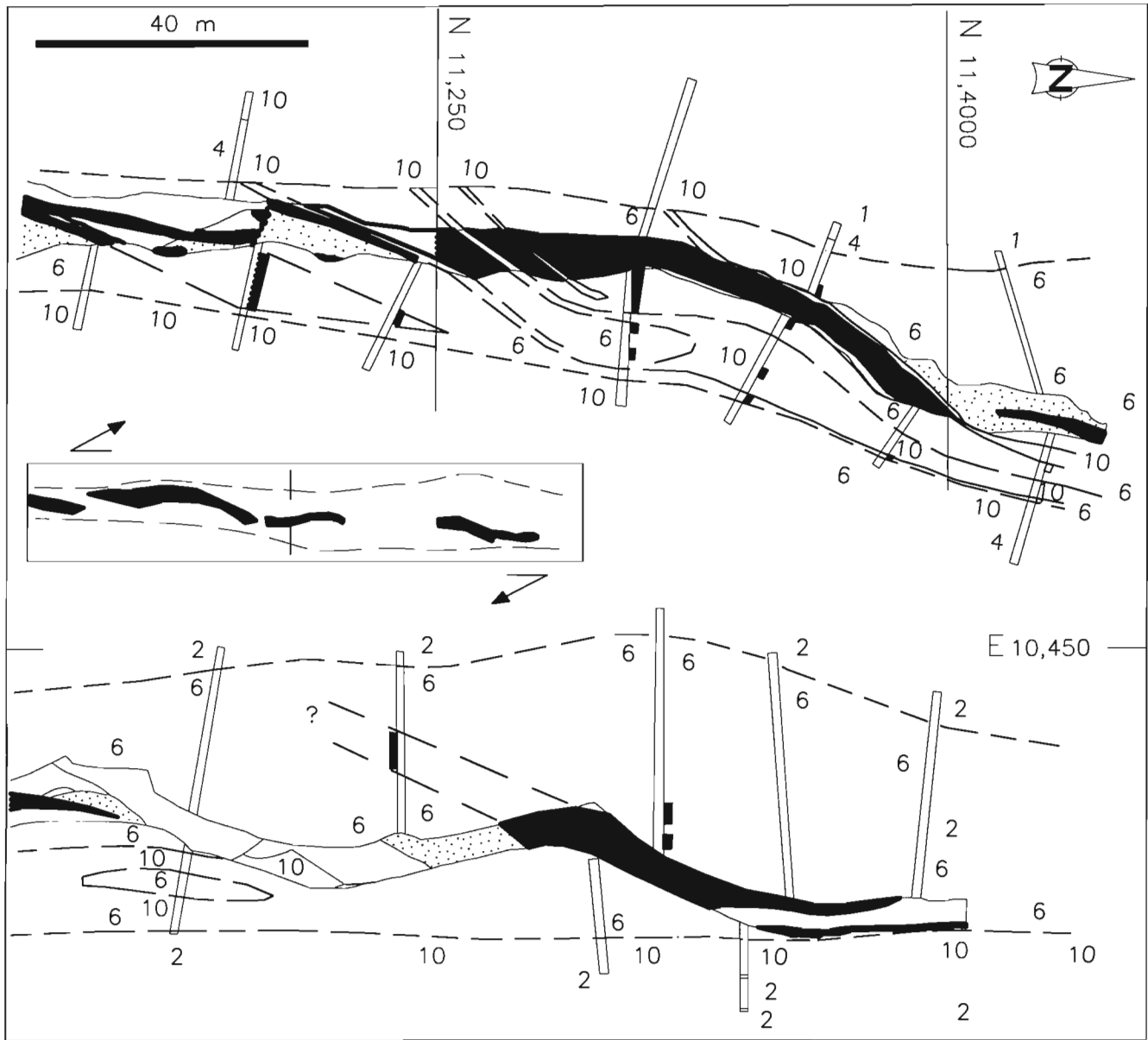


**Figure 6.** Geological map of the Glory Hole located immediately west of Shaft #2. Note the following: (1) outcrop of massive sulphide rock at the west end cannot be traced to the east wall, which suggests a structural or stratigraphic break; (2) contact between the QTC sulphide rock and the green intermediate tuff is a shear zone; thus, whereas the latter forms a structural foot wall to the ore, it is in fact the stratigraphic hanging wall.

mineralized zone, is described as ca. 100 m in width (maximum) consisting principally of schist and carbonates. The shear was traced, from underground workings, along strike for about 1.1 km and to a depth of 350 m (James and Buffam, 1937; Richardson, 1953; Watson, 1957). Weeks (1954) refers to a shear zone on the west side of an open pit at Stirling and describes, along with James and Buffam (1937), schistosity in the felsic volcanic rocks to the northeast on the outlet brook from Five Island Lake (Framboise River). However, there are no descriptions of rocks farther north having such a schistose fabric. Weeks (1954) also noted that structures at the mine paralleled the Stirling Fault (Fig. 2), which juxtaposes rocks of the Middle River Group against the

Stirling Group, and he suggested that the two may be related. Watson (1957) also suggested that the Mine Shear and the Stirling Fault may join at depth.

In the Glory Hole the rocks are intensely deformed. Some samples are schistose, particularly along the western wall where the ore zone is in fault contact with rocks of the structural foot wall. Slabbing of material from dump piles shows the presence of abundant micro-folds and multiple fabrics. In addition, the ore material itself is characterized by a strong fabric defined, in particular, by parallel bands of sphalerite (Fig. 9). Thus, there is clear evidence of intense, ductile deformation within the deposit and this is also manifested by the distribution of the ore

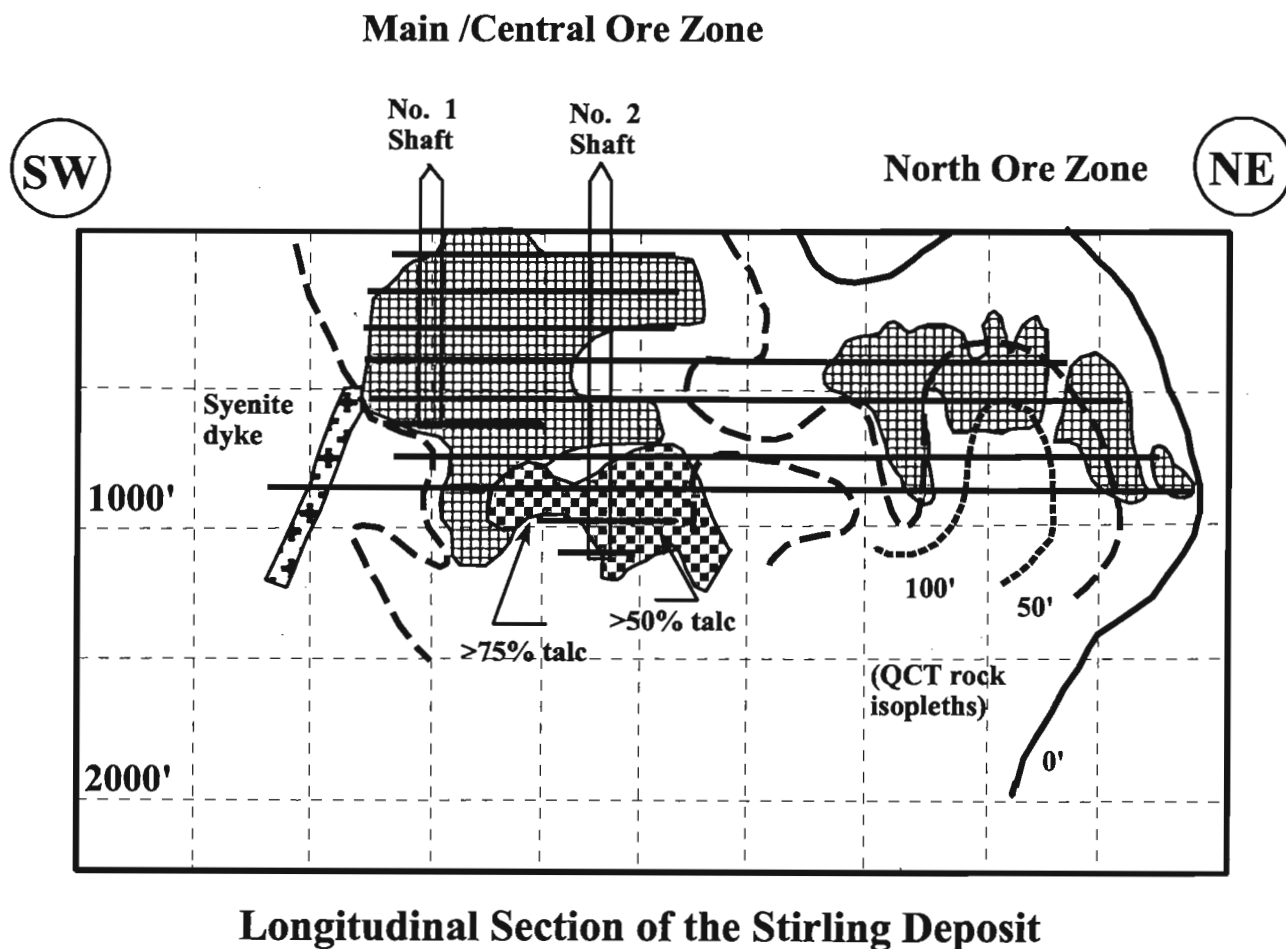


**Figure 7.** Mine level plan of part of the 418 N drift showing the nature of the ore zone. The massive sulphides are contained within QTC rock, the foot wall here is a felsic volcanic, and the hanging wall is mafic intrusive. Note that the ore zone is clearly discordant to the contact between the felsic volcanics and the QTC rock.

lenses. From examination of mine plans (e.g. Fig. 7) it is also apparent that the geology of the ore zones reflects superimposition of intense deformation, which may account for the detached lensoid to bulbous nature of the ore zones (see also mine level plans in Miller, 1979).

Some plans also indicate interleaving of units (Fig. 7) which suggests structural thickening of the ore zone.

Watson (1957) mentions crinkles in the sericite schist (probably a talc schist) that plunge to the northeast. This



**Figure 8.** Longitudinal section of the Stirling deposit (Hunter, 1989) showing the outline of the two ore zones, the Main and North zones, with isopleths for thickness of the quartz-talc-carbonate (QTC) rock. Note the presence of an unaltered syenite dyke rock that can be found as fresh boulders on surface.

plunge coincides with the rake of the ore zone, as seen in the longitudinal section (Fig. 8) and suggests a strong structural control.

### Nature and Distribution of Sulphides

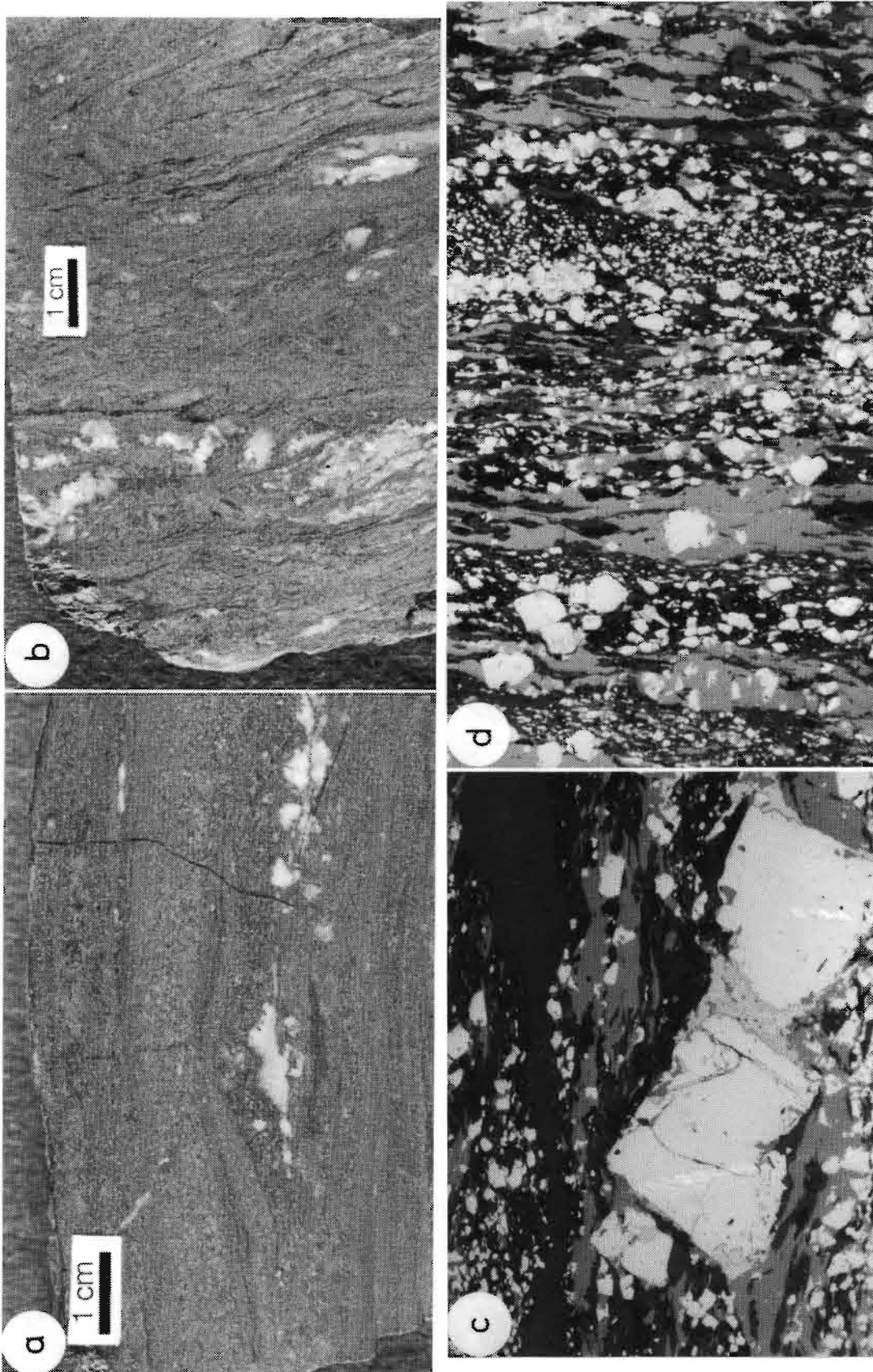
The nature and distribution of sulphides at the Stirling deposit have been ascertained by examining old mine level plans compiling assays and, examining ore material in the dump piles and limited outcrop.

#### Massive Sulphides

The Stirling deposit consists of volcanogenic-related massive sulphides (VMS; Franklin *et al.*, 1981) containing

variable amounts of pyrite, sphalerite, galena and chalcopyrite with fine-grained carbonate disseminated throughout. Dunn and Wallace (1951) noted that the pyrite is strongly anisotropic in specimens they studied, although this has not been confirmed in this work. A distinct, mm- to cm-scale, planar to wavy banding is present in most samples with layers dominated by a single sulphide phase; thus, domains are clearly evident in both hand samples and polished sections (Fig. 9c, d). Fragments of QTC are seen in samples (Fig. 9a, b), as well as a penetrative fabric or foliation (Fig. 9b, d) which is parallel to layering in the sulphides.

Massive sulphide rock occurs as discrete lenses, described by James and Buffam (1937) as lenticular shoots, which collectively trend and plunge to the northeast (Fig. 8). Two ore zones were recognized, the



**Figure 9.** Photographs of rock slabs and polished sections of massive sulphide rock from the Stirling deposit. (a) Slab of chalcopyrite-pyrite-rich rock with distinct layering defined by darker bands that are enriched in quartz-carbonate. Note the presence in centre layer of irregular fragments of carbonate material. (b) Slab of pyrite-rich rock with abundant quartz-carbonate material as both fine and coarse fragments. Note the well developed tectonic foliation in the rock, in particular where it crosses the carbonate fragments in a C-S type fabric. Although not seen at this scale, there are abundant microfolds within the rock. (c) Polished section photo (reflected light) showing a pair of coarse pyrite euhedra with chalcopyrite between the grains in a matrix of finer grained pyrite euhedra and lenses of sphalerite (grey) and carbonate (black) that together define a strong tectonic fabric. Width of photo 2.6 mm. (d) Polished section (reflected light) of sphalerite (grey), pyrite (white cubes) and carbonate rock with well-defined tectonic layering. Width of photo 2.6 mm.

Main or Central Zone and the Northern Ore Zone. The deposit has a strike length of 1.1 km and width up to 10 m, but individual ore leads are much smaller. The mineralized package is wholly contained within QTC rock (Figs. 7, 10) and lateral continuity and grade were a problem during mining, with the QTC rock causing dilution of the ore. Mine level plans by Miller (1979) show that the massive sulphides occur as pods with a variety of scales and shapes, such as bulbous, tapering, amoeboid and pinch and swell features. There are very few instances in the work of Miller (1979) or in mine level plans to indicate that laterally continuous layers of constant thickness occurred; thus, post-deposition modification of the sulphide zone is likely. In addition, the ore zone was cut by numerous mafic dykes of unpredictable distribution, orientation and width (Weeks, 1924; Watson, 1954; Miller, 1979). These dyke rocks are also deformed and altered. Preliminary study of slabs and polished sections of the ore confirms observations in the field that the rock is a tectonite with prominent microfolding and development of flattening throughout (Fig. 9). The morphology of the sulphide minerals reflects recrystallization and mobilization, which formed textures such as the coarse, equant pyrite euhedra and well developed layering in sphalerite-rich rock.

Chemical analysis of two representative samples of massive sulphide rock (Table 1) reflects the dominant mineralogy of sphalerite, chalcopyrite, galena and pyrite, similar to analyses reported by a variety of workers (e.g. Cairnes, 1917; Weeks, 1924). Moderate levels of Ag (170 and 280 ppm) are noted, occurring in tennantite, but the anomalous Bi and Sb levels have no known host phase. The occurrence of a gold-bearing mineral has not been reported in the ore assemblage, despite the presence of gold (up to 1.56 ppm; Table 1) revealed by geochemical analysis. Further mineralogy and mineral chemistry are required and this work is underway.

### **Metal Zonation within Sulphide Zones**

In order to evaluate the possibility of metal zonation within the deposit, analytical results were compiled from about 1300 samples tested for Cu, Pb and Zn from six levels in the Main Ore Zone. Such studies are important as they may indicate the presence of a vent or discharge site for the ore, which remains elusive at Stirling, and may also assist in assessing the future exploration potential of the area. The data are presented in elemental plots (Figs. 11, 12) and the following points are noted.

(1) Based on the proportions of Zn:Pb:Cu, the Stirling data correspond to the Zn-Pb-Cu group of Franklin *et al.* (1981) and Franklin (1993). (2) There is a distinct Cu enrichment for some samples from the fourth and fifth

levels, but details of the samples are, unfortunately, unknown. (3) The overall Zn-rich nature of the deposit is highlighted in the binary element plots. Based on elemental data the Stirling deposit is certainly Zn dominant and no Cu-rich zone is identified that may be considered to equate to a stringer or feeder zone.

### **Quartz-Talc-Carbonate (QTC) Rock**

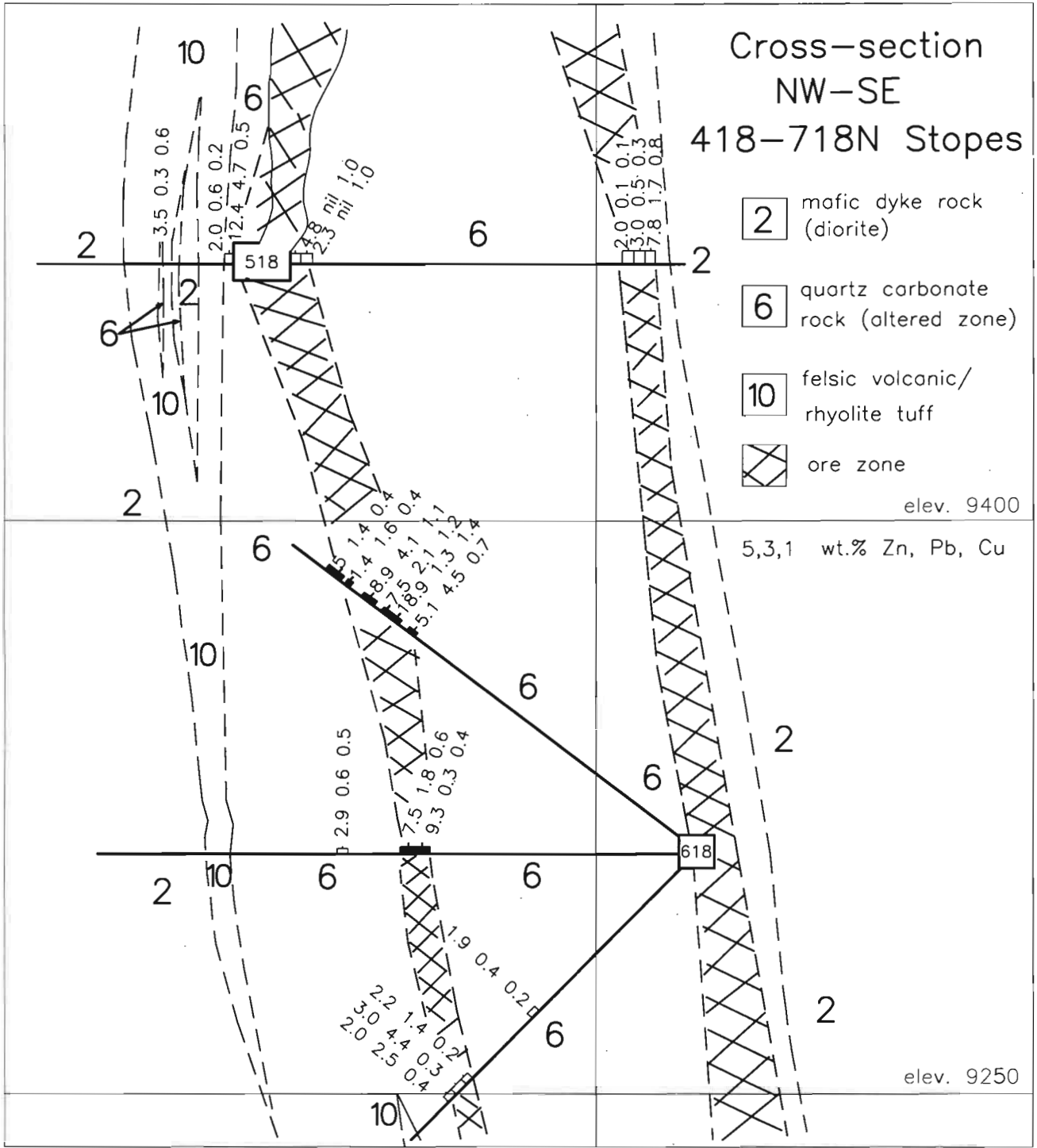
The QTC rock at Stirling is one of the more prominent features of the deposit and resolving its origin is obviously important in terms of understanding the genesis of the deposit. The first detailed description of this unit is given by Watson (1954), who recognized that it was composed of finely laminated dolomite and magnesite with laminar and colloform textures. Watson also suggested that the rock may represent deposition from a colloidal solution, but definitely was of epigenetic origin. In contrast, subsequent workers (e.g. Hunter, 1975; Hunter and Andersen, 1989; Miller, 1979) interpret the rock to be exhalative in origin.

### **Distribution of the QTC Rock**

The extent of the QTC rock has long been known to be coincident with the ore zone (e.g. Fig. 7, 10; Weeks, 1924; Alcock, 1930; Watson, 1954) and Richardson (1953) describes the dimensions and extent of the three QTC bodies, which vary from 135 to 300 m in length and 25 to 45 m in width. Between the QTC bodies occur laminated siltstones (e.g. Fig. 3), altered volcanic rocks, and mafic dyke rocks (Miller, 1979). Based on compilation of earlier work and new drillholes, Hunter and Andersen (1989) constructed a map (Fig. 9) that showed the distribution of this unit and demonstrated that it thickened at depth and became talc dominant; in fact, one of the reasons that the mine closed in the 1950s was that talc created problems with respect to both mining and metallurgy. From Figure 9 it is apparent that the actual depth of the QTC rock remains unknown, although its strike length appears to be confined.

### **Petrography of the QTC Rock**

The most detailed accounts of the mineralogy of the QTC rock are found in Watson (1954) and Miller (1979) with the following comments restricted to observations of the writer. Slabs and thin sections of a limited number of QTC samples have been examined, but more detailed work is in progress; thus, the following are preliminary results. As seen in Figures 4d and 13, the laminated and colloform textures known to characterize carbonate-rich samples of this unit (Watson, 1954) are obvious. The



**Figure 10.** Cross-section, looking northeast, of the ore deposit between the 418N and 718N stopes (from archived data in Department of Natural Resources files). The diagram shows two subparallel ore zones that are wholly contained within the quartz-talc-carbonate rock.

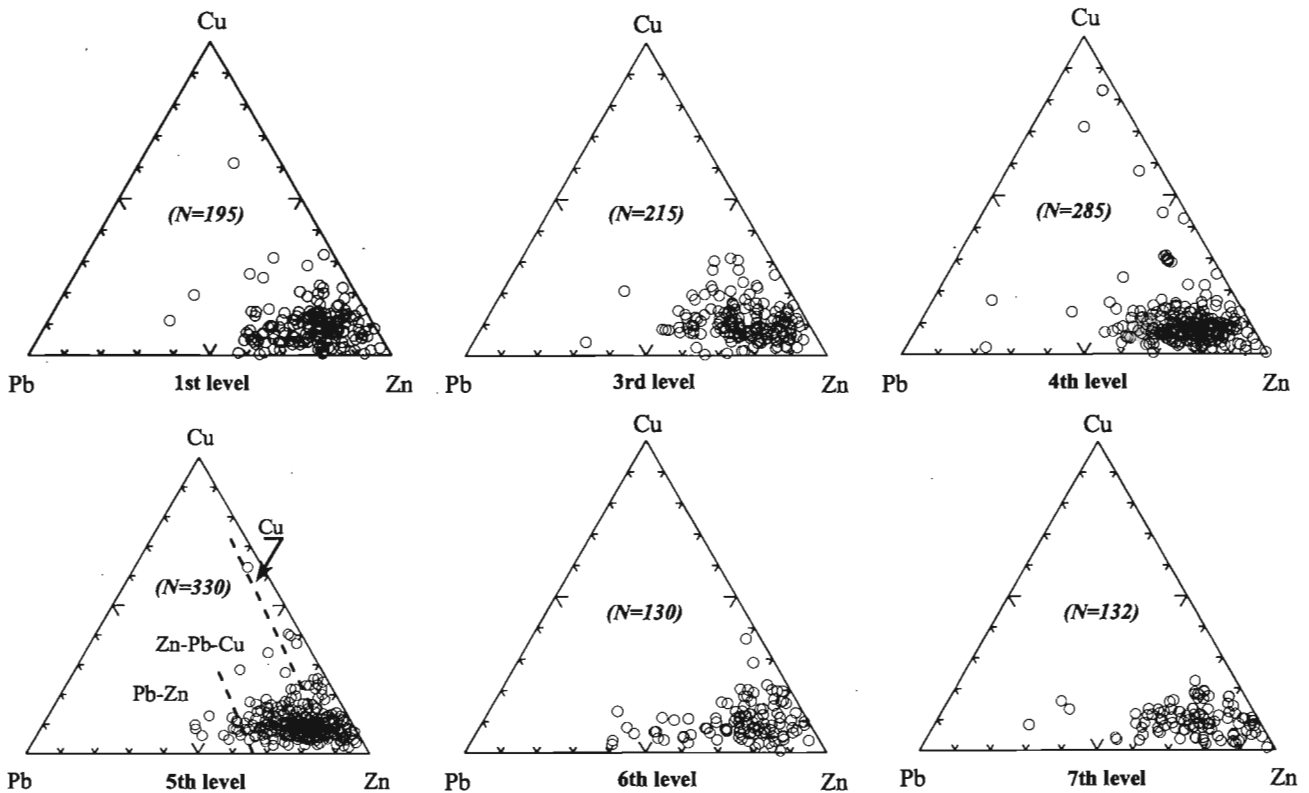
**Table 1.** Geochemistry of representative rocks from the Stirling deposit.

Carbonate-Talc Rock						Quartz Rock	Sulphide Rock	
Sample	220	221	222	224	226	228	230	231
<b>Major elements (wt.%)</b>								
Ca	6.40	12.11	24.59	16.48	15.39	-	0.87	1.10
Mg	3.70	10.93	13.40	9.01	8.59	-	1.08	0.60
Fe	9.78	9.87	0.79	0.27	10.20	-	6.57	6.03
Mn	1.03	0.82	0.69	1.50	0.05	-	0.09	0.10
CO <sub>2</sub>	12.59	33.54	36.59	27.53	31.93	-	3.23	-
S	21.50	13.00	-	0.14	15.10	2.36	22.90	29.10
SiO <sub>2</sub>	-	-	-	-	-	83.06		
Cu	1.30	0.10	-	0.01	0.02	1.12	6.59	2.51
Pb	2.20	0.04	-	0.03	0.46	0.89	6.43	6.65
Zn	13.10	0.05	-	0.01	0.51	1.80	20.80	34.80
<b>Trace elements (ppm)</b>								
Sb	6.00	-	-		26.00	840.00	620.00	380.00
Bi	132.00	-	-		16.00	138.00	138.00	480.00
In	<4	-	-		<4	<4	<4	<4
Hg	0.31	-	-		0.12	0.58	0.16	0.23
Au	0.73	0.13	-	0.00	0.22	0.57	1.23	1.56
Ag	24.00	3.10	-	0.41	15.00	79.00	170.00	280.00

carbonate-rich samples consist of finely-laminated (10 to 30  $\mu\text{m}$  width) magnesite and dolomite that have many modes of occurrence, such as crosscutting veins (Fig. 13a), fragments in QTC or sulphide (e.g. Miller, 1979), or continuous beds with laminations (Fig. 13b). As noted by Watson (1957), the brecciated nature of the rock indicates multiple episodes of deposition, brecciation and cementation. Laminations within the carbonate are uniform in width and there is a distinct fracture pattern oriented perpendicular to layering (Fig. 13b), which is similar to the fractures seen in colloform-textured magnesite (Fig. 13d). Massive, fine-grained granular carbonate consists of equant, spherical grains, which Miller (1979) noted to resemble oolites. A variation on the QTC rock is the occurrence of varying amounts of very fine-grained, massive, grey quartz. Finally, where

talc has been observed in the QTC rocks examined thus far, it always occurs as a late cross-cutting mineral (Figs. 3d, 13d), suggestive of late-stage growth.

Examination of the QTC rock using secondary electron images (Fig. 14) reveals the following additional features. (1) The carbonate layers are in fact laterally discontinuous on a mm scale with numerous terminations due to cross-cutting veinlets and corrosion features. (2) Dolomite corrodes and crosscuts earlier magnesite and forms late veinlets (Fig. 14a). (3) Magnesite shows subtle compositional variability with local Fe enrichment within the laminae (Fig. 14b). (4) Colloform dolomite is also compositionally variable (Fig. 14c). In the samples examined to date, talc is seen to postdate both the carbonates phases (Figs. 4d, 13d, 14b).



**Figure 11.** Ternary plots of Cu-Pb-Zn for drill core (5 foot lengths) and chip samples for different levels of the Stirling deposit. Data from plans and cross-sections of the deposit archived in the Department of Natural Resources files. Data are discussed in the text.

Samples of the massive, talc-rich rock that may be tens of metres thick have not yet been observed within the ore zone, but drill core of such material is available and will be studied. However, the stratigraphic foot wall to ore in the Glory Hole consists of talc schist (Fig. 6 and see below) with pods of QTC rock and layers of massive sulphide. This rock is pale buff and is very fissile due to a penetrative schistosity. Miller (1979) refers to this same outcrop as altered tuffs.

### Chemistry of the QTC Rock

Representative whole-rock analysis of carbonate-rich samples of the QTC rock was carried out at DalTech, Halifax, and the results are given in Table 1. The samples are all enriched or anomalous in base metals (Cu, Pb, Zn) and have elevated levels of Sb, Bi, Au and Ag. Electron microprobe analysis of the carbonates (Fig. 15) indicates that magnesite and dolomite are the only two carbonate phases present. There is some substitution of Fe and Mn and this is greater in magnesite than dolomite. Analysis of a quartz-rich sample of QTC rock shows it to be

anomalous in base metals, but markedly enriched in Sb and Bi compared to the carbonate-rich samples.

### Alteration Geochemistry in the Deposit Area

Three specimens of fine-grained, felsic rock were selected for geochemical study using the electron microprobe. In these specimens both mineral chemistry and whole-rock chemistry were determined, the latter by rastering the samples several times. In this approach, an area is analyzed by having the electron beam move over a selected region which varies depending on the magnification used; thus, an analysis of an area rather than a point is obtained. By rastering several areas one may determine how uniform the material is and, therefore, how representative the analytical data are. The point and raster analysis approach was used in order to obtain both mineralogical and geochemical data on specimens to ascertain the primary versus secondary mineralogy of samples, which is important with regard to determining

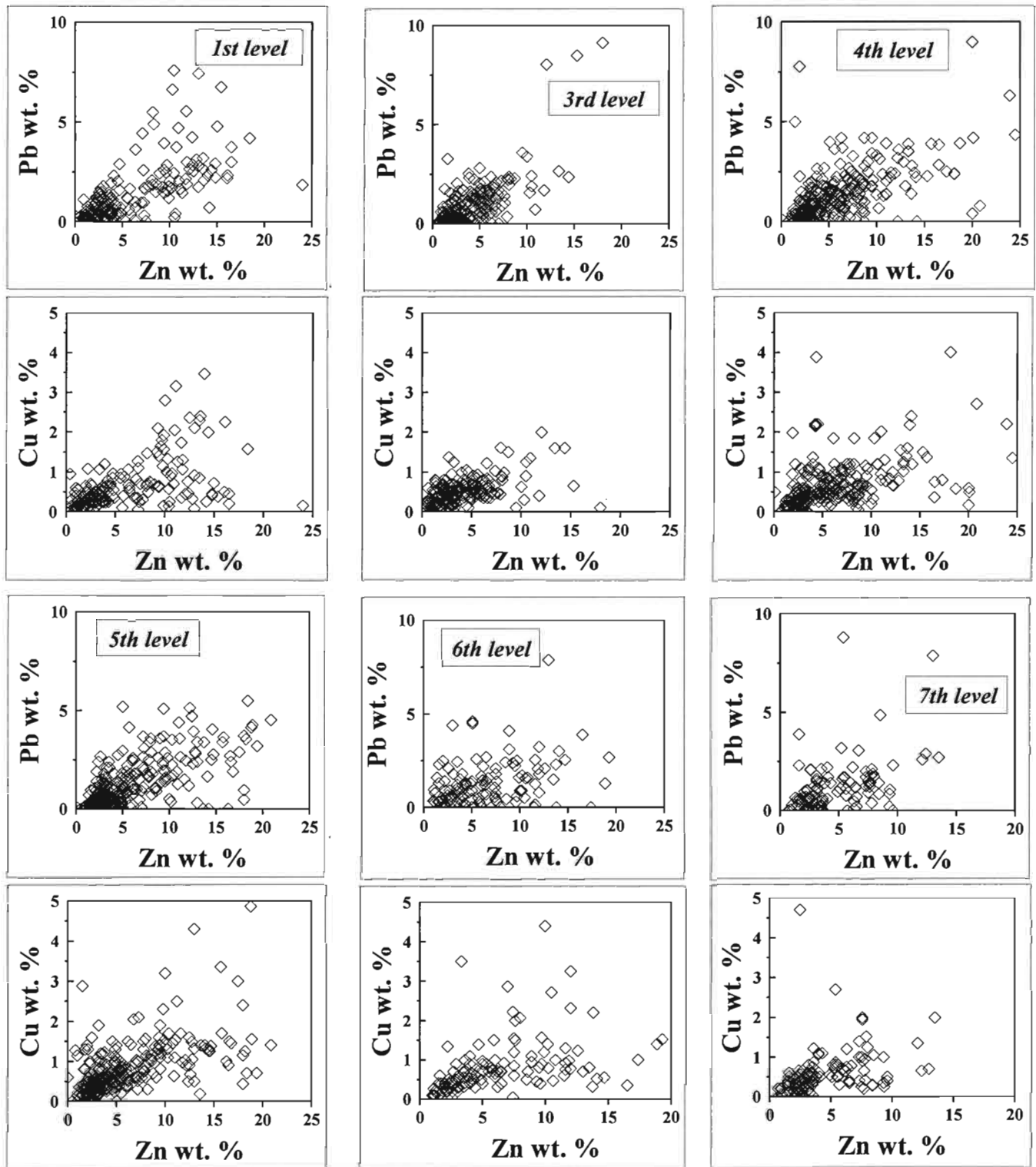
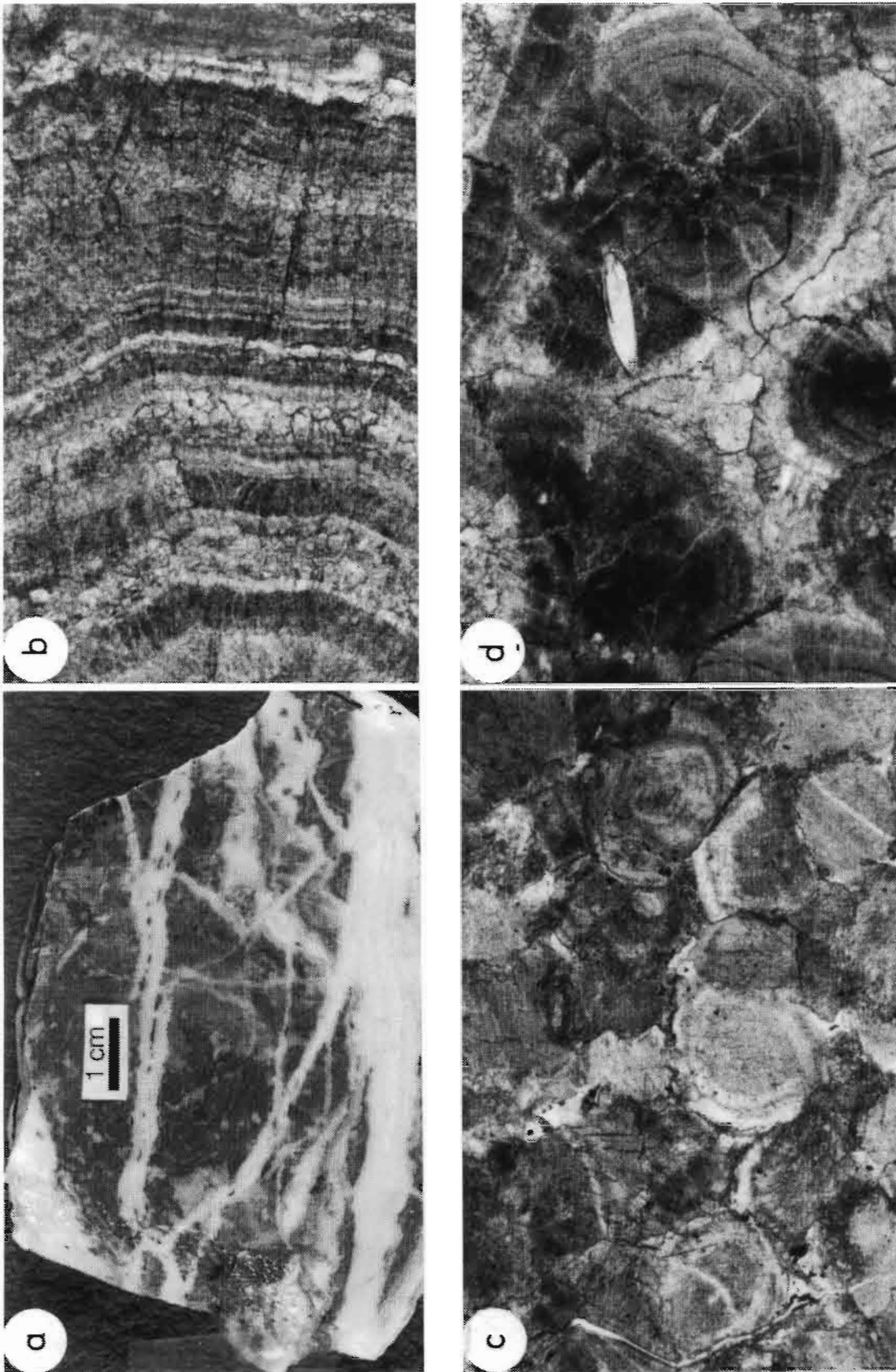
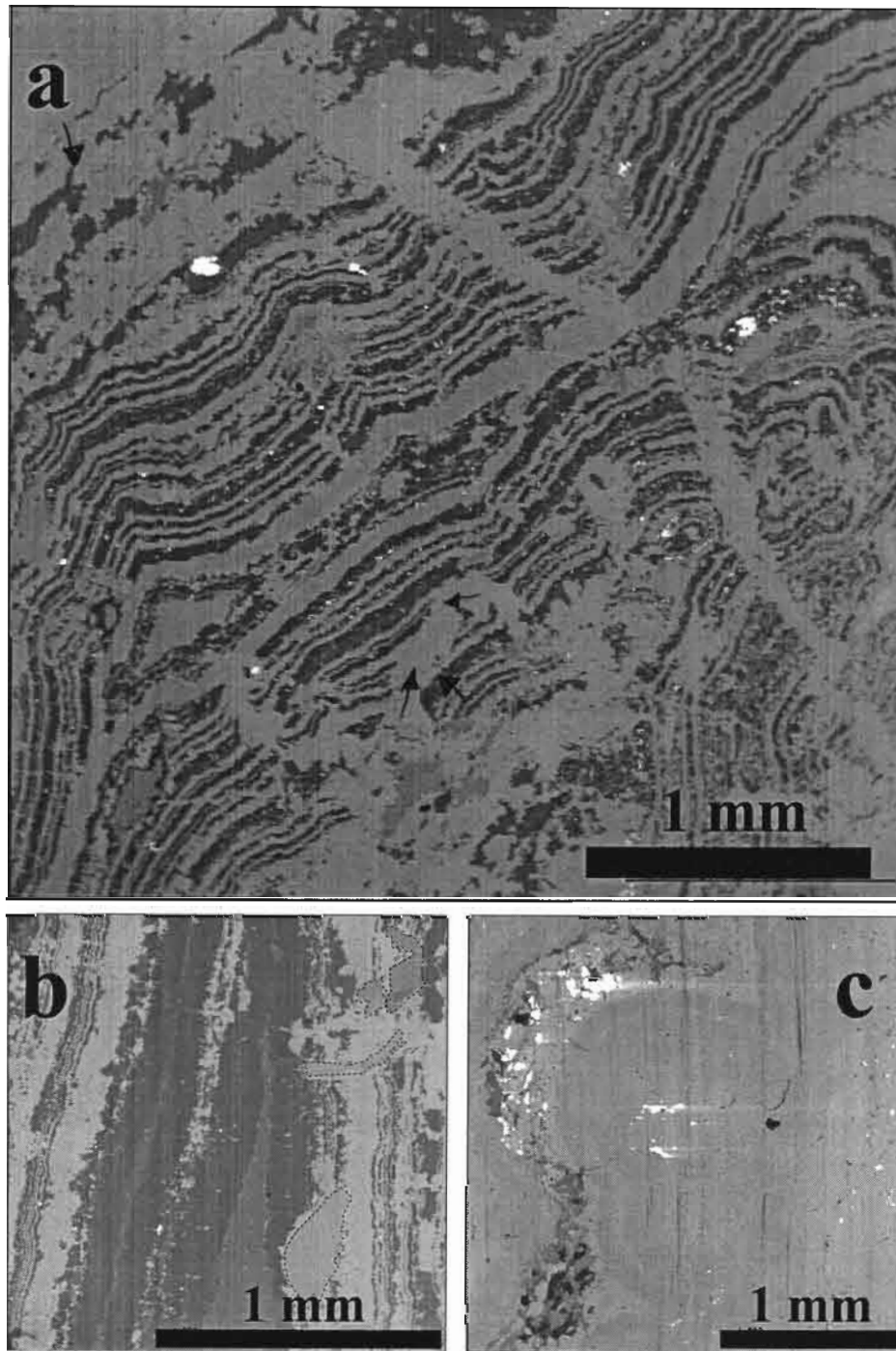


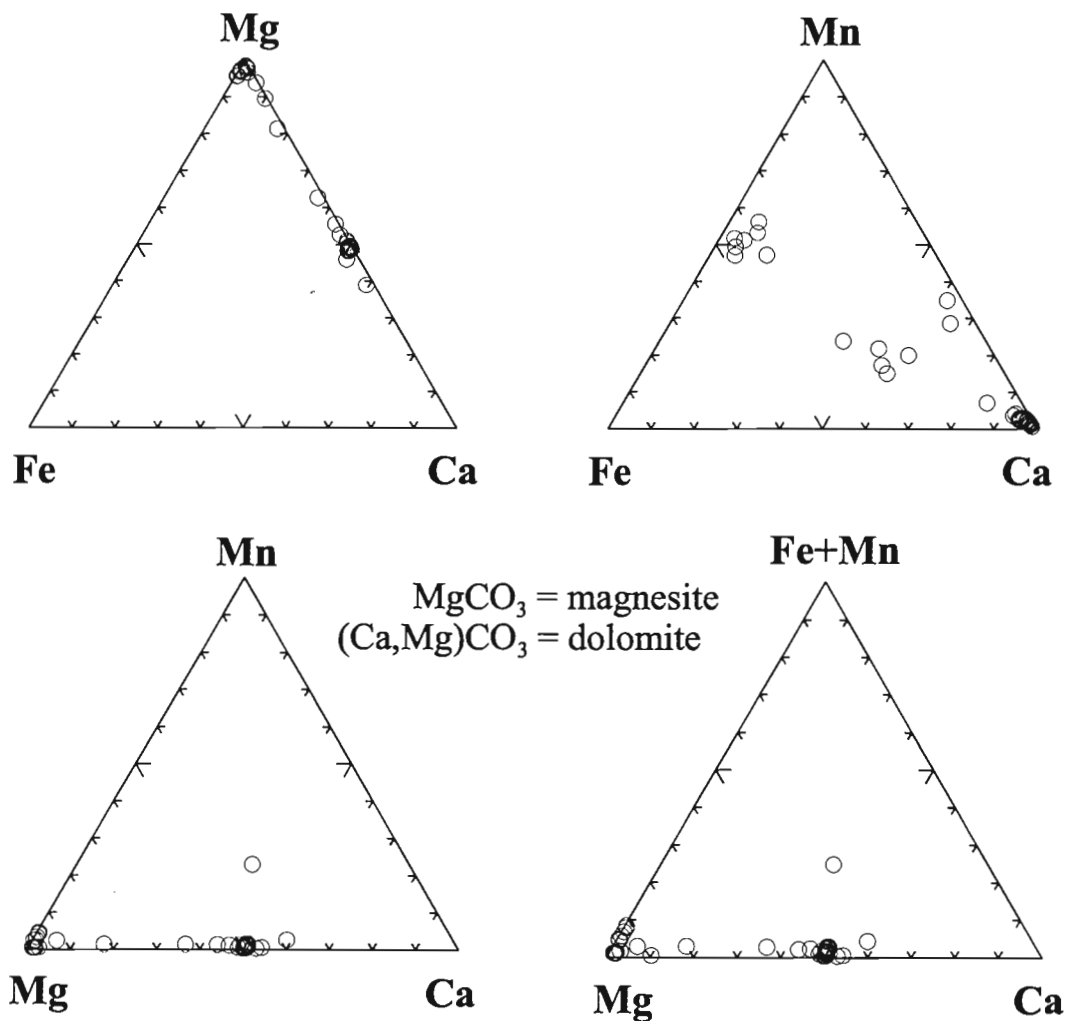
Figure 12. Binary element plots of Pb versus Zn and Cu versus Zn for drill core (5 foot lengths) and chip samples for different levels of the Stirling deposit. Data from plans and cross-sections of the deposit archived in the Department of Natural Resources files. Data are discussed in the text.



**Figure 13.** Photographs of slab and thin sections of the quartz-talc-carbonate (QTC) rock from Stirling deposit. (a) Slab of the QTC rock showing injection of late-stage, finely laminated dolomite-magnesite veins cutting sulphide-rich quartz-carbonate rock (grey material). The laminated nature of the veins indicates incremental opening rather than a single dilatational event. In addition, note the following features: (1) some carbonate veins are offset by fault zones infilled by later carbonate (indicated by arrows), and (2) colloform and banded layers in bottom of photo mimic the outline of the sulphide-rich fragment. (b) Photomicrograph of laminated magnesite-dolomite in QTC rock. Width of photo 2.3 mm. (c) Equant, zoned carbonate grains in the QTC rock. Individual grains are composite with magnesite and dolomite layers. Note the radial pattern to some grains. Width of photo 2.3 mm. (d) Colloform textures in QTC rock with isopachous layers of dominantly magnesite. The dark material is mainly magnesite and the lighter material dolomite. Again note the radial texture to the dark grains. The large white grain that overgrows the carbonate is talc. Width of photo 2.3 mm.



**Figure 14.** Secondary electron images (SEI) of laminated- and collform-textured magnesite-dolomite rock. The dark material is magnesite, the light material dolomite, the small irregular areas of grey are talc, and the bright spots are pyrite. (a) Within the laminated material dolomite appears to replace magnesite based on cross-cutting textures. Note that the veins that cross-cut the laminations are dolomite that is compositionally similar to the laminated dolomite. In the right side of image note how the laminated texture becomes contorted. (b) Laminated carbonate again showing textural evidence of dolomite replacing magnesite. Note that the brighter bands in the magnesite (centre of image) reflect local enrichment in FeO (to 3.0 wt.% FeO). Talc grains are outlined by a dotted pattern and are seen to cross-cut the carbonate laminations. (c) Collform-textured dolomite grain with minor amounts of magnesite and some late pyrite (bright grains).



**Figure 15.** Ternary plots of electron microprobe analyses of the carbonate phases in QTC rock from the Stirling deposit. Data show that the carbonate consists of magnesite and dolomite with minor amounts of Fe and Mn in the dolomite.

the extent of alteration. Samples selected for study were:

STB-97-24 - a fine-grained volcanic rock with trace quartz and feldspar phenocrysts in a spherulitic-textured matrix with minor talc, sericite and carbonate. The sample is from the foot wall rhyolite outside of the ore zone.

STB-97-26 - a buff coloured talc schist with carbonate from the east side of the Glory Hole discussed above.

STB-97-7 - fine-grained, carbonate-rich, laminated rock which may represent an altered tuff. Occurs in a sequence with massive rhyolite.

Representative raster analyses of the samples are presented in Table 2 and ternary plots of cationic proportions of the major elements are given in Figure 16. The first point to note is that the data cluster on the ternary diagrams for each sample, indicating that representative data for the samples have been obtained. Secondly, the ternary diagrams permit one to quickly assess the presence of the alteration mineralogy associated with mineralization, namely talc and carbonate phases. For example, whereas sample 97-24 is dominated by quartz - K-feldspar - albite (note albite is not shown on ternary plots) with trace talc, muscovite and carbonate, samples 97-26 and 97-6 contain varying proportions of talc, carbonate (magnesite, dolomite), chlorite, muscovite

**Table 2.** Representative raster analysis, normalized to 100 wt.%, for polished thin sections of rocks from Stirling area.

Sample	STB-97 24	STB-97 24	STB-97 7	STB-97 7	STB-97 26	STB-97 26	STB-97 26
SiO <sub>2</sub>	82.18	79.92	49.95	57.88	32.20	33.69	32.38
Al <sub>2</sub> O <sub>3</sub>	10.87	12.11	8.99	9.36	4.61	6.73	6.86
FeO	0.60	0.47	3.08	2.23	4.00	3.83	4.27
MnO	0.00	0.00	0.00	0.00	0.00	0.62	0.00
MgO	0.00	0.00	13.40	10.47	22.16	20.79	21.66
CaO	0.00	0.77	20.96	16.33	35.81	32.72	32.44
Na <sub>2</sub> O	3.02	3.75	1.45	1.60	0.00	0.00	0.00
K <sub>2</sub> O	2.06	2.05	2.17	2.14	1.20	1.63	1.32
SO <sub>4</sub>	1.27	0.93	0.00	0.00	0.00	0.00	1.07
Total*	100.00	100.00	100.00	100.00	100.00	100.00	100.00

and quartz. In addition, sample 97-26 contains much more mineralogical variation than the other two samples, based on the relatively large scatter of the data points. Examination of the actual data shows that sample 97-24 has a typical rhyolite chemistry, in fact it is similar to data for the Stirling rhyolites in Miller (1979), whereas sample 97-26 is depleted in Na<sub>2</sub>O and contains only 1-1.5 wt.% K<sub>2</sub>O, thus reflecting mobility of alkalis in this sample. Preliminary work suggests that this technique is, to a first approximation, a quick and reliable method to obtain both representative chemical analysis of fine-grained samples as well as estimates of the mineralogical constitution of the rock. Mineral chemistry is also obtained by this technique; however, the results are not presented here.

## Discussion and Conclusions

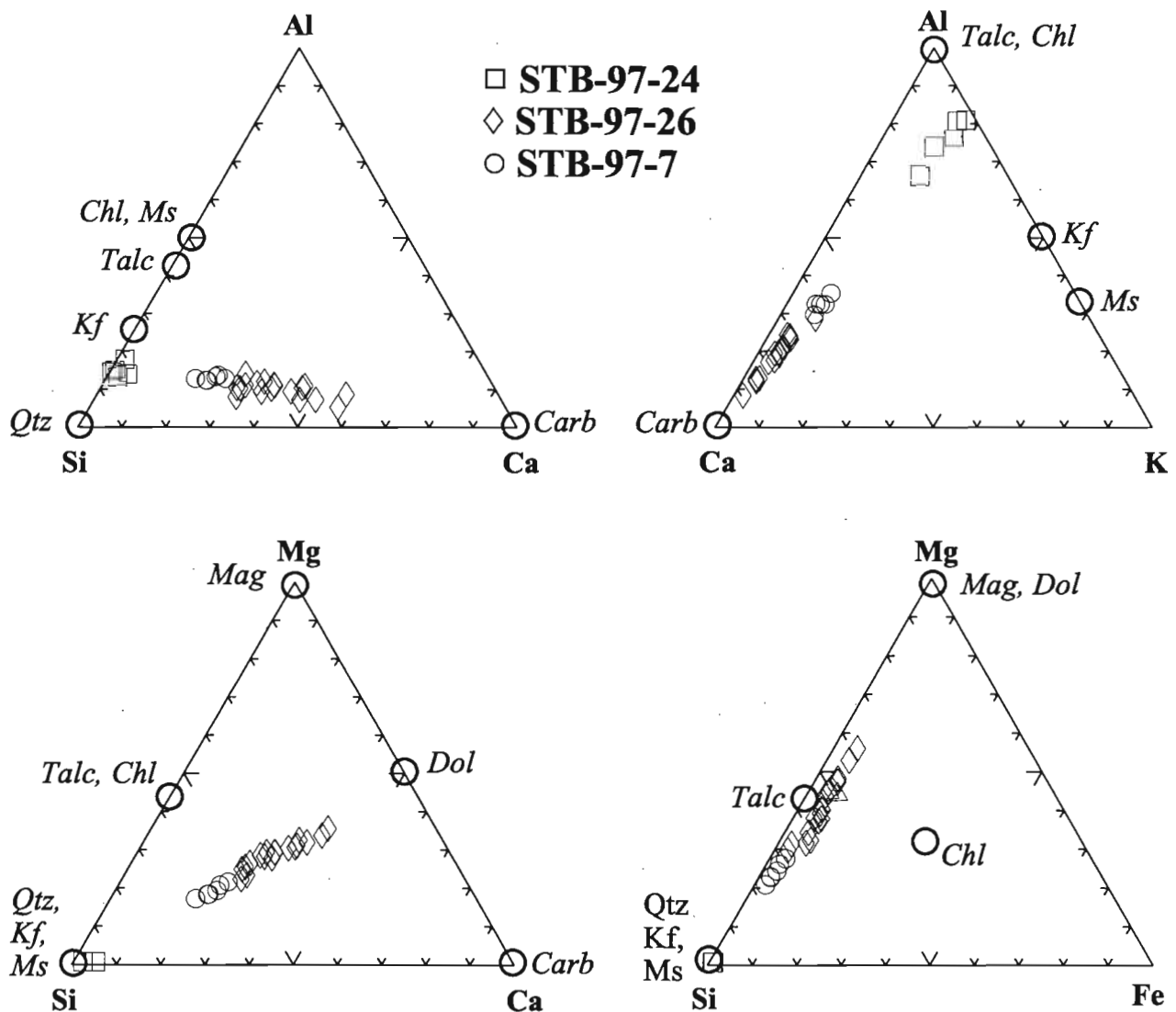
The preliminary results of work on the Stirling deposit raise several points that are worth highlighting in the context of the origin of the deposit.

(1) Rocks in the deposit area were subject to pervasive alteration. The full areal extent of this alteration remains unknown. A sample of spherulitic rhyolite from beneath the Main Ore Zone preserves primary igneous textures and composition, but also contains hydrothermal carbonate, sericite and talc that may be related to the ore-forming process. Similarly, rocks from northeast of the deposit (sample STB-97-7)

contain abundant secondary carbonate and chlorite and the chemistry of at least one sample records extreme modification which may relate to hydrothermal alteration.

(2) The deposit area records intense, localized deformation. Whereas this deformation has been recognized since initial work in the area (e.g. Cairnes, 1917; Weeks, 1924), the relationship between the deformation and disposition of the ore remains unknown. Underground maps clearly indicate that the ore lenses have been modified as a result of ductile deformation, but this has not been considered in the context of the nature and origin of the deposit. Are ore lenses concentrated in hinge zones of folds? Is there potential for ore along plunges in the folds? Such questions are important and should be addressed.

(3) Structural modification of the stratigraphy is important, as indicated from mapping of the Glory Hole. Thus, whereas a crude stratigraphy exists it is not known if there has been tectonic thickening, thinning, or dismemberment. The lack of a stringer zone beneath the deposit area may reflect the influence of structure either through intense strain or translation of the rocks. Although Miller (1979) suggests a distal type of mineralization because of the lack of a feeder zone, this need not be the case if structural complexities have separated the ore from the vent.



**Figure 16.** Ternary plots of geochemistry of selected rock samples from the Stirling area. The samples were analyzed by rastering areas in polished section using the electron microprobe (Dalhousie University, Halifax). Mineral phases plotted represent ideal end member proportions (e.g. Kf =  $\text{KAlSi}_3\text{O}_8$ ). Abbreviations: Kf = K-feldspar, Ms = muscovite, Chl = chlorite, Carb = carbonate, Mag = magnesite, Dol = dolomite, Qtz = quartz. Samples are as follows: STB-97-24 - spherulitic rhyolite from felsic unit beneath ore zone. Sample from west side of tailings pond. STB-97-26 - talc schist on south wall of Glory Hole. STB-97-7 - carbonate altered tuff.

(4) The origin of the carbonate rock remains an integral part of the genesis of the deposit. Preliminary studies suggest a paragenesis of magnesite, dolomite and finally talc. The textures and paragenesis are equivocal with respect to its origin and more work is required before the writer can commit to an exhalative model for this rock, as has been suggested since the 1970s. Future work will address the origin of this rock.

Initial work at the Stirling deposit indicates that many

of the geological features integral to understanding the origin of the deposit remain poorly constrained. Future work will address the origin of the deposit by focusing on the following: (1) petrogenesis of the foot wall rhyolite and its relationship to the ore zones; (2) stratigraphy and structure of the deposit; (3) relationship of ore to structure; (4) types of alteration and their extent; (5) nature and origin of the quartz-talc-carbonate (QTC) rock; and (6) absolute timing of events.

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