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**STRATIGRAPHY, STRUCTURE AND VOLCANOGENIC SULPHIDES,
IN SICKER GROUP VOLCANIC ROCKS ON MT. SICKER,
VANCOUVER ISLAND, B.C.**

by

Paul Alexander MacRobbie, B.Sc.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of
Master of Science

Department of Earth Sciences

Carleton University

Ottawa, Ontario

June 3, 1988

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Vancouver Island, B.C.**, submitted by
Paul Alexander MacRobbie, B.Sc.
in partial fulfillment of the requirements
for the degree of Master of Science

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ABSTRACT

The Mt. Sicker property, Vancouver Island, B.C., is underlain by a 900m thick succession of calc-alkaline basaltic andesite, dacite, and rhyolite flows and volcanoclastics of the Late Silurian to Devonian Nitinat and McLaughlin Ridge Formations, Youbou Subgroup, Sicker Group.

The 450m thick Nitinat Formation consists of interlayered pyroxene-plagioclase-phyric and plagioclase-phyric basaltic andesite vitric-crystal tuff, crystal tuff, massive flow, lapilli tuff and tuff breccia. Minor siliceous tuff and chert are present. The overlying McLaughlin Ridge Formation consists of: a) a Lower Dacite unit of well laminated tuff, vitric-crystal tuff, minor crystal tuff and dacite flow, b) a Mine Rhyolite unit composed of two rhyolite complexes each consisting of massive flow and vitric-crystal tuff, separated by dacitic to rhyolitic ash tuff, siliceous tuff, siltstone, chert, and exhalative massive sulphide, c) an Upper Dacite unit of well laminated tuff with interbedded chert, and d) an Upper Andesite unit of several upward coarsening tuff, vitric-crystal tuff, crystal tuff, lapilli tuff and tuff breccia successions.

The Lenora-Tyce deposits (mined 1898-1909), yielding 277,410 tonnes grading 3.3% Cu, 7.5% Zn, and 0.06% Pb, occur within the Mine Rhyolite as well banded and deformed massive sulphide. Mobilization and Au-Ag enrichment of the sulphides has occurred.

The volcanic succession may have formed within a marginal back-arc basin proximal to the volcanic arc. Deposition occurred through subaqueous pyroclastic flow and volcanoclastic gravity flow mechanisms. Synvolcanic structures were important in localizing the massive sulphide deposits.

A ductile phase of deformation preceeded a phase during which the Mt. Sicker Anticline and associated subvertical axial planar foliation were formed. Diorite dykes were intruded during a period of extension. During the Middle Jurassic to Late Cretaceous, the Sicker Group was uplifted and later cut into several thrust slices during the Cretaceous. Relaxation of compression resulted in the development of steep normal faults and Tertiary cross faults.

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1.0 INTRODUCTION

Interest in rocks of the Paleozoic Sicker Group has greatly increased since the 1979 discovery of the H-W Cu-Zn-Ag-Au Mine in the Buttle Lake area by Westmin Resources Ltd (Fig. 1). Proven and indicated reserves of the H-W deposit are 13,294,000 tonnes grading 2.41% Cu, 5.44% Zn, 0.32% Pb, 37.4 g/tonne Ag and 2.39 g/tonne Au. The close spatial occurrence of the H-W with the Myra, Lynx, and Price deposits make this camp an important volcanogenic massive sulphide district (Juras, 1987) (Fig. 1). Exploration in the Sicker Group led to the recent discovery of the 837,332 tonne Lara deposit by Abermin Corporation (Bailes et al., 1987) (Fig. 1).

Minnova Inc. is currently exploring massive sulphide showings on the Mount Sicker Property where Sicker Group volcanic rocks are exposed within the Cowichan-Horne Lake Uplift (Fig. 1). The Lenora-Tyce, Mona and Northeast Copper showings are located on the northwest slope of Big Sicker Mountain (Mount Sicker) 9 km northwest of Duncan, Vancouver Island, B. C. (Fig. 2).

The Lenora-Tyce massive sulphide deposits were discovered in 1898 and largely mined out by 1909 yielding 277,410 tonnes grading 3.25% Cu, 7.51% Zn, 0.06% Pb, 0.002% Cd, 82.2 g/tonne Ag, 3.7 g/tonne Au. Intermittent mining continued until 1950. Since that time exploration by Mount Sicker Mines Ltd., Ducanex Resources Ltd., and S.E.R.E.M. Ltd. was concentrated primarily in the former mine area. Minnova Inc. (formerly Corporation Falconbridge Copper) optioned the property in 1983.

Clapp (Clapp, 1912; Clapp and Cooke, 1917), first defined the Sicker Group. With the exception of work by Stevenson (1945, 1948) very little research has been undertaken on Mount Sicker. Recent work was

7

Fig. 1 Location of the three major geanticlinal uplifts cored by Sicker Group rocks, and location of the Mt. Sicker (a), Lara (b), and Buttle Lake (c) deposits (after Massey and Friday, 1987).

Fig. 2 Location of the Lenora-Tyee deposits and Mona and Northeast Copper showings, Mt. Sicker Property.

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conducted on Mount Richards to the east (Eastwood, 1980), and to the west of Duncan, north of Lake Cowichan (Fyles, 1955, Massey and Friday, 1987). For this reason, detailed mapping was undertaken with the cooperation of Minnova Inc. This research was carried out with five objectives:

1. to describe the stratigraphy within the Lenora-Tyce, Mona and Northeast Copper map areas of the Mt. Sicker property, and to correlate and characterize the volcanic rocks of the Mine Rhyolite.
2. to describe mineralogy and textures of the sulphide minerals and associated alteration.
3. to define the style of deformation and structural features which modify the volcanic succession.
4. to establish the chemical composition and affinity of volcanic rocks on Mt. Sicker.
5. to interpret the geological history of the Mt. Sicker area.

Two field seasons of mapping on Mt. Sicker were performed. The data presented is based on detailed mapping (1:100, 1:500, 1:1000) of three areas, some regional mapping and drill core logging. Field interpretation was supplemented by the examination of 126 polished thin sections and 42 whole-rock chemical analyses.

2.0 REGIONAL GEOLOGY AND SICKER GROUP STRATIGRAPHY

2.1 Tectonic Setting

Most of the rocks underlying Vancouver Island, including the Sicker Group, are representative of the Paleozoic to Mesozoic Wrangellia Terrane. This allochthonous terrane was accreted to the North American continent in the Late Cretaceous as part of a composite terrane (Jones et al., 1977; Muller, 1977; Monger et al., 1982). The Sicker Group is exposed in three separate, structural culminations: the Buttle Lake Uplift, the Cowichan-Horne Lake Uplift and the Nanoose Uplift (Fig. 1). The tectonic setting of southern Vancouver Island is described by Monger et al. (1985), Yorath et al. (1985 a,b) and Clowes et al. (1987).

2.2 Stratigraphy of Southern Vancouver Island

The Late Silurian to Early Permian Sicker Group, composed of all stratified Paleozoic rocks and intrusions on Vancouver Island, are the lowermost strata of the Wrangellia Terrane (Muller, 1977; Fyles, 1955). Tholeiitic basaltic volcanic rocks of the Late Triassic Karmutsen Formation unconformably overlie the Sicker Group. The volcanic rocks are overlain by, and interbedded with massive micrite of the Quatsino Formation, and thin-bedded tuff, siltstone and limestone of the Parson Bay Formation (Fig. 3) (Jones et al., 1977; Muller, 1977; Massey and Friday, 1987, 1988). These three formations comprise the Vancouver Group. The Early to Mid Jurassic Bonanza Group, consisting of marine sedimentary rocks and marine to subaerial basaltic to rhyolitic volcanic rocks, conformably to disconformably overlie the Vancouver Group. Late Jurassic granodioritic intrusions crosscut these rocks. Late Cretaceous siltstone, sandstone and conglomerate of the Nanaimo Group unconformably overlie the Bonanza Group. The Late Jurassic to Cretaceous Leech River Schist and the Eocene

Fig. 3 Regional geology of Vancouver Island (after Muller, 1980).

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Metchosin tholeiitic volcanic rocks were accreted to Vancouver Island during the Late Eocene as two small, distinct terranes (Clowes et al., 1987).

2.3 Stratigraphy of the Sicker Group

Stratigraphic classifications of the Sicker Group are shown in Fig. 4. The first formal stratigraphic classification of the Sicker Group was proposed by Yole (1969), who defined a lower Youbou Formation and an overlying Buttle Lake Formation (Appendix I). Muller (1980) proposed to replace the lowermost Youbou Formation with three new divisions (Appendix I).

Results from the first phase of the LITHOPROBE PROJECT on southern Vancouver Island (Yorath et al., 1985a, b) suggest that the divisions defined by Muller are of limited use due to the poor correlation of their relative stratigraphic position and of lateral continuity of units between the various uplifts. Brandon et al. (1986) suggested that the divisions proposed by Yole (1969) be retained, with those of Muller (1980) used as informal units within the Youbou Formation.

Sutherland Brown et al. (1985, 1986) suggested that the Sicker Group be divided into two Subgroups:

- 1) the Youbou Subgroup, representing the dominantly volcanic lower succession.
- 2) the Buttle Lake Subgroup, representing the dominantly sedimentary upper units.

These subgroups were to be applied to all Sicker Group rocks on Vancouver Island; however, formations within each subgroup were to be defined separately for each uplift.

Sutherland Brown et al. (1985, 1986) have suggested that in the Cowichan-Horne Lake Uplift, the Youbou Subgroup consists of two formations:

(Vole, 1969) (Muller, 1980) (Sutherland Brown, 1986; Massey and Friday, 1987, 88) (Juras, 1987)

Buttle Lake Uplift
Cowichan-Horne Lake Uplift

Fig. 4 Schematic stratigraphic columns of the Sicker Group.

- 1) the Nitinat Formation, consisting of pyroxene-phyric tholeiitic to basaltic andesite agglomerate, tuff-breccia and tuff with lesser pillowed and massive flows, and minor volcanic sedimentary rocks.
- 2) the McLaughlin Ridge Formation, consisting of massive to bedded volcanic sandstone with lesser conglomerate, pebbly sandstone, siltstone and chert and minor mafic to intermediate, pillowed to massive flows.

The Buttle Lake Subgroup consists of three formations:

- 1) the Cameron River Formation, a thinly bedded unit of siliceous argillite and shale, black chert, grey limestone, green volcanic sandstone, red and green ribbon chert and chert breccia.
- 2) the Mt. Mark Formation, consisting of thick bioclastic limestone.
- 3) the St Mary's Lake Formation composed of thinly bedded sandstone and shale.

Juras (1987) has suggested similar divisions in the Buttle Lake Uplift (Appendix I) (Fig. 4). He tentatively correlated the Price and Myra Formations with the Youbou Subgroup, and the Henshaw and Buttle Lake Formations with the Buttle Lake Subgroup (Fig. 4). The Thelwood and Flower Ridge Formations may correlate with either the McLaughlin Ridge Formation (Youbou Subgroup) or the Cameron River Formation (Buttle Lake Subgroup). The nomenclature of the Sicker Group is not the focus of this thesis and the subdivisions described by Sutherland Brown et al. (1986) will be used throughout.

2.4 Structure and Metamorphism of the Sicker Group

Massey and Friday (1988) summarize the deformational events and their effect on the Sicker Group. Southern Vancouver Island is characterized by horizontal shortening across the northwesterly trending axis of the Island, resulting in numerous east-verging thrust faults. The Cowichan-Horne Lake Uplift was created in the Late Cretaceous by easterly dipping west-northwesterly trending thrust faults (Yorath et

al., 1985a, b). Sicker Group rocks are dissected by a set of west-northwesterly trending thrust faults. The rocks comprise northwesterly trending folds with variably developed axial planar cleavage (Muller, 1980; Yorath et al., 1985a, b; Massey and Friday, 1987, 1988).

Rocks of the Sicker Group are metamorphosed to lower greenschist facies, and metabasaltic rocks consist of assemblages of epidote, actinolite, chlorite, and albite. Locally, amphibolite-grade rocks are adjacent to the Island Intrusions (Muller, 1980; Massey and Friday, 1986, 1987).

3.0 GEOLOGY OF THE MOUNT SICKER PROPERTY

3.1 Geology and Structure of Mt. Sicker

The Mt. Sicker Property is underlain by rocks of the Nitinat and McLaughlin Ridge Formations, Youbou Subgroup. The Nitinat Formation, 500-600m in thickness, is exposed along Highway 1 and on the east slope of Little Sicker Mountain.

The Nitinat Formation consists of a thick intercalated feldspar-phyric and pyroxene-feldspar-phyric vitric-crystal tuff and crystal tuff (Fig. 5). Minor feldspar-phyric siliceous tuff and chert are also present. Feldspar crystals comprise 10-40% of the rock and occur as 0.5-2mm, euhedra and subhedra or broken laths and glomerocrysts. Pyroxene comprises 0-30% of the rock and occurs as 0.5-13mm euhedra and subhedra. No flow structures, flow breccia or amygdules were observed in the Nitinat Formation. The formation is dissected by numerous subvertical, east-trending faults which are parallel to the strong penetrative foliation. Locally, elongated pyroxene- and feldspar-rich lenses occur, which may represent boudinaged beds transposed parallel to the foliation. Epidote alteration and moderate to strong chloritic alteration are common in the tuff. Weak silicification is observed locally.

The Nitinat Formation is overlain by a 300-155m thick sequence of feldspar-phyric, crystal-vitric tuff with occasional lapilli fragments. This tuff is texturally, mineralogically and chemically similar to the Nitinat Formation feldspar-phyric tuff. Based on geology and chemistry, this tuff is included in the Nitinat Formation (see Chapters 4, 5). The feldspar-phyric tuff contains 20-60% weak to strongly saussuritized feldspar

Fig. 5 Geology of the Mt. Sicker property.

crystals in a fine-grained chloritic matrix. About 0-5% siliceous and epidotized, light green-grey, subrounded lithic fragments, up to 5cm in diameter also occur. A locally developed coarse lapilli-ash tuff containing 20-30%, flattened pyroxene- and feldspar-rich lithic fragments can mark the base of this tuff.

The overlying McLaughlin Ridge Formation includes all other Sicker Group rocks on Mt. Sicker. This formation consists of a strongly foliated andesitic to rhyolitic, quartz-feldspar-phyric and feldspar-phyric tuff with minor massive rhyolite and dacite flow, tuffaceous chert, chert, graphitic mudstone, siltstone and volcanogenic massive sulphide. Weak to moderate sericitization, chloritization and silicification are characteristic of all these rocks. Rocks in close proximity to the Lenora-Tyce deposits are strongly sericitized and silicified. Strong, semi-conformable chlorite-pyrite alteration is found in the Northeast Copper area.

Mt. Sicker is structurally dominated by a large, asymmetric, west-northwest trending, west-plunging anticline (Massey and Friday, 1988; Muller, 1980)(Fig. 5). The Lenora-Tyce and Mona areas are located on the south limb, close to the hinge of the Mt. Sicker Anticline whereas the Northeast Copper area lies on the north limb. The lowest stratigraphic unit, the Nitinat Formation, occurs to the east suggesting the structure plunges to the west. The relative intensity of the foliation is controlled by the rock type, position with respect to the anticlinal axis and proximity to west- and northeast-trending faults.

3.1a Classification of Sicker Group volcanic rock

Volcanic rocks of the Sicker Group are defined on a basis of original volcanic textures although primary textures are obscured by

deformation and alteration. Virtually all volcanoclastic rocks on Mt. Sicker are ash tuff, based on grain size classifications (Appendix II) (Fisher, 1961, 1966; Easton and Johns, 1986). Only minor lapilli tuff and lapilli-ash tuff are present. In general, fragments consisting of aggregates of quartz and sericite are interpreted as lithic fragments. Chloritized fragments are interpreted as vitric fragments. More than 50% of the rock consists of microcrystalline quartz, sericite and chlorite, interpreted as a glassy ash matrix. In this study, rocks were also classified by fragment composition and proportion; i.e., crystal tuffs (>50% crystals), vitric-crystal tuff (10-50% crystals) and vitric tuff (<10% crystals) (Appendix II).

Andesitic volcanic rocks on Mt. Sicker are medium to dark green and feldspar pyroxene-phyric. Dacitic rocks are light to medium green to blue grey and generally feldspar-phyric, but can contain up to 5% quartz crystals. Rhyolitic to rhyodacitic rocks are light green-grey to grey and quartz feldspar-phyric.

3.2 The LENORA-TYEE Area

3.2a Stratigraphy

The Lenora-Tyce area and Zn-Cu-Au-Ag-Ba massive sulphide deposits are located on the south limb of the Mt. Sicker Anticline. The 200m x 400m area, mapped at 1:500 and 1:1000 scales, is bounded by the Lenora Fault to the north, and the Mine Fault to the south (Fig. 6). The volcanic and sedimentary rocks are cross-cut by steeply dipping and subhorizontal diorite dykes (Fig. 6, 7, 8).

The Lenora-Tyce stratigraphy is complex and consists of 9 subunits of the McLaughlin Ridge Formation (Fig. 9). The McLaughlin Ridge Formation on Mt. Sicker consists of 4 major stratigraphic units

Lenora-Tyce: Schematic Stratigraphic Section

B

C

Fig. 9 Schematic stratigraphic section from the Lenora-Tyce area. See Fig. 7 for location of the columns. Numbers refer to subunits described in text.

described in Chapter 4. The lower 5 subunits of the Lenora-Tyee stratigraphy are representative of the Mine Rhyolite while the uppermost 4 subunits are representative of the Upper Dacite (Chapter 4, Fig. 19). Tuffaceous rocks south of the Mine Fault and north of the steeply dipping diorite dyke represent rocks stratigraphically lower in the succession.

Subunit 1 3b

The lowest stratigraphic subunit is exposed only on the south Lenora Pit wall (Fig. 8). This subunit consists of massive, indistinctly bedded, quartz-feldspar-phyric vitric-crystal to crystal tuff. The colour of the tuff varies from light to medium green-grey, due to weak to moderate sericite and chlorite alteration. Quartz occurs as well rounded, skeletal, euhedral crystals and angular crystal fragments, up to 6mm in size. Feldspar fragments (<1-2mm) occur as intact, euhedral to subhedral laths and broken crystals. The glassy matrix comprises 50-80% of the tuff and is altered to microcrystalline sericite, quartz and chlorite. Rare chloritic streaks represent either original vitric fragments or discontinuous laminations. The modal percentage of quartz and feldspar crystal fragments varies from 15-35% and 0-15% of the rock respectively. The high quartz crystal fragment content make this tuff distinct from other tuffs of other subunits, but it is similar to tuffs associated with the younger quartz-feldspar-phyric flow (Subunit 5). In the Lenora Pit, subunit 1 contains 2-5% disseminated fine-grained pyrite and chalcopyrite and numerous 5-30mm wide veinlets of quartz, calcite, and barite with trace-3% disseminated pyrite and chalcopyrite. Malachite staining is present along foliation planes. This tuff is strongly foliated and moderately sericitized. It

is only recognized at this location. Subunit 1 is in sharp contact with the overlying subunit.

Subunit 2 4c,d

Subunit 2 is composed of graphitic and non-graphitic mudstone with minor siltstone and siliceous tuff containing cherty interlaminae. Subunit 2 overlies the quartz-feldspar-phyric tuff of Subunit 1 and provides a useful marker interval on Mt. Sicker. At the Lenora Pit, this sedimentary subunit consists of a thinly laminated to thin-bedded, graphitic mudstone with minor interbedded light grey ash or tuffaceous siltstone. Pyrite (<5%) is disseminated parallel to bedding laminations or mobilized into quartz veins. The mudstone is thickest (6m) on the north side of the pit and abruptly thins toward the portal of Lenora Adit 1 where two thin beds (10-20cm thick) of argillite-siltstone occur (Fig. 8). Thinly laminated to very thinly bedded (<1-10cm) black, weakly graphitic argillite grades into light grey to white, aphyric, fine-grained tuffaceous siltstone interbeds.

South of Lenora Adit 2, black graphitic argillite and mudstone are exposed in a down-dropped fault block. Interbedded dark grey chert, 4-6cm thick, containing 5-20% fine- to medium-grained pyrite, chalcopryite, sphalerite and minor galena occur in the mudstone. Pyritic veins less than 1 cm in width are present. To the north, this subunit contains 2-5% very fine-grained disseminated pyrite chalcopryite and is interbedded with a chloritized fine-grained tuff containing approximately 5% disseminated pyrite. The upper contact is gradational into light grey feldspar-phyric tuff of Subunit 4.

Subunit 3 Massive sulphide

At the Lenora Pit, a 0.74m thick, banded, massive sulphide subunit is composed of thin interlaminated to interbedded sphalerite-barite-pyrite-galena-chalcopyrite-quartz-calcite-rich and pyrite-chalcopyrite-sphalerite-galena-barite-quartz-calcite-rich bands.

Subunit 3 occurs near the basal contact of Subunit 4. The contacts of the massive sulphides with the tuff of Subunit 4 are either sharp or fault-bounded, marked with gouge.

Subunit 4 3,2d,c,b, minor 4b

This 4-14m thick subunit consists of massive, indistinctly bedded rhyolitic to rhyodacitic fine-grained tuff, rhyodacitic to dacitic fine to coarse, vitric-crystal tuff and minor siliceous tuff and tuffaceous chert. Subunit 4 is thinnest at the Lenora Pit and thickens to the north, away from the Mine Fault. The matrix consists of microcrystalline sericite, quartz, feldspar, chlorite, epidote and calcite and composes 75-90% of the subunit. Feldspar, 5-20%, occurs as single euhedral laths or glomerocrysts or as angular, irregular crystal fragments. Quartz, 0-7%, occurs as <0.5-1mm rounded to subrounded crystals or subangular crystal fragments. The distribution of feldspar and quartz crystal fragments defines a crude discontinuous layering which may represent bedding.

The Subunit 4 tuff coarsens upward and changes compositionally. Feldspar and minor quartz crystals comprise up to 40% of these rocks. Fine to coarse ash sized pumice fragments, 50%, and lithic fragments, <10% also occur. The pumice is altered to chlorite and minor quartz. Lithic fragments are altered to quartz, sericite and minor chlorite.

Subunit 4 contains minor 1-10cm interbeds of chert and siliceous tuff that contains up to 5% disseminated pyrite. The subunit is moderately to weakly silicified and sericitized, and weakly chloritized.

Subunit 5 3a,b

Subunit 4 is overlain by a quartz-feldspar-phyric to quartz-phyric flow containing about 5% euhedral, skeletal quartz phenocrysts (1-10mm) and <15% feldspar phenocrysts (less than 2mm) in a microcrystalline sericite, quartz, feldspar, chlorite matrix. The Subunit 5 flow is distinguished from Subunit 4 by its massive, well indurated character. Quartz phenocrysts are unbroken, euhedral and contain embayments and inclusions of groundmass, typical of skeletal phenocrysts (Vernon, 1986). Feldspar crystals are parallel to the subhorizontal foliation and are weakly to strongly altered to epidote, carbonate, quartz, sericite and chlorite. The flow commonly contains subhorizontal chloritic streaks, which may represent flow banding. No flow-top or flow-bottom breccias or amygdules are present. Field relationships suggest that the flow forms a localized dome that is thickest against the Mine Fault and thins to the north and east.

The Subunit 5 flow grades laterally into strongly foliated, 4-5m thick vitric-crystal tuff that contains fragments of quartz crystals (2-7%, <1-4mm) and feldspar crystals (<10% and <0.5-1.5mm). This vitric-crystal tuff is similar mineralogically and texturally to the Subunit 1 tuff.

Subunit 6 2c minor 4b

The quartz-feldspar-phyric flow is overlain by Subunit 6, composed of 3.5m of medium to dark green dacitic tuff. The matrix comprises 60-70% of the rock and consists of microcrystalline sericite,

chlorite, quartz and feldspar. Flattened and rounded lithic fragments, 20%, are altered to sericite, quartz and chlorite. Flattened subangular vitric fragments, 5-10, are altered to chlorite and quartz. Feldspar and rare quartz crystal fragments comprise 5-10% of the rock. Feldspar fragments are weakly chloritized and sericitized. Interbeds of 1 to 2.5 cm thick tuffaceous chert occur.

Subunit 7 4a

Subunit 7 consists of a 1.5-2m thick massive, well-laminated to thinly bedded, light brown-grey to medium grey chert that is composed of microcrystalline quartz, sericite, chlorite, trace calcite and 5-10% disseminated hematite. Variations in the percentage of sericite, chlorite and hematite produce the laminations. The distinct light brown coloration is due to hematite.

Subunit 8 3f

Subunit 7 is overlain by a 2m thick light green-grey to white heterolithic lapilli-ash tuff. The lapilli-ash tuff contains 20-40% lapilli to block sized fragments consisting primarily of chert with lesser tuffaceous and felsic intrusive fragments. Subrounded tuffaceous fragments are fine-grained and occasionally feldspar-phyric. Felsic intrusive fragments consist of fine equigranular feldspar. The chert and feldspar-rich fragments are subrounded to angular and relatively undeformed. The lithic fragments are randomly oriented and matrix supported. The variably silicified matrix contains 5-30% broken quartz crystal and feldspar crystal fragments, 0.3-7mm and 0.2-2.5mm respectively, and flattened chloritic fragments, 5-10%, which may

Plate 1. Photographs of polished rock slabs and outcrop representing the major lithologies mapped at Lenora-Tyce.

Scale bar equals 2 cm.

Plate 1a. Well laminated to bedded chert (Unit 7). Laminations represent variations in sericite, hematite and chlorite content.

Plate 1b. Heterolithic lapilli-ash tuff (Unit 8) containing rounded to angular chert fragments (A), tuffaceous fragments, felsic intrusive fragments (B), and quartz and feldspar crystal fragments within a silicified microcrystalline matrix. Note the matrix supported and relatively undeformed nature of the lapilli.

Plate 1c. Massive quartz-feldspar-phyric flow (Unit 5). Ovoid quartz phenocrysts define a moderate to strong mineral lineation. The dark chloritic streaks may represent either flow banding or altered mafic minerals.

Plate 1d. Well bedded dacitic vitric-crystal tuff and fine-grained tuff located north of the steeply dipping intrusive diorite. This rock likely represents rocks of the Lower Dacite. Note the crude grading of feldspar crystal fragments and phenocryst fragments:

Plate 1e. Strong crenulation and tight folding of tuff (Unit 4) produced a subvertical axial planar foliation. This transposition foliation formed through rotation of a preexisting foliation.

Plate 1f. Thinly laminated to thinly bedded, weakly graphitic siltstone (Unit 2) with occasional compositionally graded beds. Tight crenulation and folding are typical.

Plate 1g. Indistinctly bedded, rhyodacitic to dacitic fine grained tuff with minor vitric-crystal tuff (Unit 4). Note the tight crenulation of the pre-existing foliation. (Hammer at top right).

Plate 1h. Massive to indistinctly bedded quartz-feldspar-phyric vitric-crystal to crystal-vitric tuff (Unit 1) located on the south wall of the Lenora Pit. This tuff has been tightly folded about a shallow east plunging fold axis. (Hammer at bottom).

Plate 1.

Plate 2. Photomicrographs of quartz-feldspar phyric flow and tuff in thin section at the Lemora-Tyee map area.

- Plate 2a. Skeletal octahedral quartz phenocryst within the quartz-feldspar-phyric flow (Unit 5). Note the foliated microcrystalline matrix of sericite, quartz, feldspar and chlorite and undeformed inclusions of matrix within the crystal. Scale bar equals 1.75mm.
- Plate 2b. Quartz phenocryst within the quartz-feldspar-phyric flow (Unit 5). Note the inclusions and embayments of groundmass typical of skeletal crystal forms. Scale bar equals 1.75mm.
- Plate 2c. Well foliated fine tuff (Unit 4) contains irregularly subrounded to subangular quartz crystal fragments (A), and occasional subrounded feldspar crystal fragments (B). Note subrounded quartz, sericite, chlorite aggregates interpreted as lithic fragments. Scale bar equals 1.75mm.
- Plate 2d. Laminations are defined by the content of feldspar crystal fragments with a feldspar-quartz-phyric vitric-crystal tuff (Unit 4). Broken feldspar crystals are twinned and frequently brecciated with pressure fringes of chlorite, quartz and sericite. Scale bar equals 1.75mm.
- Plate 2e. Fragment-rich fine tuff (Unit 4). Undeformed feldspar laths (A) are weakly sericitized. Subrounded lithic fragments (B) have altered to quartz, sericite, and chlorite aggregates. Vitric pumice fragments (C) altered to chlorite and quartz appear elongate and subangular. Scale bar equals 1.75mm.
- Plate 2f. Weakly foliated vitric tuff located north of the Mine Fault, contains impinging spherical quartz and chlorite forms interpreted as perlitic fragments. Perlitic cracks and glass have altered to chlorite and quartz respectively. Scale bar equals 0.44mm.
- Plate 2g. Zoned feldspar glomerocrysts and crystal fragments in a chloritized dacite to andesite crystal tuff found north of the subvertical diorite intrusion. Feldspar fragments are weakly sericitized and chloritized. Scale bar equals 1.75mm.
- Plate 2h. Angular feldspar crystal glomerocryst fragments with a quartz, feldspar, chlorite and sericite microcrystalline matrix from a vitric-crystal to crystal tuff south of the Mine Fault. Scale bar equals 0.88mm.

Plate 2.

represent altered mafic minerals or vitric fragments. The matrix consists of microcrystalline quartz, sericite and minor chlorite.

Subunit 9 2d,c

Subunit 8 grades vertically into a white to medium-green fine-grained dacitic tuff, 2-4m thick. The fine-grained tuff contains 5-10% feldspar and rare quartz crystal fragments, less than 0.5mm. The microcrystalline matrix consists of talc/sericite, chlorite, quartz and feldspar. Both Subunits 8 and 9 are strongly talc/sericite altered.

Intrusive Rocks

Steeply dipping and subhorizontal diorite dykes up to 45m thick cross-cut the volcanic and sedimentary succession at the Lenora-Tyce area. The intrusions are variably textured, the most prominent being medium-grained equigranular diorite and feldspar porphyritic diorite. Toward the Lenora and Mine Faults, the diorite decreases in grain size and is moderately to strongly foliated. Talc and silicic alteration of Subunit 8 reflects a contact metamorphic aureole surrounding this intrusion.

Barren quartz veins up to 1m thick are found along the south wall of the Lenora Pit, parallel to the Mine Fault and in the Lenora Fault. Fragments of diorite are frequently found in these veins.

3.2b Zn-Cu-Au-Ag-Ba Massive Sulphide Deposits

Two elongate, lenticular massive-sulphide deposits known as the North and South 'orebodies' were mined by two companies, between 1898 and 1909, as the Lenora and Tyce deposits. The North and South 'orebodies' were stratiform deposits that were folded into tight synclines and anticlines within fault-bounded blocks. The South

'orebody' had a strike length of 609m, a down-dip extension of 46m and a thickness of 6m (Stevenson, 1945, 1948). At the Tyce shaft, it was folded into an anticline bounded by the Mine Fault and the North Fault, as described by Stevenson (1945). The North 'orebody' had a strike length of 516m, a down dip extension of 36m and a thickness of 0.3-3m (Stevenson, 1948). The North 'orebody' was folded into a syncline, north of the North Fault. The North Fault has down dropped the North orebody about 61m relative to the South orebody (Stevenson, 1948).

Two mineralogical types of ore were described by Stevenson (1948): a) 'Barite ore' consisting of fine-grained pyrite, chalcopyrite, sphalerite, and galena in a barite, quartz, and calcite gangue b) 'Quartz ore' consisting of quartz, pyrite, and chalcopyrite.

Mapping, recent trenching (Fig. 8) and petrography (Appendix III) have revealed that sulphides occur as five morphological types.

A Banded massive sulphide

Banded massive sulphide, Subunit 3, forms a dark grey, 0.74m thick interval exposed over a strike length of 5m at the west end of the Lenora Pit. Subunit 3 consists of discontinuous, thinly interlaminated to bedded, fine-grained but recrystallized sphalerite-barite-pyrite-galena-chalcopyrite and pyrite-chalcopyrite-sphalerite-galena-barite-rich bands that contain 40% and 65% sulphides respectively. The bands are 0.4-1.5cm thick. The matrix is composed of an anhedral mosaic of microcrystalline barite, quartz, calcite, and sericite in the proportions 8:4:1:1. Light grey to white, thinly laminated barite, generally less than 1.5mm thick, occurs. Assays of 3 samples are given in Appendix VII.

In the pyrite-rich bands, chalcopyrite and sphalerite proportions vary, producing pyrite-chalcopyrite- and pyrite-sphalerite-rich layers. The grain size and percentage of pyrite varies to a lesser extent. Gold occurs as electrum (Appendix VII) included in chalcopyrite, and infilling brecciated pyrite with chalcopyrite. Rare grains of hessite are associated with galena.

The banded massive sulphide is folded into a tight, overturned syncline. Minor tight parasitic folds occur in the banded ore. At the Lenora Pit, the fold axis plunges about 13°E . At the west end of the Pit, the fold axis is drag folded and rotated subvertically, due to movement along the Mine Fault. The north limb of this unit is thinned by shearing. A thick crudely layered massive sulphide body occupies the fold hinge area and was probably formed by mobilization of sulphides during folding.

B Deformed massive sulphide

The east wall of the Lenora Pit exposes a fault zone (Fig. 8) that is bounded to the south by the Mine Fault and to the north by a fault possibly equivalent to the North Fault (Stevenson, 1948). Two small exposures of massive sulphide occur there, both having sheared contacts. The deformed massive sulphide contains 65-80% chalcopyrite, pyrite, sphalerite, and galena with 2-3% tennantite. Brecciation and cataclasis of pyrite is characteristic. Hand samples have a fragmental and smeared texture (Craig and Vaughan, 1981). The deformed massive sulphide contains 10-20%, chalcopyrite-rich and sphalerite-rich fragments and 5% barite-rich fragments, 2mm-8cm. Subrounded to rounded chalcopyrite-rich fragments (0.5-4mm) contain chalcopyrite, sphalerite, pyrite, galena and tennantite. Subangular to subrounded sphalerite-rich

fragments consist of sphalerite, chalcopyrite and pyrite and barite-rich fragments contain calcite, barite, sphalerite, galena, chalcopyrite and pyrite with trace quartz and sericite. The matrix to all fragments is composed of 30-40% strongly brecciated pyrite, 20-30% disseminated chalcopyrite, sphalerite and tennantite within 15-30% Fe-oxide, calcite, barite, quartz and sericite. Cross-cutting veinlets of calcite, trace barite, quartz and sericite are parallel and perpendicular to the foliation. All primary textures are obliterated. Electrum is included in chalcopyrite but is rarely found along chalcopyrite-sphalerite grain boundaries. Rare grains of hessite are associated with galena.

The deformed massive sulphide likely represents much of the 'barite ore' of the South orebody. Old stopes, adits and shafts are parallel to and located in the shear zone between the North and Mine Faults (Fig. 6). The Lenora-Tyee deposits are interpreted to have been discontinuous, boudinaged, elongate pods in the fault zone associated with the Mine Fault.

E Feldspar pods

Feldspar pods are 0.35-3m, elliptical bodies that are exposed in the Lenora Pit. These pods occur parallel to and along the massive sulphide-tuff and sediment-tuff contacts and major and minor faults (Fig. 8). Pods adjacent to the massive sulphide contain chalcopyrite, sphalerite, pyrite, tennantite and trace galena. Sulphide minerals occur as disseminations in a mosaic of fine- to medium-grained twinned plagioclase and rare quartz, and as veinlets associated with calcite and sericite. Silver occurs in tennantite. No electrum or hessite are present. The feldspar matrix is relatively undeformed.

Plate 3. Photographs of rock slabs and photomicrographs of sulphide minerals, gold and hessite in polished section.

Scale bar for rock slab 3a equals 4cm, for other rock slabs, 2cm.

Plate 3a. Banded massive sulphide exposed in the Lenora Pit (Unit 3) consists of interlaminated to interbedded sphalerite-barite-pyrite-galena-chalcopyrite-quartz-calcite-rich (A), and pyrite-chalcopyrite-sphalerite-galena-barite-quartz-calcite-rich (B) bands. Note white to grey barite laminations (far left), barite veinlets (lower centre) and internal folding.

Plate 3b. Deformed massive sulphide found within the shear zone at the east end of the Lenora Pit. Note the fragmental texture, most noticeably the barite-rich fragments (A), and cross cutting barite veinlets.

Plate 3c. Quartz vein from the east end of the Lenora Pit containing 35-40% sphalerite, pyrite, chalcopyrite, and galena.

Plate 3d. Feldspar pod from the Lenora Pit containing chalcopyrite, pyrite, sphalerite, tennantite, and galena. Sulphide minerals occur as disseminations in a mosaic of twinned plagioclase and rare quartz and as veinlets associated with calcite and sericite.

Plate 3e. Photomicrograph of banded massive sulphide illustrating the two compositional bands described in Plate 3a. Scale bar is 1.75mm.

Plate 3f. Photomicrograph of deformed massive sulphide illustrating the fragmental texture described in Plate 3c. Subrounded barite-sphalerite-galena-pyrite-tetrahedrite-rich fragments (top left), subangular to subrounded sphalerite fragments (A) and angular to subrounded chalcopyrite-pyrite-sphalerite-quartz-rich fragments (B) occur within a matrix of cataclastically deformed pyrite, minor chalcopyrite, sphalerite, tennantite and gangue. Scale bar equals 1.75mm.

Plate 3g. Photomicrograph of hessite grains (hess) occurring along sphalerite (sp), chalcopyrite (ccp) and galena (gn) grain boundaries within the quartz veins described in Plate 3f. Scale bar equals 0.12mm.

Plate 3h. Photomicrograph of electrum occurring with chalcopyrite infilling brecciated pyrite. Scale bar equals 0.12mm.

Plate 3i. Photomicrograph of electrum, hessite, sphalerite and chalcopyrite in an inclusion with pyrite. Scale bar equals 0.12mm.

Plate 3.

3.2c Structure

The structural geology of the rocks in the Lenora-Tyce area is dominated by a strong axial planar foliation and associated minor folds and crenulations. The Mine Fault includes an 18m wide fault zone exposed at the east end of the Lenora Pit (Fig. 8). Other minor faults also parallel the axial planar foliation. Numerous phases of deformation have affected the strata.

Phase 1

The earliest phase of deformation is characterized by a subhorizontal foliation (S_1), parallel to bedding, which is well exposed in the graphitic and non-graphitic mudstone and siltstone of Subunit 2. Thin shear zones are locally expressed as seams of graphitic clay along the sediment-tuff contacts. A moderate to strong quartz lineation is well developed in the quartz-phyric to quartz-feldspar-phyric flow (Fig. 7, 10). Most pressure fringes are symmetrical about the quartz phenocrysts. Where they are asymmetric, conflicting senses of shear are implied. Beds of siliceous tuff in the felsic vitric-crystal tuff of Subunit 4 are locally boudinaged reflecting a 100° - 103° extension direction.

Massey and Friday (1988) describe an early syn-Sicker Group, Late-Devonian deformation which produced open folds in the Nitinat and McLaughlin Ridge Formations. Subsequent uplift and erosion produced the unconformity at the base of a Cameron River Formation (Massey and Friday, 1987, 1988). Whether this phase formed during this Late Devonian event or as an early event associated with the second more brittle phase of deformation is not known.

A

Axial Planar Foliations

mean - $103^{\circ} / 82^{\circ}S$

n - 108

B

Quartz Lineations

mean - $105 / 13 E$

n - 18

C

Minor Fold Axes

mean - $109^{\circ} / 13^{\circ}E$

n - 38

- measured
- + calculated

Fig. 10 Equal area stereographic projections of structural data from the Lenora-Tyce area. (A) poles to cleavage (B) quartz lineations (C) minor fold axes.

Phase 2

Phase 2 deformation is related to the development of the Mt. Sicker Anticline. A strong transposition foliation (S_2) is well developed. This transposition involves the rotation of a preexisting foliation by tight isoclinal folding into an orientation that is approximately parallel to the axial plane of the folds (Hobbs et al., 1976). Abundant faults trend parallel to the axial plane of the anticlinal structure. At the Lenora-Tyce area, bedding on a small scale has an average orientation of $103^\circ/80^\circ$, parallel to the foliation. However, on a large scale, bedding strikes approximately northeast-southwest and dips parallel to the plunge of the minor folds (Fig. 7). The chert of Subunit 7 is oriented $035^\circ/23^\circ$ SE.

Tight minor folds and crenulations are well developed in tuffs and sediments. Variations in foliation dip likely represent different limbs of minor folds. Quartz lineations are oriented $105^\circ/13^\circ$ E, approximately parallel to the minor fold axis of $109^\circ/13^\circ$ E (Fig. 10). This post-Lower Permian to pre-Middle Triassic phase of deformation has affected all Sicker Group rocks, but has not overturned the stratigraphy (Massey and Friday, 1988).

Phase 3

Phase 3 deformation occurred during crustal extension and is possibly related to the extrusion of the Late Triassic Karmutsen Formation (Massey and Friday, 1987, 1988). The dykes emplaced at this time are steeply oriented or shallowly dipping and relatively undeformed. Steeply oriented dykes may feed the relatively thicker, shallowly oriented dykes.

Phase 4

Post-Middle Jurassic to pre-Late Cretaceous deformation (phase 4) resulted in the three major geanticlinal uplifts cored by the Sicker Group (Massey and Friday, 1987, 1988).

Phase 5

Large scale, Late Cretaceous west-northwesterly trending thrust faults (phase 5) cut the Cowichan-Horne Lake Uplift into several slices (Fig. 1, 5). These faults, including the Fulford Fault, are high angle reverse faults that parallel the earlier foliation. Minor imbrications, such as the Mine Fault and associated fault zone, could also have been active at this time. Regional tilting is probably related to the subsequent emplacement of terranes to the west (Yorath et al., 1985a, 1985b).

Phase 6

Subsequent relaxation of the compressive regime resulted in normal faults. Thrust faults formed during phases 4 and 5 were reactivated as normal faults (phase 6). In particular the Mine Fault and North Fault (Figs. 5, 7) have normal displacements of about 250m and 61m respectively.

Phase 7

Numerous steeply oriented, north-northeast trending faults (phase 7), including the Lenora Fault (Fig. 7), crosscut the previous structural features. Phase 7 faults have variable and inconsistent normal and reverse displacements. Massey and Friday (1987, 1988) describe these faults as Tertiary structures.

3.3 The MONA Showing

3.3a Stratigraphy

The Mona map area (Fig. 5), is located on the south limb of the Mt. Sicker Anticline. The 500m x 425m area was mapped at a scale of 1:1000. Diamond drilling and surface mapping indicate a shallow (20°-30°), south-dipping succession of pyroclastic volcanics with minor tuffaceous chert, bounded to the west by the Fortuna Fault and to the south by a shallow south dipping diorite dyke.

The Mona stratigraphy is made up of 14 subunits of the McLaughlin Ridge Formation (Fig. 12, Appendix IV). The lowermost 5 subunits are representative of the Lower Dacite. The overlying 7 subunits are representative of the Mine Rhyolite, and the uppermost 2 subunits are representative of the Upper Dacite.

Subunit 1 2a minor f

Subunit 1 occurs at the north end of the Mona area and consists of a light grey-green, massive and indistinctly bedded vitric-crystal tuff. The vitric-crystal tuff contains 15-30% feldspar, as crystals and crystal fragments; the distribution of which defines a crude layering. Pressure fringes about feldspar fragments are filled with chlorite, quartz, feldspar, sericite and minor epidote. Up to 15% angular and variably shaped chloritic fragments, ≤ 2 cm, may represent altered pumice fragments. The matrix consists of microcrystalline sericite, chlorite, feldspar, and quartz. Foliation is weak to moderate. Chloritization and sericitization are moderately developed.

Subunit 2 1a

Mona: Schematic Stratigraphic Section

Fig. 12 Schematic stratigraphic section from the Mona area showing distribution of sulphides. Columns A and B includes lithologies from the west and east end of the map area (Fig. 11). Numbers refer to subunits described in text.

Subunit 2 is a 4-5m thick interval consisting of a dark green andesitic vitric-crystal tuff. The vitric-crystal tuff contains 30% feldspar occurring as 1-4mm crystal or glomerocryst fragments. About 5% rounded and strongly chloritized lithic fragments, 3-10mm, are disseminated throughout. Chert fragments up to 5mm occur locally. Chlorite-poor bands, up to 5mm thick and parallel to the foliation, may represent original laminations.

Subunit 2 is strongly chloritized. Variable saussuritization of feldspar crystals is typical.

Subunit 3 2,3c

The overlying Subunit 3 is a 8.5m thick light grey-green dacitic vitric-crystal tuff. Feldspar crystal fragments, up to 20%, range from 0.5-2.5mm. Quartz crystal fragments are rare. The variable size and modal content of feldspar fragments defines a crude indistinct layering. The matrix consists of microcrystalline sericite, quartz, feldspar, and minor chlorite.

Subunit 4 3d,c

Subunit 4 is a 6.2m thick, light to medium green rhyolitic tuff containing 10-35% subrounded lithic fragments, 1-3mm. Lithic fragments are altered to fine-grained aggregates of epidote, chlorite, sericite, quartz and feldspar. Quartz crystal fragments, 0.1-3.5mm, comprise 5-30% of the rock. The microcrystalline matrix consists of quartz, sericite, chlorite, feldspar, epidote, and minor calcite.

The tuff is moderately chloritized and sericitized. Foliation is strong. Quartz crystal fragments are strongly deformed as reflected in subgrain development along deformation bands. Pressure fringes are filled with chlorite, quartz, calcite, and sericite.

Subunit 5 2,3c minor f

The overlying Subunit 5 is a fine-grained dacitic tuff, 6.8m thick to the east and an unknown thickness to the west. This subunit contains up to 20% feldspar crystals, ≤ 1 mm, concentrated in thin elongate and discontinuous laminations which may represent bedding. The laminations are oriented subparallel to the foliation. The matrix consists of microcrystalline quartz, sericite, chlorite and minor epidote.

Intercalated fine-grained feldspar-phyric and aphyric ash beds, < 1 cm, locally define bedding. Rare siliceous fragments occur in the east. Subangular chert fragments ($< 10\%$, 2×20 mm) are found in the west and near the top of the subunit. The subunit is coarser-grained and includes more and larger lithic fragments to the west.

Moderate sericitization, chloritization and weaker silicification are typical. Chloritic pressure shadows about feldspar crystals give a streaked appearance to the rock.

Subunit 6 3,2o,d minor f

Subunit 6 is light grey, and varies in thickness from 13.5m in the east to 17m in the west. Compositionally, it can be subdivided into two submembers. The basal submember consists of massive homogeneous rhyolitic vitric-crystal tuff. The microcrystalline matrix of feldspar, sericite, chlorite, and quartz contains 10-30% feldspar crystal fragments, 0.2-1.5mm. Minor chert fragments (5mm-30cm) occur throughout, and subangular quartz crystal fragments are rare. Toward the stratigraphic top of the submember the tuff is finer-grained, indistinctly bedded and increases from 0 to 5% in quartz crystal fragment content.

The tuff grades into an overlying submember of fine, light grey-green siliceous vitric tuff containing 5-10% feldspar crystals ($\leq 1.5\text{mm}$), trace quartz crystals, and occasional chert fragments ($\leq 2\text{cm}$). Moderate sericitization and weak to moderate silicification and chloritization are typical. The top of the subunit is marked by 3-5cm thick interbeds of andesitic and dacitic vitric-crystal tuff and tuffaceous chert.

Subunit 7 2c,d

The overlying Subunit 7 is 9m thick in the west. To the east, the subunit thins rapidly and pinches out. This dark grey-green dacitic vitric-crystal tuff contains 15-40% euhedral to subhedral feldspar crystal and crystal fragments ($\leq 5\text{mm}$). Toward the stratigraphic top of the subunit the percentage and size of crystal fragments vary to produce light grey-green interlaminated to interbedded vitric tuffs with 5-10% feldspar crystal fragments.

Crude crystal grading, in a few thin ash beds, indicate tops to the southwest. Bedding appears to be tightly folded as at the Lenora-Tyce area. Moderate chlorite alteration is pervasive.

Subunit 8 1a

A dark green andesitic tuff overlies Subunits 7 and 6 and is a distinctive marker horizon. The subunit has a thickness of 4-5m over its strike length and consists of a basal fine ash tuff grading upward into massive and crudely bedded fine-grained tuff, vitric-crystal/crystal tuff and lapilli-ash tuff. Feldspar crystal fragments and glomerocrysts, < 1 to 6mm , are strongly saussuritized. Beds, 0.5-4cm, are defined by the varying sizes and percentage of feldspar crystals, 10-40%, and the degree of matrix chloritization. The fine ash tuff is aphyric and strongly chloritic. Elongate thin chloritic streaks

occur in the fine-grained tuff and may represent flattened and altered vitric fragments. The percentage and grain size of feldspar crystal fragments decrease from east to west. Minor lapilli-ash tuff occurs only in the east. Chlorite and epidote alteration is characteristic of this subunit.

A characteristic feature of Subunit 8 is the presence of 2-5% rounded and elongate quartz 'fragments' composed of quartz subgrains which represent boudinaged quartz-pyrite stringers or deformed and elongate amygdules. Both the locally developed radial structure and the low abundance of sulphides suggest the latter. Interbedded aphyric and feldspar-phyric tuff suggest tight isoclinal folding about a subhorizontal fold axis.

Subunit 9 2,3c

Subunit 9 consists of a massive homogeneous light green-grey dacitic to rhyolitic vitric-crystal and crystal tuff. To the west, the subunit is over 12m thick, but pinches out to the east. Feldspar, 10-20%, occurs as euhedral to subhedral crystals and angular crystal fragments (0.25 to 1.5mm), in a microcrystalline matrix of sericite, quartz, feldspar, epidote, chlorite and opaques. Toward the stratigraphic top of the subunit, the varying proportion of feldspars, 10-30%, define a crude 1-10cm thick layering. Few rounded, irregular quartz fragments are present. Fragments (5%) up to 3cm of coarse feldspar-phyric tuff occur.

Brecciated feldspar crystals are variably replaced by sericite, chlorite, and epidote. Quartz, sericite, chlorite, and epidote infill pressure fringes and pull-apart structures giving the rock a streaked appearance.

Subunit 10 3,2f

An outcrop of light green-grey, heterolithic lapilli-ash tuff is found immediately west of the Mona Shaft (Subunit 10). The subunit thickens to the west but is truncated by a shallowly oriented diorite dyke. The lapilli-ash tuff contains 10-30% lapilli consisting of flattened and subrounded chert/siliceous tuff (1-2cm), subrounded and flattened fine ash tuff (0.6-1cm) and minor chloritic fragments (≤ 1.5 cm). The aphanitic matrix of sericite, feldspar, chlorite, and quartz contains 10-15% feldspar crystal fragments, 0.5-2mm in size.

Subunit 11 3d,4b

The overlying subunit consists of a 2-5m thick interval of light grey siliceous tuff and tuffaceous chert. To the west, tuffaceous chert interbeds (1-30cm), are thinner and interlaminated with the more predominant siliceous tuff. The siliceous tuff contains 2% feldspar crystal fragments (≤ 1 mm) and abundant chloritic streaks.

Subunit 12 3b and 3,2c,b

Subunit 12 consists of a basal and upper submember. The basal submember is a 17m thick, light grey-green quartz-feldspar-phyric and minor feldspar-quartz-phyric vitric-crystal tuff. Embayed, subangular to rounded quartz crystal fragments (0-10%, 0.4-5.5mm) are randomly distributed. Euhedral to subhedral, broken and rounded feldspar crystal fragments (<25%, 0.3-4mm) are variably altered to epidote, sericite, and chlorite.

Varying feldspar content, and to a lesser extent quartz content, produces an indistinct and discontinuous layering reflecting original bedding. The layering can be defined by the alignment of single crystals.

The matrix consists of microcrystalline sericite, quartz, feldspar, chlorite and minor epidote, and opaques. Development of subgrains and deformation bands reflect strong deformation.

The basal submember grades upward into 23m of light grey to medium green, fine to coarse vitric-crystal tuff. This tuff contains 10-20% rounded lithic fragments altered to quartz and sericite, 5-10% strongly epidotized feldspar glomerocryst fragments, up to 3.5mm, and subangular to rounded quartz crystal fragments, 2-3% and 0.2-0.5mm in size. Minor siliceous ash tuff and thin chert interbeds occur locally. Moderate sericitic and weak silicic and chloritic alteration are pervasive. Subunit 12 grades upward in grain size and bed thickness.

Subunit 13 3d,4b,a

Subunit 13 is a 4.5 m thick interval consisting of a basal green to dark grey laminated to bedded chert grading upward into tuffaceous chert and fine tuff. The fine tuff contains 5-10% weakly sericitized anhedral feldspar crystals ($\leq 0.2\text{mm}$), and 2% embayed, euhedral to subhedral quartz crystal fragments (0.2-0.8mm), in a microcrystalline matrix of sericite, quartz, feldspar, and chlorite. The fine tuff is strongly sericitized and weakly silicified.

Subunit 14 2a,d

The highest stratigraphic interval is Subunit 14. It is a light-medium green-grey dacitic feldspar-phyric vitric-crystal tuff. Subunit 14 is characterized by the presence of 20-35% feldspar crystals and crystal fragments (0.2-1.7mm). Feldspars occur as euhedral to anhedral crystals and broken subrounded crystal fragments. Strong sericite and moderate silica, epidote and calcite replacement of feldspars is typical. Rare quartz crystal fragments up to 0.4mm occur. The matrix

Plate 4. Photographs of rock slabs and photomicrographs of textures of lithologies mapped at the Mona showing.

Scale bar on rock slabs equal 2 cm.

Plate 4a. Dacite vitric-crystal tuff (Unit 1) containing feldspar crystals and glomerocryst fragments (A) with chloritic pressure fringes. Flattened chloritic fragments (B) are interpreted as altered pumice fragments.

Plate 4b. Andesite vitric-crystal tuff (Unit 8). Note saussuritized feldspar-phyric fragments and elongate thin chloritic streaks (A) interpreted as flattened and altered vitric pumice fragments.

Plate 4c. Dacite vitric-crystal to crystal tuff (Unit 9) consisting of abundant feldspar crystal fragments in a microcrystalline matrix. Note the lithic fragments of coarser grained crystal-rich tuff with chloritic matrix (A) possibly representing fragments of the underlying andesitic tuff.

Plate 4d. Quartz-feldspar-phyric vitric-crystal tuff (Unit 12) illustrating crude bedding defined by the content and size of feldspar crystal fragments. Note chloritic fragments (lower left) and pressure fringes about the crystal fragments.

Plate 4e. Photomicrograph of Unit 1 described in Plate 4a, illustrating size and shape variations of weakly sericitized and locally twinned feldspar crystal fragments. Pressure fringes and pull apart structures are infilled with chlorite, quartz, feldspar, sericite and epidote. Scale bar equals 1.75mm.

Plate 4f. Photomicrograph of the andesite vitric-crystal tuff described in Plate 4b illustrating strong saussuritization of feldspar crystal fragments and chlorite-epidote alteration of the matrix. Scale bar equals 1.75mm.

Plate 4g. Photomicrograph of the dacite tuff described in Plate 4c. Weakly sericitized and occasionally twinned broken feldspar crystal fragments illustrate variable sizes and shapes and define a crude layering. Pressure fringes consist of quartz, sericite, chlorite and epidote. Scale bar equals 1.75mm.

Plate 4h. Photomicrograph of quartz-feldspar phyric vitric-crystal tuff described in Plate 4d. Rounded quartz phenocrysts, with occasional inclusions of matrix, and euhedral feldspar phenocrysts, altered to epidote, sericite and chlorite, occur within a microcrystalline matrix of sericite, quartz, feldspar, chlorite, epidote and opaques. Scale bar equals 1.75mm.

Plate 4.

is moderately silicified and sericitized consisting of microcrystalline quartz, sericite, feldspar, chlorite and minor epidote. Chlorite, epidote, quartz, sericite and calcite occur as pressure fringes and infill pull apart structures in feldspars.

Intrusive Rocks

A north-northwest trending massive, weakly foliated dacite to rhyolite dyke outcrops east of the Mona Shaft (Fig. 11). It consists of 30% feldspar phenocrysts occurring as individual euhedral to anhedral laths (0.5-3mm) and locally radiating glomerocrysts, and 5% disseminated and altered mafic minerals (≤ 1.5 mm) in a siliceous, medium green-grey microcrystalline matrix. Feldspars are variably epidotized. No flow banding or preferred orientation of feldspars exists. This dyke can be traced over 90m to the north. A xenolith of this dyke occurs along strike within the diorite dyke. The weakly foliated dyke has a distinctive medium brown colour, due to alteration and contact metamorphic effects from the enclosing diorite.

Massive fine-grained diorite dykes, <5m wide, occur oriented parallel to the foliation. The sill-like diorite intrusion, which bounds the Mona area to the south, (Fig. 11) dips approximately 20-25° to the south and steepens at depth (Pers. Comm. G. Wells, 1988). The diorite dyke west of the Fortuna Fault may be the same intrusion.

This diorite has a 10-15cm, fine-grained, dark green chloritic chill zone which grades into porphyritic diorite containing 5% subhedral feldspar in a very fine-grained aphanitic matrix. The porphyritic diorite grades into a fine to medium-grained massive, homogeneous, subophitic diorite containing 25-30% plagioclase phenocrysts, actinolite, magnetite, ilmenite and leucoxene.

3.3b Sulphide Concentrations

Pyrite and rare chalcopyrite occur as stringers (2mm-70cm wide), disseminations (1-5%), and as discontinuous laminations or fragments (Fig. 11, 12). Stringers are composed of fine to medium-grained pyrite, trace chalcopyrite, quartz, and sericite. The granular, porous textured veins are typically oriented parallel to the foliation and have sharp to indistinct contacts with the tuffs. Sulphide mineral content is 50-70%. Quartz occurs occasionally as microcrystalline chert. The host rocks are generally silicified and sericitized. No distinct alteration halos are present.

In Subunit 5, 20-30% disseminated coarse-grained pyrite occurs in 5-30mm wide stringers (Fig. 11, 12). Fine-grained disseminated pyrite (5%) is present throughout the subunit. Locally thin, $<1 \times 5$ mm discontinuous streaks of fine-grained pyrite occur, possibly representing flattened and boudinaged pyritic laminations. A single angular fragment (3x4cm) of medium-grained pyrite was found.

The tuffaceous chert and siliceous tuff of subunit 13 contain 5% disseminated fine-grained pyrite throughout. Locally 1-3mm veinlets containing pyrite with minor chalcopyrite and quartz occur. Fine-grained pyrite occurs as up to 3% disseminations in siliceous tuff and up to 10-15% disseminations within 2-4mm thick interlaminated chert.

The most significant sulphide concentration occurs in Subunit 11. Thin chert interlaminations contain 10-30% disseminated fine-to coarse-grained pyrite, and locally contain thin discontinuous laminations of pyrite. The ash tuff contains 3% disseminated pyrite throughout and minor large pyrite stringers, with minor chalcopyrite and quartz. Recent drilling indicates that at depth, Subunit 11 appears to grade

laterally, east to west, from thin interbedded chert and tuff to a 50cm thick pyritic ash (15-25% pyrite), with occasional chert and tuff fragments, to a 4.3m thick lapilli-ash tuff containing 15-30% chert and tuff and rare pyritic fragments in an ash matrix containing 15% disseminated pyrite. Increase in subunit thickness and lapilli and sulphide content suggest a source to the west. Subunit 11 remains the prime exploration target for the Mona area.

3.3c Structure

The structure of the Mona area is difficult to decipher due to poor, two dimensional exposures; however, several phases of deformation can be identified.

Phase 1

Phase 1 is characterized by a moderate to strong quartz lineation trending 307°, well developed in Subunit 12 (Fig. 11, 13). Pressure fringes are symmetric. Interbeds and interlamination of siliceous tuff and tuffaceous chert are locally boudinaged also suggesting a northwest-southeast extension.

Phase 2

As at the Lenora-Tyce area, phase 2 is characterized by the development of a strong, steeply oriented foliation (S_2), axial planar to the Mt. Sicker Anticline (Fig. 13). The foliation cross-cuts the units on a large scale and likely represents a transposition foliation, as developed at the Lenora-Tyce area. Minor tight normal folds are recognised in two places. The average quartz lineation is rotated parallel to the plunge of the minor fold axis (Fig. 13). Drill hole

Axial Planar Foliations

mean - 310° / 88°NE

n - 74

Minor Fold Axes and Quartz Lineations

+ Fold Axes

mean - 307° / 14°NW

n - 2

• Quartz Lineations

mean - 307° / 14°NW

n - 10

Fig. 13 Equal area stereographic projections of structural data from the Mona area. (A) poles to cleavage (B) lineations and minor fold axes.

The change in plunge of the quartz lineations between the Mona and Lenora-Tyce areas may reflect a later warping of the Mt. Sicker Anticline. Widely spaced crenulations, oriented approximately north-northeast, are developed throughout the property and may reflect this late warping.

Phase 3

Phase 3 involves the emplacement of the steeply oriented and shallow dipping dilatant diorite dykes, during a period of crustal extension.

Phase 7

The northeast trending Fortuna fault cross-cuts all previous structures and likely represents a Tertiary cross fault (Massey and Friday, 1988).

3.4 The NORTHEAST COPPER Showing

3.4a Stratigraphy

The Northeast Copper area is situated on the north limb of the Mt. Sicker Anticline (Fig. 5). The 500m x 400m area was mapped at a scale of 1:1000. The volcanic succession appears folded into a minor syncline trending WNW-ESE. This is interpreted to reflect draping of the strata over a paleotopographic high. The area is bounded by diorite dykes to the north and south. The strata have been downdropped 50m to the east of the Tom Fault (Fig. 14).

The Northeast Copper stratigraphy is made up of 3 units (Fig. 15). Unit 1 is representative of the Mine Rhyolite, Unit 2 is representative of the Upper Dacite, and Unit 3 is representative of the Upper andesite (see Chapter 4).

Northeast Copper:

Schematic Stratigraphic Column

Fig. 15 Schematic stratigraphic column from the Northeast copper area. Numbers refer to units described in text.

Unit 1 3a,b,3b,3c

The lowermost unit consists of a heterogeneous succession of light to medium green-grey felsic rocks. A basal subunit of quartz-phyric to quartz-feldspar-phyric vitric-crystal tuff and minor flow grades upward into an overlying middle subunit of quartz-feldspar-phyric vitric-crystal to crystal tuff and finally into a thin upper subunit of feldspar-quartz-phyric vitric-crystal tuff (Fig. 14, 15).

Unit 1 thickens rapidly toward the Tom Fault from about 15m thick, 130m from the fault, to 35m at the fault. The lower subunit thins rapidly away from the fault while the overlying middle subunit thickens away from the fault. The upper subunit is not continuous but thickens rapidly toward the fault and possibly down dip.

Homogeneous rhyolite flows of the lower subunit are similar mineralogically and texturally to the flow at the Lenora-Tyce area. Quartz phenocrysts are euhedral to subhedral, skeletal, embayed and often contain inclusions of groundmass. The groundmass is microcrystalline. Feldspar phenocrysts or glomerocrysts are moderately to strongly sericitized and are subrounded to angular. Quartz-phyric vitric-crystal tuff, interbedded with the flow, contains fragmented skeletal quartz crystals and minor amounts of feldspar crystals.

The overlying quartz-feldspar-phyric tuffaceous subunit contains skeletal quartz crystal fragments. This middle subunit appears laminated in thin section. Feldspar-rich coarse crystal tuff laminations, up to 3mm, containing 40-50% euhedral-subhedral broken feldspar laths, glomerocrysts and minor skeletal quartz crystal fragments, are interlaminated with fine crystal tuff containing 2-10% quartz fragments up to 6mm. The laminations are tightly folded and

strongly foliated parallel to the axial plane. The size of feldspar crystal fragments is variable. Quartz crystal fragments vary in size, shape, and proportion relative to feldspar.

The overlying upper subunit is a much finer-grained feldspar-quartz-phyric vitric-crystal tuff containing rare quartz crystal fragments greater than 2mm. The quartz fragments rarely show skeletal or embayed textures. The light to medium green colour and occasional quartz crystal fragments distinguish it from overlying tuff of Unit 2.

Unit 2 2d,c

Unit 2 consists of dacitic fine tuff with interbedded massive chert and minor rhyolitic to dacitic coarse ash to lapilli-ash tuff (Fig. 14, 15). The thickness of this unit varies from 25-40m. Individual ash and chert beds thicken away from the Tom Fault and onlap Unit 1 (Fig. 14, 16).

The dacite tuff of Unit 2 is strongly chloritized and moderately sericitized. The fresh surface is dark green. The tuff consists of a locally well laminated fine-grained ash containing subrounded to angular dark grey chert fragments (6mm and 7.5cm). Rounded fragments, 1-3% and 1-3mm, composed of quartz subgrains and minor pyrite, represent remnants of boudinaged stringers. Where an overlying tuff is in contact with chert, the tuff contains 3-5% subangular chert fragments (<7.5cm).

Locally developed coarse ash to lapilli-ash, feldspar-phyric tuff contain up to 10% feldspar crystal and glomerocryst fragments, subsequently altered to sericite and chlorite. Elongate, flattened chloritic fragments occur.

On the north limb of the minor syncline, a felsic quartz-phyric coarse ash to lapilli-ash tuff is in faulted contact with two chert

Fig. 16 Schematic structural cross-section of the Northeast Copper area. See Fig. 13 for the location of the section.

intervals (Fig. 14, 16). This tuff is light to medium green and contains 10-15% quartz crystal fragments (0.1-0.25mm). About 30-40% fragments, (0.1-1.5mm), consisting of quartz and sericite represent either chert or lithic fragments. This massive homogeneous tuff grades upward into 2cm thick bedded and locally graded tuff and well laminated chert.

The uppermost interval is a dacitic to andesitic tuff containing 2-5% quartz crystal fragments (0.2-0.8mm) and 10-15% round amygdules (0.2-1.5mm) composed of fine quartz subgrains. Strongly chloritized and sericitized vitric or lithic fragments are abundant. Massive andesite fragments are rare.

Chert interbeds, 2-15cm thick, generally occur near the upper contacts of tuff intervals. Light to dark green grey chert intervals, 1.5-0.5m thick, occur at four stratigraphic levels within the dacitic tuff (Fig. 15). Two minor chert intervals onlap and pinch out to the east. These intervals are homogeneous, massive and not laminated. Thin laminations, <1-3mm, in one location indicate dips to the south. Chert intervals contain occasional 1.5-8cm elongate and rounded, in some cases nodular, fragments of fine granular quartz, sericite and pyrite.

Unit 3 1g

The stratigraphically highest Unit consists of a fine-grained medium green-grey massive andesite flow, variably altered to chlorite and sericite (Fig. 15, Appendix V). The flow is amygdaloidal, trachytic, weakly variolitic and shows 'swallow tail' and 'belt buckle' quench textures. East of the Tom Fault this andesite flow has a basal flow breccia 1m thick. The breccia consists of 10-15% chloritized tuff fragments with minor vitric-crystal tuff, chert, and occasional quartz

Plate 5. Photographs of outcrop and a photomicrograph from Unit 12 at the Mona showing (Plates 5a, b, c, d) and of lithologies from the Northeast Copper showing (Plates 5e, f, g, h).

Plate 5a. Massive quartz-feldspar phyric vitric-crystal tuff showing streaked nature. Note thin, single crystal thick laminations defined by feldspar crystal fragments (A).

Plate 5b. Indistinct bedding within massive quartz-feldspar-phyric vitric-crystal tuff defined by the percentage and size of feldspar crystal fragments (A). Note the consistent size and distribution of quartz fragments (B).

Plate 5c. Photomicrograph of interlaminated feldspar-quartz phyric vitric-crystal tuff. Note the presence of angular broken feldspar crystal fragments. Feldspar crystals are variably altered to epidote, sericite and chlorite. Scale bar equals 1.75mm.

Plate 5d. Plan view of outcrop. An interbed of siliceous ash tuff (A) is exposed within the hinge of a shallow west plunging tight minor syncline. Note the fold axis plunges to the right. The interbeds occur within quartz-feldspar-phyric vitric-crystal tuff.

Plate 5e. Strongly chloritized dacitic ash tuff (Unit 2) containing chert rip ups (circled) from an underlying chert horizon. Chert fragments are found only within 20 cm of the chert-tuff contact and appear to grade away from the contact.

Plate 5f. Within Unit 2 a felsic vitric-crystal tuff shows an upward decrease in bed thickness and upward grading within each bed. These features have been termed 'doubly-graded' by Fiske and Matsuda (1964). This tuff grades into an overlying well laminated chert.

Plate 5g. Quartz-feldspar phyric vitric-crystal tuff (Unit 1) containing angular to euhedral quartz fragments. The size and shape variation of the quartz suggest the unit is a tuff and not a flow.

Plate 5h. Photomicrograph of a massive andesite flow (Unit 3) showing trachytic, variolitic and skeletal crystal textures ('swallow tail' and 'belt buckle' textures). Scale bar equals 0.88mm.

Plate 5.

crystal fragments in a strongly silicified, trachytic andesite flow matrix.

3.4b Sulphide Concentration

Sulfide minerals are common at Northeast Copper as: a) pervasive, 5-15% disseminations of fine-grained, euhedral to anhedral pyrite and chalcopyrite; trace sphalerite occurs as inclusions in pyrite, b) 0.1-16cm stringers of pyrite, chalcopyrite, sphalerite, chlorite, quartz, and sericite, and c) rare stratiform disseminations of fine-grained pyrite. Stringers consist of 40-80% fine to coarse-grained, recrystallised pyrite with minor intergranular chalcopyrite. Both chalcopyrite and sphalerite are included in pyrite.

Unit 1 contains up to 15% pyrite and trace chalcopyrite as disseminations restricted to an unconformable zone (Fig. 17). Rocks outside this zone contain few sulphide minerals. Stringers, up to 15cm in width are found in float originating from the Tom Shaft. These stringers contain fine to medium-grained pyrite, chalcopyrite, quartz, and sericite and have a granular, porous texture.

The overlying dacite tuff and interbedded chert of Unit 2 contain disseminated pyrite, 5-20%, and rare chalcopyrite, primarily concentrated in the lower half of this unit. Disseminated sulphides, up to 40%, occur locally along the contacts with interbedded cherts. Stringers, 1-20mm, may comprise 20-25% of the rock and consist of 40-60% pyrite and 2% chalcopyrite.

The massive chert intervals of Unit 2 contain 5-20% disseminated, very fine-grained pyrite and chalcopyrite. Abundant stringers, 1-50mm in width, are composed of up to 70% pyrite and 5% chalcopyrite. One

Sulphide concentrations and alteration at the Northeast Copper area

Fig. 17 Areal distribution of sulphides and alteration of the Northeast Copper area.

chert interval contains 16cm of fine to medium-grained pyrite and chalcopyrite, possibly a stringer.

The overlying andesite flow of Unit 3 contains 2-3% disseminated, fine-grained pyrite and minor, 1-5mm wide pyrite veinlets. Both the dacite ash tuff and chert intervals are more sulphide-rich to the south suggesting that sulphide mineralization may have been restricted to a zone on the south flank of a paleotopographic high, represented by Unit 1.

3.4c Alteration

Due to the spatial variability of sulphides and associated alteration within Unit 1, the mapping and delineation of different alteration facies was attempted. Poor outcrop distribution, weathering and strong deformation inhibited any detailed subdivision.

Three pervasive alteration types were mapped (Fig. 17). In order of increasing intensity they are: a) sericite-quartz b) sericite-chlorite-pyrite, and c) chlorite-pyrite.

The sericite-quartz alteration is restricted to rocks adjacent to, and outside of sulphide-rich areas (Fig. 17). The matrix is weakly to moderately altered and contains 2% disseminated fine-grained pyrite. Sericite-quartz altered rocks represent least altered rocks.

The sericite-chlorite-pyrite type of alteration occurs in areas characterized by disseminations of 2-5%, fine to medium-grained pyrite. The matrix contains streaks of sericite and chlorite. The light to medium green colour reflects an increased sericite and chlorite content relative to quartz.

The chlorite-pyrite type of alteration is restricted to a 10-15m wide zone within Unit 1, in spatial association with areas of 10%

pyrite±chalcopyrite stringers (Fig. 17). Unit 2 is pervasively chlorite-quartz altered. It is characterized by 5-25% disseminations of fine to coarse-grained pyrite in a dark green, pervasively chloritized matrix.

In order of increasing alteration intensity, the following symmetrical assemblages were observed in thin sections of Unit 1:

1. albite-sericite-quartz-chlorite-hematite-zircon
pyrite±sphalerite
2. sericite-quartz-chlorite-albite-hematite-pyrite-
sphene±chalcopyrite
3. chlorite-sericite-quartz-pyrite-hematite-chalcopyrite-
epidote±zircon

Alteration assemblage 2 is characterized by increased sericite, chlorite and pyrite contents and relatively small decreases in quartz content relative to assemblage 1. This alteration forms a discordant zone across Unit 1, and affects most of Units 2 and 3 as a patchy, or semi-concordant alteration (Fig. 17).

Alteration assemblage 3 occurs as a 10-30m wide, pipe-like zone within Unit 1 and as patchy alteration zones within Unit 2 (Fig. 17). It is characterized by further increases in chlorite and pyrite content, and diminished sericite and quartz content. Up to 20% disseminated pyrite occurs as fine-grained euhedra. Trace anhedral disseminated chalcopyrite also occurs. Alteration assemblage 3 is found also as 1-30mm wide halos about stringers within areas of moderate alteration.

Chemical analyses from unit 1 are presented in order of increasing alteration intensity (Appendix VI, Table VIb). Due to the lack of unaltered samples and the apparent original chemical

heterogeneities in this subunit, no quantitative description of the alteration assemblages has been attempted.

3.4d Structure

Poor exposure, strong alteration and few bedding indicators inhibit a structural interpretation. However, several phases of deformation are recognizable.

Phase 1

As at the Lenora-Tyce and Mona areas, the early, phase 1 involves the formation of a moderate to strong quartz lineation trending 310° , in Unit 1 (Fig. 14, 18). Pull apart structures and pressure fringes are asymmetric and filled with quartz and chlorite.

Chert intervals appear to be boudinaged, as indicated by the lateral facies change from chert to chert breccia (containing 20-40% elongate and irregular chert fragments, 2-15cm in size, in a tuffaceous matrix) to massive chert, within 50m (Fig. 14). These structures also suggest a period of east-west extension.

Phase 2

This phase is characterised by folds, faults, and a strong axial planar foliation, related to the Mt. Sicker Anticline. The Northeast Copper area is located on the north limb of this structure. Bedding appears to dip $30-65^\circ$ to the north (Fig. 16). The axial planar foliation trends 299° and dips 66° NE (Fig. 14, 18). The quartz lineations parallel the fold axis of the major and minor folds and plunge to the west-northwest.

A minor, west-northwest plunging 'syncline' has developed either as a minor parasitic fold on the Mt. Sicker structure or as a reflection of a primary topographic feature. Unit 1 may represent a localized,

Axial Planar Foliations

mean - $299^{\circ}/ 66^{\circ}\text{NE}$

n - 75

Bedding and Quartz Lineation

▲ Poles to Bedding

North dipping

mean - $287^{\circ}/ 48^{\circ}\text{NE}$

n - 8

South dipping

mean - $308^{\circ}/ 20^{\circ}\text{SW}$

n - 4

● Quartz Lineations

mean - $310^{\circ}/ 1^{\circ}\text{NW}$

n - 8

Fig. 18 Equal area stereographic projections of structural data from the Northeast Copper area. (A) poles to cleavage (B) lineations and poles to bedding.

thick rhyolite flow and tuff complex. Dacite ash and chert of Unit 2 onlap and pinch out against the complex. Upon tilting of the stratigraphy, a syncline-like structure may be produced (Fig. 16).

The succession of south-dipping chert exhibits both conformable basal contacts and structural contacts. Minor faults are subparallel to the strike of the units and dip 65-80° NE, offsetting the chert intervals (Fig. 16). Due to the large competency contrast between the chert and tuff, faulting has occurred subparallel to the axial plane of the major fold during compression.

Phase 3

A subsequent phase of crustal extension resulted in the emplacement of steeply and shallowly dipping diorite sheets and dykes.

Phase 7

Steeply oriented north-northeast trending cross faults, such as the Tom Fault, cross-cut all previous structures. The Tom Fault appears to have a left-lateral displacement of up to 65m.

4.0 STRATIGRAPHIC CORRELATION OF THE MT. SICKER PROPERTY

To correlate and define the stratigraphy among the map areas and over the property, five diamond drill holes (MTS-26, -27, -29, -30, -32) were selected for detailed study. These five holes were drilled approximately perpendicular to the stratigraphy and are located on the south limb, hinge and north limb of the Mt. Sicker Anticline. Three of the holes are located in close proximity to the three areas mapped in detail.

To obtain a measured stratigraphic section, each hole was logged and sampled. True unit thicknesses were calculated using measurements of layering from drill core, in conjunction with the large-scale bedding orientations inferred from the mapping and structural interpretation of the property.

Using this data base, the Mt. Sicker rocks were subdivided into six lithologically and chemically distinct units; from oldest to youngest they are (Fig. 19):

1. Nitinat Formation
2. Lower Andesite
3. Lower Dacite
4. Mine Rhyolite
5. Upper Dacite
6. Upper Andesite

Nitinat Formation

Muller (1980) defined the Nitinat Formation as the basal formation of the Sicker Group, exposed in the Cowichan-Horne Lake

Uplift. The Nitinat Formation consists of mafic massive to pillowed tuff breccia, and medium-grained tuff. The distinguishing feature of the Nitinat Formation is the presence of pyroxene phenocrysts (Muller, 1980). Sutherland Brown et al.(1986) and Massey and Friday (1987, 1988) have similarly defined the Nitinat Formation in the Cowichan Lake area.

In the Mt. Sicker area, the Nitinat Formation is composed of an 500-600m thick interlayered succession of 30-350m thick intervals of pyroxene-feldspar- and feldspar-phyric vitric-crystal tuff, crystal tuff, and minor massive andesite flow, lapilli tuff and tuff-breccia. Euhedral to subhedral pyroxene crystals (0.5-7mm) comprise 2-20% of pyroxene-bearing tuff and flow. Euhedral to subhedral feldspar crystal and crystal fragments, 0.5-2.5mm, comprise 10-50% of the pyroxene-feldspar-phyric intervals and 25-50% of feldspar-phyric intervals. Interbeds of feldspar-phyric siliceous tuff with minor chert (15m thick), medium to dark grey-green chert (5m thick) and siliceous tuff/chert (45cm thick) occur near the bottom of the succession.

The definition of the Nitinat Formation as a pyroxene-bearing, mafic volcanic succession (Muller, 1980) appears inappropriate in the Mt. Sicker area. Here, the Nitinat Formation is a predominantly andesitic succession that contains thick intervals of pyroxene-and non-pyroxene-bearing volcanoclastics and volcanics and minor felsic volcanics and chemical sediments.

Lower Andesite

The Lower Andesite is interpreted to conformably overlie the Nitinat Formation. A lapilli-ash tuff containing 20-40% rounded and elongate pyroxene-phyric blocks and lapilli in a feldspar-phyric vitric-crystal tuff matrix marks the base of the Lower Andesite. The Lower

Andesite consists of a >155m thick succession of massive, homogeneous, medium to dark green andesitic crystal, vitric-crystal and fine ash tuff with locally well developed bedding (Fig. 19). Thin lapilli tuff beds are rare. Minor thin dacite and rhyolite ash and vitric-crystal tuff are interlayered and comprise approximately 10% of the Lower Andesite.

Weak to strong epidote alteration is characterized by the development of 0-25% spherical epidote balls and irregular, diffuse, 3-10mm wide epidote patches. Epidote balls are <8cm rounded knots of epidote, quartz, and feldspar. The matrix of Lower Andesite tuffaceous rocks is moderately to strongly chloritized. Feldspar crystal fragments and weakly to moderately saussuritized. Up to 25% fine-grained disseminated pyrite and minor chalcopyrite are associated with 1-20mm wide stringers, of pyrite, chalcopyrite, quartz and chlorite.

Rocks of the Lower Andesite appear identical mineralogically, texturally and in style of alteration and sulphide concentration to feldspar-phyric subunits of the underlying Nitinat Formation. It is suggested that the Lower Andesite be included in the Nitinat Formation and not the McLaughlin Ridge Formation.

Lower Dacite

The Lower Dacite consists of 75% dacite tuff and vitric-crystal tuff, 15% rhyolite vitric-crystal tuff and 10% andesitic vitric-crystal and ash tuff. In DDH MTS-29, the 60m thick Lower Dacite is composed of a lower 34m thick subunit of well laminated dacite ash and vitric-crystal tuff and an upper 12m thick subunit of light to medium greenish-grey, crudely bedded, fine-grained dacite tuff (Fig. 19). Locally, normally graded beds indicate that the succession is upright. Two light green-grey vitric-crystal tuff subunits, containing 5-10% quartz

crystals, occur in, and at the base of, the Lower Dacite Unit. These rhyolite tuffs separate the two dacite subunits.

In the Lenora-Tyce area (Fig. 19), the 55m thick Lower Dacite consists of a basal rhyolite vitric-crystal tuff and flow which grades into an overlying thick dacite vitric-crystal tuff. The dacite tuff grades upward into a 5.5m thick dacite flow and flow breccia. An overlying 2.5m andesitic ash and vitric-crystal tuff grades upward into a 15m well laminated dacitic ash tuff. The top of the Lower Dacite is marked by a 7m thick andesitic/dacitic vitric-crystal and crystal tuff.

In the Mona area, the Lower Dacite consists of weakly layered dacitic fine-grained vitric-crystal tuff with minor intercalated fine-grained rhyolite and andesite vitric-crystal tuff.

The Lower Dacite is variably sericitized and chloritized. Patchy, bleached zones indicate weak to moderate silicification of the dacite. Feldspar crystals are moderately to strongly saussuritized. Fine-grained disseminated pyrite, 1-15%, occurs throughout. Pyrite and trace-2% chalcopyrite occur within 2-8mm wide stringers.

Mine Rhyolite

The Mine Rhyolite consists of 90-95% rhyolite and rhyodacite tuff and flow with minor dacite tuff, mudstone, chert and massive sulphide. Andesites are rare. Only the Lenora-Tyce and Mona sections have a complete stratigraphic section of the Mine Rhyolite Unit (Fig. 19). In the Lenora-Tyce and Northeast Copper areas the Mine Rhyolite has a true thickness of about 90m. The unit thins to 47m at the Mona area.

In the Lenora-Tyce area, the unit consists of two rhyolite complexes. The basal rhyolite complex, 33m thick, is composed of two flows and associated overlying quartz-feldspar-phyric vitric-crystal tuff.

Thin dacite ash to vitric-crystal tuff can occur interbedded in the rhyolite quartz-feldspar-phyric tuff. The basal rhyolite complex is overlain by a 6m thick graphitic and non-graphitic mudstone, 0.74m thick massive sulphide and an 8.5m thick rhyolite ash to vitric-crystal tuff (Figs. 19). The overlying upper rhyolite complex does not exceed 40m, and consists of a massive quartz-feldspar-phyric flow (Fig. 19). The massive flow of the upper rhyolite complex grades laterally into a quartz-feldspar-phyric vitric-crystal tuff.

In the Mona area the Mine Rhyolite stratigraphy is repeated. Upper and lower rhyolite complexes consist primarily of quartz-feldspar-phyric vitric-crystal tuff. The complexes are separated by a 3m thick interval of interbedded dacite tuff, lapilli-ash tuff and minor rhyolitic vitric-crystal tuff. Within the lapilli-ash tuff, a 10cm section containing 15% finely disseminated pyrite may represent the stratigraphic equivalent of the Lenora-Tyee deposits.

To the north of the Lenora-Tyee area, the Mine Rhyolite consists of a basal subunit of interbedded fine vitric-crystal tuff, siliceous tuff, and cherty tuff and minor chert overlain by a thick upper rhyolite complex. The basal rhyolite complex is missing. A 0.35m thick, crudely layered, siliceous ironstone (magnetite-quartz-chlorite) occurs in a siliceous tuff near the base of unit.

In the Northeast Copper area, the upper rhyolite complex consists of several quartz-feldspar-phyric massive rhyolite flows and interbedded tuffs. The rhyolite complex is underlain by a felsic vitric-crystal and lapilli tuff and a 0.4m thick light grey, laminated fine ash and siliceous tuff at the base of DDH MTS-32. DDH MTS-26 did not penetrate the upper rhyolite complex (Fig. 19).

Upper Dacite

A complete succession, 78m thick, of the Upper Dacite is well represented in DDH MTS-26, on the north limb of the Mt. Sicker Anticline. In this area the Upper Dacite consists of thick and crudely laminated, light green-grey, fine-grained dacitic tuff and interbedded, 0.3-85cm thick, massive grey chert and siliceous tuff. Chert intervals generally have sharp basal contacts and gradational upper contacts with ash and lapilli-ash tuff. Dark green-grey chloritic and chert fragments occur locally.

In the Northeast Copper area, the succession of dacite tuff and interbedded chert is texturally similar to the 39m thick Upper Dacite rocks exposed in DDH MTS-26. Chert at Northeast Copper, and in DDH MTS-26, typically contains elongate fine-grained nodules (0.5-7cm) of pyrite, quartz and chlorite.

At the Mona area the stratigraphically youngest subunits were a fine siliceous ash tuff and interbedded chert which are overlain by a thick succession of dacitic vitric-crystal and ash tuff. These subunits are correlated with the Upper Dacite. Similarly, in the Lenora-Tyce area, the 3 highest subunits are dacitic ash tuff with interbedded, well laminated chert and a minor thin lapilli-ash tuff.

The fine dacite tuff of the Upper Dacite is characteristically moderately to strongly chloritized and weakly sericitized. Disseminated 3-5% pyrite occurs throughout. Areas of abundant stringers contain up to 25% pyrite and 5% chalcopyrite. The chert intervals contain 1-3mm thick pyritic laminae, disseminated pyrite and thin stringers.

Upper Andesite

The Upper Andesite consists of 92m of upward coarsening and intercalated medium-dark green, massive and locally bedded andesitic fine ash tuff, vitric-crystal tuff, lapilli tuff and lapilli-tuff breccia. Massive ash tuff is fine-grained and crudely bedded. Several thin interbeds of accretionary lapilli-ash tuff occur rarely within this tuff. Scoriaceous andesite fragments, 0.5-11cm in size, are randomly distributed and supported in the fine feldspar-phyric matrix. The andesite fragments contain 20-30% elongate amygdules, 0.5-3mm in size, that define chilled rims around the fragments. A single thin massive flow that contains 5-15% amygdules up to 8mm in diameter is found near the base of the Upper Andesite succession. In the Northeast Copper area, a 10m thick aphanitic, amygdaloidal flow and associated flow breccia correlates with the Upper Andesite.

Feldspar crystals and andesitic fragments are preferentially epidotized in a strongly chloritized ash-tuff matrix. Trace to 15% pyrite, pyrrhotite and chalcopyrite occur throughout as disseminations, preferentially associated with areas of strong epidote alteration and anastomosing stringers.

Plate 6. Photographs of polished core samples representing the major stratigraphic units at Mt. Sicker.

Scale bar equals 2cm.

Plate 6a. DDH MTS-30 515.5m. Lower Andesite. Andesite feldspar-phyric vitric-crystal/crystal tuff. Rock consists of weakly to strongly saussuritized feldspar crystal fragments (1mm avg.) in a chloritic matrix. Note crude bedding and quartz-calcite veinlets.

Plate 6b. DDH MTS-29 407.8m. Lower Andesite. Andesite fine-grained ash tuff containing 5-10% lapilli sized, matrix-supported siliceous fragments, in sharp contact with aphyric ash tuff.

Plate 6c. DDH MTS-29 332.5m. Lower Dacite. Fine dacitic ash tuff showing well developed and occasionally normally graded laminations. Top is to the right.

Plate 6d. DDH MTS-29 376.7m. Lower Dacite. Medium-dark green dacite/andesite interlaminated to interbedded fine ash tuff. Note normal grading of laminations. Top is to the left.

Plate 6e. DDH MTS-27 85.2m. Mine Rhyolite. Thick bedded, feldspar-quartz-phyric vitric-crystal tuff. Note crude layering and patchy chloritization associated with fine-grained dissemination of 5% pyrite.

Plate 6f. DDH MTS-29 79.3m. Mine Rhyolite. Quartz-phyric vitric-crystal tuff containing 5-15 quartz fragments (A). Note layering defined by the content and size of quartz fragments.

Plate 6g. DDH MTS-29 57.2m. Mine Rhyolite. Weakly foliated siliceous feldspar-phyric vitric-crystal tuff. Note thin interbed of lithic-crystal tuff. Lithic fragments (A) are weakly chloritized.

Plate 6h. DDH MTS-29 56.1m. Mine Rhyolite. Interbedded quartz-feldspar-phyric vitric-crystal and crystal tuff. Quartz crystal fragments size and content (5-10%) is consistent throughout. Bedding is defined by the percentage of feldspar crystal fragments.

Plate 6i. DDH MTS-32 32.0m. Mine Rhyolite. Massive quartz-phyric flow containing 10% quartz phenocrysts (A) and 25% chlorite altered mafic phenocrysts in a weakly sericitic, microcrystalline matrix.

Plate 6j. DDH MTS-26 160.8m. Upper Dacite. Fine-grained dacite ash tuff containing light grey amygdaloidal fragments containing up to 20% dark grey amygdules. Fragments are subrounded, flattened and up to 3.5cm. Note anastomosing and discontinuous stringers of pyrite, quartz, and chlorite and 2% disseminated fine-grained pyrite.

Plate 6k. DDH MTS-26 157.4m. Upper Dacite. Light grey dacite ash to lapilli ash tuff containing subrounded to elongate dark grey chert/siliceous fragments, 0.5-7mm. The fine ash matrix contain 5-10% very fine-grained disseminated pyrite.

Plate 6l. DDH MTS-26 195.5m. Upper Dacite. Massive, medium to dark green-grey chert containing 2% disseminated chalcopyrite and pyrite and irregular, cross-cutting pyrite, quartz, chlorite stringers.

Plate 6m. DDH MTS-26 122.7m. Upper Andesite. Fine accretionary lapilli-ash tuff. Lapilli have been altered to a fine intergrowth of epidote, feldspar, quartz. Weak concentric zones defined by epidote are rarely seen in thin section. The matrix is moderately-strongly chloritized.

Plate 6n. DDH MTS-26 107.1m. Upper Andesite. Crudely bedded fine andesite ash tuff.

Plate 6o. DDH MTS-26 100.8m. Upper Andesite. Lapilli-ash tuff containing 20-30% irregular and subangular, amygdaloidal andesite fragments. Fragments have been epidotized. Chlorite infills amygdules.

Plate 6p. DDH MTS-26 50.7m. Upper Andesite. Andesite tuff-breccia containing a scoriaceous andesite block with a strongly chloritic and epidotized crystal/vitric-crystal tuff matrix. Note the zoning of amygdules defining a chilled margin to the fragment. The andesite fragments have been epidotized.

Plate 6.

5.0 LITHOGEOCHEMISTRY

Twenty-four whole-rock samples were collected from DDH MTS-29 and along highway 1 (Fig. 19, Appendix VI) in order to

1) describe the chemical composition and affinity of least altered rock types in support of mapping,

2) characterize the Mine Rhyolite, Lower Dacite, Lower Andesite and Nitinat Formation chemically. From the geologic and chemical data, the placement of the contact between the Nitinat and McLaughlin Ridge Formations in the Mt. Sicker area is established.

DDH MTS-29 provided a continuous record of unweathered rocks from which homogeneous, vein-free, and least altered samples were collected. Road cuts provided sampling localities for relatively unweathered, least altered samples of the Nitinat Formation. No sample analyzed can be considered unaltered.

Major-element analyses of SiO_2 , Al_2O_3 , total Fe as FeO, MgO, CaO, Na_2O , K_2O , TiO_2 , MnO, S, loss-on-ignition, and Cu, Pb, Zn, Ni, Ag, Au were performed at Metric Lab in Montreal. Rare-earth element (REE) analyses were performed at Ecole Polytechnique in Montreal. Data and analytical techniques, and calculated precision and accuracy, are found in Appendix VI.

5.1 Results and Interpretation

In this study, the nomenclature based on silica content proposed by Gill (1981) is used where basalt is <53 wt.% SiO_2 , basaltic andesite is 53-57 wt.% SiO_2 , andesite is 57-63 wt.% SiO_2 , dacite is 63-70 wt.% SiO_2 and rhyolite is >70 wt.% SiO_2 .

Since the analyzed samples represent least altered and not fresh rock, mobility of elements used in classifications must be considered.

Fig. 20 Harker variation diagram of major oxides vs. SiO_2 .

Variations of the major oxides with respect to SiO_2 are shown in Fig. 20. The mobility of Na, K and Ca is clear. Ca, as found in epidote, is significantly high in the basaltic andesites and one rhyolite sample. Increasing K_2O and decreasing Na_2O , with increasing SiO_2 , reflect increasing sericitization of feldspars in dacitic and rhyolitic rocks. Na_2O values of less than 1.0 wt.% are typical of sodic depletion in the rocks on Mt. Sicker, and are used as a guide to alteration associated with massive sulphide deposits (Hashiguchi et al., 1983).

Due to Na and K mobility, the AFM diagram (Irvine and Baragar, 1971) and alkali subdivisions proposed by LeBas et al. (1986) are not used. The SiO_2 versus FeO/MgO plot of Miyashiro (1974) (Fig. 21) indicates a calc-alkaline affinity for all rock-types. The Jensen plot (Fig. 22) also shows a calc-alkaline trend; however, the rhyolites plot within the dacite field, dacites plot within the andesite field and andesites plot within the basalt field.

Basaltic andesites appear to trend from the Mg-rich tholeiitic basalt field to the calc-alkaline basalt field, as defined by Jensen (1976). Basaltic andesites and andesites of the Nitinat Formation and Lower Andesite contain <1 wt. % TiO_2 , typical of orogenic andesites (Gill, 1981).

Rare earth elements (REE) have been used in petrographic studies because of similarities in their chemical and physical properties (Henderson, 1983; Haskin, 1983; Hanson, 1980). However, REE mobility during hydrothermal alteration is a potential problem. Campbell et al. (1984), Leshner et al. (1986), Whitford et al. (1988) and Dickin and Jones (1983) suggested that REE, especially the LREE, are mobile in strongly altered zones proximal to massive sulphide deposits. The same

Fig. 21 $\text{FeO}(\text{total})/\text{MgO}$ vs. SiO_2 diagram (after Miyashiro, 1974).

Fig. 22 Jensen plot of samples taken from DDH MTS-29 and along Highway 1. Open squares represent pyroxene phyric basaltic andesite of the Nitinat Formation. Closed squares represent feldspar phyric basaltic andesite of the Nitinat Formation and Lower Andesite. Open triangles represent dacite. Closed circles represent rhyolite. See Fig. 19 for sample locations in DDH MTS-29.

authors suggested that REE are relatively immobile under conditions of weak hydrothermal alteration, although the behaviour of REE in weakly altered rocks is known to vary between different deposits (Whitford, 1988). A consensus as to the extent to which alteration can modify primary REE patterns has not been reached. If the samples analyzed are considered to be least altered representatives, distal to any deposits, the REE may be considered immobile. Chondrite-normalized (cn) REE patterns (Fig. 23) were calculated using chondritic values from Boynton (1983).

Basaltic andesites of the Nitinat Formation (Fig. 23a) exhibit relatively flat and unfractionated REE patterns with La/Sm_{cn} 1.5 to 2.1, Gd/Lu_{cn} 1.1 to 1.5 and Eu/Eu^* 0.72 to 0.96.

The REE distributions for the basaltic andesites of the Lower Andesite unit are shown in Fig. 23b. The patterns are also relatively flat and unfractionated, with La/Sm_{cn} 1.3 to 1.9, Gd/Lu_{cn} 1.0 to 1.3 and Eu/Eu^* 0.75 to 0.93. Low total REE abundances between 30x and 7x chondrite values are typical.

REE patterns of pyroxene-feldspar-phyric and feldspar-phyric vitric-crystal tuff of the Nitinat Formation and feldspar-phyric vitric-crystal tuff of the Lower Andesite are indistinct. Similarities in the REE patterns and major-oxide compositions between the Lower Andesite and Nitinat Formation andesites suggest that the two are comagmatic. The Lower Andesite may be related through fractional crystallization of the Nitinat Formation source magma, as inferred by: a) the similar slope of the REE patterns, b) the slight increase in total MREE and HREE abundances of Lower Andesite basaltic andesites (Fig. 23c), and c) the consistent weak Eu anomaly (Haskin, 1983). The chemical similarities

Fig. 23 Chondrite-normalized REE distributions. (A) pyroxene- and non-pyroxene-bearing basaltic andesites of the Nitinat Formation. (B) Feldspar-phyric basaltic andesites of the Lower Andesite. (C) Dacites of the Lower dacite. (D) Rhyolites of the Mine Rhyolite (1,2,3,4), Lower Dacite (6,8) and Lower Andesite (14). (E) Nitinat normalized REE distributions. Open square is average basaltic andesite of the Lower Andesite. Open triangle is average dacite of the Lower Dacite. Closed circle is an average rhyolite.

between the Nitinat Formation and Lower Andesite support the suggestion that the Lower Andesite be included within the Nitinat Formation (see Chapter 4).

The Lower Dacite tuffs have a fractionated LREE pattern ($\text{La}/\text{Sm}_{\text{cn}}$ 2.4 to 2.5) and an unfractionated flat HREE pattern ($\text{Gd}/\text{Lu}_{\text{cn}}$ 0.9 to 1.0) (Fig. 23c). The patterns are concave up and show a large Eu anomaly (Eu/Eu^* 0.40). Total REE abundances of between 32x and 2.5x chondrite values are comparable to total abundances in Nitinat Formation and Lower Andesite basaltic andesites.

Rhyolites of the Mine Rhyolite, Lower Dacite and Lower Andesite are characterised by strong concave upward REE patterns (Fig. 23d). REE distributions show strongly fractionated LREE pattern ($\text{La}/\text{Sm}_{\text{cn}}$ 2.3 to 3.9) and depleted HREE patterns ($\text{Gd}/\text{Lu}_{\text{cn}}$ 0.68 to 0.89). Total REE abundances range from 42x to 2.8x chondrite values.

Rhyolites from the Mine Rhyolite show two groups of REE distributions which differ in the magnitude of the Eu anomaly, from 0.33 and 0.39 (samples 1, 4) to 0.77 and 0.78 (samples 2, 3) (Fig. 23d). Sample 3, a feldspar-phyric siliceous vitric-crystal tuff contains anomalously low LREE abundances. Chemically, sample 3 is CaO - Na_2O -rich and K_2O -poor relative to the other rhyolites. Rhyolitic rocks from the Lower Dacite (samples 6, 8) have REE patterns identical to rhyolites of the Mine Rhyolite and Eu anomalies intermediate to the two groups described from the Mine Rhyolite (Eu/Eu^* for sample 6 and 8 are 0.5 and 0.69, respectively). A rhyolite from the Lower Andesite (sample 14) has a REE pattern similar to rhyolites of the Mine Rhyolite (i.e. Eu/Eu^* 0.78, $\text{La}/\text{Sm}_{\text{cn}}$ 3.2 and $\text{Gd}/\text{Lu}_{\text{cn}}$ of 1.0).

Rhyolitic rocks are slightly enriched in La, Ce, and Lu but strongly depleted in the MREE, relative to rocks of the Nitinat Formation (and Lower Andesite) and Lower Dacite Unit (Fig. 23c). Eu abundances of the rhyolites and dacites are similar.

REE patterns of the four units described are distinctive in their total REE abundance, the degree of LREE and HREE fractionation, and extent of the Eu anomaly (Fig. 23c). However, in the case of rhyolitic rocks, the REE patterns cannot be used to distinguish between the different units.

The succession described is thought to have been deposited in marginal basins associated with an island-arc (see Chapter 6). Back-arc basin basalts and basaltic andesites in oceanic island-arc settings are described as chemically transitional between N-type MORB tholeiites and island-arc tholeiites (Saunders and Tarney, 1984; Hawkins et al., 1984; Jenner et al., 1987). The similarities of back-arc basin basalts with MORB and island-arc tholeiites suggest a similar depleted mantle source. However, the back-arc basin basalt source has been subsequently enriched in large ion lithophile elements, including the LREE, with respect to high field strength elements and HREE, by the dehydration of a descending, subducting slab. N-MORB tholeiites evolve into back-arc basin basalts, which evolve into island-arc tholeiites and finally calc-alkaline island-arc rocks as the island-arc matures. This range of compositions can be explained by invoking chemical variations in the composition of the mantle source by either contamination by fluids or possibly repeated melt extraction during basalt genesis (Saunders and Tarney, 1984).

The volcanic setting of the succession on Mt. Sicker and REE distributions suggest that the basaltic andesites of the Nitinat Formation formed from similar depleted mantle sources. The relatively unfractionated pattern and low total REE abundances are similar to those presented by Thurston and Fryer (1983) and Jenner (1981), who suggested a hydrous partial melt of previously depleted mantle as a source.

Predicted REE behaviour using mineral/melt distribution coefficients, as described by Haskin (1978) and Hanson (1980), suggest that during fractional crystallization, REE abundances and degree of negative Eu anomaly will increase in the melt and the slope of the pattern will remain constant. The Lower Dacite magma may be related to the Nitinat Formation through such processes. The strong MREE and HREE depletion of rhyolites with respect to the Nitinat Formation and Lower Dacite suggests a different magma source. If the rhyolites were derived by continued fractional crystallization of the Lower Dacite source magma, the total REE abundance and Eu anomaly would increase relative to the Lower Dacite (Haskin, 1978; Hanson, 1980; Thurston, 1980). The existence of two distinct REE patterns for rhyolitic rocks may reflect differing mineral assemblages undergoing partial melting or fractional crystallization of the source (Hanson, 1980), or source magma modification by assimilation or magma injection.

2

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6.0 DISCUSSION

6.1 Volcanic Setting

An understanding of the volcano-tectonic setting, in which andesitic to rhyolitic rocks of the Nitinat and McLaughlin Ridge Formations formed, is necessary in the exploration for massive sulphide deposits on Mt. Sicker.

A subaqueous environment of deposition is indicated by the presence of several different lithologies throughout the succession. Pillowed andesite flows occur within the lowermost Nitinat Formation (Muller, 1980). The presence of graphitic mudstone, siltstone, massive sulphide and exhalative chert in the Mine Rhyolite and interbedded chert in the Upper and Lower Dacite also indicate subaqueous deposition.

The volcanic succession exposed on Mt. Sicker is primarily pyroclastic, as suggested by the morphology of crystal fragments and high crystal content, abundance of vitric fragments, presence of penecontemporaneous volcanism and lack of a significant fraction of epiclastic material. Subaqueous deposits may be classified as pyroclastic if the fragments are derived directly from volcanic eruptions in submarine or close to shore environments, regardless of the depositional mechanism.

The 800 to 900m thick succession exposed on Mt. Sicker is interpreted to have formed in a marginal basin. Voluminous submarine volcanoclastic deposits are most abundant in marginal basins associated with island-arcs (Fisher, 1984), including back-arc and intra-arc basins. Carey and Sigurdsson (1984) provided a detailed model for volcanogenic sedimentation within marginal basins. In this environment, volcanoclastics are supplied to the marginal basin from three source areas. The two major source areas include the bordering volcanic-arc

and the back-arc spreading area (Fig. 24). A third source may be the remnant-arc.

Volcaniclastic debris may be derived directly from eruptions, from remobilization of juvenile volcaniclastics, or from epiclastic material formed above sea level (Fisher, 1984). Volcaniclastics are widely dispersed by three kinds of marine transport mechanisms: slides, sediment gravity flows and suspension fallout. The prominent kinds of subaqueous volcaniclastic sediment gravity flows are debris flows, pyroclastic flows and turbidites (Yamada, 1973; Fiske and Matsuda, 1964; Fisher, 1977, 1982, 1984). Pyroclastic material formed from subaerial and subaqueous eruptions are transported to the marginal basin by suspension fallout and subaqueous pyroclastic flows (Fig. 24). Pyroclastic and epiclastic material may also be transported by slide, debris flow and turbidity current mechanisms (Fig. 24) (Cas and Wright, 1987; Cas, 1978; Tass et al., 1978; Sigurdsson, 1982). Back-arc spreading centres contribute hydroclastic material and hydrothermal volcanogenic sediment (Fig. 24). The remnant-arc may be a minor source of epiclastic material.

On Mt. Sicker the facies distribution and abrupt lateral changes in thickness of lithologies are thought to reflect the paleotopography of the marginal basin. The basin is envisaged as consisting of a series of fault-bounded ridges and troughs oriented approximately parallel to the volcanic-arc and cut at high angles by numerous faults. These structures act as barriers, providing localized traps for the accumulation of clastic material.

The Nitinat Formation contains both effusive (massive flows) and explosive (vitric-crystal and crystal tuffs) products. The explosive style is dependent on water depth, volatile content, magma composition

Fig. 24 Block diagram illustrating the sources for and mechanisms by which volcanoclastic material is deposited in a marginal basin. Sources of volcanoclastic material include (1) the active volcanic arc, (2) the back arc spreading area, and (3) the remnant arc. Pyroclasts formed from subaerial eruptions can be transported by suspension fallout (1a), and subaqueous pyroclastic flows (1b). Pyroclastic and epiclastic material can also be transported as debris flows and turbidity currents (1c). The back arc spreading area may provide hydroclastic (2a) and hydrothermal volcanogenic sediment including massive sulphide deposits (2b). The remnant arc is likely a minor source of material

and the extent of water/rock interaction (Fisher and Schmincke, 1984; Kokelaar et al., 1986; Fisher, 1984). For basaltic magmas, explosive eruptions caused by the exsolution of volatiles can occur at water depths less than 500m (Fisher, 1984). The massive unstratified vitric-crystal and crystal tuff of the Nitinat Formation are similar texturally to the crystal-rich basal part of subaqueous pyroclastic flow deposits, described by Niem (1977), indicating a similar mode of deposition. The anomalous high crystal content of tuffs of the Lower Andesite may be due to eruption of a highly crystallized magma, physical fractionation and sorting processes, including elutriation of glassy ash during transport or epiclastic reworking and redeposition. The crystal-rich nature of Nitinat Formation tuffs does not, in themselves, indicate proximity to a vent area. The Nitinat Formation may represent widespread submarine volcanism related to the building of an oceanic island-arc.

The overlying Lower Dacite is thickest at DDH MTS-29. There the unit consists of laminated tuff with normally graded beds. To the south, at DDH MTS-30, the Lower Dacite is thinner but coarser-grained and contains both dacite and rhyolite flows. In the Mona area, the Lower Dacite is also coarse-grained, consisting of dacitic, andesitic and rhyolitic vitric-crystal tuff. Facies transitions suggest that the Lower Dacite tuffs were deposited as ash-turbidites and/or suspension fallout from a source to the south. Textures and sedimentary structures suggest that the dacite tuff from DDH MTS-29 represents distal accumulation from low concentration turbidity currents, as opposed to submarine fallout deposits which thicken toward the source (Fisher and Schmincke, 1984). The thick accumulation of ash, at DDH MTS-29, may reflect the infilling of a paleotopographic low. The thickness,

homogeneous composition and lack of interbedded sediments suggest a single continuously active magma source.

The Mine Rhyolite is composed of an upper and lower rhyolite complex separated by dacitic to rhyolitic tuff, siliceous tuff, graphitic mudstone/siltstone, exhalative chert and massive sulphide. The two rhyolite complexes consist of massive rhyolite flows and vitric-crystal tuffs.

The interpretation of a subunit as a flow is based on its morphology, massive structure and presence of euhedral, skeletal quartz phenocrysts. Vernon (1986) stated that quartz phenocrysts may remain undeformed even though the surrounding fine-grained matrix has undergone extensive deformation and recrystallization. A deep water environment was suggested by Cas (1978a) for subaqueous rhyolite flows, texturally similar to the flow at the Lenora-Tyee area. In this environment, high hydrostatic pressure would inhibit the escape of volatiles resulting in a more fluid and mobile lava. However, the rhyolite flow at the Lenora-Tyee area grades both vertically and laterally into quartz-feldspar-phyric vitric-crystal tuff suggesting that both explosive and effusive eruptions occurred. A depth of approximately 1000m (Fisher and Schmincke, 1984) is suggested as the depth above which explosive rhyolitic volcanism can occur.

The associated vitric-crystal tuff may form as subaqueous pyroclastic flows as described by Fiske (1962), Yamada (1973, 1983) and Fiske and Matsuda (1964). The massive, unstratified nature of the tuff at the Lenora-Tyee area, and its relatively high crystal and inferred glassy ash content, suggest deposition from underwater eruptions of a rapidly vesiculating magma. The lack of internal vertical stratification, lithic fragments, rip up clasts and association with

massive flows suggest deposition proximal to a vent. The slightly increased crystal content of the associated tuff, relative to the massive flow, suggests some mechanism of crystal concentration such as elutriation of ash and pumice from the eruption column. At the Mona and Northeast Copper areas, there is an upward grading in the tuff from thick, massive vitric-crystal tuff to thin-bedded fine-grained vitric-crystal tuff and siliceous tuff. This vertical gradation is suggestive of a more distal subaqueous pyroclastic flow deposit (Fiske and Matsuda, 1964; Yamada, 1973, 1984). In the Mona area, a streaked, crudely laminated tuff with well developed, discontinuous feldspar crystal laminations (alignment bedding), containing abundant broken crystal and glassy fragments, is texturally similar to subaqueous pyroclastic flows (Fiske and Matsuda, 1964; Yamada, 1973; Fisher and Schmincke, 1984). The vertical grading of this tuff at the Mona and Northeast Copper areas may also reflect the waning stages of a submarine eruption.

A volcanic hiatus separates the upper and lower rhyolite complexes of the Mine Rhyolite. During this period, numerous fault-bounded ridge and trough structures developed. Vitric-crystal tuffs and interbedded siliceous tuffs, representing distal turbidites, were deposited. Influxes of epiclastics deposited graphitic and non-graphitic siltstone as suspension fallout or distal turbidites.

Within the tectonic framework of a marginal basin, hydrothermal activity is concentrated in areas of high heat flow by synvolcanic structures along the back-arc spreading zone or flanks of the volcanic-arc (Carey and Sigurdsson, 1984). The elongate Lenora-Tyce massive sulphide deposits may have formed within graben-like structures oriented parallel to the Mine Fault. The bounding faults likely acted as conduits for the hydrothermal fluids. Thick and localized deposits of

epiclastic graphitic sediments were likely trapped and preserved within the same or similar trough structures. The distribution of the two rhyolite complexes and the overall thickness and lateral facies changes of the Mine Rhyolite suggest that the Mine Fault was an active synvolcanic structure.

To the east of the Northeast Copper area, crosscutting quartz-feldspar-phyric dykes are interpreted as feeders to the Mine Rhyolite. These dykes appear related to granodioritic stocks known as the Saltspring Intrusions, exposed on Saltspring Island. U-Pb ages of zircons indicate Late Silurian to Devonian ages for the Saltspring Intrusion (Brandon et al., 1986; Muller, 1980). These intrusions may represent part of the eroded volcanic-arc or remnant-arc. The Mine Rhyolite may represent felsic volcanic and hydrothermal products proximal to a back-arc spreading zone or flank of an island-arc.

The overlying Upper Dacite is exposed to the north and northeast in DDH MTS-26 and -32 respectively. The interbedded dacite tuff and massive to laminated chert represent influxes of pyroclastic and/or epiclastic debris, as distal ash turbidites or pyroclastic flows, separated by periods of quiescent chemical sedimentation. A minor massive dacite to rhyolite vitric-crystal tuff in the Northeast Copper area grades upward into bedded and locally graded vitric-crystal tuff and finally into laminated chert. This double grading suggests that the subunit formed as a subaqueous pyroclastic flow (Fiske and Matsuda, 1964). Thinning of the Upper Dacite at the Northeast Copper area reflects the paleotopographic high produced by the underlying Mine Rhyolite.

The overlying Upper Andesite appears to reflect a shoaling of the volcanic succession. The Upper Andesite contains several upward

coarsening sequences of tuff, lapilli-ash tuff, lapilli tuff and tuff breccia, reflecting intensifying explosive eruptions. Scoriaceous andesite fragments of the lapilli tuff/tuff breccia have chilled margins suggesting shallow water or subaerial explosive eruptions. The occurrence of three thin intervals of accretionary lapilli tuff also support a shallow water or subaerial environment. However, the presence of accretionary lapilli does not indicate proximity to a vent and is not indicative of deposition by a pyroclastic fall (Fisher and Schmincke, 1984). Accretionary lapilli are common in pyroclastic base-surge deposits (Cas and Wright, 1987) and may be found in pyroclastic flow deposits (Yamada, 1984). The fine-grained matrices of the ash tuff and lapilli-ash tuff are texturally similar suggesting deposition as pyroclastic fall deposits with an increasing proportion of ballistic lapilli or block fragments higher in the sequence. Coarser-grained lapilli tuff and tuff breccia may reflect either pyroclastic fall or scoria-flow deposits.

6.2 Sulphide Mineral Concentration

The Zn-Cu Lenora-Tyce deposits may be compared to the Kuroko deposits of Japan. The massive sulphides exposed in the Lenora Pit are mineralogically, texturally and possibly spatially similar to Kuroko black, semi-black and barite ores (Eldridge et al., 1983; Lambert and Sato, 1974; Shimazaki, 1974; Franklin et al., 1981). The volcanoclastic succession at Mt. Sicker is texturally and chemically similar to host rocks of Kuroko deposits (Tanimura et al., 1983; Franklin et al., 1981). The Green Tuff of Japan and the Sicker Group exposed on Mt. Sicker are thought to have been deposited in similar volcanic settings (Ohmoto, 1983; Ohmoto and Takahashi, 1983; Cathles et al., 1983). Footwall alteration exposed in the Lenora Pit is typical of Kuroko deposits, as

described by Franklin et al. (1981). Strong discordant chlorite and pyrite alteration zones, as in the Northeast Copper area, may reflect higher fluid temperatures, high exiting velocities, and a more localized vent area (Franklin, 1986) than the system at the Lenora-Tyce area.

The development of fault structures and accompanying hydrothermal sediment and massive sulphide in back-arc or intra-arc basins is discussed by Carey and Sigurdsson (1984), and applied as a model to the Butte Lake deposits by Juras (1987). In their model, massive sulphide can accumulate in areas of high heat flow associated with complex ridge and trough structures formed along the rift basin floor. Half graben or graben structures would provide localized traps in which sulphides could accumulate. These paleotopographic lows may provide anoxic conditions in which massive sulphides may be preserved as indicated by the presence of graphitic mudstone stratigraphically below the Lenora-Tyce deposits. The resultant massive sulphide deposits would have elongate, linear morphologies similar to the South and North deposits and showings along strike in the Mona area. Coincident precipitation of hydrothermal silica may produce distal deposits of pyritic chert or siliceous tuff similar to the cherty tuff at the base of the Mine Rhyolite in DDH MTS-29. The mechanism driving the hydrothermal system could be from shallowly emplaced magma chambers (Cathles et al., 1983).

Influx of pyroclastic material and development of the Upper Rhyolite complex appears to have choked the hydrothermal activity before the system developed to maturity as at the H-W deposit (Juras, 1987).

The presence of pyrite and chalcopyrite stringers and disseminated pyrite in strongly altered hangingwall tuffs in the Lenora-Tyce area and the Upper Rhyolite complex at the Mona area, indicate continued sulphide mineralization. At the Northeast Copper area, intense chlorite-pyrite

alteration of the Mine Rhyolite and Upper Dacite also indicate continued hydrothermal activity. The possibility of a series of stacked massive sulphide lenses cannot be overlooked.

One feature of the Lenora-Tyce deposits is the high Au and Ag grades, 8.4-27.6 g/tonne and 108-301 g/tonne, respectively. The Au and Ag concentrations may be explained by a combination of syngenetic and epigenetic processes. Hannington et al. (1986) explained anomalous Au concentration of 6.7 g/tonne in sea floor sulphide mounds by mobilization of Au from high temperature sulphides and redeposition and concentration in the cooler, outer parts of a growing sulphide mound by low temperature fluids. Taube (1986) explained the anomalous 4.8 g/tonne Au grade at the Mt. Morgan deposit, Australia, by enrichment of the previously formed massive sulphides by late, structurally controlled, Au- and Ag-bearing hydrothermal fluids. At Mt. Sicker, the occurrence of mobilized sulphides in quartz veins and feldspar pods, the presence of a silver telluride and electrum with a Au/Au+Ag ratio of 0.65, and the Au/Ag ratio of the deposits averaging 0.13, all suggest a later phase of Au±Ag enrichment. Gold-bearing veins along fault zones are noted to occur on Mt. Sicker by Massey and Friday (1988).

The Lenora-Tyce deposits have also been compared to the Buttle Lake, Lynx, Myra, Price and H-W orebodies (Muller, 1977, 1980; Juras, 1987). The volcanic and tectonic settings of both areas are similar (Juras, 1987). The Buttle Lake deposits show strong structural control typical of a marginal basin setting.

The H-W deposit is located at a lower stratigraphic level (the Price-Myra Formation contact) than the other Buttle Lake orebodies (Juras, 1987). The equivalent stratigraphic level in other uplifts is presently being explored. On Mt. Sicker, the Nitinat-McLaughlin Ridge

Formation contact is a target based on this model. This suggests a correlation between the Myra Formation in the Buttle Lake Uplift, and the McLaughlin Ridge Formation in the Cowichan-Horne Lake Uplift, as speculated by Sutherland Brown et al. (1986), Brandon et al. (1986), Massey and Friday (1987, 1988) and Juras (1987).

On Mt. Sicker, the Nitinat Formation can be distinguished by the presence of pyroxene-phyric rocks, but not vice versa. At Buttle Lake, the four lowermost formations contain pyroxene-bearing rocks (Juras, 1987). Thus, the presence of pyroxene-bearing rocks at Buttle Lake is not relevant in defining the stratigraphy. The top of the Price Formation is defined as the first appearance of rhyolitic volcanics (Juras, 1987). However, on Mt. Sicker, the Nitinat Formation contains minor rhyolite and dacite rocks throughout the succession. Thus the presence of rhyolitic rocks, in themselves, cannot be used to define the stratigraphic position.

The unconformity locally found at the top of the Myra Formation (Juras, 1987) is likely the same unconformity mapped by Massey and Friday (1987, 1988) north of Lake Cowichan. This unconformity presumably overlies the succession on Mt. Sicker. However, whether the McLaughlin Ridge Formation is stratigraphically equivalent to, or older or younger than, the Myra Formation is uncertain. Without further detailed work, especially isotopic age determinations, the correlation between the Myra and McLaughlin Ridge Formations will remain unclear.

7.0 CONCLUSIONS

The Mt. Sicker property on Vancouver Island, B.C., is underlain by a 800 to 900 m thick succession of calc-alkaline basaltic andesite, dacite and rhyolite of the Nitinat and McLaughlin Ridge Formations.

The Nitinat Formation consists of thick intercalations of pyroxene-feldspar-phyric and feldspar-phyric vitric-crystal, crystal, and lapilli tuff and minor tuff-breccia and massive flow. The uppermost part of the Nitinat Formation consists of feldspar-phyric vitric-crystal and crystal tuff. Minor felsic siliceous tuff and chert occur throughout.

The McLaughlin Ridge Formation conformably overlies the Nitinat Formation. Four units characterize the McLaughlin Ridge Formation. The Lower Dacite consists of a 60m succession of fine, laminated tuff, vitric-crystal tuff, minor crystal tuff and massive flow. Minor rhyolitic vitric-crystal tuff occur at two stratigraphic levels. The overlying 70m thick Mine Rhyolite is composed of two rhyolite complexes consisting of massive quartz-feldspar-phyric flows which grade vertically and laterally into quartz-feldspar-phyric vitric-crystal tuff. The rhyolite complexes are separated by dacitic and rhyolitic fine tuff, siliceous tuff, chert and massive sulphide. The overlying 60m thick Upper Dacite consists of thinly laminated to massive bedded tuff containing minor lapilli fragments. Several interbedded massive chert intervals (1.5m) occur throughout. The Upper Dacite is overlain by a 90m thick Upper Andesite consisting of several upward coarsening tuff, vitric-crystal/crystal tuff, lapilli-ash tuff, lapilli tuff and tuff breccia sequences. Scoriaceous andesite fragments predominate.

The 277,410 tonne Lenora-Tyce deposits (mined 1898-1902) occur in the Mine Rhyolite and consist of banded and deformed massive sulphide. Sulphide minerals have been mobilized into quartz veins and feldspar pods. The stratigraphic level which hosts the Lenora-Tyce deposits remains the prime exploration target.

Hydrothermal activity appears to have been continuous into the overlying Upper Dacite.

The volcanic succession and massive sulphide mineralization formed in a marginal basin environment, proximal to a volcanic arc. Deposition occurred through subaqueous pyroclastic flow, and volcanoclastic gravity flow mechanisms. Fault bounded ridge and trough structures provided paleotopographic lows in which epiclastic and hydrothermal sediment were deposited and preserved. Synvolcanic faults served as conduits for hydrothermal fluids and feeder zones for massive flows.

Geochemical analyses and REE distribution suggest that the Nitinat Formation should include rocks of the Lower Andesite. The REE distributions of the Lower Dacite, though distinct, suggest a relationship with the Nitinat Formation. Rhyolites have distinctive REE patterns, suggestive of a different magma source.

Structural deformation is complex, reflecting the tectonic environment of southern Vancouver Island. Early deformation produced shallow dipping extensional features. Subsequent deformation produced the Mt. Sicker Anticline, parasitic folds and axial planar transposition foliation. During crustal extension, diorite dykes dilated the strata. The Cowichan-Horne Lake Uplift formed during the Middle Jurassic to Late Cretaceous and was dissected by west-northwest trending thrusts during the Late Cretaceous. Relaxation of compression resulted in the development of steep west-northwest trending normal faults and north-northeast trending Tertiary cross faults.

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APPENDIX I

Summary of Sicker Group stratigraphic divisions

Yole (1969) All Sicker Group Rocks on Vancouver Island.

Youbou Formation, consisting of all stratified rocks below the Buttle Lake Formation, including volcanic and volcanoclastic rocks and minor sedimentary rocks.

Buttle Lake Formation consisting of crinoidal limestone and lesser amounts of clastic chert.

Unnamed, thin-bedded clastic rocks.

Muller (1980) All Sicker Group Volcanic Rocks on Vancouver Island.

Nitinat Formation, composed of pyroxene-phyric, massive to pillowed, basaltic andesite flow and flow-breccia and minor tuff, described in the Cowichan-Horne Uplift.

Myra Formation, consisting of rhyolitic to andesitic tuff, flow and breccia, argillite, siltstone, wacke and minor conglomerate. This formation was defined in the Buttle Lake Uplift and is host to volcanogenic massive sulphide.

Sediment-Sill Unit (informal name) composed of massive to bedded sedimentary rocks intruded by numerous diabase sills.

Buttle Lake Formation consisting of crinoidal limestone and lesser amounts of clastic chert.

Sutherland Brown (1985, 1986) Cowichan-Horne Lake Uplift
Youbou Subgroup

St. Mary's Fm.
Mt. Mark Fm.
Cameron River Fm.
McLaughlin Ridge Fm.
Nitinat Fm.

Nitinat Formation, consisting of pyroxene-phyric tholeiitic to basaltic andesite agglomerate, tuff-breccia and tuff with lesser pillowed and massive flow, and minor volcanic sedimentary rocks.

McLaughlin Ridge Formation, consisting of massive to bedded volcanic sandstone with lesser conglomerate, pebbly sandstone, siltstone and chert and minor mafic to intermediate, pillowed to massive flow.

Buttle Lake Subgroup

Cameron River Formation, a thinly bedded unit of siliceous argillite and shale, black chert, grey limestone, green volcanic sandstone, red and green ribbon chert and chert breccia.

Mt. Mark Formation, consisting of thick bioclastic limestone.

St Mary's Lake Formation composed of thinly bedded sandstone and shale.

Juras (1987) Buttle Lake Uplift

Henshaw Fm.
Buttle Lake Fm.
Flower Ridge Fm.
Thelwood Fm.
Myra Fm.
Price Fm.

Price Formation, consisting of feldspar and/or pyroxene-phyric andesite flow and associated breccia with minor volcanoclastic rocks.

Myra Formation, composed of basaltic and rhyolitic flows and volcanic rocks with lesser amounts of epiclastic sandstone, argillite and chert, and massive sulphide.

Thelwood Formation, consisting of siliceous tuffaceous sedimentary rocks, subaqueous volcanoclastic debris flows, pyroclastic deposits and intrusive mafic sills.

Flower Ridge Formation, composed of amygdaloidal basaltic lapilli tuff, tuff and breccia with minor flow, tuffaceous sandstone and siltstone with minor mudstone and argillite.

Buttle Lake Formation: crinoidal limestone with minor chert and argillite.

Henshaw Formation, composed of conglomerate, pyroclastic tuff and breccia and sedimentary rocks.

APPENDIX II

**Legend for maps in pocket,
list of mineral abbreviations and
legend for summary of petrography tables**

LEGEND**6 Late Mafic Intrusive (Late Triassic)**

- a shallow dipping diorite dykes
- b subvertical diorite dykes

Slicker Group (L. Silurian-Devonian)**Youbou Subgroup****McLaughlin Ridge Formation****Sedimentary Rocks**

- 4
 - a chert
 - b tuffaceous chert
 - c graphitic and non-graphitic argillite
 - d siltstone and mudstone

Pyroclastic volcanics (minor extrusive, rare intrusive)**3 felsic (rhyolitic-rhyodacitic)**

- a quartz-phyric, quartz-feldspar-phyric flow
- b quartz-feldspar-phyric, quartz $\pm$ feldspar-phyric vitric-crystal tuff
- c feldspar $\pm$ quartz-phyric vitric-crystal tuff
- d aphyric/siliceous tuff
- e feldspar-phyric dyke
- f lapilli tuff

2 intermediate (dacitic)

- a feldspar-phyric vitric-crystal tuff
- c feldspar $\pm$ quartz-phyric vitric-crystal tuff
- d aphyric tuff
- e feldspar-phyric dyke
- f lapilli tuff

1 mafic (andesitic)

- a feldspar-phyric vitric-crystal tuff
- b pyroxene-phyric vitric-crystal tuff
- e dyke
- g massive flow
- h flow breccia

SYMBOLS

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outcrops; large, small
creek
roads; driveable, undriveable
topography; break in slope, talus/tailings slope
	trench, adit
	pit, collapsed adit
	abandoned shaft
	minor fault, major fault
	defined contact
	approximate contact
	inferred contact
	intrusive contact
	foliations; with dip, subvertical
	bedding; with dip
	lineations; with plunge
	minor fold axes; synform, antiform, overturned antiform, overturned synform, 'S' and 'Z' folds
	major fold axis
	diamond drill hole
	sample for analysis

Sulphide Concentration

exhalative massive sulfide and deformed
massive sulfide

quartz veins and feldspar pods

stringer zone

A

Size mm	Pyroclast	
256 64	coarse	Blocks or Bombs
	fine	
2	Lapilli	
1/16	coarse	Ash
	fine

Fig. 25 Classification scheme for pyroclastic rocks. A. Granulometric classification for unconsolidated pyroclastics. B. Granulometric classification of pyroclastic rocks. C. Subdivision of tuffs based on the fragmental composition. D. Further subdivision of tuffs based on the relative proportion of fragments, in this case, crystal and glass fragments. (after Fisher and Schmincke, 1984; Niem, 1977)

Primary Textures

BDG	bedding
FLM	flame structures
GRD	graded beds
LAM	laminations

Composition

A	andesite
D	dacite
R	rhyolite

Matrix

%C	modal percent carbon
----	----------------------

Phenocrysts

%	modal percent
A	anhedral
BRT	becciated
DB	deformation bands
E	euohedral
INC	found as inclusions
INCL	containing inclusions
MIG	myrmekitic intergrowths
OP	ophitic texture
PRF	pressure fringes
PSD	pseudomorph
QOG	quartz overgrowths
Rd	rounded
RIM	found as rimings
RXT	recrystallized
S	subhedral
Sg	subgrains
Skl	skeletal
SOP	subophitic texture
SUT	sutured grain boundaries
TW	twinned
UEx	undulose extinction

Fragments

%	modal %
%L	modal % lapilli
ALT	alteration
COM	composition
Gl	glomerocryst
L	lithic
PHEN	phenocrysts
PRF	pressure fringes
SHP	shape
TW	twinned
UEx	undulose extinction
V	vitric
XTL	crystal
ZN	zoning

Shape

An	angular
B	broken
C	cloudy
Emb	embayed
Fl	flattened
Ir	irregular
L	laths
Og	overgrowth
Rd	rounded
Sb	shear band
Sg	subgrain
Skl	skeletal
Sr	subrounded

Sulphides

ANL	annealed
BRX	brecciated
DIS	disseminated
FRAC	within fractures
INCL	included
PLAN	parallel lamination
RXT	recrystallized

Alteration*

PSD	pseudomorph
PRF	pressure fringes
VL	veinlets
DIS	disseminated
wk	weak
mod	moderate
stg	strong
altn	alteration product
tr	trace
oc	occasional

Deformation

lin	lineation
MF	microfracture (parallel to)
S ₁	foliation
S ₂	kinked foliation
SB	shear band

Mineral Abbreviations

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Silicates

Actinolite	act
Albite	ab
Apatite	ap
Barite	brt
Clinopyroxene	cpx
Calcite	cal
Chlorite	chl
Epidote	ep
Goethite	gt
Graphite	gr
Hematite	hem
Hornblende	hbl
K feldspar	kfs
Plagioclase	pl
Quartz	qtz
Sericite	ser
Sphene	spn
Talc	tlc
Tremolite	tr
Zircon	zrn

Opaques

Arsenopyrite	apy
Bornite	bn
Chalcopyrite	ccp
Covellite	cv
Galena	gn
Hessite	hess
Ilmenite	ilm
Magnetite	mag
Pyrite	py
Sphalerite	sp
Tennantite	tenn
Opaque	opq
Gangue	gang

(after Kretz, 1983)

APPENDIX III

Summary of petrography for the Lenora-Tyce area

Table 111d SUMMARY OF SEDIMENTARY ROCK PETROGRAPHY

Rock type	Primary Textures		Fragments										Matrix				Sulfides										Foliation	
	MOD	LAM	GRD	FLM	%	SIZE	COM	SMP	UEN	PMF	TV	%C	SIZE	COM	PT	SP	CCP	CH	BRT	EXT	ALA	PLAN	INCL	PMAC	OIS	S1	S2	
Graphitic argillite (62)			<0.1		5	<3.08	fs	Rd				10-30	<0.03	qtz	5-10%													
							qtz	Sr						ser		<1%

Table III SUMMARY OF SULFIDE PETROGRAPHY: MINERALOGY AND TEXTURES

Rock Type	Annealing				Replaced by				Deformation				Inclusions				Comments/occurrence		
	Z	E	S	A	RXT	POR	INTG	PB	PSD	ATL	BAR	INF	CCL	CAT	PY	SP	CCP	OR TENN	NESS AU
Feldspar Pods (101)																			
Pyrite	1	X			X	X						X	gang			X			
Chalcopyrite	10	X			X	X		sp							X	X			
Sphalerite	1	X			X	X	ccp												
Tennantite	1	X			X	X		term											
Galena	tr															X			
Quartz Vein (93a,b)																			
Pyrite	10-15	X	X	X	X			sp		sp	X	gang	gn, sp		X	X			
										gn			ccp, apy						
Arsenopyrite	tr-2	X						gn											
Chalcopyrite	5	X	X					sp			X	ccp			X	X			
Sphalerite	5-25	X	X		X		ccp	gn				apy			X	X			
Galena	1-5	X	X		X			ccp				gang							
Wessite	tr															X	X	X	X
Tennantite	rare	X																	

-occurs within gangue and veinlets
 -occurs in sp (ccp disease)
 as subhedral grains and along
 sp/gn grain boundaries
 -subhedral-irregular grains,
 recrystallized
 -intergranular to sp, ccp
 -occurs within and along gn grain
 boundaries

-irregular and discontinuous veinlets,
 intergranular to silicates

Table III (cont.)

Rock Type	Annealing				Replaced by				Deformation				Inclusions				Comments/occurrence				
	X	E	S	A	RPT	POB	INTG	PS	PSD	ATL	BRE	IMP	DCL	CAT	PT	SP	CCP	Ca	TENN	MESS	AU
Sphalerite	10-15	X	X	X	X		ccp	ccp	ccp	ccp							X				
Chalcopyrite	20-30				X	X		gang	gang	gang											
Galena	2-3				X			ccp	ccp	ccp							X	X	X	X	
								term													
								sp													
Ironmanite	2-3				X			ccp													
Hessite	rare				X																
Au	rare				X																
Massive Sulphide (102)																					
Pyrite	20-30	X	X	X	X	X		ccp	ccp	ccp	X	gang	ccp	sp	gang		X	X	X	X	X
								sp	sp	sp		ccp									
Sphalerite	10-20	X	X	X	X			gang	gang	gang		sp									
Chalcopyrite	20-30	X	X	X	X			ccp	ccp	ccp							X	X			
Galena	2-5	X	X	X	X			sp	sp	sp							X	X			
Hessite	tr-1							sp													
Au	tr				X																
Bornite	1-2																				
Covellite	tr-1																				

-occurs in sp, gn, term, brt fragments
Irregular grains in ccp

-occurs as inclusions in ccp and
within baritic fragments

-associated with gn as above
-included within ccp

-bedded to laminated, 2-15cm,
sp-brt-py-gn-ccp/-qtz
and py-ccp-sp-brt-gn/-qtz

-along ccp and gn grain boundaries;
associated with Au

-occurs within ccp, infills brecciated
py, as inclusions with ccp in py

-late oxidation of ccp along grain
boundaries and fractures

- occurs in sp, gn, term, brt fragments
irregular grains in ccp

- occurs as inclusions in ccp and
within baritic fragments

- associated with gn as above
- included within ccp

- bedded to laminated, 2-15mm,
sp-brt-py-gn-ccp/-qtz
and py-ccp-sp-brt-gn/-qtz

- along ccp and gn grain boundaries;
associated with Au

- occurs within ccp, infills brecciated
py, as inclusions with ccp in py
- late oxidation of ccp along grain
boundaries and fractures

APPENDIX IV

Summary of petrography for the Mona area

Table IVa SUMMARY OF FELDSPAR PORPHYRITIC DYKE PETROGRAPHY

Rock Type	feldspar Phenocrysts												Groundmass								Secondary Minerals											
	%	SIZE	E	S	A	Zn	IV	CL	UEK	SG	RHT	PRF	OG	SIZE	QTZ/FS	SER	CNL	EP	CAL	OPG	QTZ	SER	CNL	EP	CAL	PSD	PRF	VLT				
feldspar porphyritic dyke (5,23)	10-15	0.15-2.2	X	X	X	X	X	X	X	X	X	X	oc	<0.07	40-70	30-20	5-20	tr	10	1-2	wt mod-	wt-	wt	wt	ser	cal	qtz					

Table IVb SUMMARY OF VITRIC, VITRIC-CRYSTAL, CRYSTAL AND LAPILLI-ASH TUFF PETROGRAPHY

Rock type	Fragments										Matrix				Deformation				Alteration						
	X	ZL	V	L	MIL	CON	SIZE	SNP	ZN	TU	LEX	PHF	ALT	COMP	S1	S2	VTL	CHL	SER	EP	QTZ	CAL	A	D	R
feldspar-phyrlic vitric-crystal/ crystal tuff (64.21)	40-50	S	X			X	fs 0.1- 15	An ₈ Gl C	OC			chl mod- fs stg qtz ep		chl ep fs (qtz)	stg	stg		stg	stg						X
Quartz-feldspar- phyrlic to feldspar- quartz-phyrlic vitric-crystal coarse ash tuff (39.40)	15-40	2-15	X			X	qtz 0.2- 2.3	Ed Sr An ₈ Sg Og Sb				X	qtz ser chl mod- ser	ser qtz, fs chl ep opa	stg	stg	stg	stg	stg	stg					X
Lithic-bearing vitric tuff (43)	S		X			X	qtz 0.2- 0.5	Ed Ir				X	ser (qtz, chl)	ser chl qtz, fs ep opa	stg	stg		mod	stg						X
Crystal-bearing vitric tuff (31)	2-3		X			X	fs 0.15- 0.25	An ₈ C				X	chl qtz (ser)	ser fs, qtz opa tr sp py	stg	stg		stg							X
Lithic-bearing vitric tuff (32)	15	10-15	X			X	ep 1.5	Sr Ir				X	qtz cal (ser)	qtz fs ser chl (ser) ep	stg	stg	stg	mod	stg	mod	mod				X
	2-10		X			X	qtz 0.3	Ir				X	qtz cal (ser)	qtz fs ser chl (ser) ep	stg	stg	stg	mod	stg	mod	mod				X

APPENDIX V

Summary of petrography for the Northeast Copper area

Table Vb SUMMARY OF QUARTZ-PHYRIC, QUARTZ-FELDSPAR-PHYRIC AND FELDSPAR-QUARTZ-PHYRIC-VITRIC-CRYSTAL TUFF/FLOW HT 10,000MPT

Rock type	Fragments										Comments	Matrix				Alteration				Sulphides		A	B	R
	X	ZL	V	L	HTL	PHEN	CON	SIZE	SMP	Zn		TU	GL	UEX	PHF	ALT	Chl	SER	EP	CAL	QTZ				A	B	R
Feldspar-quartz-phyric	15-20							fs	0.1-0.75	An,B		OC	X	ser,qtz	uk ser									
vitric-crystal tuff (40)	30-40							qtz	0.1-0.7	A,B			X	ser,qtz	fs,chl									
Quartz-feldspar-phyric	2-10	5						qtz	0.15-6	A,B			X	qtz,chl	ser,qtz									
crystal tuff (36)	40-50	10-15						fs	0.15-3	A,B			X	qtz,chl	fs,chl									
								E,S		Sg				+/ser	mod									
Quartz-phyric	10-20	10						qtz	0.2-7	An,B			X	ser,qtz	fs,qtz									
vitric-crystal tuff (62,46)								E,S		Skl				chl	ser,chl									
								0.5g																
	2-5							fs	0.2-0.7	B,A ⁺			X	ser,chl	fs,qtz									
														qtz	mod									
Quartz-phyric to Quartz-feldspar-phyric flow/vitric-crystal tuff (33,51)	5-10	3						qtz	0.4-3	E,S			X	chl,ser	qtz,ser									
										Skl				qtz	chl									
										Emb ^a														
										B.Og														
	20							fs	0.25-1.4	E,A			X	mod-stg	qtz,ser									
										R,Sf					trace fs									
										An														

Table VB. SUMMARY OF TUFFACEOUS ROCK PETROGRAPHY

Rock type	Fragments										Comments	Matrix				Alteration				Sulphides	A D R																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
	X	ZL	V	L	HT	COM	SIZE	SHP	TW	GL		DEX	PRF	ALT	CHL	SER	QTZ	EP	CAL																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
Fine tuff with amygdules (c. 31)	20	10-15	X			chl, ser 0.3x1 to 1.1r (qtz) 1x6		fl, lr					stg chl																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										

2-10% diss. pyrite recrystallized with chl/qtz Pst and associated rim veinlets, hematite rim

1-2% diss. pyrite with qtz, chl Pst

5% diss. (fine-grained) pyrite

possible chert or felsic fragments

well rounded amygdules

(1) contains trace amphibole A, lr, <0.15 possible boudinaged veinlets

possible vitric fragments or patchy chloritic alteration

Table Vc SUMMARY OF ANDESITE FLOW PETROGRAPHY

Rock type	Crystallinity	Granularity	fabric/texture	Mineralogy					Sulphides					Alteration					Foliation	Comments
				PL	CHL	SER	SPH	HEM	EP	QZ	PY	SP	CHL	SER	EP	QZ				
Massive Andesite flow (17, 19, 6)	holocrystalline	fine-grained ($<0.3\text{mm}$) equigranular	-trachytic -variolitic -amygdaloidal (2-55, 0.15-1.4mm, filled with Qtz, chl, trace epd)	40-70	20-30	0-30	5-10	10-15	2-5	1-5	tr	rare	stg	wt-stg			wt-mod	-stg patchy sericitization results in fragmental texture -stg chloritization of matrix intergranular to pl and wt-mod alteration of pl laths -wt-stg sericitization of pl		

Table Vd SUMMARY OF MAFIC DYE PETROGRAPHY

.....																								
.....																								
.....																								
.....																								
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APPENDIX VI

Analytical geochemical data,
microprobe analyses, assays and
REE chondrite values

Table Via ANALYTICAL DATA FOR SAMPLES FROM DOW HTS-29 AND SURFACE EXPOSURES ALONG HIGHWAY 1.

	1	2	3*	4*	5	6	7	8*	9	10	11	12*	13	14	15	100*	20	21	22	24
SiO ₂	74.3	72.6	75.1	80.2	68.6	75.8	64.4	75.9	55.3	53.9	54.3	57.0	55.6	69.7	58.4	55.4	54.1	53.9	54.1	57.2
Al ₂ O ₃	13.08	16.25	13.21	10.73	14.17	12.43	14.92	12.49	17.42	16.71	17.00	17.08	17.74	16.29	17.00	15.36	12.85	15.82	15.36	16.89
FeO	3.14	2.77	1.19	1.22	4.45	2.78	4.50	1.81	7.78	8.02	7.68	6.86	7.08	3.16	6.61	7.23	7.33	6.81	7.43	7.79
MgO	2.12	2.99	1.84	1.76	4.62	2.35	7.13	2.78	7.49	8.95	7.16	7.23	6.76	4.07	6.72	6.17	9.12	7.27	7.63	5.90
CaO	0.35	0.64	2.66	0.73	0.66	0.18	0.59	0.21	2.28	3.13	4.24	2.05	2.79	0.49	1.52	8.22	10.77	8.21	7.13	3.23
MnO	0.26	0.53	3.40	1.40	0.26	0.13	1.08	0.40	3.37	3.14	2.50	2.69	4.22	2.91	2.53	3.90	2.02	4.15	4.09	4.28
K ₂ O	3.29	2.83	0.86	2.05	2.89	3.08	2.05	2.87	0.81	0.22	0.71	1.47	0.46	1.89	1.79	0.18	0.36	0.12	0.35	0.23
NaO	0.32	0.32	0.32	0.27	0.49	0.30	0.49	0.31	0.76	0.76	0.90	0.75	0.83	0.38	0.62	0.76	0.59	0.81	0.83	0.77
H ₂ O	0.03	0.03	0.02	0.01	0.05	0.03	0.06	0.03	0.15	0.18	0.16	0.13	0.16	0.06	0.10	0.17	0.23	0.19	0.23	0.15
S	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
LOI	2.78	2.83	1.44	1.51	3.64	2.72	4.60	2.58	4.42	4.77	4.74	4.54	3.97	2.87	2.25	2.35	4.57	2.55	3.36	
SUM	99.77	99.80	99.82	99.87	99.84	99.79	99.83	99.86	99.79	99.79	99.78	99.74	99.70	99.83	99.77	99.78	99.73	99.86	99.71	99.81
Cu	8	12	3	2	15	4	6	62	102	15	298	12	10	7	7	96	23	60	120	12
Pb	2	3	1	1	4	2	6	2	9	11	10	10	10	5	10	4	3	6	5	8
Zn	9	10	9	5	17	15	26	12	40	65	51	46	43	23	32	27	38	69	44	47
Mn	4	3	4	3	23	4	29	4	13	27	19	20	18	4	23	19	21	18	28	16
Ag	0.4	0.3	0.1	0.1	0.6	0.4	0.8	0.2	0.9	1.2	1.9	0.9	0.9	0.4	0.8	0.4	0.4	0.8	0.5	0.9
Au**	7	5	6	9	11	8	7	8	10	7	5	9	7	6	7	8	6	9	7	10
Li	12.9	10.6	3.5	7.0	8.9	10.0	2.0	2.0	9.3	6.9	6.6	4.3	8.7	10.7	5.9	7.2	3.6	8.4	9.0	7.2
Ce	26.7	22.1	6.8	16.6	19.7	20.1	19.4	23.0	20.4	16.1	16.4	10.7	20.6	22.9	13.7	16.5	8.1	18.0	21.0	15.7
Nd	10.5	8.5	3.0	6.3	8.8	7.4	9.6	9.5	11.9	9.5	9.6	6.6	12.3	9.0	7.3	9.2	4.7	9.9	11.9	9.5
Sm	2.50	1.84	0.97	1.49	2.20	1.68	2.43	1.83	3.07	2.72	2.38	2.06	3.02	2.08	2.19	2.38	1.53	2.70	2.68	2.55
Eu	0.28	0.46	0.30	0.20	0.28	0.39	0.41	0.92	0.85	0.81	0.67	0.69	0.52	0.59	0.73	0.51	0.83	0.80	0.84	
Tb	0.45	0.35	0.25	0.27	0.49	0.29	0.49	0.30	0.60	0.59	0.46	0.46	0.51	0.32	0.48	0.46	0.38	0.53	0.37	0.52
Dy	3.1	2.2	1.8	2.1	3.4	2.0	3.6	2.1	3.8	3.5	3.3	2.9	3.3	1.9	3.1	2.9	2.2	3.1	2.5	3.2
Ho	0.66	0.44	0.41	0.50	0.72	0.46	0.76	0.47	0.76	0.72	0.67	0.60	0.69	0.58	0.64	0.63	0.47	0.66	0.54	0.63
Er	1.9	1.3	1.20	1.20	2.00	1.10	1.90	1.10	1.90	1.60	1.50	1.60	1.60	1.00	1.60	1.60	1.3	1.6	1.4	1.4
Yb	2.48	1.55	1.40	1.62	2.07	1.49	2.12	1.56	2.02	1.76	1.86	1.67	1.60	1.48	1.84	1.76	1.24	2.02	1.54	2.09
Lu	0.41	0.28	0.28	0.28	0.37	0.26	0.36	0.27	0.35	0.34	0.28	0.32	0.29	0.24	0.26	0.28	0.20	0.24	0.24	0.30

Analyses of major oxides is in wt.%, trace metals and REE, except ** (ppb), are in ppm.

FeO is total iron.

Totals calculated by using major oxides + LOI, S was excluded.

Samples collected by P. MacDobbs.

Analyses of major oxides and trace metals by Metric Lab, Montreal.

REE analyses performed by Ecole Polytechnique de Montreal.

Samples 19, 20, 21, 22 and 24 collected along Highway 1.

Samples 3*, 8*, 12* and 19* are averages of 2 duplicates.

Location of samples from DOW HTS-29 in Figure 19.

Table VII ANALYTICAL DATA FOR SAMPLES FROM UNIT 1 AT THE NORTHEAST COPPER AREA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SiO ₂	76.0	75.9	75.5	75.4	75.0	74.2	74.0	74.0	73.6	73.4	72.7	71.7	70.4	69.7	69.4	68.3	66.7	55.1
Al ₂ O ₃	13.48	13.24	12.76	12.03	11.73	13.51	13.26	12.18	13.53	11.77	14.03	12.35	14.01	14.80	13.72	14.30	15.08	15.95
FeO	2.29	2.29	3.19	3.37	4.12	3.19	3.90	4.21	3.86	5.09	2.93	6.18	4.23	4.10	5.93	6.07	5.38	11.58
MgO	1.29	1.42	1.42	1.43	1.87	1.77	1.70	1.12	1.43	1.74	1.15	1.99	2.43	1.86	2.47	2.40	3.20	5.13
CaO	0.04	0.06	0.08	0.05	0.08	0.07	0.04	0.18	0.05	0.07	0.17	0.07	0.37	0.57	0.10	0.11	0.23	0.12
MnO	0.13	0.13	0.33	0.39	0.40	0.13	0.13	0.91	0.13	0.13	2.40	0.26	0.13	0.13	0.26	0.13	2.36	2.15
K ₂ O	3.73	3.80	3.59	3.57	2.77	3.67	3.43	3.01	3.85	3.10	2.86	2.87	3.73	4.19	3.19	3.43	2.46	2.82
Na ₂ O	0.32	0.33	0.29	0.27	0.27	0.32	0.29	0.29	0.28	0.31	0.29	0.37	0.48	0.51	0.41	0.54	0.48	0.81
H ₂ O	0.01	0.03	0.01	0.03	0.04	0.02	0.02	0.01	0.02	0.04	0.03	0.04	0.04	0.02	0.06	0.06	0.05	0.13
S	0.01	0.01	0.01	0.01	0.39	0.01	0.01	1.87	0.01	0.73	0.50	0.56	0.61	1.36	0.56	0.50	0.39	1.47
LOI	2.44	2.58	2.81	2.75	3.13	2.94	3.07	3.48	3.04	3.43	2.71	3.42	3.35	3.79	3.78	3.87	3.41	5.71
SUM	99.74	99.79	99.77	100.10	99.78	99.83	99.85	101.26	99.80	99.81	99.77	99.83	99.78	101.03	99.88	99.71	99.75	100.27
Cu	128	167	447	341	502	35	351	98	153	634	101	159	23	9	574	207	207	498
Pb	2	2	3	2	3	3	2	2	3	4	2	4	4	3	7	5	6	10
Zn	13	15	22	25	26	14	16	8	27	37	13	40	18	12	32	28	36	41
Mn	3	3	4	4	7	3	3	4	4	5	4	8	5	6	9	6	9	18
Ag	0.6	0.4	0.7	0.7	0.6	0.5	0.7	0.3	1.0	0.7	0.5	0.8	0.6	0.4	0.9	0.7	0.8	1.4
Au	7	5	5	5	7	5	9	5	7	6	7	9	6	6	5	5	5	6

Analyses of major oxides is in wt.%, trace metals and REE, except ** (ppb), are in ppm.

FeO is total iron.

Trace calculated by using major oxides + LOI, S was excluded.

Samples collected by P. MacRobbie.

Analyses of major oxides and trace metals by Metric Lab, Montreal.

Location of samples on Fig. 14b.

extraction		method	Lower detection limit	Estimate of Validity	
Major oxides			(%)	(%absolute)	(%relative)
SiO ₂		XRF	2.0	2.0	
Al ₂ O ₃	HF-HCl-H ₂ SO ₄	AA	0.01		10.0
FeO	HF-HCl-H ₂ SO ₄	AA	0.01		10.0
MgO	HF-HCl-H ₂ SO ₄	AA	0.01		10.0
CaO	HF-HCl-H ₂ SO ₄	AA	0.06		10.0
Na ₂ O	HF-HCl-H ₂ SO ₄	AA	0.01		10.0
K ₂ O	HF-HCl-H ₂ SO ₄	AA	0.01		10.0
TiO ₂		XRF	0.01		10.0
MnO	HF-HCl-H ₂ SO ₄	AA	0.01		10.0
S		XRF	0.01		10.0
LOI	1050°	gravimetric	0.01		5.0
Trace metals			(ppm)		
Cu	HNO ₃ -HCl-HF	AA	1.0		
Pb	HNO ₃ -HCl-HF	AA	1.0		
Zn	HNO ₃ -HCl-HF	AA	1.0		
Ni	HNO ₃ -HCl-HF	AA	1.0		
Ag	HNO ₃ -HCl-HF	AA	0.2		
Au	aqua regia	Fire Assay AA	1.0 ppb		

Data supplied by Metric Lab, Montreal

AA atomic absorption spectrometry

XRF x-ray fluorescence

Table VIC (con't)

	method	Lower detection limit
Rare earth elements		(ppm)
La	INNA	0.1
Ce	INNA	1.0
Nd	INNA	1.0
Sm	INNA	0.05
Eu	INNA	0.05
Tb	INNA	0.1
Dy	INNA	0.1
Ho	INNA	0.1
Er	INNA	100.0
Tb	INNA	1.0
Lu	INNA	0.05

Data supplied by Ecole Polytechnique, Montreal

INNA instrumental neutron activation

Table VII Duplicates, Standard and Calculation of Precision and Accuracy

	Duplicates												Standard BE ₁₀		Precision		Accuracy	
	3	16	8	17	12	18	19	23	obs				1	2	(mean % avg. deviation)		(mean % relative error)	
									known				(-/+%)		(+/-%)		(+/-%)	
SiO ₂	75.7	74.5	75.6	76.2	57.0	56.9	54.2	56.5	-	-	-	-	-	-	-	-	-	-
Al ₂ O ₃	12.76	13.66	12.63	12.35	17.34	16.81	15.93	16.78	-	-	-	-	-	-	-	-	-	-
FeO	0.96	1.22	2.4	2.23	6.64	7.07	7.4	7.46	-	-	-	-	-	-	-	-	-	-
MgO	1.86	1.81	2.92	2.63	6.82	7.63	6.41	5.93	-	-	-	-	-	-	-	-	-	-
CaO	3.19	2.13	0.21	0.2	2.14	1.96	8.19	8.25	-	-	-	-	-	-	-	-	-	-
MnO	2.95	3.85	0.4	0.39	3.09	2.29	4.01	3.78	-	-	-	-	-	-	-	-	-	-
K ₂ O	0.4	0.92	2.84	2.89	1.5	1.44	0.24	0.12	-	-	-	-	-	-	-	-	-	-
Na ₂ O	0.29	0.34	0.31	0.3	0.74	0.76	0.76	0.76	-	-	-	-	-	-	-	-	-	-
H ₂ O	0.01	0.02	0.03	0.02	0.12	0.14	0.17	0.16	-	-	-	-	-	-	-	-	-	-
S	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	-	-	-	-	-	-	-	-	-
LOI	1.27	1.36	2.57	2.58	4.29	4.78	2.48	2.01	-	-	-	-	-	-	-	-	-	-
SUM	99.82	99.82	99.92	99.8	99.69	99.79	99.8	99.76	-	-	-	-	-	-	-	-	-	-
Cu	3	3	3	9	20	3	79	112	-	-	-	-	-	-	-	-	-	-
Pb	1	1	2	1	9	10	4	4	-	-	-	-	-	-	-	-	-	-
Zn	8	10	12	12	43	49	25	28	-	-	-	-	-	-	-	-	-	-
Mn	3	5	3	4	19	21	17	21	-	-	-	-	-	-	-	-	-	-
Ag	0.1	0.1	0.2	0.1	0.9	0.9	0.4	0.4	-	-	-	-	-	-	-	-	-	-
Ag**	5	6	6	10	11	6	7	9	-	-	-	-	-	-	-	-	-	-
La	3.5	3.5	11.2	-	4.3	-	7.3	7.1	-	-	-	-	-	-	-	-	-	-
Ce	6.4	7.1	23.0	-	10.7	-	16.3	16.8	-	-	-	-	-	-	-	-	-	-
Yb	3.0	3.0	9.5	-	6.6	-	9.3	9.1	-	-	-	-	-	-	-	-	-	-
Sm	0.97	0.97	1.83	-	2.06	-	2.37	2.39	-	-	-	-	-	-	-	-	-	-
Eu	0.3	0.29	0.41	-	0.67	-	0.78	0.68	-	-	-	-	-	-	-	-	-	-
Tb	0.27	0.23	0.3	-	0.46	-	0.42	0.49	-	-	-	-	-	-	-	-	-	-
Tm	1.9	1.8	2.1	-	2.9	-	2.9	2.8	-	-	-	-	-	-	-	-	-	-
Yb	0.38	0.44	0.47	-	0.6	-	0.56	0.69	-	-	-	-	-	-	-	-	-	-
Er	1.3	1.1	1.1	-	1.6	-	1.4	1.7	-	-	-	-	-	-	-	-	-	-
Pr	1.56	1.65	1.56	-	1.67	-	1.78	1.74	-	-	-	-	-	-	-	-	-	-
Lu	0.26	0.24	0.27	-	0.32	-	0.29	0.26	-	-	-	-	-	-	-	-	-	-

Analyses of major oxides is in wt. %, trace metals and REE, except ** (ppb), are in ppm.

FeO is total iron

Fig. 4 calculated by using major oxides + LOI, S was excluded.

Samples collected by a hand-dredge

Standard BE₁₀ is 1 measured values.

2 independently estimated values & for Mn, except by Mn.

Precision calculated using mean % average deviation derived from Sloog and West (1962)

Precision for major oxides and traces using Mn, for REE using Mn.

Accuracy calculated using mean % relative error derived from Sloog and West (1962).

LOI = duplicate of standard BE₁₀.

Sample

1. DDH MTS-29 31.4m Light green-grey, rhyolite, quartz-feldspar-phyric vitric-crystal tuff containing 10-15% quartz, 0.5-5mm, and 2-3% feldspar, <1-1.5mm. Sample from a 1-2m thick quartz-rich tuff beds. Weak pervasive sericitization is typical. Feldspars appear relatively fresh.
2. DDH MTS-29 68.9m Green-grey, rhyolite-rhyodacite, vitric-crystal tuff containing 5-10% quartz, <1-3mm and <3% feldspar, <1mm. Sample from a section of interbedded, 2-30cm thick, feldspar-quartz and quartz-feldspar-phyric vitric-crystal tuff.
3. DDH MTS-29 89.4m Light grey, rhyolite vitric-crystal tuff composed of 20-35% feldspar, <1-2mm, in a siliceous, aphanitic matrix. Trace to weak sericite/chlorite alteration and no sulphides are present.
4. DDH MTS-29 96.0m Light grey-green siliceous fine ash tuff containing up to 10% quartz, <1mm and contains discontinuous <1mm thick chloritic seams throughout.
5. DDH MTS-29 315.8m Medium green-grey dacite fine ash tuff, locally well laminated which contains 3-5% fine-grained pyrite disseminated throughout.
6. DDH MTS-29 326.1m Light grey, rhyolite, quartz-phyric vitric-crystal tuff containing 5-10% quartz, <1-3mm, 2-5% disseminated fine-grained pyrite and occasional feldspar, <1mm.
7. DDH MTS-29 341.8m Medium green-grey dacite vitric-crystal tuff composed of 15-20% feldspar $\leq$ 1mm within a fine aphanitic ash matrix. Possible mafic minerals 5% and <1.5mm occur. Up to 3% disseminated fine grained pyrite throughout.
8. DDH MTS-29 387.3m Rhyodacite, light-medium green to grey, quartz-phyric vitric-crystal tuff consisting of 5-10% quartz, <1-4.5mm and trace feldspar, <1mm, set in a fine ash matrix. Fine-grained disseminated pyrite, 1-2%, is present.
9. DDH MTS-29 435.5m Medium grey-green, massive homogeneous andesite ash tuff containing 2-3% feldspar, <1mm, and 1-2% disseminated pyrite. Weak chlorite alteration is present.

10. DDH MTS-29 493.4m Medium to dark green, massive andesite vitric-crystal tuff containing 15-20% feldspar, <1-2mm. Weak to moderate chlorite alteration of matrix, and trace epidote alteration of feldspars is apparent. Trace-2% disseminated pyrite occur throughout. 137
11. DDH MTS-29 526.5m Medium to dark green andesite vitric-crystal tuff containing 3-15% feldspar, <1-2mm, defining a crude layering. Weak chlorite alteration of the matrix and weak epidote alteration of feldspar crystal rims is evident. Disseminated fine-grained pyrite, 1-2%, occurs throughout.
12. DDH MTS-29 586.4m Medium to dark green-grey massive andesite fine ash tuff and fine vitric-crystal tuff containing 5-10%, <1mm feldspar. Trace-3% disseminated pyrite is present.
13. DDH MTS-29 610.5m Medium to dark green-grey, massive andesite, vitric-crystal tuff with 5-20% feldspar, <1-2mm, defining a crude layering. Weakly chlorite altered; weakly developed epidote patches (5x5mm) and epidote alteration of feldspars is evident. Disseminated fine-grained pyrite, 1-2%, occurs throughout.
14. DDH MTS-29 628.8m Light-grey rhyodacite feldspar-quartz-phyric vitric-crystal tuff containing 15-20% feldspar, <1-2mm, and 5% quartz, <1-4mm, in a aphanitic matrix. Weak sericitization and silicification and disseminated pyrite, 2-3%, is present.
15. DDH MTS-29 686.6m Medium to dark green-grey, andesite fine vitric-crystal tuff containing 5-15% feldspar, <1mm, and possible quartz, <1mm. Feldspar content is variable defining a crude layering. The sample is weakly to moderately chloritized and epidotized.
19. Highway 1, (second outcrop on left, travelling south from the intersection of the Crofton highway). Dark green andesite pyroxene-feldspar-phyric vitric-crystal tuff or massive flow containing 5-25% pyroxene, <1-8mm, and 10-15% feldspar, <1mm. Weak to moderate chlorite and epidote alteration is present. Feldspars appear saussuritized.
20. Highway 1, (third outcrop on left, travelling south from the intersection of the Crofton highway). Dark to medium green andesite pyroxene-phyric vitric-crystal tuff containing 5-15% pyroxene, <2mm, and occasional feldspar. Matrix is aphanitic. The sample is weakly epidote altered.

21. 'Transition Zone' west of Highway 1 (considered equivalent to the Lower Andesite). Medium to dark green andesite, vitric-crystal/crystal tuff containing 25-60% feldspar, <1-2.5mm, in a weakly chloritized matrix. Feldspar crystals appear relatively unaltered. 138
22. DDH MTS-34 174.5m Medium to dark green andesite pyroxene-feldspar-phyric vitric-crystal tuff containing 5-10% pyroxene, $\leq$ 1-4mm. Sample is weakly chlorite and epidote altered.
24. 'Transition Zone' west of Highway 1. Medium to dark green andesite vitric-crystal tuff containing 20-25% feldspar, $\leq$ 1.5mm in a weakly chlorite+epidote altered aphanitic matrix. Feldspars appear unaltered.

Samples were analyzed with a Cambridge Microscan 5 electron probe using synthetic precious metal and sulphide standards by P. Jones, Carleton University. Operating conditions were: 25kv accelerating potential and 30 n Amperes. Absorbed current measured on a pure gold standard. Raw x-ray data were reduced using a modified version of computer program of Rucklidge and Gasparinni (1969).

Gold

Sample 102a

	WT.PC	MOL.PC	Au/Au+Ag
Circle 3, Sp 1			0.661
Ag	21.68	0.339	
Au	77.06	0.661	
	98.74 Total		

Circle 3, Sp 2

Ag	22.16	0.342	0.658
Au	77.93	0.658	
	100.10 Total		

Circle 2, Sp 1

Ag	21.93	0.347	0.653
Au	77.93	0.653	
	97.21 Total		

Circle 1, Sp 1

Ag	19.48	0.346	0.654
Au	67.34	0.654	
	86.82 Total		

Sample 102d

Sp1			0.646
Ag	22.70	0.354	
Au	75.64	0.646	
	98.34 Total		

Microprobe Analyses (con't)

140

Hessite

	WT.PC	MOL.PC
HH1		
Ag	60.07	0.654
Tc	37.58	0.346
	97.66 Total	

HH2		
Ag	60.82	0.659
Tc	37.19	0.341
	98.01 Total	

Sample LT93-a

Sp 1		
Ag	60.89	0.659
Tc	37.25	0.341
Au	00.00	0.000
	98.14 Total	

Sp 2		
Ag	60.41	0.656
Tc	37.51	0.344
Au	00.02	0.000
	97.93 Total	

Sp 3		
Ag	60.50	0.656
Tc	37.51	0.344
Au	00.00	0.000
	98.01 Total	

Microprobe Analyses (con't)

141

Tennantite

Sample LT 102

	WT.PC	MOL.PC
Sp 1		
Cu	41.86	0.341
Fe	2.45	0.023
Zn	5.72	0.045
As	18.62	0.128
Sb	1.82	0.008
Ag	0.30	0.001
S	28.15	0.454
	98.92 Total	
Sp 2		
Cu	41.52	0.340
Fe	2.16	0.020
Zn	6.04	0.048
As	18.24	0.127
Sb	2.56	0.011
Ag	0.43	0.002
S	27.94	0.453
	98.89 Total	
Sp 3		
Cu	42.17	0.341
Fe	4.97	0.046
Zn	3.00	0.024
As	19.53	0.134
Sb	0.66	0.003
Ag	0.56	0.003
S	28.11	0.450
	99.01 Total	
Sp 4		
Cu	41.77	0.339
Fe	2.19	0.020
Zn	6.54	0.052
As	19.22	0.132
Sb	0.79	0.033
Ag	0.30	0.001
S	28.19	0.453
	99.00 Total	

Microprobe Analyses (con't)

Tennantite

Sample LT 94

	WT.PC	MOL.PC
Sp 1		
Cu	41.01	0.332
Fe	4.61	0.042
Zn	4.82	0.038
As	19.00	0.130
Sb	0.80	0.003
Ag	0.50	0.002
S	28.14	0.452
	98.88 Total	

Sample LT 94A

Sp 2		
Cu	41.67	0.336
Fe	4.89	0.045
Zn	4.48	0.035
As	18.54	0.127
Sb	0.82	0.004
Ag	0.47	0.002
S	28.22	0.415
	99.09 Total	

Precious and base-metal assays of banded massive sulphide
at the west end of the Lenora Pit

	%Cu	%Zn	%Pb	g/tAu	g/tAg	Au/Ag	width
L1	2.10	14.80	0.35	27.6	112.0	0.25	0.45
L2	19.10	9.40	0.51	12.2	301.0	0.04	0.17
L3	2.23	17.80	1.68	8.24	108.0	0.08	0.12
wt. avg.	6.0	14.05	0.60	20.91	154.6	0.14	0.74

(from Minnova Inc.)

CHONDRITE VALUES USED TO NORMALIZE
REE DATA

144

=====	
La	0.310
Ce	0.808
Nd	0.600
Sm	0.195
Eu	0.0735
Tb	0.0474
Dy	0.322
Ho	0.0718
Er	0.210
Yb	0.209
Lu	0.0322
=====	

(Boynton, 1984)

3

MICROD

M. 00 E 7

6 00 S

M. 00 E 7

6 00 S

6a

6a

6b

6b

6b

L 2 0 0 W
6 0 0 S

L 1 0 0 W
6 0 0 S

6a

6a

6b

6b

6b

600 S

0007

600 S

LENORA FAULT

3c

3c

3,2c,d

3d

6a

6a

40

80

6b

85

85

LENORA FAULT

6a

81

3c

8 87
82 74

3c

85 3,2c,d

85
3d

6b

6b

6b

6b

B

North Fault (?)

minor 4b

2,1a

2,3c

3c

2,2c

4c minor 4d

3d

3d minor 4d

3d

3b

3d

3a

3a

3d,b

3d

3b,c

3b,c

3,2c

4a,b

6a

6a

6a

6a

6a

6a

3c

3,2c,d

3d

6b

6b

4d

C

4c

2,3d minor 4c

3b

3b

3c

6a

6a

6a

Two shaft

85
3,2c,d

85
3d

6b

72

6b (30)

minor 4d

4c

29

40

2,3d minor 4c

41

83

3b

3b

57

80

3c

6a

6a

6a

Tye shaft

8 50 S

8 50 S

6a

6a

Tyee shaft

MINE FAULT

8 50 S

8 50 S

LENORA - TYEE

Geology, Topography

A,B,C location of stratigraphic sections in Fig. 9

0 10 30 50 m

SCALE: 1 : 500

FIG. NO.:

DRAWN BY: P.M.

DATE: Fall /87

N.T.S.

6

LENORA - TYEE

Geology, Structural data

0 10 30 50 m

SCALE: 1 : 500

			FIG. NO.:
	DRAWN BY: P. M.		7a
	DATE: fall /87	N.T.S.	

1. $\frac{1}{2} \log \frac{1}{2}$
 2. $\frac{1}{2} \log \frac{1}{2}$
 3. $\frac{1}{2} \log \frac{1}{2}$
 4. $\frac{1}{2} \log \frac{1}{2}$

sig. due
to f^2

$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$

40

80

[illegible]

64

10

DC

64

6a

10-11-1964

80

6b

6b

85

0

6b

[illegible]

3c

87

74

3c

3,2c,d

1. Die ersten drei
 2. Die ersten drei
 3. Die ersten drei
 4. Die ersten drei
 5. Die ersten drei
 6. Die ersten drei
 7. Die ersten drei
 8. Die ersten drei
 9. Die ersten drei
 10. Die ersten drei

2

Washed 25 ml
C F

Lenora adit 2

Lenora adit 1

North Fault (?)

6b

6b

6b

85 3,2c,d

85 3d

6b

72

6b

minor 4d

4c

29

2,3d minor 4c

40

3' 11" (94.44 cm)
30' 10" (94.20 cm)
3' 10" (94.10 cm)

41

83

3b

3b

57

80

3c

6a

1' 10" (50.80 cm)
3' 10" (94.10 cm)
3' 10" (94.10 cm)

81

6a

6a

Tree shaft

6a

6a

6a

Tye shaft

MINE FAULT

LENORA - TYEE

Geology, Structural data
and Field notes

0 10 30 50 m

SCALE: 1:500

DRAWN BY: P.M.

DATE: Fall /87

N.T.S.

FIG. NO.:

7b

LENORA OPEN PIT

Geology ; Structural data

SCALE: 1:100

DRAWN BY: P. M.

DATE: 1st / 87

N.T.S.

FIG. NO.:

8a

4

INFORMATION SYSTEMS DIVISION
Micro-D
A BULL GROUP COMPANY

3d

3,2d

3d

3a

1800 E
5 50 S

1800 E
6 75 S

18 00 E
5 50 S

18 00 E
5 75 S

110 00 E
5 75 S

11 00 E
5 50 S

12 00 E
5 75 S

2,3d

3b

6a

2c minor f

1a

2,3c minor f

3,2d,c

3,2c minor f

2c

2,3e

6a

6a

87

2,3c

minor f

L 11 00 E

5 50 S

L 12 00 E

5 75 S

L 13 00 E

5 75 S

2c minor f

1a

2,3c

[illegible]

34

3c,d

3d,4c minor 4d

[illegible]

27

3d.b

4c

4c

3c,d

3d.b

4c

36

3d

3d

3a

3a

3a

100 ft. 20' 10" 100 ft. 20' 10" 100 ft. 20' 10" 100 ft. 20' 10"

100 ft. 20' 10" 100 ft. 20' 10" 100 ft. 20' 10" 100 ft. 20' 10"

100 ft. 20' 10" 100 ft. 20' 10" 100 ft. 20' 10" 100 ft. 20' 10"

100 ft. 20' 10" 100 ft. 20' 10" 100 ft. 20' 10" 100 ft. 20' 10"

North Fault (?)

3d

3d

3d,b

3a

FORTUNA FAULT

Mona shaft

2c

6a

6a

3,2d,c

2c

74

3,2c minor f

6b

1a

2c

2,3e

1a

2,3c

85

6a

3,2f

82

2,3c

3d,4b

6a

2,3e

6a

2,3e

27

6a

3d,c

4,3c

1a

3d,c

2,3c

2,3c minor f

3,2c minor f

3,2d,c

1a

1a

3d,4b

3b

or 3c

3,2b,c

3,2c,b

minor 4b

3,2c,b

3,2d,c

76

77

Geology and Field notes

SCALE: 1:100

			FIG. NO.:
	DRAWN BY: P. M.		8b
	DATE: Feb / 87	N.T.S.	

10 00 S

10 25 S

3d,4b

-6a

3,2d

00

11

3d,4b

2a,d

3,2c

2a,d

4b,a

81

6a

+ 10 25 S

0.00 S

+ 10 50 S

+ 10 50 S

+ 11 25 S

2d,

3,2d,c

76

77

3d,4b

2a,d

3,2c

2a,d

4b,a

6a

10 50 S

11 25 S

11 25 S

MONA

Geology, Structural Data

0 10 50 100 m

SCALE: 1:1000

DRAWN BY: P.M.

DATE: winter / 87 N.T.S.

FIG. NO.:

11a

L 8 00 E

5 50 S

L 9 00 E

5 75 S

L 10 00 E

5 75 S

L 11 00 E

5 50 S

L 12 00 E

5 75 S

15° 21' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W

2,3d

180°
200°
220°
240°
260°
280°
300°
320°
340°
360°

15° 21' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W

15° 21' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W

15° 21' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W
15 20' N, 150° 00' W

2c minor f

1a

3,2d,c

3,2c minor f

2,3c

L 11 00 E

5 50 S

L 12 00 E

5 75 S

L 13 00 E

5 75 S

49909
S 15.1 E 3m labeled
the complete history of the
object photo 85 up to 2m long
not 15 ft
red ink

2c minor f

1a

49909
10 20% F 1-3m scale of
silver epoxy matrix mod. 100% chit
on white streak

87

2,3c

49909
possible 1st column
white 10% or mod 100% chit

2,3c

L 21 00 E

0 00

L 22 00 E

0 00

L 23 00 E

0 00

L 25 00 E

000

L 26 00 E

000

6b

1g

62

00

FORTUNA FAULT

6a

6a

3,2d,c

3,2c minor

2c

6b

2,3a

2c

1a

83

2,3c

85

6a

Mona shaft

3d,4b

6a

2,3a

6a

2,3a

6a

6a
The area shown is a
part of the Fortuna
Fault zone. It is a
series of faults which
have been active since
the Miocene. The
faults are of the
normal type and are
generally oriented
N. 30° E. to N. 60° E.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.

6a
The area shown is a
part of the Fortuna
Fault zone. It is a
series of faults which
have been active since
the Miocene. The
faults are of the
normal type and are
generally oriented
N. 30° E. to N. 60° E.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.

6a
The area shown is a
part of the Fortuna
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the Miocene. The
faults are of the
normal type and are
generally oriented
N. 30° E. to N. 60° E.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.

6a
The area shown is a
part of the Fortuna
Fault zone. It is a
series of faults which
have been active since
the Miocene. The
faults are of the
normal type and are
generally oriented
N. 30° E. to N. 60° E.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.

6a
The area shown is a
part of the Fortuna
Fault zone. It is a
series of faults which
have been active since
the Miocene. The
faults are of the
normal type and are
generally oriented
N. 30° E. to N. 60° E.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.
The faults are
generally 100 to
200 feet wide and
are filled with
breccia and sand.

1a

2,3c minor f

2.3c

3d,c

3.2c minor f

3,2d,c

3d,4b

nor 3c

3b

3,2b,c

- minor 4b

3,2c,b .

3,2d,c

77

3 50 S

3 50 S

6b

1g

62

81

2,1d

1h

2,3d,c

4a

2d,c

4a

87

2d,c

3b

77

62

3a,b

6a

10 00 S

10 25 S

6a

3.10.0

10 00 S

10 25 S

10 50 S

10 50 S

11 25 S

00

77

3d,4b

2a,d

Major debris
3700' from base
from north
slope

Discontinuity
Surface

6a

2a,d

4b,a

3,2c

81

MONA

Geology, Structural Data
and Field notes

0 10 50 100 m

SCALE: 1:1000

DRAWN BY: P.M.

DATE: winter / 87 N.T.S.

FIG. NO.:

11b

3 50 S

3 50 S

TOM FAULT

4 00 S

6a

3 50 S

TOM FAULT

4 00 S

4 00 S

4 00 S

4 00 S

4 00 S

4 00 S

NORTHEAST COPPER

Geology, Structural data

0 10 50 100 m

SCALE: 1:1000

DRAWN BY: P.M.

DATE: winter 87

N.T.B.

FIG. NO.:

14a

5 of/de 5

MicroD

L 22 00 E

L 23 00 E

L 24 00 E

L 25 00 E

L 26 00 E

000

000

000

000

000

10-120 ft peak 1-4m
* 5-10m deep 1-10m deep
* 10-15m deep 1-10m deep
* 15-20m deep 1-10m deep

A'

62

6b

1-3 ft water depth
* 1-3 ft water depth
* 1-3 ft water depth
* 1-3 ft water depth

1g

2d

63

65

1-3 ft water depth
* 1-3 ft water depth
* 1-3 ft water depth
* 1-3 ft water depth

63

65

72

2d

1g

83

6b

4a

64

3,2d

4a

minor 4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

2,3d,c

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

4a

1g,d

78

2d

2d

2d

2d

2d

2d

2d

2d

2d

2d

1g

62

61

7

L 25 00 E

0 00

L 26 00 E

0 00

4-5' alt and
cliff top line

2-3' alt and up to
cliff edge
trace of
cliff top line

6b

3' alt and up to
cliff edge
trace of
cliff top line

1g

62

60

81

60

4-5' alt and
cliff top line
trace of
cliff top line
to cliff edge

cliff top line
trace of
cliff top line
to cliff edge

cliff top line
trace of
cliff top line
to cliff edge

Fence Diagram of the Stratigraphy,

Mt. Sicker Property

Lenore-Tyee

MTS-30

MTS-29

MTS-28

Mine

Rhyolite

massive sulphide

Upper Andesite

Upper Dacite

Lower
Dacite

Lower Andesite

2

3 50 S

3509

6b

2.5 ft up 15m
Tuffaceous sandstone
bedrock

1g 62
4 ft. v. white
0.5 ft. ash py
5 ft. red ash congl
+ 2 ft. pyroclastic
+ 6 ft. detrital sand

apical, large (thin)
pyroclastic
congl. - 10 ft. thick
above 15 ft. up 15m
apical 15 ft. up 15m

5-10 ft. v. white
ashm - 20 ft.
congl. - 10 ft.
fine grained 10 ft. thick

2,1d 1h

15 ft. v. white
10 ft. up 15m
ashm

2,3d,c

4a

even - 10 ft. up
massive, pyroclastic
2-5 ft. ash py (usually 2-4 ft. thick)

2d,c

10 ft. v. white
5-10 ft. ash py
up 15m

up to 10 ft.
up to 10 ft. ash py (usually 10 ft. thick)

4a

87

2d,c

2-3 ft. ashm
post normally graded

3b

5-10 ft. v. white
up 15m
ashm

77

3a,b

15 ft. up 15m

5-10 ft. v. white
up 15m
ashm

6a

with 1 m. radius
10 ft. up 15m
ashm
pyroclastic
congl. - 10 ft.
up 15m

Lower Andesite

Mono

MTS-27

Northeast Copper

MTS-32

Lunora-Tyee, Mono and Northeast Copper sections constructed using DDH and surface mapping data

datum is the base of the Mono Rhyolite

2 geochemical sample

note: all intrusive rocks have been removed

3508

3'50 S

TOM FAULT

+ 400 S

6a

3 50 S

TOM FAULT

4 00 S

4 00 S

4 00 S

4 00 S

400 S

400 S

NORTHEAST COPPER

Geology, Structural data

and Field notes

SCALE: 1 : 1000

DRAWN BY: **P.M.**

DATE: **winter 87** N.T.S.

FIG. NO.:

14b

END

26-07-89

FIN