VOLCANIC STRATIGRAPHY AND LITHOGEOCHEMISTRY OF THE SENECA PROSPECT, SOUTHWESTERN BRITISH COLUMBIA (92H/5W)

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INTRODUCTION

The Seneca property in southwestern British Columbia is located approximately 120 kilometres east of Vancouver (Figure 1). The property is accessible from the Lougheed Highway at Harrison Mills by the Morris Valley Road and the Chehalis-Fleetwood logging road.

The property has been described as a zinc-copper-lead-barite volcanogenic massive sulphide environment similar in many aspects to the Kuroko-type deposits (Urabe et al., 1983; McKinley et al., 1994). There are three major zones of sulphide mineralization on the property; the Pit area, the Vent zone and the Fleetwood zone, within a 4.5 by 3 kilometre area east of the Chehalis River (Figure 1). Current geological reserves are estimated at 1.5 million tonnes grading 3.57% Zn, 0.60% Cu and 0.14% Pb. Mineralization occurs as replacement sulphides associated with volcaniclastic sediments and as stockwork-style stringer sulphides hosted in a sequence of felsic to intermediate volcanic rocks of the Harrison Lake Formation.

The objective of this study is to better constrain the spatial, temporal, and geochemical relationships of the various rock units and the accompanying alteration and mineralization. Fieldwork in the 1994 season involved the logging of diamond-drill cores to complete a longitudinal geological cross-section through the property, as well as some outcrop examination.

EXPLORATION HISTORY

The Seneca prospect, formerly known as the Lucky Jim property, was discovered in 1951 as an indirect result of logging operations and was optioned by Noranda Exploration Company at that time (Thompson, 1972). The sulphide mineralization was believed to be part of a steeply dipping vein or shear system. In 1961 stripping, trenching and some underground work were carried out, but the results were not encouraging. The property was held by Noland Mines, Ltd. from 1964 to 1965 and was bought by Zenith Mining Corporation, Ltd. in 1969. Cominco Ltd. optioned the property in 197 and carried out further exploration based on the concept that the zone represented Kuroko-style conformable mineralization. The property was acquired by Chevron Standard Ltd. in 1977 and further diamond drilling was completed over the next ten years in joint ventures with International Curator Resources Ltd. and B.P. Canada Inc. Further logging in the area led to the discovery in 1986 of the Vent zone stockwork mineralization 1.75 kilometres to the west of the original discovery. In 199 drilling by Minnova, Inc., 1 kilometre to the west of the Vent zone, led to the discovery of the Fleetwood zone. The property is currently held by International Curator Resources Ltd. and is under option to Metall Mining Corporation.

REGIONAL GEOLOGY

The Harrison Terrane on the west side of Harrison Lake comprises a sequence of Triassic to Cretaceous volcanic and sedimentary rocks. The stratigraphically lower part of the sequence is intruded by Upper Jurassic quartz diorite batholiths west and north of the property (Monger, 1970; Mahoney, 1994). The Harrison Lake Formation, within the Harrison Terrane, is a Lower to Middle Jurassic succession up to 2500 metres thick that strikes north-northwest with gentle to moderate easterly dips (Mahoney, 1994). From oldest to youngest, the Harrison Lake Formation is composed of the Celia Cove Member, the Francis Lake Member, the Weaver Lake Member and the Echo Island Member (Arthur, 1986; Mahoney, 1994). The Celia Cove Member comprises mostly deep water sedimentary rocks unconformably overlying Triassic rocks. The Francis Lake Member represents the onset of volcanism that characterizes the Harrison Lake Formation. Regionally the Weaver Lake Member is dominated by intermediate to felsic volcanic rocks and related intrusions and is overlain by the Echo Island Member which comprises mostly volcaniclastic sediments (Mahoney, 1994). Although not fully constrained, the Seneca property is interpreted to lie within the upper part Weaver Lake Member.

GEOLOGY OF THE SENECA PROPERTY

In general the strata on the property strike approximately northwest and are essentially flat lying or moder-

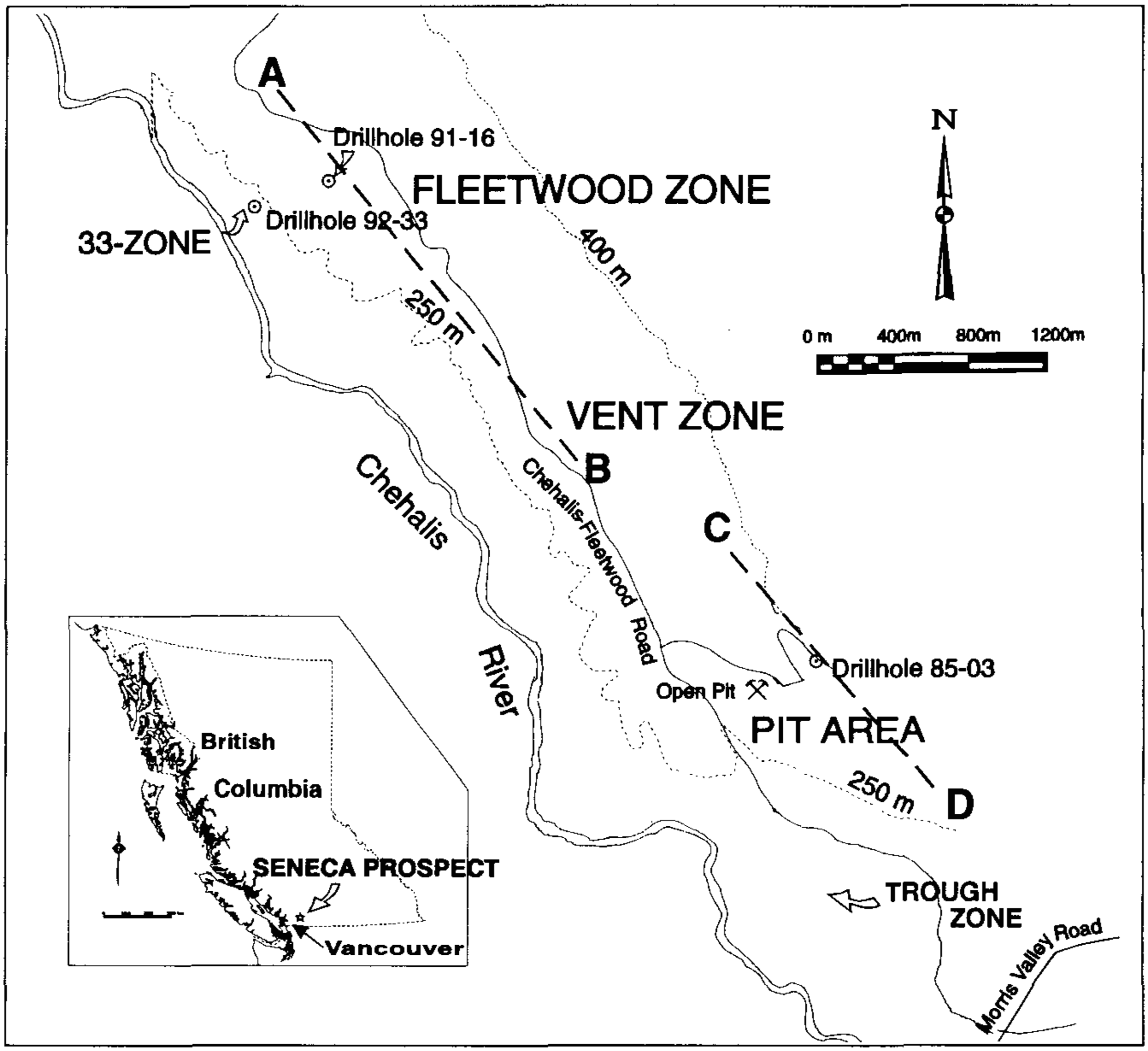

Figure 1: Location map of the Seneca prospect and the mineralized zones on the property.(A-B and C-D are longitudinal geological sections shown in Figure 2)

ately dipping in an easterly direction. The Seneca stratigraphy has undergone very little deformation or metamorphism and, in general, the rocks retain pristine volcanic textures. Metamorphic grade in the Seneca area is zeolite facies. The major lithologic units are subdivided into three principal volcanic facies as follows (see Figure 2):

- Facies 1 - Lavas (vent- proximal facies) consist of basaltic to rhyolitic composition flows, domes and associated *in situ* hyaloclastites and autoclastic breccias.
- Facies 2 - Volcaniclastic rocks (vent-proximal to distal facies) consist of juvenile to reworked coarse volcanic breccias and tuffs to fine grained siltstones and ashes.
- Facies 3 - Synvolcanic intrusions consist of basaltic to rhyolitic sills and dikes that have intruded lavas and wet volcaniclastic sediments.

A fourth facies consists of an argillite that often contains flattened quartz-feldspar-phyric pumice clasts (fiamme) and is often in close proximity to mineralization. However, this facies is spatially restricted to the Pit area and does not correlate across the property. The three principal facies are generally seen in all drillholes, but their relative abundances vary greatly from hole to hole.

FACIES 1: LAVAS

Lava flows are defined by their contact relationships and the occurrence of flow textures and autobrecciation. The felsic lavas contain 5 to 15 % subhedral to euhedral plagioclase phenocrysts that are typically 1 to 2 millimetres long. Quartz phenocrysts are less common, but may comprise up to 7 % of the rock. They are generally

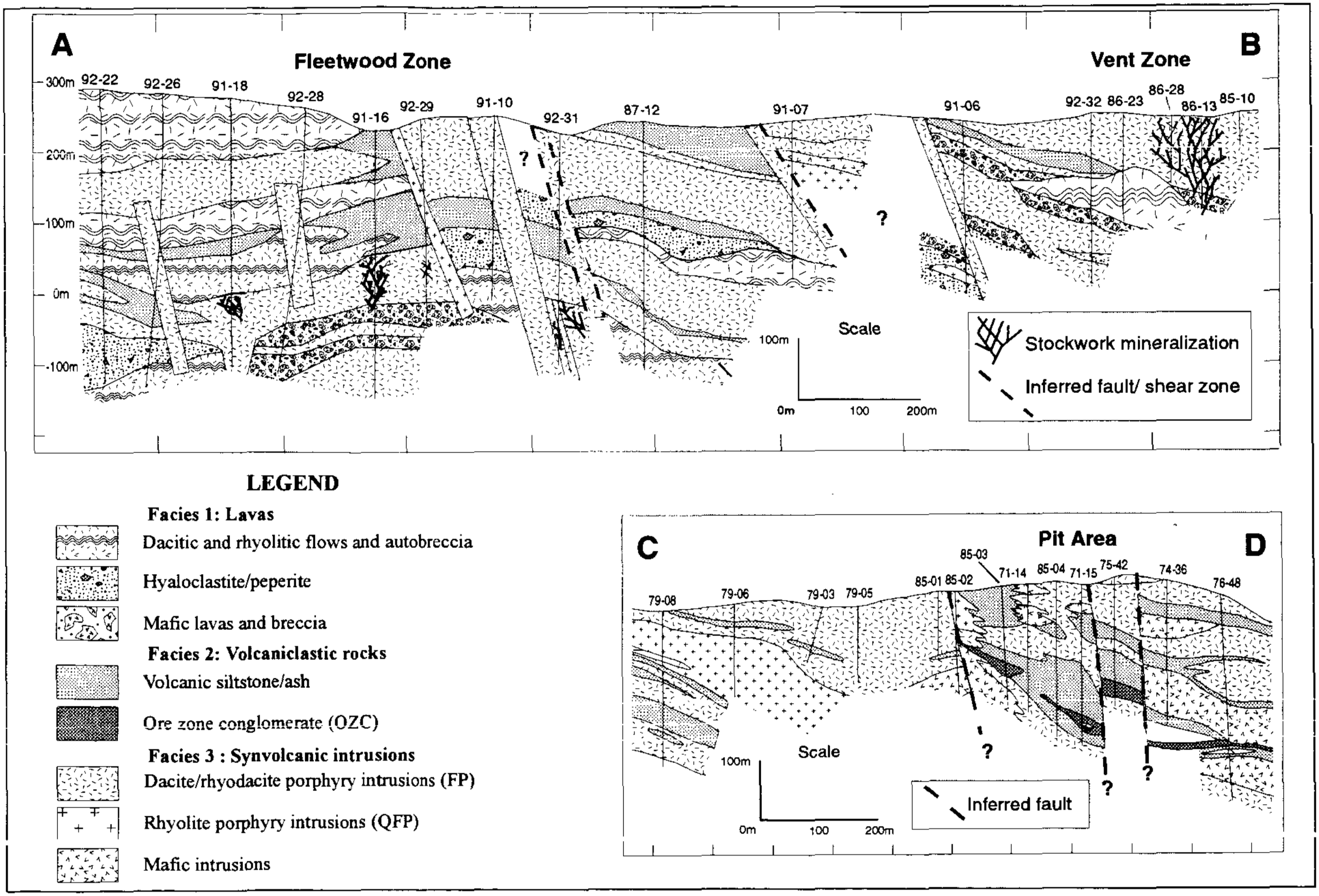

Figure 2. Simplified longitudinal geological sections of the Fleetwood and Vent zones (upper section) and the Pit area (lower section) at the Seneca prospect.

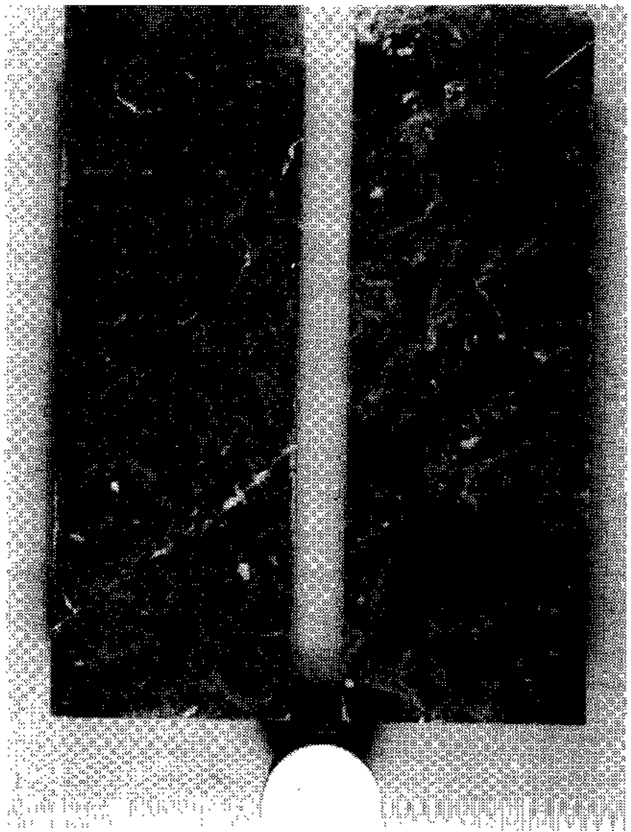

Photo 1. Basaltic lavas (facies1) from the Fleetwood zone. Amoeboid-shaped lava clasts (fire fountain debris) are in a matrix of chloritized glass.

subrounded and less than 5 millimetres in diameter. Chloritized hornblende laths are also usually present (up to 5 %) and average 1 to 2 millimetres in size. Individual felsic flows range from one to several tens of metres thick, and have flow brecciated upper contacts and chilled and/or slightly brecciated lower contacts. The flow breccias have generally been weakly to moderately silicified, probably by syndepositional seawater interaction. In some instances several coherent flow-flow breccia sequences occur in vertical succession up to 100 metres thick, but less than 200 metres in lateral extent, forming a dome-like morphology. The cores of the thicker flows are typically massive and greyish green in colour, and are often accompanied by a lateral transition from autobreccia to reworked hyaloclastite and volcaniclastics at the margins. These relationships suggest that the felsic flows have both tabular and dome-like morphologies similar to those described by McPhie and Allen (1992) for the Mount Read volcanics in western Tasmania. The domes and flows are intruded into and extruded through other lavas, fine-grained volcaniclastics and coarse lava clast breccias (Figure 2).

Unbrecciated andesites at Seneca tend to be featureless and without pillow forms. However, massive coherent mafic flows are inferred by the presence of stretched amygdules and their association with autoclastic breccia. A unit that consists of subrounded to amoeboid fragments of vesicular basaltic andesite surrounded by angular andesite clasts and hyaloclastite occurs in the western part of the property (Photo 1). The fragments are typically 1 to 10 centimetres in size, are light green or purplish grey in colour and consist of a core of massive andesite with chilled or brecciated rims. The textures of the fragments, together with their amoeboid shape and tail-like ends, suggests that they were ejected as molten material either subaqueously or subaerially and landed in water while still semi-molten (R. Allen, pers-onal communication, 1993). This unit is interpreted to be a vent-proximal facies as the surrounding angular hyalo-clastite has not been reworked. This facies is referred to as 'fire fountain debris' and is only seen in lower parts of the drillholes.

FACIES 2: VOLCANICLASTIC SEDIMENTS

There is a variety of volcanic-derived sediments and breccias on the Seneca property with clasts ranging from silt size to block size (<15 cm). These units represent the deposition and reworking of volcanic debris derived from lava flows, domes and eruptions, with the probable addition of fine sediments of more distal origin. They are subdivided into four facies:

- Facies 2.1. Monolithic to heterolithic, massive to well bedded or laminated and normal density graded, moderately to poorly sorted lava clast breccias, pebble conglomerates, vitric-crystal tuffs and volcanic sandstones, interpreted to have been deposited as debris flow deposits and turbidites.
- Facies 2.2. Massive to well laminated volcanic siltstone and fine ash deposited subaqueously by gravity settling.
- Facies 2.3. Dacitic to rhyolitic pumice beds (often flattened).
- Facies 2.4. Reworked dacitic debris flow deposits and conglomerate interpreted to have been deposited in a fluvial or deltaic environment.

The 'ore zone conglomerate', located in the Pit area, hosts disseminated to massive sulphide mineralization, and varies from 1 to 15 metres in thickness. The unit consists of moderately silicified, mostly subrounded dacite lava clasts ranging from sand size up to 3 centi-metres in diameter in a sandy or silty matrix. The unit can be matrix or clast supported, and also contains clasts and matrix that have been replaced and/or infilled by sulphides. It should be noted that the term ore zone conglomerate refers to the entire unit which hosts sulphide mineralization and that much of the unit contains only sulphides, but is texturally distinct from other volcaniclastic units.

A dacite lava clast breccia (facies 2.1) occurs stratigraphically below the ore zone conglomerate in the Pit area, and generally above the major mafic units in the Fleetwood and Vent zones (Photo 2). Typically the unit is clast supported (up to 90% clasts up to 10 cm in diameter) and consists dominantly of subangular dense fragments of feldspar-phyric dacite lava and lesser amounts of dark green vitric or pumiceous clasts, andesitic fragments and occasional silty rip-up clasts.

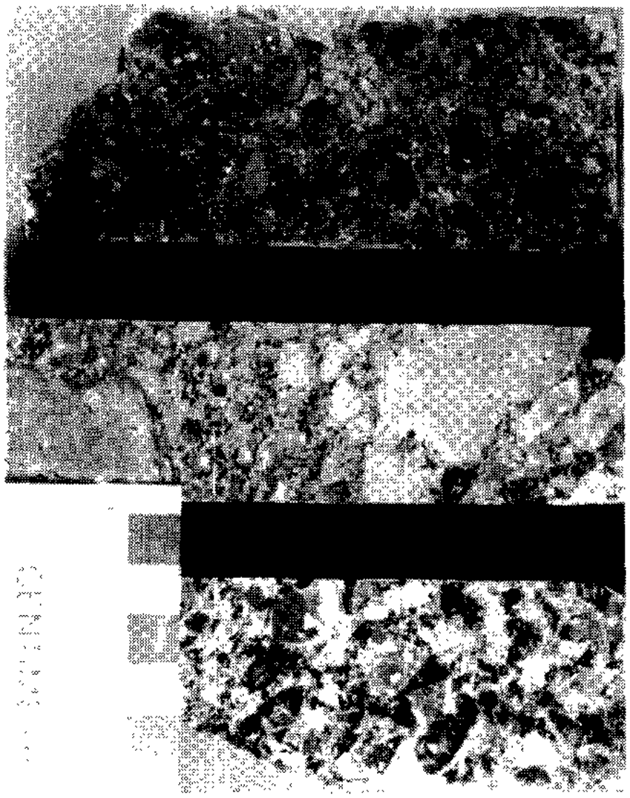

Photo 2. Coarse volcaniclastic breccias (facies 2). These consist dominantly of dacite lava clasts deposited by debris flows

The dacite clasts vary in colour from light grey to reddish tan, possibly repre-senting subaerial deposition and later reworking. The unit is moderately to poorly sorted, suggesting deposition by debris flows.

Compared to the Pit area, the Fleetwood and Vent zones contain a greater abundance of reworked andesitic lava clast breccias, comprising centimetre-size, subangular, amygdaloidal andesite fragments and hyaloclastite, and up to 30% dacite lava clasts. The true thickness of the unit is difficult to determine due to dilation by synvolcanic intrusions, but individual intersections are some 5 to 10 metres thick. Andesite lava clast breccias are less common at higher stratigraphic levels, and where they do occur, contain smaller clasts that are more rounded.

Fine-grained volcaniclastic sediments (facies 2.1 and 2.2) are common throughout the property, particularly in the upper part of the stratigraphy (Photo 3). The sediments form light to dark grey beds of silt to coarse sand-sized material. Individual beds range from 2 centimetres to 5 metres thick, and vary from massive to well laminated and normal graded. The basal contacts of normal graded beds are often sharp and are characterized by coarse sand to gravel-sized material, often with a component of dacite pumice fragments, glassy shards and feldspar crystals. These beds grade upward through massive or weakly laminated sands to well-laminated and occasionally cross bedded fine sand, silt and mud and may represent individual turbidite layers. Graded beds become more common higher in the stratigraphy.

In the Trough zone, in the southeastern part of the property (Figure 1), drillhole 91-03 intersected an uninterrupted sequence of facies 2.1 and 2.2 volcani-clastic sandstone and siltstone. This interval lacks the felsic intrusions and flows that are ubiquitous elsewhere on the property. There is a gradual fining upwards in the sequence and the upper parts are well bedded and laminated. The upper part contains a component of quartz-feldspar-phyric rhyolite pumice clasts 2 to 10 centimetres in size, suspended in fine-grained ash. The pumice and the ash/siltstone are possibly derived from a subaerial felsic eruption. The Trough zone is interpreted as a more distal facies of the Pit area stratigraphy.

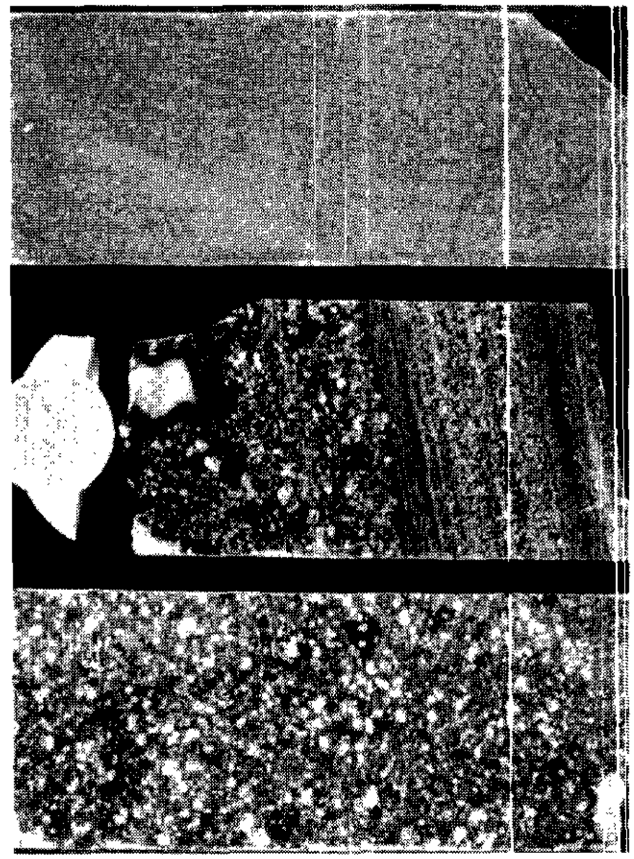

Photo 3. Volcaniclastic rocks. Top: massive volcanic siltstone (facies 2.2); Centre: bedded volcanic sandstone (facies 2.1); Bottom: crystal-rich dacitic tuff.

FACIES 3: SYNVOLCANIC INTRUSIONS

Synvolcanic intrusions are distinguished from flows by their contact relationships and textural features. Commonly, the contacts are bedding parallel, and the units lack flow banding and autobreccia (Photo 4). Chilled margins and contacts at high angles to stratigraphy provide simple criteria for the recognition of dikes.

The most common intrusions are feldspar-phyric dacite to rhyodacite porphyry sills. They range from one to several tens of metres thick, and are often columnar jointed in outcrop. Mineralogically, and often texturally, these rocks are identical to the dacite flows described earlier and are only distinguishable by their contact relationships. Dacite sills, where they cut other intrusions

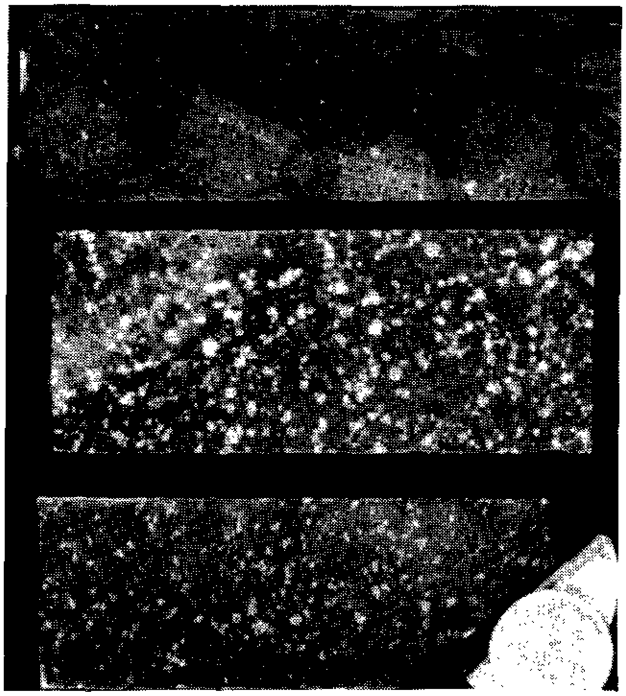

Photo 4. Synvolcanic intrusions. Bottom: feldspar-phyric dacite porphyry (FP); Centre: quartz-feldspar-phyric rhyolite porphyry (QFP); Top: Andesite sill showing peperitic textures.

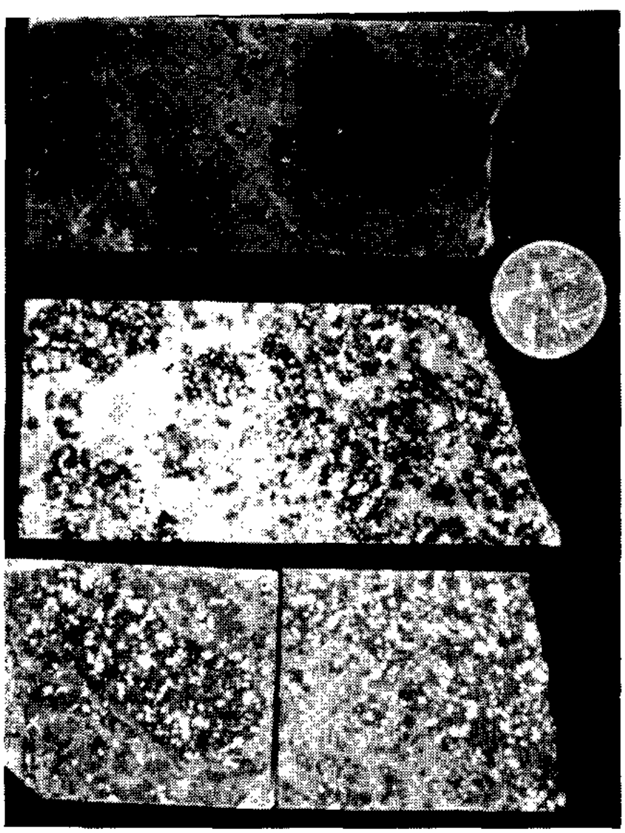

Photo 5. Peperitic textures from a sediment-sill contact zone. Drillcore samples show a downward progression from a mixed zone of siltstone and hyaloclastite at the contact (top) to the main body of the sill below the contact showing decreasing intensities of quenching, fracturing and alteration downwards (centre and at bottom).

or flows, commonly have chilled contacts over widths of 10 centimetres to more than 1 metre, and are only slightly brecciated. Where the sills intrude the volcaniclastic sediments and breccias, the contacts commonly have peperitic textures (Photo 5). In peperitic zones the contacts tend to be quenched and brecciated with angular to cus-pate hyaloclastic fragments less than 1 centimetre to 20 centimetres in size in a matrix of the finer volcaniclastic sediment. These interaction zones reach thicknesses of several metres and usually occur at the top of the sills. The textures indicate that the sills have intruded into wet, unconsolidated sediments (*cf.* McPhie and Allen, 1992).

Mafic intrusions are less common than felsic bodies and tend to occur in the lower part of the stratigraphy. Similar to the dacite porphyries, they have both cross-cutting and bedding-parallel contacts with chilled margins. The andesites are generally massive and dark green with chlorite-filled amygdules 0.5 to 1 millimetre in diameter. Where the andesites intrude sediments, they exhibit quenching, brecciation, and mixing similar to the felsic intrusions, except that brecciated zones tend to be more extensive (in the range of several metres). In many of the drillholes in the Pit area, these mafic sills intrude the ore zone conglomerate and units immediately above and below it.

The third type of intrusion is quartz-feldspar-phyric rhyolite porphyry. These rocks are less common than the other two types and their mode of emplacement is uncertain. They occur at higher levels in the stratigraphy and as a result their upper contacts are not always seen. Their size and massive nature suggest that they may be synvolcanic sills, but they may also represent emergent domes. The rhyolite porphyries are easily distinguishable from the dacite porphyries by their greyish brown groundmass and by the presence of up to 10% subrounded quartz phenocrysts 2 to 7 millimetres in diameter. There are also 5 to 15% plagioclase phenocrysts 1 to 2 millimetres in size, as well as minor hornblende. The rhyolite porphyry bodies range from a few to more than 30 metres thick.

MINERALIZED ZONES

Three types of mineralized zones are present at Seneca (Figure 2):

- Conformable massive sulphide lenses.
- Semi-massive and disseminated sulphides associated with volcaniclastic rocks.
- Stockwork and stringer mineralized zones.

Conformable, stratabound lenses of semi-massive sphalerite, pyrite, and chalcopyrite with lesser galena are exposed in the Pit area, and to a lesser degree in an intersection (drillhole 92-33) in the 33-zone in the Fleetwood area. The sulphides in both locations are hosted by fragmental rocks and occur as discontinuous pods that do not correlate between adjacent drillholes. In the 33-zone, a 2-metre intersection of massive sulphides is underlain by a quartz-carbonate-chlorite zone and a dacite porphyry intrusion, and is sharply overlain by a cherty sulphide

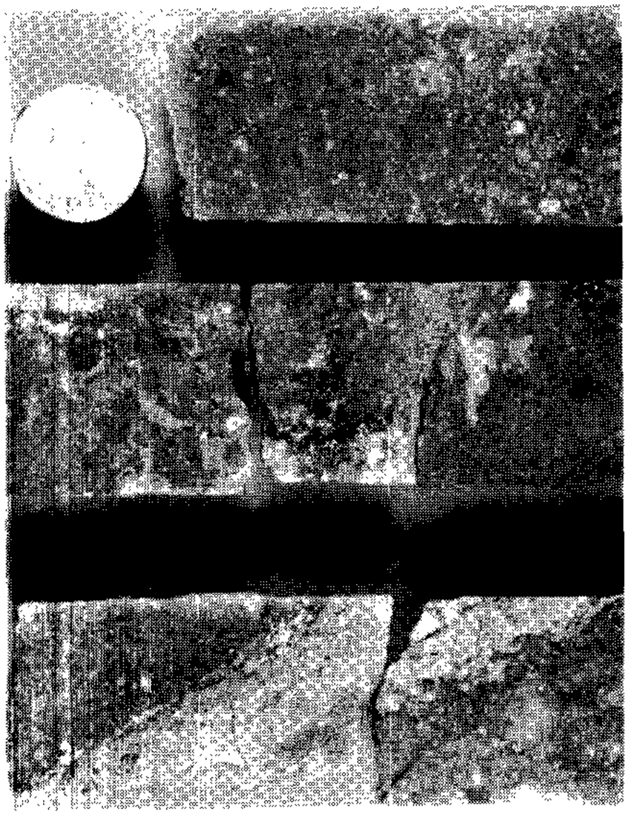

Photo 6. Ore zone conglomerate (OZC). Drillcore samples show variations within this mineralized unit. The samples contain disseminated, semi-massive and stringer pyrite-sphalerite-chalcopyrite mineralization hosted by strongly altered volcaniclastic rocks.

layer and a zone of strongly chloritized fragmental material. Unlike the 33-zone, the massive sulphides in the Pit area are underlain by siliceous stringer and disseminated mineralization. Blades of barite are intergrown with the sulphides in both locations.

Massive to disseminated sulphides are associated with the volcaniclastic ore zone conglomerate (Photo 6) and tend to be restricted to the upper portions of the unit. The best such intersection is 0.5 metres of massive pyrite, sphal-erite and barite with lesser chalcopyrite, underlain by 3.5 metres of mostly semi-massive pyrite (drillhole 85-03). More commonly the mineralization hosted by the ore zone conglomerate consists of clasts that are partially replaced, or matrix that is partly infilled by pyrite and occasionally sphalerite. Some of the clasts are rimmed by later pyrite. There is no evidence of bedded clastic sulphides.

Stockwork and stringer sulphides are the dominant style of mineralization in the Fleetwood and Vent zones (Photo 7). The Vent zone stockwork consists of veinlets up to 1 centimetre wide of sphalerite, pyrite and quartz (± chalcopyrite) in strongly altered dacitic flows, breccias, intrusions, and mixed lava clast breccia. In the Fleetwood zone (drillhole 91-16) 1.1 metres of massive sphalerite, pyrite and chalcopyrite occur immediately above about 30 metres of stockwork sphalerite-pyrite-chalcopyrite-quartz -anhydrite veinlets in altered dacite and fine volcaniclastics similar to the Vent zone. Shorter intersections of

Plate 7. Vent zone stockwork. The sample from outcrop consists of pyrite-sphalerite-quartz veins in strongly altered dacite porphyry.

similar stockwork mineralization occur in drillholes between the Fleetwood and Vent zones.

All of the mineralized zones in the Fleetwood Area occur at about the same stratigraphic level and have similar lithologic associations (Figure 2a). The stockwork zones are most commonly hosted by felsic lavas and autobreccias which immediately overlie mafic lavas and reworked mafic-dominated volcaniclastic rocks (facies 2.1), and which occur below the fine-grained volcaniclastics (facies 2.2). These overlying fine volcaniclastics are essentially unmineralized and unaltered except for occasional fine sulphide laminations. The mineralized zones are often associated with narrow fault zones and moderate to strong, fine anhydrite veining. Similar lithologic relationships are also seen in the Vent zone.

ALTERATION

Typically most of the rocks at the Seneca property are relatively unaltered, with pristine preservation of volcanic textures. Macroscopically recognizable alteration is restricted to the Vent and Fleetwood zones where it is characterized by intense silicification and sericitization associated with massive to flow-banded and flow-brecciated dacite porphyry. The stockwork veining is restricted to the dacites, but alteration extends 10 to 20 metres into the surrounding fragmental rocks, obliterating the original textures. The dacites are identified on the basis of the relict feldspar "ghosts" left by the alteration. Alteration in the Pit area is mostly restricted to the ore zone conglomerate which is commonly strongly silicified and/or clay altered. There appears to be little footwall alteration below this horizon except for occasional clay alteration of some of the coarse felsic volcaniclastics. This suggests that the alteration and

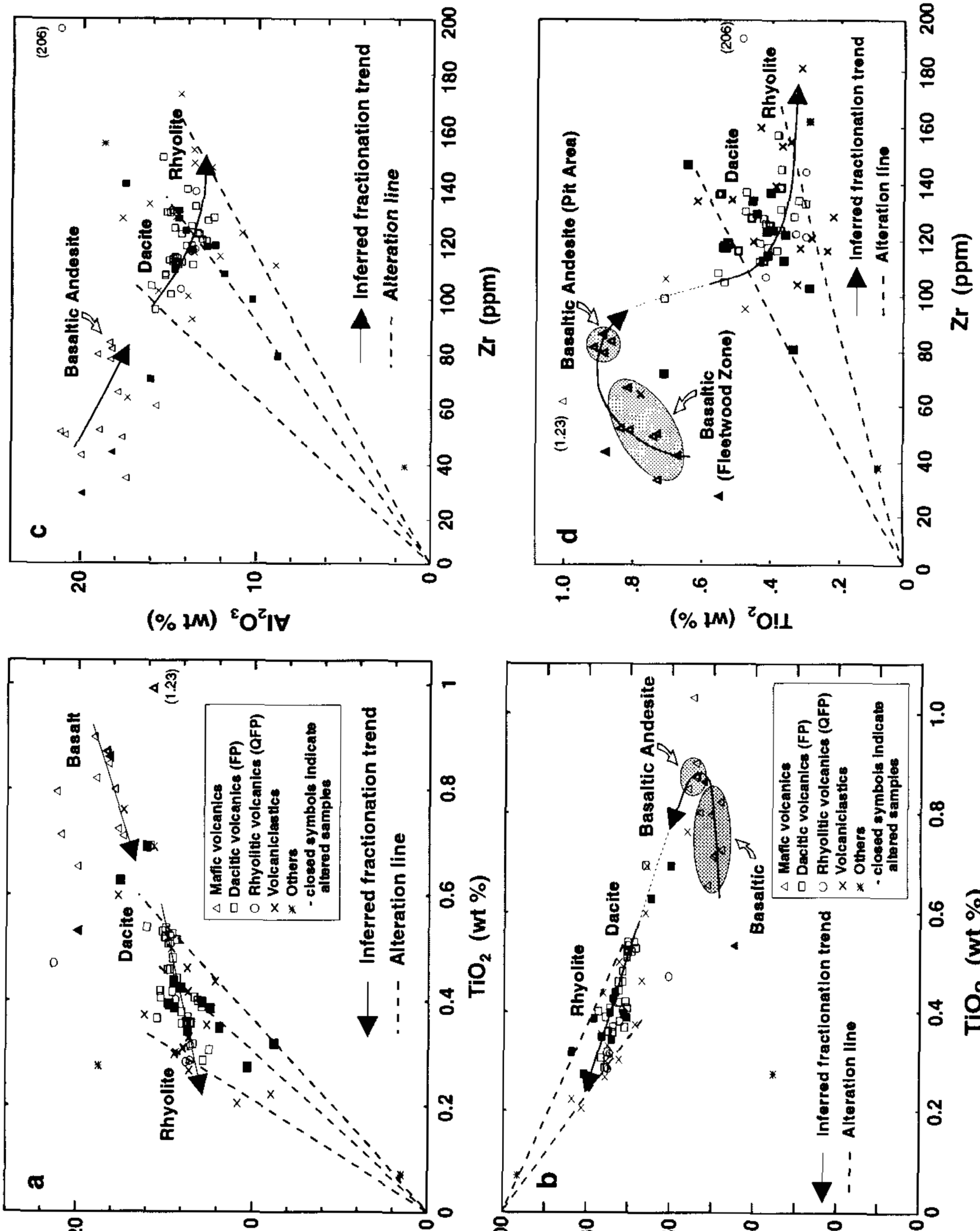

Figure 3. Plots of major and trace element lithogeochemical data for volcanic rocks at the Seneca prospect.

mineralization may have been controlled by the porosity and permeability in the coarse-grained host.

LITHOGEOCHEMISTRY

A suite of 82 samples was analysed for major and trace elements using x-ray fluorescence at McGill University in Montreal. The samples were selected to be representative of the major lithologies on the Seneca property.

Plots of major and trace element geochemical data are used in this study to illustrate fractionation and alteration trends in the volcanic rocks (Figure 3). Inferred fractionation trends were established using vari-ous pairs of compatible, incompatible, mobile and imm-obile elements, with the igneous incompatible element being used as the monitor of fractionation. Zirconium is used most often as a monitor of fraction-ation as it is immobile, relatively abundant and can be measured accurately using XRF techniques (MacLean, 1990). Figures 3a and 3b both show near continuous linear to curvilinear trends from rocks of basaltic andesite composition to dacite and rhyolite compositions. However, there is a 'gap' in the data set corresponding to compositions of about 55 to 63% SiO_2, This suggests that the data set is bimodal. However, the data of Mahoney (1994) do not support a bimodal nature for the entire Weaver Lake Member. As the majority of the samples are relatively unaltered, we believe that the near linear or curvilinear trends in the felsic samples are related to fractionation. Further geochemical work is required to determine if the felsic and mafic rocks are directly related by fractionation.

Within the mafic rocks, there appear to be two groupings of samples (Figure 3); one of these has a basaltic andesite composition and the other has a less evolved basaltic composition with lower titanium and zirconium contents. The mafic samples are inferred to lie along a curving trend in Figures 3b and 3d, in which the initial increase in TiO_2 reflects the enrichment of titanium in the residual magma during the early stages of crystallization, with the subsequent decrease corresponding to the onset of crystallization of titanium-bearing phases (Winchester and Floyd, 1977). The basaltic samples also have lower Zr/Y ratios consistent with a tholeiitic to transitional magmatic affinity. The andesitic samples are synvolcanic sills taken entirely from the Pit area, whereas the basaltic samples are extrusive lavas and intrusions from the Fleetwood and Vent zones. The relative stratigraphic positions of these samples suggests that the more evolved basaltic andesites intruded at a slightly higher stratigraphic level.

In immobile-incompatible element and immobile-immobile plots, altered samples lie along lines that extend from the unaltered precursor composition to the origin. Such trends involving the altered felsic samples are best shown in Figures 3a and 3c. The effect of silicification, which is the dominant alteration in many rocks, is shown in Figure 3b where the altered samples lie along alteration lines which trend towards 100% SiO_2. These altered samples are from mineralized stock-works in the Fleetwood and Vent zones.

The volcaniclastic samples consist of fine-grained facies 2.1 and 2.2 volcanic siltstones and fine sandstones. All of them, except for one of mafic composition, lie within the same field as the dacitic to rhyolitic lavas and intrusions and were probably derived from flows or pyroclastic eruptions of these compositions, with little or no addition of mafic material. Mafic volcaniclastic rocks on the Seneca property are less prevalent than those of felsic composition.

DISCUSSION

The volcanic sequence at the Seneca Prospect consists of felsic and mafic lava flows and massive to normal-graded volcaniclastic sediments that were intruded prior to lithification by synvolcanic sills and dikes. The volcaniclastic rocks were deposited by mass flows, turbidites and gravity settling. These units become progressively finer grained and better graded upwards in the succession. Felsic porphyries intrude all levels of stratigraphy, including the earlier mafic intrusives. Mineralization consists of conformable lenses of massive, semi-massive and disseminated sulphides in the Pit area and the 33 zone, and stockwork-style sphalerite-pyrite-chalcopyrite-quartz veinlets and stringers in the Vent and Fleetwood zones. Major zones of silicification and sericitization are associated with the stockwork zones.

The lower most parts of the Seneca stratigraphy are dominated by vent-proximal, mafic lavas and breccias, and slightly reworked coarse-grained mafic volcaniclastic rocks. Mafic volcanism was followed by the onset of extrusive felsic volcanism. Felsic flows, domes and autoclastic and hydroclastic breccias often directly overlie the mafic extrusive rocks and are accompanied by felsic synvolcanic intrusions. The felsic flows are interlayered with and overlain by fine-grained and reworked felsic volcaniclastic rocks (facies 2.2). The greater proportion of fine-grained volcaniclastic rocks compared with flows and breccias in the upper parts of the Seneca stratigraphy, and the fining upward nature of the entire sequence, may reflect an overall deepening of the depositional basin and/or a transition towards a more quiescent setting dominated by sedimentary processes.

The mineralized stockworks are interpreted to have formed at about the same time and stratigraphic level. Their association with flow-top breccias and their proximity to enclosing volcaniclastic units suggests that they formed at or near the paleoseafloor. This mineraliz-ing event also roughly corresponds to the onset of extrusive felsic volcanism. The deposition of the finer volcaniclastics was probably contemporaneous with, or post-dated, the mineralizing event. The zones of alteration and mineralization occur along a roughly linear trend that approximately parallels the inferred strike of the units; these zones taper out rapidly at their upper and lower contacts. Thus, it is possible that the mineralizing fluids were channelled by a single or several related, steeply dipping sructure(s). Such structures may also have been the feeders for the extrusive felsic domes and flows which host the mineralization.

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