

Geology and volcanic setting of the Horne deposit, Rouyn-Noranda, Quebec: initial results of a new research project

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Geology and volcanic setting of the Horne deposit, Rouyn-Noranda, Quebec: initial results of a new research project

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Abstract: The Horne deposit in the Noranda mining camp, northwestern Quebec, represents one of the largest volcanic-hosted massive-sulphide deposits in the world. Between 1927 and 1976, the mine produced 260 t of Au and 1.13 Mt of Cu making it the largest gold producer of its class. A new mapping program has been initiated to constrain the volcanological and stratigraphic setting of the deposit and to understand the geological factors that contributed to its unusual size and gold-rich nature. Initial fieldwork focused on the Horne West area that contains one of the best exposed and preserved sections of the Horne stratigraphy. Volcanic facies analysis revealed that this volcanic succession is dominated by a proximal facies association comprising coherent rhyolite and associated volcanoclastic rocks that formed by autobrecciation and quench fragmentation. Effusive and shallow intrusive volcanism in the Horne West area occurred broadly contemporaneously with the deposition of mass-flow-derived volcanic debris containing pyroclasts generated by explosive eruptions of a felsic volcanic source. In addition to a reconstruction of the volcanic facies architecture, the study highlights the mineral potential of the Horne West area. Disseminated sulphide mineralization and associated hydrothermal alteration are a conspicuous feature of this portion of the Horne stratigraphy. Elevated gold grades were encountered in the immediate footwall of two paleoseafloor positions within the volcanic succession that are particularly prospective for seafloor massive-sulphide accumulations. The research contributed to the initiation of a new exploration program involving about 3700 m of diamond drilling.

Résumé : Le gisement Horne dans le camp minier de Noranda, dans le nord-ouest du Québec, représente un des plus gros gîtes de sulfures massifs dans des roches volcaniques au monde. Entre 1927 et 1976, la mine a produit 260 t de Au et 1,13 Mt de Cu, ce qui en fait le plus important producteur d'or de sa classe. Un nouveau programme de cartographie a été entrepris en vue de circonscrire le cadre volcanologique et stratigraphique du gisement et de comprendre les facteurs géologiques qui ont contribué à sa taille inhabituelle et à son riche contenu en or. Les travaux initiaux sur le terrain ont porté sur la zone Horne Ouest, qui contient l'une des coupes les mieux exposées et préservées de la stratigraphie du gisement Horne. L'analyse des faciès volcaniques a révélé que cette succession volcanique est dominée par une association de faciès proximaux composés de rhyolite cohérente et de roches volcanoclastiques associées qui ont été formées par autobréchification et fragmentation par refroidissement rapide. Le volcanisme effusif et la mise en place d'intrusions à faible profondeur dans la zone Horne Ouest ont été à peu près contemporains du dépôt de débris volcaniques dérivés d'écoulements en masse contenant des pyroclastes projetés par les éruptions explosives d'une source volcanique felsique. Outre la reconstitution de l'organisation géométrique des faciès volcaniques, l'étude met en lumière le potentiel minéral de la zone Horne Ouest. La minéralisation en sulfures disséminés et l'altération hydrothermale associée sont l'une des caractéristiques des plus évidentes de cette partie de la stratigraphie du gisement Horne. On a trouvé des teneurs en or élevées dans le mur immédiat de deux anciennes surfaces du fond marin à l'intérieur de la succession volcanique, qui sont particulièrement prometteuses pour des accumulations de sulfures massifs sur les fonds marins. La recherche a contribué au lancement d'un nouveau programme d'exploration comportant près de 3700 m de forage au diamant.

INTRODUCTION

The discovery of the Horne deposit in 1923 was an outstanding event in the history of the Canadian mining industry, not only because of the size and grade of this giant volcanic-hosted massive-sulphide deposit, but also because the exploration that ensued ultimately led to the discovery of the Noranda mining camp and the settlement of northwestern Quebec (Roberts, 1956). In total, 20 massive-sulphide deposits have been mined in the area (Gibson and Galley, 2007) and recent exploration success indicates that significant discoveries can still be made in one of Canada's most mature base-metal and gold camps.

Despite decades of intensive research and exploration, the stratigraphy and structural setting of the Horne deposit, the most important volcanic-hosted massive-sulphide deposit in the Noranda camp, remains poorly understood. The Horne mine accounted for about 60% of the total ore reserves of the camp, and contained more than 60% of the total copper and 80% of the total gold. Between 1927 and 1976, the mine produced 260 t of Au and 1.13 Mt of Cu from 53.7 Mt of ore that graded 2.22 weight per cent Cu and 6.1 g/t Au (Kerr and Mason, 1990), making it the largest gold producer of its class in the world (Hannington et al., 1999; Dubé et al., 2007). The geological factors that contributed to the unusual size and precious-metal content of the Horne deposit are enigmatic and represent the most compelling unresolved issue in the Noranda camp.

To better constrain the processes responsible for gold enrichment at Horne, a new Geological Survey of Canada Targeted Geoscience Initiative (TGI-3) Abitibi Subproject was initiated to undertake a detailed volcanological, stratigraphic, litho-geochemical, and geochronological study on the host-rock succession of this giant deposit. In addition to enhancing the understanding of the geology and setting of the Horne deposit, the aim is to stimulate exploration efforts by providing new information on the stratigraphy, as well as controls on the distribution of alteration minerals and mineralization in the mine area.

GEOLOGICAL SETTING

Geology of the Noranda volcanic complex

Volcanic-hosted massive-sulphide deposits of the Noranda camp are hosted by the Archean Blake River Group, which consists of a bimodal tholeiitic to calc-alkaline volcanic succession, defining an east-west oriented belt in the south-central portion of the Abitibi Greenstone Belt (Goodwin, 1982). Rocks of the Blake River Group outcrop over a distance of approximately 140 km and belong to a number of distinct volcanic centres (Dimroth et al., 1982, 1983a; Goodwin, 1982).

The Noranda volcanic complex represents one of the largest volcanic centres within the Blake River Group. It has an approximate diameter of 35 km and is composed of 7.5 km to 9 km of bimodal volcanic strata of predominantly tholeiitic affinity comprising numerous alternating mafic and felsic units crosscut by synvolcanic dykes of dioritic and gabbroic composition (Gélinas et al., 1984; Gibson and Watkinson, 1990; Péloquin et al., 1990; Kerr and Gibson, 1993). Following the work of Spence and de Rosen-Spence (1975), Gibson (1990) subdivided the volcanic succession of the Noranda volcanic complex into five cycles of volcanism, each cycle consisting of lower basaltic and andesitic units overlain by intercalated mafic and felsic upper units (Fig. 1). Volcanism of the Noranda volcanic complex took place over a comparably short time span at ca. 2700 Ma to 2696 Ma (Mortensen, 1993; Lafrance et al., 2005; David et al., 2006).

The volcanic stratigraphy of the Noranda volcanic complex is intruded by the synvolcanic Flavrian and Powell plutons. The Flavrian Pluton is composed of sill-like intrusions that are characterized by shallow dips to the east and generally conformable contacts with the overlying volcanic strata (Wilson, 1941). Goldie (1978, 1979) and Kennedy (1985) showed that this pluton is a composite intrusion that consists of at least five separate intrusive phases. The chemical similarity of some of these phases to the enclosing volcanic strata and lack of a significant contact metamorphic aureole led Goldie (1978, 1979) and Paradis et al. (1988) to interpret the Flavrian Pluton as the intrusive equivalent of a shallow magma chamber within the shield volcano represented by the Noranda volcanic complex. Geochemical and petrographic evidence suggests that the Powell Pluton, located south of the Beauchastel fault (Fig. 1), represents a faulted equivalent to the Flavrian Pluton (Spence and de Rosen-Spence, 1975; Goldie, 1978).

Several smaller intrusive complexes have been recognized in the Noranda volcanic complex (Fig. 1). The Lac Dufault Pluton in the eastern part of the Noranda volcanic complex crosscuts the surrounding stratigraphy and is divisible into two phases. The western phase is associated with a pronounced metamorphic aureole that extensively overprinted the surrounding volcanic rocks (de Rosen-Spence, 1969). In contrast, the eastern phase is not surrounded by a contact metamorphic aureole and the hydrothermal alteration zone associated with the Gallen deposit, which occurs as a roof pendant within the intrusion, is not contact metamorphosed. This suggests that the eastern phase of the Lac Dufault Pluton is synvolcanic.

The Noranda volcanic complex has been subdivided into a number of structural blocks, which are delimited by major faults and their extrapolations (Spence, 1976; Péloquin et al., 1990). Lithological correlation between the different structural blocks has proven to be difficult in most cases. The area north of the Hunter Creek fault is referred to as the Hunter block. The areas between the Hunter Creek and Beauchastel faults, and the Beauchastel and Horne Creek

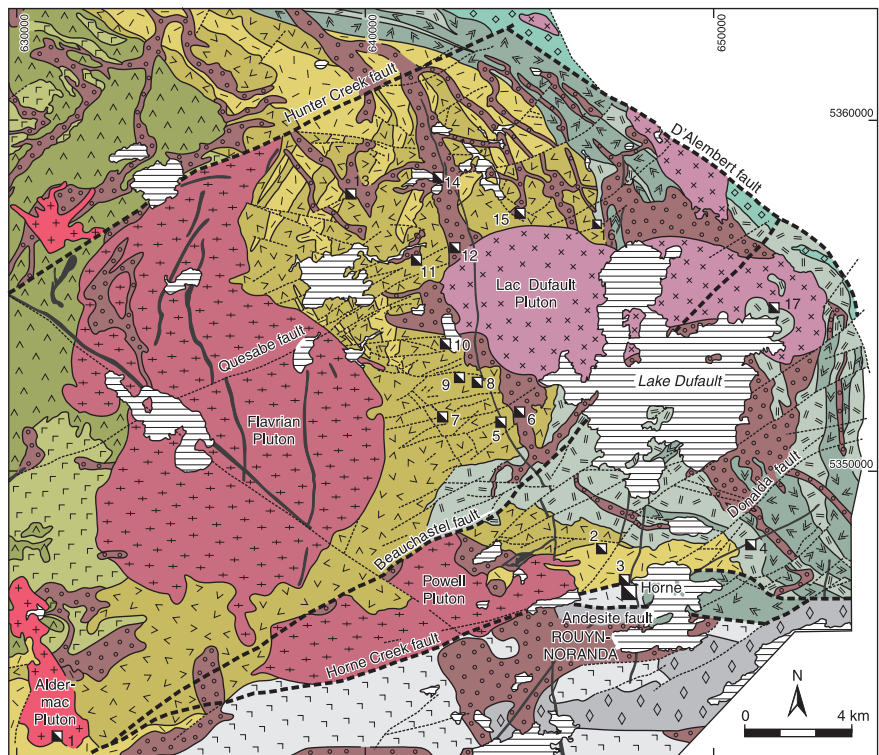


Figure 1. Generalized geological map of the Noranda mining camp, showing major structural elements and the distribution of extrusive and intrusive rocks. The locations of volcanic-hosted massive-sulphide deposits are highlighted (modified from Santaguida, 1999). UTM co-ordinates (NAD83, Zone 17) are used.

Volcanic-hosted massive sulphide deposits: 1 = Aldermac, 2 = Joliet, 3 = Quemont, 4 = Delbridge, 5 = D68, 6 = Millenbach, 7 = Corbet, 8 = Amulet A, 9 = Amulet C, 10 = Amulet F, 11 = Old Waite, 12 = East Waite, 13 = Ansil, 14 = Vauze, 15 = Norbec, 16 = Newbec, and 17 = Gallen

Archean extrusive rocks	Cycle 3	Archean intrusive rocks	Proterozoic intrusive rocks
Undifferentiated	Rhyolite	Syenite	Diabase
Rhyolite	Basalt, andesite	Granodiorite	Major fault
Basalt, andesite	Rhyolite	Trondhjemite, tonalite	Minor fault
Cycle 1+2	Basalt, andesite	Gabbro, quartz diorite	Deposit
Rhyolite			
Basalt, andesite	Cycle 4		
	Rhyolite		
	Basalt, andesite		
	Cycle 5		
	Basalt, andesite		

faults are referred to as the Flavrian and Powell blocks, respectively. The Horne block lies between the Horne Creek and the Andesite faults (Fig. 1, 2).

Previous research largely focused on the Flavrian and Powell blocks in the central part of the Noranda volcanic complex, where most of the known massive-sulphide deposits occur. The volcanic stratigraphy in both blocks, collectively referred to as the Central Mine Sequence, shows similarities and is correlative across the Beauchastel fault (Gibson et al., 1984). The Central Mine Sequence is dominated by coherent basalt, andesite, and rhyolite that are intercalated with lesser amounts (<5%) of volcanoclastic deposits. Mafic volcanic rocks form predominantly pillowed and massive flows, whereas the rhyolite units were typically emplaced as tabular flows and low-relief domes (Spence and de Rosen-Spence, 1975; Kerr and Gibson, 1993). Volcanism of the Central Mine Sequence occurred in a below-storm-wave-base, presumably deep, marine environment; however, local shoaling has been postulated for strata in the Powell area, which occurs at the southern limit of the Central Mine Sequence (Lichtblau and Dimroth, 1980).

The volcanic units within the Central Mine Sequence strike north to northeast, are gently folded about east-trending and -plunging axes, and dip from 5°E to 55°E (Spence and de Rosen-Spence, 1975; Gibson and Watkinson, 1990). They are interpreted to have been deposited within a volcano-tectonic subsidence structure, which is referred to as the Noranda cauldron (Dimroth et al., 1982; Gibson, 1990; Gibson and Watkinson, 1990; Kerr and Gibson, 1993). Recently, Pearson (2005), Daigneault and Pearson (2006), and Pearson and Daigneault (2006) proposed that the Noranda cauldron may be superimposed on two larger and older calderas, the New Senator caldera, which encompasses the Noranda volcanic complex and an older, Misema caldera, which encloses the entire Blake River Group.

All Archean volcanic rocks in the Noranda camp have been regionally metamorphosed to prehnite-pumpellyite or lower greenschist-facies conditions (Jolly, 1980; Dimroth et al., 1983b; Powell et al., 1995). Within the Noranda volcanic complex, regional metamorphic isograds overprint synvolcanic hydrothermal alteration as well as contact metamorphic aureoles including those surrounding the Lac Dufault Pluton (Powell et al., 1995).

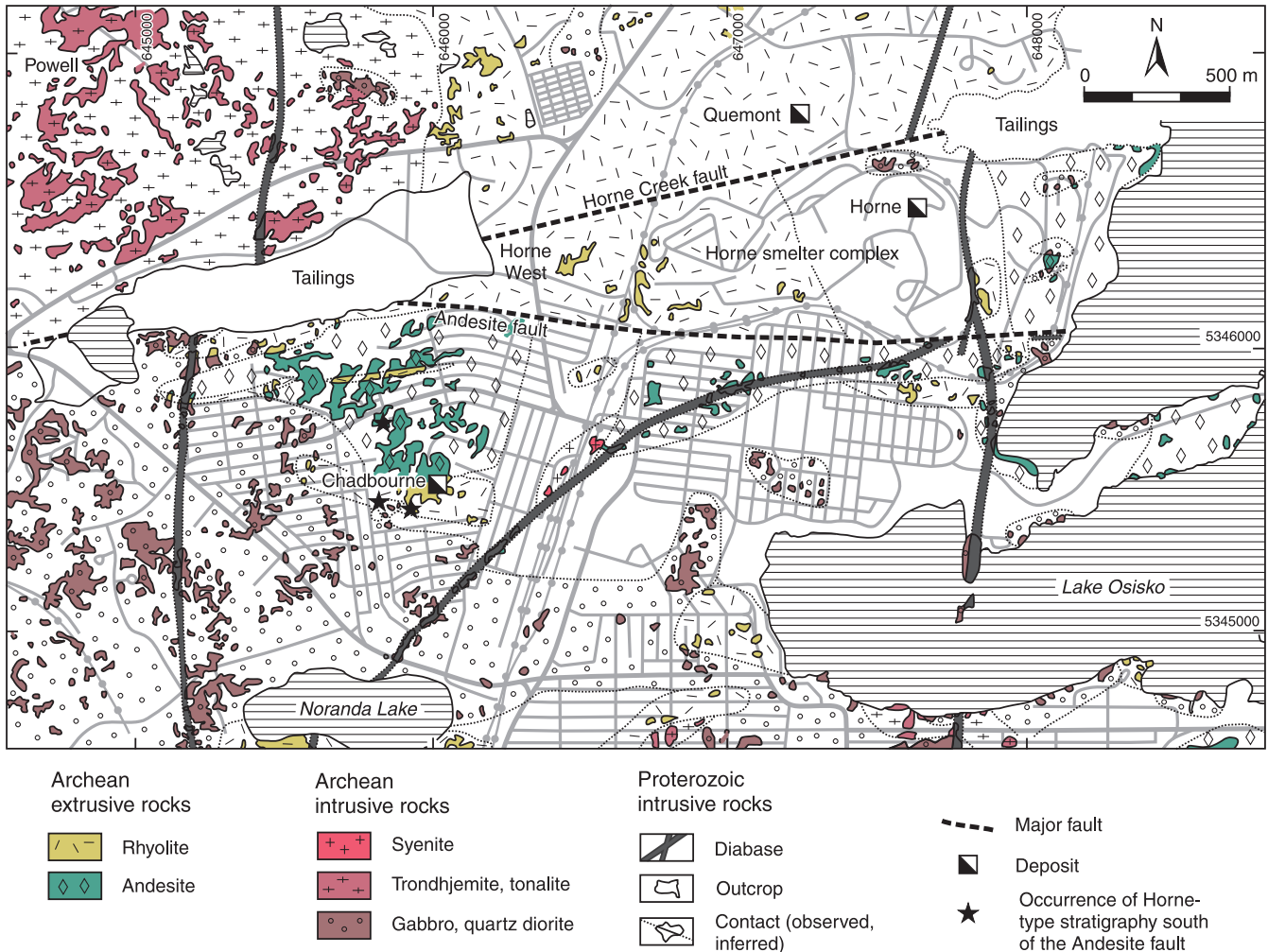


Figure 2. Geology of the Horne block and surrounding areas (*modified from Wilson, 1941*). The observed occurrences of Horne-type stratigraphy south of the Andesite fault are indicated. UTM co-ordinates (NAD83, Zone 17) are used.

Geology of the Horne block

The Horne deposit is located within an east-trending package of dominantly felsic volcanic rocks that forms part of the Horne block. The volcanic stratigraphy within the mine area faces to the north, strikes approximately west-northwest, and steeply dips to the north (Wilson, 1941; Hodge, 1967; Sinclair, 1971; Kerr and Mason, 1990; Kerr and Gibson, 1993; Gibson et al., 2000). The bounding Horne and Andesite faults converge approximately 2.2 km to the west of the Horne deposit and dip steeply toward one another (Fig. 2).

Due to the lack of detailed surface mapping, the sense and magnitude of displacement along the bounding faults is uncertain. Underground exposure in the Horne and Quemont mines revealed that the Horne Creek and Andesite faults are composite and show evidence of repeated movement (Wilson, 1941). Within the mine area, the zone of intense shearing along the Horne Creek fault varies from about 50 m to 150 m in thickness. The Andesite fault has

been interpreted to be a subsidiary of the Horne Creek fault (Hodge, 1967) and the zone of intense shearing along this fault ranges from less than 1 m to 10 m in width (Wilson, 1941); however, considerable structural complications within the mine area are caused by a northeast-trending set of curvilinear splays off the Andesite fault that slice the volcanic succession and the mineralization into a number of smaller blocks (Gibson et al., 2000).

Attempts to stratigraphically or geochronologically correlate the host-rock succession of the Horne deposit with volcanic units outside the Horne block, especially those belonging to the Central Mine Sequence, have been largely unsuccessful (Péloquin et al., 1990; Gibson et al., 2000). Immediately on the north side of the Horne Creek fault lies the Quemont massive-sulphide deposit that is hosted by rhyolite breccia and porphyritic coherent rhyolite (Ryznar et al., 1967; Weeks, 1967). Volcanic rocks showing similar textural characteristics have not been recognized within the Horne block; however, intrusive rocks similar to those of the Powell Pluton outcropping farther to the west along the

northern side of the Horne Creek fault have been encountered during deep drilling at the western tip of the Horne block (Kerr and Mason, 1990). Rocks south of the Andesite fault are mainly andesitic to basaltic in composition (Fig. 2), strike approximately east, but also show a subvertical dip. Initial fieldwork carried out as a part of the present study indicates that felsic volcanoclastic rocks containing sulphide clasts and with textural characteristics similar to volcanic deposits within the Horne block occur south of the Andesite fault, in the Chadbourne area (Fig. 2).

Geological relationships at the eastern limit of the Horne succession are poorly constrained at present. Historical mine-level plans indicate that the felsic volcanic rocks are in contact with a wedge-shaped package of mafic rocks located to the northeast. This package of mafic rocks appears to thicken toward the east, separating the orebodies from the Horne Creek fault. The contact between the felsic volcanic rocks hosting the orebodies and the package of mafic rocks parallels bedding and strikes approximately west-northwest, suggesting a conformable contact relationship, which would imply that the mafic rocks were emplaced as either flows or sills; however, the wedge-shaped package of mafic rocks has previously been interpreted to be entirely intrusive (Price, 1934). In addition to this package of mafic rocks, Wilson (1941) noted the occurrence of extrusive andesite along the western shore of Lake Osisko. The distribution of surface outcrops in this area defined a north-striking contact relationship between the package of felsic volcanic rocks hosting the Horne deposit and the Lake Osisko andesite (Fig. 2), indicating an angular discordance (possible unconformity) between these units.

The dominantly felsic volcanic succession hosting the Horne deposit consists mainly of coherent rhyolite and related volcanoclastic deposits, interpreted to represent subaqueous lava flows with lesser synvolcanic intrusions, redeposited syneruptive volcanoclastic deposits, and possible primary pyroclastic deposits (Kerr and Mason, 1990; Kerr and Gibson, 1993; Gibson et al., 2000). Kerr and Gibson (1993) informally divided the volcanic host rocks of the Horne deposit into three conformable formations which, from stratigraphic footwall to hanging wall, include the West 3919, Main Mine, and Remnor formations. All three formations host massive to disseminated Cu-Au-Ag-(Zn) sulphide mineralization.

Nearly all historical production from the Horne deposit came from the Upper H and Lower H orebodies, which occur near the top of the Main Mine formation. The Upper H body extended from surface to a mine depth of 395 m, whereas the Lower H orebody was located at a mine depth of 365 m to 945 m. These two orebodies were approximately circular in horizontal cross-section, but were elongate and plunged steeply to the east, parallel to the dip of the surrounding volcanic host rocks (Price, 1934; Hodge, 1967; Gibson et al., 2000). The Lower H orebody is stratigraphically overlain by a massive to semimassive-sulphide body, referred to as the No. 5 zone (Sinclair, 1971). This tabular

zone consists of numerous lenses of massive pyrite interbedded with intensely altered felsic volcanoclastic rocks. The No. 5 zone extends for a strike length of more than 1000 m to a depth of at least 2650 m and ranges from approximately 30 m to 140 m in thickness (Sinclair, 1971; Fisher, 1974; Gibson et al., 2000). Due to low metal grades, this zone has not been mined extensively (Gibson et al., 2000). A small massive pyrite lens, referred to as the G zone, is located in the Remnor formation, which stratigraphically overlies the volcanic rocks hosting the Upper H and Lower H orebodies as well as the No. 5 zone (Kerr and Mason, 1990; Gibson et al., 2000).

The sulphide mineralization of the Horne deposit is crosscut by two suites of intrusive rocks that are interpreted to be synvolcanic. The oldest intrusions are porphyritic cryptodomes of intermediate composition that cut the western side of the Upper H orebody (Kerr and Gibson, 1993; Gibson et al., 2000). In addition, the occurrence of basaltic dykes and sills is widespread. The mafic intrusions commonly form dyke swarms that extend toward the package of mafic rocks located to the northeast of the Horne deposit. Assuming that this package is in part extrusive or a sequence of sills, the mafic dykes may represent the feeders for the basalt flows and sills that were emplaced in the hanging wall of the Horne deposit.

The volcanic host rocks of the Horne deposit are crosscut by narrow (<5 m), postmetamorphic, northeast-striking quartz syenite dykes (Price, 1934; Wilson, 1941) interpreted to be Late Archean (Gibson et al., 2000). The youngest intrusive rocks crosscutting the volcanic stratigraphy in the mine area are two subvertical Proterozoic diabase dykes that trend north and northeast, respectively (Wilson, 1941). The two dykes range from 20 m to 30 m in width and are generally unaltered and free of sulphide mineralization; however, in locations where the dykes crosscut sulphide mineralization, veins of chalcopyrite, pyrrhotite, and pyrite occur within the diabase (Price, 1934; Suffel, 1935). Underground intersections in the Horne and Quemont mines revealed that the north-striking diabase dyke was displaced horizontally along the Horne Creek fault by approximately 200 m with a sinistral sense of movement; however, it is not offset by the Andesite fault (Wilson, 1941). This suggests that most of the movement along the Horne Creek and Andesite faults occurred prior to emplacement of the Proterozoic dyke.

GEOLOGY OF THE HORNE WEST AREA

Initial mapping carried out as a part of the present study focused on one of the best exposed sections of the Horne stratigraphy, which was stripped of overburden and washed in 1985 by Noranda Exploration Ltd. The investigated area, referred to as the Horne West area, forms part of the West 3919 formation as defined by Kerr and Gibson (1993). According to these authors, the volcanic succession exposed

in the Horne West area forms part of the footwall of the giant Horne deposit and is probably positioned several hundreds of metres below the Upper H and Lower H orebodies. The outcrop is located approximately 1 km to the west of the Horne deposit (Fig. 2).

Due to its accessibility, the Horne West area forms part of most academic and professional field trips in the Noranda area. Recently, the outcrop attracted renewed scientific interest because some of the volcanic rocks occurring in the stratigraphically central portion of the Horne West area were proposed to be megabreccia units deposited within the newly recognized New Senator Caldera (Daigneault and Pearson, 2006). Initial fieldwork was designed to better define the distribution of volcanic facies in the Horne West area. Fieldwork involved detailed mapping at a scale of 1:200 employing a 1 m x 1 m surface grid that was georeferenced using a GPS (typical accuracy of ± 5 m). In addition, logging of selected exploration diamond-drill cores was performed at a scale of 1:100.

Volcanic facies architecture

Based on surface mapping and drill-core investigations, a number of volcanic facies were distinguished using textural criteria and other distinctive characteristics that included composition, geometry, volcanic or sedimentary structures, bed forms, and pre-tectonic contact relationships. Facies names have been assigned using the terminology presented by McPhie et al. (1993). Figure 3 shows a simplified map of the Horne West outcrop illustrating the distribution of volcanic facies. The facies recognized are traceable along strike for about 200 m to the east toward the Horne deposit. Correlation to the west is hampered by structural complications and a lack of outcrops and diamond drilling.

The lower part of the Horne West succession is dominated by aphyric and aphanitic coherent rhyolite (Fig. 4a) that commonly shows a granular texture due to the presence of spherulites. These consist of up to 1 mm large, radiating arrays of crystal fibres. The spherulites and the local presence of perlitic cracks indicate that the rhyolite was originally, at least in part, glassy in nature (McPhie et al., 1993). Distinction of individual emplacement units in the field was hampered by the limited continuity of surface outcrops and the absence of phenocrysts, the sizes, abundances, and distributions of which may vary between adjacent rhyolitic units; however, the occurrence of autoclastic deposits between intervals of coherent rhyolite, as observed in drill core, indicates that more than one felsic emplacement unit is present at this stratigraphic position.

The coherent rhyolite typically grades into, or is in contact with, nonstratified monomict blocky-clast rhyolite breccia interpreted to have formed by a combination of auto-brecciation and quench fragmentation. Drill-core logging established that this facies commonly coincides with the margins of individual rhyolite units. The breccia is typically

densely packed and characterized by a clast-supported framework. Individual clasts are blocky with subplanar or ragged margins. Textures range from in situ, jigsaw-fit breccia to a breccia containing abundant rotated clasts, some of which exhibit evidence for abrasion such as rounded to sub-rounded corners. In addition to blocky-clast rhyolite breccia, nonstratified monomict curvilinear-clast rhyolite breccia is present that is interpreted to have formed as a hyaloclastite. In this breccia type, the rhyolite clasts are typified by subplanar to curvilinear margins and are surrounded by a fine-grained matrix consisting of small, splintery rhyolite fragments (Fig. 4b). The breccia commonly exhibits jigsaw-fit textures although evidence for differential movement of individual clasts is locally present.

A third type of rhyolite breccia is present in drill core. This stratified polymict rhyolite breccia is clast supported and consists of a mixture of at least two texturally distinct, aphyric, rhyolite clast populations, namely nonamygdaloidal clasts and distinctly amygdaloidal fragments. The latter typically exhibit a flow foliation defined by up to 1 mm large quartz amygdaloids. The shapes of the rhyolite fragments range from blocky and angular to irregular, with distinctly serrated or sinuous margins.

Chlorite and sericite alteration are widespread in the lower portion of the Horne West succession. Coherent rhyolite and associated breccia in this stratigraphic position contain variable amounts of disseminated pyrite (Fig. 4a). Sulphide veinlets are abundant and locally stringer sulphide veins having thicknesses of up to 2 cm were observed (Fig. 4c). At surface, rhyolite containing elevated sulphide concentrations is marked by gossanous outcrops.

Rhyolite in the lower part of the Horne West succession is overlain by, and locally intercalated with, volcanoclastic deposits containing abundant chlorite wisps and lithic fragments. This unit has a stratigraphic thickness of at least 50 m and, overall, is doubly graded, i.e. each individual bed is normally graded and the entire unit becomes finer grained upward. Preliminary mapping and core logging allowed a subdivision of this unit into two facies having distinct characteristics.

The lower portion of the unit is dominated by a chlorite-wisp-bearing lithic breccia facies. The beds are typically several metres thick and consist of rhyolite fragments and chlorite wisps set in an irresolvable, fine-grained matrix (Fig. 4d). Within individual beds, the lithic fragments and chlorite wisps exhibit a poorly defined normal grading, although the base of the beds are commonly inversely graded. The pinkish to greyish white rhyolite fragments are angular to subrounded with the largest fragments having diameters of up to 15 cm. The rhyolite is aphyric and typically non-amygdaloidal. Chlorite wisps are an additional essential and conspicuous component of this facies. The large wisps, up to several centimetres, are interpreted to represent nonwelded pumice shreds, compacted pumice fragments, or once-glassy fragments. Due to compaction and/or deformation-related

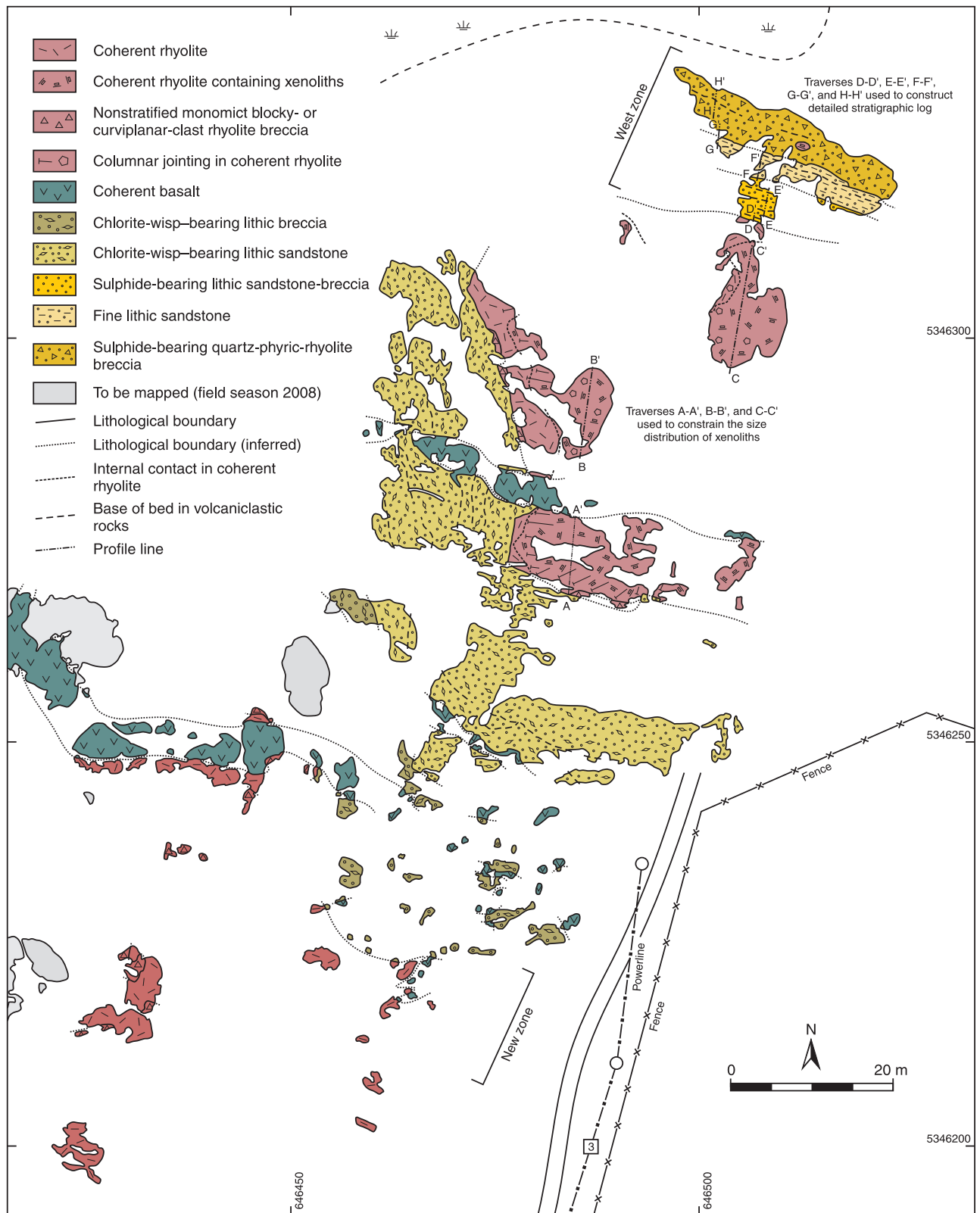


Figure 3. Map of the Horne West outcrop showing the distribution of major volcanic facies. Note that detailed mapping of the surface outcrop is still in progress. UTM co-ordinates (NAD83, Zone 17) are used.

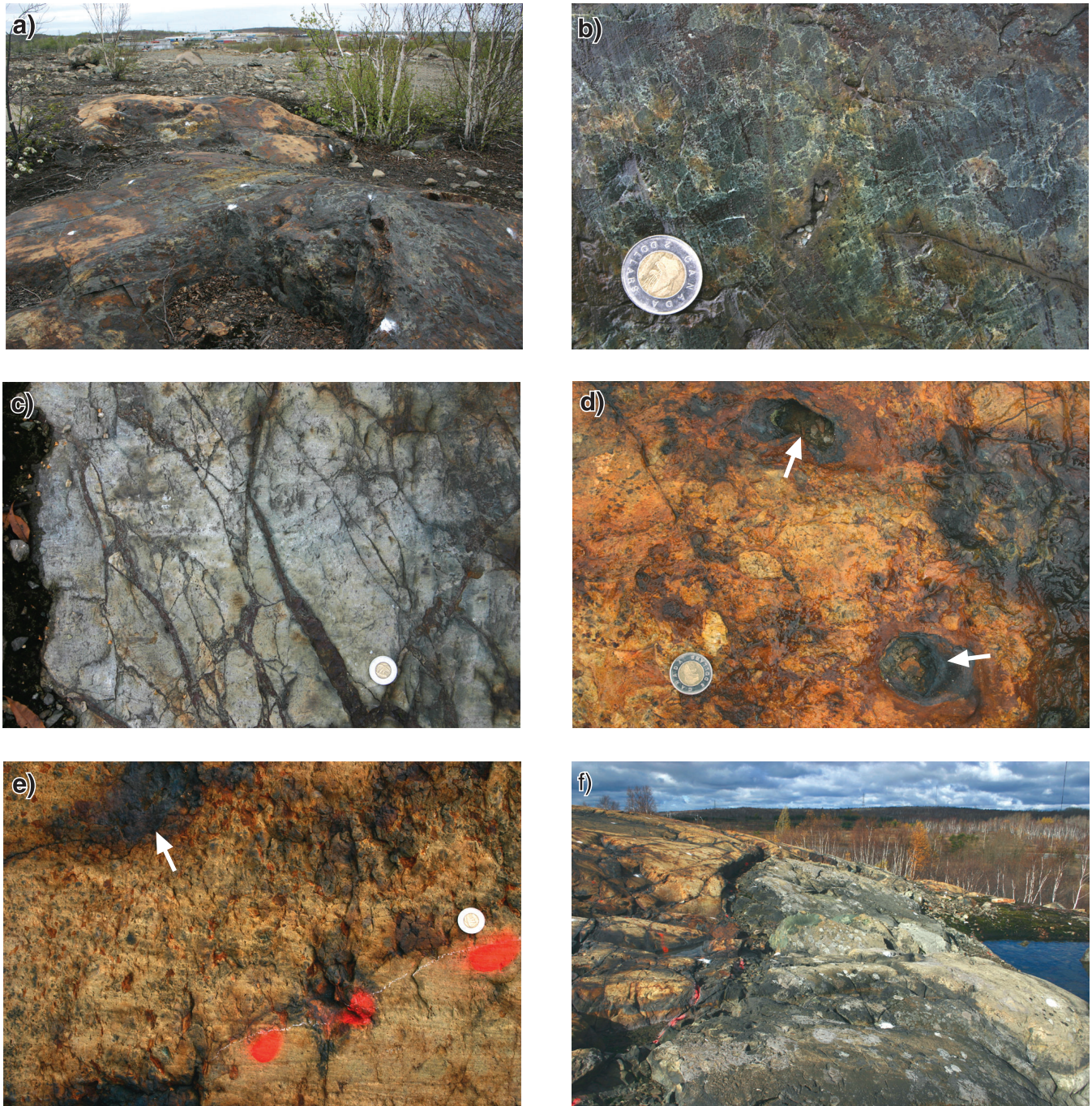


Figure 4. Photographs of volcanic facies and mineralization observed in the lower portion of the Horne West succession (white spray paint marks define a 1 m x 1 m grid; coin is 2.8 cm). **a)** Hydrothermally altered coherent rhyolite. Sulphide veinlets and disseminations are extensively weathered, resulting in the gossanous appearance of the outcrop. **b)** Nonstratified monomict curvilinear-clast rhyolite breccia marking the top contact of a coherent rhyolite unit. The blocky to splintery rhyolite clasts are separated by a fine-grained matrix of the same composition. Some of the clasts have distinct curvilinear margins. Groups of clasts and splintery fragments locally display a jigsaw-fit texture. **c)** Sulphide stringer veins in coherent rhyolite. **d)** Outcrop of the chlorite-wisp-bearing lithic breccia facies. The bed consists of closely packed rhyolite fragments and chlorite wisps set in a fine matrix. Sulphide clasts contained in the volcanoclastic deposit are intensely weathered and now marked by the occurrence of circular pits in the surface outcrop (arrows). **e)** Chlorite-wisp-bearing lithic sandstone facies in surface outcrop. The base of a relatively coarse bed is marked by orange spray paint. Oxidation of disseminated sulphide mineralization resulted in black staining of the outcrop (arrow). **f)** Massive basaltic intrusion in the central portion of the outcrop. The basalt exhibits several centimetre-wide chilled margins in contact with the enclosing volcanic strata.

flattening and stretching, the formerly glassy particles now define a slightly irregular, bedding-parallel foliation in outcrop and drill core. In addition to the lithic fragments and chlorite wisps, most beds contain pyrite-rich sulphide fragments (Fig. 4d) that are concentrated in the coarse basal parts of the beds. The clastic components of the chlorite-wisp-bearing lithic breccia facies are set in a finer grained matrix of lithic or formerly vitric material. The matrix is largely replaced by secondary minerals and contains abundant disseminated sulphides.

Beds in the upper portion of the doubly graded unit are compositionally similar, but the grain size of the lithic fragments and chlorite wisps ranges from fine to coarse sand with some beds dominated by granule- to small pebble-sized clasts. Beds belonging to the chlorite-wisp-bearing lithic sandstone facies exhibit clear evidence of normal grading (Fig. 4e). Inverse grading at the base of individual beds is typically absent. The beds are typically thin (<1 m) although some fine-grained beds toward the top of the facies reach thicknesses of up to 10 m. Sulphide clasts are rare; however, the amount of disseminated sulphides and small sulphide veinlets generally increases toward the top of the facies. Locally, the sand-sized volcanoclastic material contains up to 10% of sulphides that impregnate the fine matrix between the lithic fragments and chlorite wisps. In places, preferential replacement of the formerly glassy fragments by sulphides was observed. In outcrop, zones of increased sulphide abundance are typified by extensive surface staining (Fig. 4e).

Bedding in the two chlorite-wisp-bearing volcanoclastic facies strikes approximately west-northwest and has a subvertical dip. Beds are typically laterally continuous in outcrop, but local channel scouring is present. A significant change in the bedding orientation occurs to the west of 646470 mE, where bedding strikes north-northwest to north (Fig. 3). It is uncertain whether the change in bedding orientation is caused by faulting or, more likely, by folding (synvolcanic block folding or later ductile deformation). No axial-planar cleavage has been observed.

Coherent basalt is widespread in the lower and central portion of the Horne West succession forming a set of intrusions that, individually, are up to 5 m thick (Fig. 3). The dark greenish grey basalt is aphyric and aphanitic. Amygdales are generally absent. Contacts between the massive basalt and the host strata are typically sharp with the basaltic bodies exhibiting chilled margins that are several centimetres in width (Fig. 4f). The contacts between the mafic intrusions and enclosing volcanoclastic strata are usually concordant. This suggests that the intrusions were largely emplaced as sills that locally branch into swarms of irregular, centimetre- to decimetre-wide apophyses resulting in an intricate interpenetration of the basaltic intrusions and the felsic volcanoclastic facies. Induration of volcanoclastic material enclosed in the coherent facies is common. The textural relationships suggest that these basaltic intrusions were, at least locally, emplaced into poorly consolidated

volcanoclastic material. Visual examination suggests that the basaltic intrusions are variably altered, ranging from weakly altered to bleached and sericite altered.

A coherent rhyolite is exposed in the stratigraphically central portion of the Horne West succession (Fig. 3), where previous work indicated the occurrence of a megabreccia (Daigneault and Pearson, 2006). The aphanitic and aphyric rhyolite weathers from white-buff to yellow-white and green depending upon alteration type (sericite or chlorite alteration) and intensity. On weathered surfaces, the unit locally has a granular texture at the millimetre scale. The rhyolite shows a distinct flow foliation, defined by planar and parallel to contorted and folded, millimetre- to several centimetre-wide bands having slightly different colours (Fig. 5a). The felsic unit contains 1–5% pyrite as disseminated grains and in fractures, some of which have a pale yellow sericitic envelope that is up to 2 cm wide.

The rhyolite unit is typified by a core zone that contains abundant mafic xenoliths (Fig. 5b). The clasts range from 1–2 cm to 1.5 m in size, are grey to green, and have a distinct granular texture. The xenoliths contain up to 8% pyrite as fine disseminated grains and as blebs that are up to 1 cm. Contacts between the xenoliths and the enclosing rhyolite are sharp, but range from straight to irregular and scalloped. Flow bands within the host unit typically envelop the xenoliths, but are locally truncated. Rhyolite within centimetres to millimetres from the contact with the xenoliths is locally lighter coloured, presumably due to rapid cooling or reaction with the clasts (Fig. 5b). Measurement of the xenolith size along a traverse indicates that the size of xenoliths decreases stratigraphically upwards (Fig. 6) and that the xenoliths are concentrated in a core zone that is surrounded by a zone that typically lacks xenoliths (Fig. 3). The internal contact between the xenolith-rich and xenolith-poor phases is approximately parallel to the contact of the overall coherent rhyolite unit with the surrounding volcanoclastic facies. The outer zone lacking abundant xenoliths has a maximum thickness of about 5 m.

The contact between the coherent rhyolite and the surrounding volcanoclastic facies is sharp and locally marked by a thin, centimetre- to decimetre-wide, discontinuous zone of nonstratified in situ, and less frequently clast-rotated, monomict blocky-clast rhyolite breccia (Fig. 5c, d). Due to the commonly granular texture of the rhyolite, the contact between the felsic unit and the surrounding volcanoclastic deposits is extremely difficult to recognize in outcrop and drill core unless characterized by the occurrence of the nonstratified, monomict, blocky-clast, rhyolite breccia facies. An additional conspicuous feature of the rhyolite is the presence of columnar jointing, which is particularly well developed in the outer margin of the unit. Joints interpreted to represent the sides of the columns are regularly spaced and have orientations perpendicular to the contact (Fig. 5e). The joints typically do not crosscut the xenoliths. Distinct polygonal joint patterns are developed in the core zone and the stratigraphically upper portion of the rhyolite unit

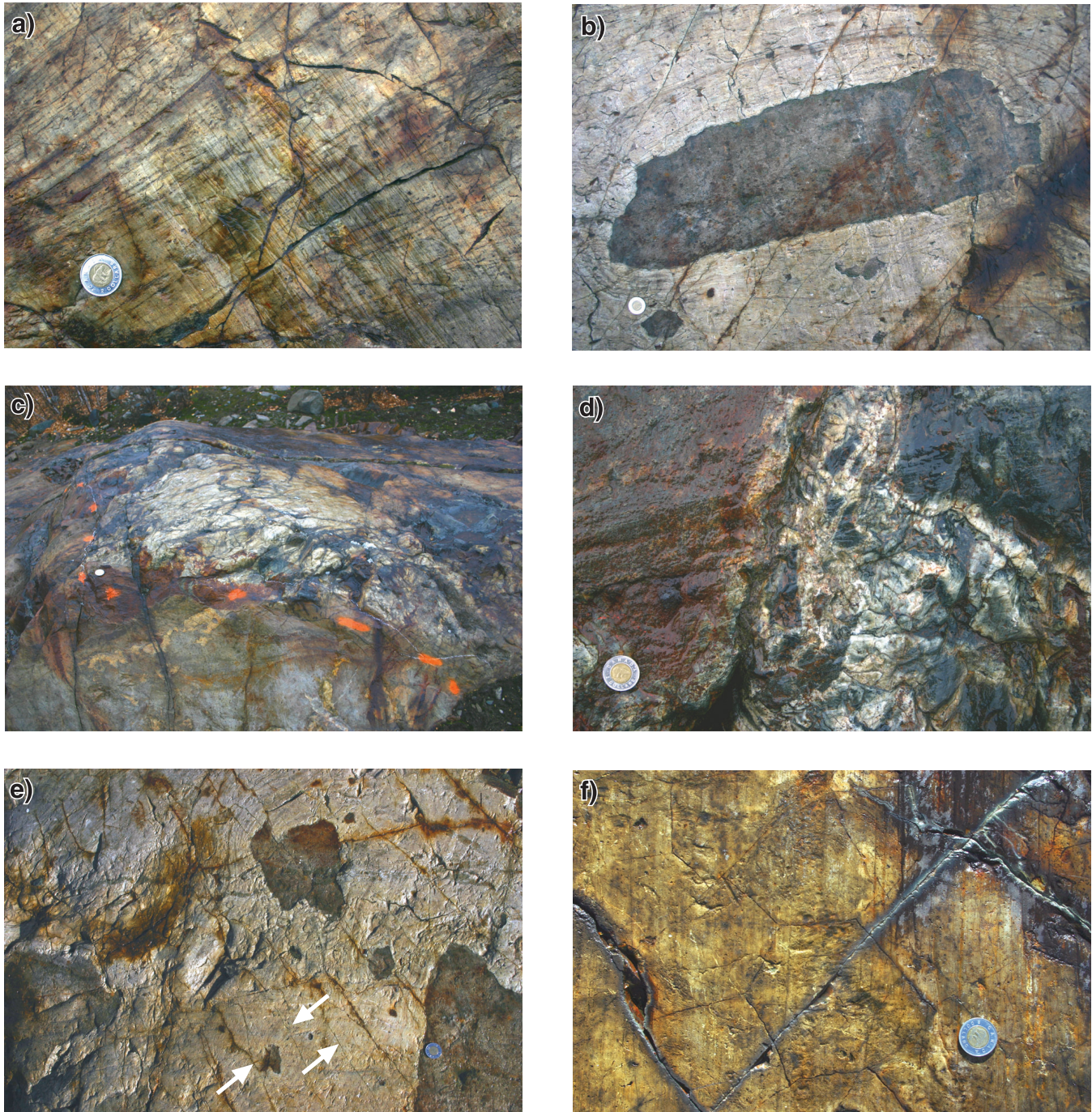


Figure 5. Photographs of common textures encountered in the rhyolite unit occupying the central portion of the Horne West succession (coin is 2.8 cm). **a)** Subplanar and laterally continuous flow foliation in the coherent rhyolite is defined by thin bands of slightly different colour. **b)** Xenolith in the core zone of the coherent rhyolite unit. The xenolith is characterized by a highly irregular and scalloped outline. Flow bands within the felsic unit envelop the xenolith. The rhyolite becomes lighter adjacent to the xenolith, presumably due to rapid cooling or reaction with the clast. **c)** The contact between the rhyolite unit and the surrounding chlorite-wisp-bearing lithic sandstone facies is irregular and variable in orientation with respect to bedding of the volcanoclastic rocks. The contact is highlighted by orange spray paint. **d)** Nonstratified monomict blocky-clast rhyolite breccia with a jigsaw-fit texture at the contact between the coherent rhyolite and the surrounding facies. **e)** Regular columnar joints in the coherent rhyolite strike approximately perpendicular to the contact with the surrounding volcanoclastic facies. As an example, three adjacent joints are marked by arrows. **f)** In cross-section, the columnar joints have distinct polygonal outlines. Variations in the orientation of the columnar joints in outcrop define the paleocooling surface.

(Fig. 5f). Variations in the orientation of the columnar joints are interpreted to record the position of cooling fronts following emplacement of the rhyolite.

Due to the typically sharp and/or sheared upper rhyolite contact, surface mapping and core logging have not provided conclusive evidence for the emplacement mechanism of the rhyolite unit (i.e. emplacement as a lava flow or subvolcanic intrusion); however, the stratigraphic position of the upper rhyolite contact varies along strike and downdip, implying that the margin of the rhyolite unit was at least locally intrusive. Additional constraints are provided by the occurrence of two large (150 cm x 100 cm and 65 cm x 33 cm, respectively), xenolith-bearing rhyolite

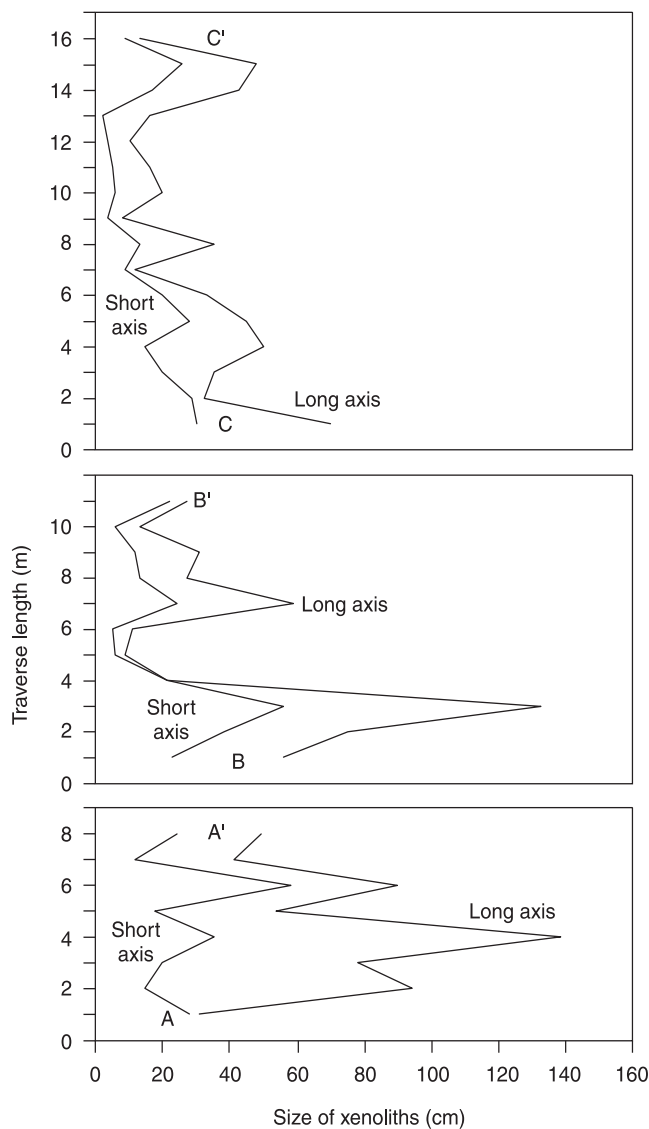


Figure 6. Size distribution of xenoliths in the coherent rhyolite occurring in the central portion of the Horne West outcrop. The plot illustrates that the size of the xenoliths broadly decreases stratigraphically upwards. The clast sizes were measured along a traverse across the rhyolite unit, the position of which is shown in Figure 3.

clasts in the volcaniclastic facies that overlies the rhyolite, as observed in outcrop. Incorporation of rhyolite clasts into the mass-flow emplaced volcaniclastic deposits provides evidence that the rhyolite locally emerged at the ancient seafloor. The rhyolite may have breached the seafloor during emplacement or, alternatively, it became exposed in response to synvolcanic faulting.

A second, relatively thick unit of volcaniclastic rocks occurs stratigraphically above the coherent rhyolite in the northern portion of the Horne West outcrop. These rocks are divided into three volcaniclastic facies (Fig. 3, 7). At surface, the coherent rhyolite is in contact with a sulphide-bearing lithic sandstone-breccia facies (Fig. 8a). This facies consists of a series of up to 1 m thick, laterally continuous, massive or normally graded beds that comprise aphyric rhyolite fragments and subordinate amounts of pyrite-dominated sulphide clasts. The sulphide fragments are concentrated at the base of individual beds. Erosional surfaces between adjacent beds are common as evidenced by the presence of basal scours and channels (Fig. 8a). The coarse or medium gravelly to very coarse sandy beds grade into, or are intercalated with, intervals of laminated to thinly bedded, fine lithic sandstone. These intervals of distinctly finer grained material are typically less than 30 cm in thickness. Clastic components of the sulphide-bearing lithic sandstone-breccia facies are set in a fine-grained, extensively sericitized matrix that contains variable amounts of disseminated sulphide minerals.

The sulphide-bearing lithic sandstone-breccia facies is overlain by a 3 m thick, fine lithic sandstone facies. Individual beds are typically planar and laterally continuous, but the presence of scoured surfaces suggests that deposition of the facies was sometimes accompanied by erosion of the substrate material. Beds belonging to the fine lithic sandstone facies are massive or show a poorly defined normal grading. Intercalation with coarser lithic material texturally similar to the sulphide-bearing lithic sandstone-breccia facies occurs (Fig. 8b). Several ballistic clasts of aphyric rhyolite were observed, the largest of which has a long axis of approximately 20 cm. Bedding sags beneath these ballistic fragments indicate that the fine lithic sandstone was wet and cohesive when the projectiles landed (Fig. 8c). Although a pyroclastic origin is the preferred interpretation for the rhyolite clasts, it is difficult to rule out conclusively that these fragments were not derived by sedimentation from a nearby topographic high. Sericite alteration of the fine lithic sandstone facies hosting the fragments is widespread and disseminated sulphides infiltrating the fine-grained material are abundant.

Deposition of the fine lithic sandstone facies was followed by a drastic change in sedimentation as manifested by the presence of overlying beds of sulphide-bearing quartz-phyric-rhyolite breccia (Fig. 8d). This facies is very thickly bedded with some beds exceeding a stratigraphic thickness of 5 m. Beds in this facies are massive or normally graded and laterally continuous. Pronounced inverse grading at the base of individual beds is common. The breccia contains

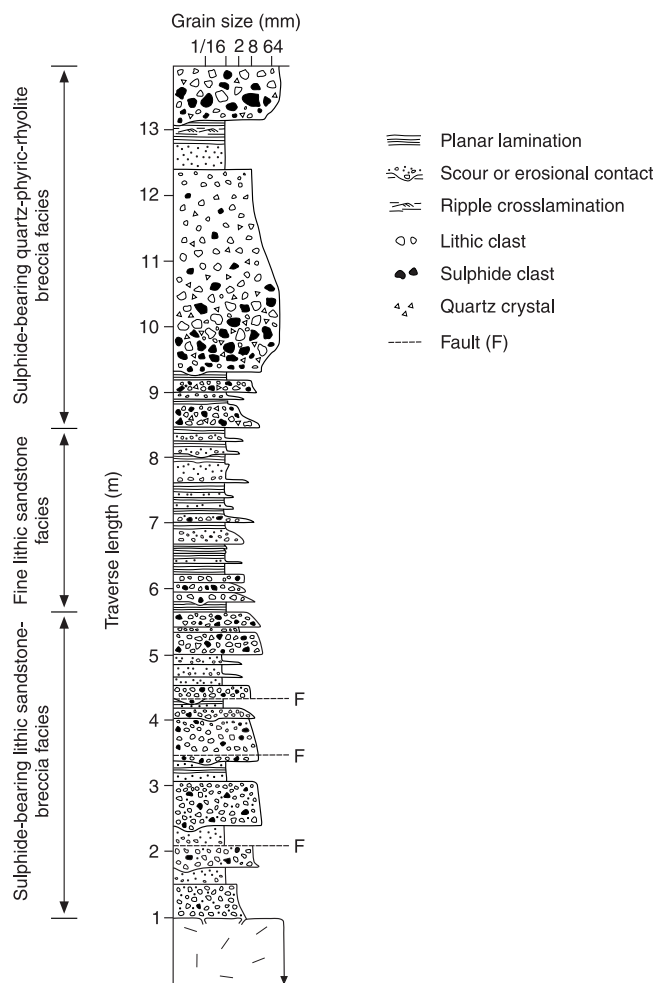


Figure 7. Schematic graphic log of the upper portion of the Horne West succession. The log is based on outcrop observations. The location of the traverse used is shown in Figure 3.

abundant rhyolite fragments, some of which are distinctly quartz-phyric. By contrast, the underlying units are essentially devoid of quartz crystals. The coarse portions of the breccia beds are framework supported and contain abundant cobble- to boulder-sized rhyolite fragments. In addition, large pyrite-dominated sulphide clasts occur that are typically concentrated in the lower portion of individual beds (Fig. 8d). Most sulphide clasts are recessive and weathered, and their locations are marked by extensive pitting of the outcrop surface. Some of the pits exceed 50 cm in diameter suggesting that the sulphide clasts were of substantial size. The matrix of this facies is typically intensely sericitized and infiltrated by disseminated pyrite. Quartz crystals and crystal fragments as well as occasional chlorite wisps are present in the otherwise irresolvable matrix. Coarse beds of the sulphide-bearing quartz-phyric-rhyolite breccia facies grade into, or are locally intercalated with, fine to coarse sandy intervals that locally contain sulphide laminations. Contacts between fine-grained intervals and overlying coarse beds are sharp and possibly erosional.

The uppermost portion of the Horne West succession is not exposed in outcrop. In the drill core investigated, the sulphide-bearing quartz-phyric-rhyolite breccia facies is overlain by a lithic-pumice breccia (Fig. 8e). This facies comprises variably thick beds that range from massive to normally graded. Long-tube pumice clasts and rhyolite fragments represent the most abundant components of this facies. The rhyolite fragments are aphyric or quartz-phyric. Sulphide clasts are present, but represent only a minor component. The lower portion of the lithic-pumice breccia is weakly to moderately sericitized and typically contains less than 5% disseminated pyrite. Volcanic textures are generally well preserved in the least altered upper portion of this facies.

The lithic-pumice breccia is overlain by a unit of aphyric coherent rhyolite. This unit is less intensely altered than the coherent rhyolite exposed in the lower and central portions of the Horne West outcrop. The most conspicuous alteration style is a fracture-controlled reddish coloration (Fig. 8f), possibly caused by the formation of secondary feldspar. The lower contact of the rhyolite unit is irregular, showing an intricate interpenetration between the lava and the lithic-pumice breccia facies. The upper contact has not been intersected by the drill holes investigated.

Mineralization

Surface mapping and logging of selected diamond-drill core during the first phase of the present study demonstrated a significant mineral potential for the Horne West area. Along with these results, the compilation and modelling of historical exploration data by Xstrata Copper Canada established that the gold-zinc mineralization at Horne West may have the potential to represent a new gold and base-metal deposit.

In a press release on November 30, 2006, the Joint Venture of Alexis Minerals Corporation and Xstrata Copper Canada announced that historical gold grades include 4.56 g/t Au over 14.63 m (hole RN-S-573), 4.27 g/t Au over 9.32 m (hole RN-9-26), 5.49 g/t Au over 20.63 m (hole RN-9-90), and 3.37 g/t Au over 15.85 m (hole RN-9-73) warranting a new exploration program in the area. In addition to the high gold grades, significant zinc mineralization was encountered. Where sampled, zinc values of 1.0 to 3.6 weight per cent over 7 to 15 m have been identified. On March 15, 2007, Alexis Minerals made public that a new surface diamond-drilling program at Horne West would test the along-strike and downplunge extent of the recognized gold-zinc zones between vertical depths of 135 m and 560 m. This new exploration program was designed to infill historical drilling carried out during the late 1930s, with the most recent drilling conducted in the late 1980s. The new drilling was completed in early 2007, totalling approximately 3700 m.

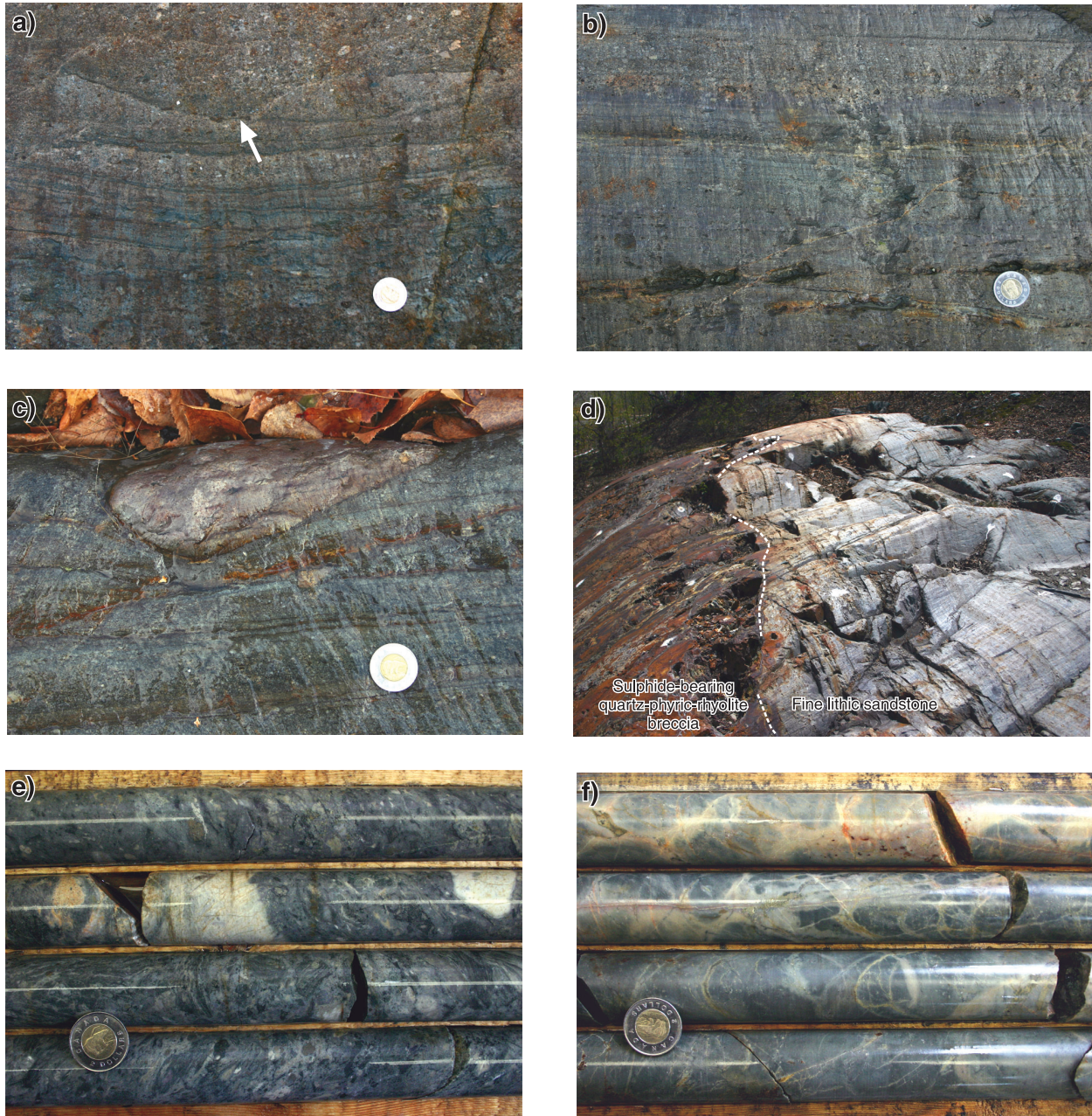


Figure 8. Photographs of volcaniclastic and coherent facies occurring in the upper portion of the Horne West succession (white spray paint marks define a 1 m x 1 m grid; coin is 2.8 cm). **a)** Erosional surface separating a bed of the sulphide-bearing lithic sandstone-breccia from an underlying interval of plane-bedded, fine lithic sandstone. The steep dip of the volcanic strata and the orientation of the channel axis of the basal scour (arrow) suggest that the mass flow was sourced more or less vertically above or below present-day outcrop. **b)** Interval of laminated to very thinly planar bedded, fine lithic sandstone. The facies is intercalated with a thin sulphide-bearing lithic sandstone-breccia bed in the upper portion of the photograph. **c)** Ballistic clast of aphyric rhyolite hosted by the fine lithic sandstone facies. Bedding sags beneath the ballistic fragment suggesting that the volcaniclastic material was wet and cohesive when the projectile landed. **d)** Contact between the planar bedded, fine lithic sandstone facies and an overlying very coarse bed of the sulphide-bearing quartz-phyric-rhyolite breccia (dashed line). The surface separating both facies is erosional. Abundant sulphide clasts occur at the base of the sulphide-bearing quartz-phyric-rhyolite breccia, the locations of which are marked by pitting of the surface outcrop. **e)** Lithic-pumice breccia in drill core. The breccia contains clasts of deformed and altered long-tube pumice that are several centimetres in size. These clasts have various orientations suggesting that the deposit is not welded. The breccia contains aphyric rhyolite clasts and minor sulphide clasts (drillhole S714 at 44–50 m). **f)** Coherent rhyolite occurring in the uppermost portion of the Horne West succession. Noticeable alteration is restricted to halos or selvages adjacent to small fractures and probably involved the formation of secondary feldspar (drillhole S714 32–38 m).

Correlation of the core logs prepared in the present study with the historical assay data suggests that the gold mineralization is largely confined to two stratigraphic intervals. Significant gold grades were encountered in the lower portion of the volcanic succession and typically correlate with stringer veins and sulphide impregnations in coherent rhyolite and associated volcanoclastic facies. Mineralization at this stratigraphic position is referred to as the New zone (Fig. 3). In addition, elevated gold grades typically occur at the top of the chlorite-wisp-bearing lithic sandstone facies and within the volcanoclastic facies occurring in the immediate footwall of the sulphide-bearing quartz-phyric-rhyolite breccia. Because the fine-grained volcanoclastic rocks at this stratigraphic position contain no significant proportions of sulphide clasts, the gold mineralization is interpreted to be associated with sulphides that formed by infiltration and replacement of the volcanoclastic debris. Mineralization in this stratigraphic position is confined to a steeply east-plunging ore zone, referred to as the West zone (Fig. 3). Preliminary observations suggest that mineralization in both stratigraphic positions is accompanied by intense sericite alteration of the host strata.

DISCUSSION AND CONCLUSIONS

The present study has established that volcanic rocks of the Horne West succession were deposited in a subaqueous environment that was characterized by effusive or shallow intrusive rhyolitic volcanism. The coherent rhyolite units that occur at several stratigraphic positions are interpreted to have been emplaced near their vents where quenching in the subaqueous environment and mixing with unconsolidated or poorly consolidated volcanoclastic material along intrusive contacts limited the areal extent of the rhyolitic lava. The limited sizes of the coherent rhyolite units (stratigraphic thicknesses of <50 m) suggest eruption of small-volume magma batches. In addition to the coherent units, voluminous, mass-flow-derived coarse volcanoclastic deposits form an important component of the Horne West succession. The abundance of chlorite wisps that are interpreted to represent formerly glassy particles and the occurrence of altered pumice clasts within these deposits suggest that the debris was, at least in part, a product of explosive felsic volcanism taking place within or outside the immediate study area. The explosive volcanic activity is interpreted to have been broadly contemporaneously with the effusive or shallow intrusive rhyolitic volcanism in the Horne West area.

The results of the present study do not confirm the suggestion of previous workers that the Horne West outcrop provides evidence supporting the occurrence of a nearby caldera margin. Detailed mapping showed that the volcanic unit in the central portion of the stratigraphy represents a coherent rhyolite body. The coherent rhyolite is associated with autoclastic breccia deposits and shows columnar joints and flow foliation. This unit has previously been regarded to

be a megabreccia (Daigneault and Pearson, 2006), presumably due to the occurrence of the unusually large xenoliths and the presence of flow banding surrounding the xenoliths, which faintly resembles contorted bedding.

Combined with drill-core investigations, surface mapping established that the Horne West succession has been subjected to hydrothermal alteration associated with widespread sulphide infiltration and replacement of the volcanic strata. Limited core logging indicates that the alteration intensity decreases noticeably within the lithic-pumice breccia, suggesting that the hydrothermal activity did not outlive the felsic volcanism. The strong asymmetry of the alteration halo and the absence of structural controls on the spatial distribution of alteration minerals in the surface outcrop suggest that the sulphide infiltration and replacement is of synvolcanic origin.

Economic gold grades have been recorded in two distinct stratigraphic positions within the Horne West succession. In the drill core investigated, elevated gold values occur in the immediate footwall of coarse volcanoclastic rocks containing abundant sulphide clasts. These mass-flow-derived volcanoclastic deposits define paleoseafloor positions within the volcanic succession that are particularly prospective for massive-sulphide mineralization. Assuming that the gold-rich disseminated sulphide mineralization occurring immediately below these two paleoseafloor positions formed in spatial and temporal association with the seafloor massive sulphides representing the source of the sulphide clasts, the mineralization at the Horne West outcrop may have formed at the fringe of, or marginal to, a long-lived, stratigraphically stacked, hydrothermal ore system. The steep dip of the volcanic strata combined with the orientation of the channel axes of basal scours suggest that the source area of the sulphide clasts is located more or less vertically below today's Horne West outcrop or, alternatively, has been eroded.

Toward the waning stage of the hydrothermal activity, volcanism in the Horne West area appears to have shifted in composition. Mafic dykes and sills present in the Horne West succession were only affected by weak sericite alteration or show no evidence for interaction with hydrothermal fluids related to the sulphide mineralization. Textural evidence suggests, however, that volcanoclastic rocks of the Horne West succession were, at least in some cases, not entirely consolidated at the time of the basalt emplacement. The basaltic dykes and sills in the Horne West succession are interpreted to correlate with widespread basaltic volcanism in the Horne block, which may record a major phase of extension, rifting, and subsidence.

Despite the fact that the Horne deposit has been mined extensively for decades, the results of the present study illustrate that the Horne block may still be prospective from an exploration point of view. Disseminated gold and zinc mineralization comparable to the Horne West area may be widespread in the felsic volcanic succession hosting the Horne deposit, warranting a re-evaluation of the economic

potential of smaller sulphide occurrences. Initial fieldwork also highlights the potential for Horne-type stratigraphy south of the Andesite fault, an area that is probably less extensively explored for this style of mineralization.

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