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GEOLOGY OF A NEWLY DISCOVERED CLUSTER OF BLIND MASSIVE-SULPHIDE DEPOSITS, PILLEY'S ISLAND, CENTRAL NEWFOUNDLAND

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ABSTRACT

An exploration program conducted by Phelps Dodge Corporation of Canada Limited, has resulted in the discovery of three new massive- and breccia-sulphide deposits, 2 to 3 km west of the old Pilley's Island Mine. The deposits are only partially delineated by widespaced drilling but are evidently members of a larger population within a partially explored volume of felsic volcanic rocks. Though larger than the Pilley's Island deposits, with massive-sulphide intersections up to 35 m, base-metal grades (to date) are low. The deposits are accompanied by a very large alteration system dominated by sericite and pyrite but also include chlorite, silica, epidote and K-feldspar alteration facies. The distribution of alteration and mineralization within the felsic-flow complex was controlled, in part, by the widespread development of perlitic cracks.

The recognition and correlation of a number of important low-angle thrust faults has been a key element in the exploration program. The Spencer's Dock deposits occur within a south-plunging antiformal stack that occurs at the same structural horizon as a separate, but similar stack to the east, which hosts the previously known Pilley's Island deposits. Within the Spencer's Dock antiformal stack, sulphide deposits occur within two of three relatively thin, shallowly dipping panels of felsic volcanic rocks.

The prognosis for exploration remains good with a large volume of favourable rock yet to be explored. The model employed puts the discoveries to date within the pyritic periphery of an ore-grade, massive-sulphide system.

INTRODUCTION

Phelps Dodge Corporation of Canada Limited, have been conducting a mineral exploration program on Pilley's Island since late 1993. A new massive-sulphide deposit was discovered by diamond drilling at Spencer's Dock less than three months after the beginning of geological mapping, and subsequent downdip discoveries of the Rowsell's Cove and Jane's Cove deposits followed. This short paper is designed to summarize the new geological thinking that has emerged, to briefly describe the nature of the massive-sulphide deposits and to complement the multidisciplinary studies ongoing by the Newfoundland Geological Survey as described elsewhere in this volume (e.g., Kerr, *this volume*).

EXPLORATION AND PRODUCTION HISTORY

There is a long history of mining and exploration on Pilley's Island dating back to the turn of the century when 425 000 tonnes of cupriferous massive pyrite were extracted between 1881 and 1908. Substantial exploration programs were conducted by Frobisher Mines during the 1950s and by Brinco Mining Limited in the 1960s and 1980s. Brinex calculated remaining reserves to be 1 159 000 tonnes of 1.23 percent Cu (Grimley, 1968), discovered the high-grade Bull Road showing and later discovered the 3B zone in 1984 (Epp, 1984). The Bull Road showing is of particular exploration significance as it is a coarse, polylithic breccia deposit containing abundant, high-grade sulphide clasts, which texturally resemble the transported ores at Buchans (cf. Thurlow and Swanson, 1981).

STRUCTURE OF THE SPENCER'S DOCK AREA

The regional geology of the Ordovician Roberts Arm Group has been described in detail by Bostock (1988) and structural relationships have been updated by Kerr (*this volume,* and Figure 1). Geological mapping, re-logging of existing drill core and new drilling by Phelps Dodge has resulted in a number of advances in the understanding of the local geology. A series of low-angle thrust faults have been identified and traced across southern Pilley's Island. The faults define an antiformal stack structure comprising a floor thrust, termed the "Liquor Street Fault Zone," and a roof thrust termed the "Hoskin's Cove Fault" (Figures 2, 3 and 4).

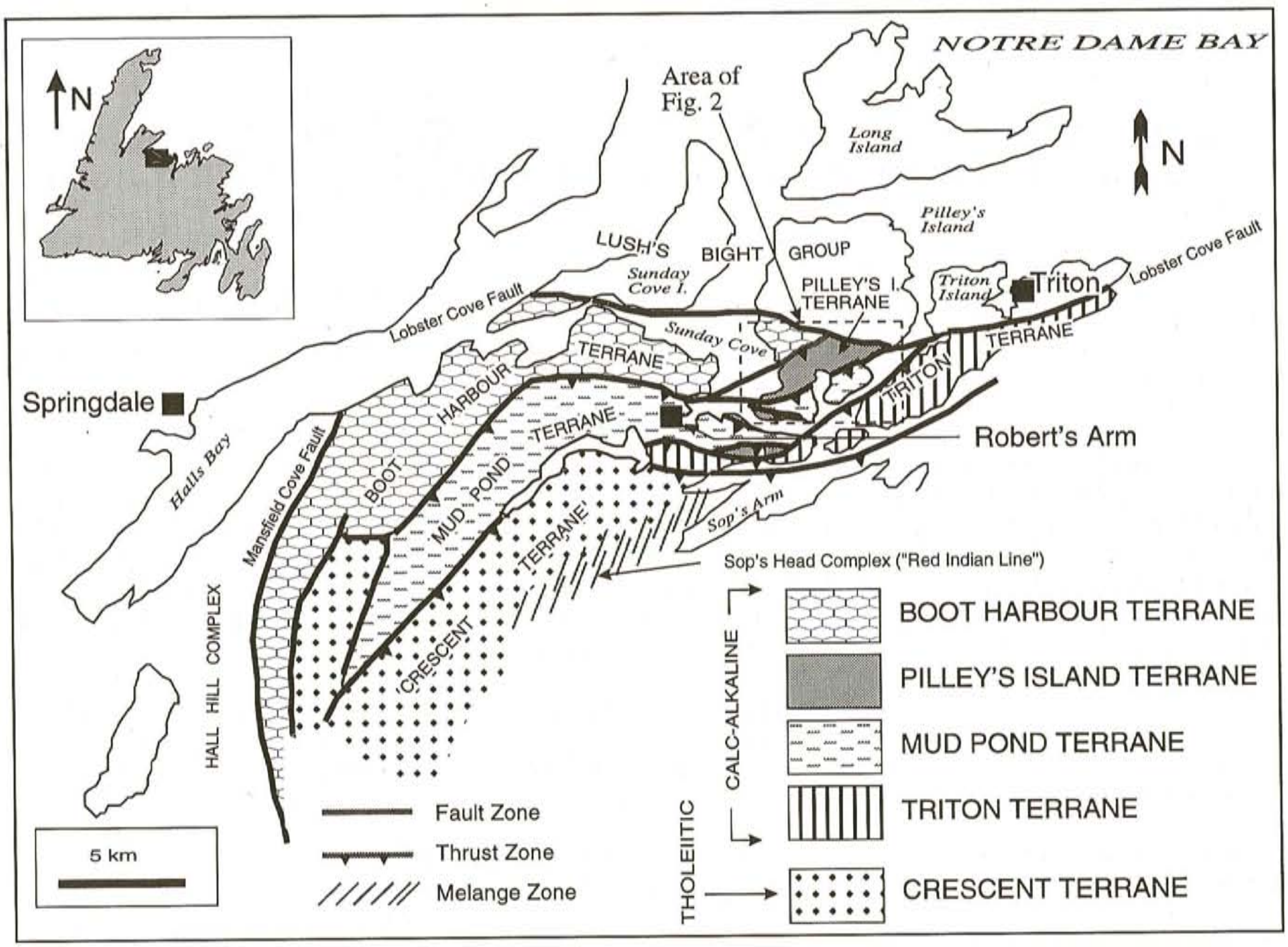

Figure 1. *Geological terranes within the Roberts Arm Group in the Pilley's Island area (after Kerr,* this volume); *area of Figure 2 is indicated.*

The antiformal stack is composed mainly of altered felsic volcanic rocks, which have been dissected internally by several other important and well-correlated faults. Unaltered basaltic rocks form both the floor and roof to the stack.

The Liquor Street Fault Zone is exposed as a spectacular melange along Pittman's Road (known as "Liquor Street" during prohibition years) and forms the base of a series of panels of altered and mineralized felsic volcanic rocks containing the massive-sulphide deposits of the Spencer's Dock area. It dips 30 to 45° to the southwest (Figures 3 and 4) and varies in thickness from less than 1 m to over 10 m in drill core. It consists of cataclasite and fault gouge containing blocks of altered mafic and felsic volcanic rocks, synvolcanic intrusive rocks and massive-sulphide lithons that exceed 5 m thickness in drill core. It juxtaposes altered and mineralized rocks above, against relatively much less altered basaltic rocks beneath the fault. The shallow dip and lithological contrast strongly suggest a thrust motion along this movement zone. The recognition of the altered and mineralized rocks in this low-angle thrust fault was the key geological observation that governed the placement of the initial discovery drillholes.

The Hoskin's Cove Fault, exposed in outcrop in Hoskin's Cove, brings a panel of unaltered pillow lava and volcaniclastic rocks above the Spencer's Dock antiformal stack (Figures 2 to 4). The floor and roof thrusts meet at a branch point near the Pilley's Island Cemetery defining the eastern limit of the antiformal stack (Figures 2, 3 and 5). The branch line can be traced in three dimensions between drillholes, as a shallowly south-plunging linear element. The surface projection of the branch line is depicted in Figure 5 and a subsurface branch point in cross section is identified on Figure 3. This branch line is parallel to a second branch line defined by the intersection of the Liquor Street Fault Zone and the "Tectonized Zone," an important thrust within the stack (Figures 3 and 4). Significantly, lithological units and volcanic facies have greater continuity in the north – south direction, parallel to the branch lines. The same observation

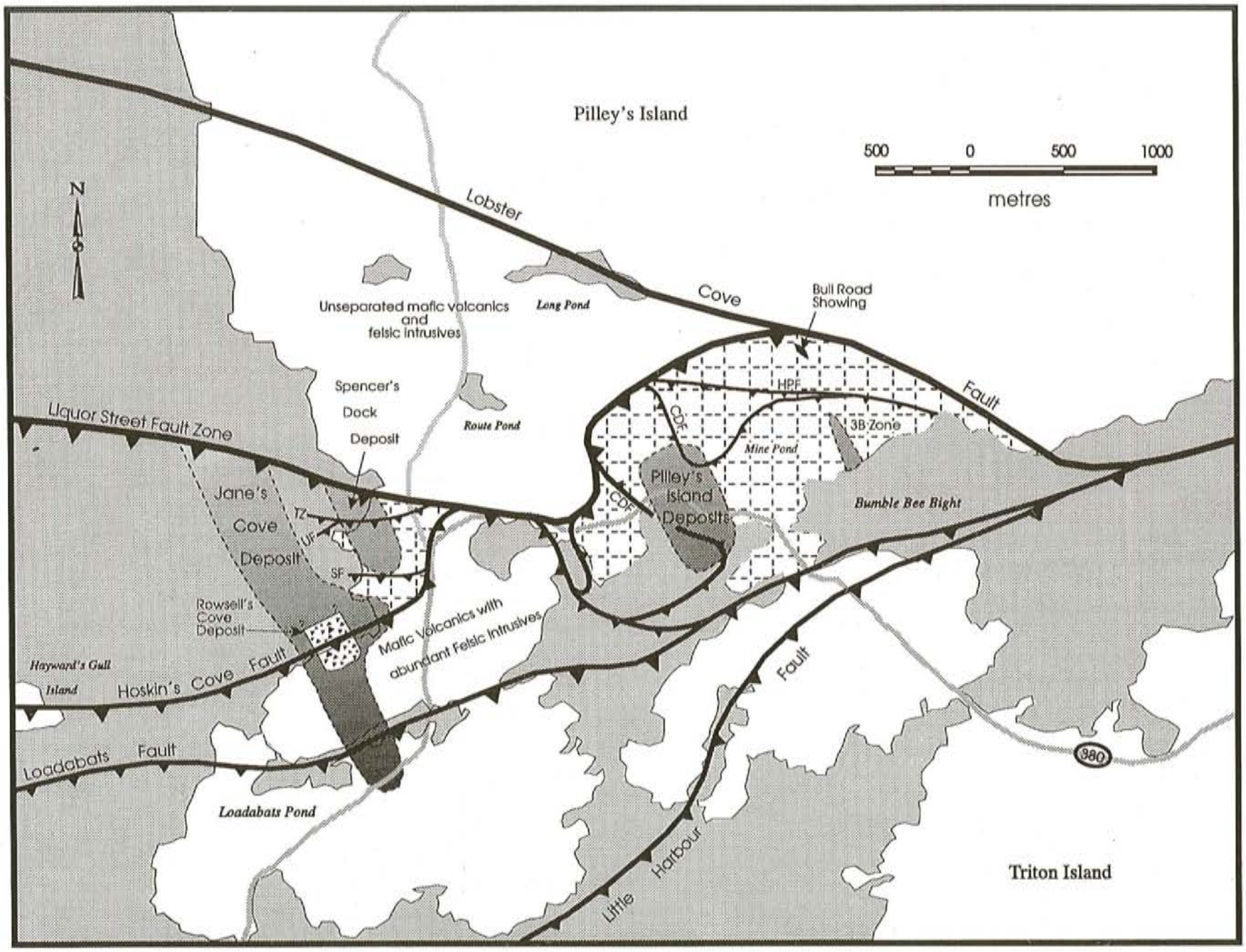

Figure 2. *Generalized geology of southern Pilley's island with sulphide deposits projected to surface. TZ = "Tectonized Zone", UF = Upper Fault, SF = Steep Fault, CDF = Ches' Dome Fault, HPF = Head's Pond Fault. Stippled are exposed areas of altered, dominantly felsic volcanic rocks within separate antiformal stacks at Spencer's Dock and in the rea of the Pilley's Island Mine. The Rowsell's Cove deposit lies 220 m above the Jane's Cove deposit.*

was made at Buchans, where it was established that early synvolcanic normal faults, which controlled the distribution of volcanic facies and mineral deposits, were inverted on later thrust faults (Thurlow and Swanson, 1987). The lithological continuity at Pilley's Island might also be caused by these stratigraphic and structural controls. The consistency of branch-line orientation suggests a frontal ramp situation (cf. Boyer and Elliott, 1981) and that thrust motion might therefore have been normal to the branch lines, i.e., easterly or westerly directed.

The Hoskin's Cove – Liquor Street branch line defines the eastern margin of the south-plunging antiformal stack that opens to the west under the waters of Sunday Cove. This stack is the mirror image of a second, separate stack to the east which hosts the historically known, south-plunging Pilley's Island massive-sulphide deposits. A poorly understood culmination in basaltic rocks below the Liquor Street Fault Zone (coincidentally?) occurs in the area between the two overlying, mineralized stacks.

"Loadabats Fault" occupies an important topographic lineament that traverses the length of Loadabats Pond (Figure 2) an is another important thrust, which emplaces hematitic pillow lavas of the Mud Pond Terrane (Kerr, *this volume*) to the south, above the mineralized and altered rocks to the north. Significantly, another panel of mineralized and altered felsic volcanic rocks, identical to those in the Spencer's Dock stack, lies structurally above these basalts and has been the subject of preliminary exploration.

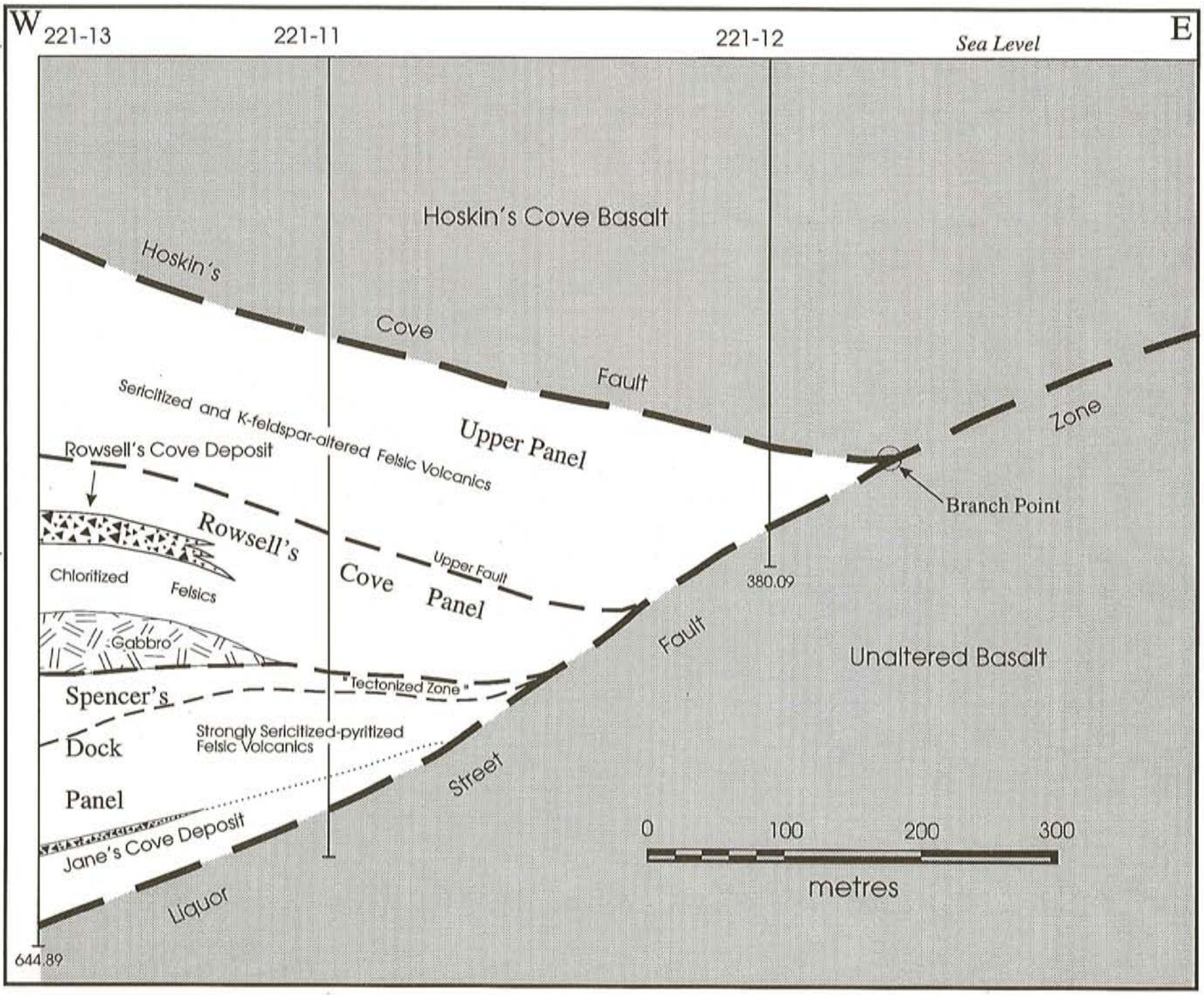

Figure 3. *East – west section showing interaction of fault panels and the branch point of the Hoskin's Cove and Liquor Street faults, marking the eastern extent of the mineralized and altered antiformal stack.*

FACING DIRECTIONS

Bostock (1988) recorded widespread overturning of the calc-alkaline terrane of the Roberts Arm Group, which Kerr (*this volume*) has verified. Observations during exploration indicate that pillow lavas both above and below the mineralized thrust stacks are demonstrably overturned, implying that the shallowly dipping mineralized panels are also overturned. However, within the felsic panels, there are rare occurrences of resedimented volcaniclastic rocks having apparently upright-facing graded beds. As well, the polarity of alteration facies around the massive-sulphide deposits suggests upright stratigraphy (see section on alteration, below). The morphology of the antiformal stacks, with flat bottoms and rounded tops, suggests that these developed while the stratigraphy was in its present (either upright or overturned) orientation. The resolution of all of these structural contradictions is not yet evident.

GEOLOGY OF THE ALTERED AND MINERALIZED FELSIC VOLCANIC ROCKS

STRUCTURE

Three panels of altered and mineralized felsic volcanic rocks, separated by low-angle thrusts, comprise the altered and mineralized thrust stack at Spencer's Dock. These panels, illustrated on Figures 3 and 4, are, from top to bottom, the "Upper Panel," "Rowsell's Cove Panel" and the "Spencer's Dock Panel."

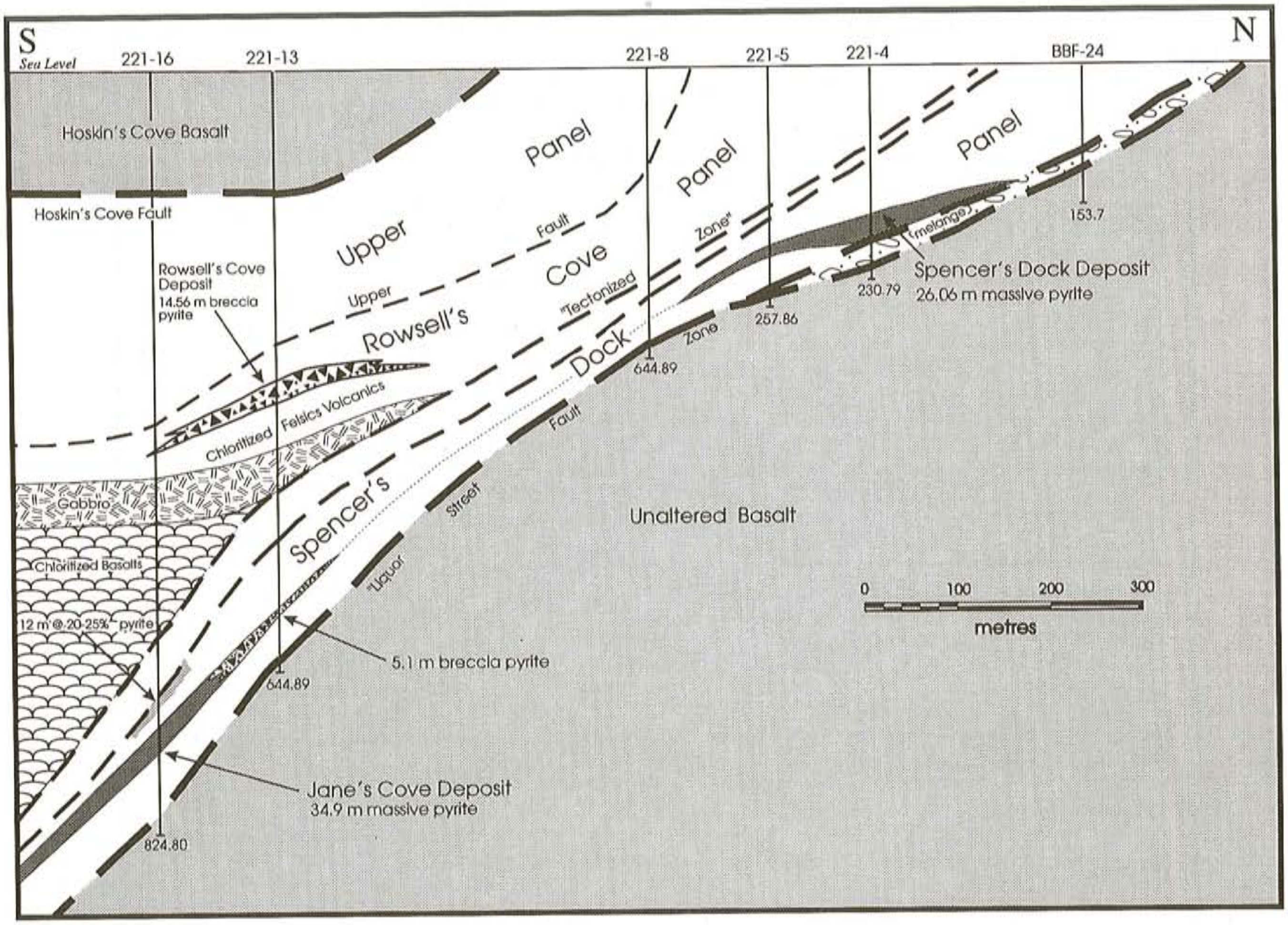

Figure 4. *North – south cross-section through the Spencer's Dock area showing major thrust panels and the relationships between sulphide deposits.*

ROCK TYPES

The Spencer's Dock area is dominated by dacitic flows with lesser hyaloclastic breccias, basaltic volcanic rocks and related volcaniclastic rocks, and synvolcanic dacitic and gabbroic intrusive rocks.

The felsic flows are light greenish to greyish, have silica contents in the 66 to 70 percent range and are characterized by widespread vesicles, amygdules and perlitic cracks. Compared to many VMS environments, there is relatively little autobreccia and volcaniclastic rocks, and little evidence of explosive volcanic activity. No quartz phenocrysts have been observed and plagioclase laths are not common. Dacitic flows of the Upper Panel (Figures 3 and 4) are characterized by spectacular contorted flow-banding and, locally, by anomalous 10-cm-spheroidal structures having irregular hollow cores (geodes?). Abundant fine, stretched tube vesicles are common in some flows suggesting flow of frothy pumice. Perlitic cracks in originally glassy material are very common and pseudo-fragmental textures, caused by alteration along perlitic cracks, are widespread and very well developed.

Sills of altered, synvolcanic dacite are common and are distinguished by their leucocratic aspect, aligned silica-filled amygdules and a distinctive "curdled" matrix texture. Contacts with host dacite in drill core are generally nebulous, although a few distinct, weakly chilled contacts were observed.

Basaltic flows and volcaniclastic rocks are subordinate to the dacitic volcanic rocks above the Liquor Street Fault Zone. Basalts are normally amygdular (quartz and calcite-filled) and locally pillowed. Distinctive volcaniclastic rocks characterized by reddish, hematized fragments in a greenish, non-hematized matrix are present both above and below the Liquor Street Fault Zone. An important, altered and mineralized, synvolcanic gabbro sill occurs in the structural footwall of the Rowsell's Cove deposit (Figure 4).

Fairly significant areas of surface outcrop are composed of shallowly dipping, enigmatic felsic sills. Lithogeochemically, they resemble volcanic rocks, and are probably syn- or late-volcanic. They display a perplexing and grad-

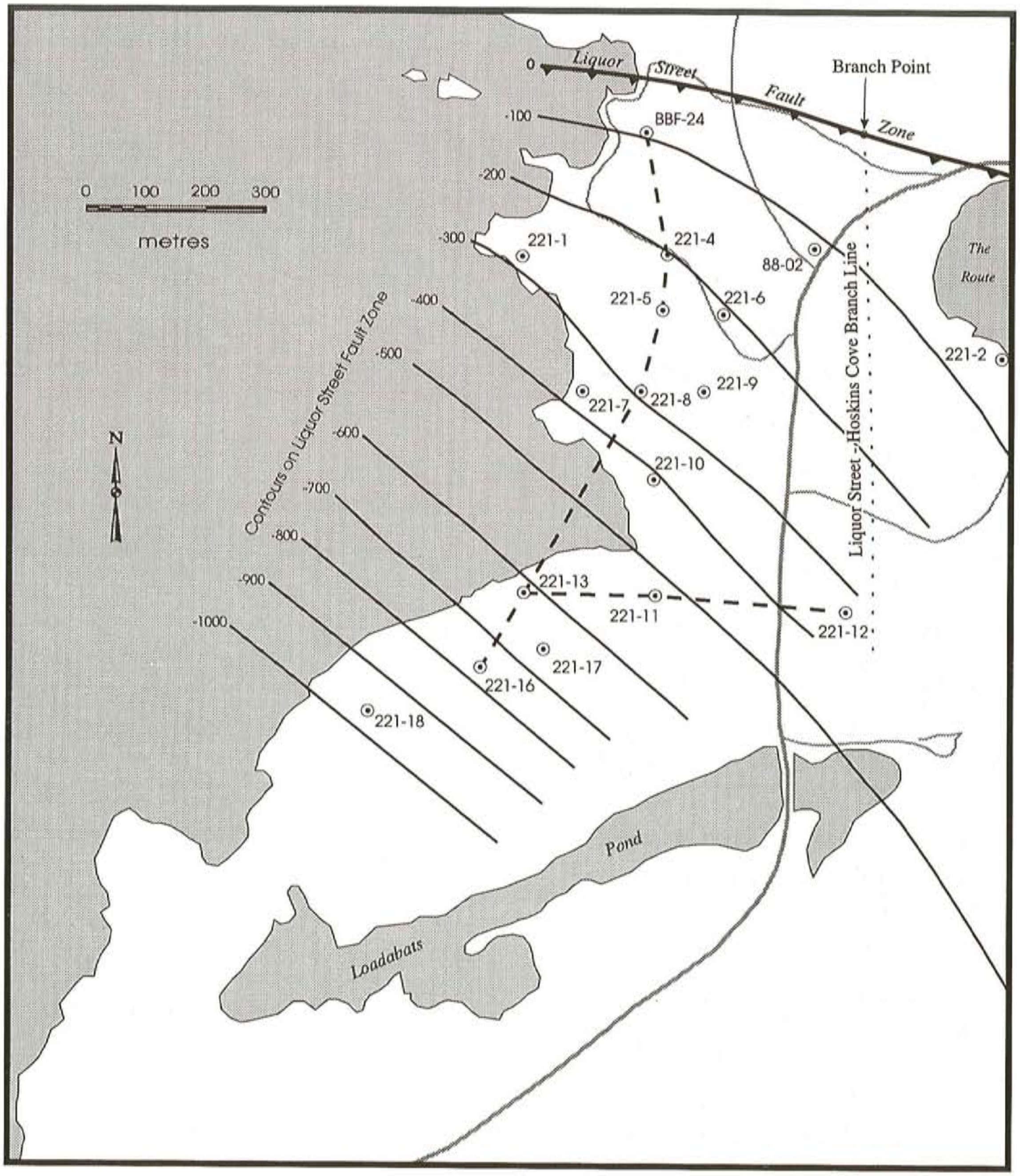

Figure 5. *Structural contours on the Liquor Street Fault Zone, measured in metres below sea level. Drillhole locations, which are data points for the contours, are identified. Dashed lines show location of section lines of Figures 3 and 4. Branch point of Liquor Street and Hoskin's Cove faults is indicated as is the branch line (dotted).*

ational array of textures caused by the overprint of alteration on a heterogeneous, high-level host. There is an association between the occurrence of these intrusive sills and the presence of thrust faults, although it is clear that the bulk of comminution along the thrusts is post-intrusion.

STRATIGRAPHY

There are several impediments to the recognition of the original volcanic stratigraphy and the primary distribution of alteration facies in the Spencer's Dock area. These include the thin-skinned thrust tectonics, abundant flows and relative lack of volcaniclastic rocks, a lack of preserved conformable contacts, complex facies changes, wide-spaced drilling and uncertainty as to stratigraphic tops. Accordingly, stratigraphic knowledge is scarce and, with the recognition of widespread thrust faulting, earlier stratigraphic models (e.g., Tuach, 1990) must be revised. It has been determined that the felsic volcanic rocks lie conformably above the mafic volcanic rocks and that a resedimented breccia/volcaniclastic horizon lies above the massive-sulphide horizon in almost all instances.

ALTERATION

Sericitic, chloritic, silicic, pyritic and Fe-carbonate alteration are widespread and readily identifiable in the Spencer's Dock area. Less evident in the field, but equally significant volumetrically, is the presence of fine-grained K-feldspar alteration. In general, the strength of alteration and abundance of disseminated and veinlet pyrite increases downward from the Upper Panel to the Rowsell's Cove Panel to the Spencer's Dock Panel. Lithogeochemical alteration scores, defined by $(K_2O+MgO)*100/(K_2O+MgO+CaO+Na_2O)$ are consistently above 90 in all three panels. The scale of alteration at Spencer's Dock is large compared to most Appalachian VMS systems, including Buchans, and may be commensurate with the size of the poorly defined known massive sulphides and of deposits that remain, as yet, undiscovered.

A significant feature of the mineralized felsic lavas is their porosity, generated by abundant amygdules and fine vesicles and their considerable permeability, developed as a consequence of widespread perlitic cracking. This latter feature is a significant control on the distribution and strength of alteration and therefore on the distribution of massive sulphides.

Sericitization is the most widespread alteration facies, variably affecting all rocks in the Spencer's Dock area. Weak silicification, possibly isochemical during devitrification/alteration, normally accompanies the sericitization of the glassy lavas. Disseminated pyrite generally accompanies the sericitic alteration and low-grade disseminated sphalerite and chalcopyrite are widespread as void-fillings in the sericitized lavas.

Chloritic alteration is the most proximal alteration facies occurring mainly in the structural footwall of the massive-sulphide deposits. Chlorite at the Spencer's Dock deposit forms a thin sheet in the immediate footwall of the massive sulphide, which extends beyond the deposit as a blanket-shaped stratigraphically controlled feature. Basaltic and gabbroic rocks below the Rowsell's Cove deposit are strongly chloritized and pyritized but this alteration is truncated by an important thrust, the "Tectonized Zone." Alteration in the gabbro is particularly interesting as proximal chlorite-pyrite alteration with significant base-metal-bearing veins near the upper contact grade into a less robust epidote – pyrite association within the interior of the gabbro. Chlorite is the dominant alteration facies within basaltic rocks below the Old Mine massive sulphides and forms an equant chlorite – pyrite alteration zone, at least 200 m thick, which decreases in intensity away from the sulphide deposits, both with depth and along strike.

K-feldspar alteration is best developed structurally above the massive sulphides in the Upper Panel (Figure 3). Macroscopically, these rocks are unremarkable light grey-green, pyrite-free, hard, dacitic lavas having a weakly silicified aspect. However, despite a lack of sericite, they typically contain 6 to 11 percent K_2O, well above the 3 to 5 percent K_2O, which is typical of ambient weakly to strongly sericitized dacite. The bullseye airborne potassium anomaly recorded over the Spencer's Dock area (Ford, 1992) is caused by good exposure of outcrop with high-K_2O contents. Santaguida *et al.* (1992) report that K-feldspar alteration is a hanging-wall alteration facies at the Pilley's Island Mine and is absent from the mineralized horizon and from the footwall. These observations are valid at Spencer's Dock as well.

Carbonate alteration (presumed to be ferroan) produces areas of characteristically rusty-weathering outcrops in felsic rocks that are notable for their complete lack of pyrite. This alteration locally responds to HCl with weak effervescence. Fine-grained, disseminated carbonate alteration is generally accompanied by an anomalous light-green (sericitic?) alteration. The relationship between the carbonate-altered rocks and the more proximal sericitized rocks prior to thrusting is not yet clear, though the carbonate-altered felsic rocks clearly intrude basaltic rocks. A substantial lithon of carbonate-altered felsic rock occurs within cataclasite of the Liquor Street Fault Zone below the Spencer's Dock massive-sulphide body indicating that the carbonate alteration did not occur after thrusting.

Silicic alteration is widespread and most easily recognized as void fillings in both mafic and felsic rocks. Pervasive silicification locally occurs in association with vermiform silicic, sulphidic veining.

Disseminated *pyrite* (1 to 3 percent) is common throughout the felsic volcanic rocks of the Rowsell's Cove and Spencer's Dock panels but rocks affected by carbonate and K-feldspar alteration can be almost barren of sulphides. The largely blind panel of rock containing the Spencer's Dock and Jane's Cove massive-sulphide deposits is strongly sericitized and pyritized; these rocks are exposed on surface only at

Spencer's Dock itself and as "knockers" in the Liquor Street Fault Zone. Massive pyrite veins, locally exceeding 30 cm width, occur in association with the massive-sulphide deposits, although large volumes of stringer-style veining are not present.

Epidote – pyrite alteration is confined to the deeper parts of the basaltic pile below the Old Mine and the synvolcanic gabbro body beneath the Rowsell's Cove deposit. In both cases, it is evidently a peripheral alteration facies and an indicator of the presence of stronger nearby VMS-style alteration. The relationship between this epidote and the widespread regional epidotization of pillow lavas within the northern Roberts Arm Group has not been firmly established though Swinden and Wilson (1994) consider the latter to have no relation to the massive sulphides.

SULPHIDE DEPOSITS

Spencer's Dock Deposit

The Spencer's Dock deposit is the shallowest new sulphide deposit consisting of 26 m of massive pyrite at depths between 165.64 and 198.2 m in hole PI-221-4 and 11.6 m of massive pyrite downdip in hole 221-5 (Figure 4). Pyrite grain size is medium to coarse with some 10 mm pyrite crystals; grain size tends to be coarsest toward the centre of the body. Base-metal sulphides and precious metals are present only in trace amounts. Sericite with lesser silica – carbonate are the main gangue minerals and are interstitial to pyrite. The sulphides are generally structureless with a planar aspect developed only in more sericitic sections. Contacts with altered and pyritized host rocks are fairly sharp or are sheared.

The deposit is floored at its updip end by a spectacular thrust/melange zone, the Liquor Street Fault Zone. The fault contains numerous massive-sulphide lithons that have been derived from the adjacent massive sulphides, which have become dismembered where they are cut off by the fault. Basaltic rocks below the Liquor Street Fault Zone are unaltered The massive sulphide is overlain by, and inter-layered with strongly sericitized and pyritized felsic volcanic rocks.

Rowsell's Cove Deposit

This deposit is distinct from the Spencer's Dock and Jane's Cove deposits in several regards. It occurs in the structurally higher Rowsell's Cove panel, 220 m above the Jane's Cove deposit and is composed entirely of a breccia containing abundant massive pyrite clasts that contain low-grade chalcopyrite. Hole 221-13 intersected 14.6 m of breccia mineralization containing 0.34 percent Cu. The pyrite-rich breccia flanks a domal dacitic body and is interbedded with dacitic hyaloclastic breccia. Pyrite clasts comprise 70 percent of the breccia having clasts that average 10 cm size but reach a maximum diameter of 65 cm. Clasts of sericitized and silicified felsic volcanic rocks, some with altered rims, form the balance of the fairly tightly packed, but matrix-supported breccia.

Jane's Cove Deposit

This is the largest and deepest massive-sulphide zone and has been only partially delineated by widespaced drilling. It occurs relatively close to the Liquor Street Fault Zone (Figure 4), in a structural position very similar to the Spencer's Dock deposit. Mineralogically and texturally, it is also very similar to the Spencer's Dock deposit. It apparently covers a large area and is represented by 35 m of massive pyrite in hole 221-16, 5.1 m of breccia sulphide in hole 221-13 and 1.1 m of massive pyrite in hole 221-10. Beyond the deposit, a siliceous, weakly hematitic horizon, reminiscent of a Kuroko tetsusekei horizon, is locally present.

COMMENTS ON GENESIS OF THE SULPHIDE DEPOSITS

Well-developed perlitic cracks are characteristic of the massive dacitic flows of the Spencer's Dock area. In areas of incipient alteration, the exploitation of perlitic cracks by the alteration and mineralization is evident and results in the widespread development of pseudofragmental textures (cf., Allen, 1988). Disseminated pyrite, which accompanies the alteration, becomes more abundant in proximity to the sulphide bodies. Though contacts with the massive pyrite are generally quite sharp, some contacts are characterized by a gradation, over several metres, from disseminated to semi-massive to massive pyrite. Relict perlitic cracks can be seen within the strongly sericitized and silicified semi-massive (50 percent) pyrite sections. This suggests that the massive sulphides formed, at least in part, by replacement of a glassy felsic flow lithology with pyrite during alteration.

CORRELATION WITH THE OLD MINE AREA

As discussed above, the felsic volcanic rocks of the Spencer's Dock area and those of the Old Mine area occur at the same structural level but are in entirely separate antiformal stack structures. As such, there is no direct, continuous correlation between the two areas. Nonetheless, the rock types, alteration facies, mineral deposits and structural stacking of panels are all very similar.

EXPLORATION PROGNOSIS

Despite the thick massive pyrite intersections, and the very large volume of strong sericitic alteration with accompanying disseminated and veinlet pyrite and base metals, it is felt that the prime focus for hydrothermal activity on this property has not yet been discovered. Indeed, the system outlined to date is thought to represent peripheral, largely replacement deposits in porous/permeable volcanic rocks around a source of stronger mineralization. It is felt that this source area will be characterized by more proximal breccia deposits, by widespread chlorite alteration in felsic volcanic rocks, by stronger stringer and stockwork mineralization and possibly by large, ore-grade massive-sulphide deposits.

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