# STRUCTURAL AND STRATIGRAPHIC CONTROLS ON MINERALIZATION AT THE BEAVER BROOK ANTIMONY DEPOSIT, CENTRAL NEWFOUNDLAND

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# ABSTRACT

In 1989, antimony mineralization was discovered about 45 km south of Glenwood, central Newfoundland, and, following extensive exploration and development, was subsequently brought into production as the Beaver Brook antimony mine in 1998. The mine has inferred, and indicated, resources of over 2 million tonnes, making it one of the largest antimony deposits in the world.

The ore consists almost entirely of stibnite, with trace amounts of pyrite, as the only other sulphide present. Where stibnite has been exposed to surficial weathering, the minerals stibiconite and valentinite are developed. The principal gangue minerals are quartz and dolomite. Epithermal textures are common, including crustiform and colliform quartz and quartz replacement of stibnite.

Mineralization is structurally controlled, most commonly forming the cement to re-healed fault breccias. Host rocks to the mineralization include both the Ordovician Davidsville Group and Late Silurian Indian Islands Group. Field mapping during 2005 indicates that the Davidsville Group was imbricately thrust over the Indian Islands Group in the vicinity of the deposit. This fault system may also be the structure that hosts most of the antimony mineralization.

# **INTRODUCTION**

This project was undertaken, in cooperation with the Newfoundland and Labrador Department of Natural Resources, Geological Survey, to study the Beaver Brook antimony deposit of central Newfoundland. The mine, located 43 km south of Glenwood (Figure 1), has the potential to produce 5 percent of the world's antimony supply. Resources have been estimated to total 2.1 million tonnes at an average grade of 4.3% Sb; 23 000 tonnes of ore were produced before shutdown in 1998. Production facilities consist of a mine decline, a mill with a capacity of 400 tonnes per day, and associated support infrastructure.

This deposit, despite its world-class nature, has not previously been examined in detail. This study will attempt to redress this situation by providing information on the nature and timing of the mineralization. The derived data might then be used to spur further exploration for antimony in Newfoundland and Labrador and elsewhere in the Appalachians. China is the world's major antimony producer, supplying 90 percent of the world's demand (100 000 tonnes) in 2004. Production is centred on the Xikuangshan deposit (~2 110 000 tonnes of recoverable antimony; ore tonnage and grade are unknown), which is exploited from four large mines and many smaller ones. The balance of the world's antimony production comes from the Murchison Greenstone belt in South Africa and smaller mines in Russia and Bolivia. There are currently no North American producers of antimony. The Sunshine mine located in Idaho, USA, did produce antimony as a by-product from silver mining, but has been closed since 2001.

Of all the commonly used elements, antimony may well be the least well understood. Even amongst geologists it is best known as a pathfinder element in gold exploration programs. Historically, antimony has been used as a lead hardener, most notably in lead-acid storage batteries, but it is also a component in ammunition and a constituent in alloys such as Britannia and Pewter. Production of lead-acid batteries continues to be a major use, but much of the antimo-



ny used for this purpose is reclaimed from the recycling of lead-acid batteries. For "new" antimony, the major uses include decolourization of optical glass, incorporation in Babbit metal to produce frictionless bearings, and as flame retardant in plastics. Antimony is not a flame retardant in itself, but it enhances the effect of other compounds that are.

## LOCATION, ACCESS AND PHYSIOGRAPHY

The deposit consists of three prospects, the Xingchang, Hunan and Szechwan, respectively (also known as the West, Central, and East zones), that extend for a distance of over 4 km, northwest of the Northwest Gander River (Figure 1). The mine site is actually part of the Szechwan Prospect. The prospects are readily accessed via the Salmon River allweather gravel forestry access road that extends southward from Glenwood. The Beaver Brook mine and facilities (Szechwan Prospect) are located 43 km south of Glenwood along this road. The Hunan Prospect is actually in the roadbed of a spur road off this main logging road, 3 km southwest of the Szechwan Prospect. The Xingchang Prospect is 1 km to the southwest of the Hunan Prospect and can only be reached via an overgrown skidder trail that branches off the spur road. Locations of the three prospects are shown in Figure 1.

Physiographically the region around the deposit is nominally thickly wooded, but extensive logging over the past decade has significantly reduced the forest cover; Black Spruce is the dominant tree type, with lesser amounts of Balsam Fir, White Birch and Aspen and White Pine is locally common. The prospects are located on the west side of the valley cut by the Northwest Gander River. Elevation change is relatively rapid, limiting the size and number of ponds and marshes in the area. Creeks and streams draining the sides of this valley into the Northwest Gander River express this elevation change with rapids and falls, in some cases up 10 m high.

## HISTORY OF EXPLORATION

In 1989, prospectors working for the Noranda/Noront Grubline Syndicate discovered massive stibnite boulders in Beaver Brook. Follow-up soil sampling indicated an 8 by 1 km antimony anomaly with three areas identified for more detailed work. These were designated as the Szechwan, Xingchang, and Hunan prospects, but are also known as the East, West and Central zones, respectively. Six diamonddrill holes totaling 584.3 m were completed on the West Zone, but returned disappointing results and, hence, work on the property was suspended (Bourgoin, 2003). A private company joint-ventured with the Syndicate in 1992, assuming a 50 percent interest in the property. Twenty-three drillholes with a cumulative depth of 2308 m tested the Central Zone; however, only limited mineralization was encountered (Bourgoin, *op. cit.*).

In 1993, Roycefield Resources obtained a 50 percent interest in the property and the Central Zone was tested by 19 diamond-drill holes totaling 2369 m. Limited mineralization was once more encountered (Bourgoin, 2003).

Roycefield Resources obtained a 100 percent interest in the property in 1994. Soil cover on the Central Zone was stripped and the exposed veins were mapped and sampled. Forty-six holes, totaling 6462 m were drilled through the East Zone and returned encouraging results. An underground ramp was constructed in 1995 to test the East Zone mineralization as defined by the drilling. Coupled with an additional 22 holes that had a cumulative depth of 4214 m, the underground mining confirmed the presence of a significant ore body. An independent review of the drilling data indicated a measured resource of 898 400 tonnes of ore at an average grade of 3.7% Sb (Bourgoin, 2003). Twelve additional holes totaling 1457 m were completed in 1996 (*op. cit.*).

Drilling and underground exploration increased resource estimates to 2 119 880 tonnes with an average grade of 4.41% Sb. Based on this new resource calculation, Roycefield Resources Ltd. decided to commence mine construction. A mill was constructed and began processing 23 000 tonnes of development muck in 1997 (Bourgoin, 2003). However, in 1998, record low antimony prices led Roycefield Resources Ltd. to cease operations and place the mine on care and maintenance status.

In 2003, VVC Exploration Corp. announced that it had entered into an agreement to acquire all the mine assets from Beaver Brook Resources Ltd. for \$17 million in cash, stocks and future considerations. The deal was finalized on March 1, 2004. Late in the summer of 2004, VVC announced that it had completed a 13 000-m diamond-drilling program designed to verify the grade, tonnage and continuity of the deposit. Assay results were reported for the first 35 drillholes and VVC interpreted the results to support the continuity of mineralization as well as identifying several new zones of mineralization (VVC Press Release, 2004).

On August 4, 2005, VVC announced that it had renegotiated its \$16 million debt on the project by issuing shares of VVC and its wholly-owned subsidiary, Beaver Brook Antimony Mines Inc., as well as \$250 000 cash, to Beaver Brook Resources Ltd. VVC Exploration now retains a 27.5 percent interest in the project with Beaver Brook Resources controlling the remainder.

#### **REGIONAL GEOLOGY**

The regional geology in the immediate mine area consists of three main components (Figure 1), viz.; the Mount Peyton Intrusive Suite to the west and a structurally mixed zone of Indian Islands Group and Davidsville Group sedimentary rocks. The Davidsville Group is characterized by black graphitic shale, sandstone, and conglomerate containing a large proportion of mafic clasts (Blackwood, 1982). Locally, the shale contains abundant graptolites that have been identified as being of Caradoc age (Williams and Tallman, 1995). The unit has been overturned and thrust toward the west.

The Indian Islands Group (IIG) is composed of shallow-marine sedimentary rocks that, in a regional sense, are believed to unconformably overlie the Davidsville Group. The IIG comprises shallow-marine, near-shore sedimentary facies consisting of shales, siltstones and limestones (Williams *et al.*, 1993). Limestone predominates near the base of the unit, but grades upward into shales and finally into interbedded red siltstones and shales with minor limestone. The bivalve *Cuneamya arata*, derived from fossiliferous strata near the top of the group, indicates an age of Pridoli (latest Silurian) to Gedinnian (earliest Devonian) (Boyce *et al.*, 1993).

To the west of the mine is the bimodal Mount Peyton Intrusive Suite (MPIS). The intrusion underlies an area of approximately 1400 km<sup>2</sup>, and is inferred to be a laccolith. Hynes and Rivers (2002) suggest that the intrusion comprises four phases, that are, from oldest to youngest: pyroxene-hornblende gabbro, quartz diorite-granodiorite, biotite granite, and biotite-hornblende granite. Only biotite-hornblende granite is present to the west of the mine area.

As described by O'Driscoll and Wilton (2005), attempts to date the various intrusive phases of the MPIS have been equivocal. Dunning (1992) dated a pegmatitic gabbro, from what he termed the southern MPIS, at  $424 \pm 2$  Ma; and later he (Dunning, 1994) dated a gabbro phase from the northern MPIS with a similar 424  $\pm$  2 Ma age. Dunning and Manser (1993) analyzed a granite phase from the MPIS from which they derived two possible age interpretations: (1) a mixing line from  $419 \pm 2$  Ma to 2680 Ma, and (2) a discordia line which intersected concordia at  $31 \pm 85$  Ma and 439.5 + 9/-6Ma; they favoured the latter age (i.e., 439.5 +9/-6 Ma). Others however, (e.g., Lawson Dickson as reported in O'Driscoll and Wilton (2005), preferred the 419  $\pm$  2 Ma age for the granite phase on geological grounds. Furthermore, geochemical data derived by Mitchinson (2001) indicated that the southern gabbro is actually part of the Caribou Hills Intrusion that was intruded by the MPIS.

The nature of the contact between the Indian Islands Group and the MPIS is unclear because of limited exposure. Williams (1993) inferred that the MPIS had intruded into the Indian Islands Group, despite the lack of a well formed metamorphic aureole like that developed on the western margin of the intrusion in the vicinity of the town of Norris Arm. Barbour (2003) suggested that the contact was at least partly structural in nature, based on brook exposures to the north of the present study area. Mapping conducted for this study indicates that the contact may, in fact, be intrusive. This is consistent with previous work by Dickson (1992) and G. Squires (unpublished data) that documented hornfels near the contact between the Indian Islands Group and the MPIS.

## LOCAL GEOLOGY

Most of the mapping for this study (Figure 1) was conducted in exposed trenches that constitute each of the three showings, road outcrops, and traverses up Cooper and Beaver brooks. The antimony mineralization in the Beaver Brook mine area is located within both the Davidsville and Indian Islands groups.

## **Davidsville Group**

Davidsville Group rocks in the area mapped are limited to an apparent fault-bounded wedge surrounded by sedimentary rocks of the Indian Islands Group. This wedge is composed of three distinct sedimentary facies, including graphitic black chert and shale, pebble greywacke and siltstone.

The siltstone is dark grey to dark blue grey, and weathers brown to rusty. The unit appears to be massive, although bedding may be obscured by the strong cleavage fabric within exposed sections of this unit. A distinctive graptolite assemblage has been described from this siltstone by Williams and Tallman (1995). The strong cleavage has led to poor preservation of many specimens, but *Aulograptus* cf. *cucullus* and *Undulograptus primus* have been identified with some confidence. These species indicate that the age of deposition was late Arenig (Williams and Tallman, *op. cit.*).

The greywacke appears to lie conformably above the siltstone, with an interbedded contact. The greywacke is a brown-weathering, grey-brown, thickly bedded and fine- to medium-grained rock. Clasts range from granule to cobble size, and consist mainly of black shale, with other sedimentary rock types. The greywacke also contains exotic clasts, the most notable being cobbles of red-weathering, vesicular, quartz-phyric porphyry, the affinities of which are unknown.

The matrix of the greywacke has been altered to assemblages dominated by chlorite and sericite. This is most obvious in the Central Zone (Hunan) trenches where sericite is common throughout the matrix, but chlorite appears to be limited to thin zones where it is commonly associated with quartz. The proximity of this alteration to a zone of antimony mineralization suggests it may be related to this mineralizing event. However, the same greywacke several kilometres distal to this zone of mineralization also shows the same alteration, suggesting that it is diagenetic and/or metamorphic in nature.

Possible scours and grading suggest facing directions in this unit are to the west, indicating that the unit lies stratigraphically above the siltstone. One portion of the greywacke was previously termed the Hunan Pebble Greywacke (Williams and Tallman, 1995); for simplicity this name has been applied to the entire greywacke unit.

The chert consists of graphitic and sulphidic black chert and shale. It is commonly fractured and brecciated, especially in areas close to faults. In the vicinity of Beaver Brook, the black shales contain graptolites, including *Pseudoclimograptus scharenbergi* (Lapworth), *Climograptus? brevis* Elles and Wood, and *Corynoides calicularis* Nicholson (Williams and Tallman, 1995). This assemblage indicates a Caradoc age, which suggests that it may correlate with other Caradocian graptolite occurrences that are present several kilometres to the southwest (Dickson, 1992), thus indicating that the Davidsville Group is much more extensive than defined by this mapping.

#### **Indian Islands Group**

The Indian Islands Group (IIG) in the map area can be divided into two distinct units. Unit 1 is thinly bedded greygreen siltstone that contains inclusions of brown-whiteweathering, fine-grained dolomitic sandstone. It is unclear whether these are diagenetic nodules, or represent dolomitic sandstone beds that have been dismembered during subsequent tectonic activity. In some localities, the nodules are situated next to each other, parallel to the strike of the beds, suggesting that they are the remnants of a broken up bed. This unit is thinly bedded, with rare load casts and flame structures, which indicate facing directions to the west (i.e., toward the MPIS). This is consistent with facing structures in other parts of the IIG. Beds in this unit dip to the east, indicating that it is overturned. Near its top, the unit becomes distinctly brown weathering, suggesting a higher carbonate content. Rare debris-flow beds in the top of the unit contain abundant fossil fragments (Plate 1). Fossils include favosites, corals, crinoids, bryozoa and trace fossils. These fauna are not diagnostic with respect to age but are identical to typical IIG fossil assemblages to the north.



**Plate 1.** Pod of fossiliferous limestone within a dolomiterich siltstone, Cooper Brook. Crinoids (C) and brachiopods (B) are visible in the picture. The fossils have been variably recrystallized but are still readily identifiable.

Therefore, Unit 1 can be considered to be part of the IIG with a high degree of confidence.

Unit 2 is a cross-laminated red sandstone similar to that which overlies the IIG in other areas (cf. Williams *et al.*, 1993). Near the inferred contact with the MPIS, the red sandstone changes from red to dark grey and becomes extremely hard, suggesting that it has been hornfelsed as a result of contact metamorphism. If this is indeed the case, it indicates that the MPIS intrudes the IIG.

#### **Mount Peyton Intrusive Suite**

The Mount Peyton Intrusive Suite (MPIS) was only observed in outcrop along the Cooper Brook traverse. It is a pink, fine- to medium-grained, biotite granite, lacking shearing or other signs of deformation. The discovery of hornfelsed IIG rocks adds further complexity to the issue of the age of the MPIS because at least that portion in the study area must be early Devonian age or younger. The conflicting ages obtained for the MPIS granite suggest that it is in fact, a composite of several different granite bodies with different ages; these will be detailed later.

#### **Intrusive Rocks**

Mafic dykes were first noted in the area near the West Zone (Xingchang Prospect) when an altered dyke was intersected in drill core during the antimony exploration program. It was described by Tallman and Evans (1994) as being "variably altered to skeletal leucoxene, coarse patchy purple leucoxene?, carbonate, chlorite, and remnant plagioclase and ranges from leucocratic to melanocratic in overall appearance". They also noted that the dyke appeared to have a 15-cm-wide chilled margin at its upper contact and was cut by several small zones of fault gouge.

Several dykes were intersected during the 2004 drilling program on the Szechwan Prospect (East Zone). These dykes were uniformly dark grey-green, and fine grained and have phenocrysts of possible olivine and plagioclase. The dykes appear to be fresh and unaltered, with preserved chill margins on several samples. One altered section of core recovered in 2004, with a matrix of chlorite and leucoxene similar to that described above, may also be a dyke, but this has not been confirmed. It may in fact be an altered mafic block, as the drilling intersected several intervals that contain large, altered, apparently mafic clasts, altered to carbonate and leucoxene. In one case, a section of apparently fresh dyke recovered in drill core crumbled to sand size clasts only one month after drilling. The reason for this is unknown at this time but is probably related to the composition of dyke.

These dykes are particularly important because recent geochronological studies of dykes to the north have provided ages that are both equivalent to MPIS phases, together with some that are significantly younger than any others in the region. O'Driscoll and Wilton (2005) reported a ca. 430 Ma age for linear gabbro dykes near Twin Ponds, just north of the Trans-Canada Highway. The dykes may be fractionates from the main MPIS gabbro suite. In terms of younger ages, a mineralized dyke at the Titan showing, Gander Bay, ~ 75 km to the north has been dated at 381 Ma  $\pm$  5 Ma (McNicoll *et al., this volume*). An age of 411  $\pm$  5 Ma has also been obtained from a dyke 30 km to the north of the study area (McNicoll *et al., op. cit.*). This suggests there is an episode of Devonian age magmatism that has not previously been noted in central Newfoundland.

An attempt will be made to geochemically fingerprint the dykes at the antimony prospects and compare them with the dated Devonian and Silurian dykes, helping to constrain the age of the antimony mineralization. Several of the dykes encountered in the drill core appear to have been altered, suggesting that they predate mineralization. If this is in fact the case, it would mean the antimony prospects are significantly younger than previously believed. Unfortunately, the samples of dykes from the core are likely too small to be dated by U–Pb methods, although Sm–Nd or Pb–Pb dating may be possible.

# STRUCTURAL GEOLOGY

Mapping in the study area is difficult due to the thick overburden and poor bedrock exposure. The brook sections

provide the best exposures, and, because they generally cut across stratigraphy, provide ready-made cross-sections. To this end, a traverse was completed along Cooper Brook, which provided valuable insight into the regional structural geology in the mine area.

Bedding-cleavage relationships in the Ordovician rocks are unclear due to the extremely thick nature of the beds. Furthermore, in certain intervals, cleavage is extremely erratic, changing without any discernible pattern over very short intervals. Those areas where bedding-cleavage relationships are exposed, however, suggest that this group of rocks is folded, with folds plunging steeply to the east.

Indian Islands Group rocks exhibit a prominent  $S_1$  cleavage that varies from parallel to sub-parallel to bedding. This cleavage has subsequently been folded by an  $F_2$  event that locally produced a very weak  $S_2$  cleavage. The presence of folds is inferred from changes in bedding-cleavage relationships. These folds apparently have wavelengths in the tens of metres and plunge steeply toward the northeast. However, no fold hinges were observed during mapping.

#### The Cooper Brook Thrust

Previous workers (Anderson and Williams, 1970; Dickson, 1992) inferred that the Davidsville Group-like rocks in the map area are present as a fault-bounded wedge. From the mapping conducted for this study, it has become clear that the wedge is actually enclosed by IIG sedimentary rocks. Furthermore, the juxtaposition of Ordovician and Silurian rocks can only be explained if a thrust is present. Such a feature has not previously been inferred to exist. Diamond-drill holes that tested the Central Zone (Hunan Prospect) indicate that the cover of Ordovician rocks is relatively thin, with numerous holes penetrating carbonate-rich sandstones and limestones (Tallman and Evans, 1994) that can only be designated as IIG.

Tallman and Evans (1994) mentioned "donuts" within limestone beds below the Davidsville greywacke, which they suggested might be worm burrows. Re-logging of the core for this study indicated that these were most likely cross-sections of crinoids, confirming these rocks are IIG (Plate 2). This suggests that the Davidsville thrust slice is relatively thin. The greywacke and black chert/shale repeat several times throughout the wedge of Ordovician rocks. Based on the inferred strike of the wedge and the location of these units, it is most likely that the wedge is composed of two thrust slices that repeat the stratigraphy in an imbricate fashion.



**Plate 2.** Crinoids and favosites coral in drill core from the Szechwan Prospect; the presence of these distinctive fossils strongly indicates that the Szechwan Prospect is hosted by the Indian Islands Group. The crinoids were previously identified as "donuts" and were thought to be worm burrows.

#### **Antimony Prospects/Zones**

#### West Zone – Xingchang Prospect

The Xingchang (West Zone) showing is the westernmost of the three zones of stibnite veining exposed in the study area. It is also the smallest and least well known. The boulders that led to the discovery of the entire antimony system in the mine region were, however, likely derived from this showing because it is located 150 m from Beaver Brook. The showing consists of massive, coarse-grained stibnite, cutting highly silicified black shale. Stibnite needles up to 10 cm long constitute the only sulphide visible in hand sample. Weathered surfaces on stibnite have a cream to brown rind that resembles weathered wood; this is most likely stibiconite (Sb<sub>3</sub>O<sub>6</sub>(OH)).

Quartz textures within the black shale consist of finegrained, comb quartz coating vugs. Colliform quartz, quartz breccia and silica replacement of either calcite or barite blades is also exhibited in outcrop, suggesting that highlevel epithermal processes were active. The host rock exhibits no other obvious forms of alteration (Plate 3). It is also worth noting that 1 km southeast from this showing, black shales crop out that contain abundant barite. If this barite can be proven to be hydrothermal in nature, then it would suggest that the hydrothermal system that formed the west zone was more widespread than previously thought.

Six diamond-drill holes were drilled through this zone, but the assay results were disappointing with a single notable intersection of 33% Sb over 0.5 m. Assessment



**Plate 3.** *Quartz veins in black shale at the Xingchang Prospect. Vugs within the veins are lined with comb- and colliform-textured quartz; note the stibnite vein in the lower left-hand corner of the picture.* 

reports recommend further drilling of this zone; thus the true potential of this zone has not likely been tested. The locations of these drillholes are shown on Figure 2.

#### Central Zone – Hunan Prospect

The Hunan Prospect, or Central Zone, is the best exposed of the three zones and was the focus of exploration between 1990 and 1994. The overburden has been removed, providing excellent insight into the nature of the mineralization. The showing consists of numerous discontinuous stibnite veins that are between 1 and 10 cm thick and which generally trend 050°. The grain size of the stibnite is variable, with individual crystals being as long as 15 cm. Much of the mineralization, however, consists of massive aggregates of crystals less than 1 cm long. The stibnite crystals at the Central Zone are more variable than those seen at the other two zones, exhibiting striae and blue luster. Certain veins also weather black and contain tiny intergrown grains of an, as yet, unidentified, salmon pink mineral. Weathering of the stibnite crystals has produced stibiconite and a red, soft mineral that is most likely an antimony oxide, possibly valentinite or kermesite (Plate 4).

At this prospect, silification and brecciation features are exposed that are similar to those at the west zone, suggesting that epithermal processes were also at work (Plate 5). Furthermore, there seems to be a correlation between antimony content and the intensity of brecciation, with areas that have more intense brecciation containing more mineralization. Stibnite fills vugs in these breccias and is common-



Figure 2. Close-up showing the location of drillholes at the west and central zones (see Figure 1 for map location).

ly associated with red-weathering Fe-rich(?) dolomite. In some cases, the vugs have a lining of dolomite, with an interior of massive stibuite.

One interesting feature is the quartz needles that appear to be silica replacements of a pre-existing mineral; the shape and size of the quartz needles suggest that they are replacing stibnite. This may be equivalent to silica replacement of barite or calcite in low sulphidation epithermal type environments (cf. Dong *et al.*, 1995). Some pyrite is present in the prospect, but it is commonly intergrown with chlorite and not obviously associated with stibnite. Field observations suggest this pyrite may in fact be flattened nodules that are diagenetic in nature. These nodules appear to be associated with the black shale clasts within the greywacke.

The host rocks at the Central Zone–Hunan Prospect are different from those at the West Zone as they consist predominately of pebble greywacke with minor interbedded black shale. As described above, the greywacke contains abundant sericite in the matrix, however, it is unclear whether this sericite is related to the stibnite mineralization, or represents an earlier event in the history of the greywacke, possibly a metamorphic event. As described above, this greywacke has been thrust over sediments of the IIG. This has been confirmed with drill core sections containing fossils (Tallman and Evans, 1994), indicating the thrust slice is relatively thin.

Mineralization in the Central Zone has been tested by a total of 41 diamond-drill holes, collared between 1990 and 1994. The results of this drilling and trenching suggest an indicated resource of 148, 646 tonnes with an average grade of 5.62% Sb, assuming a cut off grade of 2% Sb. The locations of the drill holes that define the Central Zone in relation to geology are shown on Figure 2.



**Plate 4.** Weathered stibuite vein; the red mineral is likely valentinite or kermesite. The brecciated nature of the vein, suggests that it formed under epithermal-type conditions.

### East Zone – Szechwan Prospect

The East Zone hosts the Beaver Brook Antimony Mine. It was discovered as a soil geochemical anomaly, however, a lack of surface outcrop precluded further exploration until 1994, when Roycefield Resources drilled the anomaly and intersected significant thicknesses of high-grade stibnite mineralization. These intersections formed the resource for the subsequent antimony mine.

The zone is mineralogically identical to the others, with stibnite as the only sulphide present in appreciable quantities, although traces of pyrite can be found. The gangue minerals are similar as well, normally being dolomite and quartz. Dolomite is present in the same unusual crystal habit as at the Hunan Prospect, but is normally not associated with stibnite. It commonly forms veins up to 10 cm thick in the drill core and is commonly very vuggy. One vug is lined with tiny, well formed pyrite cubes, a feature not seen anywhere else in the mine map area. Rare calcite veins are present as well. Little to no alteration of surrounding host rocks was observed.

The nature of the mineralization is different from that seen in the West and Central zones because evidence for epithermal deposition of the stibnite is limited. Rare quartz breccias are present, but they are usually not mineralized. Instead, stibnite and fine-grained blue quartz most commonly occur as the matrices to re-healed fault gouges. Tallman and Evans (1994) described antimony-bearing fault gouges at the Hunan Prospect, but that observation was not confirmed by this study. A correlation exists between the size and intensity of zones of fault gouge, and the quantity of stibnite that they host. Massive veins of stibnite are present but normally occur in less deformed portions of fault zones where they may have exploited single fractures in the host rock.



**Plate 5.** Well-formed hydrothermal breccia in Davidsville Group greywacke at the Hunan showing; note the greybrown stibiconite weathering rind on the stibnite vein in the upper left-hand corner.

The host rocks at the East Zone are correlated with the Indian Islands Group on the basis that they are predominately green-grey siltstones that grade into sandstones of various colours, and also the presence of numerous horizons containing a fossil assemblage similar to that exposed in Cooper Brook and in known IIG rocks to the north. These fossil assemblages were intersected in 34 of the 76 diamond-drill holes collared during the 2004 program. Flame structures and crosslaminations were common in both the siltstone and the sandstone and indicate that the rocks are overturned. It is unclear if this sandstone is the equivalent to the red sandstone in the Cooper Brook section.

In addition to the 74 drill holes collared in 2004, the East Zone was tested by an additional 108 drill holes between 1994 and 1997. The locations of these drill holes and their relation to associated mine infrastructure, including the mine decline, are shown on Figure 3. Also shown on Figure 3 is the inferred trace of the mineralization as defined from the limited mapping conducted before underground mining ceased. The mineralization is nearly on strike with this thrust and consists predominantly of rehealed fault gouge and breccia, suggesting that the thrust extends into the IIG and also acted as the conduit which focussed the hydrothermal fluids that deposited the stibnite.

# DISCUSSION AND CONCLUSIONS

Fossil evidence and rocks confirm that most of the strata in the Cooper Brook section and East Zone are part of the Indian Islands Group. Structural work confirms previous interpretations that Ordovician rocks in the area of the antimony prospects are confined to a fault-bound wedge. This differs from Tallman and Evans (1994), who suggested that all the mineralization was hosted by Ordovician rocks. The



Figure 3. Drillhole locations in the East Zone and associated mine infrastructure (see Figure 1 for map location).

fact that mineralization is hosted by differing rock types indicates that structure is the dominant factor in determining where the antimony mineralization formed.

A fault zone similar to that in Cooper Brook is present 10 km to the north in Clarke's Brook. Like the Cooper Brook zone, this has been inferred (Barbour, 2003) to be an imbricate thrust zone with predominately brittle deformation, consistent with what is seen in Cooper Brook and drill core. It may be possible to link these thrusts into one zone, which would substantially increase the area that could potentially host antimony mineralization.

Although the three zones share similar characteristics and were undoubtedly related to a common metallogenic event, there are some subtle differences that may reflect deposition at different structural levels within the ore-forming system. For instance, in the Western and Central zones, the stibnite mineralization is coarser grained, associated with more intense alteration of the host rocks, and is present in epithermal breccias. These factors suggest that the oreforming processes were longer lived in these zones, allowing for the formation of stibnite crystals up to 15 cm long.

In contrast, the Eastern Zone mineralization is finer grained, has minimal wall-rock alteration, is associated with blue quartz, and fills fractures without epithermal-style breccias. These factors suggest that the shears in this zone were flooded by a silica-rich fluid or gel, which rapidly precipitated fine-grained quartz. Similar processes may have operated to deposit the rare calcite veins, which are also quite fine-grained. The lack of alteration in surrounding host rocks suggests that the ore-forming processes in this zone were relatively short-lived and involved a relatively cool fluid. Thus, the Eastern Zone may represent a structurally higher, i.e., closer to surface, system and the other zones formed deeper in the crust.

The timing of mineralization remains a significant, unanswered question. Based on the results of this study, it appears that the MPIS is intrusive into the IIG. This would suggest an age of granite intrusion that is early Devonian or younger. It also means that the MPIS still represents a potential heat source to drive the antimony mineralizing system. However, since recently derived geochronological data suggest that gold mineralization to the north is younger than the middle to lower Devonian (McNicoll *et al., this volume*), it is possible that the antimony mineralization dates may have a similar age.

The source of the antimony is also an unanswered question. Antimony is a relatively rare element, so formation of a deposit the size of Beaver Brook requires either a source extremely enriched in antimony, an extremely large hydrothermal system to obtain antimony from a large volume of rock, or a combination of both. Black shales can be quite enriched in antimony, so perhaps it was initially derived from the Davidsville Group. However, further work is required to support this hypothesis.

# FUTURE WORK

This research will continue as an M.Sc. study by J.W.L. Lake at the Department of Earth Sciences, Memorial University, the aim of which is to document the conditions that led to the formation of the Beaver Brook antimony deposit and surrounding showings. Specifically, this research will involve: 1) examination of sulphur, carbon and oxygen isotope ratios from sulphide and carbonate mineral separates to determine possible fluid sources, 2) study of fluid inclusions in quartz and carbonate phases to determine ore-fluid temperature and chemistry, 3) derivation of geochemical data for host rocks surrounding the mineralization to determine the degree of alteration, and 4) obtaining geochemical and geochronological data for the mafic dykes intersected in drill core.

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