Current Research (1986) Newfoundland Department of Mines and Energy
Mineral Development Division, Report 86-1, pages 65-78

EPITHERMAL GOLD MINERALIZATION IN LATE PRECAMBRIAN VOLCANIC ROCKS ON THE BURIN PENINSULA

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INTRODUCTION

The project was initiated in 1984 to document gold-bearing rocks in the area of the Swift Current Granite and was continued and expanded during the 1985 field season. Its objectives were: 1) to see if the alteration belts defined by Huard and O'Driscoll (1985) extended to the south, 2) to do reconnaissance exploration for similar or related rocks around the Cape Roger Mountain Batholith and the 'Knee granitoids' (informal name), and 3) to determine the extent and gold content of the specularite-rich breccias at the Hickey's Pond showing, which were shown in 1984 to contain the highest gold concentrations.

The map areas (Figure 1) were previously included in 1:250,000 scale mapping by Anderson (1965), and 1:50,000 scale mapping by Bradley (1962), O'Driscoll and Hussey (1978), O'Driscoll (1978), O'Brien and Taylor (1979, 1983), O'Brien and Nunn (1980) and O'Brien *et al.* (1984). The mineral potential of the area was discussed by Taylor *et al.* (1979). Reconnaissance exploration for fluorite and base metals was carried out by Allied Chemical Corporation (Fitzpatrick and Howse, 1973) and Serem Ltée (Schrijver, 1972, 1973).

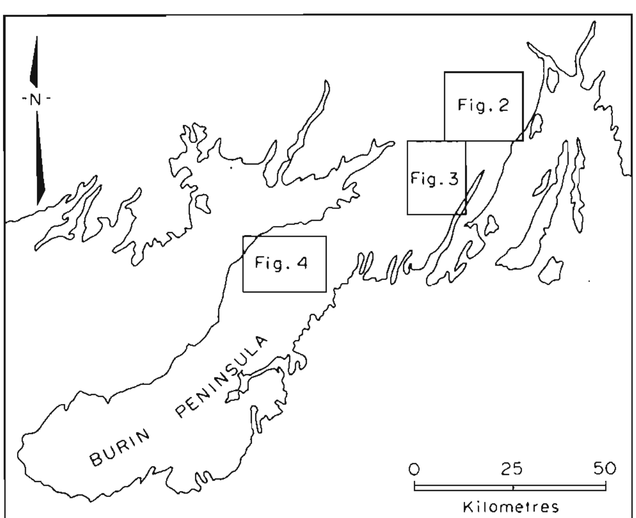


Figure 1: *Burin Peninsula showing location of Figures 2, 3 and 4.*

The specularite showing at Hickey's Pond was examined in the 1930's as a potential source of iron (Dahl, 1934; Bainbridge, 1934). Howland (1938, 1940), in a study which dismissed the deposit's iron potential, noted the presence of alunite ($KAl_3 (SO_4) (OH)_6$). Hussey (1978a,b), with the aid of X-ray diffraction analyses, showed that the 'alunite' was actually the Na-rich analogue, natroalunite. He also recognized pyrophyllite as an important constituent at Hickey's Pond and suggested that the area may have economic potential for precious metals. Other workers in the area have also suggested that the volcanic rocks of the Love Cove Group and associated Precambrian intrusions have a high potential for precious metal mineralization (O'Brien and Taylor, 1979, 1983; Taylor *et al.*, 1979).

In 1982, Selco staked the area in the vicinity of Hickey's Pond. The discovery, in 1983, of a quartz-specularite-pyrophyllite-lazulite body 13 km southwest of Hickey's Pond (Tuach, 1984) renewed interest in the area and prompted the initiation of this study. O'Driscoll (1984), in following up Husseys's suggestion of precious metal potential, demonstrated anomalous gold values in rocks collected by Hussey in the Hickey's Pond area. Seven rocks were analyzed for gold with the highest concentration being 850 mg/t, in a banded rock containing specularite, natroalunite, quartz and pyrophyllite.

Work during 1984 (O'Driscoll and Huard, 1984; Huard and O'Driscoll, 1985) defined a north-northeast-trending alteration belt on each side of the Swift Current Granite. These belts are marked by the occurrence of hydrothermal exhalations of chert ($\pm$ alunite $\pm$ specularite $\pm$ pyrite), and variably altered volcanic rocks (now sericite $\pm$ pyrophyllite $\pm$ pyrite schists).

GENERAL GEOLOGY

All of the alteration assemblages are in volcanic rocks of the Late Precambrian Love Cove Group (Figures 2, 3 and 4). Isoclinal folding and flattening of the volcanic rocks have obscured facing criteria and preclude estimation of

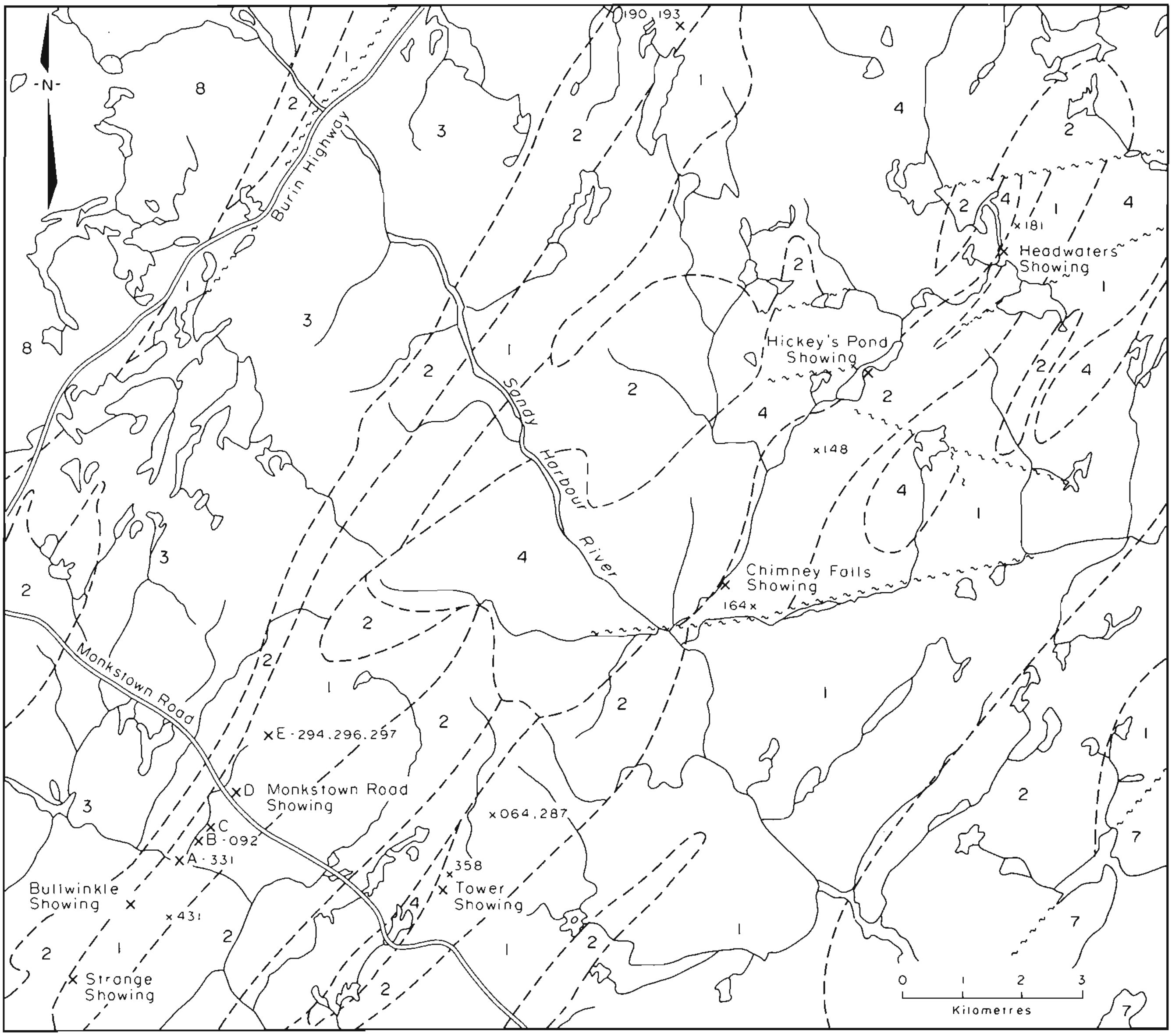


Figure 2: *General geology of the Eastern and Western alteration belts, showing locations of selected samples and specularite showings.*

stratigraphic thicknesses. Near the Swift Current Granite, mafic flows that are presumed to form the lowermost units of the volcanic sequence are in fault contact (the Paradise Sound Fault) with Cambrian and older clastic sedimentary rocks of the Musgravetown Group, Random Formation and Bonavista Formation to the east. These flows are commonly porphyritic and may include porphyritic intermediate flows. Higher in the sequence, lithic tuffs with a mafic matrix grade into crystal-lithic tuffs, rhyolite flows and welded(?) tuffs. Small-scale interlayering of these units can be observed in the field, indicating this 'stratigraphy' is a simplification of a more complex interlayered sequence. Detailed stratigraphy is not available, due to the discontinuous nature of the members along strike, and the difficulty in distinguishing depositional repetition from structural repetition. The volcanic sequence is overlain conformably (Hussey, 1978a,b) by graywackes and conglomerates of the Sandy Harbour River Formation and equivalent rocks to the southwest (O'Brien and Taylor, 1983; O'Brien *et al.*, 1984). The Swift Current Granite, Cape Roger Mountain Batholith and the Knee granitoids intrude the volcanic and sedimentary sequences.

Age Relationships and Geochronology

The Late Precambrian stratified rocks are a conformable sequence; however, the detailed stratigraphy is complicated by depositional and structural repetition. In general, mafic flows pass upward into mafic lithic tuffs and felsic tuffs, which grade into coarse grained, water-lain, clastic sedimentary rocks. Field relationships between the Swift Current Granite and the Love Cove Group suggest the two are coeval. Although granite dikes intrude the volcanic rocks, granite clasts occur in some tuff beds. These observations can be reconciled if the granite is interpreted as a synvolcanic intrusion.

LEGEND

DEVONIAN

ACKLEY GRANITE

8 Massive, pink, coarse grained, feldspar-megacrystic, biotite granite.

MUSGRAVETOWN GROUP, RANDOM FORMATION AND BONAVISTA FORMATION

7 Green to red sandstone, siltstone and conglomerate; minor mafic flows and tuffs; white quartzite and interbedded sandstone; purple to green slate containing pink limestone nodules.

CAMBRIAN OR EARLIER

SWIFT CURRENT GRANITE (4), CAPE ROGER MOUNTAIN BATHOLITH (5) AND KNEE GRANITOIDS (6)

4,5,6 Medium grained, foliated to massive, hornblende-biotite granite, granodiorite, and syenite.

HADRYNIAN OR EARLIER

LOVE COVE GROUP

3 Green graywacke, arkosic sandstone, and conglomerate.

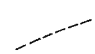
2 Predominantly felsic pyroclastics and flows. Minor mafic flows and tuffs, and minor mafic dikes.

1 Predominantly mafic flows, tuffs and dikes, including minor intercalated felsic tuffs.

SYMBOLS

sample locality .... ×

specularite showing .... ×

geological contact (approximate) .... 

fault (assumed) .... 

This interpretation is supported by the geochronologic investigation of Dallmeyer *et al.* (1981). Crystallization dates of 580±20 and 590±30 Ma were obtained for the Swift Current Granite and Love Cove Group volcanic rocks respectively, by U-Pb determinations on zircon fractions. It was concluded that the rocks are comagmatic, and that the granite is subvolcanic.

The Cape Roger Mountain Batholith is petrographically similar to the Swift Current Granite and the two are interpreted to be the same age (O'Brien *et al.*, 1984). The intrusions in the 'Knee' area of the Burin Peninsula are all pretectonic, and are considered to be cogenetic with the main period of intrusive activity that occurred during the Late Proterozoic (O'Brien and Taylor, 1983).

Structure

Most of the volcanic rocks have a well developed, steeply dipping cleavage; most dikes, quartz veins and flow boundaries are parallel to this foliation. Also, clasts in lithic tuffs are flattened in the fabric planes. This hinders positive identification of bedding and determination of younging directions. The cleavage is axial planar to isoclinal folds of quartz veins, and is interpreted to be related to large scale folds as well. A single cleavage-bedding intersection on Paradise River indicates that the beds there are upward facing. Also, clasts are flattened on the cleavage plane and not on the bedding plane, which is at a 30° angle to the cleavage. Dallmeyer *et al.* (1983) dated, by $^{40}Ar/^{39}Ar$ age spectra, sericite that had crystallized on this regional foliation. Two samples from this study area yielded ages of 386 ± 10 Ma and 388 ± 10 Ma. They concluded that the deformation and recrystallization occurred during the Devonian Acadian Orogeny. Locally, the regional foliation was crenulated and folded by the development of a widely spaced strain-slip cleavage.

The regional foliation is locally developed in the granites and is defined by oriented mafic minerals, numerous joint sets, and small faults.

Metamorphism

All rocks in the study areas were regionally metamorphosed at greenschist facies conditions. Assemblages containing various combinations of sericite, chlorite, epidote, quartz, calcite, actinolite and minor biotite have developed syntectonically (Hussey, 1978b; O'Brien and Taylor, 1983). Syn to posttectonic chloritoid occurs in pyrophyllite schists on both sides of the Swift Current Granite. This mineral is common in highly aluminous rocks that have been subjected to greenschist facies metamorphism.

According to O'Brien and Taylor (1983), the effects of thermal metamorphism, varying from albite-epidote to hornblende-hornfels facies, occur throughout the areas adjacent to the Proterozoic granites. Such metamorphism, however, is not evident along the eastern contact of the Swift Current Granite.

DESCRIPTIONS OF SHOWINGS

Eastern Alteration Belt

The Eastern alteration belt as defined by Huard and O'Driscoll (1985) includes three main showings which are in fault contact with the Swift Current Granite to the west (Figure 2). The showing at Chimney Falls is composed of soft quartz-pyrophyllite (± specularite ± chloritoid ± pyrite) schists. Rounded and embayed quartz phenocrysts in the schists attest to the volcanic origin of these highly altered rocks. A 40 cm thick, resistant siliceous zone occurs within the schists. It is fragmental, consisting of clasts of microcrystalline quartz, minor pyrophyllite and minor isolated alunite crystals in a specularite- and quartz-rich matrix. Several rounded quartz phenocrysts indicate that this rock was also of volcanic origin.

The showing at the headwaters of Hickey's Brook consists of quartz-rich, sericite and pyrophyllite schists. Similar rocks occur at the edge of a small pond 500 m to the north-northeast, and in the area between these two points.

The main showing in the Eastern alteration belt is at Hickey's Pond. The showing occurs in a very siliceous resistant body approximately 250 m by 50 m and is elongated in a north-northeast direction. The host rock is typically banded, consisting of layers of various combinations of quartz alunite ± pyrophyllite ± specularite ± pyrite ± rutile. Rutile and pyrophyllite are rarely present in modal proportions greater than 1 percent. Rutile is usually found either as very small rounded crystals concentrated in very fine bands or, less commonly, as small euhedral aggregates of the small crystals. Specularite and pyrite, which are mutually exclusive within bands, can comprise a few percent of the rock, and alunite can reach approximately 35 percent. Very small lithic fragments, now composed predominantly of quartz and alunite, are visible in thin section. These lithic clasts occur rarely as the main component of discrete bands up to 1 cm thick.

The other rock type at Hickey's Pond is fragmental, consisting of quartz-alunite clasts in a specularite-rich matrix. The clasts are usually less than 2 cm long but have widely varying size, size-sorting and shape. The matrix typically contains equal amounts of specularite and quartz with minor alunite, but locally consists of nearly pure specularite. Euhedral, tan-colored aggregates of rutile, up to 2 mm long, occur in the matrix and clasts. The breccias are found in a lenticular, north-northeast-trending zone that is 150 m long and up to 5 m wide.

The showing at Hickey's Pond is bounded on three sides by the pond and on the fourth side by a bog. The rocks immediately to the east-southeast of the bog, approximately 100 m from the showing, are unaltered, felsic, crystal tuffs. No phenocrysts were observed in samples from this showing.

A large showing (referred to here as the Tower showing) similar to the one at Hickey's Pond was discovered along strike 11 km to the south-southwest. It occurs in four resistant mounds separated by narrow bogs. The mounds rise approximately 5 m above the bog and form a straight, north-northeast-striking zone at least 450 m long. It strikes southward into a low ridge of glacial till almost 500 m wide and was not observed to the south of this ridge. It strikes northward into a 500 m wide pond. The showing's contacts in the east and west are covered by bog; however, rocks encountered 25 m toward the east are unaltered felsic crystal tuffs. Toward the west, a narrow zone of pyritiferous, altered, volcanic rocks separates the showing from unaltered granite.

The rocks at the Tower showing are variable assemblages of quartz, alunite, pyrophyllite, specularite, pyrite and rutile. Alunite and specularite are best developed on the western flank of the showing, where dark-gray specularite-rich bands alternate with pink, specularite-free, quartz-alunite rock. Toward the east, gray, pyritiferous, quartz-alunite assemblages pass into massive gray chert.

There are significant differences between the Tower and Hickey's Pond showings. For example, quartz phenocrysts occur in the Tower showing, whereas none have been seen at Hickey's Pond. Lithic fragments, on the other hand, occur sporadically at the Hickey's Pond showing but none have been recognized at the Tower showing. The quartz phenocrysts at the Tower showing demonstrate that the quartz-alunite-specularite assemblage represents an extremely altered volcanic rock. This type of alteration will be discussed later.

Western Alteration Belt

The Western alteration belt as defined by Huard and O'Driscoll (1985) includes five specularite showings which define a north-northeast-trending zone 2.5 km long. Its trace is 5 km west of the Eastern alteration belt, on the west side of the Swift Current Granite (Figure 2).

Where the Monkstown Road crosses the alteration belt, a showing (the Monkstown Road showing) occurs in a swamp approximately 100 m north of the road (Locality D on Figure 2). It is an extremely siliceous, north-trending, elongated body approximately 40 m by 10 m. Most of the outcrop is tan-colored, fragmental, siliceous rock. Fragments are angular and range up to 10 cm across. The matrix is brown quartz, which commonly displays chalcedonic banding (Plate 1). These bands persist for only short distances, on the order of 10 cm, and may represent either fragmented fissure fillings in the subsurface or silica sinter at the surface. Part of the southwest corner of the outcrop is hydrothermally brecciated (Plate 2). An elongated triangular zone, 20 cm long, contains angular fragments of chert 'floating' in a black, specularite-rich matrix. The brecciation passes upward into thin veinlets of specularite. Specularite is also present in syntectonic quartz veins, where coarsely crystalline varieties of quartz and specularite define a vertical lineation on a steep, northwest-dipping, fault plane. Brilliant-blue lazulite occurs in similar quartz-specularite veins throughout the showing.

Plate 1: *Chalcedonic banding in fragmental siliceous rock at the Monkstown Road showing.*

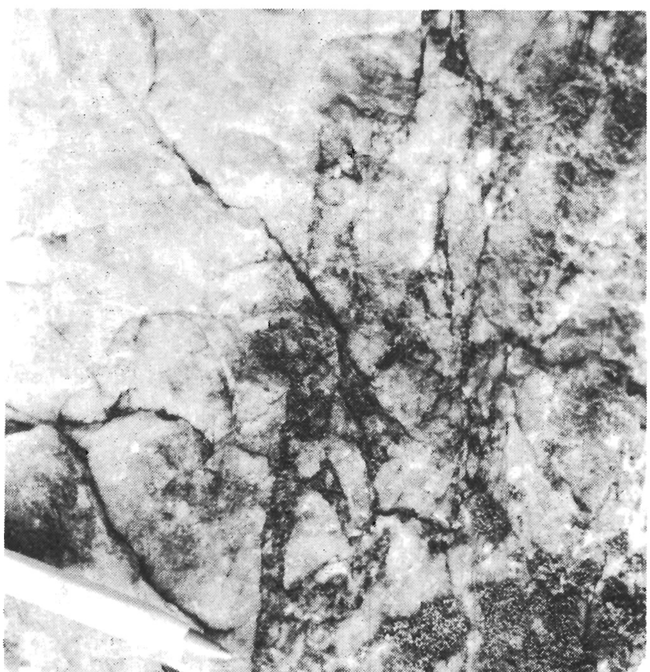


Plate 2: *Hydrothermal breccia at the Monkstown Road showing containing chert fragments in a black, specularite-rich matrix.*

Similar rocks also occur 0.5 km south-southwest of the Monkstown Road showing (Locality C on Figure 2). This is another resistant body surrounded by bog, but it is only 3 m long. Another specularite showing occurs 0.75 km south-southwest of the Monkstown Road showing (Locality B on Figure 2). Black bands of quartz-specularite-chloritoid-rutile alternate with white to tan chert. No alunite was observed in the rocks at Localities B, C and D.

Locality E, 2.25 km north-northeast of the Monkstown Road showing, consists mostly of scattered outcrops of gray, extremely siliceous rock in a north-northeast-trending, 200 m by 40 m zone. On the showing's western edge, pink alunite-rich rocks containing black specularite-rich bands occur. Pyrophyllite and chloritoid also occur at this showing. Chloritoid, which occurs as small crystals in the schistose pyrophyllite-rich zones, appear to be porphyroblasts.

Siliceous, spheroidal nodules comprise half the rock at the southernmost outcrop of this showing (Plate 3). Concentric 'shells' can be observed in the outcrop. In thin section, they are seen to be shells of either extremely fine grained recrystallized quartz, or quartz and alunite surrounding coarse grained quartz nucleii. The 'matrix' around these nodules is a much coarser grained assemblage of quartz, alunite, specularite and pyrophyllite.

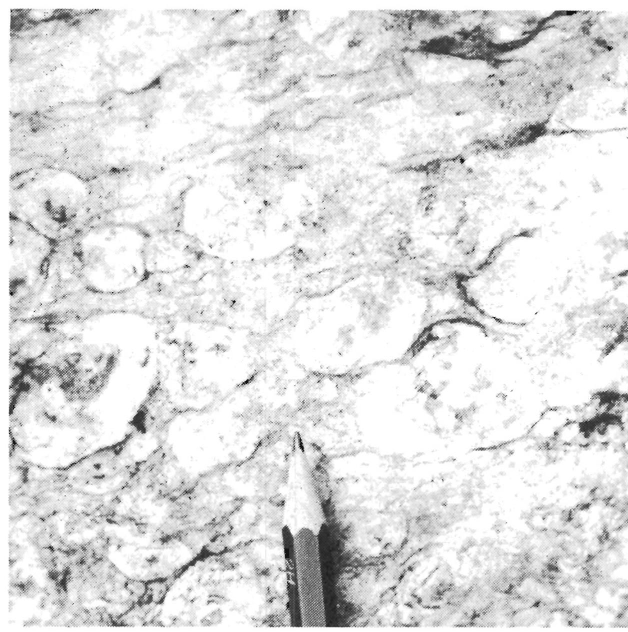


Plate 3: *Siliceous, spheroidal nodules containing concentric layers of finely recrystallized quartz and quartz-alunite around coarse grained quartz nucleii (Locality E on Figure 2).*

The showing at Locality A is a resistant, circular, siliceous mound 30 m in diameter that rises approximately 5 m above the surrounding area. It is predominantly gray, siliceous rock, but can also include alunite, pyrite, specularite and pyrophyllite. These rocks form the northern bank of Paradise River at this locality. They continue south under the river as a shallow ledge and also outcrop on the southern bank.

A major specularite showing (referred to here as the Bullwinkle showing) was found in 1985 along strike from the Western alteration belt. It is centred 1 km south-southwest of the showing at Locality A, and is approximately 900 m long. The Bullwinkle showing is defined by the occurrence of resistant rocks composed of varying proportions of quartz, alunite, specularite, pyrite, pyrophyllite and rutile. These rocks are disposed in two parallel, northeast-trending zones, 175 m apart. The outcrops in each zone are approximately 30 m wide at their widest point, but taper off at both ends.

Specularite occurs with quartz and alunite as black bands within the pink quartz-alunite rock. Pyritiferous quartz-alunite rocks are volumetrically less important. They are absent at the northern end of the eastern outcrop zone but account for half of the rock in the southern end of this zone. Two outcrops of specularite-rich breccia occur 25 m apart in the centre of the eastern outcrop zone. Some of the breccia is similar to that at Hickey's Pond, i.e., it consists of angular quartz-alunite-rutile clasts in a matrix of specularite-quartz-alunite-rutile. At the Bullwinkle showing, however, the breccia is more flattened and stretched. A quartz phenocryst, the only one observed at this showing, occurs in a quartz-specularite fragment in this breccia.

Another type of breccia found at the Bullwinkle showing is unlike any from Hickey's Pond. It contains subrounded, unsorted quartz-alunite-specularite fragments of varying color, texture and composition in a matrix of quartz, specularite and alunite.

At the northern end of the eastern outcrop zone, rounded purple fragments up to 10 cm long occur in a band that parallels the compositional banding in the quartz-alunite specularite rock (Plate 4). These fragments are themselves fragmental, consisting of quartz-specularite-rutile fragments in a stockwork of quartz and specularite. The rutile is especially well developed in these fragments as coarse euhedra up to 2 mm long.

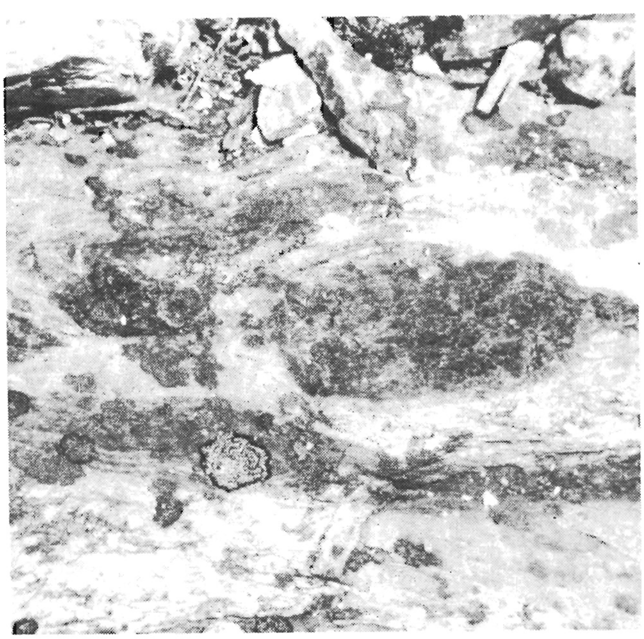


Plate 4: *Breccia fragments in a band that parallels compositional banding; dark band under fragments is specularite rich. Field of view is 20 cm (Bullwinkle showing).*

The Bullwinkle showing is bounded to the east and west by mafic volcanic rocks. The rocks on the eastern side are pyritiferous, and grade into unaltered mafic rocks approximately 200 m east of the showing.

A specularite showing (referred to here as the Strange showing) was discovered 1.5 km south-southwest of the centre of the Bullwinkle showing. It is a small low outcrop, only 3 m across, composed of black, vitreous, siliceous rock. The rock is intensely flattened and consists of fine grained quartz and wispy bands of recrystallized specularite that occur parallel to the foliation. Minor rutile(?) forms small crystal aggregates oriented parallel to the fabric. No alunite was observed in this rock. Within a metre of this rock, across a probable intrusive contact, there is a bright-pink rhyolite dike containing, deformed blebs of pyrite.

Cape Roger Mountain Batholith Area

The Eastern alteration belt in the Swift Current Granite area is coincident with the fault contact between the granite and volcanic rocks. A southern extrapolation of this contact occurs along the eastern margin of the Cape Roger Mountain Batholith, but it is unexposed (Figure 3). However, a zone of alteration 5 km long parallels it, 1 km to the east. This zone is characterized by sericite schist, pyritiferous sericite schist, and two occurrences of gray chert boulders. A small outcrop of gray chert occurs in this belt at UTM grid reference 811691 in the Terrenceville (1M/10) map area (Figure 3; sample 375). Several kilometres to the north-northeast (sample 383), specularite occurs in very small veinlets and as disseminations in rhyolites.

Burin Peninsula Knee Area

Pyritiferous chert, which may be a sinter, occurs as discontinuous outcrops in a zone 700 m long at UTM grid reference 520544 in the Baine Harbour (1M/7) map area (Figure 4; samples 411, 413). The northernmost part of the zone is parallel to the regional northeast-trending cleavage. However, toward the south, the chert bodies are gradually rotated into, and then parallel for several hundred metres, an east-southeast-striking shear zone (mapped by O'Brien and Taylor, 1983). Pyritiferous sericite schist, and pyritiferous silicified rock are found in several localities near the margins of the Knee granitoids (Figure 4).

PETROGENESIS

The rocks at Hickey's Pond and the other showings do not resemble volcanic rocks in mineralogy or texture. Nor is there a continuum between these resistant siliceous rocks and the surrounding volcanic rocks. However, at Chimney Falls, the auriferous mineralization is exclusively an alteration feature of easily recognized volcanic rocks. The quartz phenocrysts readily seen in thin sections of the quartz-pyrophyllite ($\pm$ specularite $\pm$ pyrite) schists prove this. This showing, however, is not representative. The other showings are much more siliceous and resistant, unlike the easily eroded rocks at Chimney Falls, and they are characterized by an abundance of alunite.

The formation of alunite is regarded as a near surface phenomenon involving 3 steps: 1) boiling of an ascending hydrothermal fluid and partitioning of H_2S into the vapour

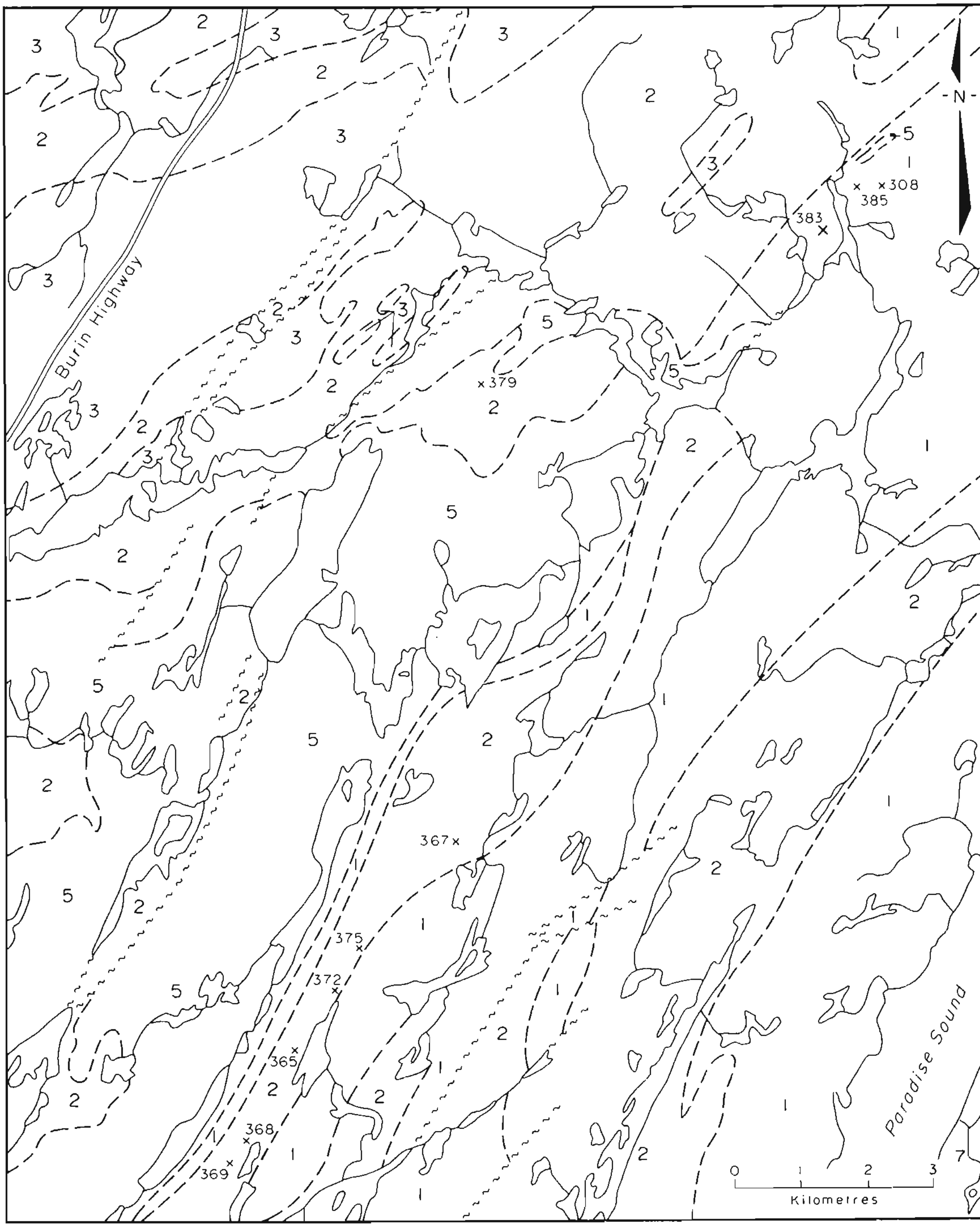


Figure 3: *General geology of the Cape Roger Mountain Batholith area (modified from O'Brien et al., 1984), showing locations of selected samples. See Figure 2 for Legend.*

phase, 2) upward transport of the vapour followed by cooling, condensation and oxidation to form H_2SO_4-rich waters, and 3) interaction of these waters with the surrounding shallow rocks (Raymahashay, 1968; Henley and Ellis, 1983; Cunningham *et al.*, 1984). Cunningham *et al.* (1984) suggest that the oxidation required to produce the alunite assemblages took place above the water table. Raymahashay (1968) described near-surface alunitization and the formation of alunite as a direct chemical precipitate at an acid hot spring. Thus, alunite is an indicator of the highest part of an epithermal system, either as an alteration product or as a surficial precipitate. This is an important consideration concerning the showings on the Burin Peninsula—are they chemical precipitates or alteration products? The fact that alunite can form in either situation prevents its occurrence from resolving this question. The other minerals found at these showings will now be considered with this question in mind.

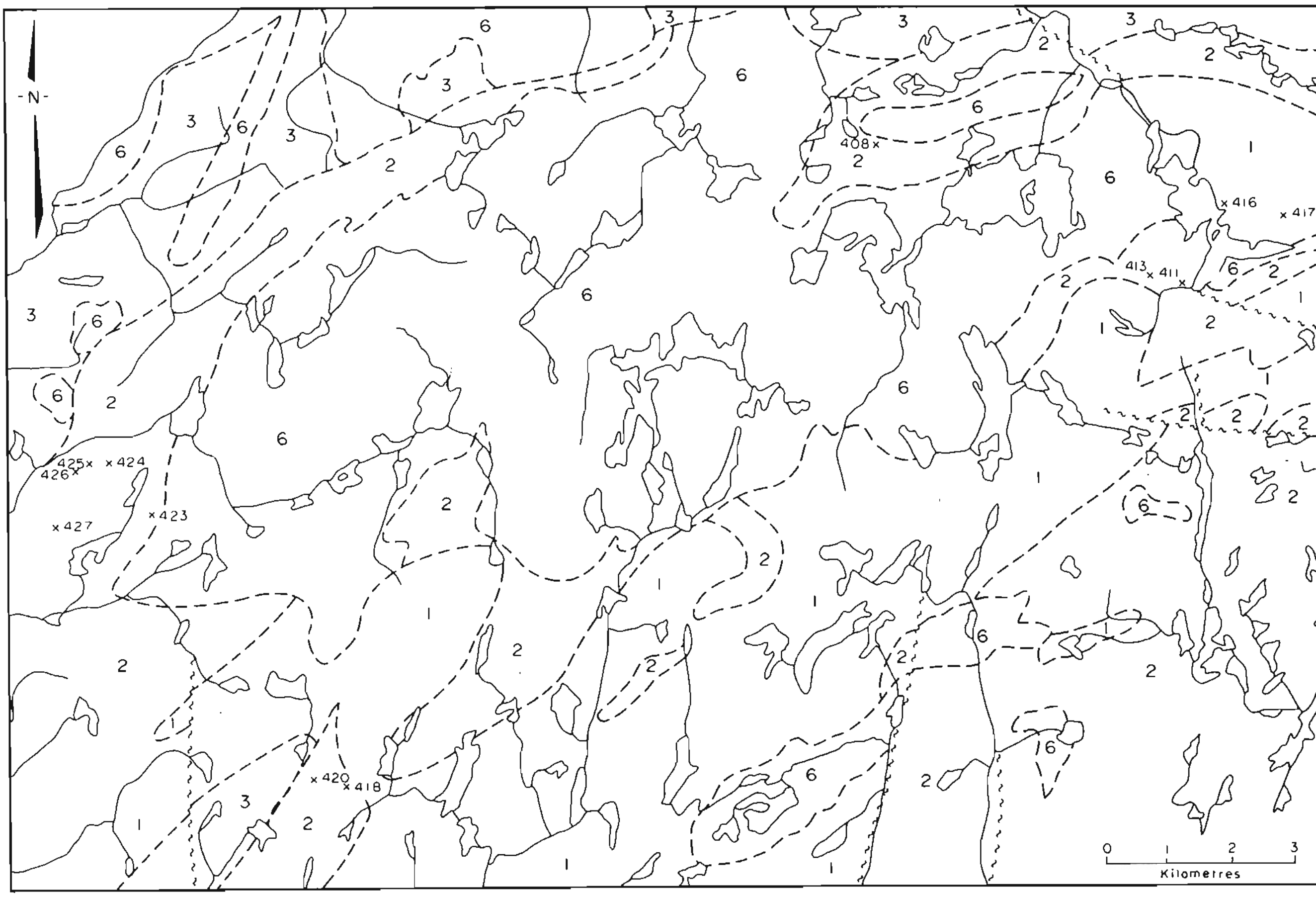


Figure 4: *General geology of the Burin Peninsula Knee area (after O'Brien and Taylor, 1983), showing locations of selected samples. See Figure 2 for Legend.*

Quartz is the most commonly precipitated mineral at hot springs, where it usually forms amorphous masses. The quartz in the Burin Peninsula showings is microcrystalline, a texture easily attributed to recrystallization of an originally amorphous silica during subsequent deformation and metamorphism. Silica is also abundant, however, in acid-leached rocks.

Pyrophyllite and kaolinite are common products of acid leaching. Knight (1977) showed that pyrophyllite can be in equilibrium with a very low temperature fluid if it is supersaturated with silica. Otherwise, kaolinite will be the stable aluminous phase. Raymahashay (1968) describes kaolinite in several hot springs. Preliminary X-ray diffraction studies of clay minerals from the Hickey's Pond and Bullwinkle showings reveal them to be dominantly pyrophyllite. However, small peaks which correspond to kaolinite were also recorded, indicating a few percent kaolinite in the clays. This can be accounted for by postulating a metamorphic reaction in which kaolinite was almost completely replaced by pyrophyllite.

Specularite was reported by Cunningham *et al.* (1984) in alunitized Tertiary volcanic rocks near Marysvale, Utah. They also described its occurrence in the sinters overlying the alteration. Rutile could represent the residue of an altered titanium-bearing phase in an altered volcanic rock. On the other hand, anatase (another polymorph of TiO_2) is described by Buchanan (1981) in sinters that cap epithermal systems. Finally, the occurrence of pyrite is too ubiquitous to differentiate between the two possible origins of these rocks.

Thus, the mineral assemblage quartz-alunite-specularite-pyrite-pyrophyllite-rutile, in light of the deformation and metamorphism undergone by these rocks, cannot be used to distinguish whether these are sinters or altered volcanic rocks. Other lines of evidence are needed. The best evidence is the occurrence of quartz phenocrysts in the quartz-alunite-specularite rocks on the west side of the Tower showing, which clearly shows that these are intensely altered felsic volcanic rocks. The massive cherty rocks a few metres to the east may represent a silica sinter. Although quartz phenocrysts were not observed at Hickey's Pond, and only one was seen at the Bullwinkle showing, this does not preclude these rocks from having a volcanic origin. There are, however, several lines of evidence that are not compatible with an alteration model.

Pyrite and specularite are mutually exclusive in centimetre-scale bands that persist for several metres. This mineralogical banding is best developed at Hickey's Pond, where the bands maintain their identity even though they are isoclinally folded; the banding is therefore pretectonic. It is interpreted to be a primary chemical banding, reflecting changing oxygen and sulfur fugacities in the fluid from which these minerals precipitated. This interpretation is supported by the occurrence of specularite-bearing fragments in the pyritiferous rocks.

The lithic fragments at the Hickey's Pond and the Bullwinkle showings support a surficial origin for these rocks, as opposed to an alteration model. The fragments at Hickey's Pond are light gray, rounded, very slightly elongate and up to 3 mm in length. The light gray material forms a framework in an originally, highly porous (approximately 70 percent) rock; the 'pores' are circular to slightly ellipsoidal, and are now filled with quartz and minor alunite (Plate 5). Texturally these fragments are pumice, and their existence is strong evidence against an alteration model, as they should be the most easily altered component of any rock. Their incorporation is easily explained, either by erosion and transport from nearby ash falls, which are common in the study area, or by direct eruption into an active hot spring in which the Hickey's Pond showing was forming. Elsewhere at the Hickey's Pond showing, pumice occurs as more intensely deformed fragments.

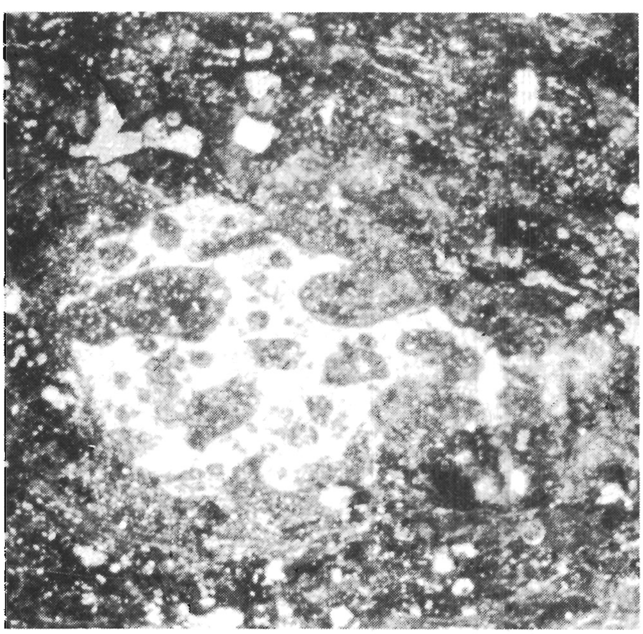


Plate 5: *Light-colored, rounded, lithic fragment containing circular to ellipsoidal 'pores' filled with quartz and minor alunite (Hickey's Pond showing). The field of view is approximately 4 mm.*

A different type of lithic fragment, occurs at the Bullwinkle showing. These fragments are specularite-rich breccias and their presence not only argues against an alteration model, but has strong implications to be discussed below, for the origin of these breccias.

The concentrically shelled, siliceous nodules observed at Locality E (Plate 3) are interpreted to be geyserite eggs, as described by Rinehart (1980) and Spence *et al.* (1980). This interpretation can only be reconciled with a surficial origin for this quartz-alunite-specularite-pyrophyllite showing.

Specularite-Rich Breccias

Fragmental rocks with specularite-rich matrices occur at the Chimney Falls, Hickey's Pond, Bullwinkle and Strange showings. The specularite gives these rocks a very dark color which commonly conceals their fragmental nature in outcrop. The breccias might be interpreted as 1) fault breccias which were later cemented with specularite-quartz-alunite-rutile, 2) hydrothermal breccias occurring at the place of brecciation in either volcanic rock or sinter, and 3) aprons of hydrothermal explosion breccia disposed around the orifice of a vent in an active hot spring. Cunningham *et al.* (1984) describe hydrothermal breccias with hematite-bearing matrices in the sinters near Marysvale, Utah. This might be a modern analogue to (3) above.

Observations relevant to the origin of the breccias are summarized below:

1) The breccias at Chimney Falls are in contact with altered volcanic rock. They contain quartz phenocrysts that have slightly undulatory extinction but are not seriously strained.

2) Demonstrable fault gouge at Hickey's Pond is confined to zones less than 5 cm thick. It is schistose, pyrophyllite rich, and texturally and mineralogically unlike the breccias.

3) Breccias at Hickey's Pond define an elongate lenticular belt with maximum dimensions of 150 m by 5 m that parallels the regional structural trend and the presumed fault contact with the Swift Current Granite to the west.

4) Incipient gas brecciation occurs at the breccia pipe at the Monkstown Road showing.

5) Clasts of specularite-rich hydrothermal breccia are incorporated in the sinters at the Bullwinkle showing.

6) Axial planes of folds in banded rock at Hickey's Pond continue into the breccias as joints. The breccias are therefore pretectonic.

7) Rutile occurs as large euhedral 'crystals' (leucoxenes?) in the breccias at Hickey's Pond and the Tower showing. In obviously tectonically deformed rocks, e.g., the Strange showing and some banded rocks at any of the major showings, the rutile can be seen in various stages of deformation, culminating in wispy bands of very small, rounded crystals.

8) Some of the breccias at the Bullwinkle showing are polylithic.

9) The fragment size decreases and the size-sorting improves away from the centre, toward both ends of the breccia zone at Hickey's Pond.

10) The main breccia zone is conformable with the banding at Hickey's Pond, although narrow bodies of breccia show disconformable relationships in places.

11) All the breccias have a variably developed tectonic fabric.

The breccia at Chimney Falls is clearly a hydrothermal stockwork breccia in altered volcanic rocks. The interpretation that the breccias at Hickey's Pond and the Bullwinkle showing are hydrothermal explosion-breccia aprons is supported by their shape (3), sedimentary features (9) and contacts (10). The few disconformable contacts observed could represent subsurface intrusive breccias associated with the main breccia. Supporting the idea that these are tectonic breccias is their elongate shape (3) and their tectonic fabric (11). However, their dissimilarity with known fault-related rocks at Hickey's Pond (2), their rare polylithic nature (8), their variable and commonly minor deformation (1, 7), their pretectonic origin (6), and their pre to syndepositional relationship with the hot springs (5) mitigate strongly against a tectonic origin for these breccias. Nor can they be considered *in situ* breccias as their shape (3), sedimentary features (9), and most of the contacts (10, bearing in mind the intrusive breccias) are not consistent with this model.

Conclusion

Various parts of the highest level of an epithermal system are represented by these rocks. The stockwork breccia in volcanic rocks at Chimney Falls is the deepest part, representing the ascent of hydrothermal fluid. This stockwork is surrounded by alunitized, pyrophyllitized (originally kaolinized?) and sericitized zones, which commonly contain specularite and pyrite. Higher in the system, widespread alunitization, silicification and specularitization of volcanic rocks occurred, such as that at the Tower showing. Finally, the fluids reached the surface and precipitated the showings described here. Geysers were active near some of these hot springs. Breccia aprons formed explosively, were eroded and incorporated as clasts, along with other clastic detritus, in the thickening sinter. Eventually, the sinters were buried by volcanic rocks.

GOLD GEOCHEMISTRY

Approximately 250 whole-rock samples were analysed for gold in the course of this study. They represent various stages of alteration in the volcanic rocks and the different hot spring related assemblages. Table 1 shows selected analyses.

Table 1. Selected Gold Analyses

Sample Number	Description	mg/t
	SWIFT CURRENT GRANITE AREA (FIGURE 2)	
064	pyritiferous quartz-sericite schist	10
092	specularite-rich chert	5
148	quartz-sericite schist	5
164	pyritiferous quartz-sericite schist	5
181	quartz-pyrophyllite schist	100
190	chlorite-sericite schist	5
193	quartz vein containing minor specularite	5
287	pyritiferous, silicified, crystal tuff	5
294	quartz-pyrophyllite-specularite schist	5
296	banded alunite-specularite-rich chert	5
297	siliceous rock containing geyserite eggs	5
331	banded alunite-specularite-rich chert	5
358	pyritiferous quartz-sericite schist	5
431	pyritiferous, silicified, crystal tuff	1
Headwaters Showing		
144	pyritiferous quartz-sericite-pyrophyllite schist	10
335	quartz-pyrophyllite schist	15
Hickey's Pond Showing		
135	banded alunite-specularite-rich chert	350
170	pyritiferous chert	2530
227	alunite-rich chert	1450
232	alunite-specularite-rich chert	170
235	specularite-rich chert breccia	5400
254	specularite-rich chert breccia	45
255	specularite-rich chert breccia	4710
341	specularite-rich chert breccia	4950

Table 1 (*continued*)

Chimney Falls Showing		
154	quartz-pyrophyllite-specularite schist	5
156	specularite-rich stockwork breccia	335
161	quartz-pyrophyllite-specularite schist	45
Tower Showing		
271	gray pyritiferous chert	30
276	alunite-specularite-rich rock	5
283	quartz-alunite-specularite-pyrophyllite rock	5
428	pyritiferous chert containing minor pyrophyllite	36
Monkstown Road Showing		
094	quartz-pyrophyllite schist	5
096	specularite-rich chert	5
101	pyritiferous quartz-sericite schist	75
Bullwinkle Showing		
311	banded specularite-rich chert	5
316	banded alunite-specularite-rich chert	5
321	specularite-rich chert breccia	5
330	pyritiferous chert	45
435	pyritiferous chert	47
436	banded alunite-specularite-rich chert	121
443	pyritiferous chert	110
Strange Showing		
327	intensely sheared, specularite-rich, chert breccia	800
328	pyritiferous rhyolite dike	5
440	intensely sheared, specularite-rich, chert breccia	276
441	intensely sheared, specularite-rich, chert breccia	813
	CAPE ROGER MOUNTAIN BATHOLITH AREA (FIGURE 3)	
308	pyritiferous quartz-sericite schist	5
365	pyritiferous, silicified, crystal tuff	1
367	pyritiferous quartz-sericite schist	1
368	pyritiferous quartz-sericite schist	2
369	pyritiferous quartz-sericite schist	1
372	pyritiferous, silicified, crystal tuff	
375	gray chert and minor pyrophyllite	1
379	crystal tuff containing minor pyrite	1
383	rhyolite containing blebs of specularite	1
385	pyritiferous quartz-sericite schist	14
	KNEE GRANITOIDS AREA (FIGURE 4)	
408	pyritiferous quartz-sericite schist	4
411	pyritiferous chert	1
413	pyritiferous chert	1
416	pyritiferous sericite schist	3
417	pyritiferous chlorite-sericite schist	2
418	pyritiferous silicified rock from boulder	73
420	pyritiferous silicified rock	8
423	pyritiferous, silicified, crystal tuff	1
424	pyritiferous quartz-sericite schist	15
425	quartz-sericite schist	2
426	pyritiferous silicified rock	1
427	pyritiferous quartz-sericite schist	2

The following observations concerning gold mineralization can be made:

1) The gold concentrations in a given rock type can vary significantly within and between showings.

2) The showing at Hickey's Pond has the highest gold numbers.

3) The breccias at Hickey's Pond return the highest analyses, but they are not consistently high.

4) At Chimney Falls, gold is especially high in the stockwork breccia (335 mg/t in sample 156) but falls off abruptly in the pyrophyllitized volcanic rocks.

5) At the Tower and Bullwinkle showings, gold is more commonly found in pyritiferous rocks than specularite-bearing ones.

6) The specularite-rich breccias of the Bullwinkle showing are barren.

7) The Strange showing returns the highest gold concentrations (813 mg/t) outside the Hickey's Pond area.

8) The only gold detected at Locality E (5 mg/t in sample 297) from 8 samples taken was in the rock composed of geyserite eggs.

9) With the exception of the Chimney Falls showing, the various assemblages of altered volcanic rocks contain less than 100 mg/t gold. When all the data on these rocks are considered, those around the western contact of the Knee granitoids give (proportionally) the largest number of 'kicks' and one of the largest assays (73 mg/t in sample 418).

Preliminary microanalyses at Memorial University have revealed that native gold with very minor silver occurs as grains up to 0.03 mm across in the specularite in the breccia matrices. Gold telluride occurs within pyrite in sample 170. Also observed were compounds of uncertain mineralogy containing various combinations of Cu, Ag, Au, As, Sb, Bi, S, Se and Te. This suite of elements is characteristically related to gold in the epithermal environment (Boyle, 1979).

Discussion

Perhaps more surprising than the apparently low concentrations of gold at the Tower and Bullwinkle showings is the high concentration of gold at Hickey's Pond. The 'precious metal horizon' in epithermal systems has a lower limit marked at the depth of boiling, and an upper limit marked by the highest upward movement of the precious metals. This upper limit is often hundreds of metres below the surface (Buchanan, 1981). Occurrences of gold in sinters, such as those at the Broadlands and Waiotapu geothermal fields in New Zealand, are uncommon (Weissberg, 1969). There, however, the sinters contain up to 85,000 mg/t gold. These auriferous sinters are precipitating from waters with temperatures ranging from 75° C to 95° C and pH's from 5.7 to 7.0. A much different type of water precipitating a different type of sinter occurs at Frying Pan Lake, Waimangu, New Zealand. The water is cooler (67° C), has a lower pH (3.8), and has over twice the sulfate ion concentration as the other waters. No gold was detected in this sinter. However, it has unusually high W, P, and As, as well as approximately 10 percent Fe_2O_3 (Weissberg, 1969).

This 'barren' sinter described by Weissberg (1969) is analogous to that at the Bullwinkle showing in that it is iron-rich and precipitated from an acid-sulfate solution. The pH of the water is critical in that condensed, oxidized, H_2S-rich vapour could not have transported gold but would have a low pH. The importance of the low-pH assemblage in a sinter is that it points to the precipitation of precious metals at depth, where boiling occurred. The gold at Hickey's Pond might be the result of very high-level boiling and the direct discharge of some of the boiling fluid into a hot spring dominated by condensed, oxidized H_2S-rich vapour. The particularly gold-rich breccias at Hickey's Pond may attest to this boiling. Although breccias are present at the Bullwinkle showing, they are by volume much less significant than those at Hickey's Pond. This fact, coupled with the polylithic nature of the breccias (including fragments of altered volcanic rock), may point to boiling at a deeper level than that exposed at Hickey's Pond, and the precipitation of precious metals at this level.

CONCLUSIONS

Gold is associated with sinters, high-level specularite and alunite-bearing stockworks, and to a lesser extent, variably altered volcanic rocks on the northern Burin Peninsula. The large, siliceous, resistant sinters are the most easily located parts of the ancient hydrothermal systems that acted on the accumulating volcanic pile. Even so, two of the largest sinters, situated very near a road, were only discovered during the 1985 field season. Using the sinters as starting points, exploration for gold must consider the underlying parts of the hydrothermal system. These will not have the marked surface expression of the sinters, but may well be located with the aid of their anticipated geochemical signatures.

ACKNOWLEDGEMENTS

Simon O'Brien and Dave Molloy are thanked for their excellent field asistance. The manuscript was critically reviewed and improved by D.F. Strong, H.S. Swinden and D.H. Wilton. This project is part of an M.Sc. study at Memorial University of Newfoundland, where the senior author is funded by an NSERC postgraduate scholarship. Paul Dean is thanked for his discussion and support.

Our condolences are extended to the moose family that lost one of its members during the course of this field study.

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