Prospectivity of epithermal and porphyry Au-(Cu) prospects, Burin peninsula, Newfoundland

Stewart prospect, looking NE to E to altered volcanic rocks sandwiched between granite and distant hills of diabase; large trench area previously drilled, newly-exposed sheeted quartz veins 600 m NE, and quartz-alunite ~2 km NE

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Summary and recommendations

The Burin peninsula represents a Neoproterozoic magmatic arc of volcanic and sub-volcanic rocks. Numerous elongate zones of alteration are present, mainly typified by advanced argillic alteration with silicic cores, the latter with variable Au and other anomalies. The ductile deformation and greenschist metamorphism has contributed to the structural complexity of these variably folded units, but the lithocap-type of epithermal alteration and local mineralization with high-sulfidation affinity has long been recognized. In addition, there are numerous intrusions and sub-volcanic features such as sheeted quartz veins and heterolithic breccias that are consistent with the upper portions of porphyry systems being exposed, possibly in blocks that have been tilted or upthrown relative to other areas.

The complete 15-km long trend centered on Hickey’s Pond appears to have potential that remains largely untested, with most previous work focused on a few 100 m of the trend, due to the relative lack of outcrop and the attraction of the silicic zone at Hickey’s Pond, where grades up to 15 g/t Au are present. Clearly, Hickey’s Pond deserves continued attention – starting with careful mapping that includes attention to the effects of both ductile deformation as well as folding and fault displacement of the original position of the potential ore zones – but the whole trend must be adequately assessed all the way to Tower, 10 km to the SW.

The Paradise trend, offset to the south on the western margin of the principal volcanic package, near the contact with the younger sedimentary package further west, also has pods of silicic alteration scattered from Monkstown Road SW through Bullwinkle and Strange, with local gold anomalies, hosted by strongly deformed advanced argillic alteration. At present this trend appears to have smaller silicic zones and lower gold anomalies than the Hickey’s Pond trend, but assessment has been restricted to the few outcropping zones.

Further southwest ~50 km, the Stewart prospect has many intriguing features, several recently revealed by stripping of the soil in shallow trenches. This area is sandwiched between the contemporaneous Swift Current granite to the west, and a weakly altered diabase to the east. Original sampling and drilling focused on an area of quartz-pyrophyllite±alunite schist with Au and Cu anomalies, although the Au anomalies are to date an order of magnitude lower than at Hickey’s Pond. There is a soil anomaly over 700 x 500 m in size of highs in Au to >400 ppb, elongate NE, with corresponding Cu (areas >100 ppm, up to 245 ppm) and Mo (areas >80 ppm, up to 145 ppm) tending to correspond to the best Au anomalies. Copper is more significant than at other prospects, up to 0.23 wt%, consistent with the recent recognition of sheeted quartz veins in the NE portion of the area with strong soil anomalies. There is a lack of strong silicic alteration in the drilled area as well as the area of quartz veining, whereas ~2 km NE silicic and quartz-alunite alteration is present, albeit without a recognized gold anomaly. Recent TerraSpec identification of topaz and diaspore at this prospect, the presence of quartz veins and lack of silicic alteration in the area of Cu anomaly suggests that much of this prospect represents a sub-volcanic level of exposure, with porphyry potential to be considered. As such, this prospect appears to have the most immediate interest and potential in contrast with the elongate zones of advanced argillic alteration, some associated zones of massive silicic alteration that locally host elevated Au mineralization.

Recommendations: Stewart prospect

- At Stewart the most critical aspect at present is to 1) conduct detailed mapping (now underway) of rock and alteration type (the latter supported by TerraSpec, paying attention
to the offset of intrusions and alteration types that may indicate faulting and folding), 2) conduct representative sampling, particularly in the veined areas, 3) integrate all observations to arrive at a model of the complete system (considering both the porphyry and epithermal levels of erosion that are indicated in different parts of this large system)

- Prior to disturbing the area further for exposure and trenches, consideration should be given to the usefulness to repeat the original soil sampling, or at least extend it adjacent to the areas of best coincident Au, Cu and Mo anomalies. An alternative is to simply extend the trenching along previous grid lines and conduct extensive bedrock sampling. Also consider collecting representative samples of veins (at least 10 vein samples per locality) to assess their style by examining the fluid inclusion characteristics

- Based on the results of mapping and sampling, a new geophysical survey may be warranted, starting with an extensive ground magnetic study over the whole area to identify the center(s) of local intrusion(s) and magnetite stable (and destructive) alteration, and extension of the IP-resistivity survey to the NE to the Bat zone

- Based on the mapping, sample results, and possible geophysical surveys, it is thought likely that targets will be generated that will justify drill testing, after considering the porphyry characteristics of the area, and incorporating these into any model to be tested

Recommendations: Hickey’s Pond and Paradise trends, and Lode Star

- The elongate belts of advanced argillic alteration with local zones of silicic alteration, some with gold mineralization, must first be mapped, including the effects of ductile strain and folding on the region. Consider the possibility that silicic zones may be restricted in area because of extension followed by steep tilting (cf. Kutemajärvi)

- While mapping, much more representative channel sampling of the silicic zones must be conducted. Also, silt sampling in the winter of all ponds along each belt will help to determine if additional trenching is warranted between the areas of outcrop

- No further work is recommended at this time at Lode Star, given the priorities above, but if regional work is considered (see below), further examination of this prospect, both for its potential and indications about other potential in the peninsula, may be warranted

Recommendations: Regional exploration of the Burin peninsula:

- Test the efficacy of the lake sediment anomalies near known alteration and mineralization; if positive, extend lake sediment sampling, first along all known alteration trends and on extensions. Reprocess ASTER imagery, using ground truth results from TerraSpec, and combine with known alteration systems, as well as with lake sediment anomalies, to integrate with knowledge of levels of erosion within the arc

- Extend lake sediment sampling and ASTER imagery west into the arenaceous sedimentary sequence, since alteration zones are known to occur wholly within this stratigraphic package; subtle alteration may have been missed in these sedimentary rocks

- Consider not only epithermal but also porphyry potential of the peninsula, as exhibited by Stewart. Has folding and/or faulting of large blocks resulted in the sub-volcanic environment being exposed? Is a regional air magnetic survey warranted?
Introduction

Mr. Mike Basha, VP Exploration of Cornerstone Resources, Inc., requested the author to revisit the Burin peninsula, eastern Newfoundland, to examine several zones of advanced argillic alteration with reports of gold mineralization; a previous visit in late 2006 introduced the author to the area and some of the prospects. The author was accompanied in the field by Basha as well as George Smith, exploration manager, Brad Dyke, project geologist, Servio Loayza, Magner Turner, Steve Tsang and Brent Thomas, from 9 to 12 August. Warren Pratt, a specialist mapper from the UK, was also part of the group, at the start of a three-week field mapping exercise on the prospects with several Cornerstone staff. Discussions in St. John’s with Sean O’Brien, Department of Mines and Energy, were fruitful and appreciated. This report incorporates comments from these individuals, with thanks.

One day was spent on the Hickey’s Pond trend, including Tower, a morning on the Paradise trend, and an afternoon at Stewart, with access provided by helicopter; a previous visit for a day by helicopter was made to Hickey’s Pond and Stewart, accompanied by Basha and O’Brien. Lode Star was visited for part of the final day, accompanied by Leroy Smith plus Basha and Smith, as well as a Mo occurrence, on return from Marystown to St. John’s by car.

Geology of the Burin peninsula

The Burin peninsula is dominated by the Neoproterozoic Marystown Group (590-575 Ma) (Fig. 1), a sequence of basal basalt flows and tuffs on the eastern margin, followed rhyolitic volcanic products and epiclastic material with minor mafic tuffs and porphyry intrusions, and capped to the west by an arenaceous sedimentary sequence of siltstones to conglomerates, with felsic and mafic tuffs (detail on Fig. 2). The Swift Current granite (580-575 Ma) intruded the Marystown Group as it was being deposited (Figs. 1 and 2).

Numerous elongate zones of alteration, dominated by muscovite and pyrophyllite with pyrite, alunite and minor topaz and andalusite, occur throughout the peninsula (Fig. 1), several of which have Au anomalies of 1-15 g/t in grab samples, most commonly associated with silicic lenses (O’Brien et al., 1999, Newfoundland Dept Mines and Energy, Geological Survey, Report 99-1, on which much of this summary is based). O’Brien et al. (1999) suggest that many of the elongate alteration zones (with the common pyrophyllite and alunite association included in the advanced argillic assemblage) follow two belts, an eastern belt near the eastern margin of the granite, and a western belt near the volcanic and arenaceous sedimentary contact. Along with the silicic lenses, such advanced argillic alteration zones are consistent with the style of lithocap alteration that typically host high-sulfidation (enargite) Au-(Cu) ore deposits in younger volcanic arcs around the world.

The Hope Brook mine (1.5 Moz Au, 13.5 kt Cu), a high-sulfidation deposit within a sliver of the same Avalonian terrane 250 km to the west (Fig. 1), has been dated by Dubé et al. (1998, Economic Geology) in the range of 578 Ma (host rock age) to 574 Ma (post-mineral dike). This overlaps the age of the major intrusive event of the Burin peninsula, and may be similar to the ages of the alteration in the Burin. The peninsula is antiformal in nature, cored by the granite, meaning that the elongate zones and belts of alteration may correlate in time to one another. It is also possible that some of the alteration zones may occur in different stratigraphic horizons, thus indicating more than one period of major hydrothermal events on the Burin.
Fig. 1: Simplified Neoproterozoic geology of the Burin peninsula, Newfoundland, and the location of alteration zones, including the prospects visited, from southwest to northeast, Stewart, Tower, Hickey’s Pond (on the eastern alteration belt of O’Brien et al., 1999), and Paradise (Monkstown Road), including Strange and Bullwinkle (on the western alteration belt), as well as Lode Star. Eastern belt suggested to follow eastern contact of granite with volcanic rocks, whereas western belt is near the volcanic and arenaceous sedimentary contact (with Henry’s Pond alteration hosted by sedimentary rocks). Over 20 areas of alteration occur along >150 km of magmatic arc in the Burin peninsula. Inset shows Hope Brook high-sulfidation deposit (1.5 Moz) in the same Avalonian terrane, 250 km to the west. From O’Brien et al., 1999, Newfoundland Dept Mines and Energy, Geological Survey, Report 99-1.

Subsequent to the formation of the volcanic succession of the Marystown Group, similar to other magmatic arcs in the Appalachian Avalonian terrane, the Neoproterozoic rocks and Cambrian sedimentary sequences were variously subjected to low-grade metamorphism during the Siluro-Devonian. The deformation associated with ductile thrusting was locally intense, particularly near some of the alteration zones (e.g., Hickey’s Pond), although this deformation is less intense to the southwest, near the Kelstone alteration zone, where there are fewer intrusions outcropping. Overall, the Marystown Group rocks and alteration zones were subjected to greenschist facies metamorphism that does not appear to have had a major effect on alteration mineralogy, although the common specular hematite has crystallized in foliations, and other minerals appear to have suffered some recrystallization during formation of schists, e.g., mica and alunite.
Fig. 2: Details of the geology of the central Burin peninsula, from Hickey’s Pond southwest to Stewart prospects (large dots); other prospects shown with X. Most prospects are in the volcanic horizons (yellow) Symbols: MA, Marystown Group (590-575 Ma); MAP3m, basalt flows and tuffs plus sills and other intrusions (base of sequence; blue); MAP3f, rhyolitic ash flow tuff, flows, volcanic breccia, and epiclastic rocks, minor mafic tuffs and rhyolitic porphyry (yellow); MAP3s, litharenite, conglomerate, sandstone, siltstone, plus felsic and mafic tuffs (top of sequence?, light brown); P3SC, Swift Current hb-bt granite (reddish, 580-575 Ma). From the Newfoundland Geological Survey map sheet.

Several questions remain about the regional geology that affect the interpretation of the mineral prospects and their assessment, including the degree of folding and faulting (offset) of parts of individual prospects, the level(s) of erosion through the peninsula, and the possibility that major folding and/or faulting may have resulted in the exposure of different levels (volcanic to subvolcanic, epithermal to porphyry) in different blocks. This aspect must be kept in mind, both during assessment of individual prospects and trends, as well as during assessment of the peninsula-wide potential.
**Hickey’s Pond trend, including Tower**

The Hickey’s Pond trend (Fig. 1) includes several discontinuous zones of similar alteration, elongated NE-SW and on strike with each other over >15 km length. The prospect include, from NE to SW, White Hills (with a grab sample reported to contain 55 g/t Au), Eric’s, Headwaters, Hickey’s Pond (up to 12.4 g/t Au in a channel sample, and 15.4 g/t in a grab sample), Chimney Falls (0.34 g/t Au in a grab sample), and Tower (up to 1 g/t Au in grab samples from recent trenches); all but White Hills and Chimney Falls were visited on this trip. Hickey’s Pond has received the most attention since its first recognition in the 1930s as the site of hematite with alunite. Pyrophyllite was recognized in the 1970s, and its association with alunite led to the suggestion of economic potential for precious metals. Following the discovery of mineralization at Hope Brook, associated with similar alteration, the area was sampled by BP Selco in the 1980s, and gold anomalies were identified; in a similar period, government mapping and geochemical surveys also indicated the gold potential for the rocks (O’Brien et al., 1999). BP Selco conducted magnetic, VLF-EM and IP-resistivity surveys, followed by 5 shallow drillholes (maximum ~148 m long). Corona subsequently sampled the area and drilled 4 more holes in the late 1980s, with maximum channel samples returning 12.4 g/t Au over 1.2 m; maximum drill hole results were more than an order of magnitude lower, although it is unsure if the best mineralization in silicic zones at the surface were intersected. Corona reported one drill hole (90-03), under the pond, that returned 0.1 to 0.6 g/t Au along much of its 75 m length, in pyritic silicic and quartz-mica schist, reportedly altering an intrusion with porphyry texture. In the last few years, Geovector conducted mapping and sampling (up to 5 g/t Au) for Western Keltic, but no further drilling.

![Fig. 3: Looking south along the SW trending silicic zone of Hickey’s Pond that returned the best gold anomalies.](image)

The outcropping hill (Fig. 3) is cored by sulfide-poor massive silicic alteration, with grab samples returning up to 15.4 g/t Au (as well as 15 g/t Ag, 0.28 wt% As, and 0.29 wt% Sb); a
local sulfide lense consisting of quartz-alunite-tennantite returned up to 7.5 g/t Au (plus 109 g/t Ag, 3.4 wt% Cu, 1.5 wt% As, and 0.8 wt% Sb) (O’Brien et al., 1999). The silicic body is enveloped by pyritic quartz-alunite (locally with pyrophyllite, or minor lazulite, a phosphate-bearing mineral, perhaps similar to aluminum-phosphate sulfate minerals – APS – that are commonly associated with alunite in similar unmetamorphosed settings). This halo pinches out along strike, passing outward to quartz-mica schist, all of which have been deformed, with a strong near-vertical foliation. O’Brien et al. (1999) reports that the S1 foliation contains a moderate to steeply southwest-plunging stretching lineation, as well as variably plunging F2 folds; strain increases to the west, where the granite has been thrust over the alteration zone.

Within the advanced argillic zones pyrite and specularite are common, and in addition to gold, there are reports of calaverite, tetrahedrite-tennantite, and chalcopyrite (Huard, 1990, MSc thesis, Memorial University). Previous work discussed by O’Brien et al. (1998, Newfoundland Dept. Mineral and Energy, Geological Survey Report 98-1) found up to 3.2 g/t Au, 76 g/t Ag, and 1040 ppm Cu, 4600 ppm As, and 2077 ppm Sb at Hickey’s Pond. Quartz-pyrophyllite at the surface returned values of 200-600 ppb.

The IP-resistivity survey by BP Selco was conducted on lines spaced at 100 to 200 m, run perpendicular to the trend of the outcrops. A NE-trending IP high, 700 m long, was centered under the SW part of the pond (Fig. 3); at the NE end of this IP high there was a small resistivity high, corresponding to the peninsula with silicic outcrop. The magnetic survey had no response.
locally, with the area located in a broad regional magnetic low. The BP Selco holes that were drilled to test the IP-resistivity anomaly returned Au values of 20-50 ppb up to 0.7 g/t; As was very low, 10 to 40 ppm, as were combined Cu, Pb and Zn, at 100 to 500 ppm, usually dominated by Cu. The hole with the best Au results, HP5 to the NE of the silicic zone, was outside the IP-resistivity anomaly.

Further to the NE ~3-4 km there are other areas of alteration, e.g., at Headwaters, of strongly foliated quartz-alunite-pyrophylite schist, with reports of local gold anomalies. The Tower prospect occurs ~10 km SW of Hickey’s Pond, with discontinuous outcrops of alteration along the trend, e.g., at Chimney Falls. There has been no systematic sampling at either prospect.

Paradise trend, including Strange and Bullwinkle

This trend of advanced argillic alteration, near the western limit of the volcanic package, is hosted largely by rhyolitic tuffs altered to quartz-mica-pyrite schist, with local chlorite and illite-smectite to illite (PIMA results by Geovector). Pyrophyllite, diaspore and rutile have also been reported, as well as possible alunite.

At Strange, a 300-m series of discontinuous outcrops (Fig. 6) were examined by Geovector, who mapped and sampled the area for Western Keltic; their grab samples reported up to 1.39 g/t Au to the SW and 1.66 g/t Au to the NE (associated with a massive silicic zone; Fig. 7). The As and Sb were very low, as were the base metals, even in samples with >1 g/t Au; Ba reported up to 770 ppm.

At Bullwinkle, a couple of km NE of Strange, a cliff outcrop, upheld by a narrow but massive silicic core (Fig. 8) did not return sizeable Au anomalies.

Overall, this trend seems less well developed than the one associated with Hickey’s Pond, but a real comparison cannot be made until mapping helps to fill in the gaps between identified outcrops of alteration.
Fig. 6: Looking NNE at Strange, Paradise trend, western alteration belt. Outcrops define a ~300 m trend of discontinuous silicic alteration enveloped by quartz-mica-pyrophyllite schists, locally intruded by a magnetitic intermediate composition dike weakly altered to epidote.

Fig. 7: Strange prospect, Paradise trend. a) Massive silicic zone at NE end. b) Laminated silicic zone, 1.66 g/t Au.

Fig. 8: Bullwinkle prospect, Paradise trend. a) Looking south. b) Near-vertical silicic zone with mica schist margins.
Stewart prospect

The pyrophyllite alteration associated with the Stewart area was discovered by Kennecott corporation in 1985 following the recognition of the style of alteration associated with Hope Brook mineralization 250 km west in similar Avalonian terrane. The known alteration zone is about 4 km long and 400 to 700 m wide (O’Brien et al., 1999), with the area of advanced argillic alteration grading outward to muscovite and a clay halo; disseminated pyrite is common (Dimmell and MacGillivray, 1993, Newfoundland Dept. of Mines and Energy, Geological Survey Miscellaneous Publication).

Novamin optioned the area from Kennecott and subsequently sampled the area and conducted a geophysical survey, concluding with drilling of 4 holes. Soil sampling indicates a large area, about 500 x 700 m, of highly anomalous gold, >100 ppb, in lenses trending NE, with maxima of 440 to 1440 ppb Au. The most anomalous Cu and Mo, up to 250 and 145 ppm, respectively, tend to be associated with the areas of the best Au anomalies. As reported by Dimmell and MacGillivray (1993), the >100 ppm Cu and >80 ppm Mo anomalies in soil extend, in elongate fashion, up to 900-1000 m NE of the lake.

Several trenches were dug with SE-NW orientations, and in one, Trench 2, 330 to 1570 ppb Au was present in B-zone soil samples. A sampling program of basal till returned <5 to 1030 ppb Au. VLF-EM and magnetic surveys did not provide clear anomalies, whereas the IP survey identified zones of pyrite mineralization; an assessment of resistivity, to map the zones of greatest silicic alteration, was apparently not conducted. Four holes were drilled to the SE at 45 degrees in 1986 (830 m total) on the IP anomalies, and returned pyritic zones with 20 to 90 m intervals of 100 to 400 ppb Au; Cu was generally >0.1 wt% in intervals with >100 ppb Au. The Novamin drill hole NG-1, with up to 0.23 wt% Cu associated with 0.3 to 0.4 g/t Au, was sited 700 m NE of the subsequent Corona drill hole 90-02 (relatively near the area recently identified as containing quartz veins; see below).

Corona examined the property in 1988 and conducted further sampling, including trenching and channelling, followed by drilling of 3 holes in 1990 (430 m total) on the NW side of the anomalies, all oriented to the NW. One hole returned a maximum of 93 ppb, whereas the other two holes has narrow intervals of better grade, 5 m of 0.24 g/t Au, and 1 m of 2.9 g/t Au within a 63 m interval of 0.25 g/t Au. The best result, 2.9 g/t Au over 1 m in drill hole 90-02, was possibly associated with bornite. Other minerals reported are chalcopyrite, molybdenite, azurite and cuprite, the latter two due to weathering.

Evidence for abundant faulting, including fault offset, has been suggested in the area (Dimmell and MacGillivray, 1993), although it should be noted that this is common in such areas of advanced argillic alteration, where the alteration contacts are very sharp; in many of the (undeformed) cases these sharp alteration contacts are not due to fault offset.

During this visit, two large areas had been stripped of soil cover (Frontispiece photograph), near the sites of previous drilling, one just north of the lake, and the other about 600 m further NE. One area in the south of broken sheeted (?) quartz veins (Fig. 9a) is present. The degree of strain in this area is illustrated by a late dike (Fig. 10a; outline traced by dotted line), which varies from 20 cm to 80 cm thick; it is locally boudined and discontinuous, but in general can be traced for 25 m; nearby there is an isolated boudined quartz zone (possible vein?; Fig. 10b).

About 600 m NE, a large outcrop of sheeted to stockwork quartz veins is present (Fig. 9b-c), clearly pre-foliation (Fig. 19d), but not strongly folded or faulted, although locally in areas of
high strain there is evidence of boudinage. These quartz veins contained sulfides, now largely weathered. They do not have a clearly developed center line, and the quartz appears to possibly have been recrystallized during the development of foliation. The may be related to a deeper porphyry type of system, consistent with the elevated Cu and Mo anomalies in the area, and pyrophyllite (+ topaz) occurrence with muscovite that is present over some porphyry deposits.

Fig. 9: Abundant sheeted veins, broken, in southern Stewart area. b-d) Central Stewart area, outcrop of sheeted (b) to stockwork (c) veins, locally folded with foliation imparted on recrystallized quartz vein, which deflects foliation (d).

Fig. 10: Southern portion of Stewart, with uncovered area exposing a deformed and boudined mafic dike in quartz-mica schist (outlined). b) Boudined quartz horizon.
Northeast of the southern area 2.3 km (~1.6 km NE of the vein zone; Frontispiece photograph), there is an outcrop of massive silicic alteration with associated pyrophyllite and alunite on the margin in the Bat zone (Fig. 11). The few samples collected in the area by Cornerstone are limited to <50 ppb Au.

Fig. 11: Looking south over strongly silicic outcrop of the Bat area, 2.3 km north of the southern portion of Stewart (~1.5 km north of the principle vein outcrops). Grab samples locally returned <50 ppb Au. b) Massive silicic alteration with disseminated pyrite and pods of alunite; the outcrop has margins of quartz-pyrophyllite alteration, broken during foliation.

If the area of veins to the SW is a sub-volcanic exposure and the Bat zone is associated with it, the latter may represent an epithermal level of erosion with much stronger silicic alteration. If so, then there must be either tilting, folding, and/or faulting between the SW and NE areas to account for the different erosional levels at essentially the same elevation, since massive silicic alteration is restricted to levels shallower than several 100 m depth, whereas such veins and pyrophyllite (+ topaz) probably indicate original depths of close to 1000 m or more. However, collapse of the former on to the latter is known in places (e.g., advanced argillic alteration and high-sulfidation mineralization overprinting potassic alteration of porphyry deposits in areas of rapid syn-hydrothermal uplift, such as Papua New Guinea). In addition, there are deposits where pyrophyllite (± diaspore, topaz, andalusite, dumortierite) closely overlie porphyry mineralization, such as at distinctly different deposits at Island Copper, British Columbia; El Salvador, Chile; and Oyu Tolgoi, Mongolia (see below). Mineralization within such alteration styles is typically low grade, even though it is associated at each of these three locations with ore at greater depth.
Lode Star prospect

The Lode Star prospect in the northern Burin peninsula (Fig. 1) is associated with a variety of heterolithic breccias (Fig. 12) cutting a 603 Ma gabbro, and cut by a 603 Ma aplite dike, i.e., mineralization is about 25-30 m.yr. older than the 578-574 Ma Hope Brook deposit and likely the other mineralization related to advanced argillie alteration on the Burin peninsula.

Gold mineralization is associated with sulfide-rich cement of the breccia, dominated by arsenopyrite plus pyrite and chalcopyrite (Fig. 12b). One 5-m channel returned 1-m intervals with up to 10.6 g/t Au and 0.37 wt% Cu. The best channel overall reported 5.6 g/t Au over 8.5 m, with up to 12 g/t in one sample. The breccia fragments vary from quartz-eye porphyry, itself cut by pre-brecciation veinlets, to a variety of intrusive (largely felsic) and sedimentary fragments (Fig. 12). Alteration consists of epidote-chlorite, with magnetite locally. Linear optioned the property and conducted geophysical surveys over the area, including ground magnetics and IP-resistivity. They subsequently drilled four holes, largely on the IP anomaly, but failed to test the west to NW trending polyphase breccia outcrop.

Clearly there was felsic intrusive activity into the gabbro, which is likely relatively thin in this area, overlying the sedimentary basement (based on the abundance of sedimentary fragments and reworked sedimentary material in some matrices). It is not clear if there was any pre-brecciation mineralization associated with the felsic fragments, or if the Au-(Cu) mineralization is principally related to the breccia cement.

Fig. 12: Lode Star prospect, northern Burin peninsula, with a variety of polyphase, heterolithic breccias cemented by Au-bearing sulfides, including arsenopyrite.
Discussion

The silicic zones of the Burin peninsula are variably mineralized with gold, and have halos of advanced argillic alteration. The characteristics are similar to lithocap-hosted gold mineralization in younger volcanic arcs, particularly if the strain and metamorphic effects are removed.

The Hickey’s Pond area has had a reasonable amount of surface assessment focused on the central area of silicic core with the best Au results, as well as nine short holes within a few 100 m of this area. It is not clear if these shallow holes fully tested either the steeply dipping and plunging silicic body, both in terms of position of the holes and their extent (several stopped well short of target). One possibility is that this silicic body is rod-like and steeply plunging, similar to the ore zones at Kutemajärvi, Finland (see below), and that drilling did not adequately test this zone. Another possibility is that the silicic zone, which pinches out to the NE, and possibly to the SW, also pinches out with depth (as lithocaps do); if so, this may be because the original size was small and/or this level is near the base of the original silicic zone, or alternatively, there has been fault dismemberment or ductile extension of the zone.

Several km to the NE there are outcrops of strongly foliated advanced argillic alteration, with reports of local gold anomalies (in silicic bodies?). About 10 km to the SW, a significant silicic zone outcrops at Tower on the same trend, with limited grab samples in recent trenches.

There is clear evidence of a variable degree of strain in these and other prospects on the Burin (O’Brien et al., 1999), and this must be kept in mind when assessing individual outcrops, as well as outcrops along trends in which there is only scattered outcrop. Many of the outcrops as well as possibly contiguous trends (up to 10+ km long) have length to width ratios of at least 10:1. Although original lithocaps also have a lithology-controlled high aspect ratio, it is likely that ductile behaviour of the advanced argillic alteration – particularly the pyrophyllite, kaolinite, and even alunite – out to the micaceous zone, would have suffered significant strain, more so than the more competent silicic cores (as can be seen in other examples, below). Thus, the question is whether or not all of the more resistant silicic bodies outcrop along trends, and the more recessive advanced argillic alteration largely does not outcrop.

In the Burin peninsula, neither high (enargite) or low (arsenopyrite, pyrrhotite) sulfidation-state sulfides are abundant or common. Rather, minor chalcopyrite is common, along with other Cu sulfides (bornite, azurite, cuprite, although the latter two are likely weathering products), and at Hickey’s Pond, tennantite has been reported (O’Brien et al., 1999), a Cu-As intermediate sulfidation-state sulfide (sulfosalt) typical of the roots of high-sulfidation deposits. Hematite is common, although clearly it formed during foliation development; whether it is a recrystallized hydrothermal product – consistent with intermediate sulfidation-state conditions – or was introduced during metamorphism, is not certain; it is not a typical mineral associated with epithermal deposits in general, despite its common occurrence in the Avalon zone.

The most intriguing prospect yet visited is Stewart, with the recent exposures highlighting the presence of sheeted and stockwork quartz veins of the style that may be associated with porphyry Cu deposits. This is consistent with the lack of strong silicic alteration in the southern areas, although the Bat zone, over 2 km to the NE, has characteristics more similar to the Hickey’s Pond trend. This possibility, that Stewart represents a more deeply exposed part of a magmatic hydrothermal system, closer to a tentative porphyry zone, must be considered during its assessment, particularly how this affects interpretation of alteration zoning, metal anomalies, and geophysical results.
Other examples of metamorphosed Proterozoic deposits

The Hope Brook deposit (Dubé et al., 1998, Economic Geology) is located ~250 km west of the Burin peninsula in a sliver of Avalonian terrane. This deposit (11.2 Mt at 4.54 g/t Au) produced 1.5 Moz Au, and also had Cu-rich zones (a total of 13,500 t Cu, with local grades ~1 wt%). Host rocks and post-mineral dikes have been dated at 578 and 574 Ma, closely constraining hydrothermal activity to overlap with the age of the Marystown Group and Swift Current granite on the Burin peninsula. The silicic ore zone (Fig. 13a) is up to 100 m wide, 800 m long, and extends for over 700 m down dip (Fig. 13b). Pyrite-rich silicic rocks (1000 m on surface, but 1500 m at depth) and advanced argillic alteration are present to the NW and SE of the ore zone,

Fig. 13: a) top: Plan (4960 level) of the Hope Brook deposit. b) left: Section (11,700E) through the Hope Brook deposit, looking east.
respectively, the latter a schist consisting of quartz with andalusite, pyrophyllite, white mica, and kaolinite, as well as topaz, rutile, alunite, etc. The ore zone at Hope Brook contains pyrite, and below surface there are Cu-rich zones with chalcopyrite, bornite and pyrite, as well as minor tennantite and galena and traces of enargite, tetrahedrite, colusite, barite, and calaverite, mineralogy typical of high-sulfidation deposits; the As and Sb are atypically low, <50-100 ppm.

Fig. 14: Ore zone of the Enåsen Au deposit, with gold distribution, high Au/Ag and Cu zones, and the sillimanite distribution in the quartz-sillimanite gneiss that is the ore host. From Hallberg, 1994, Mineralium Deposita.

Fig. 15: Result of amphibolite-grade metamorphic overprint, strain, and tilting on the Enåsen Au deposit. Original deposit likely had a root system and lithocap of residual silicic alteration with Au-Cu ore, surrounded by a halo of advanced argillic alteration that was aluminum-rich (e.g., kaolinite, dickite, pyrophyllite), upper left. Increasing amounts of strain results in the strong elongation of the sillimanite-containing silicic zone (estimated to be a 1500 x 600 m disc up to 35 m thick, after strain and prior to faulting); the ore is contained within this quartz-sillimanite schist. The aluminous halo converted to sillimanite during metamorphism, with common topaz and rutile. The enclosing metamorphosed alteration consists of quartz-mica and quartz-feldspar; the footwall consists of quartz-Mg biotite schist (originally chlorite?). From Hallberg and Fallick, 1994, Mineralium Deposita.
The Enåsen deposit is Paleoproterozoic in age, located in south central Sweden (1.7 Mt at 3 g/t Au, mined), in Svecofennian terrane (Hallberg, 1994, and Hallberg and Fallick, 1994, Mineralium Deposita). The ore zone contains variable amounts of sillimanite, and has a Cu-rich zone at its top (Fig. 14). This deposit is an extreme example of the effects of amphibolite-grade metamorphism and strain on a silicic zone (Fig. 15). The strain has resulted in a deposit with originally similar dimensions being sheared to 1500 m long by a maximum of 35 m thick.

Fig. 16: Plan (top) and sections (a, b) of Kutemajärvi (Orivesi mine), Finland. The Kutema lodes (pipes 5-20 x 20-50 m) have been mined to a depth of ~700 m below surface, and there are indications that they extend to >1000 m depth; the adjacent Sarvisuo lode, ~250 m east, extends to at least 600 m depth, possibly to >1000 m (other pipes are suggested by Dragon Mining). From Eilu et al., 2003, modified from Poutiainen and Grönholm, 1996, both Economic Geology.
The Kutemajärvi deposit, located in the Paleoproterozoic Tampere schist belt of SW Finland, has been metamorphosed to greenschist facies (Poutiainen and Grönholm, 1996, Economic Geology, incorrectly concluded that it was a metamorphic deposit). From 1994-2003, ~0.4 Moz Au was produced from a deposit at ~9+ g/t Au; since then the Sarvisuo body was identified. Reserves and resources are 0.26 and 0.66 Mt, averaging 11 and 10 g/t Au, respectively, for Kutema and Sarvisuo combined; total deposit size is >2 Mt. The outer alteration zone (Fig. 16) consists of white mica and chlorite between the deposit and a porphyritic to equigranular granodiorite to granite, about 500 m to the north (i.e., below the deposit, prior to rotation ~90 degrees. The elongated ore zones are now near-vertical pipes (Figs. 16a, b) of massive silicic alteration (Fig. 17a), and they have a halo of quartz-mica; andalusite, phlogopite, and rutile are common, as is an increasing amount of topaz, fluorite (Fig. 17b), pyrophyllite, and kaolinite inwards. Pyrite accompanies gold and calaverite, with high Hg and Bi; in addition to pyrite, there is minor arsenopyrite, as well as chalcopyrite, sphalerite and trace tetrahedrite, boulangerite, and bournonite. Pyrrhotite occurs in boudins of quartz, in pressure shadows, and with pyrite in veins.

Fig. 17: Samples from the Kutemarjärvi deposit, SW Finland. a) Massive silicic ore zone, with weak foliation due to greenschist-facies metamorphism. b) Topaz-fluorite-rich rock closely associated with the ore zone.

In addition to these deposits just discussed, there are other similar to younger ore deposits around the world that have been metamorphosed subsequent to mineralization. These include the Neoproterozoic Brewer deposit in South Carolina (Zwaschka and Scheetz, 1995, Economic Geology), also in Avalonian terrane, and the Paleozoic Temora (Thompson et al., 1986, Economic Geology) and Peak Hill (Masterman et al., 2002, SEG Newsletter) deposits in New South Wales, Australia.

Relation to Burin deposits

Comparison of the Burin prospects to these other old, metamorphosed epithermal Au-(Cu) deposits hosted by silicic lithocaps (some with high sulfidation-state sulfides) raises several observations that may be pertinent. The Hope Brook deposit (Fig. 13), 250 km west in the same terrane, the same age, and with similar metamorphic and strain history, is the closest analogy. Older, Paleoproterozoic deposits in Fennoscandia, Enåsen in Sweden (Figs. 14, 15) and Kutamajärvi in Finland (Fig. 16), have similar silicic cores with advanced argillic halos, although the metamorphic and strain history is stronger, with sillimanite developed at the former (amphibolite grade), and vertical, >1000 m pipes of silicic-hosted ore at the latter.
At both Hope Brook and Enåsen, the silicic horizon is disc shaped, up to >1 km long and at least half as wide, up to ~100 m thick at the former and 35 m at the latter (perhaps due to greater extension); the advanced argillic halo is even larger around each. In each case, the ore body has been tipped by ~70 and ~20 degrees from horizontal. By contrast, ore zones at Kutemajärvi are narrow pipes, <20 x <50 m in size but >1000 m long, with the long dimension rotated in to a vertical position. The elongated direction of the original silicic zone would have been near horizontal, following an original lithology, hence the development of a lithocap, with a structure-controlled root zone (Fig. 15a), subsequently extended due to strain and rotated due to folding. Clearly exploration for and assessment of similar prospects must understand the degree of extension, as well as the extent of local to regional rotation, as well as local faulting (in all cases faulting is locally important; at Enåsen, the faulting has been eliminated on the sections).

Unlike Hope Brook in Newfoundland, with chalcopyrite, tennantite, tetrahedrite, colusite as well as traces of enargite, the Paleoproterozoic metamorphosed quartz-rich gold deposits in Svecofennian terrane are largely sulfide poor. The latter have been called metamorphosed high sulfidation deposits; however, by definition, they are now anything but high sulfidation, since there is no indication of high sulfidation-state sulfides (such as enargite). Enåsen and Kutemajärvi now have sillimanite-topaz and pyrophyllite-topaz halos to the quartz-rich (originally residual silicic) gold ore zones, respectively, consistent with amphibolite and greenschist facies metamorphism. In addition to pyrite, the sulfides include pyrrhotite and arsenopyrite, respectively, both low sulfidation-state sulfides, as well as some chalcopyrite (intermediate sulfidation state), and traces of various Au selenides and tellurides. There are two possible explanations in these lithocap-hosted deposits. Either the rocks were leached and then Au and Cu mineralization occurred at low to intermediate sulfidation states, or there was Au with high-sulfidation sulfides, e.g., enargite, but during metamorphism to amphibolite and mid-greenschist facies, respectively, heating caused the system to outgas sulfur, and the enargite converted to chalcopyrite as well as low sulfidation-state sulfides; the latter may be possible, as some of the pyrrhotite at Kutemajärvi is clearly related to the metamorphic event.

The abundance of pyrophyllite, as well as the local occurrence of topaz, diaspore, dumortierite, and andalusite (e.g., the former two at Steward, and the latter two at Stroud’s Pond), are not necessarily related to epithermal-level advanced argillic alteration. They indicate higher temperatures of formation (andalusite does not have to be explained by metamorphism of aluminous minerals; it is a trace mineral in several porphyry deposits, e.g., El Salvador).

For example, at El Salvador, Chile, Watanabe and Hedenquist (2001) argue that most of the pyrophyllite that acts as a cap to the deeper ore zone (Fig. 18) is a retrograde alteration of muscovite as the system cooled, rather than being associated with condensation of the magmatic vapor, and in which environment pyrophyllite is also stable (Fig. 19). Thus, mapping of the muscovite, pyrophyllite, and combined zones is essential to determine the possible relationship to an underlying intrusive center that may also be mineralized.

Similarly, at Oyu Tolgoi porphyry Cu-Au deposit in Mongolia, pyrophyllite (+ topaz, diaspore, etc.), as well as deep alunite, overlie the deeper muscovite-related ore zone (Fig. 20).
Fig. 18: Alteration zoning over the top of the porphyry deposit at El Salvador, Chile (Watanabe and Hedenquist, 2001). The Cu ore zone is located ~500 m below the area of pyrophyllite outlined here.

Fig. 19: The two environments of pyrophyllite formation (Watanabe and Hedenquist, 2001, after J.J. Hemley). In the case of a deep, muscovite-(andalusite) stable fluid that ascends and cools (A-B-C), pyrophyllite may become stable, along with diaspore, topaz, etc. Where condensation of magmatic vapor occurs near the surface, the acidic fluid (low log K/H ratio) will generate an advanced argillic assemblage that can include alunite and, at sufficiently high temperature, also pyrophyllite.
Fig. 20: Cross section through the Hugo Dummett North ore body, Oyu Tolgoi, Mongolia (Khashgerel et al., 2006, Economic Geology), showing the relationship of advanced argillic alteration to the ore body in this atypical porphyry deposit; note the quartz-pyrophylite-(topaz) and quartz-alunite zones that overlie the ore zone.
**Summary and conclusions**

The Burin peninsula represents a Neoproterozoic magmatic arc of volcanic and sub-volcanic rocks of largely calc-alkaline affiliation known as the Marystown Group. Numerous elongate zones of alteration are present, mainly typified by advanced argillic alteration with silicic cores, the latter with variable Au and other anomalies. The ductile deformation and greenschist metamorphism has contributed to the structural complexity of these variably folded units, but the lithocap-type of epithermal alteration has long been recognized (O’Brien et al., 1999, and references therein). In addition, there are numerous intrusions and sub-volcanic features such as sheeted quartz veins and heterolithic breccias that are consistent with the upper portions of porphyry systems being exposed. Exposure varies from reasonable to poor, in part because of the recessive nature of erosion of the advanced argillic alteration, although quartz-pyrophyllite±alunite schists, as well as quartz-mica schists locally form good outcrop.

The complete 15-km long trend centered on Hickey’s Pond appears to have potential that remains largely untested, with most previous work focused on a few 100 m of the trend, due to the relative lack of outcrop and the attraction of the silicic zone at Hickey’s Pond, where grades up to 15 g/t Au are present. Clearly, Hickey’s Pond deserves continued attention – starting with careful mapping that includes attention to the effects of both ductile deformation as well as faulting, as well as folding and displacement of the original position of the potential ore zones – but the whole trend must be adequately assessed all the way to Tower, 10 km to the SW.

The Paradise trend, offset to the south on the western margin of the principal volcanic package, near the contact with the younger sedimentary package further west, also has pods of silicic alteration scattered from Monkstown Road SW through Bullwinkle and Strange, with local gold anomalies, hosted by strongly deformed advanced argillic alteration. At present this trend appears to have smaller silicic zones and lower gold anomalies than the Hickey’s Pond trend, but assessment has been restricted to the few outcropping zones along what is likely a continuous zone, unless deformation has thinned the alteration.

Further southwest ~50 km, the Stewart prospect has many intriguing features, several recently revealed by stripping of the soil in shallow trenches. This area is sandwiched between the contemporaneous Swift Current granite to the west, and a weakly altered diabase to the east. Original sampling and drilling focused on an area of quartz-pyrophyllite±alunite schist with Au and Cu anomalies, although the Au anomalies are to date an order of magnitude lower than at Hickey’s Pond. However, Cu is more significant, up to 0.23 wt%, consistent with the recent recognition of sheeted quartz veins in the NE portion of the area with strong Au, Cu and Mo anomalies in soils. There is a lack of strong silicic alteration in the drilled area as well as the area of quartz veining, whereas ~2 km NE silicic and quartz-alunite alteration is present, albeit without a recognized gold anomaly. Recent TerraSpec recognition of topaz and diaspore at this prospect, the presence of quartz veins and lack of silicic alteration in the area of Cu anomaly suggests that much of this prospect represents a sub-volcanic level of exposure, with porphyry potential to be considered. As such, this prospect appears to have the most imminent interest and potential in contrast with the elongate zones of advanced argillic alteration, some associated zones of massive silicic alteration that locally host elevated Au mineralization.
Recommendations

Stewart prospect

- At Stewart the most critical aspect at present is to 1) conduct detailed mapping (now underway) of rock and alteration type (the latter supported by TerraSpec, paying attention to the offset of intrusions and alteration types that may indicate faulting and folding, 2) conduct representative sampling, particularly in the veined areas, 3) integrate all observations to arrive at a model of the complete system (considering both the porphyry and epithermal levels of erosion that are indicated in different parts of this large system).

- Prior to disturbing the area further for exposure and trenches, consideration should be given to the usefulness to repeat the original soil sampling, or at least extend it adjacent to the areas of best coincident Au, Cu and Mo anomalies. An alternative is to simply extend the trenching along previous grid lines and conduct extensive bedrock sampling.

- If more extensive areas of quartz veins are identified, collect representative samples (at least 10 vein samples per locality) to assess their style by examining the fluid inclusion characteristics; if not totally destroyed by the effects of metamorphism, which is unlikely, these characteristics will help to reconstruct the level of sub-volcanic system that is exposed.

- Based on the results of mapping and sampling, a new geophysical survey may be warranted, starting with an extensive ground magnetic study over the whole area to identify the center(s) of local intrusion(s) and magnetite stable (and destructive) alteration. Extending the IP-resistivity survey to the NE to the Bat zone may be warranted.

- Based on the mapping, sample results, and possibly geophysical surveys, it is thought likely that targets will be generated that will justify drill testing, after considering the porphyry characteristics of the area, and incorporating these into any model to be tested.

Hickey’s Pond and Paradise trends

- The elongate belts of advanced argillic alteration with local zones of silicic alteration, some with gold mineralization, must first be mapped, including the effects of ductile strain and folding on the region. Consider the possibility that silicic zones may be restricted in area because of extension followed by steep tilting (cf. Kutemajärvi).

- While mapping, much more representative sampling of the silicic zones must be conducted, after cutting channels across the outcrops.

- Silt sampling in the winter of all ponds along each belt will help to determine if additional trenching is warranted between the areas of outcrop.

Lode Star

- No further work is recommended at this time, given the priorities above, but if regional work is considered (see below), further examination of this prospect, both for its potential and what it may indicate about other potential in the peninsula, may be warranted.
Regional exploration of the Burin peninsula:

• First test the efficacy of the lake sediment anomalies near known alteration and mineralization; if positive, extend lake sediment sampling, first along all known alteration trends, later on extensions of alteration trends

• Reprocess ASTER imagery, using ground truth results from TerraSpec, and integrate this with known alteration systems, as well as with lake sediment anomalies, based on what is learned about levels of erosion, folding, and faulting within the magmatic arc

• Extend lake sediment sampling and ASTER imagery west into the arenaceous sedimentary sequence, since alteration zones are known to occur wholly within this stratigraphic package (e.g., Henry’s Pond), but subtle alteration may have been missed in these sedimentary rocks (cf. pyrophyllite alteration of argillic sandstones of the Chimu Formation in Peru that host the Alto Chicama high-sulfidation gold deposit – 10+ Moz)

• Such ground truth information on metal anomalies and alteration is thought to be more useful at first pass than any airborne geophysical survey. However, once further anomalies are established, an air magnetic survey may be warranted, when there is a good understanding of the relationship of the geology – particularly intrusions – to the presently identified prospects, both epithermal and porphyry

• Consider not only epithermal but also porphyry potential of the peninsula, as exhibited by Stewart. For example, the andalusite and dumortierite occurrences at Stroud’s Pond are suggestive of a high-temperature, porphyry environment. Has folding and/or faulting of large blocks resulted in the sub-volcanic environment being exposed in areas other than Stewart, and/or are there other styles of mineralization, e.g., Lode Star, that may indicate porphyry or related mineral potential?
• **Qualifications**

I, Jeffrey W. Hedenquist, of Ottawa, Canada, hereby certify that:

- I am President of Hedenquist Consulting, Inc., incorporated within the province of Ontario. I am an independent consulting geologist with an office at 74 Greenfield Avenue, Ottawa, Ontario, K1S 0X7, Canada; telephone 1-613-230-9191.
- I am a graduate of Macalester College, St. Paul, Minnesota, USA (B.A, Geology, 1975), The Johns Hopkins University, Baltimore, Maryland, USA (M.A., Geology, 1978), and the University of Auckland, Auckland, New Zealand (Ph.D, Geology, 1983).
- I have practiced my profession as a geologist continuously since 1975, working as a researcher for the U.S. Geological Survey, the New Zealand Department of Scientific and Industrial Research – Chemistry Division, and the Geological Survey of Japan until the end of 1998. I have published widely in international refereed journals on subjects related to epithermal and porphyry ore-deposit formation and active hydrothermal systems. I consulted to the mineral industry and various governments as a New Zealand government scientist from 1985 to 1989, and I have been an independent consultant since January, 1999.
- I am a Fellow of the Society of Economic Geologists and have served as an executive officer, and am a member of the Society of Resource Geology of Japan and the Geochemical Society. I was Editor of the 100th Anniversary Publications of Economic Geology, am Associate Editor of Economic Geology, an editorial board member of Resource Geology, and have previously served as editorial board member of Economic Geology, Geology, Geothermics, Journal of Exploration Geochemistry, Geochemical Journal and Mineralium Deposita.
- This report is based on information provided to me by Cornerstone Resources, publicly available reports, published or on the Internet, and personal observations in the field.
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Date: August, 2007  
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