Low-sulphidation Epithermal Gold Potential at Warwick Mountain, Northeastern Cobequid Highlands, Colchester County, Nova Scotia

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Introduction

The eastern Cobequid Highlands are host to a large volume of Late Devonian to Early Carboniferous bimodal volcanic rocks. This volcanism was coeval with the much more regionally widespread siliciclastic sedimentation of the Horton Group (Dessureau *et al*., 2000; Dunning *et al*., 2002). The volcanism occurs in two distinct formations, distinguished primarily on whether they are dominantly felsic or mafic. The lower unit is the primarily rhyolitic and felsic volcaniclastic Byers Brook Formation, and this is overlain by the predominantly basaltic Diamond Brook Formation. This volcanic package has a total thickness of roughly 8 km and is tilted to near-vertical, allowing for a complete profile of the units.

Mapping and prospecting has been ongoing in the area since 2011 to assess the potential for low-sulphidation-type (adularia-sericite) epithermal gold mineralization. Interest in this potential is due to the geotectonic similarities of the Late Devonian-Early Carboniferous Cobequid Highlands to other continental-rift-related systems, such as the Great Basin, western United States, which hosts numerous such deposits and contains a significant gold resource (e.g. John, 2001). Furthermore, gold grains have been recovered from stream sediments collected from areas draining this volcanic package (e.g. Hogg, 1990). Detailed work conducted in 2011 resulted in the discovery of several areas of significant potassic and silicic alteration in the vicinity of Warwick Mountain, Colchester County, as well as low levels of gold mineralization in some samples (MacHattie, 2013), the discovery of which lead to increased exploration in the area for gold, including diamond drilling (Jensen, 2012). Consequently, more detailed work in the area was conducted in summer 2015 to attempt to better understand the nature and location of low-sulphidation epithermal gold mineralization in the Warwick Mountain area.

Geological Framework and Tectonic Setting

A large component of the eastern Cobequid Highlands is underlain by Late Devonian to Early Carboniferous bimodal volcanic rocks, consisting of the felsic (rhyolite and felsic volcaniclastic) Byers Brook Formation and the overlying mafic (basalt and minor volcaniclastic) Diamond Brook Formation (e.g. Donohoe and Wallace, 1982). These volcanic rocks overlie the granite of the Hart Lake-Byers Lake Pluton, are unconformably overlain by Late Carboniferous sedimentary rocks of the Cumberland Basin to the north, and are in faulted contact with Neoproterozoic and Silurian rocks to the northeast (Donohoe and Wallace, 1982). Broadly, magmatic events in the northeastern Cobequid Highlands can be subdivided into two events: (1) the ca. 365-355 Ma emplacement of the felsic volcanic Byers Brook Formation and the coeval and cogenetic intrusion of the Hart Lake-Byers Lake pluton, and (2) the subsequent (ca. 355-350 Ma) emplaced of the mafic Diamond Brook Formation and coeval intrusion of diabase and diorite dykes, sills and other intrusions lower in the magmatic package (Dunning *et al*., 2002). The entire magmatic package was uplifted and tilted to near vertical and subsequently exhumed between 350 and 310 Ma, resulting in its current orientation.

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Several workers have identified the within-plate magmatic characteristics of this volcanic package (e.g. Dessureau *et al*., 2000; MacHattie, 2011). These characteristics taken together with the bimodal volcanic character of the package and its synchronicity with the initiation of sedimentation in the Maritimes basin indicate that the package was emplaced in a continental-rift-type environment, likely a strike-slip pull-apart basin, a geological environment known to host epithermal gold systems in Miocene and Recent correlatives in the western United States and New Zealand (e.g. John, 2001).

Methods

Detailed mapping and prospecting were conducted on areas where known alteration (potassic and silicic alteration and pyritization) had been previously documented by MacHattie (2013), with a focus on identifying areas of maximum prospectivity for low-sulphidation epithermal gold, as well as developing an exploration model for potential deposits in the area. Mapping resulted in 400 field stations over a 35 km strike length between Wentworth, Cumberland County, and Earltown, Colchester County, primarily in the rhyolitic Byers Brook Formation and basaltic Diamond Brook Formation (Fig. 1). Three hundred and eighteen samples were collected at these stations, all of which were cut into slabs and subsequently analyzed by portable XRF (Innovex X-5000) at Nova Scotia Department of Natural Resources (DNR). Of these, 48 samples, predominantly from the Warwick Mountain area, were chosen—based on either the presence of anomalous levels of gold tracer elements (e.g. As) or by the degree of observed alteration—to be sent to Activation Laboratories Ltd. of Ancaster, Ontario for geochemical analysis. Samples were crushed and split, and ~250 g of material of each sample were pulverized in mild steel (preparation code RX2). Major elements were analyzed by fusion-XRF (code 4C), and a large suit of 60 trace (and some major) elements was analyzed by aqua regia partial digestion ICP-MS and ICP-OES (variable depending on the element), including Au and Hg (Code Ultratrace 2). All 48 samples prepared for geochemistry were also sent to Acadia University to have polished thin sections prepared.

Results

Previous work has indicated that the most promising area for gold mineralization in the study area is Warwick Mountain (area A in Fig. 1), and that lower prospectivity is in the vicinity of Nuttby Mountain (area B in Fig. 1) at the eastern end of the volcanic belt (MacHattie, 2013). Sulphidation, silicification and potassic alteration is observable

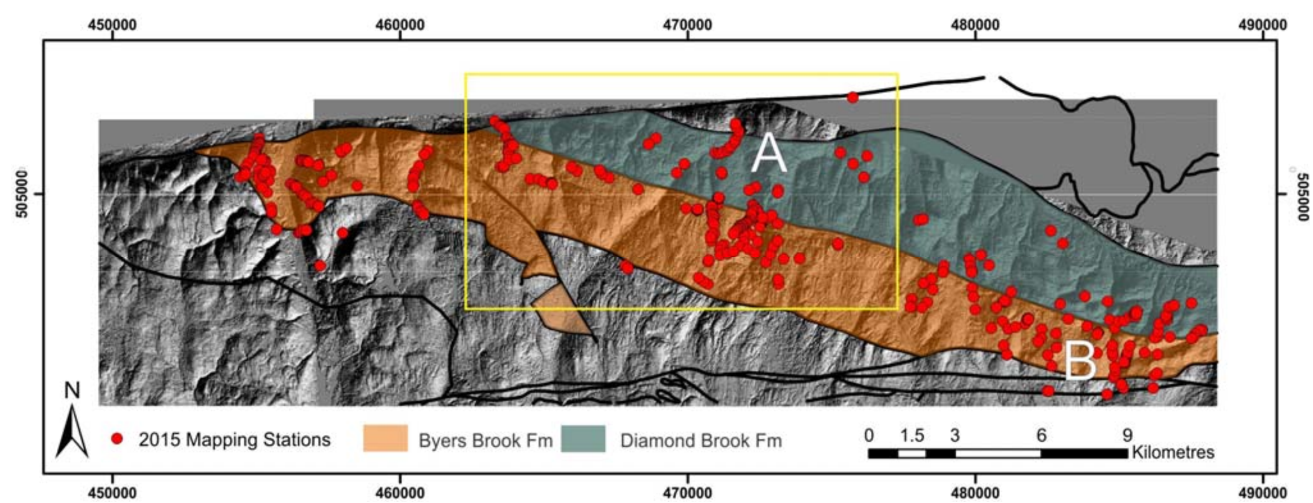


Figure 1. Location and geology map of Devono-Carboniferous volcanics of the Fountain Lake Group in the eastern Cobequid Highlands, Nova Scotia. Map extent is from the Wentworth Valley in the west to Earltown in the east. The yellow box is the approximate extent of other maps in this report. Major areas of study, Warwick Mountain (A) and Nuttby Mountain (B), are indicated.

near the top of the Byers Brook Formation rhyolites across the entire belt, and initial field studies placed the most focus on exploring the extent of this zone of alteration, as well as the intensity and mineralization potential of this zone. While this zone is laterally extensive over a >30 km E-W strike length, only locally does it contain more than pervasive silicification and sulphidation, primarily in the bed to the French River (immediately east of Warwick Mountain) and in areas to the west of the river. These altered areas include localized zones of intense brecciation, both unsulphidized (Fig. 2A) and containing large (to 1 cm) blebs of pyrite (Fig. 2B; Figs. 3A, B) and high degrees of alteration of the brecciated rhyolitic wall rock. Farther to the west, a siliceous paleosinter deposit is preserved at the contact between the Byers Brook and Diamond Brook formations, suggesting a potentially prolonged period of volcanic quiescence and active hydrothermal venting between the emplacement of the rhyolitic and basaltic rocks (Figs. 2C, D, E; Figs. 3C, D). The presence of the sinter, however, at approximately the same stratigraphic height as the zone of alteration in the rhyolite is discouraging for the prospectivity of this zone because most models for epithermal gold mineralization call for mineralization to occur some depth below active vent sites.

Basalts of the Diamond Brook Formation lack the widespread, regional alteration observed at the top of the Byers Brook Formation, and instead variably contains extensive carbonate amygdules and localized, discrete epidote-carbonate-quartz veining with limited alteration of the wall rock. Like the Byers Brook Formation, however, this changes west of the French River where the basalt is frequently more pervasively altered and has modestly elevated background As concentrations. This change was observed in both this study and previous work (e.g. MacHattie, 2013). The nature and degree of alteration in this area are highly variable; the area includes zones of intense pyrite-calcite veining in otherwise moderately altered basalt (Fig. 2F) and zones of basalt that have been so intensely altered (potassic, silicic and sulphidized) that the protolith is nearly unidentifiable without bulk rock geochemistry (Fig. 3E). Of note, rhyolitic flows and sills in the vicinity of such intensely altered basalts show similar degrees of alteration, predominantly silicification (Fig. 3F). These most heavily altered areas (as well as the pyrite veining) are located along Whirley Brook road in the immediate vicinity of the drilling location of Jensen (2012) and are similar to altered rocks reported therein.

Preliminary geochemical results did not result in any major discovery of gold mineralization; the maximum detected gold concentrations were 11.1 ppb. The most anomalous samples were located in the altered basalt area described above, and minor, localized anomalies were located in the upper part of the rhyolite of the Byers Brooks Formation (Fig. 4A). Likewise, while As values were elevated above expected concentrations for both rhyolites and basalts, the highest concentrations detected, on the magnitude of several hundred parts per million, were also obtained from the most highly altered basalt samples (Fig. 4B). These samples also showed extremely elevated concentrations of Hg (Fig. 5A) and, to a lesser degree, Sb (Fig. 5B). Although the Au concentrations are not impressive themselves, the geochemical footprint for Au itself is often quite small and non-pervasive away from the deposit itself, which in low-sulphidation epithermal systems is typically hosted in discrete veins. The geochemical footprint for many of the tracer elements, including As, Hg and Sb can be much larger, and the presence and size of these anomalies (particularly the Hg values of up to 1380 ppb) are very encouraging for the potential for significant low-sulphidation epithermal gold in the vicinity of Warwick Mountain.

Discussion

The observed increase in the degree of alteration of the rhyolite west of the French River, as well as the presence of substantial anomalies in many tracer elements for gold mineralization, suggests that this region is the most prospective part of the volcanic belt. This observation is significant as it is further substantiated by several lines of geophysical evidence. High-resolution airborne geophysical data (magnetics and radiometrics) collected by Tripple Uranium Resources Inc. in 2007 (Cole and Janes, 2008) show interesting trends in the

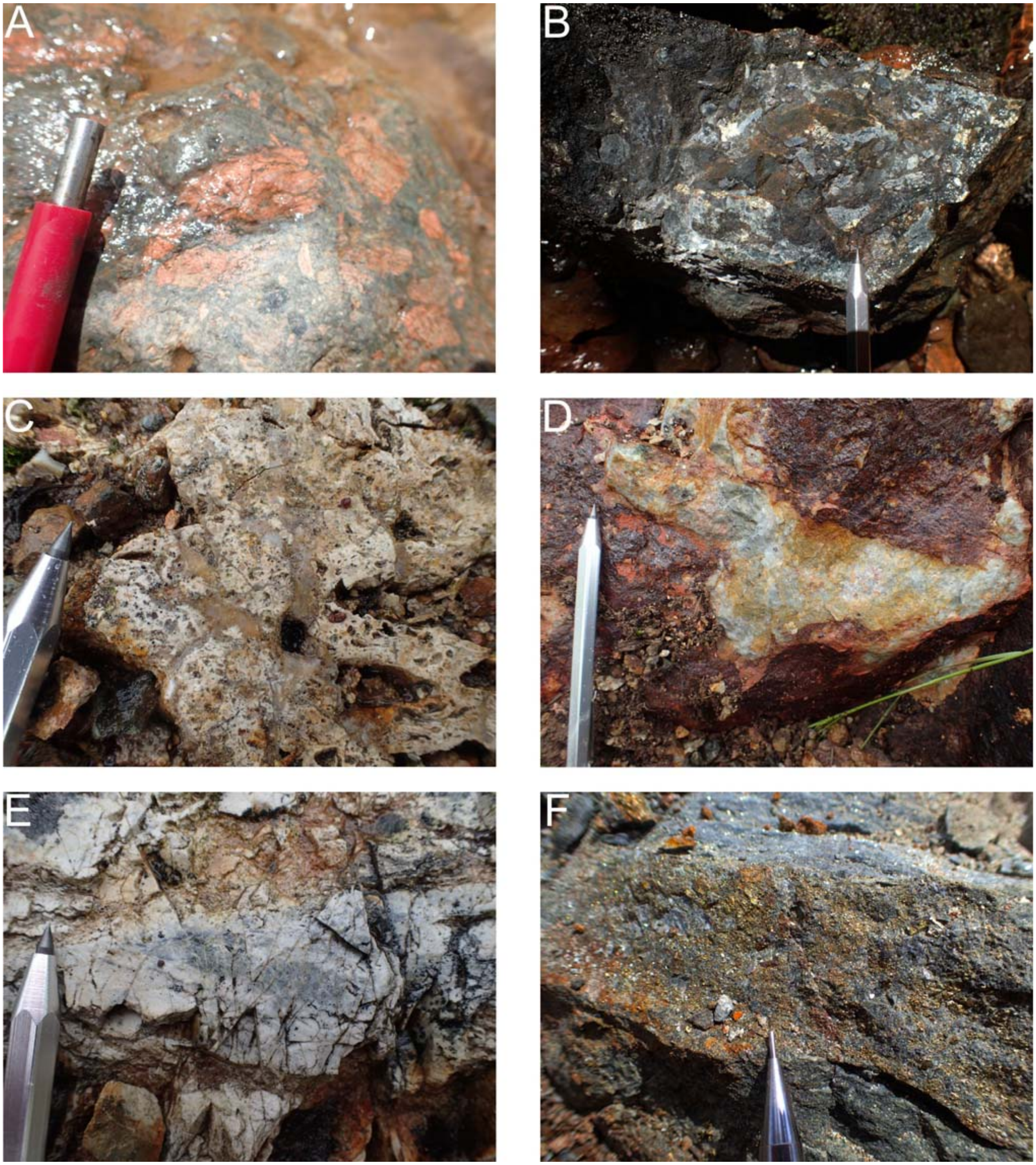


Figure 2. Field Photographs from the Warwick Mountain area. (A) Brecciated and hematized flow-banded rhyolite interbed in the Diamond Brook Formation from Whirley Brook Road. (B) Brecciated polymictic rhyolite breccia with large blebs of pyrite (to 0.5 cm). (C) Vuggy and silicified rhyolite and silica veins from the sinter deposit to the SW of Whirley Brook. (D) Highly sulphidized and silicified rhyolite from the sinter deposit. (E) Bleached and silicified rhyolite and microcrystalline quartz from the sinter. (F) Pyrite vein from the quarry on Whirley Brook Road. The basalts in the quarry are variably altered and contain extensive calcite and pyrite veining.

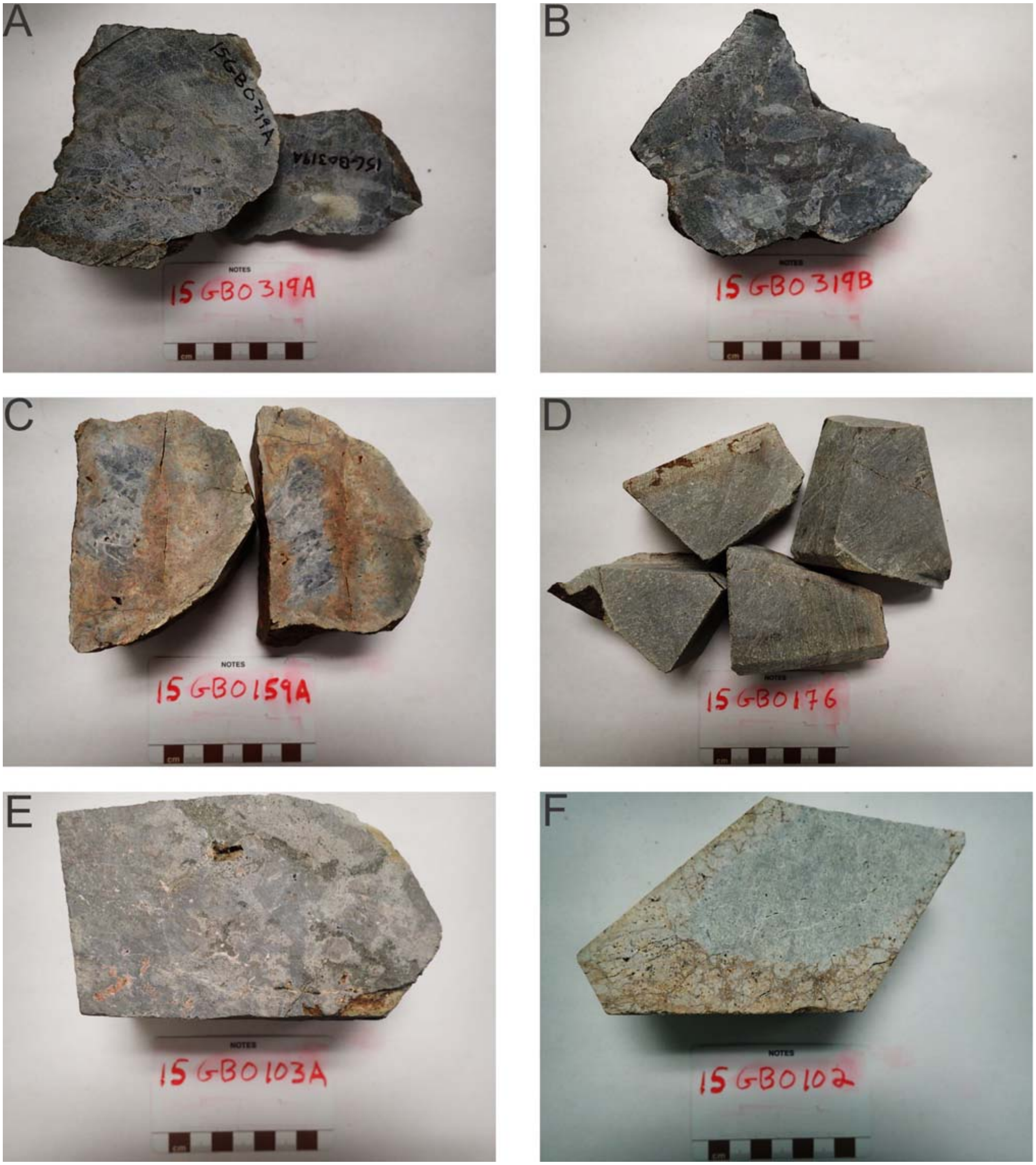


Figure 3. Photographs of hand specimens from the Warwick Mountain area. (A, B) Multi-phase, polymictic, brecciated rhyolite with patchy potassic alteration and blebs of pyrite to 0.5 cm (see Fig. 2B). (C) Bladed silica lathes suggesting boiling textures from the sinter site SW of Whirley Brook. (D) Silicified and sulphidized flow-banded rhyolite from sinter site. Flow bands have been replaced by laminated silica and pyrite. (E) Extremely altered and sulphidized basalt from Whirley Brook Road. Sample contains 6.3 ppb Au. (F) Highly silicified and bleached rhyolite from Whirley Brook Road. Rhyolite occurs as an interbed in the basalts of the Diamond Brook Formation. Sample contains 9.4 ppb Au.

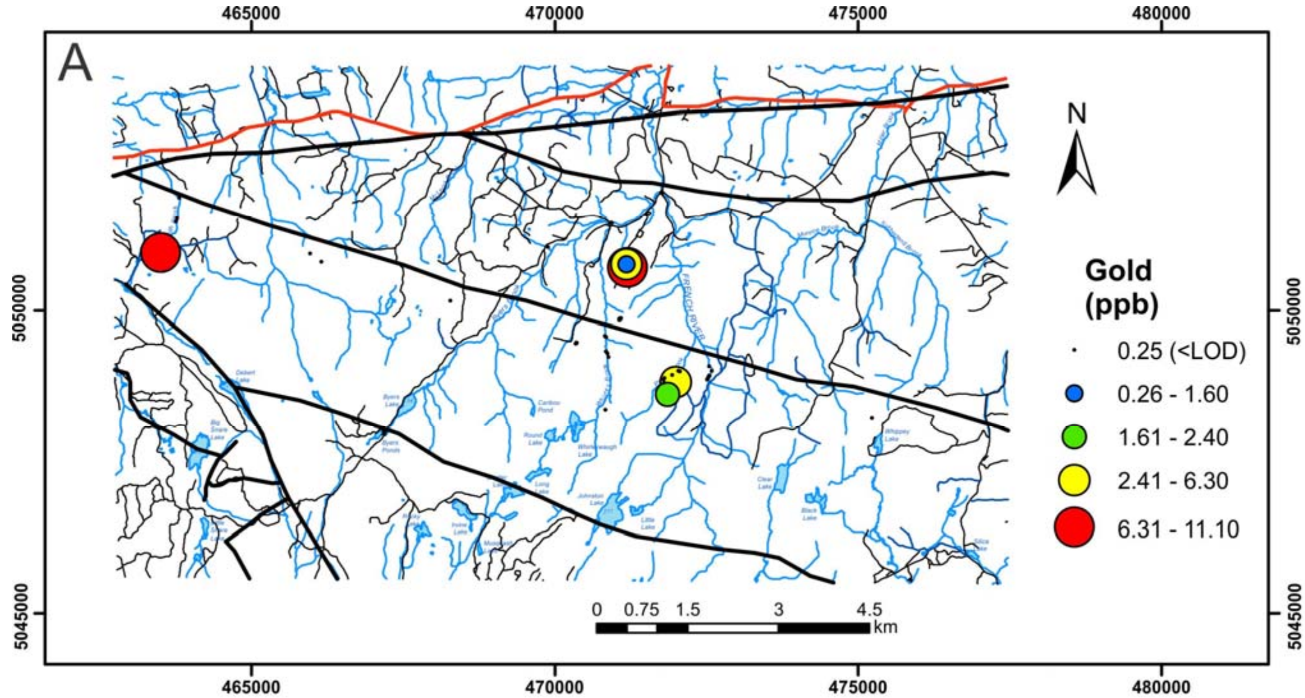
Diamond Brook Formation in both the Total Magnetic Intensity (TMI) and in the potassium (K) radiometric counts. The TMI map (Fig. 6A) shows a very sharp break in the magnetic intensity of the basalts of the Diamond Brook Formation at approximately the French River, with the basalts west of the river far less magnetic than the strongly magnetic rocks to the east of the river. Similarly, but much less intensely, the K count radiometrics show a break in the vicinity of Warwick Mountain, wherein the K counts to the west of Warwick Mountain are much stronger than to the east (Fig. 6B). There are several possible explanations for this break in the data, including alteration, the intercalation of more felsic rocks with the basalt, and the intercalation of siliciclastic sedimentary rocks, all three of which appear to be true to varying degrees.

In the westernmost exposures of the Diamond Brook Formation, the basalt does contain significant interbeds of rhyolite and felsic volcanic rocks, as well as an increase in the volcaniclastic proportion of the basalts and siliciclastic rocks (Donohoe and Wallace, 1982). All of this would result in an increase in the potassium content of the rocks in this area and the relative intensity of the K radiometric emissions. It does not, however, account for the degree of the change in intensity, and suggests that potassic alteration, such as is common in low-sulphidation-type epithermal gold deposits, could be a potential cause. The much sharper change in the TMI at the French River is more likely to be the product of alteration. Despite the intercalation of less mafic rocks in the west, the area is still dominantly basalt, but much of which has a much lower magnetic susceptibility than east of the French River. This observed drop in magnetic intensity of the western basalts may be explained through the breakdown of magnetic minerals such as magnetite in the basalt through the movement of mineralizing fluids, providing a possible indicator of prospective areas.

The geophysical, geological and geochemical data all strongly indicate that the most prospective area of the Byers Brook and Diamond Brook formations occurs in the Diamond Brook Formation west of the French River. The marked change in all of the available data at this site suggests that a major geological break at the time of volcanism and mineralization was present at this location. Donohoe and Wallace (1982) mapped a fault with an uncertain sense of movement that roughly followed the course of the French River or one of the sides of its valley. The observed presence of some of the most intensely brecciated rhyolite in the Byers Brook Formation in the streambed in the upper parts of this river supports this, as well as the pervasive and extensive carbonate alteration in basalts from along the river (MacHattie, pers. comm. 2015). Significant fault gouge in the basalt where this fault is suggested to intersect Byers Brook further corroborates the presence of this fault. Although it appears to have been reactivated at some point during or following the uplift, overturning and exhumation of the Byers Brook and Diamond Brook formations, it appears that this fault had been syn-volcanically active, possibly as a basin-bounding fault, such as the edge of a graben or caldera. At a minimum, it provided a fluid conduit, allowing for the hydrothermal alteration and potential mineralization of the basalts at Warwick Mountain.

Recommendations

The subject of research since 2011, the Warwick Mountain area has been mapped in substantial detail and fairly intensely prospected. This has resulted in no major discovery of mineralization, but has shown significant alteration and many of the geochemical markers indicative of low-sulphidation epithermal gold deposits. These discoveries, combined with the observations from existing geophysical data, have successfully narrowed the areas prospective for gold down to Warwick Mountain and areas to its west. The next step would be to conduct surveys that may help identify areas with a greater chance of containing economic mineralization. For this, the most effective options would be a detailed surficial geochemical survey, building on the reconnaissance-scale soil survey done by DNR in 2015 (Mills, this volume), with perhaps a focus on tight grids in the area drilled in 2011 along Whirley Brook road and other areas of interest. Additionally, some geophysical surveys may be useful, particularly a high-resolution EM (e.g. VLF-EM or VTEM) over the area and perhaps induced polarization ground surveys. This would



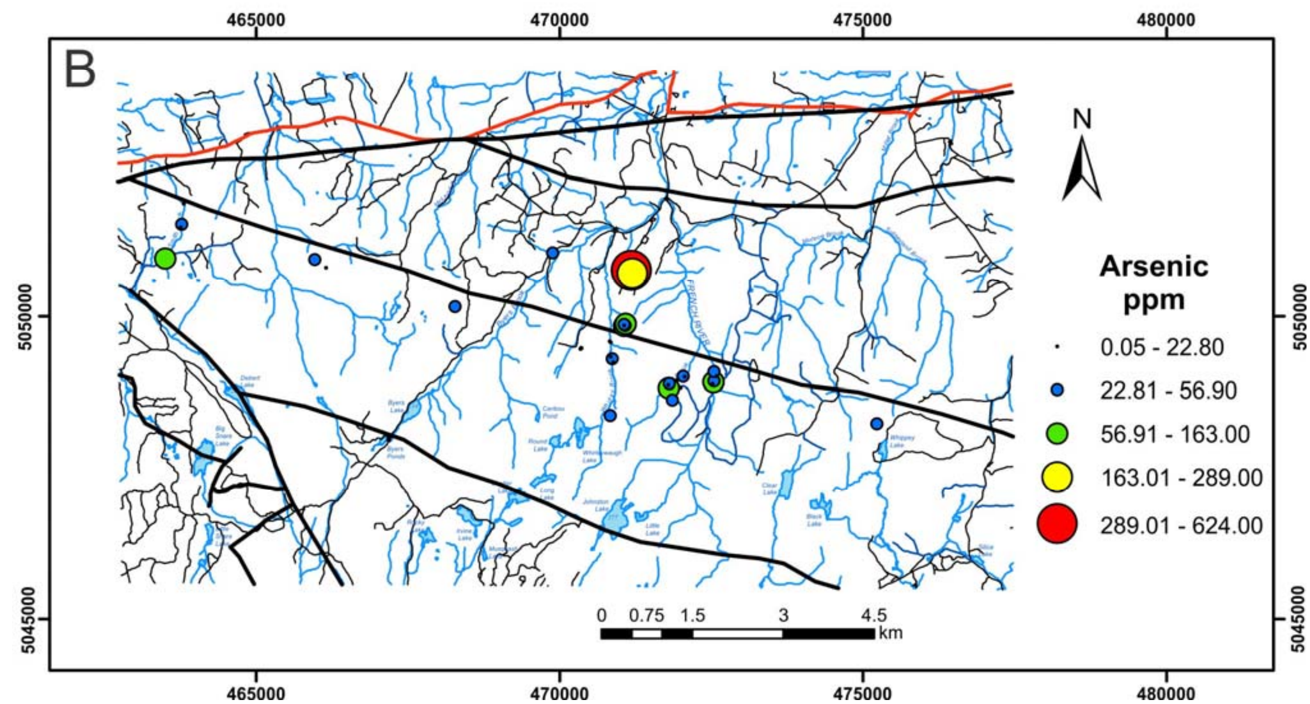


Figure 4. Bubble maps for gold (A) and arsenic (B) on select 2015 samples sent to ActLabs for aqua regia ICP-MS analysis. (A) Gold in ppb. Although all samples are fairly low concentration (max 11.1 ppb) and most samples were below the lower level of detection (LOD = 0.5 ppb, samples reported as such have here been reported as half the LLOD, or 0.25 ppb), small gold anomalies occur in the Warwick Mountain and upper French River areas, as well as in a single sample well to the west of the main study area. (B) Arsenic by aqua regia ICP-MS in ppm. Low levels of arsenic are in most rhyolite samples, but sizeable anomalies were observed in samples from the Warwick Mountain area that also contain gold.

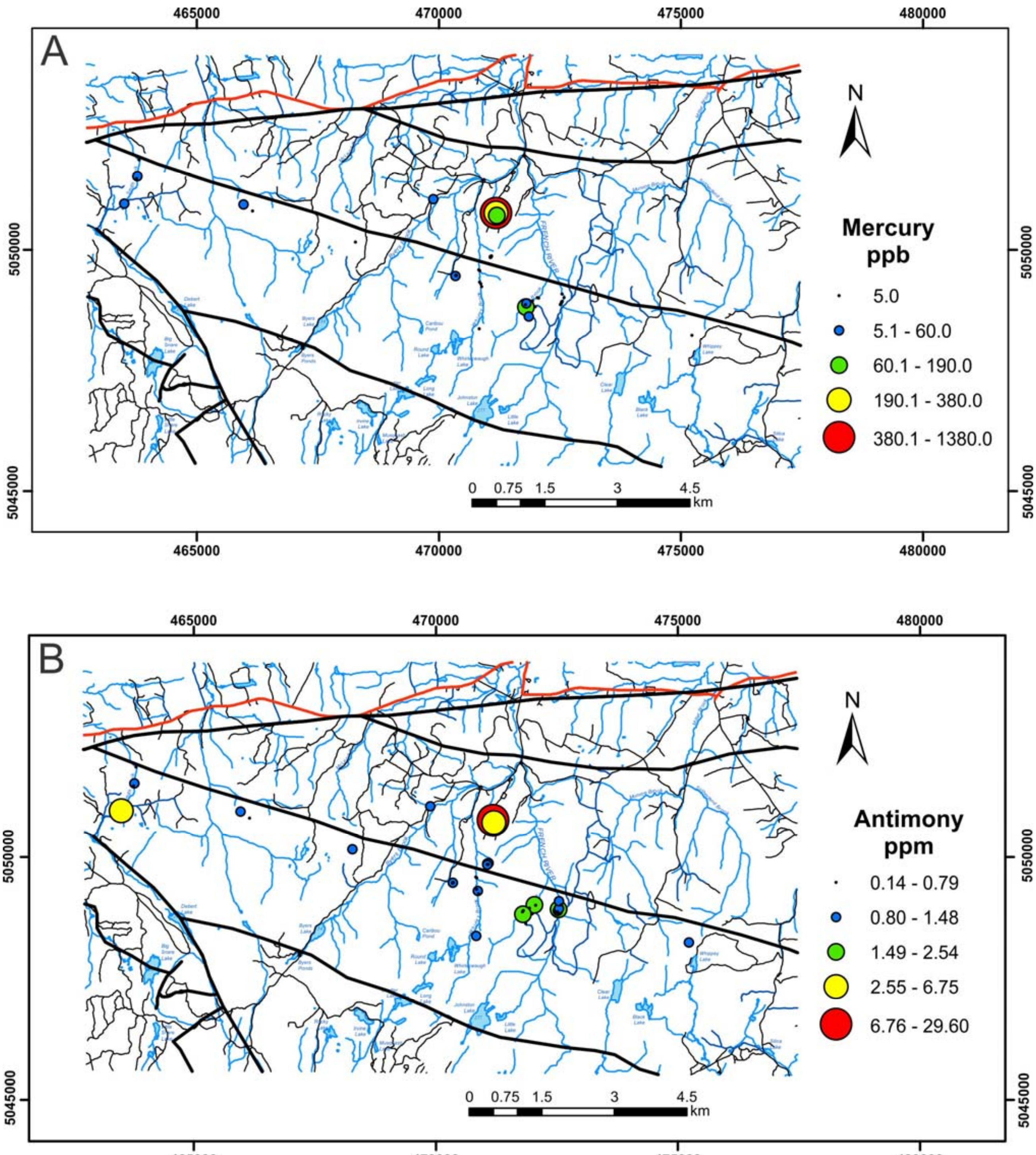


Figure 5. Bubble maps for mercury (A) and antimony (B) on select 2015 samples sent to ActLabs for aqua regia ICP-MS analysis. (A) Mercury in ppb. Mercury is a common tracer element in low-sulphidation epithermal gold systems, and here shows substantial anomalies, upwards of 1000 ppb in samples containing gold from Warwick Mountain. (B) Antimony in ppb. Like Hg and As, Sb is in much higher concentrations in samples containing gold.

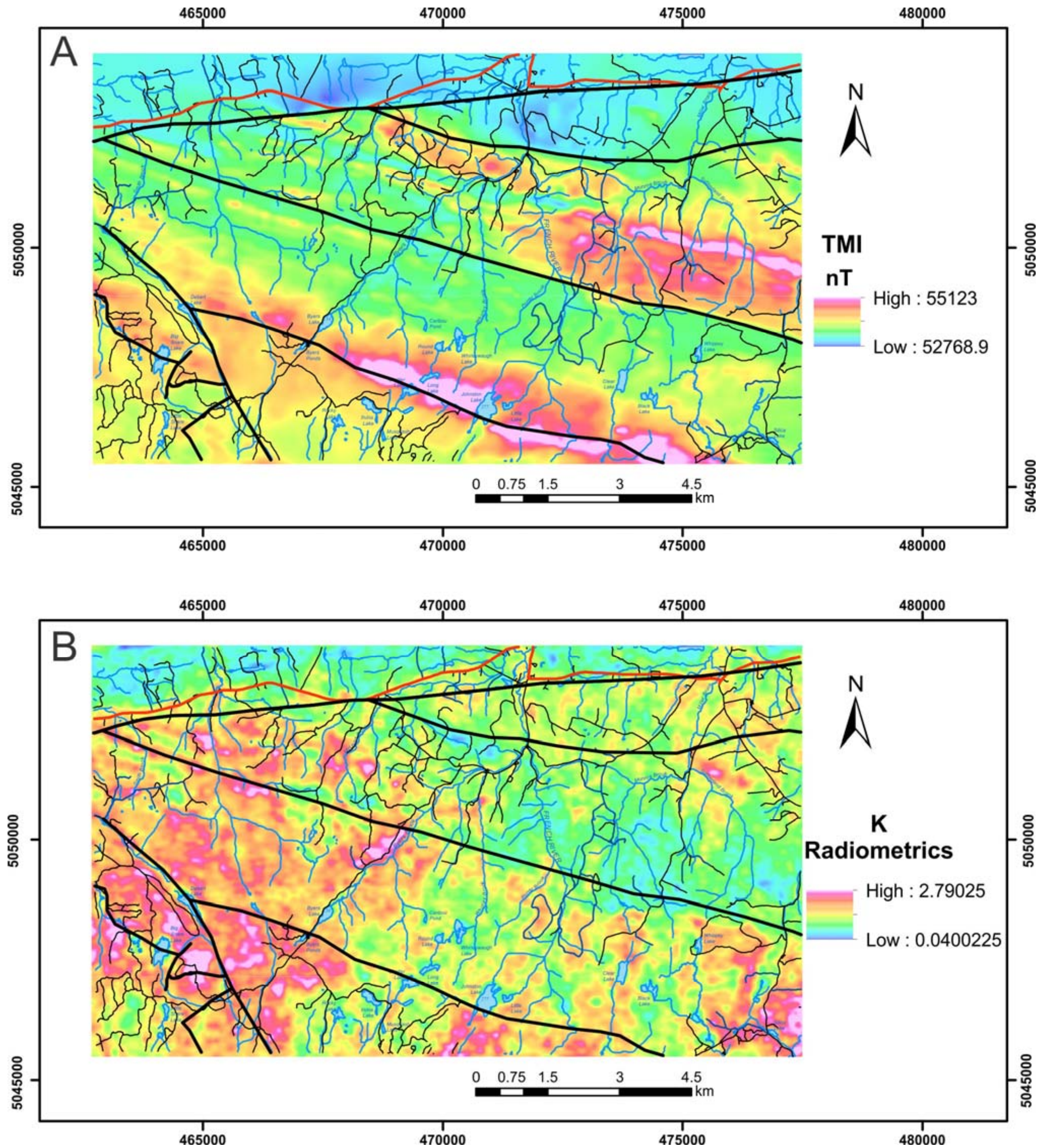


Figure 6. Airborne geophysical maps for the Warwick Mountain area (from Cole and Janes, 2008). (A) Total magnetic intensity (TMI), showing a strong decrease in magnetic intensity within the Byers Brook Formation west of the French River. This is the combined result of apparent demagnetization of basalts in this area through apparent hydrothermal alteration, as well as an increase in siliciclastic, volcaniclastic and rhyolitic interbeds in the basalt.
(B) Potassium (K) radiometric counts showing a strong increase in K emissions west of the French River. Like the drop in magnetic intensity, this is likely the result of an increased number of siliciclastic, volcaniclastic and felsic interbeds in the basalt; however, the intensity of the increase may also suggest the prevalence of widespread potassic alteration in the area of demagnetized basalts.

be able to identify areas of potential mineralization both at surface and at depth, allowing for the planning of more advanced exploration programs involving trenching or drilling.

References

Cole, B. and Janes, S. 2008: Wentworth A Property: Regional airborne geophysical surveys; First year assessment report; Nova Scotia Department of Natural Resources, Assessment Report ME 2008-051, 81 p.

Dessureau, G., Piper, D. and Pe-Piper, G. 2000: Geochemical evolution of earliest Carboniferous continental tholeiitic basalts along a crustal-scale shear zone, southwestern Maritimes basin, eastern Canada; Lithos, v. 50, p. 27-50.

Donohoe, H. V. and Wallace, P. I. 1982: Geological map of the Cobequid Highlands, Colchester, Cumberland, and Pictou counties, Nova Scotia, Sheet 1 of 4; Nova Scotia Department of Mines and Energy, Map 1982-6, scale 1:50 000.

Dunning, G. R., Barr, S. M., Giles, P. S., McGregor, D. C., Pe-Piper, G. and Piper, D. J. W. 2002: Chronology of Devonian to early Carboniferous rifting and igneous activity in southern Magdalen Basin based on U-Pb (zircon) dating; Canadian Journal of Earth Sciences, v. 39, p. 1219-1237.

Hogg, D. 1990: Assessment report on 1990 exploration program on general exploration licenses 15248, 15258, 15260, 15261, and 15516, Nuttby Mountain, Colchester County, Nova Scotia, NTS 11E/11; Seabright Explorations Incorporated; Nova Scotia Department of Natural Resources, Assessment Report 1990-165, 109 p.

Jensen, L. 2012: Drill Program; Whirley Brook Lic#09724; Colchester County, NS; Sugarloaf Resources Inc; NTS 11E/11B; Nova Scotia Department of Natural Resources, Assessment Report ME 2012-077, 93 p.

John, D. A. 2001: Miocene and Early Pliocene epithermal gold-silver deposits in the northern Great Basin, western United States: characteristics, distribution, and relationship to magmatism; Economic Geology, v. 96, p. 1827-1853.

MacHattie, T. G. 2011: Nature and setting of Late Devonian-Early Carboniferous rare earth element mineralization in the eastern Cobequid Highlands, Nova Scotia; *in* Mineral Resources Branch Report of Activities 2010; Nova Scotia Department of Natural Resources, Report ME 2011-1, p. 75-92.

MacHattie, T. G. 2013: Newly recognized epithermal-style gold occurrences associated with Late Devonian to Early Carboniferous bi-modal volcanism in the northeastern Cobequid Highlands; *in* Mineral Resources Branch, Report of Activities 2011; Nova Scotia Department of Natural Resources, Report ME 2012-001, p. 31-39.