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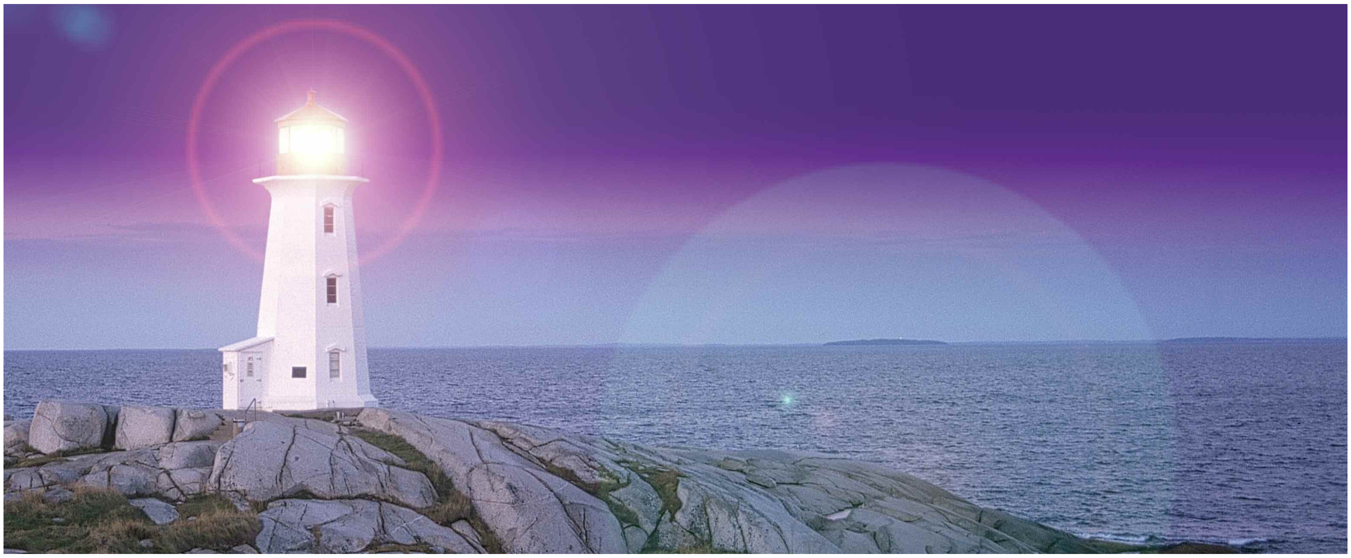

Field Trip B5

Geology and environmental geochemistry of lode gold deposits in Nova Scotia

Paul Smith, Michael Parsons, and Terry Goodwin

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FIELDTRIP FT-B5

GEOLOGY AND ENVIRONMENTAL GEOCHEMISTRY OF LODE GOLD DEPOSITS IN NOVA SCOTIA

by

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Pre- and post-conference field trips

GEOLOGY AND ENVIRONMENTAL GEOCHEMISTRY OF LODE GOLD DEPOSITS IN NOVA SCOTIA

Table of Contents

List of Figures

List of Tables

SAFETY

For personal and group safety we ask all participants to read and heed the following safety related procedures. We ask for your cooperation and common sense in making this a safe and enjoyable field trip for everyone. Thank you.

1. **ROCK HAMMERS:** Please use caution when hammering: be aware of people around you, use controlled downward blows, and do not hammer indiscriminately. When hammering, either shield your eyes or wear protective eyewear, especially since we will be examining very hard, hydrothermally altered rocks at most of our stops. Also note that only rock hammers are suitable for breaking samples—a carpenter's hammer may splinter and send metal chips flying. If using a chisel, please ensure it is approved to be used as such. Never use a second rock hammer as a chisel. Gloves are recommended when using a rock hammer.

2. **SUITABLE CLOTHING:** Participants should have adequate footwear and protection against both wet and cold, including a hat, gloves, and boots. Adequate clothing is important if you are involved in an accident or if you are required to spend an extensive period of time outdoors. Spring weather in Nova Scotia is unpredictable and can change from sunny and warm, to rain, wet snow (yes, even in May!), and high winds with little notice.

3. **HARD HATS:** Hard hats are recommended anywhere you intend to look at rocks where there are cliff faces or overhangs. They will also be mandatory for the underground tour at the Dufferin mine. We will have a supply of hard hats for use by field trip participants.

4. **UNDERGROUND TOUR:** Prior to going underground, a safety presentation outlining the policies and procedures of the Dufferin mine will be given to all participants. It is paramount that all required safety equipment is properly worn and that all rules be strictly followed.

5. **ROADSIDE STOPS:** Several stops will be made to look at roadside exposures of rock. Please exercise caution when listening to field trip leaders and when looking at outcrops. Do not venture onto the pavement unless you are crossing the road, and only cross the road with the group to minimize traffic disruption.

6. **PERSONAL VEHICLES:** If you are travelling in your own vehicle be sure to park as far off the pavement as possible, especially on 100-series highways where traffic is travelling in excess of 100 km/hr. Roads near these past-producing mines are not well-maintained and can be muddy and full of potholes so be very careful if using your personal vehicle.

7. **VANS:** While in the vans, please remain seated while the vehicles are in motion. All knapsacks, rock hammers, rock samples etc. should be safely stowed underneath your seat.

8. **CLIFFS AND FALLING ROCKS:** Falling rocks are a major hazard on field trips. Avoid unstable waste rock piles or overhanging cliffs, and watch for people below you on slopes.

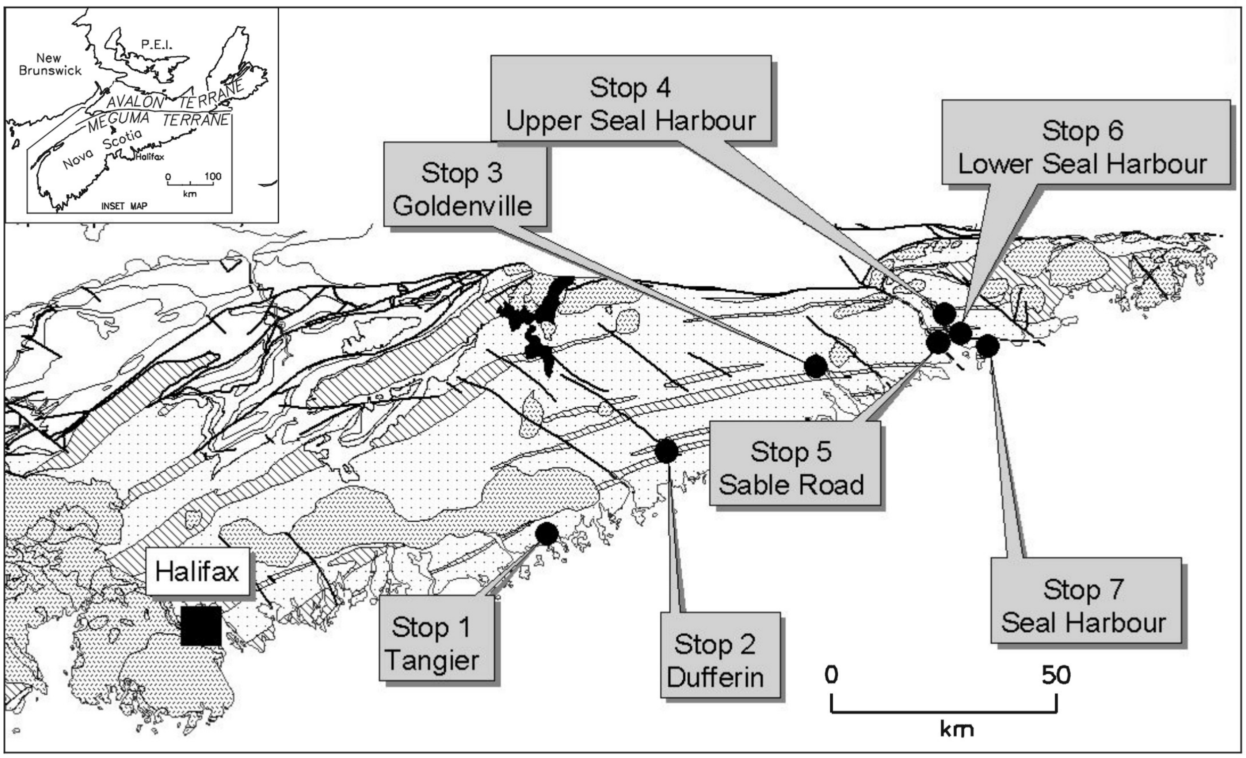
9. **ABANDONED SHAFTS AND PITS:** Mainland Nova Scotia contains more than 64 historical gold districts, most of which have been abandoned since the early 1900s. We will be visiting several of these gold districts as part of our field trip. Numerous deep shafts, open pits and trenches characterize all gold districts. Many (but not all) of these openings are flagged with warning signs and yellow tape, but they can be slumped in and overgrown near the surface giving the false impression they are shallow when, in fact, they are extremely dangerous. Please stay with the group and do not venture too close to shafts or old trenches. Listen to instructions given by the field trip leaders.

10. **FIRST AID / MEDICAL CONDITIONS:** Several First Aid kits will be located in the vans, and in the support vehicle. Terry Goodwin and Michael Parsons, co-leaders of the field trip, are certified First Aiders. Participants with valid First Aid certificates are encouraged to identify themselves at the beginning of the field trip. Field trip participants with medical conditions (allergies, diabetes, etc.) may wish to advise the field trip leaders prior to departure. All personal medical information will be treated with the strictest confidence.

11. **HAND WASHING:** The gold mine sites we will be visiting all contain tailings, the silt- to sand-sized material that was discharged to the environment after most of the gold was extracted from the ore. These tailings contain variable amounts of arsenic-bearing minerals (e.g. arsenopyrite), and other reagents (e.g. mercury) left over from historical milling and metallurgical practices. Please be careful not to drop any food onto the tailings, and wash your hands thoroughly before eating.

12. **IN THE UNLIKELY EVENT OF AN EMERGENCY, CALL *911*.** Most of the Eastern Shore has poor cellular phone coverage, so it may be necessary to use a pay/private phone.

Stop Location Map: (FT-B5)



Generalized geology of the eastern Meguma Terrane showing the location of field trip stops for FT-B5, entitled *"Geology and Environmental Geochemistry of Lode Gold Deposits in Nova Scotia."* Stops 1, 2 and 3 are on Day 1 while Stops 4, 5, 6 and 7 are on Day 2.

FIELD TRIP AGENDA

(see map on preceding page for stop locations)

Thursday, May 19th, 2005:

08:00	Leave Halifax
09:30	**STOP 1: Tangier Gold District:** Examination of gold-bearing glacial till
10:30	Leave Tangier
11:30	Bagged lunch in vans
12:00	**STOP 2: Dufferin Gold District:** Tour of recent underground workings at the Crown Reserve Mine, and historic workings of the Salmon River Mining District
14:30	Leave Dufferin
15:30	**STOP 3: Goldenville Gold District:** Overview of mine wastes at the province's largest past-producing gold district, now the site of an annual 4X4 rally
16:30	Leave Goldenville
18:00	Arrive at St. Francis Xavier University residences
19:00	Dinner & presentation at StFX

Friday, May 20th, 2005:

07:00	Breakfast at StFX
08:30	Leave Antigonish
10:00	**STOP 4: Upper Seal Harbour Gold District:** Tour of recent Boston-Richardson workings, ruins of the historic 60-stamp mill, and tailings deposits in Gold Brook
11:30	Lunch at Goldboro Interpretive Centre
12:30	**STOP 5: Seal Harbour Anticline:** Rock-hounding on the Sable Road cut
13:00	Overview of Goldboro Gas Plant
13:15	**STOP 6: Lower Seal Harbour Gold District:** Tour of historical ruins (cyanide plant, stamp mill, mine shafts) and tailings deposits
15:00	**STOP 7: Mine tailings in Seal Harbour:** Overview of intertidal mine tailings flats in Seal Harbour at the outlet of West Brook
16:00	Drive to Halifax
19:00	Arrive in Halifax

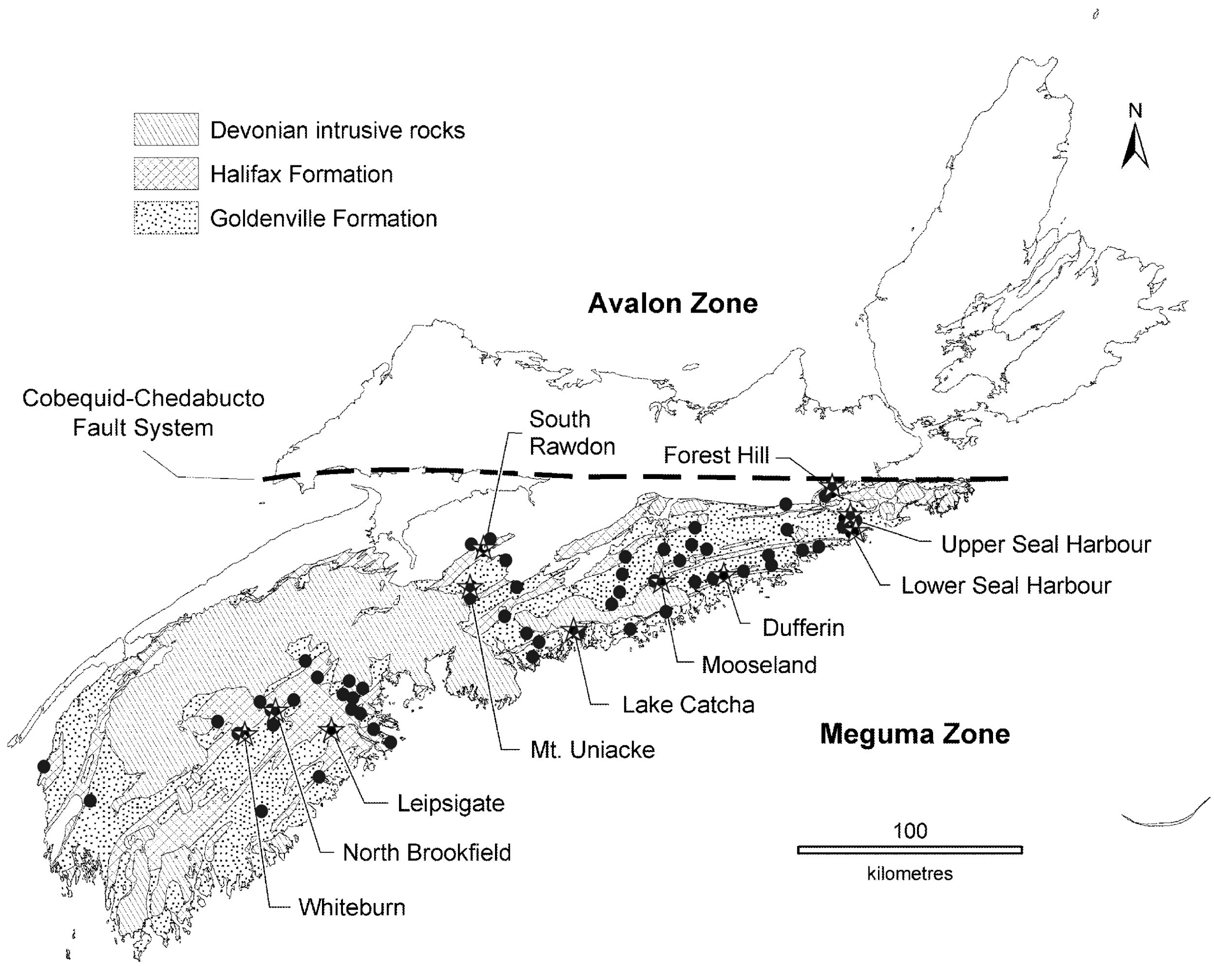


Figure 1. *Geological map of southern Nova Scotia showing gold deposits (dots) and those selected for tailings investigations (stars).*

TH' DRAPPIN' OV TH' STAMPS

I've heard many a band ov music siftin' sweetness on th' air,
An' a fiddler drawin' ov his bow, that just sounded like a prayer,
I have heard Aeolian music when the wind was on the ramps,
But no music ever was so sweet as th' drappin ov the' stamps.

When I've laid awake and listened t' th' clink, clink, clink, clank, clank,
As they drapped upon and crushed th' ore t' put moneys in th' bank,
Then I'd fall asleep a-dreamn' ov th' happiness galore,
With my pockets full ov money t' divide among th' poor.

There is music and ther's music, but ther's nothing half so fine,
As th' runnin' ov a ten-stamp mill, on a regular payin' mine.
You may talk erbout your 'cinches' an' other kinds ov clamps,
But t' me ther' is no music like th' drappin ov th' stamps.

- Unknown Nova Scotian author, as quoted in Henderson (1935)

1.0 INTRODUCTION

This two-day field trip will examine the geology of selected lode gold deposits in the Meguma Terrane of southern Nova Scotia, and the environmental impacts of historical mining and milling activities at these sites. Most of these past-producing mines are the focus of ongoing investigations as part of a three-year (2003–2006) multidisciplinary project funded primarily by the Geological Survey of Canada's Metals in the Environment (MITE) Program. This study involves partners from many different organizations, including the GSC, Nova Scotia Dept. of Natural Resources, Environment Canada, Fisheries and Oceans Canada, Geomatics Canada, Queen's University, University of Ottawa, Royal Military College, and Dalhousie University. The main goal of these multi-partner studies is to characterize the dispersion, transformation, and fate of metals and metalloids in freshwater and marine environments surrounding abandoned gold mines throughout Nova Scotia. Results from this project will be used to assess the potential ecological and human health risks associated with these sites, and will support better informed land-management decisions. This section of the field trip guide provides an overview of these recent MITE investigations, and is followed by a discussion of the bedrock and surficial geology of the Meguma Group and its associated gold mineralization.

1.1 Mining, Milling, and Metallurgical History

Since the first Nova Scotian gold rush in the early 1860s, gold mining and milling processes have generated tailings deposits containing mercury (Hg), arsenic (As), cyanide, and other potentially toxic elements (e.g. lead (Pb)). Most of the gold production has come from high-grade quartz vein systems, which occur in greenschist- to amphibolite-facies metasediments of the Cambro-Ordovician Meguma Group in southern Nova Scotia. Mining has been carried out at more than 60 formal gold districts, resulting in a total production of 37 t of gold. The majority of this production took place between 1862 and the mid-1940s, and there has been only limited mining of gold deposits since that time (Fig. 2; Bates 1987). A resurgence in the price of gold over the last four years (from US$260/oz. (March 2001) to approximately US$445/oz. (March 10, 2005)) has led to renewed interest in Nova Scotian deposits, and there are now numerous exploration programs underway, and several new gold mines in development.

In Nova Scotia, stamp milling and mercury amalgamation were the primary methods used for gold extraction. This process involved crushing the ore to sand- or silt-sized material, then washing the pulp over mercury coated copper plates. At most stamp mills in the province, amalgamation plates were located both inside and outside the stamp battery itself, and mercury was also added directly below the stamps in the mortar boxes. Some of the free gold would combine with the mercury to form an amalgam, which was periodically scraped off the plates and heated in a retort to recover the gold. As a general "rule of thumb," one ounce of mercury was used for each ounce of gold in the ore to obtain satisfactory recovery rates (Phillips 1867; Richards and Locke 1940). Hind (1872) recommended adding 1 1/5 oz. of Hg per ounce of gold in the ore, and also noted an abundance of Hg globules in the tailings at some early milling operations in Nova Scotia. The historical literature suggests that up to three times this amount of mercury was added to the mortar boxes at some mines (Moggridge Kuusisto 1978).

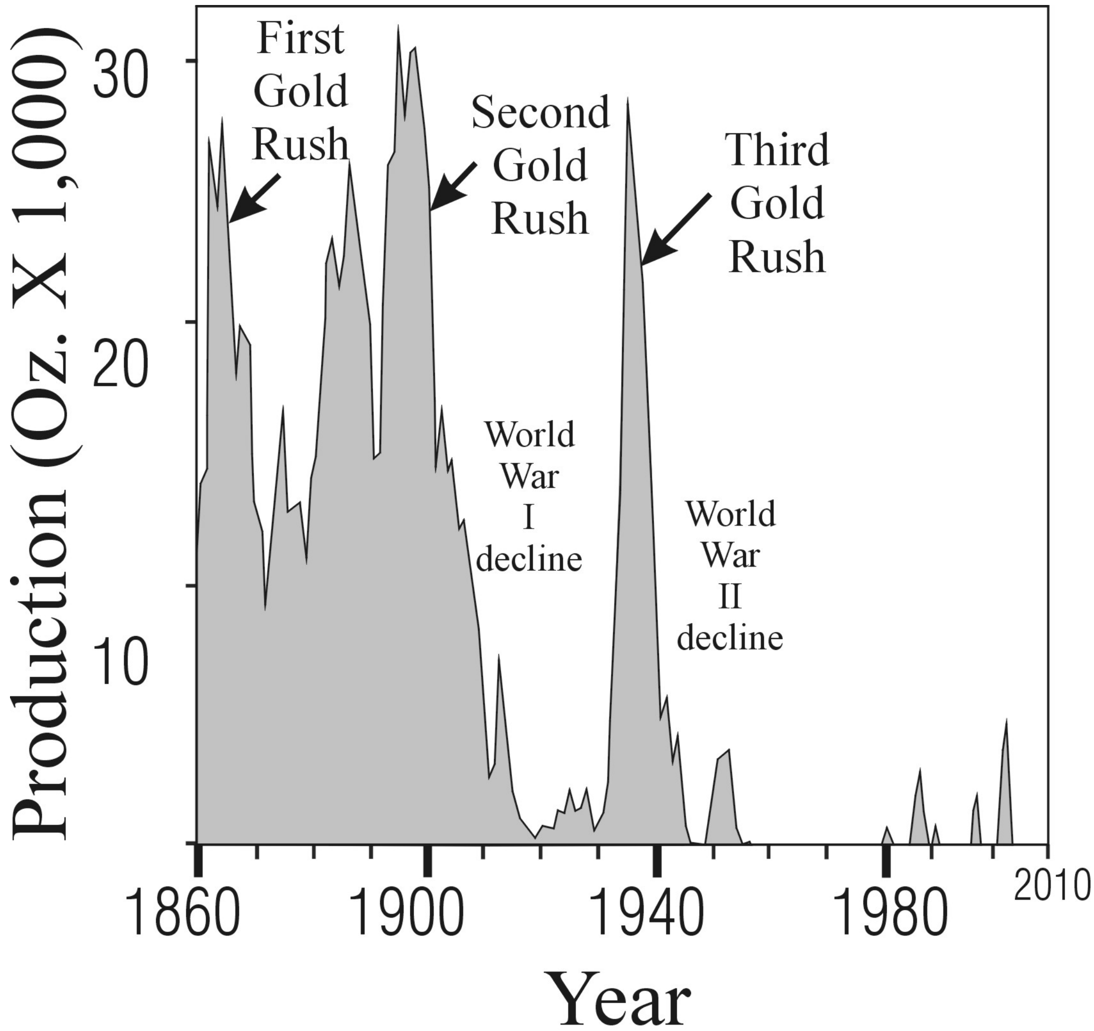


Figure 2. *Production of gold in Nova Scotia from 1862 to 2005.*

At most stamp mills, 10–25% of the mercury used in the process was lost to the environment through flouring (i.e. subdivision of the amalgam into fine particles), sickening of the mercury (i.e. formation of Hg-sulphides), evaporative losses during retorting, and careless handing of mercury by mill personnel (Henderson 1935; EPS 1978). Considering the total reported gold production of approximately 1.2 million ounces (Bates 1987), from 3700–9300 kg of Hg may have been lost to the tailings and/or atmosphere as a direct result of gold milling in Nova Scotia (assuming that 1 oz. of Hg was used for each ounce of gold produced). This estimate of Hg loss is likely a minimum, as it is well-known that the gold production at most mines was routinely under-reported to avoid paying royalties to the Province. Records of Hg loss are relatively scarce in the historical literature; however, MacKenzie (1907) reports a loss of 0.07–0.10 oz. of Hg per ton of ore crushed in the stamp mill at Lower Seal Harbour, and Henderson (1935) reports an average loss of 0.075–0.177 oz. of Hg per ton of ore crushed at Goldenville. From 1882–1949, a total of approximately 3,070,381 tons of ore were milled at various gold districts in Nova Scotia (Blakeman 1978); therefore, an average Hg loss of 0.1 oz. per ton of ore crushed represents a total loss of about 9500 kg of Hg.

Beginning in the 1880s, gravity separation, chlorination, and cyanidation were also added to the milling circuit at some mines to recover gold from sulphide minerals and/or amalgamation tailings (Malcolm 1912; 1929). Most of the gold in Nova Scotia is “free-milling” (i.e. individual particles can be liberated by crushing), but a certain percentage also occurs in sulphide minerals such as arsenopyrite and cannot be recovered by amalgamation. A variety of gravity concentration devices (e.g. shaking tables, Frue vanners, Wilfley tables) were used to treat the tailings from the amalgamation plates and separate out the sulphide minerals on the basis of their relatively high specific gravities. These concentrates were then leached with either hydrochloric acid / sodium hypochlorite or sodium cyanide solutions to recover the gold. During cyanidation, other chemicals were also added during the extraction process, including lead nitrate (used to limit the alteration of cyanide to ferrocyanides, sulphocyanates, etc.) and zinc dust (used to precipitate gold from the pregnant cyanide solutions). In general, these leaching procedures met with relatively little success (Parsons 1922) until the construction of a 200-ton-per-day cyanide plant at Lower Seal Harbour in 1936 (Roach 1937; 1940).

In the early 1920s, there was a sudden increase in the demand for arsenical insecticides in the United States following an announcement in 1919 from the U.S. Bureau of Entomology, stating that calcium arsenate [$Ca(AsO_4)_2$] was the most economical and efficient insecticide yet discovered for checking the ravages of the boll weevil in the cotton fields of the southern states (Hurst 1927). This situation prompted the operators of many gold mines in Nova Scotia to improve their recovery of arsenopyrite, and a 1924 survey of As resources in the province revealed approximately 1000 tons of arsenical concentrates (assaying from 15–25% As) stockpiled at various mines (Hurst 1924). During this field trip, we will visit two sites where these high-As concentrates, or their roasted equivalents, are exposed near old mill structures.

1.2 Previous Environmental Studies

Mine tailings from these early milling operations were generally slurried directly into local rivers, swamps, lakes, and the ocean with little or no consideration of their impacts on receiving environments (Fig. 3). In addition to the Hg added during amalgamation, potentially toxic elements (e.g. As, Pb, Sb, Tl) also occur naturally in the ore, and may be present at relatively high concentrations in the mine wastes. Over the past 30 years there have been only a limited number of environmental studies at gold districts throughout the province (Table 1). The first study of human health risks associated with these wastes took place in 1976, when a resident living near a past-producing gold district (Waverley) was diagnosed with chronic arsenic poisoning (Hindmarsh *et al*. 1977). Examination of the patient’s well established that it had been lined with arsenopyrite-rich mine tailings, and their tap water contained 5 mg/L As, 100 times the drinking water limit of 50 μg/L (this has since been lowered to 25 μg/L). A subsequent study of 642 wells in gold districts throughout Nova Scotia revealed that 13% exceeded the 50 μg/L drinking water guideline for As (Grantham and Jones 1977).

Figure 3. *Unconfined tailings disposal from stamp mills at the (a) Mooseland, and (b) Leipsigate gold mining districts in 1897 and 1904, respectively. Photos taken by E.R. Faribault, Geological Survey of Canada. Reproduced with permission from the Earth Sciences Sector Photo Library Collection, Natural Resources Canada, Ottawa.*

Table 1. *Timeline of environmental research at Nova Scotia gold mine sites*

Date	Event
1976	- Waverley resident diagnosed with chronic As intoxication from drinking well water - Provincial Arsenic Task Force appointed to study As problem in Waverley area, and in other historical gold districts throughout southern Nova Scotia
1977	- Clinical study of As exposure in 92 Waverley residents (Hindmarsh *et al*. 1977) - Grantham and Jones (1977) identify gold mine tailings as main As source - Environment Canada commissions study of Hg at abandoned amalgamation sites
1978	- Mudroch and Sandilands (1978) document elevated As and Hg levels in Waverley area lake sediments—the Hg is attributed to both gold amalgamation and historical production of Hg-fulminate explosives in the Powder Mill Lake area
1981–1982	- Published studies of As in tailings, sediment, water, and biota at Montague Gold Mines (Brooks *et al*.1981; Brooks *et al*. 1982; Dale and Freedman 1982) - Formation of Federal-Provincial study group to investigate the impact of past gold mining activities on the Shubenacadie Headwater Lakes
1984	- Published studies of As in Nova Scotian groundwater (Meranger *et al*. 1984; Bottomley 1984) document additional contamination near various gold districts
1985–1986	- Environment Canada / N.S. Dept. of the Environment report (Mudroch and Clair 1985; 1986) demonstrates significant contamination of sediment, water, and fish with As and/or Hg in the Waverley and Montague areas - Seabright Resources submits an environmental assessment of their proposed gold tailings recovery project at Oldham, which does not proceed for economic reasons
1988–1989	- Investigation of As and Hg concentrations in tailings, waters, and plants at the Oldham Gold District (Lane *et al.* 1988; 1989)
1998	- Beauchamp *et al.* (1998) report high gaseous Hg fluxes and total gaseous Hg concentrations in air over gold mine tailings at Caribou and Goldenville
1999	- Wong *et al.* (1999) publish results from an Environment Canada study of the dispersion and toxicity of metals derived from mine tailings at Goldenville - Tetford (1999) reports high levels of Hg in white perch near the Caribou gold mine
2002	- Wong *et al.* (2002) publish results from an Environment Canada study of the Caribou Gold District, showing high metal burdens in tailings and lake sediments, high gaseous Hg fluxes, and stream water / sediment toxicity to benthic biota
2003–2006	- Ongoing multidisciplinary MITE studies of metal(loid) distribution, transport, speciation, and fate at 11 gold mining districts in Nova Scotia (Parsons *et al.* 2004)

Since the late-1970s, there have been only a few studies of As and/or Hg contamination at gold districts throughout the province (Table 1), and the risks associated with these sites remain obscure. In the mid-1990s, studies at the Caribou and Goldenville mines showed that elevated concentrations of As, Cd, Hg, Pb, and Tl are present in the tailings, surrounding waters, surface sediments, and biota downstream from these sites (Wong *et al*. 1999; 2002).

Although limited published information exists on the Au content of tailings from many of these deposits, the concentrations of Hg and other elements had not been determined before the present study. The primary and secondary (weathering-related) mineralogy of the tailings was not well understood, and the speciation and potential biological impacts of metal(loid)s in the environment surrounding these sites remained largely unknown. The main objectives of the present study are to: (1) determine the concentrations, distribution, and speciation of elements near these mine sites; (2) identify and characterize processes that control the release of elements from the tailings; and, (3) quantify the off-site transport of metal(oid)s from the mine wastes, and the transformation and fate of these elements in the receiving environments.

The first year (2003) of this 3-year project focussed on identifying gold mines that are most likely to contain significant quantities of Hg in the mine wastes, and included reconnaissance-level sampling of tailings, humus, soil, till, rock, sediment, water, and vegetation at 11 gold mining districts (Fig. 1): Whiteburn (WB), North Brookfield (NB), Leipsigate (LEI), South Rawdon (RAW), Mount Uniacke (UNI), Lake Catcha (LC), Mooseland (MSL), Dufferin (DUF), Cochrane Hill (CH), Upper Seal Harbour (USH) and Lower Seal Harbour (LSH). Samples were collected from areas directly impacted by mining and milling activities, and from background sites to assess regional variations in metal(loid) concentrations. Water, tailings, and sediment samples were also taken from selected districts for microbial measurements, and methylmercury analyses (Winch *et al*. 2004). All waters were collected using field and analytical protocols suitable for low-level (i.e. ng/L, or part-per-trillion) Hg determinations. Samples of tailings, humus, soil, and till were analyzed via ICP-MS for 51 elements following a 1-hour *aqua regia* digestion at 95ºC. Water samples from all sites were analyzed for cations, anions, Hg, dissolved organic carbon, and alkalinity (Goodwin *et al.* 2004; Parsons *et al.* 2004). Ongoing studies (2004–2005) are characterizing the background levels, seasonal variability, speciation, mobility, and bioaccumulation of metal(loid)s in both freshwater and marine systems. A wide variety of methods are being employed, including sequential extractions, biological sampling (fish, frogs, clams, invertebrates, mice), and sediment/water toxicity testing.

1.3 Results from Ongoing Multi-Disciplinary Investigations

Field studies in 2003 revealed that most mine sites contain large volumes of unconfined tailings, which are generally located in low-lying areas downslope of the stamp mill sites. In some districts (e.g. DUF, USH, LSH) the tailings have been transported significant distances (>2 km) offsite by local streams and rivers. At most mines, the tailings are overgrown and often difficult to recognize; however, some tailings deposits are being actively reworked by human activities (e.g. gold panning, fill excavation, off-road vehicle usage). Anthropogenic effects were not limited to the presence of tailings. Waste rock piles, bush roads, and building foundations were common to each district sampled. Locally, drill steel, stamp mill pads, assay equipment, and related mining artifacts were observed. Recent anthropogenic effects include household and commercial garbage dumped down mine shafts, filling trenches, and sporadically strewn along bush roads and/or piled in clearings (Goodwin *et al.* 2004).

Tailings samples were collected in the field by digging pits as deep as 2 m and subsampling all layers that showed significant colour changes. In well-oxygenated areas, a typical tailings profile consists of an upper stratified, light grey-brown to yellow-brown oxidized layer, underlain by a thin (~10 cm) yellow to orange hardpan layer, which is in turn underlain by grey unoxidized tailings. X-ray diffraction results show that secondary minerals such as scorodite ($Fe^{III}AsO_4{\cdot}2H_2O$) are abundant at many sites; these phases may serve as a temporary sink for elements released from the mine wastes. Unoxidized tailings are always encountered below the water table, and in areas where vegetative cover limits oxygen penetration.

Chemical analyses of 520 tailings and sediment samples show high concentrations of Hg (<5 ppb to 350 ppm) and As (9 ppm to 31 wt.%). The highest Hg concentrations are found near mill structures, reflecting Hg loss during amalgamation and retorting. Droplets of elemental mercury (Hg^o) and particles of amalgam have been observed in the tailings at several locations; however, mercury may also exist in various secondary phases (e.g. metacinnabar, HgS), or may be sorbed to mineral surfaces and/or organic material. As shown in Fig. 4, Hg and As concentrations in the tailings and sediments at most districts vary over several orders of magnitude. In these box-and-whisker plots, maximum and minimum values are shown by the whisker extents, upper and lower quartiles define the boxes, median values are given by the horizontal line within each box, and outliers are shown as diamonds. The comparatively lower median Hg concentrations at NB, LEI, and LSH reflect the extensive use of cyanidation in the mills at these sites. Mercury concentrations in cyanidation tailings from recent (1980s) gold mining operations at Cochrane Hill (CH2) are also shown on Fig. 4. The Hg concentrations in these tailings (<5 to 25 ng/g; median 6 ng/g) are representative of natural Hg levels in various bedrock lithologies of the Meguma Terrane. The median As concentrations in most districts range from about 0.1 to 1.0 wt.%; the relatively low As concentrations in the Leipsigate Gold District reflect the extensive use of cyanidation to re-process tailings from 1903–1905.

In general, the waters draining most of these tailings deposits are circumneutral to mildly acidic, with pH values averaging about 6.0. With few exceptions, reaction with the tailings tends to increase the pH of local surface waters, reflecting dissolution of carbonate phases (ankerite, calcite, dolomite) in the mine wastes. Water chemistry data indicate that the dissolved levels of As are very high at some locations (range: 0.2–6600 µg/L; median 100 µg/L; n = 122), as

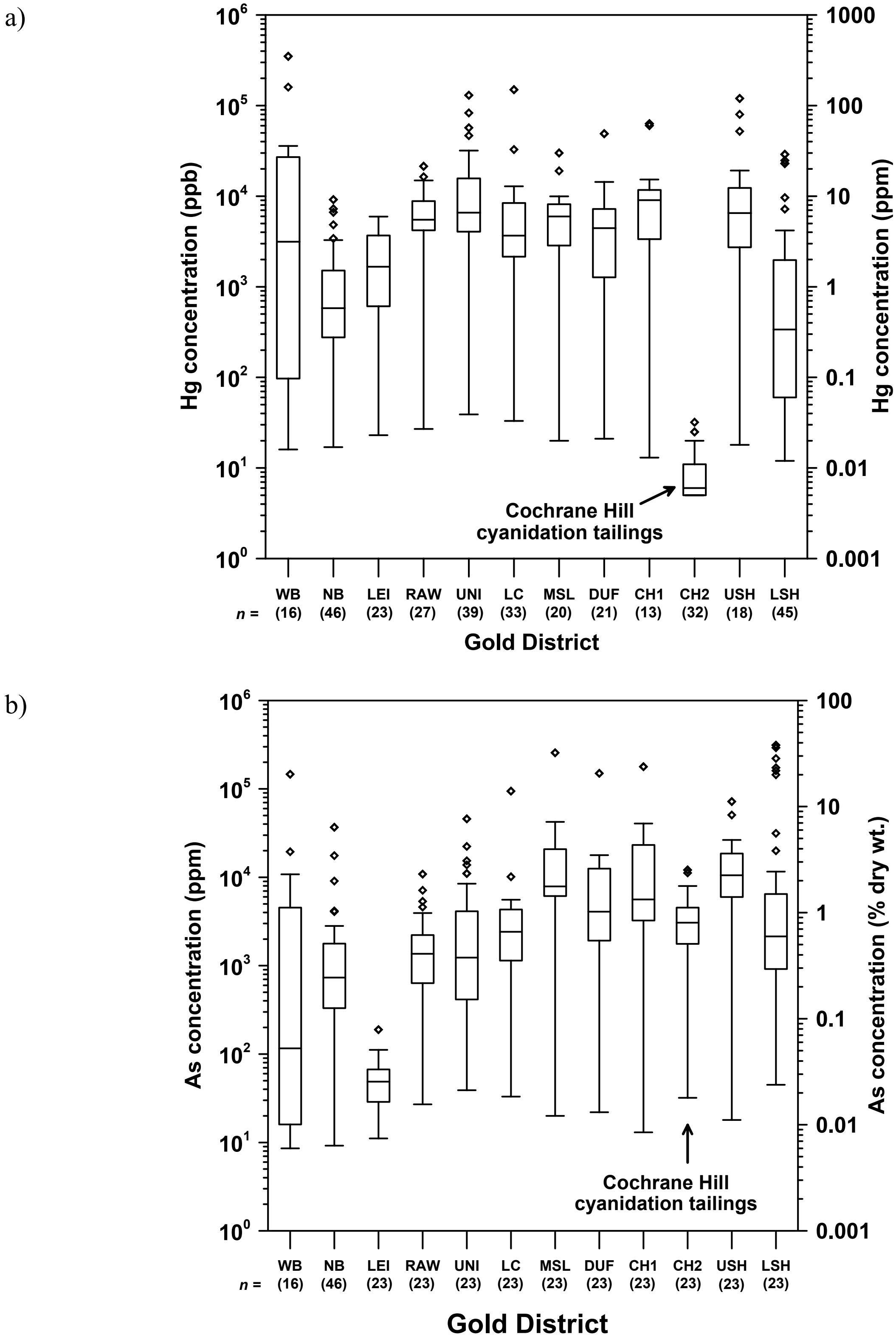


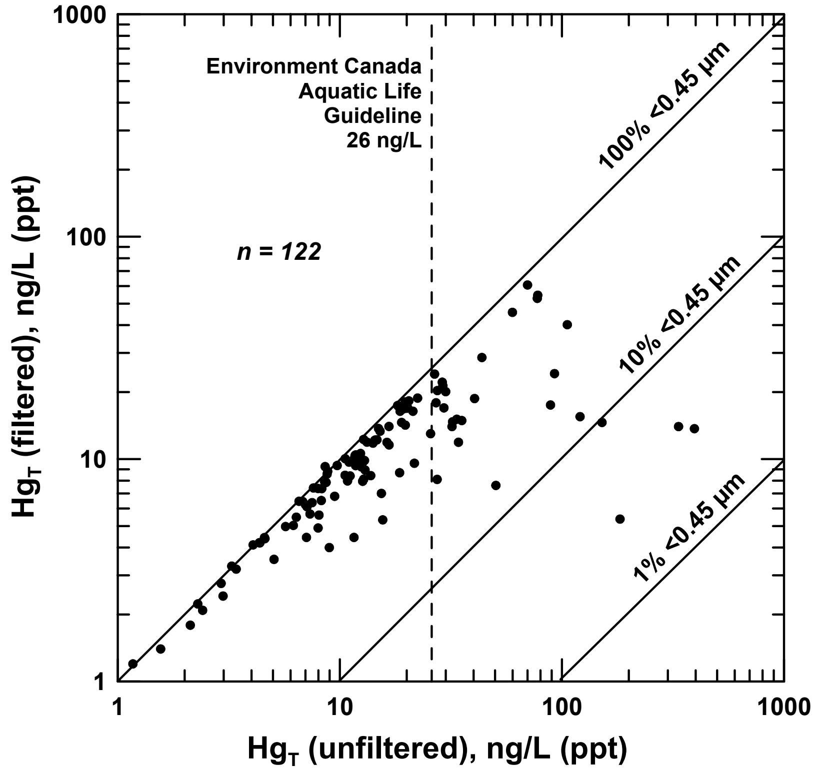
Figure 4. *Box-and-whisker plots showing (a) Hg and (b) As concentrations in tailings and contaminated stream and lake sediments from 11 gold mining districts in Nova Scotia.*

compared to background values of generally <25 μg/L (Fig. 5). Dissolved Hg levels range from 1 to 60 ng/L, and show a significant positive correlation with dissolved organic carbon at most sites. In general, the dissolved Hg concentrations in surface waters are relatively low (i.e. <20 ng/L) even in close proximity to tailings with high (i.e. >1000 μg/kg) levels of Hg, suggesting that most of the Hg is present in relatively insoluble forms (Fig. 5). Most of the total mercury concentrations (Hg_T) exceeding Environment Canada's guideline for the protection of aquatic life (26 ng/L) occur directly within the tailings and generally do not persist for significant distances downstream. Unfiltered Hg concentrations >100 ng/L were all measured within tailings pore waters and mill drainages.

1.4 Summary and Conclusions

Historical mining, milling, and metallurgical practices at lode gold deposits throughout the Meguma Terrane in southern Nova Scotia generated more than three million tons of mine tailings, which were slurried directly into local rivers, swamps, lakes, and the ocean. Of 64 past-producing gold districts in the Meguma Zone, only about five had been studied from an environmental perspective before 2003. Initial results of our ongoing MITE investigations at 11 past-producing gold districts show that the tailings at these sites contain high concentrations of Hg, As, and in some cases, other potentially toxic elements (e.g. Pb). The mine tailings are chemically reactive, and have contributed significant quantities of metal(loid)s to the environment. Ongoing studies are characterizing the background levels, seasonal variability, speciation, mobility, and bioaccumulation of metal(loid)s in both freshwater and marine systems. Results from this project will be used to assess the potential ecological and human health risks associated with these sites, and will support better informed land-management decisions.

a)



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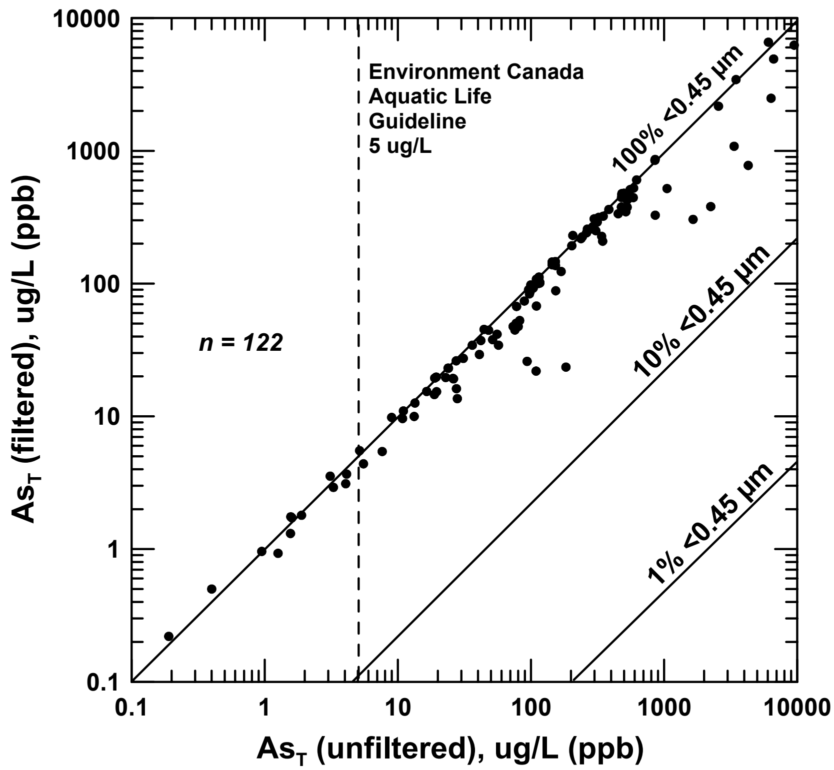


Figure 5. *Filtered and unfiltered (a) Hg and (b) As concentrations in surface waters collected from 11 gold mining districts in Nova Scotia from May 2003 to August 2004.*

2.0 MEGUMA GROUP BEDROCK GEOLOGY AND GOLD DEPOSITS

A brief overview of Meguma Group bedrock geology is given below to highlight the many new observations and resulting changes in interpretation affecting the metallogenic history of gold mineralization in southern Nova Scotia. It is hoped that this background will aid the reader towards a better understanding of the detritus constituting the tailings at the various gold districts being visited during this field excursion.

Bedrock gold mineralization in Nova Scotia was first discovered in interbedded turbidites of the lower Paleozoic Meguma Group in 1858. The Meguma Group represents a unique geological terrain hosting numerous (64) gold deposits and many gold occurrences over a 450 km strike length (Fig. 1). Of these, 63 were designated historically as producing districts near the turn of the century and had combined recorded production between 1860 and 1982 of 1,143,722 million oz (Bates 1987). Nineteen (19) of these districts had historical production exceeding 20,000 oz. (Fig. 6). Virtually all of the gold was produced from high-grade, narrow quartz veins. Although there has been much debate regarding the genesis of these auriferous veins (Graves and Zentilli 1982; Henderson and Henderson 1983; Haynes 1983, 1987; Smith and Kontak 1987, 1988; Sangster 1990), there is little question that high-grade, plunging gold ore shoots within bedding parallel veins provide the best economic potential for mining. Discordant angular veins were well known for their ability to either enrich or rob gold from these veins, and at one district (North Brookfield) a cross-cutting fissure-type vein (Libbey Fissure) constituted the main ore control. Mention of minor amounts of gold recovery from slate host rock was also made near the turn of the century, but never received much attention because it could not be as easily seen as that in the rich quartz veins. Mining activities were carried out only at shallow levels (<100 m) with only a few of the districts worked to the 300 m levels. The deepest shaft (494 m) in the Meguma Terrane is located at Oldham, north of Halifax.

2.1 Introduction

Most historical production came from narrow (10-30 cm), high-grade, low-tonnage quartz vein operations which were generally less than 100 m in depth and rarely extended to depths of >300 m (Fig. 6). Minor production has been documented from the host rocks adjacent to some quartz veins. An example occurs at the Boston Richardson vein, Upper Seal Harbour, where the potential for higher tonnage ore has been recognised.

In 1987, a new style of gold mineralization was recognized in the Touquoy Zone at Moose River. Here, a thick (150 m) sequence of interbedded, carbonate-rich, meta-siltstone and slate contains disseminated gold mineralization in association with pyrrhotite and arsenopyrite, and lacks any significant quartz veining. Current resources at that deposit now stand at 571,000 oz. Au @ 2.0 g/t. In addition, auriferous, quartz-vein free greywacke was discovered in 1987 at the Railway Showing, North Brookfield. Subsequent evaluation by the Nova Scotia Department of Natural Resources in 1992 identified complex intergrowths of this disseminated gold with intermetallic compounds consisting of native metals and compounds of Au-Ag-Pb-Cu-Zn-W-Fe associated with Fe and base metal sulphides in altered greywacke. Since that time, eight other gold districts in the Meguma Group have been found to contain similar mineralization, five of which are greywacke dominated.

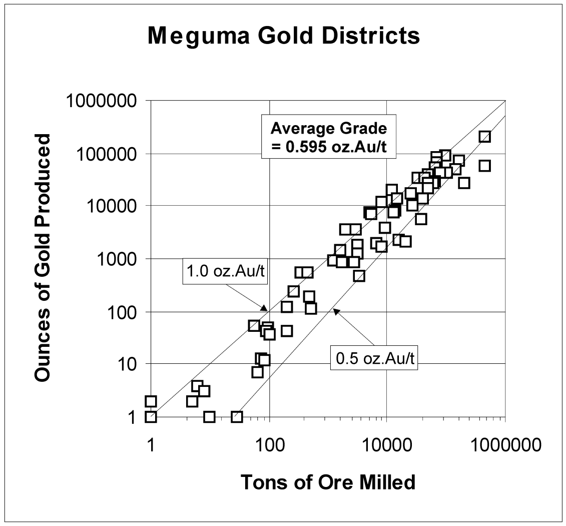


Figure 6. *Gold production vs. tons of ore milled for Nova Scotia gold districts.*

2.2 Stratigraphy and Depositional Age

The Lower Paleozoic Meguma Zone is the second-largest terrane in the Canadian Appalachians (Schenk 1997). This succession forms part of a marginal assemblage shoaling upward from deep-sea fan complexes to coastal facies. The Meguma Supergroup (Schenk 1997) forms the basal stratigraphy of this zone. The work by Schenk represents the most comprehensive summary on the stratigraphy to-date, and the reader is referred to this reference.

Earlier work by Woodman (1904) divided these strata into two mega-units, the lower Goldenville Formation, consisting of intercalated metamorphosed sandstone (greywacke), siltstone and shale (slate to schist), and the overlying conformable Halifax Formation (Ami, 1900) consisting of slates (schist), shales and siltstones with minor interbedded, fine grained, quartz-arenite and greywacke. A transitional unit separating these two formations is known as the Green Bay Formation (O'Brien 1986).

Woodman (1904) interpreted the Goldenville Formation to be a shallow marine deposit with water depths increasing to allow for accumulation of the Halifax Formation. Taylor (1967), Crosby (1962), Douglas (1938) and Malcolm (1929) have also suggested shallow marine depositional models. However, Campbell (1966) and Phinney (1961) concluded that turbidity currents deposited the Goldenville Formation within a well defined, northeastward plunging, deep-sea trough. Schenk (1970) arrived at similar conclusions but also suggested that bottom contour-currents re-deposited some of the finer sediments. Harris (1971) and Harris and Schenk (1976) interpreted the sedimentary structures of the Meguma Group to indicate deposition by cyclic or rhythmic turbidity currents represented by the sandy beds with re-sedimentation of the upper, fine-grained portion of each bed because of contour-currents.

Subdivision of the stratigraphy section along the Halifax/Goldenville transitional contact zone was carried out by O'Brien (1986, 1988) in the Mahone Bay area west of Halifax where he distinguished seven mapable units between the Goldenville and Halifax Formations. Work by

Waldron and Graves (1987) in the same area discovered a bioclastic carbonate horizon in O'Brien's Tancook Member of the Transition Zone that was defined by O'Brien (1986, 1988) in the Transition Zone.

The true stratigraphic thickness of the Meguma Group remains unknown because the base of the Goldenville Formation is nowhere exposed. However, Taylor (1967) reported over 6000 m of Goldenville Formation in south-western Nova Scotia, while Crosby (1962) estimated approximately 4000 m of Halifax Formation in the western part of the province. Therefore, the maximum thickness of the Meguma Group probably exceeds 10,000 m.

Age determination for the Meguma Group is problematic since fossil remains are scarce throughout the stratigraphic sequence, except near the Transition Zone. Its age is generally accepted to be Lower Paleozoic, based on several graptolite localities. The most common graptolite is *Dictonema flabelliforme* (Eichwald), suggesting a Late Cambrian to Early Ordovician age (Crosby, 1962; Smith, 1976). Most of the fossil localities come from near the Halifax/Goldenville contact and may not be representative of the entire group. K/Ar age determinations on detrital muscovites (Wanless *et al.* 1972) in the Spry Bay area, east of Halifax, gave ages of 506$\pm$20 and 485$\pm$19 Ma. for the Goldenville Formation. Numerous trace fossils (Smith 1976; Pickerill and Keppie 1981; Pickerill and Williams 1989) may provide further time constraints for the Meguma Group and Tremadocian acritarchs have been recovered from the Halifax Formation at several localities in the western part of the province (Keppie 1977). Poole (1971) reports a poorly preserved, probable Canadian (Arenigian) graptolite (*Didymograptus* of *Monograptus*) from near Tangier, east of Halifax and fossiliferous strata of the Kentville Formation, conformably overlying the Meguma Group, are dated as Early Silurian (Smitheringale 1960). The recognition of a 44 cm wide bioclastic carbonate horizon (containing abundant trilobite fragments and pelmatoan echinoderm ossicles) within the transitional Green Bay Formation near Mahone Bay (Waldron and Graves 1987; Pratt and Waldron, 1991), helps to establish that part of the Group as Middle Cambrian in age.

2.3 Structure

A sequence of structural events has been established for the eastern Meguma zone (Keppie 1983; O'Brien 1983; Smith 1983; Smith *et al.* 1985). In the Sherbrooke and Guysborough areas five deformation episodes ($D^1 – D^5$) associated with these events are recognised. Each of these is summarised below and depicted in both relative and absolute time frames (Fig. 7).

2.3.1 D^1 Deformation

The recognition of folds and cleavage associated with this deformation was first reported by O'Brien (1983). The dominant structural element is variably penetrative, sub-horizontal grain alignment cleavage, (S^1) defined by quartz, feldspar and metamorphic muscovite and biotite. O'Brien (1983) regards Sherbrooke, eastern Nova Scotia, as the type area for this deformation. Associated folds and cleavage are generally transposed by more intense D^2 regional deformation and only rarely have F^1 folds been preserved.

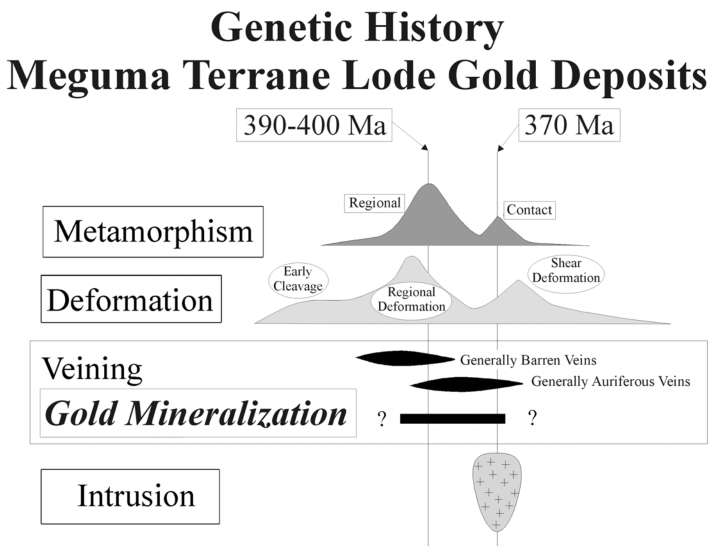


Figure 7. *Generalized genetic history of the Meguma Terrane with respect to lode gold deposits.*

2.3.2 D^2 Deformation

The regional upright fold pattern throughout the Meguma Group is dominated by east-west trending asymmetrical F^2 fold structures (Smith *et al.* 1985; Smith and Kontak 1988). Folds are gently plunging and have associated pressure solution and slaty cleavage of varying relative ages and orientations defined by the growth of muscovite and biotite. Pressure solution cleavage is well developed in the greywacke beds where it forms either divergent or convergent fans associated with major and minor folds. S^2 minerals overgrow earlier S^1 minerals and are crenulated or overgrown by S^3/S^5 and S^4 cleavage, respectively.

Gold deposits throughout the Meguma Group are spatially associated with these major fold structures (Malcolm 1929), with the formation of quartz veins documented as being emplaced over a protracted time interval starting prior to regional D_2 deformation and continuing until after *ca.* 370 granitic plutonism.

2.3.3 D^3 Deformation

Throughout the eastern Meguma Terrain a sporadically developed, S^3 sub-horizontal cleavage is manifested by either the development of a new, spaced, metamorphic biotite foliation or crenulation cleavage. This foliation has a gentle dip (0-30º) and is more easily recognized in thinly bedded lithologies where the metamorphism has reached garnet grade where it deforms earlier cleavages. Smith and Kontak (1986), interpreted this to have formed in response to dynamo thermal metamorphism associated with Devonian granitoid plutonism at *ca.* 370 Ma. Type locations occur at the Cochrane Hill, Forest Hill and Fifteen Mile Stream gold districts as well as at Country Harbour. Further descriptions are given by Smith (1983), Smith *et al.* (1985) and O'Brien (1983).

2.3.4 D^4 Deformation

An upright, variably pervasive, penetrative cleavage (S^4) post-dates regional metamorphism and plutonism (Smith *et al.* 1985; Smith and Kontak 1988) and deforms earlier cleavage minerals. It is generally defined by the development of new muscovite minerals or shear crenulation of pre-existing cleavage minerals. This cleavage is ubiquitous within strike-parallel shear zones throughout the Meguma Group and is particularly prominent at most gold districts throughout the Meguma Group. All significant (>20,000 oz.) gold deposits in south-eastern Nova Scotia bear evidence of S^4 shear cleavage formation. Commonly there is a well-developed mineral lineation within the cleavage planes that displays a predominately dip-slip sense of movement.

Relative age relationships suggest that this deformation event occurred subsequent to peraluminous granitic intrusion and associated contact metamorphism throughout the eastern Meguma Terrane (Smith and Kontak 1988; Williams and Hay 1990). However, absolute $^{40}Ar/^{39}Ar$ dating of S^4 muscovite and biotite from wall rock samples and muscovite and biotite from late stage, auriferous quartz veins from several gold districts indicates that their development is essentially synchronous with granite intrusion at *ca.* 370 Ma. (Kontak *et al.* 1990).

2.3.5 D^5 Deformation

Throughout the Meguma Group, including gold districts, there are a variety of minor structures. These are all included under D^5 deformation and include boudinage, crenulation cleavage, kink bands (flexures) and faults. They are generally only locally developed and post-date all earlier cleavages. At several gold districts (e.g. Caribou, Goldenville), these structures are directly related to important zones of high-grade gold mineralization.

2.3.6 Regional Faults

The Cobequid-Chedabucto Fault System (Minas Geofracture of Keppie, 1982) divides mainland Nova Scotia into the Meguma Terrane to the south, and the Avalon Terrane to the north along a series of east-west trending faults (Fig. 1). Pervasive post-Triassic block faulting records the youngest movement in the stratigraphic record (Donohoe and Wallace 1982).

Numerous NW-SE trending, steeply dipping, sinistral, brittle to ductile cross faults showing displacements ranging from several metres to 1 km are apparent within the Meguma (e.g. Faribault 1895a, 1895b, 1896, 1906). Aeromagnetic maps show that both small and large granitic plutons are offset by these structures as is the overlying Carboniferous cover sequence.

Giles (1985) documented the major NE trending post-Visean Tobeatic Shear Zone that sinistrally offsets the Devono-Carboniferous South Mountain Batholith as well as Carboniferous stratigraphy further east. He suggests approximately 110 km of displacement along this zone would allow reconstruction of the batholith into a circular pattern.

NW-SE trending faults are common at all gold districts in the Meguma Group and relative displacements may range from only several metres (e.g. Goldenville, Cochrane Hill, Forest Hill, Tangier, Moose River, Caribou) to ~1 km (e.g. Dufferin, Beaver Dam). In most cases, there is no obvious genetic association of these faults to gold mineralization, as they typically offset auriferous veins or mineralized zones. However, at some deposits, gold grade is elevated adjacent to these faults and intensity of alteration increases, suggesting a temporal link with late stage mineralization (e.g. Touquoy Zone, Beaver Dam). In addition, auriferous stockwork veining associated with NW-SE trending kink-band development is dramatically increased at several districts (e.g. Caribou) and may control the distribution of high-grade ore at several other districts (e.g. Upper Seal Harbour, Goldenville, Tangier, Beaver Dam).

2.4 Metamorphism

Throughout the Meguma Terrane, two distinct metamorphic events have been established (Keppie 1979). These metamorphic episodes are designated as M^1 regional metamorphism (which is syn- to post- D^2 regional deformation but pre- *ca.* 370 Ma. granitoid plutonism) and M^2 contact thermal metamorphism associated with emplacement of the Devono-Carboniferous granitoid plutons (Mahoney and Raeside 1995) and development of synkinematic D^3 structural elements (Smith *et al.* 1985).

High temperature-low pressure type regional metamorphism at greenschist and amphibolite facies is typical throughout the Meguma Terrane (Chu 1978; Keppie 1979; Raeside and Jamieson 1992). Diagnostic porphyroblastic minerals include sillimanite, andalusite, staurolite, cordierite, garnet, biotite, muscovite and chlorite. These mineral phases overgrow regional slaty S^2 cleavage, which is dated at ~410 Ma, but are variably deformed by S^4 shear cleavage dated at ~370 Ma, thus documenting both their absolute and relative age relationships. $^{39}Ar/^{40}Ar$ age dating of S^2 metamorphic mica indicates that regional metamorphism occurred between 415 and 405 Ma (Reynolds *et al*. 1987). Preliminary Pb isotope data on hydrothermal and metamorphic minerals from the Cochrane Hill gold district and surrounding areas suggest that high-grade regional metamorphism occurred at 397-405 Ma (Smith & Chatterjee 1996). Based on this and other petrographic data they suggest that either gold mineralization has a similar age of formation or that identical structural sites were utilized by later auriferous fluids, thus implying that 'site preparation' occurred prior to or synchronous with Acadian regional mineralization. $^{39}Ar/^{40}Ar$ age dating of shear-related S^4 mica which crosscuts regional metamorphic porphyroblasts indicates that their age is approximately synchronous with a thermal episode associated with Devono-Carboniferous granitoid plutonism at *ca.* 350-370 Ma. (Dallmeyer and Keppie 1987). Locally this younger fabric is observed to deform gold grains (e.g. Cochrane Hill, Tangier, Upper Seal Harbour, Pleasant River Barrens).

2.5 Igneous Intrusions

The Meguma Group is intruded by voluminous (10,000 km^2) Devono-Carboniferous peraluminous granitoid intrusions (Clarke *et al.* 1985) that are composite and zoned in nature (MacDonald and Horne 1988). These intrusive rocks are dated at *ca.* 370-360 Ma (Clarke *et al.* 1988; Clarke and Halliday 1980; Reynolds *et al.* 1981, 1987) and crosscut regional folds and metamorphic isograds but are locally deformed by shear cleavage.

2.6 Basement Lithologies

The only lithologies currently recognized as being basement to the Meguma are the intrusive, amphibolite- to granulite-facies gneisses of the Liscomb Complex (Giles and Chatterjee 1986; Clarke and Chatterjee 1988; Eberz *et al*. 1991; Clarke *et al*. 1993). The gneissic rocks are dominated by tonalites, whereas xenoliths occurring in steep, northwest trending lamprophyre dykes are mafic compositions. Ultramafic, intermediate and felsic xenoliths are also present in these dykes. Mineralogically and chemically, the xenoliths fall into two distinct groups and are interpreted to represent both meta-sedimentary and igneous protoliths from an underlying lower crust similar to the Avalon basement (Eberz *et al*. 1991).

2.7 Quartz Vein Types

With the exception of work by Henderson (1983), systematic documentation of quartz veins in the Meguma Group outside gold districts has not been attempted. Since most reported gold production has been from high-grade auriferous quartz veins, these have been more extensively studied (Graves and Zentilli 1982; Haynes 1983; Henderson 1983; Smith 1983; Mawer 1985; O'Brien 1985; Henderson and Henderson 1987; Kontak and Smith 1987; Smith and Kontak 1988a, b, c). Nonetheless, a lack of consensus remains concerning absolute timing of vein formation and the source of associated metals. Most gold production has come from narrow bedding parallel veins, but complex vein array deposits developed within structural disturbance zones have produced the largest individual deposit tonnages.

Several key observations may be summarised based on examination of vein data:

1. Vein emplacement took place over a long geologic period (pre- D^1 to post- plutonism, *ca.* 370 Ma).
2. Voluminous veining is temporally association with Devono-Carboniferous magmatism (*ca.* 370 Ma).
3. Veins formed by several mechanisms, including wall-rock replacement and fracture infilling, or a combination of these processes.
4. Many auriferous veins, particularly those sub-parallel to bedding planes (i.e. bedding parallel veins), have composite texture and probably formed by a process of systematic and repeated fluid injection and wallrock replacement along structurally favorable planes such as bedding.
5. Post regional folding development of cross structures and flexures was significant in localizing at least some of the larger, more complex vein array systems.

2.8 Alteration

In the past, Meguma Group gold deposits were generally regarded as being devoid of alteration (Boyle 1979). However, recent field and laboratory studies have documented large and intense alteration zones throughout the Meguma Group that are readily observed at all gold deposits. This alteration is also characterized by small anomalies located within broad zones of reduced airborne geophysical response (Kontak and Smith 1987; Smith and Kontak 1987).

Alteration associated with the gold deposits was first discussed by Smith (1983) in his description of siliceous meta-psammite at the Cochrane Hill gold deposit in Guysborough County. Subsequently, Smith and Kontak (1987) and Kontak and Smith (1987) documented the first occurrence of pervasive alteration associated with the Beaver Dam deposit. In addition to silicification surrounding this district, they also noted the presence of extensive carbonate, phyllic and sulphide alteration associated with other gold districts in eastern Nova Scotia.

The type area for alteration documentation is the Beaver Dam Deposit where two distinct stages are apparent. These are recognised as A^1 and A^2 with the second being of only minor significance. Development of both types was contemporaneous with vein formation and granitoid plutonism according to Smith and Kontak (1988). The first and most intense stage is characterized by pervasive silicification, carbonitization and localized sulphide and phyllic alteration. This alteration has been observed up to 5 km along strike and 1 km across strike although the detailed extent of these zones remains to be mapped. A brief description of each alteration style is presented below.

2.8.1a Silicification: A^1 Phase

Silicification is frequently restricted to specific stratigraphic intervals throughout individual districts. It is most easily recognized in greywacke beds where selective bleaching from bluish grey to a light green colour has occurred and in part may be the result of extensive chloritization of matrix material. In some cases, this alteration may have been mistaken for chert (Haynes 1983). Contacts between altered and fresh wall-rock may be either diffuse or sharp with the latter being most common. There is no systematic distribution of the silicification relative to the margins of quartz veins and zone widths range from barely detectable to several tens of metres. These frequently are stratabound over considerable strike lengths (>100 m). In fine clastic lithologies, silicification commonly produces a distinctive colour change from grey blue to dark black. This typically occurs parallel to bedding contacts and is easily overlooked as lithologic variation. Where an alteration front crosscuts bedding at a high angle the contact may be very sharp. Coarsely crystalline quartz growth in wall rocks adjacent to some quartz veins suggests significant replacement of that wall rock and in some instances is attributed to this alteration stage (Smith and Kontak 1988).

2.8.1b Phyllic Alteration: A^1 Phase

Regional distribution of phyllic alteration throughout the Meguma Group is not mapped at present but is thought to be extensive. Phyllic alteration (e.g. Caribou, Beaver Dam, Fifteen Mile Stream, etc.) is best observed in some of the interbedded grey green and blue grey siltstones that show pervasive sericite replacement of both the matrix and certain major mineral constituents. Alteration is primarily restricted to fine clastic material but its development is heterogeneous. Altered zones vary from millimeter-scale to several tens of metres in width.

2.8.1c Chlorite Alteration: A^1 Phase

Chloritization of slaty and sandy lithologies is present at most gold districts throughout the Meguma Terrane. Megascopically, sandy lithologies display mottled textures and become lighter green to whitish in colour. Slaty lithologies display a characteristic greenish colour and have softer textures. Frequently, where alteration intensity is variable these strata have a banded appearance characterized by alternating greenish and bluish laminations. Microscopically, these lithologies are characterized by pervasive chloritization of matrix minerals and the predominant breakdown of metamorphic biotite to chlorite. Chlorite development in some quartz veins (both bedding parallel and discordant) appears to be temporally associated with this stage of alteration.

2.8.1d Carbonate Alteration: A^1 Phase

Variably developed carbonate alteration is present at all gold districts in the Meguma Group. Most commonly, carbonate occurs as a significant quartz vein constituent and as disseminations constituting up to 70% of wall-rock locally. Intense carbonate alteration is generally restricted to the gold districts but has also been noted outside the influence of known gold mineralization (Smith 1983).

In selected meta-greywacke and meta-siltstone beds, porphyroblastic and disseminated matrix carbonate may constitute up to 40% of the rock. In contrast, granular carbonate at Beaver Dam and Dufferin have been observed to constitute up to 75% of particular beds (Smith and Kontak 1988). The ankerite/dolomite component of this carbonate is easily recognized in weathered diamond drill core.

In rocks that are more pelitic, carbonate alteration is represented by variable amounts of disseminated, poikiloblastic carbonate rhombs consisting of ankerite, dolomite and calcite. Although there is some debate regarding the primary versus secondary nature of this carbonate, most field and petrographic evidence indicates a secondary origin.

2.8.1e Sulphide Alteration: A^1 Phase

Sulphide content throughout the Meguma Group has frequently been regarded as a function of primary sediment enrichment (McBride 1978). However, Smith and Kontak (1988) have documented sulphide alteration halos associated with quartz vein emplacement. The Tangier, Dufferin, Goldenville and Upper Seal Harbour Gold Districts offer good examples of the style of sulphide alteration that is ubiquitous in all gold districts.

Sulphide alteration is typically dominated by arsenopyrite + pyrrhotite + pyrite assemblages which form distinct halos of both stratabound and crosscutting character. The most easily recognized manifestations of this alteration type are arsenopyrite stripes, as seen in the Papke Zone at Beaver Dam, which generally parallel bedding laminations or occur as discrete arsenopyrite veins. These were also observed both underground and in diamond drill core at Forest Hill and Upper Seal Harbour Gold District where they are as great as 30 cm in width and in excess of 100 m in strike length. Individual stripes can be shown to both pre-date and post-date auriferous quartz vein emplacement (Smith and Kontak 1987) and commonly display a folded character. In the underground workings at Tangier, a 15 m wide arsenopyrite halo is present on both sides of a discordant quartz vein and individual arsenopyrite stripes form parallel to bedding laminations up to 15 m from the vein.

2.8.2 A^2 Alteration

Type areas for second stage alteration (A^2) are present at most gold districts (e.g. Beaver Dam, Forest Hill, Upper Seal Harbour, Sable Road Cut, Wine Harbour and Mooseland gold districts). These orange to beige alteration haloes are typically up to 10 cm in width occur on either side of thin (1 to 4 mm) calcite-chlorite veinlets (Smith and Kontak, 1988) that cut stratigraphy at a high angle (i.e. Sable Road Cut). The margins of the alteration haloes are diffuse to sharp and may be either undulatory or straight in character. This alteration overprints A^1 alteration mineralogy.

2.9 Genetic Models

Numerous genetic models have been proposed for the turbidite-hosted, quartz vein deposits of southern Nova Scotia. These include: (1) the classical “saddle-reef” model (Faribault (1926); later re-iterated by Keppie (1976)); (2) granite derived (Newhouse 1936); (3) exhalative (Haynes 1983; 1987); (4) hydraulic fracturing and lateral secretion accompanying regional metamorphism and deformation (Graves and Zentilli 1982; Henderson and Henderson 1987; Hy 1987); (5) epithermal environment (Smith 1986); and (6) granite-related, polygenetic models (Smith 1983; Smith *et al.* 1985). Recent studies by Smith and Kontak (1988), Kontak and Smith (1988), and Kontak *et al*. (1988) have documented vein gold mineralization at *ca.* 370 Ma synchronous with gneissic diapiric domes, mafic intrusion and granitoid plutonism throughout eastern Nova Scotia. Table 2 presents an overview of important general observations pertaining to Meguma Group gold deposits.

Table 2. *Attributes of Meguma Group Gold Deposits*

Historical Production	1.2 million ounces recorded (actual production may be greater)
Largest Single Producing District	Goldenville (209,383 ounces)
Basement	Amphibolite to granulite facies mafic to felsic gneisses of the Liscomb Complex
Host Sequence	Lower Paleozoic Meguma Group (flysch)
Rock Types	Metamorphosed slate and greywacke with associated quartz veins
Structural Traps	1. Anticline domes 2. Stratigraphic horizons 3. Shear zones 4. NW & NE trending faults
Deformation History	Multi-phase: 5 deformation events (D1-D5) - rare, flat step folds - regional upright folds - flat banded biotite fabric - upright shear fabrics and minor folds - brittle faulting
Mineralization Style	1. High grade narrow quartz veins (bedding parallel, fissure, *en echelon*, discordant & rare saddle reef) 2. Low grade disseminations in slate & meta-siltstone 3. Low grade disseminations in meta-greywacke
Age of Vein Emplacement (& presumed age of mineralization)	1. pre-, syn- & post regional metamorphism (*ca.* 390 Ma) 2. pre-Devonian plutonism (*ca.* 370 Ma)
Common Vein Mineralogy	Gangue: quartz, carbonate, feldspar, muscovite, biotite, chlorite, tourmaline, epidote, garnet, staurolite, andalusite, sillimanite, chloritoid, sphene, diopside Sulphide/Oxide: arsenopyrite, pyrrhotite, pyrite, galena, chalcopyrite, sphalerite, ilmenite, rutile
Host Rock Alteration	silica, carbonate, sericite, sulphide minor tourmaline & epidote
Ore Deposit Geometry	1. Multiple ore shoots in quartz veins 2. Tabular bodies adjacent to cross-faults 3. Belts consisting of veins and meta-sediments
Grade & Tonnage	1. Veins: 7-30 g/t 2. Meta-sediments: 1-3 g/t
Associated Elements	Au, Ag, As, Cu, Pb, Zn, Sb, Bi, W, Te, Cd
Ore Fluids	low salinity, metamorphic, T_h = 250 -350ºC

3.0 GOLD MINERALIZATION

3.1 Introduction

For the purposes of this field guide, a four-fold classification for gold deposit types is used to reflect host lithology, morphology, occurrence and style of mineralization. These are characterized below and provide a useful reference framework:

(TYPE I) **Auriferous Meguma Quartz Veins (AMV):**
Lode gold quartz veins that are hosted primarily in slate belts (e.g. Tangier, Dufferin, Goldenville, Lower Seal Harbour); mineralization is associated with major anticlinal folds and secondary structures (e.g. faults and kink bands); gold is high purity (~5 wt. % Ag) ranging in grain size from coarse nuggets to <1 mm;

(TYPE II) **Auriferous Meguma Slates (AMS):**
Slate- and siltstone-hosted mineralization lacking a significant quartz veining component (e.g. Touquoy Zone, Moose River Gold District); gold is associated with regional anticlinal fold axis and secondary fault structures but has a strong stratigraphic control; gold has high purity (similar to vein deposits) and occurs in grains <2 mm in diameter (average ~100 mm);

(TYPE III) **Auriferous Meguma Greywacke (AMG):**
Greywacke-hosted mineralization lacking a significant quartz veining (e.g. Railway Showing at the North Brookfield Gold District); mineralization is associated with the regional anticlinal fold structure but is confined to one or more favourable lithologies in association with coarse-grained arsenopyrite; high-purity gold is predominant but intermetallic compounds may be found adjacent to favourable horizons;

(TYPE IV) **Combination Vein-Slate-Greywacke (VSG):**
Gold mineralization occurs in numerous vein types and within associated interbedded slate and greywacke lithologies throughout the Meguma Group (e.g. Upper Seal Harbour).

3.2 Deposit Mineralogy

Gold is the main ore of the Meguma deposits although minor tungsten (scheelite from Moose River) and antimony (stibnite from West Gore) have also been produced. Other associated ore minerals include arsenopyrite, base metal sulphides, pyrrhotite, pyrite, oxides, numerous Bi-Te-Ag-S complexes (including native Bi and several Bi-Te-Ag alloys) and rare greenockite (CdS). High cobalt and nickel concentrations at some deposits (e.g. Tangier) are associated with abundant magnetic pyrrhotite.

Gangue mineralogy of the veins includes plagioclase (An_{0-60}), muscovite, biotite, chlorite, tourmaline, apatite, amphibole, epidote, garnet, andalusite and minor amounts of staurolite (e.g. Cochrane Hill) as well as variabe amounts of quartz. Modal mineralogy of particular veins is dependant upon the vein type and the associated metamorphism.

3.3 Ore Controls

Perhaps the most fundamental geologic problem concerning the economic viability of gold mineralization in the Meguma Group is ore grade and continuity. If the geometry of high-grade ore shoots in vein deposits is not established, chances of a successful operation are doubtful. This problem is less critical in auriferous argillites. Equally important is the question of gold recovery due to the relatively high content (10–30 %) of micron-sized gold, some of which is trapped as disseminations within sulphides.

Several structural parameters that define these high-grade ore shoots include: (1) intra-vein slickenside lineations; (2) intersections of angular and bedding parallel vein types; (3) rapid size increase of individual bedding parallel veins along strike and down dip; and (4) spacial association with sulphide alteration. One or more of these features is associated with the high-grade ore shoots in bedding parallel veins at all Meguma Group gold districts. Orientations of ore shoots may vary dramatically between different parallel veins. Wall rocks adjacent to these vein type ore shoots will generally carry minimal ore grade. Here, argillite lithologies with associated strong alteration (carbonatization, sulphidization) are the more favorable host rock for gold mineralization.

In stockwork vein systems, rich gold mineralization is restricted to the core of the stockwork or to sulphide-rich wall rocks intersected by the stockwork (e.g. Caribou). The stockwork itself and the high-grade ore are structurally controlled to zones of brittle deformation in competent lithologies (i.e. meta-greywacke) associated with late stage cross-cutting flexures (Fig. 8). In all cases, individual parts of the stockwork occur as *en echelon* centipede-like cylindrical features confined to individual beds (i.e. ore zones have plunging tube-like geometry along bedding planes) that together define the axial place of the flexure. With respect to ore mineralization, there is no apparent stratigraphic control for these auriferous zones, other than being hosted in a structurally competent lithology that deformed by brittle deformation. At present, Caribou is the only Meguma gold district having such a flexure-controlled stockwork system. However, similar kink-type structures at Goldenville are noted to define the high-grade ore in bedding parallel veins (Hedley 1941). Detailed examination of a single zone on the stockwork (Main Zone at Caribou) has allowed for geological prediction of the unexplored remainder of the flexure zone, and presumably gold mineralization, with great success.

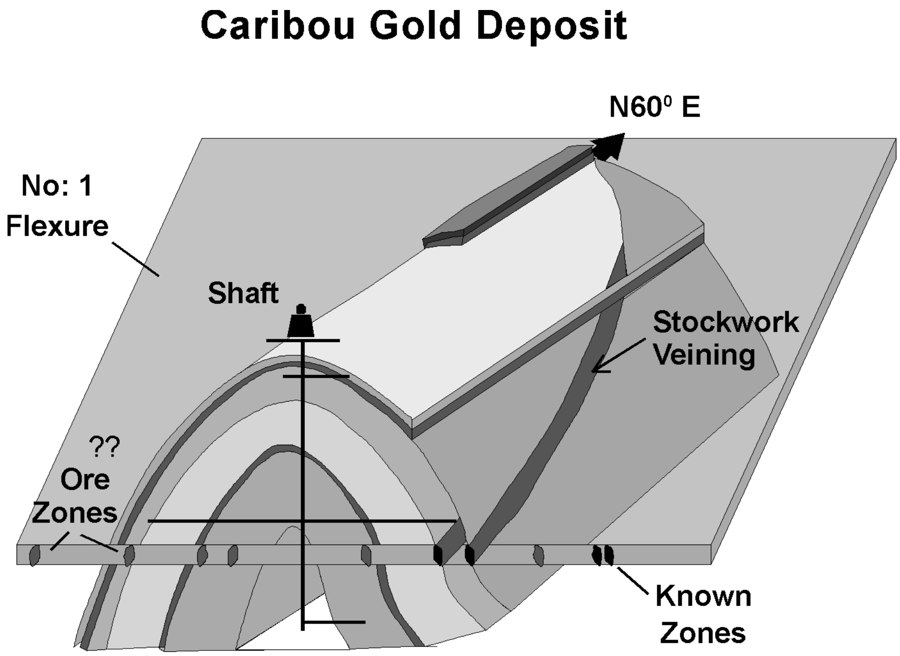


Figure 8. *Schematic block diagram showing a plunging stockwork system.*

Disseminated gold mineralization in altered argillites with no quartz veining has only recently received attention in Nova Scotia. The thick sequence of altered argillite known as the Touquoy Zone at Moose River has been bulk sampled by open pit method with encouraging results. Average ore grade from the open pit is about 1.5 g/ton with the higher grade (3.8 g/ton) part of the body lying immediately below it. The current resource stands at 571,000 oz. Au (8.43 MT @ 2.1 g/t). Carbonate alteration is pervasive throughout the argillites which host fine grained (50 µm) gold mineralization with rare grains up to 2 mm. Gravity and flotation have been effective in extracting >90% of the gold in these rocks.

Gold mineralization associated with sulphide alteration in the argillites and meta-greywackes is well known throughout southern Nova Scotia gold districts (Smith and Kontak 1988). Disseminated fine- and coarse-grained gold in wall rocks at Cochrane Hill (Smith 1983, 1984) and other deposits adjacent to quartz vein margins is also well known. However, it has generally been common practice to ignore all areas within the Meguma Group that do not have an abundance of quartz veining and associated sulphides (i.e. conventional vein-type deposits). Hence, there is now a growing interest in the potential for high tonnage, low-grade gold mineralization throughout the Meguma Group. At present, there are no clearly defined characteristics that easily predict whether a particular argillite unit may be auriferous or not. However, unusually thick (>30 m) argillites with intense carbonate alteration and superimposed secondary structures appear to provide a favorable host rock. Mineralized argillites are also present at the Fifteen Mile Stream deposit and similar lithologies (with no known mineralization) have been observed by the author (PKS) elsewhere throughout southeastern Nova Scotia.

3.4 Absolute Age

A fundamental rational for understanding the genesis of any mineral deposit is the establishment of the absolute age of mineralization. Based on early field observations, gold deposits in the Meguma were generally regarded as "old" (i.e. syn-regional D^2 deformation). More recently, $^{40}Ar/^{39}Ar$ age determinations on vein biotite, muscovite and amphibole from five gold deposits in the eastern Meguma Terrane (Kontak *et al*. 1989) have suggested that veins and mineralization are much younger. In all cases good plateau ages of ~370 Ma are interpreted to indicate the age of vein formation and gold mineralization. These dates are consistent with some of the relative geologic age relationships established by field observations, but not all. More recently, Re/Os dating on arsenopyrite revealed an age of 408 Ma for ore formation. These absolute age data suggest that vein and ore formation started relatively early in the deformation history and either continued until the emplacement of the voluminous peraluminous granitoid intrusions at ~370 Ma throughout the Meguma Terrane, or occurred in a minimum of two distinct pulses. Figure 9 shows an oblique cross-section through the southern part of the province.

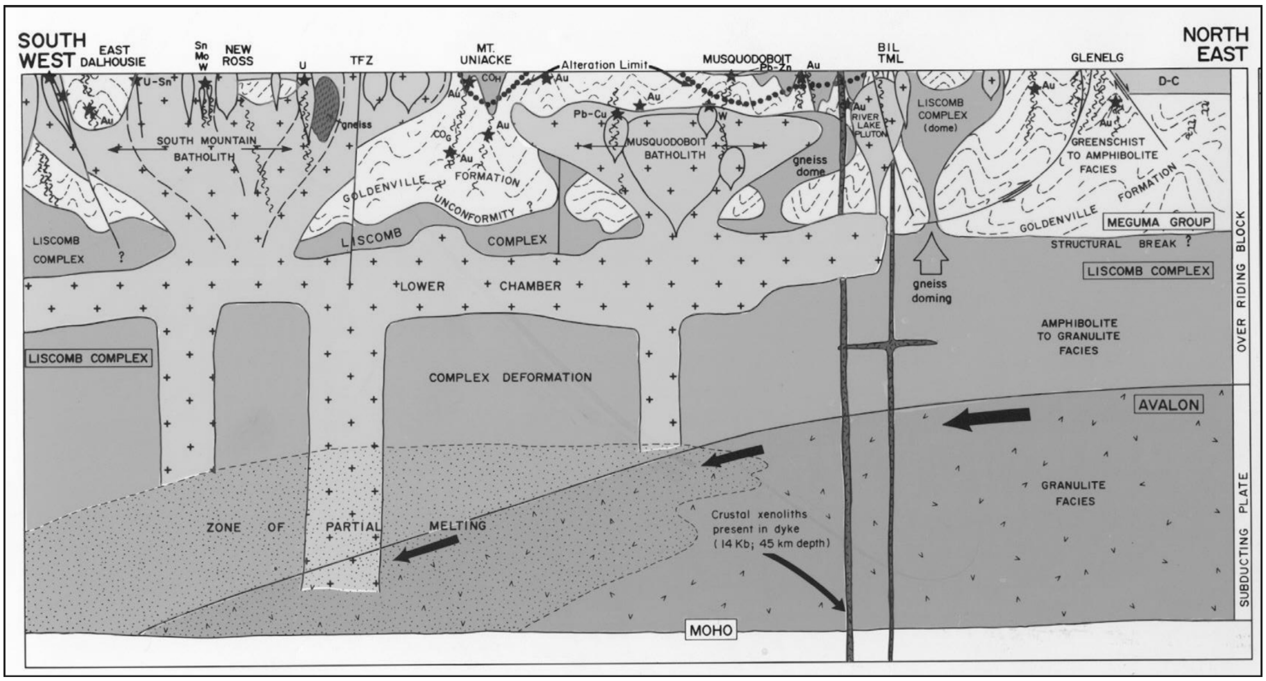


Figure 9. *Oblique ENE-WSW cross section through the Meguma Terrane depicting sub-surface geology.*

4.0 SURFICIAL GEOLOGY AND GEOCHEMISTRY

4.1 Regional Surficial Geology

Most of the surficial glacial deposits and associated landforms throughout Nova Scotia were formed within the last 70,000 years during the Wisconsinan glaciation (Lewis *et al.* 1998). Superimposed till sheets as well as various multiple-flow directional indicators have been mapped and indicate that Nova Scotia is characterized by a relatively complex ice flow history (Stea *et al.* 1992; Stea and Finck 2001).

The following paragraph from Stea and Finck (2001) briefly summarizes the glacial history of Nova Scotia during the Wisconsinan. The oldest observed ice flow indicators on land are towards the east and southeast and are responsible for the formation of the Hartlen Till associated with the Caledonia Phase (75–40 ka). South and southwest flow of the Escuminac Phase (22–18 ka) followed and is responsible for the deposition of the Lawrencetown Till. The Scotian Phase (18–15 ka), characterized by an ice divide, was situated over most of Nova Scotia and the resulting ice flow varied from northwestward in northern Nova Scotia to south and southeast in southern Nova Scotia followed by the formation of the Beaver River Till. The Chignecto Phase (13–12.5 ka) was characterized by shifting ice flow associated with several small ice caps, the remnants of waning stages of the Scotian Phase glacier.

Typically, C-horizon till exhibits a slight colour and textural change with depth. The uppermost part of the till profile (immediately underlying the B-horizon soil) is generally oxidized and tends to be characterized by subtle hues of orange-brown and red-brown. Clasts commonly exhibit obvious effects of oxidation (sulphide casts, variably oxidized sulphides, iron staining, decomposition of feldspars to kaolin) often resulting in the presence of friable clasts. With increasing depth (generally > 1.5 m), the till profile is commonly less oxidized and gradually changes colour from an olive grey-brown to a grey colour. Evidence of oxidation of clasts (and sulphides, if present) is reduced with increasing depth.

A relatively consistent, well-developed B-horizon soil has developed on top of till and other glacial sediments since the last period of glaciation approximately 12,000 years ago (Stea *et al.* 1992). The oxidized soils can be variable in colour but generally tend to range from a dark orange brown to dark red brown. Locally, a very distinct grey to grey-white leached zone may be present although this situation is not commonly the case. Clasts in soil are rare relative to their frequency/distribution in till.

Overlying the B-horizon soil is the A-horizon humus layer consisting of (i) well-decomposed plant litter material characterized by a black colour and relatively fine texture and (ii) less-decomposed material characterized by a brown-black colour and coarser texture (Fig. 10).

Figure 10. *An example of the color and textural differences between the A-horizon humus (SA10), B-horizon soil (SB10) and C-horizon till (SC10) from the Upper Seal Harbour Gold District.*

4.2 Regional Geochemistry: Previous Surveys

Nova Scotia has been extensively covered by regional geochemical surveys involving various sample media including vegetation, till, stream sediments, stream waters, lake sediment, and lake waters. Unfortunately, there is not complete coverage of the entire Province with respect to any one sample media. Complete regional geochemical sampling utilizing a single sample media, however, has been undertaken in areas underlain by Meguma Group rocks. A comprehensive regional till mapping and sampling program was completed over mainland Nova Scotia between 1977 and 1985 and included complete coverage of the Meguma Group metasediments (Stea and Fowler 1979; Stea 1982; Stea and Grant 1982; Turner and Stea 1987). Also, a comprehensive regional lake bottom sediment geochemical survey completed during 1977–1978 involved complete coverage of the Meguma Terrane (Bingley and Richardson 1978; Richardson and Bingley 1980). The main objective of both regional geochemical surveys was to promote mineral exploration within the province.

Additional regional geochemical surveys have also been completed by numerous exploration companies in their search for gold, tin, tungsten, and other commodities. For example, Seabright Resources conducted an extensive helicopter-assisted regional soil and till sampling program over large parts of the Meguma Group metasediments during 1986, 1987, and

1988 (Woodman *et al*., 1994). Further details on previous geochemical sampling of surficial materials in Nova Scotia can be found in Goodwin *et al.* (2004).

It is important to mention here that when comparing the reported results from a given survey, it is imperative that one is comparing “apples to apples”. For example, how comparable are Hg in till results from samples collected at a depth of 1.5 m, prepared to <2 microns and digested in *aqua regia* (partial extraction) to Hg in soil results from samples collected from a depth of 0.20 m, prepared to <2000 microns and digested in a four-acid solution (near-total extraction)? Or, how do you compare the aforementioned Hg in till results to the Canadian Environmental Quality Guidelines for Hg in soil in a residential or park setting?

Systematic differences in elemental concentrations from one survey to another may be the result of numerous variables (i.e. sampling depth, size fraction analyzed, digestion, analytical instrumentation, etc.), not withstanding any spatial (i.e. aerial extent, topography, changes in bedrock, surficial geology or mineralogy, etc.) or temporal variations. Recognition of these variables and how they may affect analytical results reported by a laboratory is critical when the data are being interpreted and/or compared to some base level, i.e. CCME Guidelines or geochemical results from another survey.

For details regarding the sample collection, preparation, digestion, and analytical methodologies as well as Quality Control/Quality Assurance (QA/QC) protocols, the reader is encouraged to refer to the reference(s) cited for a specific survey.

4.3 Regional Hg and As Geochemistry

Previous geochemical sampling programs have shown that enrichment of gold (Au) and arsenic (As) with lesser enrichment of copper (Cu), lead (Pb), zinc (Zn), tungsten (W), bismuth (Bi), tellurium (Te), and iron (Fe) characterize the bedrock geology of many of the gold deposits of the Meguma Terrane (Kontak and Smith 1993). These elements are commonly geochemically enriched in vegetation, soil, and till down-ice from known gold mineralization as a result of mechanical dispersion (erosion, transportation and deposition) by advancing glacial ice (Coker *et al.* 1988; Dunn *et al.* 1991). The Meguma till mapping and sampling program completed by the N.S. Dept.of Natural Resources (NSDNR, formerly the N.S. Dept. of Mines and Energy (NSDME)) in the late 1970s was undertaken to map the various till units and to classify them on the basis of their lithologic, textural, and geochemical characteristics (Stea and Fowler1979).

Table 3 is a summary of mean values for Hg and As concentrations for various till units from samples collected along the eastern shore of Nova Scotia. Unfortunately, the lower detection limit for Hg at the time of analysis is considerably less sensitive than commonly reported by 2005 standards and, therefore, is of limited use. It is clear, however, that there is variance in the mean value that is probably attributable to differences in the texture and composition of each till unit. These differences are evident in the mean As concentrations. The mean As values range from a low of 10.6 ppm in the clay facies of the Lawrencetown Till to a maximum of 42.8 ppm in the slate till. The two till units that characterize the Meguma Group metasediments, the Quartzite Till and the Slate Till, are further characterized by the highest As in till concentrations of 31.7 ppm and 42.8 ppm As, respectively.

Table 3. *Summary statistics for Eastern Shore tills (modified from Stea and Fowler 1979).*

	Hartlen Till	**Lawrencetown Till (clay facies)**	**Lawrencetown Till (sandy facies)**	**Quartzite Till**	**Slate Till**	**Granite Till**
Hg mean (ppm)	0.1	0.2	0.2	<0.1	0.2	<0.1
As mean (ppm)	17.6	10.6	14.2	31.7	42.8	25.8
***n* =**	33	155	64	122	22	14

The differences in the mean values are related to the compositional changes from one till unit to another (i.e. Hartlen Till vs. Slate Till) and textural changes within a till unit (i.e. clay facies vs. sandy facies of the Lawrencetown Till). As mentioned in Sect. 4.2, these variables (compositional and textural differences) can significantly affect geochemical results.

As part of their gold exploration program during the late 1980s, Seabright Explorations Inc. conducted a regional, helicopter-assisted B-horizon soil and C-horizon till sampling program over a large portion of the Meguma Terrane (Woodman *et al*. 1994). Unfortunately, Hg was not analyzed during this survey. Arsenic, however, was analyzed and results for 2955 B-horizon soil samples indicate As values ranged from a low of 1.0 ppm to a maximum of 5070 ppm yielding a mean of 23.2 ppm (median of 11.0 ppm). Results for 4146 C-horizon till samples indicate As attains a minimum value of 1.0 ppm and a maximum value of 12900 ppm for a mean of 35.7 ppm (median of 9.0 ppm). The means appear to be strongly influenced by several outliers in the soil and till summary statistics resulting in the mean being significantly higher than the median values. If the maximum till value of 12,900 ppm is removed and the basic statistics are re-calculated, the mean drops to around 33 ppm, a 10% decrease in the mean simply by removing one data point. It is speculated that several of the highest As values were the result of sampling (unrecognized) tailings associated with former gold mining operations. Tailings often form relatively flat and often treeless grassy areas that would have made an ideal landing site for a helicopter when dropping off a geochemical sampling crew(s).

As part our ongoing MITE investigations, humus, soil, and till samples were collected during the 2003 field season from nine gold districts throughout mainland Nova Scotia (Fig. 1; Goodwin *et al.* 2004). Compiled mean Hg and As results (<2000 microns) for 35 samples representing the nine districts are presented in Table 4. These mean Hg and As concentrations are based on several humus/soil/till profiles collected between 250 m and 1000 m up-ice, and between 250 m and 1000 m down-ice from known mill structures/shafts. These data represent, in general, natural mean background values that characterize gold districts throughout the Meguma Terrane. All samples avoided (obvious) anthropogenic influences in an attempt to establish “local” geogenic backgound within a gold district.

The data presented in Table 4 indicate that the humus layer is significantly enriched in Hg relative to the soil horizon, and even more so than the till. Conversely, As is depleted in humus relative to the soil and till horizons which yield similar mean values. Notwithstanding all the previously mentioned variables that can influence geochemical results, the data clearly demonstrate that naturally occurring (and elevated) levels of arsenic characterize the soil and till within Meguma gold districts. Elevated As in soil and till commonly occurs throughout the Meguma where no gold mineralization is known to exist.

Table 4. *Compiled mean Hg and As results (<2000 microns) for nine gold districts throughout mainland Nova Scotia (MITE 2003, unpublished).*

Element	Humus	Soil	Till
Hg (ppb)	324	117	86
As (ppm)	14	114	109

Figures 11 and 12 show the effect of glacial ice on Hg and As values in different sample media from within the Dufferin Gold District. Obvious anthropogenic effects associated with the mill structure are also clearly evident in Figures 11 and 12. Anthropogenic effects were not included in the generation of the summary statistics in Table 4.

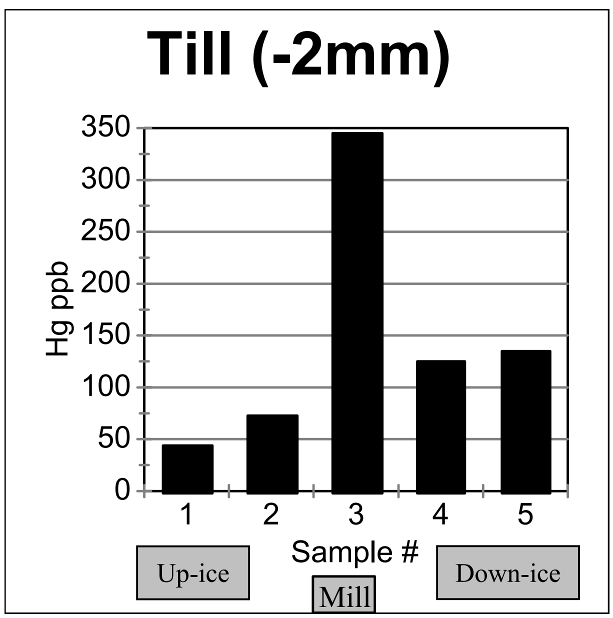


Figure 11. *Mercury in C-horizon till from the Dufferin Gold District. Samples 1 and 2 were collected 500 m and 250 m, respectively, up-ice from the mill site of the old workings west of Eagle Lake. Samples 4 and 5 were collected 250 m and 500 m, respectively, down-ice from the same mill site. Note the increasing Hg concentration in till as glacial ice advanced across the mineralized zone near the mill, and the significant anthropogenic effect contributed by the mill.*

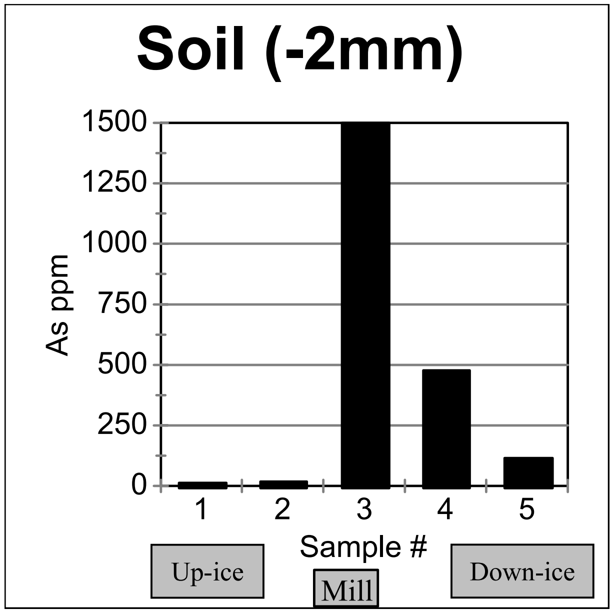


Figure 12. *Arsenic in B-horizon soil from the Dufferin Gold District. Samples 1 and 2 were collected 500 m and 250 m, respectively, up-ice from the mill site of the old workings west of Eagle Lake. Samples 4 and 5 were collected 250 m and 500 m, respectively, down-ice from the same mill site. Note the the increase and then subsequent decrease in As concentrations as glacial ice moved across the District, and the significant anthropogenic effect contributed by the mill.*

5.0 Stop #1: TANGIER GOLD DISTRICT

5.1 Bedrock Geology, Mineralization, and Geochemistry

The first stop is situated immediately south (~400 m) of the decline to the Blueberry Hill mine at Tangier. Here, a thick sequence of glacial debris (the Beaver River Till) carries placer gold.

5.1.1 Background Information

It is reported that the discovery of gold at Tangier was the first in Nova Scotia dating back to 1860 (Malcolm 1929). The main historical development at the district took place from the Kent Shaft, which is located immediately east of the present Blueberry Hill mine in the village of Tangier along the north side of highway #7 (Fig. 13a).

Recent development of this mine site was carried out by Coxheath Gold Holdings Ltd. from 1986 to 1989, when a development and production decline to the 120 m level was driven by the company, in addition to over 5 km of underground drifting and raising. All of their work was carried out primarily on the Marker, Whin, Twin and Nugget veins with minimal development on the Big and Little South veins (Fig. 13b). Poor mill recoveries eventually drove the company into receivership in 1989. Tangier Limited Partnership extended these developments further, but closed after its first year of operation because of poor gold recoveries.

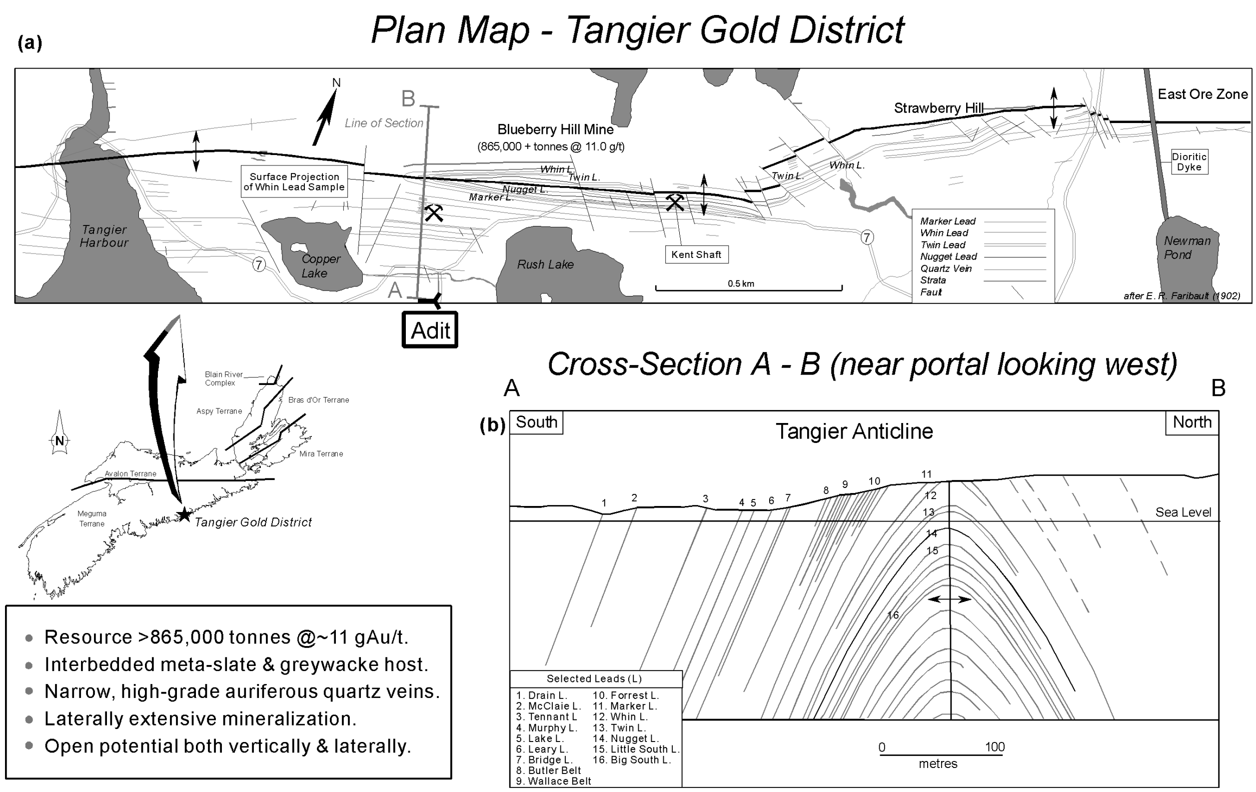


Figure 13. *Location map of the Tangier gold district showing both (a) plan and (b) cross section of selected lode gold veins. The location of the auriferous till adit is shown in (a) near the south end of the line of section "A-B".*

5.1.2 General Geology

Mineralization occurs primarily in a series of bedding-parallel veins along the south limb of the upright Tangier Anticline (Fig. 13b). Although mineralized veins carry around the hinge to the north limb of the anticline, virtually all production (26,000 oz.) came from the south limb. Approximately 70 gold-bearing veins have been identified in the Blueberry Hill mine during earlier mine history and diamond drilling. In addition to other smaller veins which occur within the mine sequence adjacent to these veins, numerous others occur along strike towards the east in the Strawberry Hill and East Zone areas (Fig. 13a).

The deposit is characterized by tight, upright regional folding with penetrative slaty and pressure solution cleavages in pelitic and psammitic lithologies, respectively. Regional biotite grade metamorphism is common throughout the district. Auriferous veins have been affected by both regional deformation and metamorphism. In addition, locally developed shear deformation is superimposed on both veins and host rocks, in part, leading to mylonitic textures in some mineralized veins (e.g. Marker Vein).

Carbonatization, sulphidization and sericitization are the main alteration types recognized at the deposit. Carbonate alteration is dominated by calcite and ankerite with lesser dolomite and traces of siderite also present. Although the limits of alteration have not been defined, the limits of mineralization extend along strike more than 3 km.

Gold mineralization is primarily restricted to quartz veins, although low-grade gold values (~1 ppm) are known from some wall rock lithologies (both pelite and psammite). Associated sulphide minerals are arsenopyrite, pyrrhotite, galena, chalcopyite and pyrite with minor sphalerite. Carbonates, biotite, chlorite and minor muscovite are the dominant gangue minerals within the quartz veins.

5.1.3 Stratigraphy

Stratigraphic continuity is well documented throughout the entire underground mine workings. Stratabound quartz veins are also continuous (although thickness varies) throughout the district and may be used to designate relative stratigraphic position. Host rock types include interbedded greywackes and argillites with minor amounts of interbedded silty argillite and thin (1 - 3 cm) carbonate-rich dykes and sills. The current mine development is restricted to that stratigraphy between the Nugget and Marker veins (Fig. 13) although ore intersections have been encountered (primarily in quartz veins) both above and below these stratigraphic positions.

5.1.3.1 Greywacke

Blue-grey to grey massive greywacke beds have variable thickness from about 30 cm to greater than 5 m where beds are amalgamated. Primary sedimentary structures are frequently preserved at the base of sandstone beds and at gradational-to-sharp upper contacts of these beds. Detrital material is dominated by quartz with lesser amounts of plagioclase. Matrix materials are clay and white mica which generally define the foliation. Chloritization of the matrix is common. Disseminated carbonate is a dominant constituent of some beds.

5.1.3.2 Argillite

These strata display a variety of colour from light grey through grey blue to black. Corresponding mineralogy is also variable with differing amounts of quartz, muscovite, carbonate, chlorite and opaques (graphite, ilmenite, rutile and sulphides). Several foliations with different relative ages are well developed in the argillites. Euhedral carbonate and chlorite porphyroblasts overgrow early regional cleavage and are locally deformed by a younger shear foliation.

5.1.4 Structure

The Tangier gold district is located on the asymmetric Tangier anticline (Fig. 13b). Current underground development is restricted to the steep south-dipping limb. A north-south trending, vertical lamprophyre dyke crosscuts the anticline along the east end of the district. This dyke has been characterized by Chatterjee and Giles (1988) and Eberz *et al.* (1988).

Throughout the eastern Meguma zone a complex sequence of deformational events have been recognized (Table 1). Of these, an appreciation of two of the events is fundamental in order to evaluate the relative age relationships of the Tangier gold deposit. These are: (1) regional deformation (D_2) and (2) a younger overprint shear deformation (D_4). The first is overprinted by regional metamorphism while the latter deforms regional metamorphic porphyroblasts. Stretching of metamorphic minerals during D_4 deformation produces a vertical mineral lineation at Tangier, as well as most other districts. Within the Tangier mine all minor folds of quartz veins are developed during D_4 deformation and have an associated axial planar cleavage. No pure F_2 generation folds of quartz veins have been recognized. However, vein fold geometry is sympathetic with the regional fold pattern at this deposit. This factor has lead to much discussion regarding the relative age of the quartz veins (i.e. pre- or post-D_2 regional deformation).

5.1.5 Metamorphism

Metamorphic grade at Tangier is characterized by chlorite with trace amounts of biotite. Chlorite alteration of muscovite defining the regional foliation is common. Chlorite porphyroblasts overgrow regional cleavage but are in turn deformed by the D_4 shear deformation. Vertically stretched mineral aggregates produced during D_4 deformation consist of chlorite, carbonate, quartz and minor opaques. The stretching direction is parallel to that observed in the boudinaged quartz veins throughout the deposit.

5.1.6 Alteration

Pervasive alteration associated with Meguma type gold deposits was documented by Smith (1983) and Kontak and Smith (1987). They outlined extensive zones of silica, carbonate, sericite and sulphide enrichment within and surrounding the mineralization.

At Tangier, silicification with associated carbonate and sulphide enrichment are the dominant types of alteration. Intense silicification occurs adjacent to late-stage, N-S trending fault zones. Carbonate enrichment occurs as euhedral ankerite (with minor calcite) porphyroblasts throughout the argillites as thin dykes and sills in various host rock and as secondary carbonate infillings in quartz veins. The distribution of carbonate porphyroblasts is ubiquitous throughout the underground development. Sulphide alteration is characterized mainly by arsenopyrite and is best developed in the argillite beds at Tangier. Here, the sulphide locally constitutes up to 30% (by volume) of individual beds. This sulphide distribution is spatially associated with late stage *en echelon* or crosscutting quartz. The halo effect is best recognized in some raises and is extremely variable in widths. Where associated veins are stratabound, the sulphide-rich argillites have been mis-interpreted to represent primary sulphide enrichment resulting from sedimentation (e.g. Haynes 1987; Sangster 1987).

5.1.7 Quartz Veins

Numerous classifications and interpretations have been proposed for the quartz veins in the Meguma Group gold districts (e.g. Graves and Zentilli l979; Henderson *et al.* l986; Haynes l987). Recent detailed investigations (Kontak *et al.* l988; Smith and Kontak, l988a) have documented the relative and absolute age of the voluminous auriferous veins at the Beaver Dam gold deposit at *ca.* 370 Ma. Similar relative age sequences are observed from other gold districts in southeastern Nova Scotia, including Tangier.

Dominant vein types at Tangier include ribbon (approximately bedding concordant), *en echelon* (arrays at various angles depending upon the amount of deformation), stratabound (confined to a specific bed), discordant (crosscut bedding at various angles) and ac (perpendicular to fold axial plane). Of these, the two dominant sets are the ribbon and *en echelon* vein types with most of the mineralization occurring in ribbon-type veins (Fig. 14). At Tangier there is considerable textural variation in any particular quartz vein along strike and down dip. This is especially true of the three main veins (Marker, Twin, Nugget) exposed in the mine workings. This is portrayed mainly by the amounts of massive white quartz (*en echelon*) relative to the amount of ribbon-type (bedding parallel) quartz. An interpretation of these vein textures is suggested by Smith and Kontak (1988b). In general, where the veins are widest there is a predominance of massive white quartz and gold concentrations increase.

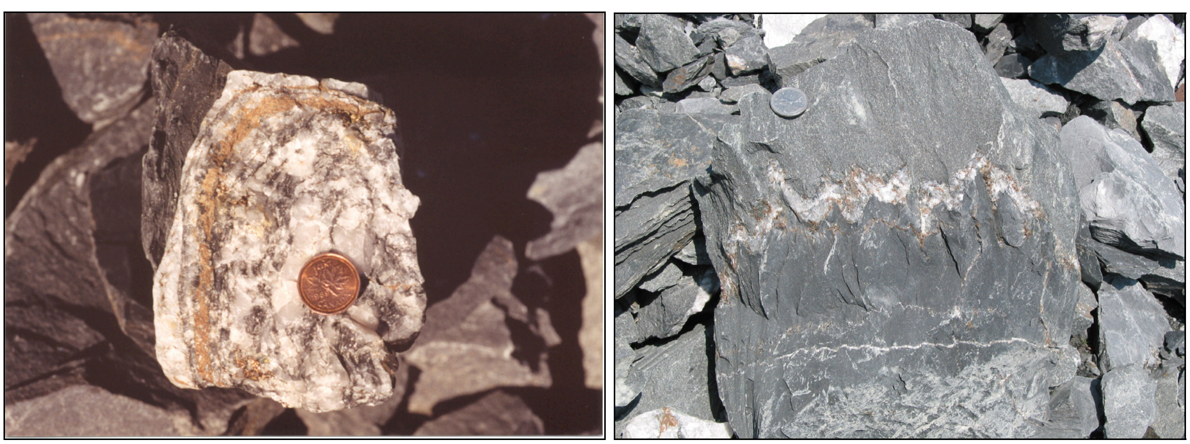


Figure 14. *Typical bedding parallel quartz-carbonate±sulphide veins from Tangier.*

5.1.8 Mineralization

Coarse grained (~1.0 mm) native gold mineralization (Fig. 15) at Tangier has euhedral shapes and is confined primarily within the quartz veins. In association with the coarse gold is a moderate amount (~20% of gold) of fine-grained gold (0.1 mm to 1.0 micron). These grains often occur on fluid inclusion planes and frequently are surrounded by fluid. Similar relationships are recognized at gold districts throughout eastern Nova Scotia as well as with other associated ore minerals (e.g. galena). In all cases gold can be demonstrated to be late in the paragenetic history. Mineralization appears to be confined but not restricted to relatively narrow ore shoots on the individual veins. The distribution of ore within the mine is open both to the east and west as well as at depth.

Associated sulphides include arsenopyrite, pyrrhotite and minor amounts of pyrite, marcasite, galena, chalcopyrite, sphalerite and minor bismuth-tellurium-sulphide complexes.

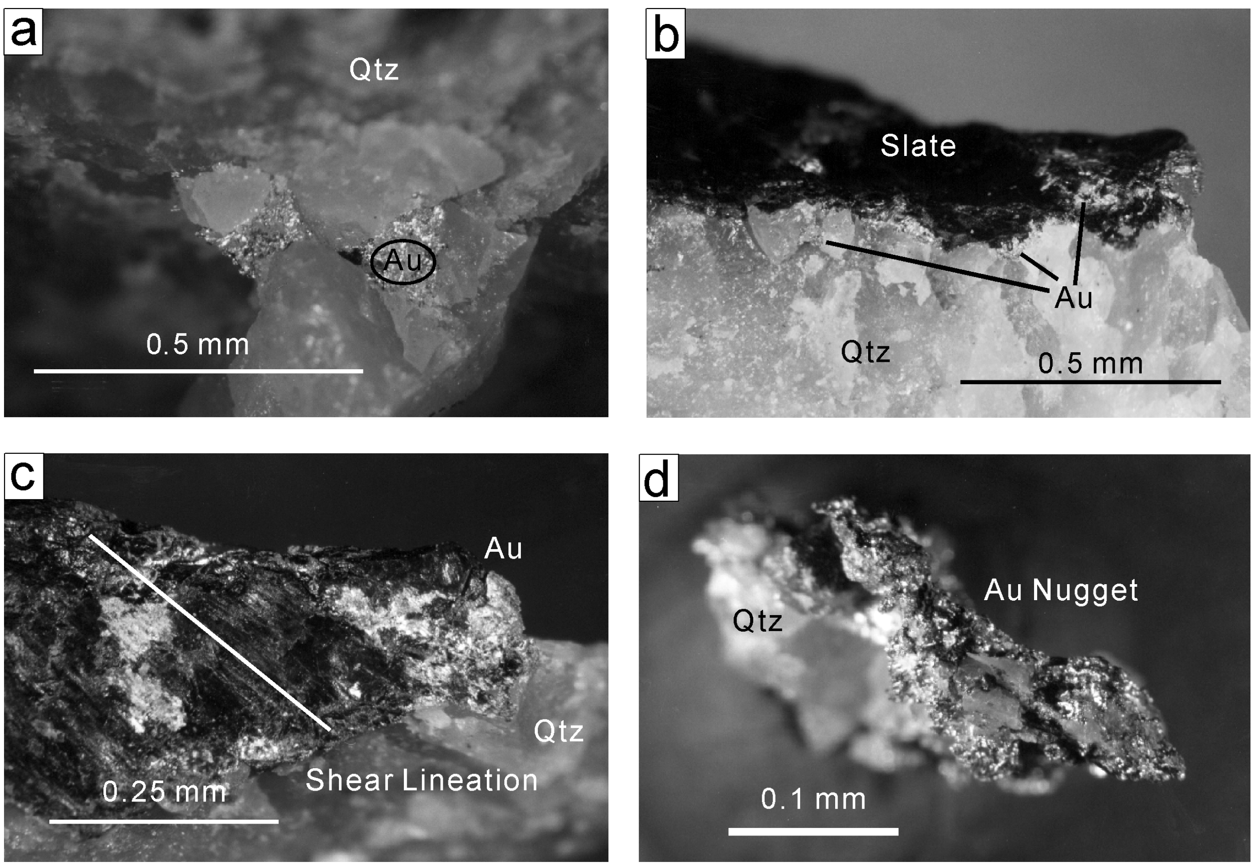


Figure 15. *A collection of gold grains from the Whin Vein at Tangier. (a) Gold observed along euhedral quartz grain boundaries, (b) gold at the slate-quartz boundary, (c) shear lineations in both slaty host rock and gold grain surfaces, and (d) delicate gold nugget with euhedral textures.*

5.1.9 Bedrock Geochemistry

Both major and trace element geochemistry have been completed on selected samples from the Blueberry Hill Mine at Tangier. Data for arsenic (Table 5) and mercury (Table 6) are shown below for the three dominant lithologies: meta-greywacke, slate and quartz vein. Consistent with underground and drill core observations, these data show that arsenic is enriched in all rock types, but is highest in the slaty lithologies (avg. = 608 ppm). Total modal arsenopyrite recovered from recent milling operations averaged ~2.5% by weight.

Table 5. *Bedrock geochemistry of selected samples for arsenic (As) at the Tangier gold deposit.*

Rock Type	n=	Minimum (As ppm)	Maximum (As ppm)	Average (As ppm)
Meta-greywacke	24	7.0	2000	471
Slate	18	13.0	5100	608
Quartz Vein	10	2.0	170	29

Data from the same samples suggest that bedrock mercury concentrations at Tangier are ~5 times more elevated than similar lithologies analysed from the western part of the Meguma Terrane (Smith, in press). However, these levels are still considered low, and typical of many other gold districts throughout the Meguma Terrane.

Table 6. *Bedrock geochemistry of selected samples for mercury (Hg) at the Tangier gold deposit.*

Rock Type	n=	Minimum (Hg ppb)	Maximum (Hg ppb)	Average (Hg ppb)
Meta-greywacke	24	12	28	17
Slate	18	10	24	18
Quartz Vein	10	12	24	19

5.1.10 Summary

A brief summation of critical points relative to the gold mineralization at the Tangier gold district is given below. Similar conclusions may be drawn from other gold districts in eastern Nova Scotia. They are as follows:

1. Economic gold mineralization is mainly confined to westerly plunging ore shoots in quartz veins regardless of their stratigraphic position.

2. The mineralization is spatially related to secondary, shear-related structures that are superimposed on the regional fold pattern. Folds may be related to either regional D_2 deformation or local D_4 shear deformation.

3. Silica, carbonate, sericite, chlorite and sulphides are the dominant alteration phase minerals.

4. Dominant N-S glaciation of the Tangier deposit has led to significant gold placer potential south of the district.

5.2 Surficial Geology

The surficial geology of the Tangier Gold District is characterized by the Quartzite Till of Stea and Fowler (1979). They describe the locally derived Quartzite Till as a bluish-greenish-grey, cobbly silt-sand till. The Quartzite Till is now referred to as the Beaver River Till, metagreywacke (or metasandstone) facies (Finck and Stea 1995).

Recent trenching within the Tangier Gold District has revealed that the Beaver River Till overlies the older Lawrencetown Till (Stea *et al.* in press). The Lawrencetown Till is characterized by its red color, finer silty matrix, geochemical signature, and allocthonous clasts derived from bedrock sources tens of kilometres to the north (Stea and Fowler 1979; Finck and Stea 1995). Stea *et al.* (in press) note striation measurements indicate the dominant ice flow direction is to the south-southeast (162–167^{o}) with an older set of striae (151^{o}) preserved within the bevelled facets of outcrops of metagreywacke (metasandstone). The preserved striae likely record movement associated with the Caledonia Phase while the dominant set of strations are part of an ice divide associated with the Scotian Phase (Stea and Finck 2001).

The potential of the Beaver River Till as an economic source of gold in the Tangier Gold District is currently being evaluated (Stea *et al.* in press). Gold grains recovered from 10 kg till samples and geochemical analysis of gold in till indicate the till is characterized by anomalous gold (Stea *et al.* in press). Anomalous gold in the heavy mineral concentrate (HMC) of till samples collected in the Tangier area was previously reported by Noranda (Dimmell 1983). Profile sampling of the till section indicates that only the local Beaver River Till is enriched in gold grains (up to 657 grains per sample) while the Lawrencetown Till is characterized by low levels of gold grains, between 4 and 7 grains per sample (Stea *et al.* in press).

The presence of abundant pristine and modified gold grains, the predominance of locally derived angular clasts, and the lack of striations on the clasts indicate the gold in the till is proximal to source and has probably been transported less than 500 m (Stea *et al.* in press). This is consistent with earlier work by Stea and Finck (2001) which suggests that extremely low renewal distances (0.2 km to 8.0 km) characterize the Beaver River Till.

6.0 Stop #2: SALMON RIVER / DUFFERIN GOLD DISTRICT

6.1 Bedrock Geology, Mineralization, and Geochemistry

6.1.1 Introduction

Much of the following documentation is taken from Horne and Jodrey (2001).

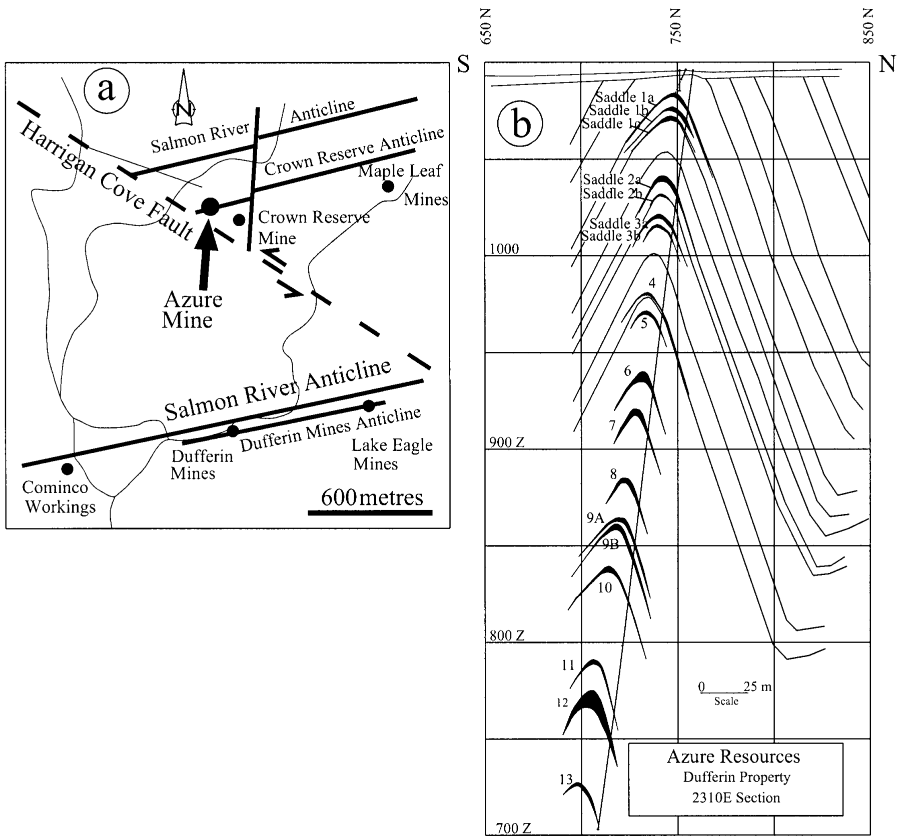


Figure 16. *Generalized location map of the Dufferin (Salmon River) gold district (a) showing the location of the Crown Reserve Mine that is faulted >1 km to the north along the Harrigan Cove Fault. A cross section of the Crown Reserve Anticline shows the generalized distribution of 13 saddle-reef zones defined by drilling.*

This report describes the geology of the Crown Reserve area Dufferin gold deposit currently being operated by Azure Resources Inc. The deposit is located approximately 8 km north of Port Dufferin and occurs in the hinge of the Crown Reserve Anticline (CRA), (Fig. 16). The CRA represents the faulted extension of the Dufferin Mines Anticline, where previous mining and exploration occurred, particularly at Dufferin Mines, where reported gold production was 41,901 oz. (Bates 1987). Previous mining on the CRA included minor development on the south limb of the fold at the Crown Reserve and Maple Leaf mines (Fig. 17). During the 1990s

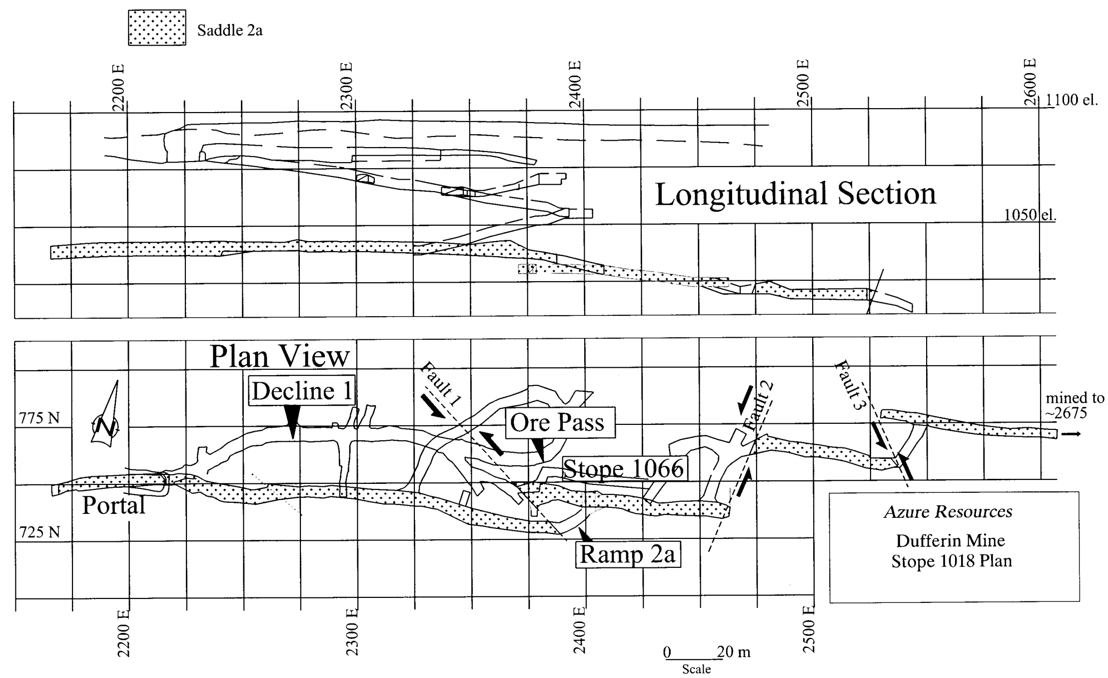


Figure 17. *Longitudinal and plan sections of partial underground workings at the Crown Reserve Mine. The stoped area of the #2 saddle-reef is indicated by the stippled pattern.*

Dufferin Resources completed further diamond-drilling which established approximately 700 m strike extension for the upper two saddle-reef veins, and potentially up to 13 saddle-reef zones as indicated by a single diamond-drill hole (Jacques Whitford and Associates 1993; Figs. 16b, 17). Underground exploration development of the deposit was started by Novagold Resources Inc., followed by further development by Enviro-gold Resources Inc. in late 2000-2002. Mine development has extended to the third saddle-reef vein with the majority of mining occurring on the second saddle-reef vein (Fig. 17). The operation was subsequently optioned to Azure Resources Inc. who continued mining the second saddle and extended the workings to the 4th saddle vein. Currently, the mill is being upgraded with floatation cells to increase gold recovery. The last ore processed through the mill for the 3rd and 4th saddles returned a grade of 7.4 g/t.

6.1.2 General Geology

Previous work has indicated that the Dufferin Mines and Crown Reserve anticlines represent the south fold of a pair of closely spaced anticlines (Fig. 16a), including the Salmon River Anticline, which define the hinge area of a regional-scale anticlinorium (Dawson 1899; Malcom 1929; Mitchell 1988). The character of the anticlinorium outside the gold mines has not been defined, and is represented by a single anticline trace on regional maps (Faribault 1897; Henderson 1986). Within the Dufferin Mines deposit (Fig. 16a) the Salmon River Anticline is described as more open than the Dufferin Mines Anticline, and the saddle vein system is apparently restricted to the southern fold (Dawson 1899). The Crown Reserve Anticline defines a tight (interlimb angle of ~47°; Fig. 16b) chevron-style fold that is steeply inclined to the south (Figs. 16b). The hinge zone of the fold typically defines a rounded arc-shaped structure approximately 5-10 m across and the limbs are uniform and straight. Variations noted in the hinge zone include local flat segments and minor M-shaped folds, where the flat segment has been folded into an open syncline. A well-developed axial planar cleavage occurs, consisting of a spaced (pressure solution) cleavage in meta-sandstone, and a fine continuous cleavage in meta-siltstone and slate. There is strong cleavage refraction, from a convergent pattern in meta-sandstone, with bedding cleavage angles of ~50°, to a divergent pattern in meta-siltstone and slate, where cleavage is commonly sub-parallel to bedding. Stratigraphy within the deposit consists predominantly of medium- to thickly-bedded meta-sandstone with lesser meta-siltstone and slate. A typical sedimentary sequence defines a fining-upward cycle of thick, massive meta-sandstone, gradationally overlain by laminated meta-siltstone, in turn overlain by black slate. An average cycle includes approximately 1 m of meta-sandstone, 5-10 cm of meta-siltstone, and l-2 cm of slate. Some cycles are almost exclusively meta-sandstone, with < 1cm of slate, whereas other cycles include over 1 m of meta-siltstone and slate. The northwest-trending Harrigan Cove Fault offsets the regional fold and vein system, with approximately 1.5 km of sinistral strike-slip separation (Fig. 16a). In addition, a significant amount of dip-slip displacement is suggested by the variance in separation of the trace of the Salmon River Anticline and the Dufferin Mines Anticline west of the fault and the Salmon River and Crown Reserve anticlines east of the fault (Fig. 16a). Three significant faults offset the Crown Reserve Anticline, and vein array, within the developed portion of the deposit. These faults are herein referred to, from west to east, as faults l, 2 and 3 (Fig. 17). Faults 1 and 3 trend northwest, parallel to the Harrigan Cove Fault, whereas fault 2 trends north-south. All three faults display oblique movement, with sinistral, east-side down displacement. The dip-slip displacement is less than the strike-slip displacement (compare plan and longitudinal sections, Fig. 17).

6.1.3 Structure and Vein Array

6.1.3.1 Introduction

The auriferous veins at the Dufferin gold deposit can be grouped into (l) saddle-reef veins, generally defining thickened *en echelon* stratabound veins in the fold hinge, and (2) leg reef veins, which represent the down-limb extension of saddle-reef veins. In addition, there are numerous discordant veins spatially associated with the saddle- and leg-reefs. The vein system is generally similar to those documented in Central Victoria, Australia (e.g. Chace 1949; Saniford and Kaeys 1986; Ramsay *et al.* 1998). Abundant evidence of bedding-parallel shear related to flexural folding occurs within the Dufferin gold deposit, recorded by minor structures within slate intervals, such as laminated bedding-parallel veins, *en echelon* shear veins and movement horizons.

6.1.3.2 Movement Horizons

Movement horizons typically consist of thin zones of grey-coloured fault gouge (clay) developed within slate horizons at the contact with overlying meta-sandstone beds (Fig. 18). The gouge is locally laminated and ranges from <l mm to ~2 cm thick. The thicker gouge zones locally host angular clasts, including quartz vein material. Striations are developed in the soft gouge, trending roughly perpendicular to the fold hinge. Movement horizons locally occur at the same stratigraphic horizon on both limbs of the fold, and can be traced across the hinge zone.

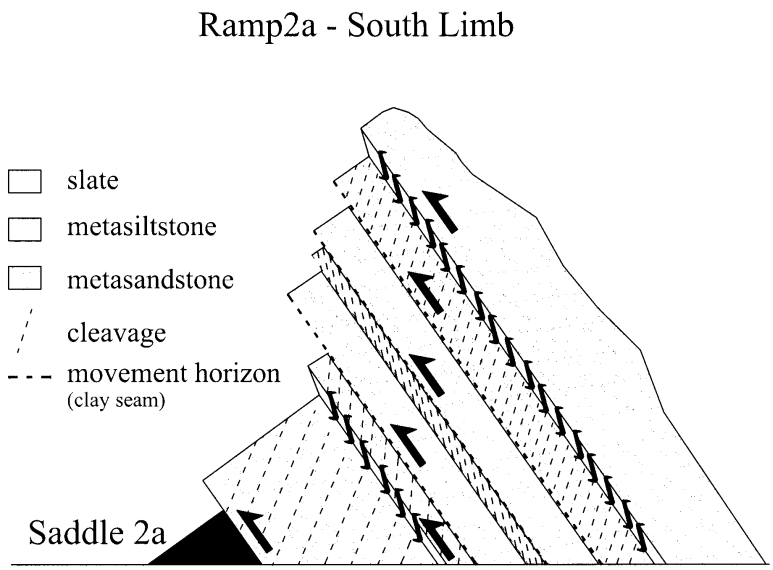


Figure 18. *A section of the south limb on saddle #2a showing the distribution of* en echelon *quartz veins and clay gouge movement horizons within slate beds between more massive meta-greywacke (metasandstone) beds.*

6.1.4 Laminated Veins

Bedding-parallel laminated quartz veins occur within slate beds at several horizons, and represent the leg-reef extensions of some saddle-reef veins. The origin of laminated veins within Meguma gold deposits, and elsewhere, has been the subject of much discussion (e.g. Chace 1949; Henderson *et al.* 1986, 1990; Tanner 1989; Jessell *et a1.* 1995; Fowler 1996). Our preliminary interpretation of laminated veins in the Crown Reserve area Dufferin gold deposit is that they represent incremental vein growth along bedding-parallel flexural-slip movement horizons. We base this on the following observations: (1) laminated veins represent leg reefs and, therefore, occur along horizons where high shear strains were required; (2) movement horizons occur within slate immediately adjacent to the veins; (3) striations occur on the surfaces between laminations within the vein. These striations are generally perpendicular to the fold hinge, although they vary between laminations, consistent with variations in slip vector between periods of vein growth. Movement horizons and striations could post-date vein formation; however, later slip would be expected to result in parallel striations on all laminations. A replacement origin for laminated veins was proposed for the central Victoria deposits by Chace (1949), who interpreted the laminations to represent the vestiges of sheared slate, including slickensides, along bedding-parallel faults. Underground observations are consistent with a replacement contribution for vein formation, noting the important concept is that vein emplacement occurred along active bedding parallel movement horizons.

6.1.5 *En Echelon* Veins

En echelon shear vein arrays are common in slate or meta-siltstone beds throughout the deposit, in many instances representing the down-limb extension of saddle-reef veins (i.e. leg-reefs). The formation of *en echelon* veins on the limbs of flexural folds is common (Fig. 19) and such veins have been described in the Meguma Group (Henderson *et al.* 1986). Veins initiated as extensional "gash" veins at low limb dips are rotated during progressive shear, initially shortened forming sigmoidal shapes, and later extended resulting in boudinage of the veins (Fig. 19). The ends of *en echelon* veins are "pegged" within meta-sandstone beds on both sides of host slate intervals. These pegs preserve the original geometric relationship with bedding, allowing for determination of the amount of shear strain recorded within the slate interval since vein formation. Locally, some veins show multiple generations of vein development. A reverse sense of shear is indicated for all *en echelon* shear veins, changing systematically across the fold hinge, and the vein-bedding intersection is parallel to the fold hinge, consistent with flexural shear perpendicular to the fold hinge. These observations clearly demonstrate a syn-folding origin for these veins.

Figure 19. En echelon *quartz veins on the south limb of the Crown Reserve Anticline adjacent to saddle-reef #1a.*

6.1.6 Saddle-reef Vein System

As outlined above, the vein system is dominated by saddle-reef veins and associated leg-reef veins. Thirteen saddle-reef zones, some consisting of two or three closely spaced saddle-reef veins, have been encountered in diamond drilling (Fig. 16b), and potential for more exists at depth. Three saddle-reef structures have been developed to-date, each of which is distinct in its geometry and makeup.

6.1.6.1 Saddle-reef #1

Saddle-reef I includes three individual saddle-reef veins with associated leg-reefs, referred to, from the structurally highest, as saddle-reef 1a, 1b and 1c (Figs. 16b, 20). Due to the close proximity of the saddle-reef veins, only saddle-reef #la was mined, although development work has locally exposed all three saddle-reefs. Saddle-reef #la (Fig. 21) is asymmetric with respect to the fold, defining a crescent-shaped vein extending from the fold hinge down the north limb (Fig. 20). The maximum thickness is 1.3 m. The saddle-reef vein is composite, consisting of mainly massive (locally vuggy), quartz with laminated quartz occurring at the margins (Fig. 20). The saddle-reef progressively tapers down the north limb and, within approximately 10 m, is represented by a thin (-6 cm) laminated bedding-parallel vein and minor *en echelon* veins (Fig. 20). On the south limb, the saddle-reef is represented by a laminated vein starting at the fold

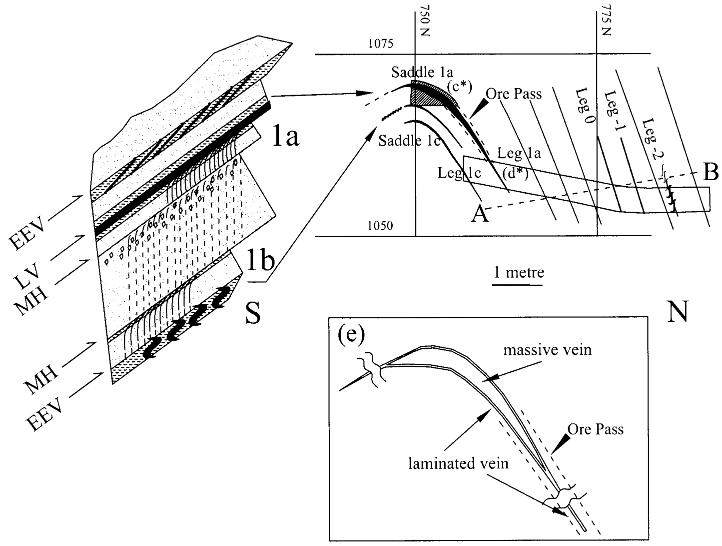


Figure 20. *Fold geometry of saddle #1a, b and c and the leg-reefs of stratigraphically higher saddle-reefs (ie., Leg 0, -1, -2). The location of* en echelon *(EEV) veins, laminated veins (LV) and movement horizons (MH) are shown in the enlargement. The relative distribution of laminated and massive quartz are shown in (e).*

hinge. The massive quartz invariably crosscuts the laminated vein, suggesting a history of laminated vein formation followed by emplacement of massive quartz. Movement horizons occur at the hanging wall contact of the vein and a significant shear zone, including *en echelon* veins and movement horizons, is locally developed in the hanging wall of the south limb. Some movement horizons on the south limb are defined by l-2 cm thick zones of fault gouge (clay) with angular quartz clasts. This shear zone and related *en echelon* veins may be analogous to the "leather jacket" structures defined in the Victoria deposits of Australia (Baragwanath 1953; Hodgson 1989). Significant arsenopyrite (a few percent) occurs as coarse crystals and clots within the vein and is disseminated throughout the adjacent wall rock. Saddle-reef #lb is locally

Figure 21. *Photo of saddle-reef #1a looking east. Note the miner on the left of the photo for scale.*

exposed and is relatively thin (max. 20 cm). The leg-reef on the south limb consists of *en echelon* shear veins right up to the hinge zone. Saddle-reef #lc is locally exposed in a crosscut. This saddle-reef is similar to saddle-reef la in size and geometry: it has a maximum thickness of approximately 1 m and is asymmetric, defining a crescent-shaped structure which extents from the hinge down the north limb. Laminated veins occur at the margins of the predominantly massive quartz saddle-reef vein. On the north limb, the leg-reef vein is defined by a massive, bedding-parallel vein and adjacent *en echelon* shear veins. Saddle-reef veins #la, lb and lc occur within slate intervals and their leg-reefs are interpreted to represent flexural shear structures. Abundant evidence of flexural shear is found in slate horizons adjacent to the leg-reefs of these saddle-reefs (Figs. 20). The leg-reefs of saddle-reefs #1a and #1c are observed at significant distance down the north limb (exposed at the-1060 level and the 1020 level), represented by laminated bedding-parallel veins and (or) *en echelon* shear veins.

6.1.6.2 Saddle-reef #2

Saddle-reef #2 includes two saddle-reef veins, referred to as #2a and #2b. Saddle-reef #2a is larger and was mined for approximately 500 m along strike (Fig. 22). Exposures of saddle-reef 2b are restricted to the leg-reefs. Saddle-reef #2a is large, measuring approximately 4+ m in height and 4+ m across the base (e.g. Fig. 22). The saddle-reef vein consists mainly of massive quartz with variable amounts of slate inclusions. The general shape is triangular, being defined in general by bedding. However, this saddle-reef is also strongly asymmetric, with a thick leg-reef extending down the north limb, whereas only a minor leg-reef extends down the south limb. The saddle-reef occurs within a slate - meta-siltstone interval, commonly with black slate in the hanging wall of the vein and a distinct laminated meta-siltstone in the footwall. *En echelon* shear veins invariably occur in the hanging wall slate on the north limb and locally define the south limb of the saddle-reef. The saddle-reef is variable in character and geometry along strike, most notably in the amount of slate wall rock. In general, the amount of quartz progressively decreases to the east turning into a series of closely spaced, amalgamated, strongly sheared *en echelon* veins (Fig. 22). The geometry of the individual *en echelon* veins is evident, defined by horizontal pegs and vertical (sheared) segments separated by septa of slate wall rock. A series of smaller scale *en echelon* veins occurs in the hanging wall of the north limb, consistent with this saddle-reef elsewhere. Note a zone of vertical, boudinaged (*en echelon*?) veins in the top centre of the saddle-reef zone (Leg-reef #2a). Mining of the north limb of saddle-reef #2a has provided good exposure of the north leg-reef of this saddle-reef. The leg-reef tapers from about 2 m thickness at the base of the saddle-reef to 10-20 cm at a distance of approximately 7 m down the limb. The leg-reef consists of a massive, coarsely laminated (widely spaced slate? bands parallel the vein margin), bedding-parallel quartz vein with a zone of *en echelon* shear veins in the hanging wall, similar to the main saddle-reef vein. The *en echelon* veins are strongly boudinaged, reflecting high shear strain. Discordant veins are abundant in the footwall of the saddle and leg-reef; however, they do not cross-cut the latter or occur in the hanging wall. Arsenopyrite is common (few percent) within the vein and wall rock. Coarse gold is common and is generally associated with galena in the leg-reef (Leg-reef #2b). Saddle-reef #2b is not exposed, although both the north and south leg-reefs of this saddle-reef are exposed in the ramp at an elevation of 1016 m. These legs reefs are variable in character, and include laminated bedding-parallel veins, massive bedding-parallel quartz veins, and *en echelon* shear veins. Exposure of the south leg-reef on the east wall of the ramp is particularly notable, consisting of a wide zone (approximately 1 m) of closely spaced (amalgamated) and boudinaged *en echelon* shear veins.

Figure 22. *Auriferous saddle-reef #2a showing its massive nature in the fold hinge (left) and its* en echelon *nature to the east (right) where the ore grade diminished dramatically.*

6.1.6.3 Saddle-reef #3

Exposure of the third saddle-reef structure has only limited development. Diamond drilling suggests there are two saddle-reef veins, #3a and #3b (Fig. 16b). However, only one, presumed to be #3a, is exposed and described here. The hinge zone at saddle-reef #3a defines a broad open arch structure and the saddle-reef vein occurs within a meta-siltstone - slate interval, with the vein typically hosted by black slate. Saddle-reef #3a displays asymmetry similar to saddle-reef 1 and 2, with the thickest part of the vein on the north limb. The saddle-reef is about 40 cm thick at the hinge, where it locally bifurcates, and thickens slightly on the north limb to approximately 50 cm. Extension down the north limb is not exposed but it is presumed to maintain this thickness for some distance based on comparison with other saddle-reef veins. The saddle-reef thins quickly to the south, where it consists of a laminated vein. The saddle-reef vein includes a laminated vein, which displays some buckling, along the vein margin, with massive quartz forming the bulk of the vein. Arsenopyrite is very abundant, occurring as disseminated crystals and massive clots within the vein and disseminated throughout the wall rock.

6.1.7 Development of Saddle-reef Veins

Formation of saddle-reefs, leg-reefs and related veins in chevron folds is well understood; such veins are associated with structures related to flexural-shear on the limbs and associated hinge zone dilation (e.g. Chace 1949; Ramsay 1974; Hodgson 1989). Saddle-reef veins are often considered in isolation, particularly in discussion of saddle-reef deposits. Additionally, the saddle-reef model is generally presented in the simplest of forms, with development of a triangular void in the hinge of an upright fold, which has experienced a simple history of amplification without hinge migration (Ramsay 1974). However, fold histories are generally not simple and several structures are known to result from the development of chevron folds simultaneous with classic saddle-reef voids (e.g. Chace 1949; Ramsay 1974; Tanner 1989). Precipitation of quartz in these various structures results in a family of saddle-reef and related veins. The structure and vein system at the Dufferin gold deposit is readily explained in a flexural-folding, saddle-reef environment. Movement horizons, laminated veins and *en echelon* veins are pervasive features, occurring within most slate intervals, and display a movement direction and shear sense consistent with flexural folding. Leg-reef veins in particular, are clearly associated with structures resulting from flexural folding and display evidence of syn-folding emplacement (e.g. *en echelon* shear veins), and a clear connection exists between leg-reefs and saddle-reefs. The various veins occur along common structures and vein relationships suggest synchronous emplacement of all veins. Laminated veins are invariably cut by massive veins, consistent with laminated veins recording the initial shear preceding development of dilational structures filled by massive quartz. The high shear strains recorded by *en echelon* veins imply that these structures record significant fold amplification. However, shear strain is focused within thin slate layers and large shear strains occur for small changes of limb dip when initial limb dips are high (Ramsay 1974). Therefore, the shear strain recorded by *en echelon* veins could reflect a small increment of fold tightening late in the fold history (cf. Horne and Culshaw 200l). Although the saddle-reef veins represent thickened reefs in the hinge zone, they display characteristics that vary from a simplistic saddle-reef model. Two notable differences include (l) the asymmetry of saddle-reef veins and (2) the significant contribution of *en echelon* veins to saddle-reef veins.

6.1.8 *En Echelon* Saddle-reef Veins

En-echelon veins are common within the deposit and it has been noted that saddle-reef veins are, at least locally, composed largely of *en echelon* veins. Saddle-reef #2a, in particular, is locally dominated by large *en echelon* veins that display a sense of shear consistent with flexural shear on the north limb (e.g. Fig. 18). The dominance of *en echelon* veins in the hinge zone indicates that much of the volume recorded by the veins results from shear, in contrast to saddle-reef voids, and that flexural-shear on the limbs extended into the hinge zone. Tanner (1989) and Ramsay (1974) illustrate extension of flexural-slip movement horizons with associated *en echelon* veins into, and across, the fold hinge along hinge thrusts and the spur veins and leather jacket vein arrays in the Australian deposits reflect bedding-parallel faults which extend beyond the hinge, locally connecting with bedding-parallel movement horizons in adjacent folds (Hodgson 1989). Development of these structures may reflect "accommodation structures" resulting from variation in thickness of competent layers (Ramsay 1974) or formation of conjugate faults accommodating post-folding shortening. However, the saddle-reef veins within the deposit are generally stratabound and there is no clear evidence of cross-cuffing thrusts in the hinge zone. Indeed, the *en echelon* veins in the hinge do not pass the fold hinge and, furthermore, the *en echelon* veins in the hinge (saddle-reef) are an extension of those on the limb (leg-reef). The thick zone of *en echelon* veins in the hinge region may simply reflect thickening of the slate layers in the hinge zone, typical of chevron folds (Ramsay 1974). Flexural shear strain is restricted to slate horizons. Therefore, as slate layers hosting *en echelon* veins thicken towards the hinge zone, the size of the *en echelon* veins increases accordingly.

6.1.9 Saddle-reef Asymmetry

As outlined above, the saddle-reef veins have a pronounced asymmetry, with saddle-reef development mainly in the hinge and north limb of the fold. Although similar asymmetry was noted in Australian deposits (Chace 1949), no explanation was provided. For saddle-reef #2a, where *en echelon* veins are an important component, the asymmetry may simply reflect variance in the shear strain between limbs. This variance in shear could reflect variance in limb length and (or) limb dip; the north limb is both shorter and steeper than the south limb. However, this is not apparent for saddle-reefs #1 or #3, where the proportion of *en echelon* veins is less apparent. The massive and vuggy quartz that constitutes the saddle-reef is interpreted to have formed within structurally developed dilation zones and, therefore, saddle-reef asymmetry is a question of asymmetric dilation.

Asymmetry of the saddle-reefs may also reflect profile shape changes of the fold during fold development. Fowler and Winsor (1996) present several potential shape changes based on experimental modeling of chevron fold development and evaluation of profiles of several chevron folds hosting saddle-reef vein systems. They have shown that vertical dilation in the flat segment of a box fold results from limb steeping. Saddle-reefs formed in this environment could be transformed onto a limb by fusion of the median segment of the box fold with a limb. This explanation is not supported by the *en echelon* veins in the hanging wall of the saddle-reef, which show opposite sense of shear on either side of the existing fold hinge. However, these veins may record the late shear associated with box fold to chevron transition. The contribution of profile shape change during folding to the asymmetry of the saddle will be better understood with exposure of additional saddle (fold hinges) at depth.

6.1.10 Comparison with Central Victoria

The vein system of the EnviroGold Dufferin deposit is similar to saddle-reef deposits of central Victoria, Australia. Chace (1949) described the Australian vein systems as including saddle-reefs, leg-reefs, neck-reefs and spurs associated with bedding-parallel faults, dilation in the hinge, and dilations associated with faults. The veins are composed of massive and laminated quartz, quartz breccia and brecciated quartz, and the distribution of laminated and massive quartz is similar to the Dufferin deposit: laminated quartz is restricted to leg- reefs and the margins of saddle-reefs. *En echelon* veins, referred to as "leather jackets" in Australia, are documented along limb thrusts associated with the saddle-reef veins (Baragwanath 1953).

6.1.11 Age of Veins

$^{40}Ar/^{39}Ar$ ages of 388 Ma and 403 Ma, obtained for slate within and adjacent to veins in the portal area of the Dufferin deposit, have been interpreted to reflect metamorphism (Kontak *et al.* 1998). No isotopic dating of the veins has been attempted. However, $^{40}Ar/^{39}Ar$ ages for vein minerals in other Meguma gold deposits of *ca.* 370 Ma are consistently younger than $^{40}Ar/^{39}Ar$ ages for whole-rock samples from the same deposits, which record metamorphism (Kontak *et al.* 1998). This has been interpreted to indicate a post-metamorphic age for vein emplacement (Kontak *et al.* 1998). Horne and Culshaw (2001) also proposed a post-metamorphic age for vein emplacement, which they relate to a late, flexural-slip re-activation of earlier flexural-flow folding. Several features support a late-folding age for vein emplacement at the Dufferin deposit. Saddle-reefs only develop after significant limb amplification, and formation of flexural shear and saddle-reef structures is accelerated with shortening (Ramsay 1974). The maturity and pronounced development of the saddles suggest significant fold development at the time of vein emplacement. Flexural shear structures are largely brittle (en-echelon gash veins, movement horizons) and clearly deform fold-related cleavage.

6.1.12 Distribution of Gold

Gold was not often noted in the mine and relatively few analytical data are available; thus, the distribution of gold within the deposit is not well understood. However, the following observations can be made. Gold (i.e. either visible gold or assay results) has been detected within all vein types, including saddle-reef, laminated leg-reef, *en echelon* and discordant veins. This is consistent with the interpretation of synchronous formation of all veins. The most consistent, and abundant, visible gold was noted in the north leg of saddle-reef #2a, where it commonly occurs near slate septa within the vein. Throughout the deposit there is an apparent positive correlation between visible gold and galena (gold generally occurs within a few centimetres of galena and locally gold decorates galena). Sphalerite is also common near gold in some samples, although less recognizable in the mine. Gold is found decorating arsenopyrite; however, the abundance of arsenopyrite offers no apparent guide to concentrations of gold. Arsenopyrite is common to abundant within all vein types and is disseminated in the adjacent wall rock as a zone of wall rock alteration. Low gold levels occur in wall rock adjacent to veins.

6.2 Surficial Geology and Geochemistry

The Dufferin Gold District is characterized by quartzite till and slate till and sporadic drumlins of Lawrencetown Till (Stea and Fowler 1979). The Quartzite Till and the Slate Till are now referred to as the Beaver River Till, metagreywacke (or metasandstone) and slate facies, respectively (Finck and Stea 1995). The Beaver River Till is relatively thin within the District averaging, generally, <5 m thick. The thickness of the till is based upon the frequency of outcrop occurrences coupled with depth to bedrock information in diamond drilling logs.

Drumlins can attain thicknesses in the order of 20 m to 30 m thick (Finck and Stea 1995). Stea and Fowler (1979) indicate the drumlins in the Dufferin Gold District are characterized by Lawrencetown Till. Mitchell (1987), however, describes the matrix of the drumlins as “the same quartzite till which covers most of the property”. Mitchell (1987) also indicates that there is less

Slate Till in the area than shown in published maps and that the till is spatially associated with synclines cored by Halifax Formation slate.

Glacial striae recorded on metasandstone outcrops exposed during trenching indicate one ice flow direction to 170° and that the overlying till was the locally derived “quartzite till” (Mitchell 1988). Mitchell (1988) also describes the presence of two drumlins on the property trending 170° +/- 5°. Mallinson (1988) describes the results of till fabric analysis from two trenches indicating glacial ice moved southeasterly (125°) and easterly (063°), inconsistent with published maps for the area (Stea and Fowler 1979; Stea *et al.* 1992). He explained this discrepancy due to the presence of a “melt out” variety of till where the direction of movement would be controlled by topography. If this is indeed the correct explanation, it implies the ice must have been relatively thin in order to be “controlled” by the topography.

6.3 Mining and Milling History

Highlights of the mining and milling history of the Salmon River / Dufferin gold district are shown in Table 7. Most of this information has been summarized from Malcolm (1929), and from assessment reports written in the late 1980s (Graham 1987b; Mitchell 1988). Gold was first reported in the Salmon River area in 1868, but mining of lode quartz veins did not begin until 1880. Throughout the history of this district, mining and milling of ore has occurred at four main locations, although there have been quartz veins worked to various degrees in many other parts of the district. The earliest operations were located directly adjacent to the Salmon River itself, where a 20-stamp water-powered mill was erected in 1881. In 1882, a 4-inch lead was discovered on the western shore of Eagle Lake (Fig. 23), and a small 8-stamp mill was transported from the Issacs Harbour gold district to process this ore. From 1883 to 1887, there was extensive mining at the Dufferin mine, and the ore was transported to the original stamp mill on the river via a half-mile long tramway (shown on Fig. 23). Gold recovery was completed by amalgamation with mercury (Fig. 24). In 1890, a new 20-stamp mill was constructed adjacent to the Salmon River (Fig. 23), and in 1898 a new 30-stamp mill was erected near the Dufferin mine (eventually expanded to 60 stamps in 1899). Both mills constructed in the 1890s contained concentrating devices to remove sulphide minerals from the tailings (MacDonald 1899). In 1903, and again in the 1930s, attempts were made to recover gold from the concentrates and/or tailings using cyanidation. The earlier operations extracted roughly 75% of the gold from stockpiled arsenopyrite concentrates, but later operations on tailings from the riverbed met with limited success (Roach 1940).

From the 1930s to the early 1980s, there was only minor exploration activity in the Dufferin area. Discovery of saddle-reef quartz veins in the hinge area of the Crown Reserve Anticline in the late 1980s led to the development of a 200-ton-per-day conventional gravity mill in the Crown Reserve area in 1990. Between 1990 and 2002, approximately 50,000 tons of gravity tailings were deposited in a tailings impoundment immediately north of the mill. The present owner, Azure Resources Inc., is currently installing a floatation circuit at the mill and plans to re-process the tailings for their gold content (Azure Resources Inc. 2005).

Table 7. *Highlights of mining and milling history, Salmon River / Dufferin Gold District*

Date	Event
1868	First reported discovery of gold at Salmon River
1880	Discovery of lode quartz vein 30–40 inches wide; 100 tons of quartz mined and milled in Harrigan Cove; first identification of saddle-reef quartz veins
1881	20-stamp, water-powered mill erected along Salmon River
1882	Original mill increased to 30 stamps; 8-stamp mill transported from Dung Cove (Isaacs Harbour gold district) and used to process ore near Eagle Lake
1883–1887	Extensive mining at Dufferin Mine—ore was transported to the mill (38-stamps by 1887) via a half-mile-long tramway; power for pumping and hoisting was transmitted from the Salmon River 3/4 of a mile by a system of pulleys and ropes
1890–1894	Dufferin Gold Mining Company constructs new 20-stamp mill in the vicinity of the original mill along the Salmon River
1898	Montreal-London Gold and Silver Development Co., Ltd. erects a 30-stamp, steam-powered mill adjacent to the Dufferin Mine, with 3 sets of hydrometric sizers and 15 Frue vanners to extract sulphide concentrates from the tailings
1899	Stamp mill expanded to 60 stamps, 8 additional Frue vanners installed
1903	Bromo-cyanide plant used to treat old sulphide concentrates from the Dufferin mill—treatment of 44 tons yielded a gold extraction efficiency of ~75%
1934–1935	Salmon River Gold Syndicate extracts tailings from the bed of the Salmon River for re-treatment using amalgamation; in 1934, the results are unsatisfactory, and large losses of mercury are reported; in 1935, the tailings are treated using a ball mill, concentrating tables, and blankets, and concentrates are stored for shipment
1985–1989	Extensive surface and diamond-drill exploration on the old Dufferin mine and its faulted extension, the Crown Reserve, leads to the discovery of saddle-reef veins in the hinge area of the Crown Reserve Anticline
1990–1991	NovaGold conducts underground development to first saddle (Crown Reserve), and constructs 200-ton-per-day conventional gravity mill
2000–2002	Envirogold continues minor surface work and underground development to the face of the Third Saddle; 55,000 tonnes mined and milled during this period
2003–present	Azure Resources (www.azureresources.com) continues underground development on 1st, 2nd, 3rd, and 4th saddles; refurbishes old gravity mill and increases its capacity to 400 tonnes/day; presently installing flotation circuit

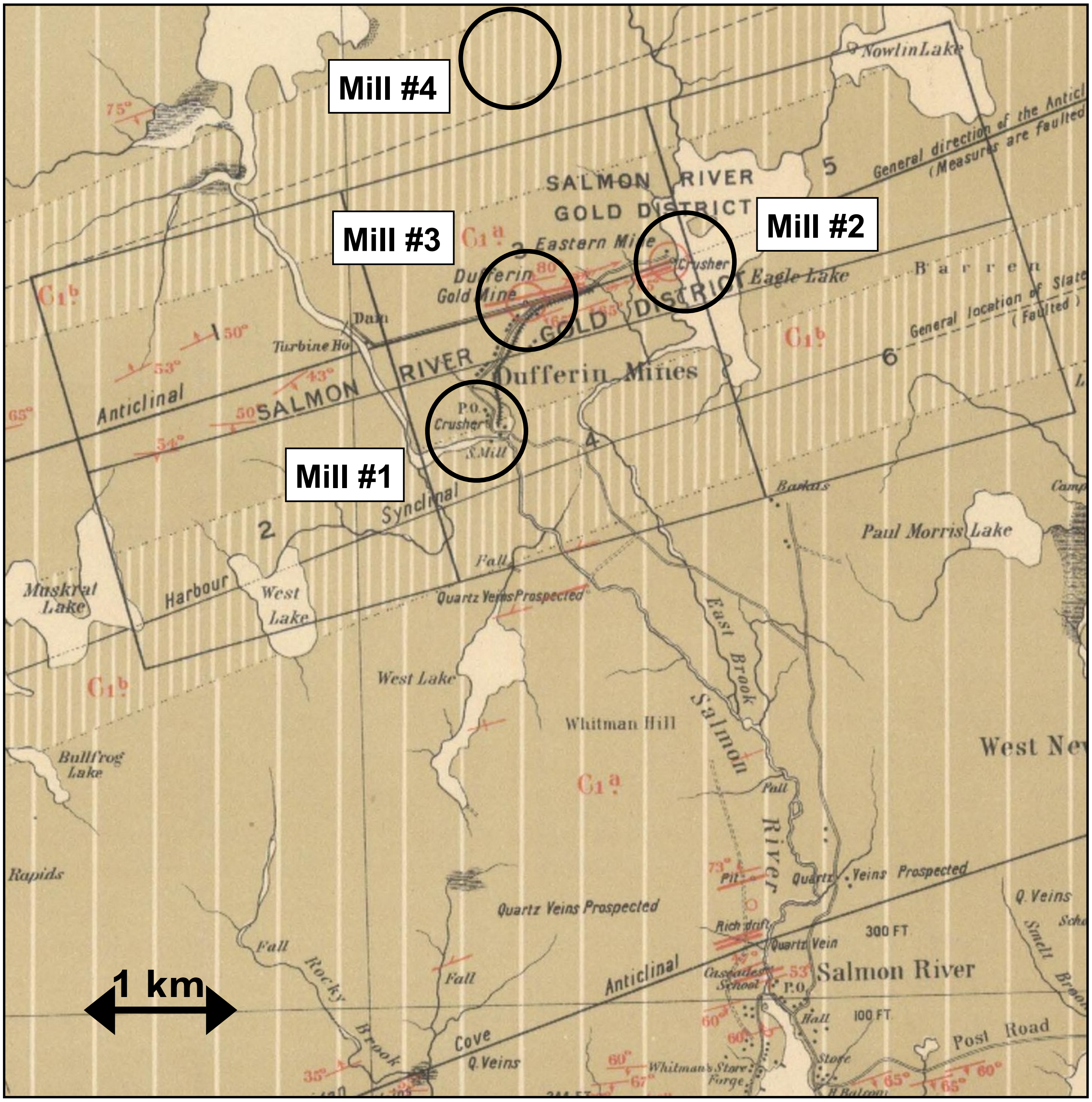


Figure 23. *Overview map of the Salmon River Gold District in 1897. The location of four stamp mill sites are circled: (1) 20/30-stamp mills along Salmon River (originally constructed in 1881); (2) 8-stamp mill on Eagle Lake (erected in 1882); (3) 60-stamp mill adjacent to the Dufferin Mine (built in 1898–99); and, (4) gravity mill at the Crown Reserve Mine (constructed in 1990). Tailings are present near each of these mill sites, and on the bed and banks of the Salmon River for a distance of at least 1 km downstream of Mill #1 (basemap from Faribault, 1897; additional detail is given in Faribault, 1898).*

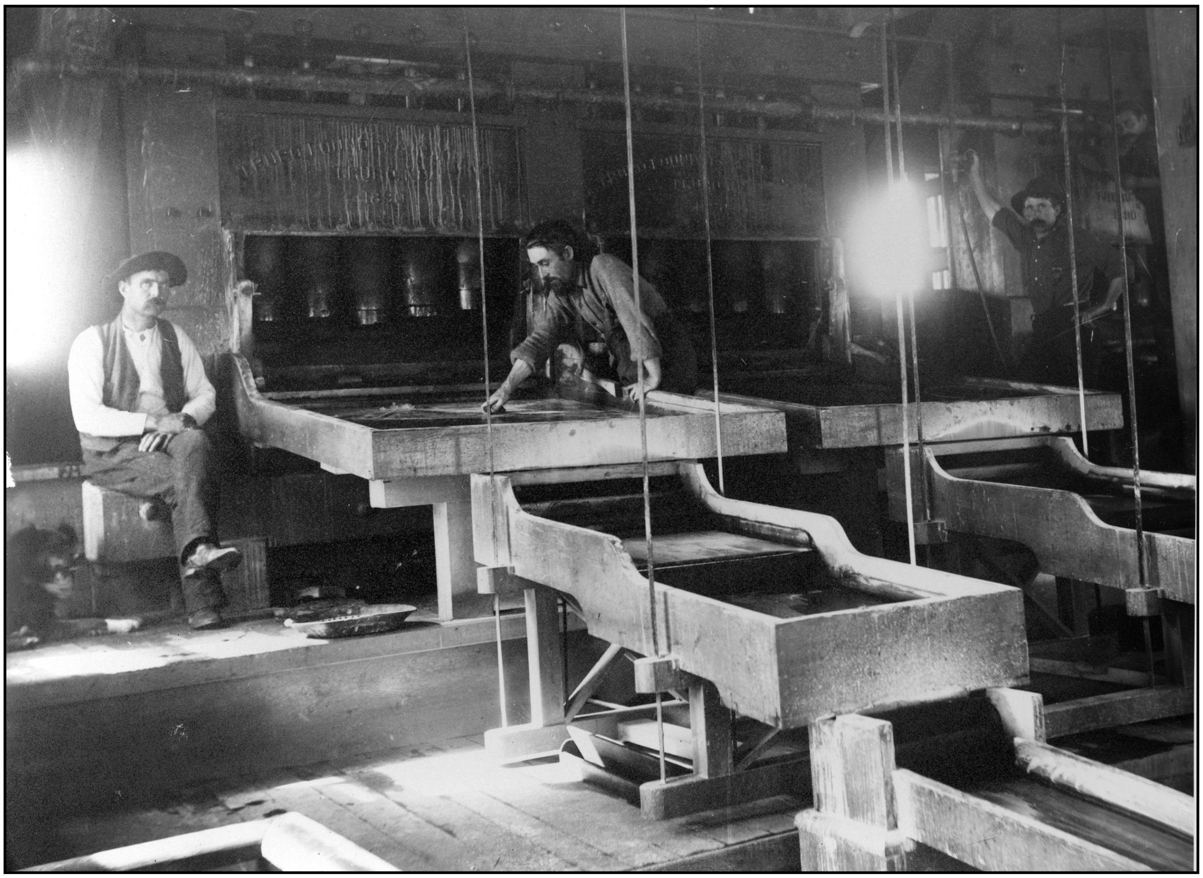


Figure 24. *Recovery of mercury amalgam from copper-plated amalgam tables in the 20-stamp mill, Dufferin Gold Mine, Salmon River, Nova Scotia, 1893. The suspended shaking tables below the amalgam plates were used to recover sulphide concentrates. Tailings from each table were discharged from the mill via a wooden trough. Photo taken by E.R. Faribault, Geological Survey of Canada. Reproduced with permission from the Earth Sciences Sector Photo Library Collection, Natural Resources Canada, Ottawa.*

6.4 Environmental Geochemistry: Bedrock, Surficial Materials, Mine Wastes and Waters

In support of ongoing MITE investigations, mean Hg and As data for humus, soil, till, and bedrock from the Salmon River / Dufferin Gold District have been compiled from exploration company assessment files and are summarized in Tables 8 and 9, respectively. Tables 8 and 9 also summarize mean Hg and As results (<2000 microns) from limited humus, soil, and till samples collected during the 2003 field season as part of the MITE Program.

Table 8. *Compiled mean Hg results for various sample media, Dufferin Gold District.*

Mean Hg (ppb)	n =	Media	Size Fraction	Reference
330	620	soil	<180 microns	Jagodits and Walker (1974)
750	52	rock	<75 microns	Mitchell (1988)
440	4	humus	<2000 microns	MITE 2004 (unpublished)
170	4	soil	<2000 microns	MITE 2004 (unpublished)
94	4	till	<2000 microns	MITE 2004 (unpublished)

Table 9. *Compiled mean As results for various sample media, Dufferin Gold District.*

Mean As (ppm)	n =	Media	Size Fraction	Reference
150	620	soil	<180 microns	Jagodits and Walker (1974)
35	418	soil	<180 microns	Mitchell (1988)
750	52	rock	<75 microns	Mitchell (1988)
150	62	rock	<75 microns	Mallinson (1988)
16	39	till	<1700 microns	Mallinson (1988)
17	4	humus	<2000 microns	MITE 2004 (unpublished)
160	4	soil	<2000 microns	MITE 2004 (unpublished)
140	4	till	<2000 microns	MITE 2004 (unpublished)

For details regarding the sample collection, preparation, digestion, and analytical methodologies as well as Quality Control/Quality Assurance (QA/QC) protocols, the reader is encouraged to refer to the reference(s) cited for a specific survey. A summary of the sample collection procedures employed in 2003 is provided in Goodwin *et al.* (2004).

The quality of the 1974 soil data is unknown. Like statistical data presented earlier, the mean is strongly influenced by the uppermost values. Similarly, the highest Hg in rock concentrations of >5000 ppb reported by Mitchell (1988) were re-visited as part of the MITE 2003 field season. Results of the 2003 rock-sampling program failed to confirm the presence of high Hg (>5000 ppb) reported by Mitchell (1988) in the area of the Maple Leaf Shaft. In fact, all Hg values for the 2003 re-sampling program reported results between 23 ppb and 68 ppb Hg. The 2003 rock samples were highly mineralized, as were those reported by Mitchell (1988), with Au up to 3300 ppb and As up to 27,150 ppm.

Tailings and surface water samples were collected during reconnaissance-scale fieldwork from August 26–27, 2003. Sampling was carried out in the vicinity of the original 1880s/1890s-era stamp mills along the Salmon River (Mill #1, Fig. 23), and in a small drainage basin immediately south of the main Dufferin mine where a 30/60-stamp mill operated from 1898–1904 (Mill #3, Fig. 23). At both locations, the tailings are very overgrown, generally saturated with water (Fig. 25a), and their full spatial extent is difficult to determine. Sampling pits excavated in the tailings at both locations revealed well-oxidized horizons up to 50 cm thick overlying grey, unoxidized tailings. Both mill sites also contain piles of bright-green scorodite-bearing waste, some of which appears to have formed in-situ from weathering of arsenopyrite-rich tailings/concentrates, and some of which appears to be a by-product of concentrate roasting operations (Fig. 25b). Riverbank samples collected nearly one kilometer south of Mill site #1 (Fig. 23) confirmed the presence of tailings on the banks of the Salmon River.

The concentrations of Hg and As in tailings and surface waters near the original Salmon River mill site (Mill #1, Fig. 23), and near the 30/60-stamp mill adjacent to the Dufferin Mine (Mill #3, Fig. 23) are shown in figures 26a, b and 27a, b, respectively. The total concentrations of Hg and As in the tailings shown on these maps represent the maximum concentrations measured in the subsamples collected at each site. In general, the highest metal(loid) concentrations occur closest to the mill sites; however, the tailings are heterogeneous and there is no clear trend of decreasing concentration with increasing distance from the mills. The variation in metal(loid) concentrations in the tailings could be the result of many factors, including changes in the composition of the ore over time, changes in milling procedures, and remobilization of Hg and As during weathering reactions. The ranges in total Hg near Mill #1 and Mill #3 are 630–13,000 ppb (mean = 3300 ppb; n= 9) and 1700–49,000 ppb (mean = 9600 ppb; n= 12), respectively. The ranges in total As near Mill #1 and Mill #3 are 140–17,000 ppm (mean = 3900 ppm; n= 9) and 1800–150,000 ppm (mean = 19,000 ppm; n= 12), respectively.

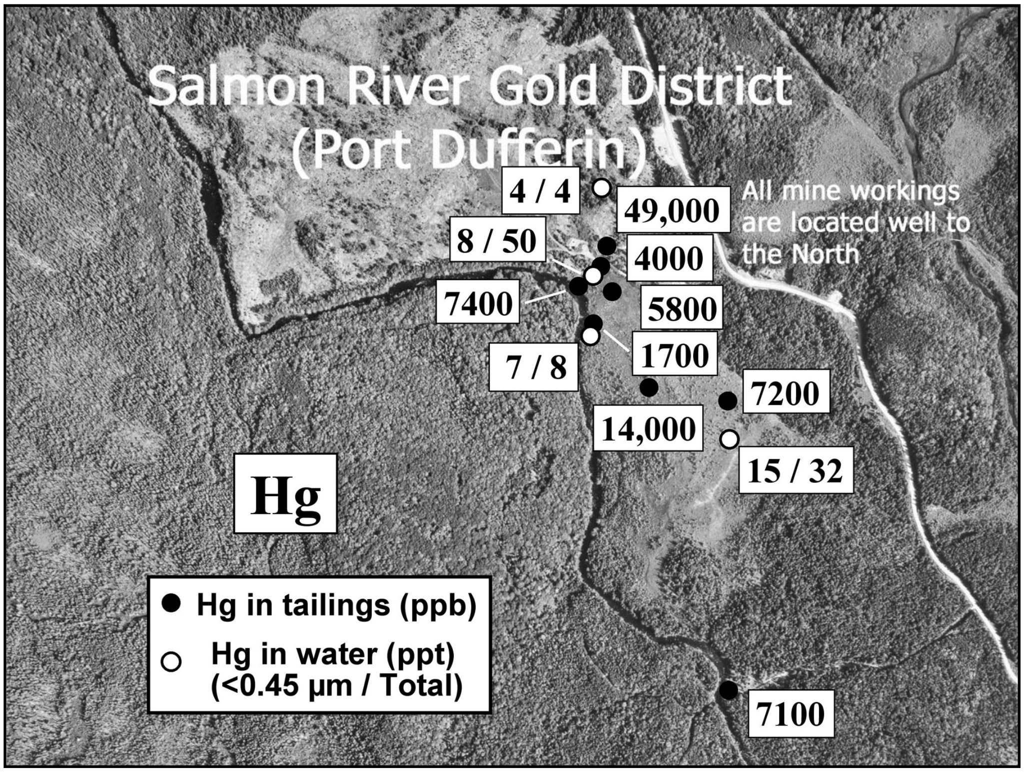
The waters draining both of these sites are mildly acidic, with pH values ranging from 4.85–6.83 (mean = 6.41, n=9). Figure 26 and 27 show the spatial distribution of Hg and As concentrations in surface waters upstream of the tailings, in standing water on the tailings, and in waters draining from the tailings at mill sites #1 and #3, respectively. In general, the dissolved (<0.45 µm) concentrations of Hg in most water samples are quite low (i.e. < 20 ppt), suggesting that Hg is present in a relatively insoluble form in the tailings. The highest dissolved Hg concentration (61 ppt) was measured in water flowing from a drill pipe through the tailings from the former 60-stamp mill near the Dufferin Mine (Figs. 25a, 27a). In contrast, dissolved As levels at both sites are very high in surface waters on, and immediately downstream of the tailings (100s to 1000s of ppb) as compared to upstream sites which generally have < 20 ppb dissolved As.

a)

b)

Figure 25. *(a) Wetland filled with gold mine tailings from the Dufferin 60-stamp mill; (b) scorodite-bearing waste pile adjacent to the Dufferin 60-stamp mill (Mill #3, Fig. 23)*

a)



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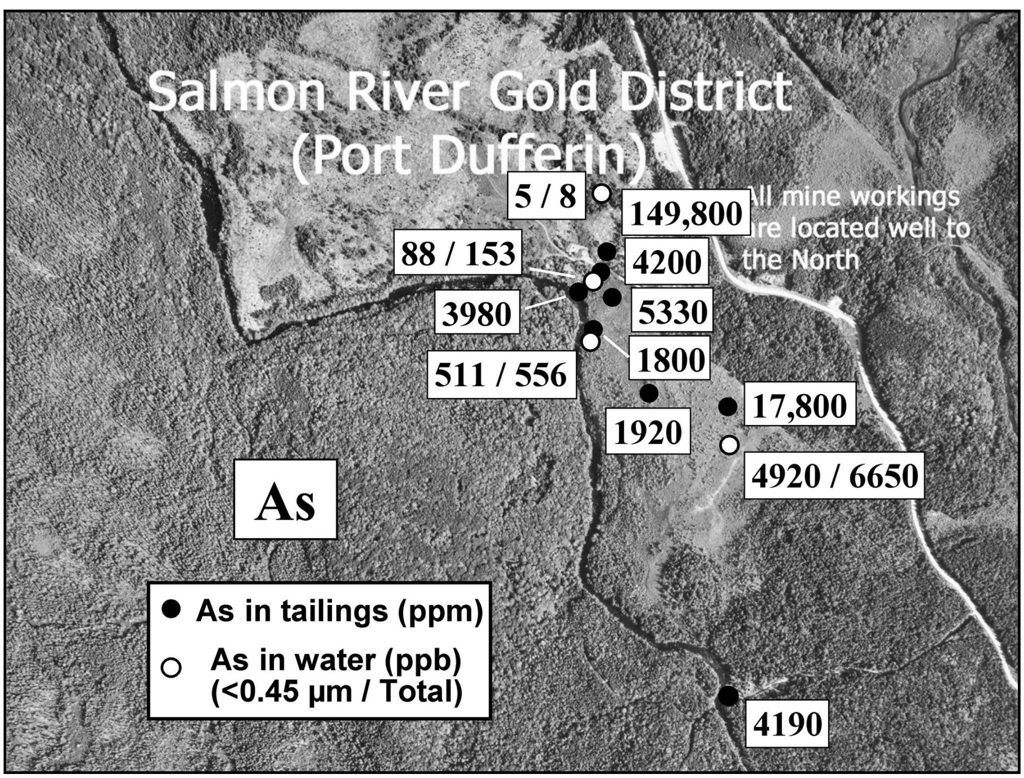
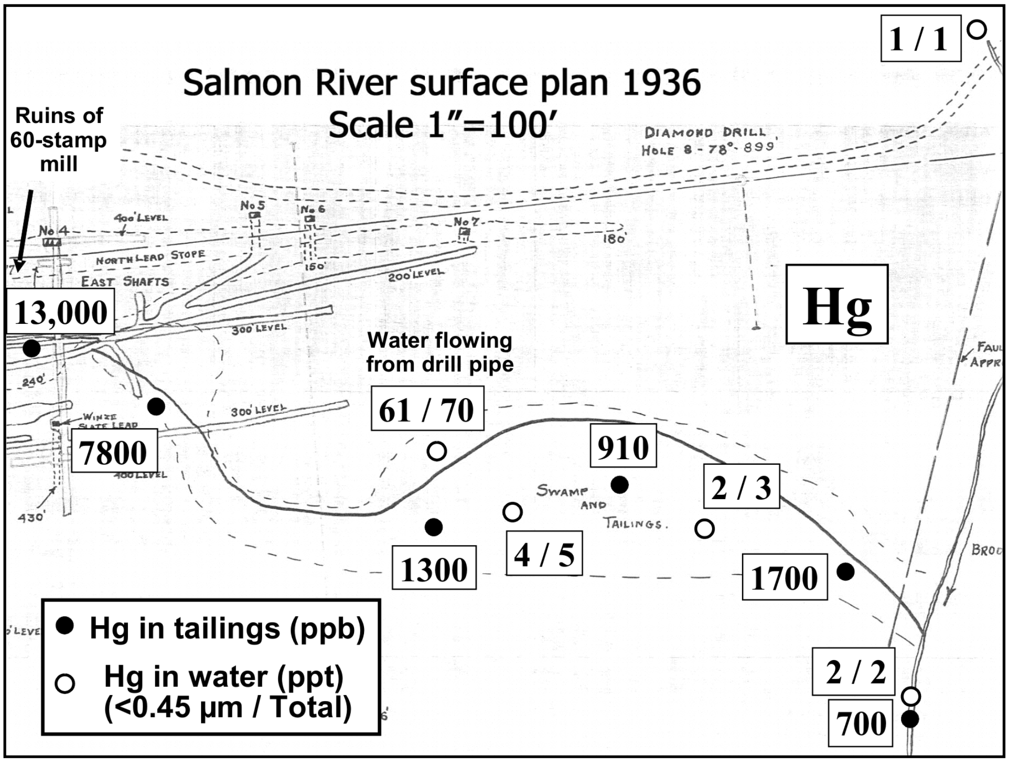


Figure 26. *Concentrations of (a) Hg and (b) As in tailings and surface waters near the site of a former 20–30 stamp mill (Mill #1, Fig. 23) near the Salmon River (Airphoto 11D-16 © 1992 Her Majesty the Queen in Right of Canada, reproduced courtesy of Land Information Services, 2005).*

a)



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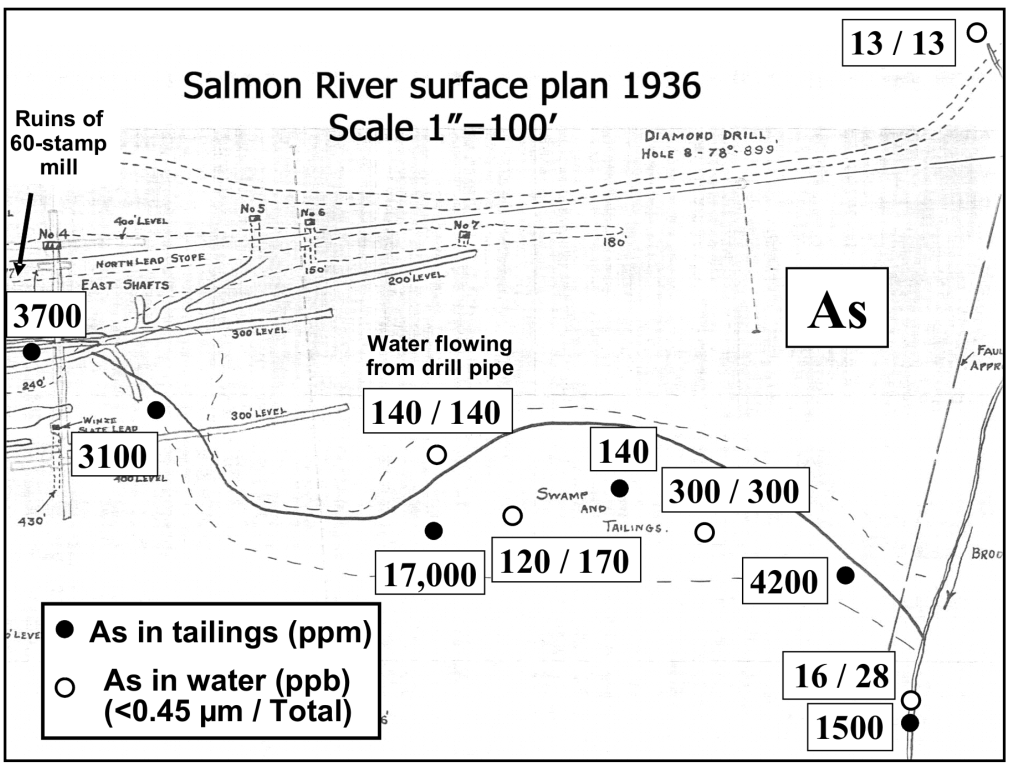


Figure 27. *Concentrations of (a) Hg and (b) As in tailings and surface waters in a wetland immediately east of a former 60-stamp mill (Mill #3, Fig. 23) near the Dufferin Mine.*

7.0 Stop #3: GOLDENVILLE GOLD DISTRICT

7.1 Bedrock Geology, Mineralization, and Geochemistry

7.1.1 Introduction

The Goldenville district has the largest historic gold production (209,383 oz. Au) of any single deposit in the province. Discovered in 1862, it is located ~3 km west of the historic Sherbrooke Village. The district includes 105 named veins (and many more that remain unnamed), principally as concordant veins along an asymmetrical, east-west trending anticline. The veins are exposed over a 518 m section across the anticlinal hinge. In addition to gold, the veins contain minor arsenopyrite, pyrrhotite, pyrite, galena and sphalerite.

7.1.2 Stratigraphy

The stratigraphic position of this district is located ~2.4 km below the base of the Halifax Formation (Malcolm, 1929). Host rocks consist of typical bouma beds of meta-greywacke, meta-siltstone and slate ranging in thickness from several centimeters to several metres. Individual slate beds are typically dark blue-grey to black in colour and contain varying amounts of sulphide minerals up to ~10%. Meta-siltstone lithologies vary in color from light grey-green to dark blue-grey, contain abundant primary structures such as cross-laminations. Meta-greywacke beds are typically light to dark grey in colour and commonly show upward fining and bottom load structures.

7.1.3 Structure

The deposit is defined by an asymmetrical, upright, east-west trending regional fold having a near vertical south limb and a more gently dipping (65°) north limb. This fold plunges between 0° and 30° west and defines a tighter geometry at its eastern edge (i.e. Bluenose Mine). Three well-defined undulations caused by secondary, NW-SE trending kink bands crosscut the deposit and appear to control the limits of highest-grade gold mineralization.

7.1.4 Metamorphism

Greenschist facies strata at Goldenville are defined by the presence of porphyroblastic biotite in slate and some meta-siltstone lithologies. Inclusion-free biotite is also observed in many barren and auriferous veins in the district, suggesting that at least some of the veins underwent regional metamorphism at *ca.* 400 Ma.

7.1.5 Alteration

Alteration at Goldenville is characterized by abundant silica flooding, sericite, carbonate and sulphide minerals. Widespread silicic alteration is most prevalent in meta-greywacke beds. Here, darker colored primary lithologies display strong bleaching effects associated with the destruction of biotite rich matrix. Sericite alteration is most commonly observed in slate lithologies in close proximity to lode mineralization. Carbonate alteration is also widespread and is most easily recognized in meta-siltstone and meta-greywacke beds. This mineralogy is dominated by ankerite and calcite that show several stages of development. Similar to seritization, sulphide minerals are restricted to close proximity to the lode systems. The sulphide assemblage is characterized by the ubiquitous presence of arsenopyrite and pyrrhotite, with lesser amounts of pyrite and base metal sulphides.

7.1.6 Mineralization

Mineralization is known to extend ~4 km along strike. One hundred forty two diamond drill holes across the property have clearly defined ~40 continuous stratigraphic belts around the anticline. Historic mining at the property indicates that the reported, mill-recovered grade of the deposit was 0.48 oz.Au/t. Gold is present in three distinct settings that include: (1) free gold nuggets and smaller grains in quartz veins, (2) free gold in thick slate lithologies and (3) free milling gold attached to, or as inclusions within sulphide minerals.

Quartz veins (Fig. 28), the dominant host for gold mineralization, occur in several

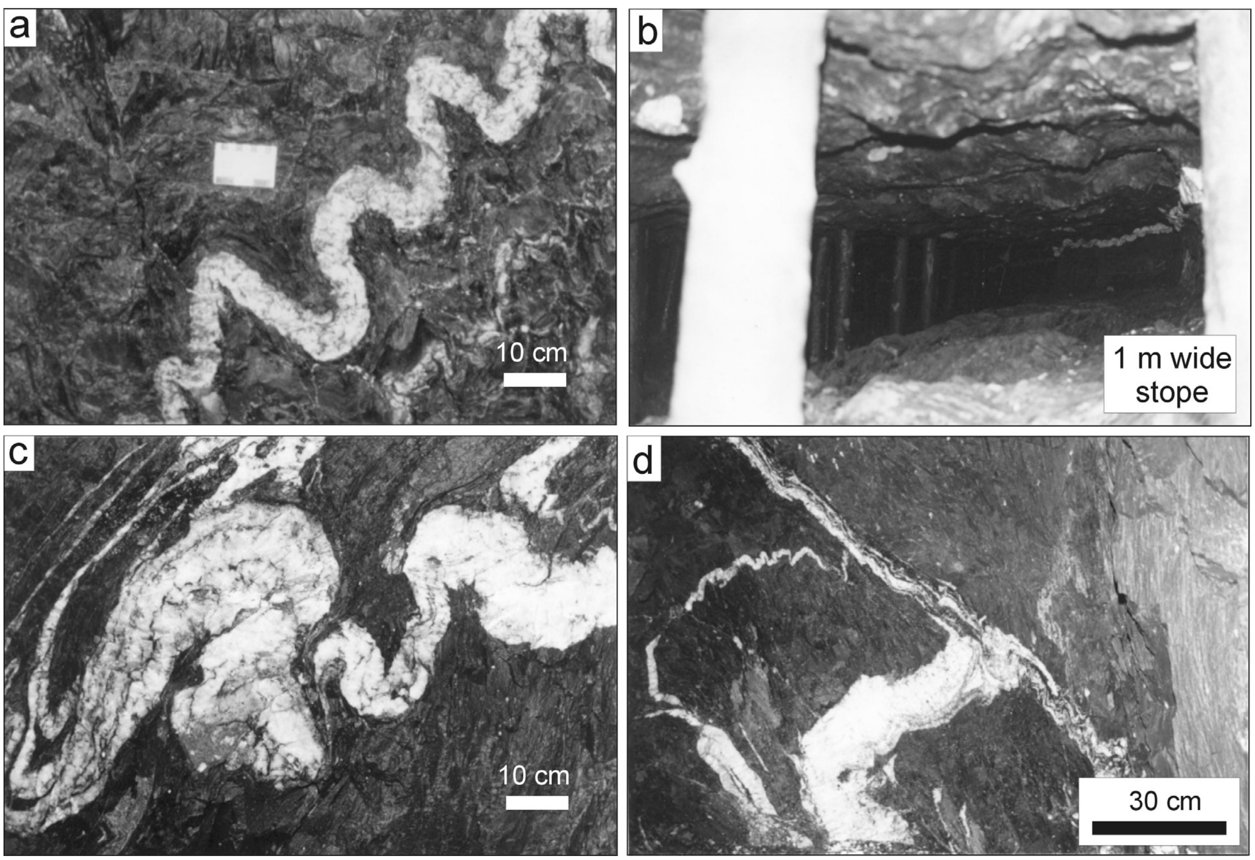


Figure 28: *Typical veins from the 260' level off the Stuart Shaft at Goldenville. (a) 5-10 cm wide bedding parallel vein with several thin stringers below it. (b) 1 m wide stope on the anticlinal hinge showing a discontinuous bedding parallel veins at the face and support timbers at the left and forefront of the photograph. (c) Composite ribbon textured discordant vein showing thickening in the hinge areas and thinning and dislocation on the limbs. (d) Intersecting discordant angular veins with a laminated bedding parallel vein.*

different forms including (1) bedding parallel, (2) stratabound, (3) discordant angulars, (4) discordant fissures, (5) *en echelon* and (6) stockwork. Veins are typically thickened in the fold hinge, but there are numerous drill-indicated examples suggesting that bedding parallel veins are either pinched out at the hinge or simply do not extend around the hinge. Veins range in thickness up to several metres, but average ~50 cm. All vein types are known to carry gold.

High grade ore at Goldenville occurs in distinct ore shoots that are defined by secondary structures. Here, NW-SE trending kind-bands that crosscut the regional fold (bedding and cleavages) are responsible for the production of large gold-rich ore shoots that parallel the intersection of kink band fold axis and bedding. This has commonly been defined as a “structure on a structure” (A. Hudgins, pers. comm.) and is well known to be responsible for development of the high grade ore mineralization at many gold deposits hosted in the Meguma Terrane.

The property is currently under license to Acadian Gold Corporation who have presented both plan and cross-section for general distribution (Figs. 29 & 30).

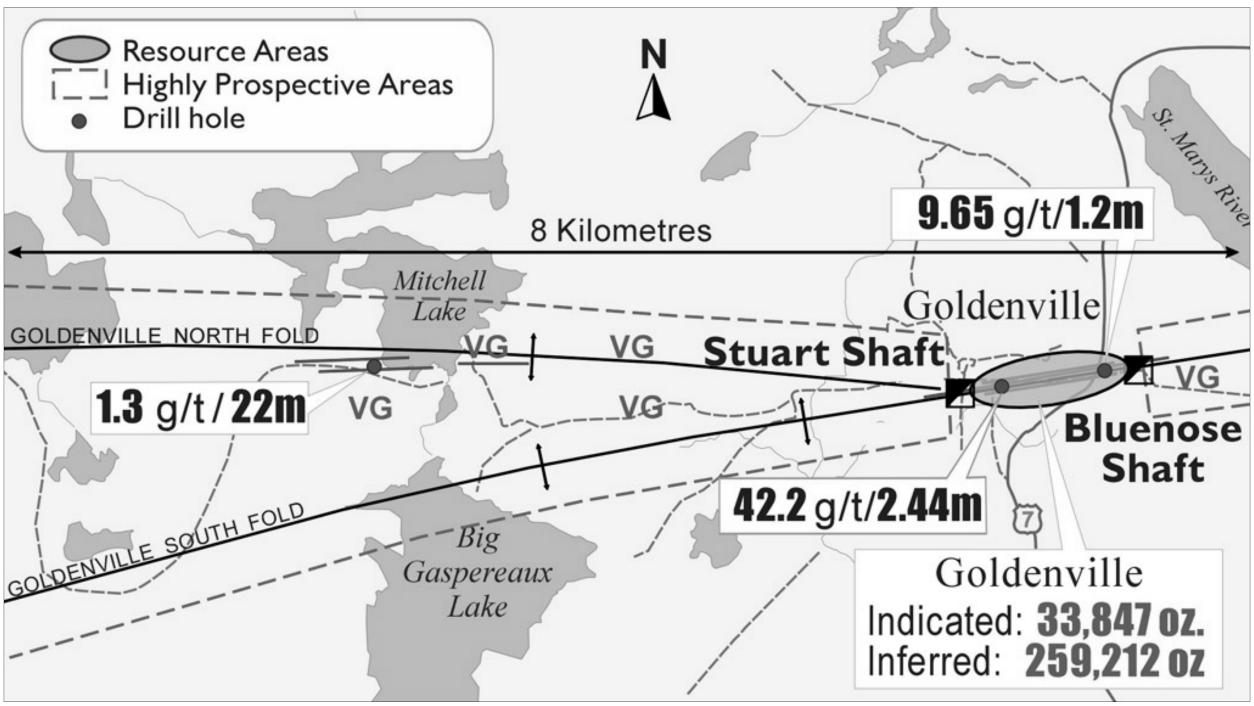


Figure 29. *Generalized plan map showing the location of the Stuart and Bluenose shafts and the current resource estimation based on 142 diamond drill holes (from Acadian Gold Corporation).*

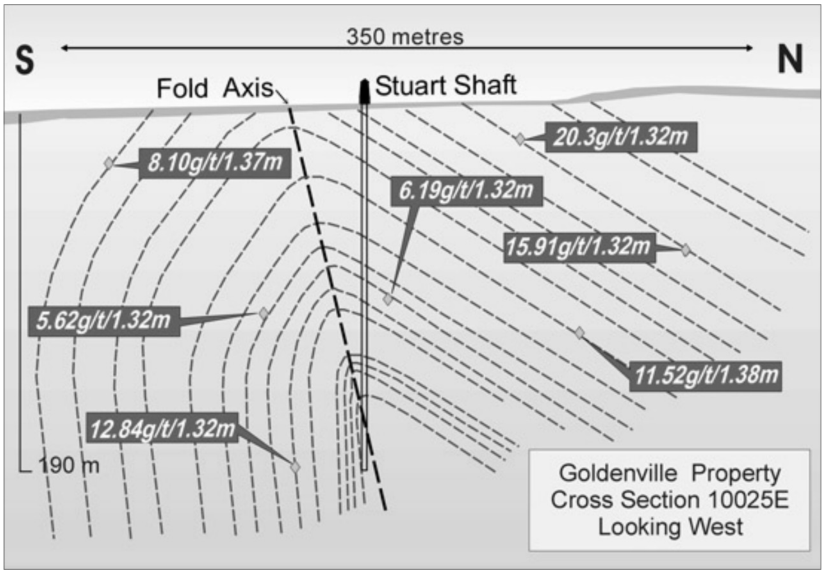


Figure 30. *Stylized cross section of the Goldenville Anticline showing the location of the Stuart Shaft, the steep south limb and the more gently dipping north limb. Gold grade and width indications are based on diamond drill intersections (from Acadian Gold Corporation).*

7.1.7 Geochemistry

Selected geochemical analyses from both drill core and surface samples show the distribution of arsenic in the deposit (Table 10). These mixed lithologies clearly indicate that the highest arsenic concentrations occur in slate, meta-siltstone and vein material, consistent with field observations. However, it should be noted that arsenopyrite content of some altered meta-greywacke beds can locally be much higher (~5%) that the values shown in this table.

Table 10. *Arsenic concentration (ppm) in selected bedrock samples from the Goldenville gold district.*

Rock Type	n=	Minimum (As ppm)	Maximum (As ppm)	Average (As ppm)
Meta-greywacke	25	4.0	970	113
Slate - meta-siltstone	16	4.0	39000	3259
Vein ± slate	10	170	28000	6108

7.2 Surficial Geology

The Goldenville Gold District is also characterized by the locally derived Quartzite Till of Stea and Fowler (1979). The Quartzite Till is now referred to as the Beaver River Till, metagreywacke (or metasandstone) facies (Finck and Stea, 1995). A single Lawrencetown drumlin has been mapped approximately 2 km SW of the village of Goldenville (Stea and Fowler, 1979). Limited striae data measured at one location along Hwy 7 immediately south of the village of Goldenville (Stea *et al.* 1992) indicate ice flowed towards the southeast (160 ^{o}).

7.3 Mining and Milling History

The Goldenville district was the largest producer of gold in Nova Scotia, and as such, has a complex history of mining and milling operations. Some of the key historical events are summarized in Table 11—this information has been compiled mainly from summaries in Malcolm (1929), Henderson (1935), and Moggridge Kuusisto (1978). During peak periods of production (e.g. the late 1860s), as many as 19 different companies were operating in this district simultaneously (Fig. 31a). Many stamp mills have been erected in this area (Fig. 31b), crushing a total of 595,950 tons of ore and leaving large quantities of tailings on the surface (Fig. 32).

Table 11. *Highlights of mining and milling history, Goldenville Gold District*

Date	Event
1861	Gold discovered in quartz boulders in a small meadow about a mile and a half west of the St. Mary's River by Nelson Nickerson of Sherbrooke
1862–1867	Vigorous prospecting and production of gold by many different companies; in 1862, the first four stamp mills were installed; in 1867, the district records its highest production of gold—9,463 oz.
1868	Five new crushers erected on-site; many companies working throughout the district; three 15-stamp crushers erected in the eastern part of the district
1869	Nineteen companies operating in the district—most of these are short-lived, and by 1872, production drops substantially
1873–1893	Mining properties worked throughout the district, in many cases by tributers (i.e. individual miners and prospectors, who worked the properties for a rental fee); lack of capital and poor mining practices hamper production at most mines; gold production decreases throughout 1880s to less than 200 oz./yr in early 1890s
1894	Improved mining and milling methods, systematic exploration based on the mapping work of E.R. Faribault (GSC), and increased investment capital generate renewed interest in mining lower-grade ores in the Goldenville district
1895–1906	Active mining by various companies, with a peak in production of 5,201 oz. in 1898; many stamp mills are operated during this period, some of which included concentrators (shaking tables, Frue vanners, or Wilfley tables) to treat the tailings from the amalgamation process. Production drops off significantly after 1906.
1909–1930	Intermittent activity by various companies (peak production of 2,215 oz. in 1915)
1935–1942	Guysborough Mines Ltd. produces 170,239 tonnes of ore at a grade of 7.12 g/t Au. Mining ceased in 1942 because of World War II.
1961–1987	Intermittent exploration (diamond drilling, geochemical & geophysical surveys), including open-pit mining of a 3,500 ton sample in 1984 for gravity concentration and a subsample for cyanidation testing.
1988–present	Surface exploration, shaft rehabilitation, and limited underground exploration.

a)

PA-053513

b)

PA-014667

Figure 31. *(a) Prospector shafts on the road into Goldenville,* ca. *1897 (Public Archives of Canada Photo PA-053513); (b) Stuart Shaft House and mill, Goldenville, 1934 (Public Archives of Canada Photo PA-014667).*

Figure 32. *Aerial photograph of the main mine area at Goldenville showing waste rock piles and mine tailings. Fluvial dispersion by the Gegogan River has transported tailings at least 6 km downstream of the Goldenville mines.*

7.4 Environmental Geochemistry: Bedrock, Surficial Materials, Mine Wastes and Waters

The dispersion and toxicity of metal(oid)s from mine tailings at Goldenville was studied by Environment Canada in the mid-1990s (Wong *et al.* 1999)—copies of this published paper will be distributed during the field trip. In brief, these authors documented high levels of As and Hg in the tailings, and showed that the mine wastes are a continuing source of As, Hg, Pb, and Tl to the downstream environment. Stream water and sediments collected from Gegogan Lake, located 4 km downstream of the mined area, were found to be toxic to benthic invertebrates, and significant negative impacts on the biological community structure were observed.

The tailings at Goldenville are now the site of an annual 4X4 rally each Labour Day weekend. This event (now in its 12th season) attracts a large crowd (several hundred people), and the trucks race directly on the mine tailings (Fig. 33). Ongoing investigations of metal(oid)s in airborne particulates at the Goldenville site will be discussed during the field trip.

a)

b)

Figure 33. *(a) Competitors in the 10th Annual Goldenville 4X4 Rally, August 30, 2003; (b) "Sand drags" at the 11th Annual Goldenville 4X4 Rally, Sept. 5, 2004; note children on tailings in foreground.*

8.0 Stop #4: UPPER SEAL HARBOUR GOLD DISTRICT

8.1 Bedrock Geology, Mineralization, and Geochemistry

8.1.1 Introduction

At Upper Seal Harbour, the Cambro-Ordovician Goldenville Formation is represented by intensely deformed and/or recrystallized meta-greywacke, siltstones and slates, metamorphosed to the biotite-cordierite grade.

Shear bands and polycrystalline quartz aggregate (± biotite) lenses are common in slaty rocks. Abundance and shape variations of the shear lenses suggests that some of the slates may have formed as residuals from sandy and silty mudstones by dissolution and removal of quartz. Consistent with this mode of origin, Upper Seal Harbour slates contain lower SiO_2 (<<55%) and higher Al_2O_3 (>20%) and K_2O (>6%) than some regional slates elsewhere in the Goldenville Formation along the Eastern Shore of mainland Nova Scotia. These high concentration of K_2O and Al_2O_3 in the Upper Seal Harbour slates may reflect either residual enrichment accompanying the loss of silica, or potassic alteration associated with lode gold development.

8.1.2 Stratigraphy

At Upper Seal Harbour the succession is comprised of alternating layers of slate, meta-siltstone and very fine- to fine-grained meta-greywacke, representing multiple cycles of deposition. Recent drill and underground exploration defined numerous auriferous slate-rich belts hosting variable amounts of lode quartz (Fig. 34). Meta-greywacke beds are typically 1-3 m thick, but are occasionally up to 14 m thick and show variable silicification. The greywacke beds are intercalated with thin to thickly bedded (25 cm up to 4 m), often alternating, and sometimes upward fining sequences of very fine-grained greywacke, siltstone, and graphitic slates. Bedding parallel and discordant quartz veins cut all lithologies throughout the gold district. Rip-up slate clasts are sometimes found at the base of meta-greywacke layers.

The lithology of the Goldenville Formation at Upper Seal Harbour has been described previously by Placer Dome Canada in 1996 on the basis of several holes penetrating both the northern and southern limbs of the Goldboro Anticline. Four stratigraphic packages were outlined in the Placer Dome Canada study. The uppermost package was described as unaltered, 10 cm to 3 m thick, grey to green, internally massive to laminated Bouma sequence. This is cut by narrow, 1 to 5 cm thick, bedding parallel quartz veins with trace amounts of sulphide. The underlying unit was named the "Boston-Richardson slate belt" during historical mining and is 2 – 8 m thick, consisting of grey to locally very black, biotite-rich slates. This belt contains up to ~40% bedding parallel and stratabound quartz veins with abundant sulphides (Fig. 35). The Boston-Richardson slate belt overlies greywacke, designated as the "Boston-Richardson arenite package." The latter is described as a 40 m thick, typically light grey in colour with a locally mottled texture resulting from intense alteration. This unit displays increasing silicification towards the bottom. Rare, 1 to 2 cm thick discordant *en echelon* quartz veins occur throughout this unit. The lowermost unit consists of 9 to 10 distinct graded bed sequences, each 1 to 2 m thick, each separated by unmineralized meta-greywacke. The associated slate is black and graphitic looking. Bedding parallel quartz veins comprise ~40% of these slates.

Upper Seal Harbour - plan map

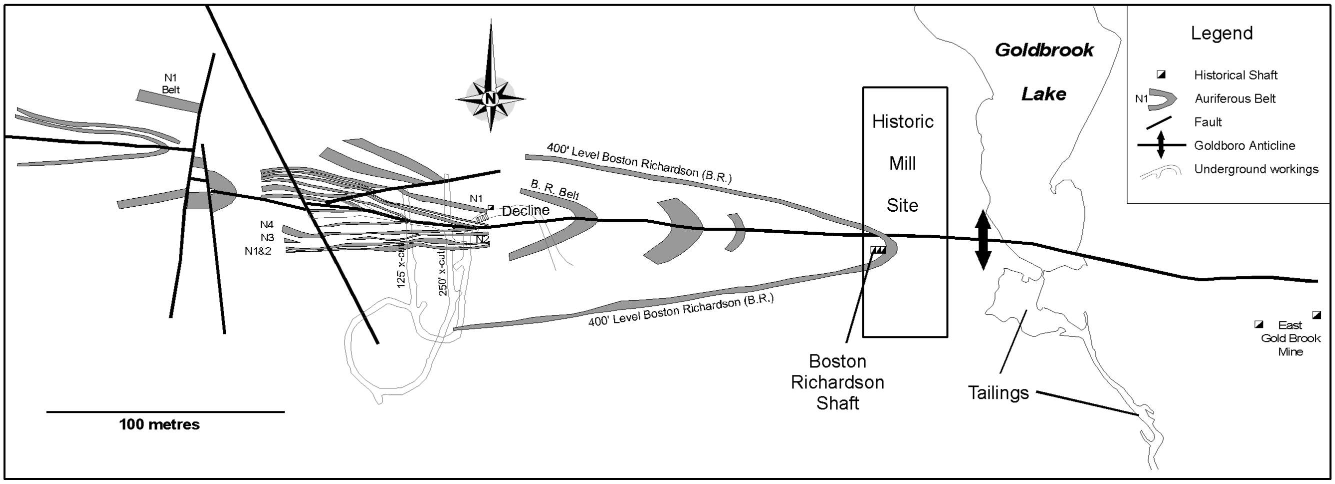


Figure 34. *Generalized plan map of the Upper Seal Harbour area showing several of the mineralized belts (N0, N1, N2, N3, N4). The surface and 400 foot level projections are shown for the Boston Richardson Belt in addition to the approximate location of the historic mill site and the proximal location of mine tailings.*

On a regional scale, strata at the Upper Seal Harbour gold district form part of the "minor sandstone package" as defined by Waldron and Jensen (1985). This consists of 5-20 m thick greywacke bodies, interlayered with thinly-graded muddy intervals (muddy sandstone, sandy mudstone, siltstone, slate) comprising up to 50% of measured sections. These are thought to represent submarine channel deposits and inter-channel fill turbidites. The minor sandstone package interdigitates with a major meta-sandstone package, which consists of 50-150 m thick meta-greywacke bodies composed almost entirely of laminated to massive, internally scoured and upward graded bedding (Waldron and Jensen, 1985).

Figure 35. *Dark silty-slate with bedding parallel quartz-carbonate vein and a meta-siltstone bed rich in carbonate, biotite and arsenopyrite. Sample is 15 cm long.*

8.1.3 Petrography

8.1.3.1 Textures and Structures

The Goldenville Formation at Upper Seal Harbour has undergone intense shear deformation and/or recrystallization. Individual grains exhibit deformational features such as undulose extinction and shear bands in quartz, deformation lamellae and kinking in feldspars and biotite, pressure shadows around sulfides, and occasionally ribbon textures in quartz veins and associated roll structures.

A prominent structural feature of the meta-greywacke lithologies is the development of a spaced pressure-solution cleavage that locally evolves into distinct shear bands. Similarly, shear lenses, consisting of polycrystalline quartz and/or biotite aggregates within sericite-rich, muddy layers are characteristic of silty and slaty rocks at Upper Seal Harbour.

8.1.3.2 Mineralogy

Meta-greywacke is composed of 65-80% quartz, 10-20% feldspars, and 5-10 % biotite, sericite, chlorite, carbonates, tourmaline, zircon, apatite, sphene, epidote, ilmenite and sulfides.

In these strata, quartz and feldspars vary from medium-grained, rounded to sub-rounded, to fine-grained, angular shape. Some rounded quartz grains have striated surfaces, while others have well-developed silica overgrowths. Detrital plagioclase grains are more abundant than alkali feldspar in these meta-greywackes, although this may be due to the selective sericitization of the alkali feldspar. Plagioclase forms two populations based on their differing degree of deformation and alteration. One has thin twin lamellae and is relatively altered and strained. The other type has thicker lamellae and a relatively fresh and unstrained appearance. In addition to common poikioblastic carbonate crystals, there is a minor amount of detrital micritic limestone. These are earth-coloured and isotropic. Tourmaline, zircon and apatite grains are both rounded and euhedral in shape.

Sericite is the most abundant mineral in the slaty rocks. It may be associated with chlorite and/or biotite and/or dark carbonaceous material. Where present, the carbonaceous material imparts a distinctly black colour to the slates. Biotite is the most common porphyroblast and there are several generations of this mineral growth. Locally it is replaced by chlorite ± muscovite. Less commonly, tourmaline, calcite, sphene and clinozoisite appear as late to post-kinematic minerals.

8.1.3.3 Sulphides and Oxides

Pyrrhotite, chalcopyrite and arsenopyrite are the most common sulphides present. Ilmenite and minor rutile are the dominant oxide minerals. Sulphide minerals are generally more abundant in silty and slaty lithologies than in meta-greywacke although exceptions do occur. In rocks consisting of alternating layers of silt and sericite, both oxide and sulphide minerals occur preferentially in the silty layers or in the cores of shear lenses. Pyrrhotite is typically anhedral and may form ribbon-like veinlets, while arsenopyrite has well-developed cubic forms, and may be very coarse (up to 1 cm). Pressure shadows are commonly developed around arsenopyrite. Both face- and displacement-controlled fibres of quartz, chlorite, biotite, and rarely of feldspars are present in these shadows. Ilmenite is particularly abundant in sericite-rich layers and commonly displays granular shape throughout the matrix. In addition, ilmenite sometimes occupies the cores of composite biotite grains.

8.1.4 Quartz Vein Morphology and Petrography

Auriferous quartz veins comprise the dominant, high grade, ore lithology at the Upper Seal Harbour gold district. Typical veins observed from the underground workings and in drill core at Upper Seal Harbour may be grouped into three distinctive types: (1) bedding-parallel, (2) *en echelon* discordant arrays, and (3) 'ac' discordant veins. A brief description of each vein type is given below.

8.1.4.1 Bedding Parallel {stratabound} veins

Within the Upper Seal Harbour Gold District this vein type may be both auriferous and barren. It is characterized by its stratabound nature and the presence of crack-seal laminations throughout. They are typically in the order of 10 cm in width and may be traced for several hundred metres along strike. In all cases these veins have suffered both regional and shear deformation in addition to regional metamorphism. Individual quartz grains show undulose extinction and common polygonal textures. Characteristic mineralogy includes quartz, biotite, chlorite, plagioclase, carbonate and wall rock inclusions in addition to sulphides (arsenopyrite, pyrrhotite, galena, chalcopyrite, sphalerite and pyrite), minor oxides (ilmenite, rutile, magnetite), minor graphite and trace amounts of tourmaline.

8.1.4.2 *En Echelon* Veins

Volumetrically, this morphologic type represents the most significant vein set at Upper Seal Harbour. It accounts for approximately 60% of the vein quartz exposed in the underground workings. Individual *en echelon* arrays are up to 20 metres wide (Fig. 36) and may displace >80% of all lithologies within that interval. These veins are characterized by their *en echelon*, discordant nature with respect to bedding. Side-spur veins, which are short, discontinuous, *en echelon* protrusions of quartz attached to either one or both sides of bedding parallel veins, commonly form an integral part of this vein morphology. Locally, these veins display a stockwork-type nature similar to that observed at other gold districts throughout Nova Scotia (e.g. Caribou Gold District). *En echelon* veins commonly have similar mineralogy as that described for bedding-parallel veins. This vein set is variably deformed by both regional and shear deformation although where individual veins are large (>2 m), evidence of internal recrystallization and shearing is less obvious. Regional metamorphic minerals are observed to overgrow the contact between veins and host rock.

Figure 36. *Photo mosaic of 4 individual photographs from the 250' level showing massive* en echelon *veining. Width of field of view is 4 m.*

8.1.4.3 'ac' Discordant Veins

Throughout the district, thin (1 - 5 mm) quartz ± carbonate ± chlorite veins crosscut stratigraphy and cleavage at a high angle normal to the fold axial plane. These veins appear to have limited extent and rarely contain gold mineralization. However, where these veinlets intersect arsenopyrite crystals within the ore zone, gold, chalcopyrite and galena may be observed. Strong bleaching of the host rock is typically observed adjacent to the vein margins. These veins in the Upper Seal Harbour gold district display only weak deformation and do not appear to have undergone regional metamorphism, as have all other vein types.

8.1.5 Whole Rock Geochemistry

8.1.5.1 Major Elements

Upper Seal Harbour strata exhibit a wide range in SiO_2 (45-78%), Al_2O_3 (10-30%) and K_2O (2 -10%), as well as in TiO_2, Fe_2O_3, MnO and MgO, all of which are similarly enriched in the slate (<57% SiO_2). CaO also has a wider range of concentration in the Upper Seal Harbour rocks, but unlike the rest of the oxides it tends to be enriched in the meta-greywacke. Na_2O and P_2O_5 concentrations at Upper Seal Harbour show relative depletion compared to regional samples from elsewhere in the Meguma.

8.1.5.2 Gold

Gold is associated with veins and slate in three distinct settings: (1) as discrete grains enclosed in vein quartz; (2) as discrete grains in sulphide minerals (mainly arsenopyrite) enclosed in vein quartz (Fig. 37); and (3) as discrete grains enclosed in slaty lithologies. Individual grains range in size from micron-scale to small nuggets (1-3 mm) and have variable textures including fine wires, flakes, crystals and irregular masses. Visible gold is observed in grain contact with arsenopyrite, galena, chalcopyrite and pyrrhotite. Fracture infillings of gold in arsenopyrite are also common. In addition to Fe-sulphide and oxides, associated ore minerals include galena, sphalerite and trace amounts of antimony and bismuth sulphide. These minerals are generally associated with galena grains either enclosed within, or, in close proximity to arsenopyrite crystals.

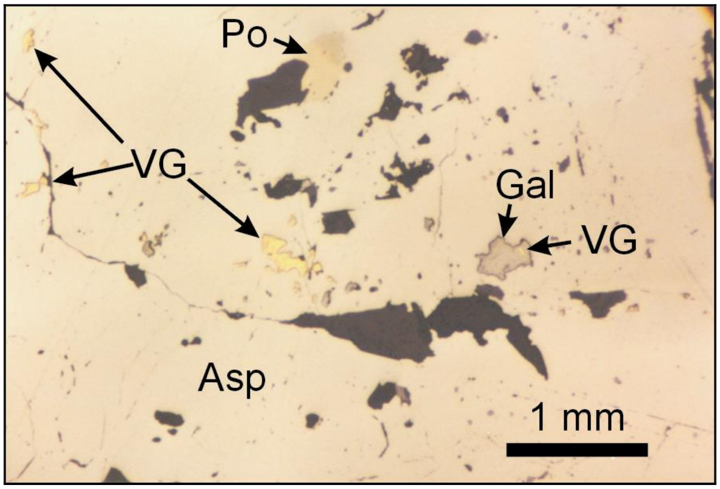


Figure 37. *Inclusions of visible gold (VG), galena (Gal) and pyrrhotite (Po) in arsenopyrite.*

Based on *aqua regia* digestion of selected bedrock samples, chemical analyses show two distinct ranges of gold concentrations in the Upper Seal Harbour rocks. The first, and lower, range varies from 0.048 ppm in meta-greywacke to 2 ppm in slate. The second range, between 3-24 ppm Au, is obtained on quartz veins and adjacent wall rock slate. Selected data shows a strong positive correlation between Au and S in these lithologies.

8.1.5.3 Arsenic

Arsenic concentrations were determined in 34 bedrock samples (Table 12). In general, all rocks from the Upper Seal Harbour district show elevated As concentrations with the highest As levels occurring in slate. This is also consistent with field observations that show the highest percentage of arsenopyrite also occurs in slate. However, abundant arsenopyrite and associated sulphide can be found in all rock types throughout the mine workings and in drill core.

Table 12. *Arsenic concentration in selected bedrock samples from the Upper Seal Harbour gold district.*

Rock Type	n=	Minimum (As ppm)	Maximum (As ppm)	Average (As ppm)
Meta-greywacke	6	20	2920	192
Meta-siltstone	4	450	5900	2503
Slate	17	30	6980	3104
Vein	7	90	6360	2740

8.2 Surficial Geology

The Upper and Lower Seal Harbour Gold Districts are characterized by the Quartzite Till of Stea and Fowler (1979). The locally derived Quartzite Till is texturally and compositionally similar to the till that characterizes previous stops at Tangier, Dufferin and Goldenville. This till is now referred to as the Beaver River Till, metagreywacke (or metasandstone) facies (Finck and Stea 1995). As in most other Meguma Gold Districts, the Beaver River Till is relatively thin within these districts, averaging <5 m thick. The thickness of the till is based upon the frequency of outcrop occurrences coupled with depth to bedrock information from diamond drilling logs.

The Upper and Lower Seal Harbour Gold Districts are further characterized by the presence of glaciaofluvial silt, sands and gravels (Stea and Fowler 1979). These deposits are spatially associated with northwest-trending harbours, i.e. Issacs Harbour, occupying northwest-trending fault zones. Exploration work (Dawe 1988a) immediately to the north of the Upper Seal Harbour Gold district indicates glacial ice advanced towards the southeast (145^{o} - 150^{o}).

8.3 Mining and Milling History

Gold mining in the Upper Seal Harbour area began in 1892, when Howard Richardson, following an anticline trace from a Geological Survey of Canada map, discovered a large body of low-grade ore that later became known as the Richardson belt. Between 1892 and 1958, approximately 57,850 oz. of gold were produced in this district (Bates 1987). Table 13 summarizes some of the key events in the mining and milling history of this area, and was compiled mainly from information in Brown (1908) and Malcolm (1929). The 60-stamp Richardson Mill was one of the largest mills in Nova Scotia (Fig. 38), and remnants of the stamps and supports for the amalgamating tables are clearly visible on the west side of Gold Brook Lake today. Across Gold Brook, another property known as the East Goldboro mine also operated in the late 1800s / early 1900s, and the foundation of a smaller stamp mill and associated tailings are clearly visible immediately south of Goldbrook Road.

8.4 Environmental Geochemistry: Bedrock, Surficial Materials, Mine Wastes and Waters

In support of ongoing MITE investigations, mean Hg and As data have been compiled from exploration company assessment files for the Upper and Lower Seal Harbour Gold Districts and surrounding area, and are summarized in Tables 14a and 14b, respectively. All rock samples reported by Dawe (1988b) were at the lower detection limit of the instrumentation used to determine the Hg concentrations. Mercury and As results from A-horizon humus, B-horizon soil and C-Horizon till samples collected in the summer of 2004 as part of the MITE program are also included.

The MITE 2004 A-horizon humus, B-horizon soil and C-horizon till samples presented in Table 14a represent regional district-scale samples. The samples were collected within an approximate 10 km by 10 km area centered on the Upper and Lower Seal Harbour Gold Districts. The samples were collected away from any known workings or other potential anthropogenic effects and represent the “local” geogenic background for the Upper and Lower Seal Harbour Gold Districts.

Table 13. *Highlights of mining and milling history, Upper Seal Harbour Gold District*

Date	Event
1892	Howard Richardson, prospecting along an anticline trace from GSC maps, discovers a large body of low-grade ore, later known as the Richardson belt
1892–1893	The Richardson Gold Mining Company erects a 15-stamp mill
1893–1896	Active mining on the Richardson belt; the ore was carried by a trestle 1200 feet long from the shaft to a mill (40 stamps by 1896) on the edge of Gold Brook Lake
1898–1899	Wilfley concentrators used to treat tailings from the mill; in 1899, 150 tons of arsenopyrite concentrate were saved from the tailings
1901	20 additional stamps added to the Richardson mill, bringing the total number to 60, and four Wilfley tables in use for recovering sulphide concentrates
1902–1905	Tailings treated without concentration in an extensive cyanide plant that had been transported from the Caribou district in Fall 1901. Initial operations were unsatisfactory, and tests were made using the bromo-cyanide process.
1905–1912	Active mining by various companies at the Richardson Mine and the East Goldboro property; tailings continued to be treated successfully in a bromo-cyanide plant containing Wilfley tables for concentration; in 1909, 83% of the gold was being recovered by amalgamation, and 17 percent by bromo-cyanide extraction of concentrate; during this period, large tonnages of arsenical concentrate were shipped first to Germany, and later to Wales for smelting
1912–1927	Intermittent activity by various companies, including treatment of tailings
1988–present	Surface exploration, shaft rehabilitation, surface and underground diamond drilling and limited underground exploration.

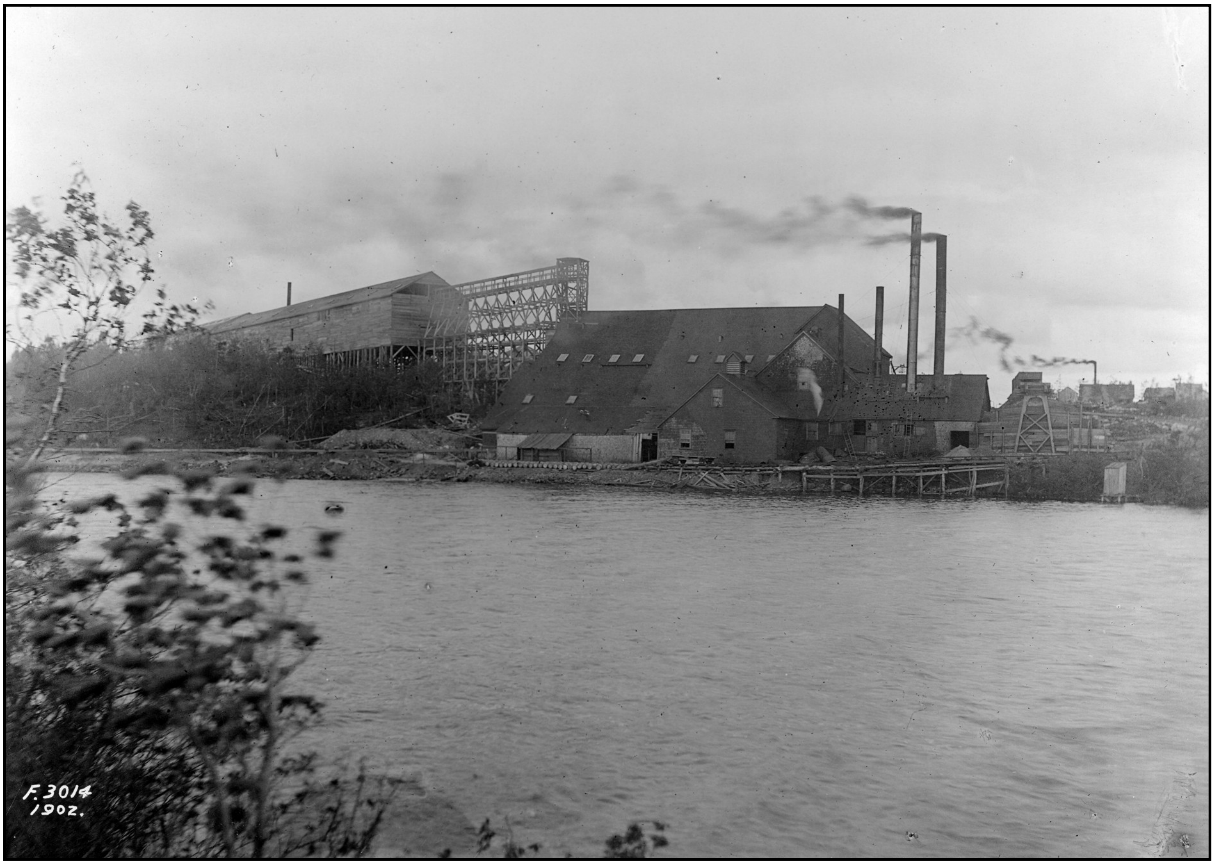


Figure 38. *Ore trestle and 60-stamp mill at the Richardson Gold Mine, Upper Seal Harbour Gold District, 1902. Gold Brook Lake is in the foreground (see Fig. 34 for location). Tailings were discharged from the mill via a wooden trough visible on the left side of the photo, and were slurried directly into the upper reaches of Gold Brook. Photo taken by E.R. Faribault, Geological Survey of Canada. Reproduced with permission from the Earth Sciences Sector Photo Library Collection, Natural Resources Canada, Ottawa.*

Table 14a. *Compiled mean Hg results for various sample media, Upper and Lower Seal Harbour Gold District and surrounding area.*

Mean (Hg ppb)	N=	Media	Size Fraction	Reference
2.5	11	rock	<75 microns	Dawe (1988b)
206.4	21	humus	<63 microns	MITE 2004 (unpublished)
205.5	21	humus	<2000 microns	MITE 2004 (unpublished)
121.1	21	soil	<63 microns	MITE 2004 (unpublished)
102.4	21	soil	<2000 microns	MITE 2004 (unpublished)
15.0	21	till	<63 microns	MITE 2004 (unpublished)
12.3	21	till	<2000 microns	MITE 2004 (unpublished)

Mean Hg concentrations for the MITE 2004 A-horizon humus and B-horizon soil samples for the Upper and Lower Seal Harbour Gold Districts (Table 14a) are considerably lower than the mean Hg values for the nine gold districts presented in Table 4. The mean Hg in till concentration is significantly lower. The reason for this is unknown at this time. It is possible that the Upper and Lower Seal Harbour Gold Districts are characterized by less naturally occurring mercury than the other gold districts sampled during this study.

Table 14b. *Compiled mean As results for various sample media, Upper and Lower Seal Harbour Gold District and surrounding area.*

Mean (As ppm)	N=	Media	Size Fraction	Reference
11.6	50	soil	<180 microns	Dawe (1988b)
7.1	2330	soil	<180 microns	Dawe (1988c)
375.8	11	rock	<75 microns	Dawe (1988b)
150.2	181	rock	<75 microns	Graham (1987)
22.54	339	till	<1700 microns	Graham (1987)
29.5	263	till (HMC)	<850 microns	Graham (1987)
21.1	93	stream sediment	<850 microns	Graham (1987)
66.3	1387	humus	<1700 microns	Miller (1987)
2.0	21	humus	<63 microns	MITE 2004 (unpublished)
1.6	21	humus	<2000 microns	MITE 2004 (unpublished)
10.5	21	soil	<63 microns	MITE 2004 (unpublished)
10.4	21	soil	<2000 microns	MITE 2004 (unpublished)
14.6	21	till	<63 microns	MITE 2004 (unpublished)
11.1	21	till	<2000 microns	MITE 2004 (unpublished)

Mean As concentrations in humus reported by Miller (1987) proximal to the old workings are, as expected, significantly higher than the mean As results from the regional, district-scale samples of the MITE 2004 program (Table 4). The high As in rocks reported by Dawe (1988b) and Graham (1987) in their search for Au mineralization likely reflect the presence of arsenopyrite (and other mineralization/alteration), a known pathfinder for Au. Similar to the Hg concentrations reported above, mean As concentrations for the the Upper and Lower Seal Harbour Gold Districts (Table 14b) are considerably lower than the mean Hg values for the nine gold districts presented in Table 4. Again, the reason for this is currently unknown.

The MITE 2004 data presented in Tables 14a and 14b indicate the fine fraction (<63 microns) returns higher Hg and As concentrations for all sample media relative to the coarse fraction (<2000 microns). This "enrichment" in the fine fraction has been previously reported by Shilts (1975).

A detailed "soil" sampling program was undertaken within and proximal to the footprint of the former Boston Richardson Mill complex in order to ascertain anthropogenic effects associated with the historical milling of the gold ore (Fig. 39). Poorly developed "soil" samples were collected on 25 m or 50 m centres on radial lines from an average sampling depth of 20 cm. Hg and As concentrations in the <63 and <2000 microns size fraction are presented in Table 15.

Figure 39 *Deteriorating cement foundations and rotted timbers are all that remain of the massive Richardson Mill building complex located on the southwestern shore of Gold Brook Lake. The Boston Richardson head frame(rebuilt in the 1980s) can be seen in the upper left.*

Table 15. *Mean Hg and As concentrations in soils collected from within the former Boston Richardson Mill complex, Upper Seal Harbour Gold District.*

Element	Size Fraction	N=	Mean	Reference
Hg (ppb)	<63 microns	11	16,900	MITE 2004 (unpublished)
As (ppm)	<63 microns	11	7650	MITE 2004 (unpublished)
Hg (ppb)	<2000 microns	11	10,200	MITE 2004 (unpublished)
As (ppm)	<2000 microns	11	7540	MITE 2004 (unpublished)

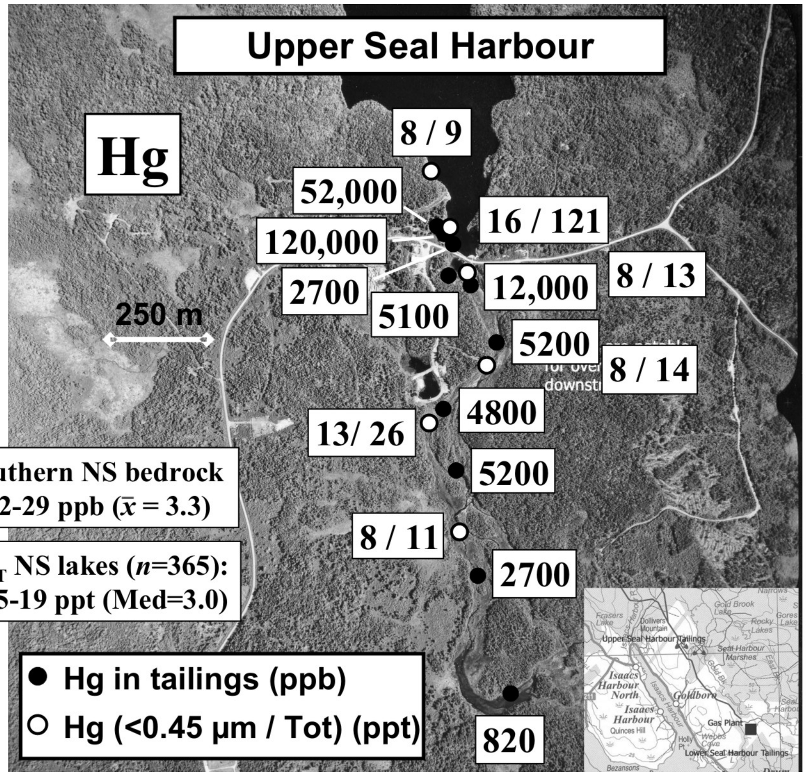
Table 15 clearly demonstrates the anthropogenic effects of the stamp-milling and amalgamation practices of recovering gold from ore when compared to mean Hg in soil concentrations (Table 14a) and mean As in soil concentrations (Table 14b) for the Upper and Lower Seal Harbour Gold Districts. It is important to note the mean As concentration reported for both the <63 µm and the <2000 µm size fraction is a minimum value because approximately 50% of the samples returned >10,000 ppm As. When calculating the mean, these very high values were all set to 10,000 ppm.

Between 1892 and the 1940s, voluminous quantities of mine tailings were slurried directly into Gold Brook. Today, these tailings are clearly visible on the floodplain for at least 4 km downstream of the Richardson Mill site. Figure 40 shows the concentrations of Hg and As in tailings and surface water along Gold Brook for a distance of ~1 km south of Gold Brook Lake. The highest concentrations of Hg (up to 120,000 ppb, or 120 ppm) and As (up to 72,000 ppm, or 7.2 wt.%) were measured directly within the foundation of the Richardson Mill. However, the tailings extend much farther south than is apparent from these maps, and high concentrations of both Hg and As are present in the tailings over a distance of at least 4 km.

As shown in Figure 40, the dissolved (<0.45 µm) concentrations of Hg in surface waters of Gold Brook are not significantly elevated about background Hg levels in Gold Brook Lake water. Considering the extremely high levels of Hg in the tailings, this suggests that Hg is present in a relatively insoluble form. The dissolved concentrations of As, however, are very high (up to 6200 ppb in standing water on the tailings), as seen in many other districts (Fig. 5b).

During the field trip, we will examine the ruins of the former Richardson Mill, and the tailings along Gold Brook. Ongoing MITE studies are assessing the potential risks to ecological and human health associated with the high levels of metal(oid)s in this mine district.

a)



b)

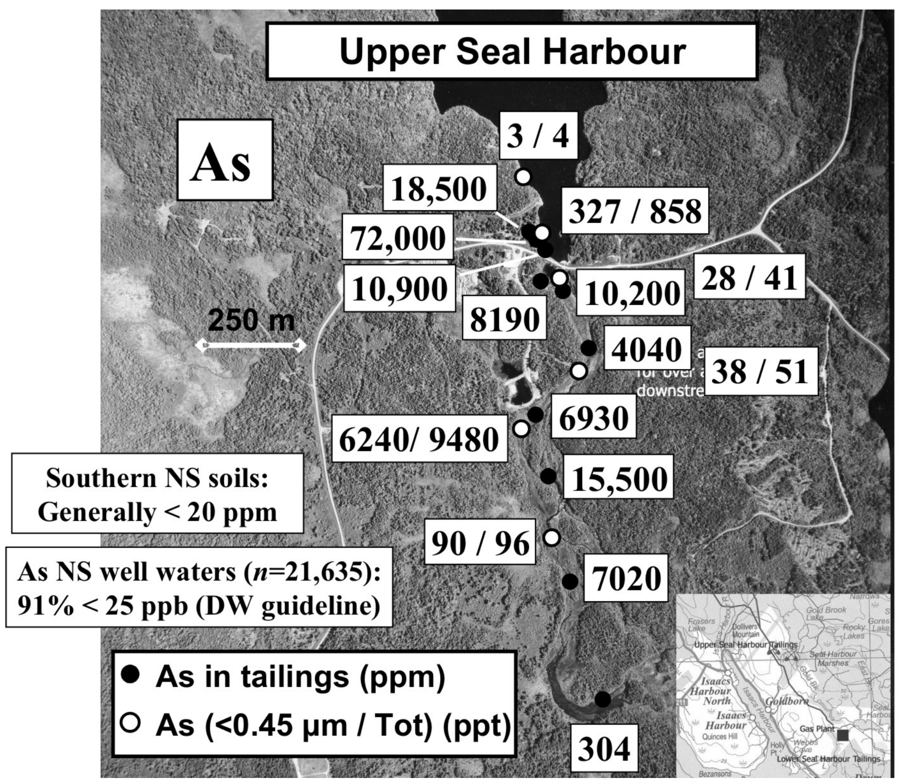


Figure 40. *Concentrations of (a) Hg and (b) As in tailings and surface waters along Gold Brook, immediately downstream of the former Richardson stamp mill (Airphoto 11F-4 © 1998 Her Majesty the Queen in Right of Canada, reproduced courtesy of Land Information Services, 2005).*

9.0 Stops #5 & #6: SABLE ROAD CUT & LOWER SEAL HARBOUR GOLD DISTRICT

Stop #5: The Sable Road Cut shows the east-plunging hinge of the Isaac's Harbour Anticline immediately west of the Skunk's Den Mine. Metagreywacke beds (30 cm to ~3 m) with minor metasiltstone and slate form the dominant south limb of the structure. At this location, *en echelon*, ac, and minor stockwork quartz veining are restricted primarily to the hinge zone, while bedding-parallel veins occur across ~200 metres of section, including the hinge. Strong sulphide, sericite and chlorite alteration associated mainly with ac type cross-veins is observed on the north limb of the fold and post-dates regional metamorphic porphyroblasts defined by orbicular mineral aggregates, termed orbs. A sinistral NW-SE trending cross-fault offsets the anticlinal hinge ~15 m. Minor gold was found at this location during the construction of the road leading to the Sable Gas Plant.

9.1 Stop #6: Bedrock Geology, Mineralization, and Geochemistry

9.1.1 Introduction

Owing to the lack of direct research on the bedrock geology of this district by the authors of this field trip guide, the following has been summarized from Malcolm (1929), Douglas (1939), and Miller (1989). The Lower Seal Harbour gold district lies on the north limb of the Isaac's Harbour Anticline about 3 km east of Isaac's Harbour. A reported 429,387 tons were milled with an average mill head grade of 0.10 oz./t for a total of 34,350 oz. Au.

9.1.2 Stratigraphy

In addition to specific lode quartz veins, work by Douglas (1939) at the district identified 14 significant slate belts with varying amounts of lode quartz (Table 16). Each was bounded by massive meta-greywacke. The Partington Belt was known to contain a significant amount of fine grained disseminated gold. Based on his 1939 report, Douglas concluded three outstanding facts:

(1) "The ore-shoots are echeloned to the northwest roughly parallel to the Isaac's Harbor Fault."
(2) "In some cases, but by no means in every case, angulars entering the bedded leads from the northeast or southwest appear to bring in gold and a bright shiny mispickel, with a dark clear quartzite gangue."
(3) "The ore-shoots occur in large swells or lenses in the beds. These lenses dip 65 degrees with the beds, have quartzite walls and plunge to the west at angles between 30 and 40 degrees."

9.1.3 Structure

This anticlinal structure plunges gently to the east and is displaced ~400 m along the Isaac's Harbour Fault. Strata, consisting of thickly bedded meta-greywacke, meta-silstone and slate dip 65-75° northward. Based on the presence of NW-SE trending fissure veins and minor faults, similar to those observed in other gold districts, it can be predicted that secondary structures have a strong influence on the location and distribution of high grade ore shoots.

Table 16. *Significant Slate±Quartz "Belts" identified by Douglas (1939) at Lower Seal Harbour. The most productive zones are indicated with a "*".*

Name of Belt	Thickness	Comment
North Victoria		
Goldfinch		Rich drift traced to this belt
"X"		100 m north of the "S" Belt
"S"		
Dan*	1.5 m	~800 m from fold hinge
Percy*	8 m	Contains 40-50% quartz
Ash-McDermot		
New*	10 m	30-40% quartz with interbedded slate and meta-greywacke
Giffin		
Partington*	2.2 m	Only minor quartz content, fine disseminated gold in slate
John Bull*	6 m	Contains quartz lenses and provided highest tonnages
Donkin*	7 m	Merges with the John Bull Belt to become 13 m thick
Taylor*	1 m	Reported to contained the highest grades
Forty		
South Twenty		

9.1.4 Metamorphism

No systematic metamorphic studies have been conducted at the deposit. However, based on samples of dump material, peak metamorphic indicator minerals are dominated by biotite, muscovite and chlorite. At the western extension of the Lower Seal Harbour gold district, along the Sable Road exposure, meta-siltstone and slate lithologies contain abundant orbicular mineral aggregates (orbs) dominated by biotite. Similar orbs may be observed in dump material at this district. These mineral aggregates are often elliptical in shape and preserve the down dip shear direction of other similar deposits (e.g. Tangier, Goldenville, Upper Seal Harbour).

9.1.5 Alteration

Disseminated carbonate, with variable amounts of sulphide minerals, documents the presence of widespread alteration at this district. Minor sericite and abundant sulphide alteration are also observed. In addition, NW-SE trending joints and thin (1 mm to 1 cm) quartz-chlorite-carbonate veinlets have relatively wide (20 cm), bleached alteration haloes adjacent to their margins. There is minor evidence of this alteration in the dump piles at Lower Seal Harbour.

9.1.6 Mineralization

Gold mineralization occurs in both smoky grey quartz veins and grey colored slate host rock in association with arsenopyrite and minor galena, pyrite, pyrrhotite, chalcopyrite and sphalerite. Auriferous quartz veins are both stratabound and discordant in form with an obvious NW-SE oriented *en echelon* geometry suggesting a close spatial association to NW trending faults. Most notable of the vein forms are the NW trending fissure veins that occur in the district, the largest (~8 m) being the "Salt and Pepper" vein, named for its crack-seal texture. Although this vein was not highly productive, similar veins at other deposits do have significant gold associated with them. Gold occurs as mainly of large flakes and crystalline grains. A set of "master angulars" oriented at 075°/47°N produce a ~30° rake where they intersect bedding-parallel quartz veins. This pitch angle is parallel to the high grade ore shoots in the district.

9.2 Surficial Geology

A brief discussion of the surficial geology of this district is provided in the preceding surficial geology section (8.2) for the Upper Seal Harbour district.

9.3 Mining and Milling History

Significant gold mineralization was not discovered in the Lower Seal Harbour district until 1904, when Percy White opened three small leads exposed by previous prospectors and found them to be part of an auriferous belt. Between 1905 and 1915, the Beaver Hat Gold Mining Company, Ltd. and the Seal Harbour Mining Company carried out underground mining on adjacent properties (Malcolm 1929). Both of these companies employed small stamp mills (Fig. 41a), which were transported from the Dolliver Mountain mine near the head of Isaac's Harbour (MacKenzie 1907). Amalgamation was the only gold extraction method used on-site during this period, and sulfide concentrates were sent to the Richardson Mill at Upper Seal Harbour for treatment in the bromo-cyanide plant. Production ceased in 1915 and resumed briefly from 1926 to 1928 using similar technology. In 1934, Seal Harbour Gold Mines Ltd. reactivated the property and carried on larger-scale mining operations until about 1941. The most significant aspect of these latter operations was the construction of a 200-ton-per-day cyanide plant in August 1936 (Fig. 41b), which treated the ore using a combination of cyanide methods and barrel amalgamation (Roach 1937, 1940). From 1905 to 1941, approximately 34,200 oz. of gold were recovered in this district from 435,000 tons of ore (Bates 1987).

9.4 Environmental Geochemistry: Mine Wastes and Waters

The historical milling operations in the Lower Seal Harbour gold district left behind a very large volume of mine tailings, which have been, and continue to be, eroded by local streams and transported more than 2 km to the ocean (Fig. 42). The tailings at this site show a wide range in Hg and As concentrations (Fig. 4), which reflects the extensive use of both amalgamation and cyanidation in this district. Dissolved concentrations of As are very elevated in surface waters draining this district, and enter Seal Harbour more than 2 km from the mine site carrying between 100 and 450 ppb As, depending on the time of year. During the field trip, we will observe several different types of mine waste in this district, including arsenopyrite concentrates containing up to 31 wt.% As.

a)

b)

Figure 41. *(a) View of stamps at the Dolliver Mountain Mine,* ca. *1902. These were transported to the Lower Seal Harbour district in 1905. Photo taken by E.R. Faribault, Geological Survey of Canada. Reproduced with permission from the Earth Sciences Sector Photo Library Collection, Natural Resources Canada, Ottawa; (b) Shaft house, mine buildings, crusher, and ore conveyer leading to the cyanide plant at the Lower Seal Harbour Mine,* ca. *1937 (Nova Scotia Museum of Cultural History Photo P270.286).*

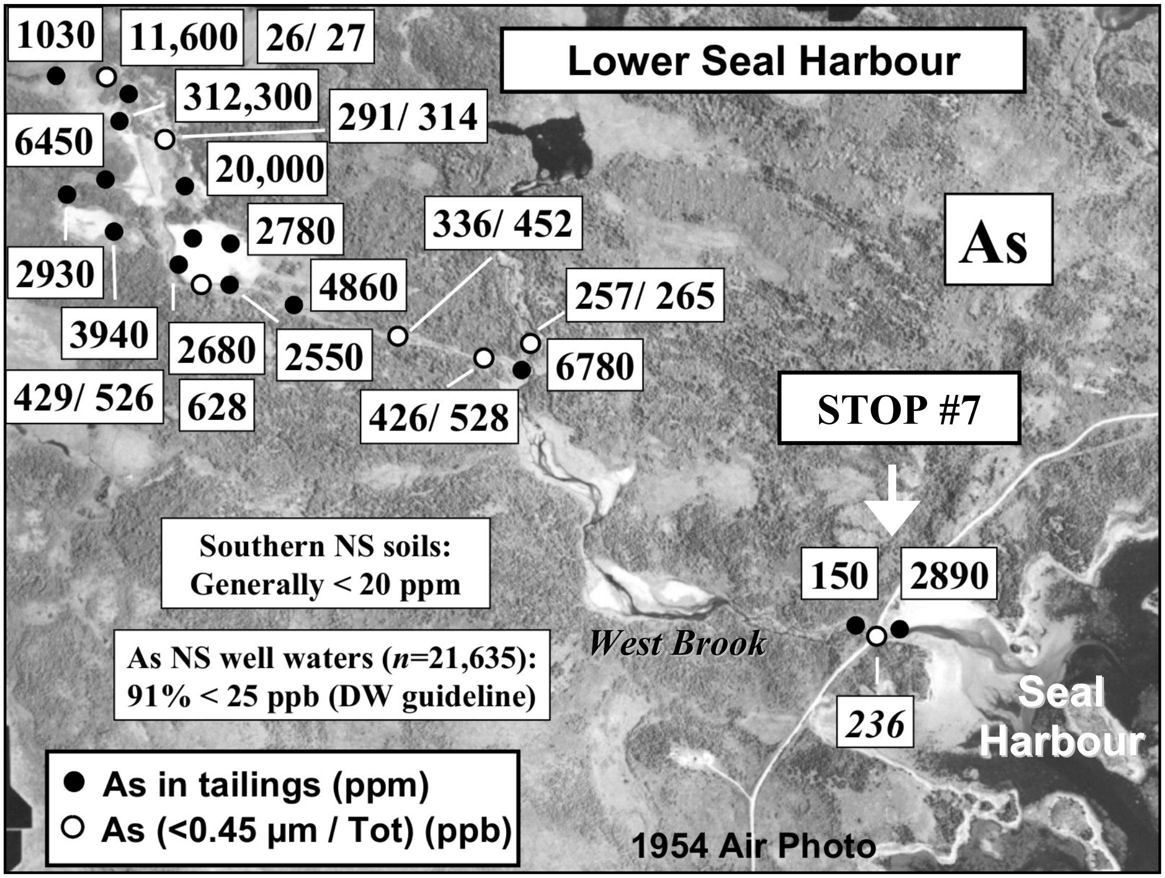


Figure 42. *Concentrations of As in tailings and surface waters in the Lower Seal Harbour Gold District, and in the West Brook drainage system leading to Seal Harbour (in the lower left corner of the image). Fluvial transport of mine tailings has contaminated the intertidal area of Seal Harbour, and led to bioaccumulation of high As levels in shellfish (Airphoto 11F-4 © 1954 Her Majesty the Queen in Right of Canada, reproduced courtesy of Land Information Services, 2005).*

10.0 Stop #7: SEAL HARBOUR

If the tides cooperate, the final stop on this field trip will examine the intertidal zone of Seal Harbour, where gold mine tailings from the Lower Seal Harbour district have entered the ocean via West Brook (Fig. 42). Recent investigations by Environment Canada under the MITE project have documented extremely high concentrations of As in clams from this area. On May 4, 2005, regulatory officials agreed to issue a Precautionary Closure to limit shellfish harvesting from Seal Harbour. Further studies are planned for Summer 2005 to assess the spatial extent of metalloid contamination in the Seal Harbour area in an effort to reduce risks to human health.

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Pre-conference Field Trips

A1 Contamination in the South Mountain Batholith and Port Mouton Pluton, southern Nova Scotia
D. Barrie Clarke and Saskia Erdmann

A2 Salt tectonics and sedimentation in western Cape Breton Island, Nova Scotia
Ian Davison and Chris Jauer

A3 Glaciation and landscapes of the Halifax region, Nova Scotia
Ralph Stea and John Gosse

A4 Structural geology and vein arrays of lode gold deposits, Meguma terrane, Nova Scotia
Rick Horne

A5 Facies heterogeneity in lacustrine basins: the transtensional Moncton Basin (Mississippian) and extensional Fundy Basin (Triassic-Jurassic), New Brunswick and Nova Scotia
David Keighley and David E. Brown

A6 Geological setting of intrusion-related gold mineralization in southwestern New Brunswick
Kathleen Thorne, Malcolm McLeod, Les Fyffe, and David Lentz

A7 The Triassic-Jurassic faunal and floral transition in the Fundy Basin, Nova Scotia
Paul Olsen, Jessica Whiteside, and Tim Fedak

Post-conference Field Trips

B1 Accretion of peri-Gondwanan terranes, northern mainland Nova Scotia and southern New Brunswick
Sandra Barr, Susan Johnson, Brendan Murphy, Georgia Pe-Piper, David Piper, and Chris White

B2 The Joggins Cliffs of Nova Scotia: Lyell & Co's "Coal Age Galapagos"
J.H. Calder, M.R. Gibling, and M.C. Rygel

B3 Geology and volcanology of the Jurassic North Mountain Basalt, southern Nova Scotia
Dan Kontak, Jarda Dostal, and John Greenough

B4 Stratigraphic setting of base-metal deposits in the Bathurst Mining Camp, New Brunswick
Steve McCutcheon, Jim Walker, Pierre Bernard, David Lentz, Warna Downey, and Sean McClenaghan

B5 Geology and environmental geochemistry of lode gold deposits in Nova Scotia
Paul Smith, Michael Parsons, and Terry Goodwin

B6 The macrotidal environment of the Minas Basin, Nova Scotia: sedimentology, morphology, and human impact
Ian Spooner, Andrew MacRae, and Danika van Proosdij

B7 Transpression and transtension along a continental transform fault: Minas Fault Zone, Nova Scotia
John W.F. Waldron, Joseph Clancy White, Elizabeth MacInnes, and Carlos G. Roselli

B8 New Brunswick Appalachian transect: bedrock and Quaternary geology of the Mount Carleton – Restigouche River area
Reginald A. Wilson, Michael A. Parkhill, and Jeffrey I. Carroll

B9 Gold metallogeny in the Newfoundland Appalachians
Andrew Kerr, Richard J. Wardle, Sean J. O'Brien, David W. Evans, and Gerald C. Squires