HALIFAX 2024

ICARD

SEPTEMBER 16 TO 20, NOVA SCOTIA, CANADA

Halifax Airport Water Treatment Plant and Montague Gold District, Nova Scotia

Field Excursion Guidebook
September 20, 2024

Field Trip Leaders

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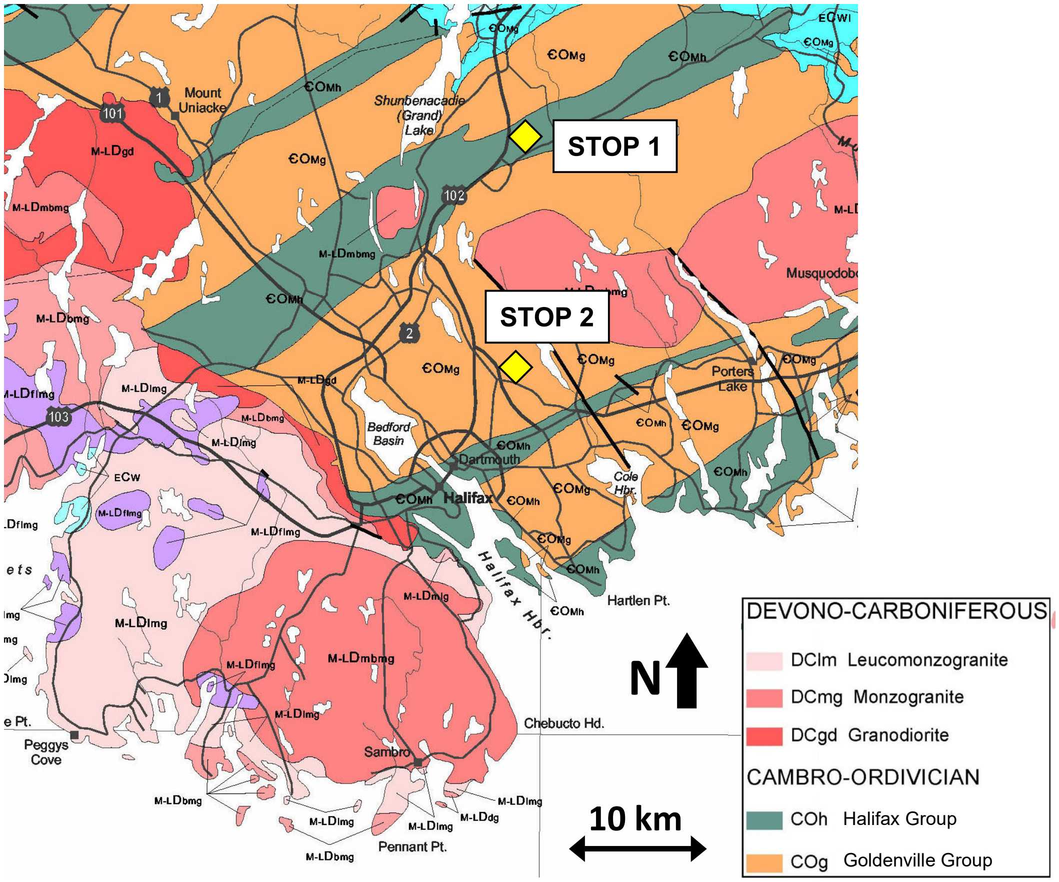
FIELD TRIP ITINERARY

Time	Event
8:30 am	*Board bus at Halifax Convention Centre*
9:30 - 11:30 am	Stop #1: Halifax Airport Water Treatment Plant
12:15 - 1:30 pm	*Lunch (Mic Mac Bar & Grill)*
1:45 - 4:00 pm	Stop #2: Montague Gold Mines
5:00 pm	*Arrive at Halifax Convention Centre*



Bedrock geology map of Halifax region (Keppie 2000)

ACKNOWLEDGMENTS

Some sections of this field guide dealing with acid rock drainage in the Halifax region were written by Terry Goodwin (formerly Senior Geologist with the Nova Scotia Dept. of Natural Resources, now with Lithium Springs, Ltd.). Melissa Lee (Sustainability & ESG Manager, Halifax International Airport Authority) is thanked for organizing our tour of the water treatment facility at the Halifax Stanfield International Airport. Finally, Chantal Murphy (Event Operations Manager, Canadian Institute of Mining, Metallurgy and Petroleum) is acknowledged for kindly arranging the bus rental and her assistance with the field trip logistics.

SAFETY PROCEDURES

1. SAFETY CLOTHING: Long pants, sturdy footwear (with closed toes), and high-visibility vests are required at both field trip stops. Safety vests will be provided at the beginning of the trip.

2. ROCK HAMMERS: If you would like to use your rock hammer at Montague, please wear protective glasses or goggles when hammering and maintain a safe distance from others.

3. ABANDONED MINE OPENINGS: We will be visiting the Montague Gold District as part of our field trip. Numerous deep shafts, open pits and trenches characterize this former mine. Many (but not all) of these openings are flagged with warning signs and flagging 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 do not venture too close to shafts or old trenches.

4. HAND WASHING: The tailings at Montague Gold Mines contain variable amounts of arsenic-bearing minerals (e.g. arsenopyrite, scorodite), and other reagents (e.g. mercury) left over from historical milling and metallurgical practices. Please be careful not to place food on the tailings and wash your hands thoroughly before eating.

5. FIRST AID: A First Aid Kit will be in the lead vehicle. One of the field trip leaders, Michael Parsons, is a certified First Aider. Field trip participants with medical conditions (allergies, diabetes, etc.) may wish to advise the field trip leaders of any concerns prior to departure. All personal medical information will be treated with the strictest confidence.

6. TICKS: Nova Scotia is home to blacklegged ticks, which can cause illnesses like Lyme disease. Ticks can be found in or near woods, shrubs, leaf litter, long grass, parks, and gardens. Please wear long pants (possibly tucked into your socks), avoid walking in tall grass, and check yourself for ticks after the field trip concludes (for more tips, see https://novascotia.ca/ticksafety/).

7. In the unlikely event of an emergency: **DIAL 911**

REGIONAL GEOLOGY OF NOVA SCOTIA

Introduction

Most of the rocks we will be seeing during this field trip belong to the Cambro-Ordovician Meguma Supergroup (Fig. 1). This supergroup consists of the lower metasandstone-dominated Goldenville Group and the overlying slate-dominated Halifax Group, with a combined vertical thickness of at least 11 km. These sediments were deformed and regionally metamorphosed to greenschist to upper amphibolite facies during the mid- to late Devonian Acadian Orogeny, then intruded by large volumes of granitoid rocks between 385 and 357 million years ago (Ma).

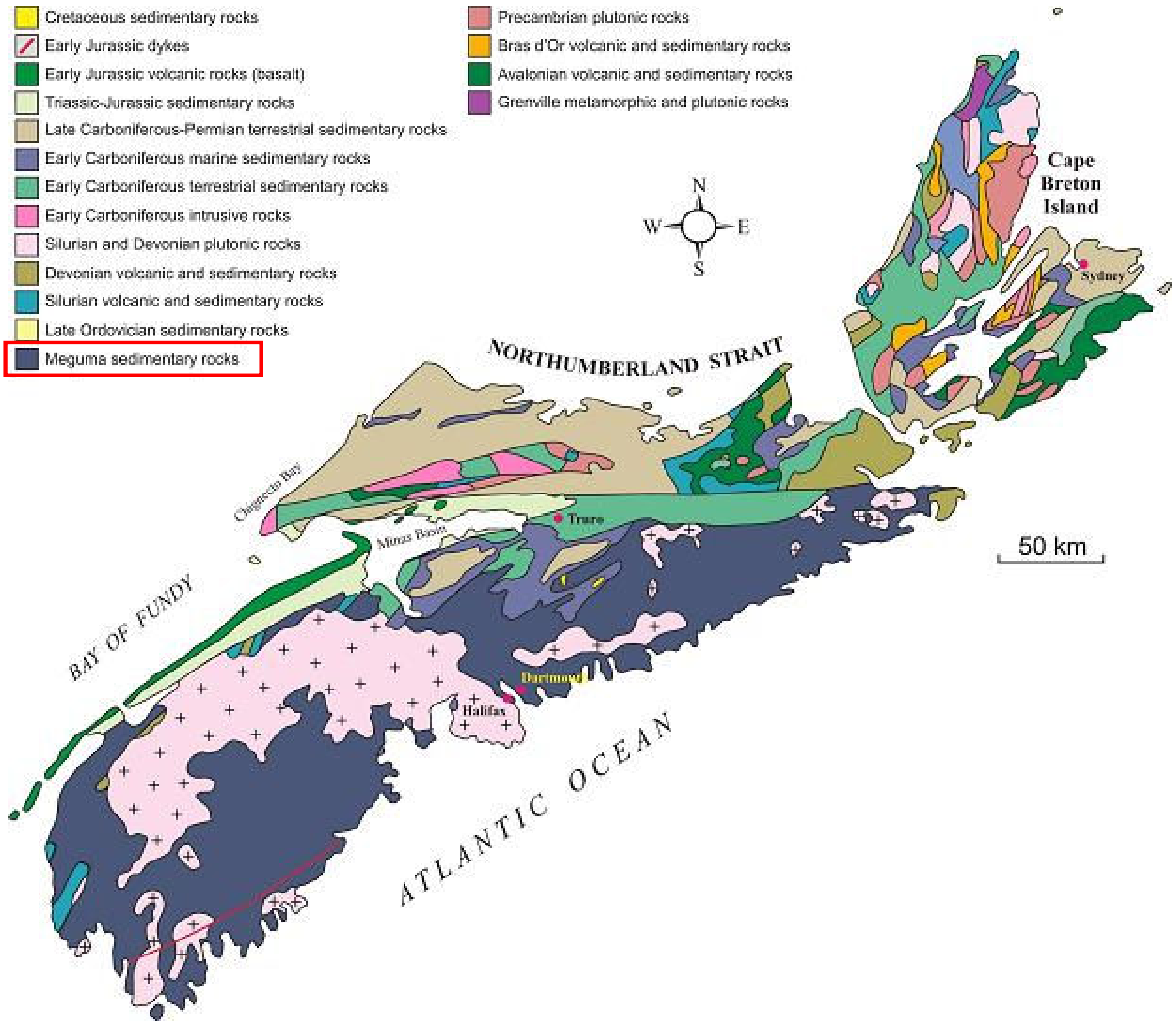


Figure 1: Simplified geology map of Nova Scotia. From Atlantic Geoscience Society (2022).

Overview of Meguma Supergroup Bedrock Geology

Mainland Nova Scotia, south of the Cobequid-Chedabucto Fault Zone, is referred to as the Meguma Terrane. The southwestern portion of the Meguma Terrane consists predominantly of Cambrian to Ordovician metasedimentary rocks intruded by granite (Figs. 1,2). Overlying these early to middle Paleozoic rocks are sequences of sedimentary and volcanic rocks of Carboniferous and Triassic age.

The Cambro-Ordovician Meguma Supergroup rocks are interpreted as a continuous sequence of deep-water turbidites (deep sea sediments). The metasedimentary sequence consists of the basal Goldenville Group characterized dominantly by metasandstone (commonly referred to as greywacke, wacke or quartzite), with lesser amounts of interbedded slate and calcareous units. The overlying Halifax Group consists of slates of various colours and lesser amounts of metasandstones, metasiltstones, and calcareous units (Fig. 2).

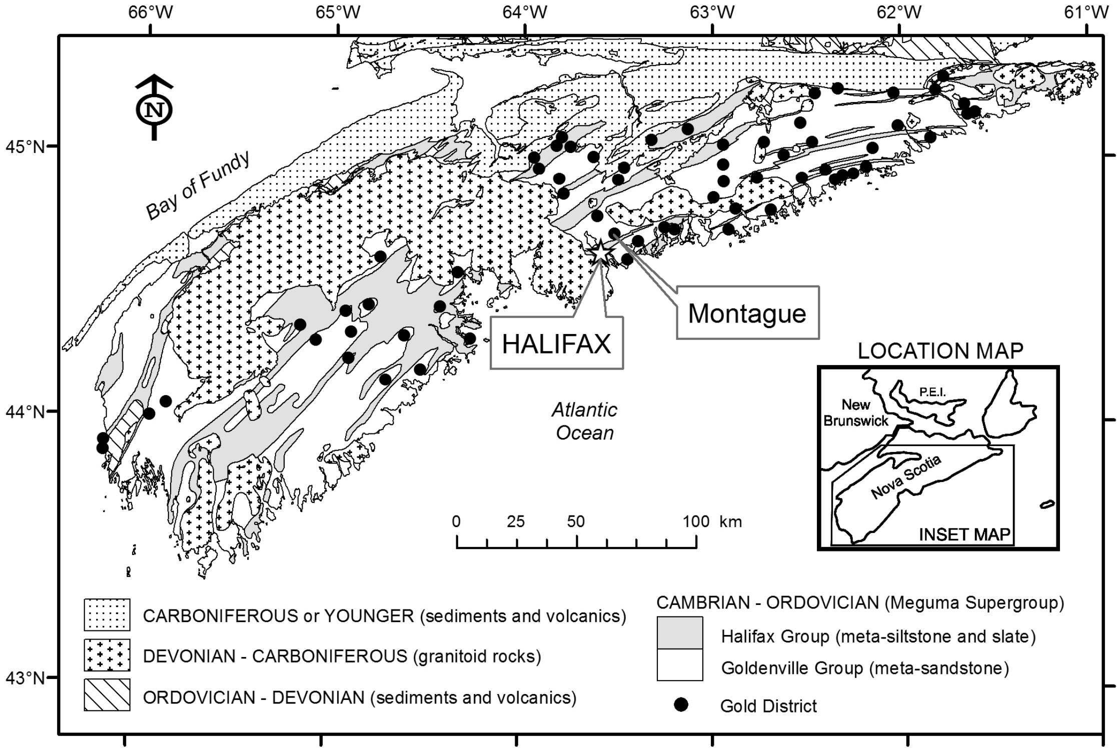


Figure 2: Generalized geological map of southern Nova Scotia, showing the Goldenville (white) and Halifax (grey) groups of the Meguma Supergroup, and the location of the Montague gold district. After Ryan and Smith (1998), with bedrock geology simplified from Keppie (2000).

The Meguma Terrane was deformed during the Devonian Acadian Orogeny (400 +/- 10 Ma) into regional scale, upright, northeast-trending folds and is characterized regionally by greenschist to amphibolite facies metamorphism that accompanied the middle-to-late stages of the Acadian deformation. The regional metamorphic grade throughout the Meguma is variable, but systematic, and ranges from chlorite and biotite grade in the central region up to andalusitestaurolite-cordierite grade and sillimanite grade in the eastern and southwestern ends.

Widespread intrusion (South Mountain Batholith) of the Meguma Zone metasedimentary rocks by post-tectonic peraluminous granite (ca. 380 Ma; Fig. 2) resulted in an extensive, superimposed thermal contact aureole. The granitic units contain the major minerals quartz, plagioclase, alkali feldspar, biotite, and muscovite in varying proportions.

Gold mineralization is present throughout the entire Meguma Supergroup stratigraphy. However, most historical gold production has come from auriferous quartz-carbonate veins within the basal Goldenville Group. Mineralization also occurs in granite of the South Mountain Batholith. For example, significant tin, lithium, and uranium deposits have been found in granite from the East Kemptville, Brazil Lake, and Millet Brook areas, respectively.

Acid Rock Drainage in the Meguma Supergroup

Throughout much of southwestern Nova Scotia, rocks of the Halifax Group contain abundant sulphide minerals, including pyrrhotite [$Fe_{1-x}S$], pyrite [FeS_2], and arsenopyrite [FeAsS]. When exposed to air, water, and bacteria, oxidation of these sulphides leads to the formation of acid rock drainage (ARD) and the release of acidity and metal(loid)s to downstream environments (Fox et al., 1997). This situation is especially true in metropolitan Halifax Regional Municipality, where slates and metasiltstones of the Cunard Formation are enriched in sulphides and continually being disturbed during construction activities (e.g. roadbuilding, housing development, well drilling). The presence of ARD is relatively easy to recognize by the rusty orange-yellow precipitates that form where iron-rich water flows out of the ground (Fig. 3).

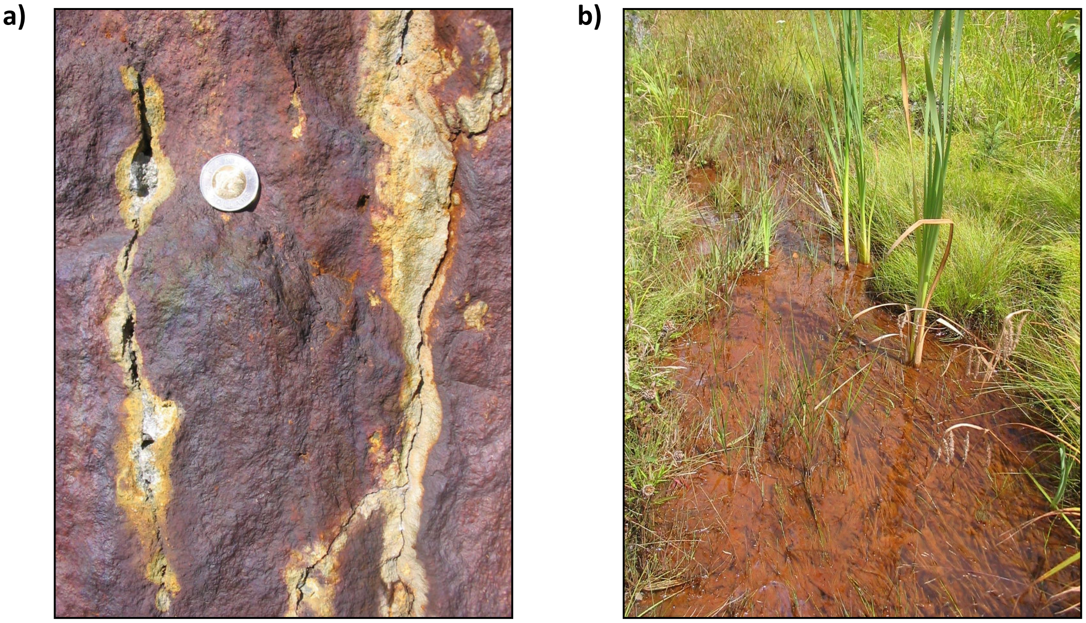


Figure 3: (a) Weathered slates of the Halifax Group showing oxidation of arsenopyrite along cleavage planes; (b) ferric (oxy)hydroxide precipitates in a roadside ditch receiving acid rock drainage.

Oxidation of sulphide minerals in the Halifax Group has led to fish kills and lake acidification throughout the Halifax region and in other areas of southwestern Nova Scotia (White and Goodwin, 2011). Acid rock drainage has also contaminated drinking water sources, adversely affected the growth and reproduction of aquatic plants and animals, and led to corrosion of infrastructure such as pipes and transmission towers. Recent geological mapping has improved our knowledge of the location of sulphide-rich bedrock throughout the province (Fig. 4) and helped to reduce costly problems associated with the onset of ARD and water treatment.

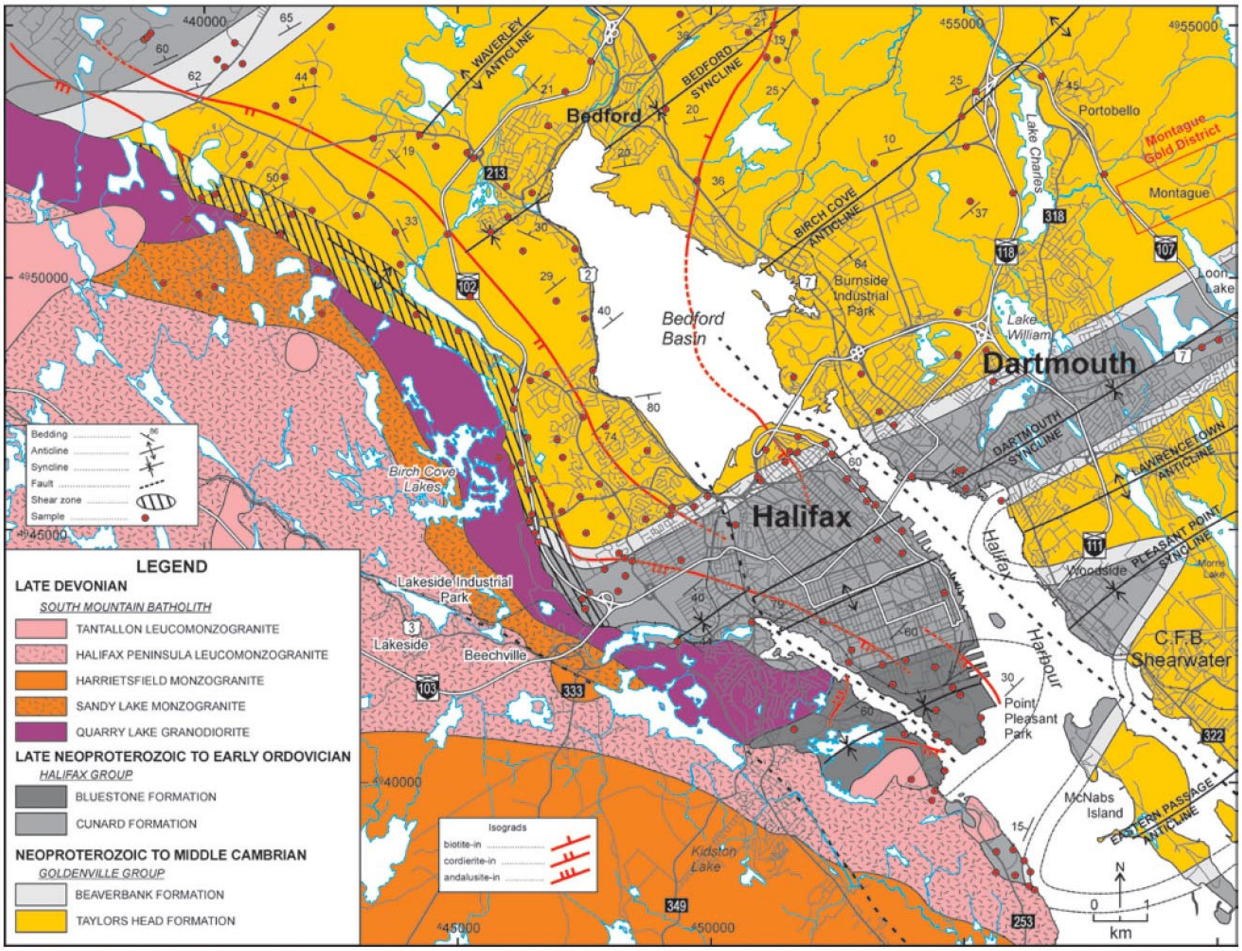


Figure 4: Simplified geological map of metropolitan Halifax (from White and Goodwin, 2011)

In 1995, the Province of Nova Scotia passed the *Sulphide Bearing Material Disposal Regulations* under the *Environment Act* to help developers identify sulphide-bearing rocks and to handle these materials effectively when they are disturbed. If disturbance is unavoidable, rocks and surficial materials with a sulphide content equal or greater than 0.4 weight percent must be managed according to these regulations and disposed only at approved sites.

STOP #1: HALIFAX AIRPORT WATER TREATMENT PLANT

Safety Hazards – This is a controlled industrial site. High-visibility vests are required. Please pay attention to the on-site safety presentation and observe all safety rules.

Introduction – The Halifax Stanfield International Airport occupies approximately 1000 hectares of land. The site was chosen because it is the highest point in the immediate area and studies indicated the site was relatively fog-free. Construction of the airport began in 1955 with the first commercial flights beginning in 1960. Abundant Cunard Formation slate was locally available and used extensively in the construction of the airport and associated infrastructure.

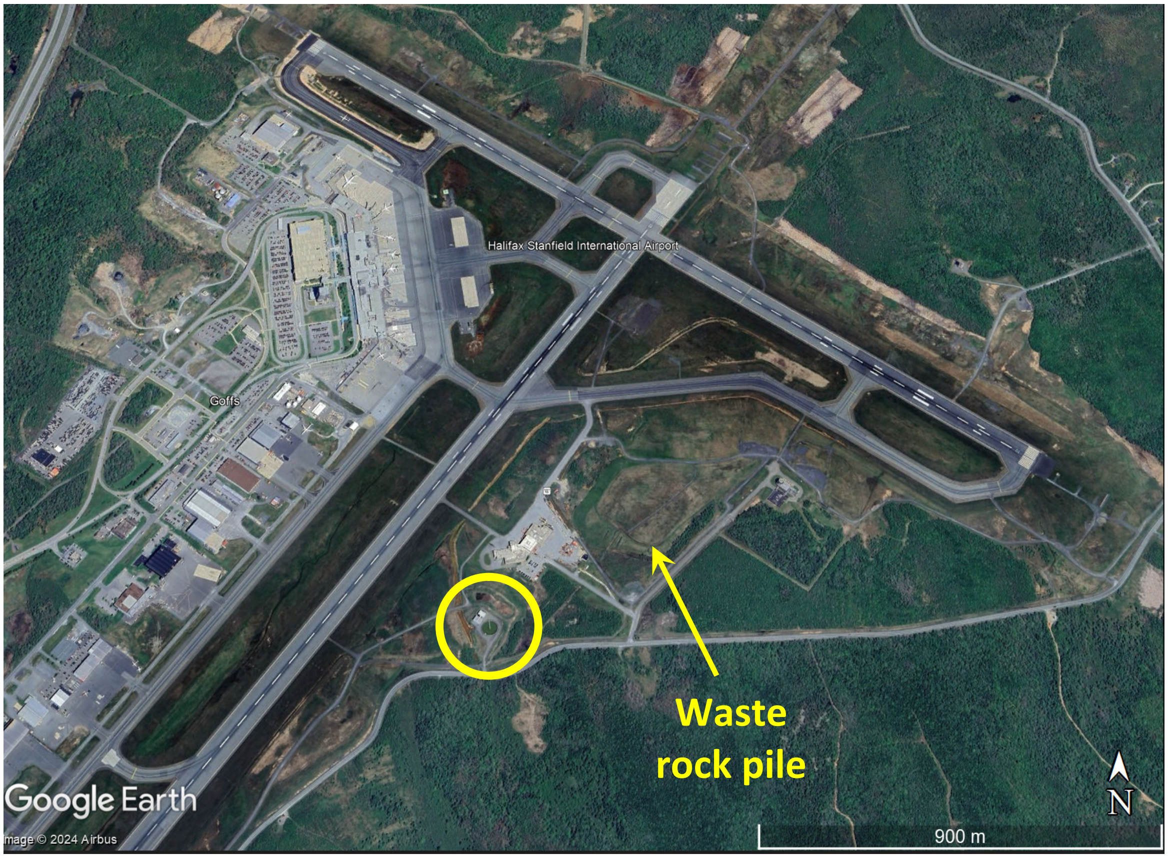


Figure 5. Water treatment plant (yellow circle) at Halifax Stanfield International Airport (Google Earth).

Bedrock Geology – The airport is underlain by slates and metasiltstones containing abundant pyrite, arsenopyrite, and pyrrhotite. Numerous quarries were used for aggregate during construction of the airport, associated infrastructure, and subsequent expansions. Five of these quarries were located in the sulphidic Cunard Formation. Besides the quarries, ground disturbance of the Cunard slates occurred during leveling and infilling of the airport and along Highway 102 including the interchange to the airport. A large waste rock pile (Fig. 5), now covered under glacial till, remains as a legacy of these activities (Lund et al. 1987; Hicks, 2003).

Mineralogy – Historical accounts of the sulphide mineralogy indicate pyrite was typically the only sulphide mineral present in the Cunard Formation slates. More recent mineralogical studies and airborne magnetic surveys show that pyrrhotite is also a major constituent (Fox et al., 1997; White and Goodwin, 2011). The abundance of pyrrhotite helps to explain the widespread occurrence of ARD in the Halifax Group, as the abiotic oxidation rate of pyrrhotite can be up to 100 times faster than the oxidation rate of pyrite (Nicholson and Scharer, 1994).

ARD Issues (History) – Fish kills attributed to the construction of the airport runways and the terminal buildings date as far back as 1960 (Table 1). It was not until 1976, however, that the cause of the fish kills was recognized as ARD emanating from the airport (and associated quarries). The magnitude of this issue became apparent in 1982 following the excavation of 300,000 cubic metres of bedrock during taxiway construction. Plans were developed to minimize the effects of ARD and to find a long-term solution to this re-occurring problem.

Table 1. Fish Kills in the Shubenacadie River downstream of the Halifax Airport (EPS, 1976)

CONSTRUCTION PROJECT	YEAR(S)	MAJOR FISH KILLS
Terminal and Runways	1957-1960	September 1960
Imperial Oil	1959-1960	
IMP Hanger (large)	1959	
IMP Hanger (small)	1961	
Air Canada Hanger	1961	
Air Halifax Hanger	1961	October 1961
Highways slate needs	1965	October 1965
Avis Service Station	1966	September 1966
Highways slate needs	1968	November 1968
Halifax Flying Club	1970	
Mobil Oil Hanger	1972	
Highway Overpass	1974	August 1974
Aircon Tank Farm	1975	October 1975
EPA Hanger	1976	September 1976

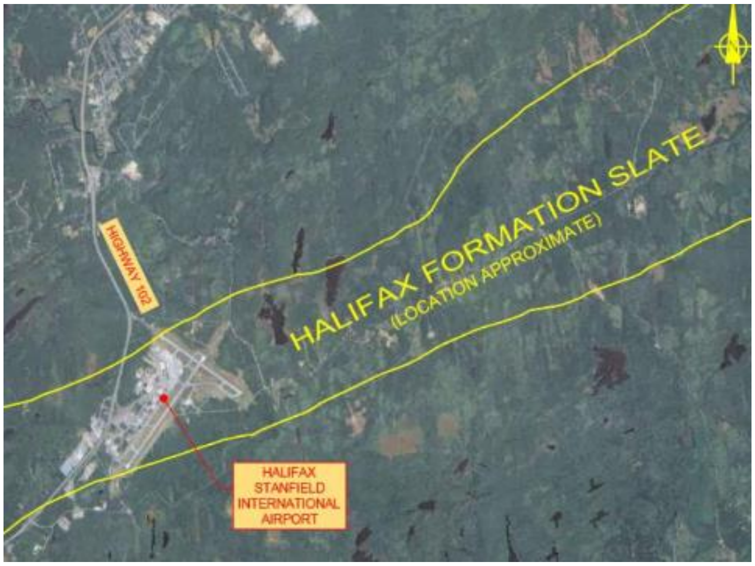
Mitigation – One of the first measures implemented in the early 1980s was the construction of a temporary lime treatment facility. By 1987, low permeability glacial till had been used to cover the waste rock pile. Surface water diversion involving the collection and subsequent treatment of all runoff and runway tile drainage is the main method used to control ARD today. A series of ditches and pumping stations drain most of the surface water and transport it to an on-site treatment facility. Locally, crushed limestone is used to treat drainage that is not diverted to the treatment facility (Hicks, 2003).

The following two-page handout from the Halifax International Airport Authority summarizes recent efforts to mitigate ARD issues at the airport over the last two decades.

Halifax Airport Treatment Plant

BACKGROUND

The Halifax International Airport Authority (HIAA) has been responsible for the operation and management of the Halifax Stanfield International Airport since 2000.



The presence of pyritic slate, often shallow, is widespread across the airport site and surrounding area. The sulphide-bearing geological formation that contributes to acid generation is the *Halifax Slate Formation* of the Meguma Group.

Development and construction of the airport terminal building and runways has resulted in the exposure of acid slate in the past. In 2001, a pyritic slate management plan was created which included the construction of a collection system and treatment facility to manage discharges of acid rock drainage (ARD) from airside areas under an operating approval issued by Nova Scotia Environment and Climate Change (NSECC). The purpose of the treatment plant is to neutralize the water and to remove total suspended solids (TSS) and metals.

TREATMENT SYSTEM

The system consists of a gravity collection system, pump stations, forcemains, and holding ponds. There are three primary watersheds on site that feed to the treatment plant including the North Brook, Leech Brook, and McDowell Brook storage areas. A dominant characteristic of the three watersheds and associated drainage system is the very shallow grade of most infrastructure. Although not ideal for typical stormwater systems, this is a product of the nature of airport runways, taxiways, and aprons which need to be very flat to allow planes to travel safely. This aspect, however, greatly reduces the ability of the site to drain efficiently and precludes any opportunity to allow for infiltration of runoff to adjacent lands without treatment. Additionally, the shallow slopes encourage water to pond and reduce the speed at which water can drain from the site during high rainfall events.

The North Brook drainage area draws water from a storage pond. The pond provides storage for large precipitation events with the intent that it would be pumped down to pre-storm levels with 3 days after a 2-year 24 hour return storm and 4 days after a 25-year 24 hour return storm.

The McDowell Brook drainage area, which is the location of the treatment plant, has a maximum design pumping rate of 1,900 m^3/hr. A storage pond receives pumped flow from Leech Brook and North Brook, in addition to gravity flow from the McDowell Brook drainage area.

The effluent from the plant is continuously monitored for pH. If the pH of the effluent is lower than the set pH value, the effluent is directed back to the McDowell Brook storage pond for additional treatment. Effluent is also recycled in the winter to maintain flow through the clarifier to prevent freeze up.

Lime neutralization is used to neutralize the ARD and generate metal hydroxides with metal cations such as iron, zinc, aluminum, manganese, cadmium, copper and lead. The hydroxide precipitate is removed in the downstream clarifier.

Polymer is added between the neutralization tank outlet and clarifier inlet. The polymer coagulates the hydroxides creating larger, denser particles with improved settling properties. The resultant sludge is settled out in the clarifier and the clarified water is then discharged. HIAA conducts weekly water quality monitoring and the resulting lab results are compared to the criteria established in the operating approval.

CLIMATE CHANGE RISK ASSESSMENT

In 2021, HIAA engaged a consultant to conduct a climate change risk assessment to analyze potential climate-related impacts to airfield assets at the airport. The project involved analyzing the vulnerability and risks associated with severe weather and climate change to the airside stormwater assets using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol. The overall objective of the assessment was to identify and prioritize actions and strategies to improve the resilience and adaptability of the airside infrastructure and operations to a changing climate. Following this study, a multi-year capital project that prioritizes risk mitigation measures at the treatment plant was developed and is now underway.

OVERVIEW OF GOLD MINING IN NOVA SCOTIA

(for details on references cited in text, see Parsons et al. 2012 (GSC Open File Report 7150) and Parsons & Jamieson, 2024 (ICARD Paper #147))

Location and Geological Setting

There are more than 300 documented gold occurrences throughout mainland Nova Scotia, most of which are located within 64 formal gold districts defined by the provincial government in the late 1800s and early 1900s for claiming purposes (Fig. 2). The gold deposits can be divided into three main types: (1) high-grade (~15 g/t Au), narrow gold-bearing quartz veins; (2) low-grade (0.5–4 g/t Au) slate-argillite hosted; and (3) low-grade (0.5–5.5 g/t Au) meta-sandstone hosted. Almost all historical production has come from high-grade quartz veins located within 200 m of the surface (Ryan and Smith, 1998). These veins are primarily hosted by metasandstones and slate of the Cambro-Ordovician Meguma Supergroup (Fig. 2).

Most of the gold-bearing quartz veins are located within the Goldenville Group, are structurally controlled, and generally occur in proximity to anticlinal fold hinges (Sangster 1990). The most abundant accessory minerals in the quartz veins include chlorite, biotite, muscovite, and plagioclase. Carbonates (ferroan dolomite to ankerite and calcite) and sulfides are associated with all types of auriferous veins. Arsenopyrite is the predominant sulfide, with variable amounts of pyrrhotite, pyrite, chalcopyrite, galena and rare sphalerite and molybdenite (Kontak and Jackson 1999, Morelli *et al.* 2005). Although there has been much debate regarding the genesis of these auriferous veins (e.g. Graves and Zentilli 1982; Haynes 1983, 1987; Kontak *et al.* 1990; Sangster 1990; Morelli *et al.* 2005), high-grade, plunging gold ore shoots within bedding-parallel veins have historically provided the best economic potential for mining. In recent years, exploration has shifted to shallow, low-grade (<1–4 g/t Au), high-tonnage (~10–20 Mt) Au resources in the Meguma terrane and mining by open pit methods (Kerr et al. 2021).

Mining and Milling History

Nova Scotia has a long history of gold mining dating back to the mid-1800s, which continues to the present day (Fig. 6). Most of this mining took place in 64 gold districts containing hundreds of individual mines located across the southern mainland of Nova Scotia (Parsons et al. 2012). Between the 1860s and 1940s, gold-bearing ore was crushed to sand- or silt-sized material using stamp mills or ball mills, then the gold was extracted using mercury (Hg) amalgamation techniques (Fig. 7). Beginning in the 1890s, gravity separation, roasting, chlorination, and cyanidation were also added to the milling circuit at some mines to recover gold from sulphide minerals and older tailings, but Hg amalgamation remained an essential part of most mills until the 1940s (Bates, 1987). During this time, approximately 3,000,000 tonnes of tailings were deposited into lakes, streams, wetlands, or other low-lying areas (Figs. 7, 8).

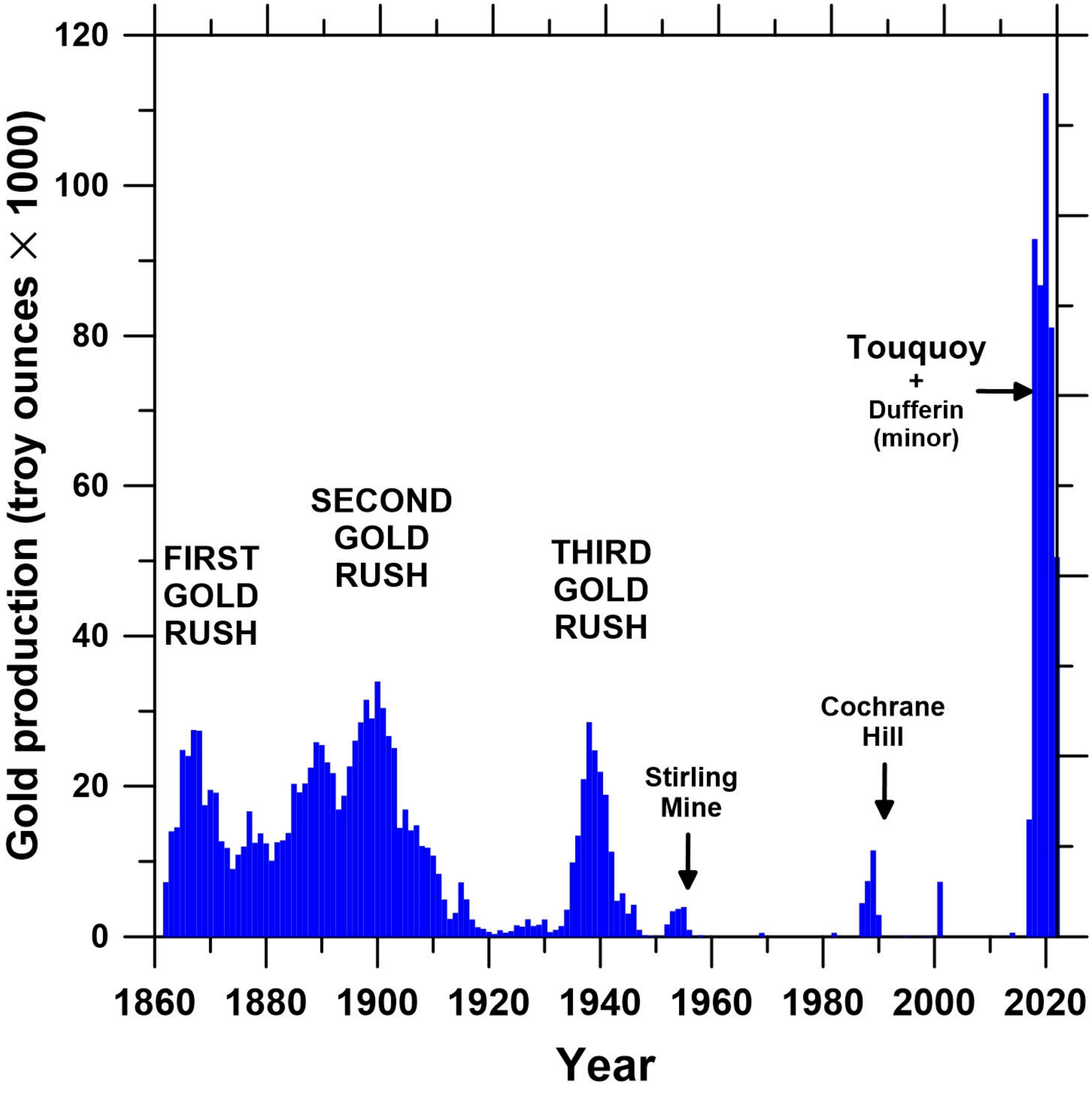


Figure 6. Production of gold in Nova Scotia from 1862 to 2022. Most historical production came from underground mines, whereas large-scale, open pit mining was used to mine disseminated gold at the Touquoy deposit in Moose River from 2017 to 2023 (after Bates (1987), Nova Scotia Department of Mines (1961), and Nova Scotia Department of Natural Resources and Renewables (2024)).

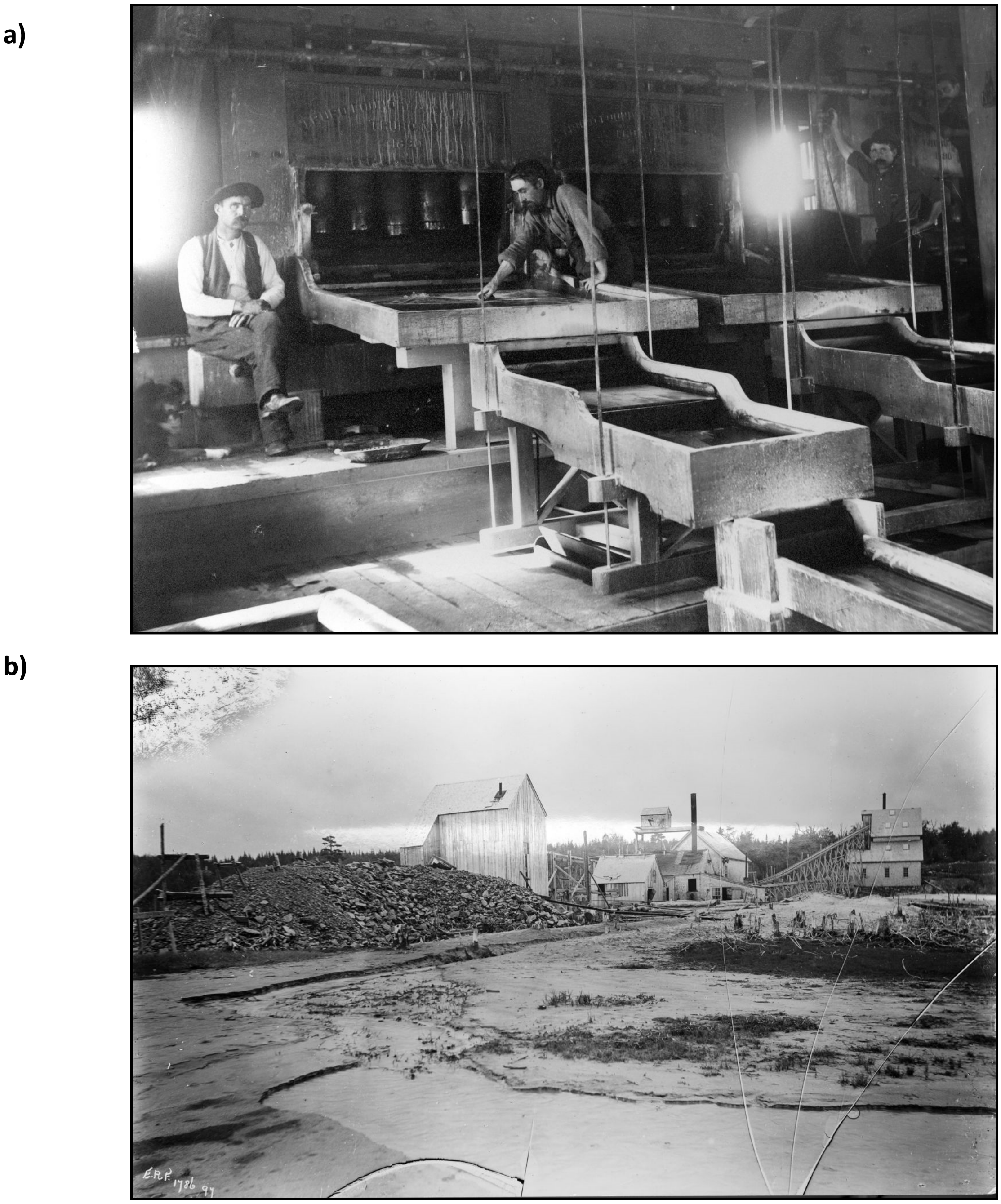


Figure 7. (a) Recovery of Hg amalgam from copper-plated amalgam tables in the 20-stamp mill, Dufferin Gold Mine, Salmon River, Nova Scotia, 1893. The suspended shaking tables below the amalgam plates were used to recover sulfide concentrates (predominantly arsenopyrite). Tailings from each table were discharged from the mill via a wooden trough. **(b)** Unconfined tailings disposal into the Tangier River from 10-stamp mill at the Mooseland gold mining district in 1897. Photos taken by E.R. Faribault, Geological Survey of Canada and reproduced with permission from NRCan**.**

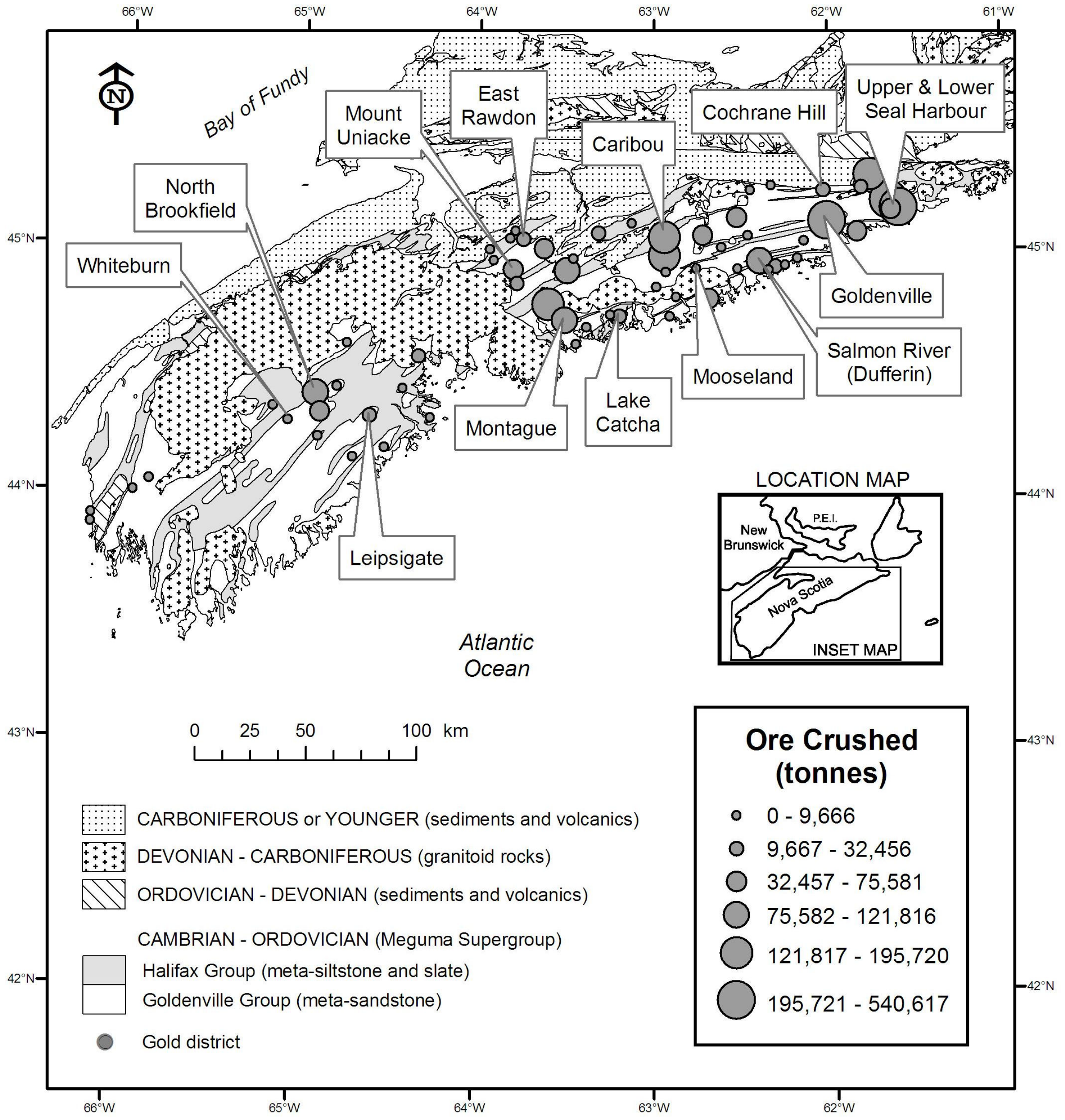


Figure 8. Generalized geological map of southern Nova Scotia, showing the location of historical gold districts within rocks of the Meguma Supergroup, after Ryan and Smith (1998), with bedrock geology simplified from Keppie (2000). Graduated symbols show the total tonnes of ore crushed in each district from 1862 to 2011 (Nova Scotia Department of Mines (1961), and pers. comm. P.K. Smith (2011)), which is roughly equivalent to the total volume of tailings at each site (Parsons et al. 2012).

Environmental Legacy of Historical Gold Mining in Nova Scotia

Although most Nova Scotian gold mining districts have been abandoned for decades, a legacy of environmental contamination remains at the historical mill sites and tailings disposal areas (Parsons et al. 2012; Drage, 2015; Hennick and Poole, 2024b). Mine tailings from these early milling operations were generally deposited in low-lying areas or local waterbodies with little or no consideration of their impacts on receiving environments. In addition to high Hg contents, the tailings typically also have elevated arsenic (As) concentrations, as arsenopyrite is a commonly occurring sulphide mineral in the auriferous veins and surrounding host rocks.

The first investigation of human health risks associated with historical gold mine wastes in the province took place in 1976, when a resident living near a past-producing gold district (Waverley) was diagnosed with chronic arsenic intoxication (Hindmarsh et al. 1977). Examination of the patient's dug well established that it was receiving groundwater from both tailings and waste rock deposits, and their tap water contained 5000 µg/L arsenic – 500 times the present-day drinking water guideline of 10 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). Investigations by the *Provincial Arsenic Task Force* in the late 1970s resulted in a list of recommendations to help protect Nova Scotians from high levels of As in groundwater, and eventually led to the provision of a new public drinking water supply based on treated surface water for residents in the Waverley area. Throughout the 1980s and 1990s, there were additional studies of gold mine wastes at some of the larger abandoned mines throughout Nova Scotia (see Parsons et al. 2012). These studies confirmed that the tailings generally have high concentrations of both As and Hg, and at some sites (e.g. Caribou, Goldenville, Montague, Oldham), these mine wastes have contaminated downstream environments. However, the potential ecosystem and human health risks at most abandoned mine sites were still not well understood, and many mining districts remained unstudied.

Over the last several decades, ongoing residential development, industrial construction, and recreational activities (e.g. ATV, dirt bike and 4X4 racing) have increased the potential for human exposure to these mine wastes. In 2003, Natural Resources Canada initiated a multi-disciplinary, multi-partner investigation of the dispersion, transformation, and fate of metals and metalloids in freshwater and marine environments surrounding 14 abandoned gold mines throughout Nova Scotia. Project partners included the Nova Scotia Department of Natural Resources, Environment Canada, Fisheries and Oceans Canada, and four universities (Queen's University, University of Ottawa, Dalhousie University, and the Royal Military College). Early results from these studies contributed to the formation of a Provincial–Federal *Historic Gold Mines Advisory Committee (HGMAC)* in 2005, which evaluated the ecological and human health risks associated with these gold mines in more detail and issued warnings to help reduce human exposure to tailings (Parsons et al. 2012, Drage 2015; Nova Scotia Environment 2017).

Since 2005, there have been many detailed studies of historical gold mine wastes throughout Nova Scotia. This research has helped to characterize the geochemistry and mineralogy of the tailings (e.g., Walker et al. 2009; Corriveau et al. 2011a, 2011b; DeSisto et al. (2011, 2016); Parsons et al. 2012) and their impact on both marine and terrestrial ecosystems (e.g. Koch et al. 2007; Whaley-Martin et al. 2012; Walker and Grant, 2015; Doe et al. 2017; see LeBlanc et al. 2020 for a review). Studies have also focused on informing environmental and human health risk assessments by examining the naturally occurring levels of As and Hg in forest soils within selected gold districts (Parsons and Little, 2015) and the bioaccessibility of As and Hg in the mine wastes (e.g., Laird et al. 2007; Meunier et al. 2010a). Recent research has also helped to optimize methods for remediating these contaminated sites (e.g., Kavalench, 2010; Hosney and Rowe, 2013; DeSisto et al. 2017; Chapman et al. 2020) and support the natural recovery of tailing-impacted wetlands (see https://www.ap.smu.ca/~lcampbel/Gold.html).

Following a preliminary analysis of potential risks at most of the 65 historical gold districts in Nova Scotia, the Province of Nova Scotia carried out Environmental Site Assessments at the Montague and Goldenville districts in 2007 and 2008 (C.J. MacLellan & Associates, Inc. 2009; Maritime Testing, Ltd. 2009). In July 2019, the Province announced plans to remediate the tailings at Montague and Goldenville and committed to evaluating dozens of other abandoned mines in the province (Build Nova Scotia, 2024). Detailed remedial design work for the Montague site has been completed and construction activities will begin in 2025.

Reprocessing of historical gold mine tailings in Nova Scotia could reduce their associated environmental liability by removing As, Hg, and sulphide minerals, while recovering valuable gold to help offset the costs of remediation activities. Modern attempts to assess and reprocess the tailings began in the 1980s, but most projects met with limited success and focused exclusively on recovering gold and not on reducing environmental impacts. Over the last decade, growing interest in mine waste reprocessing and reclamation has led to new proposals to excavate the tailings at several sites and reprocess these using modern milling technologies and novel metallurgical flowsheets. Ideally, these methods would recover gold, reduce the concentrations of deleterious elements, minimize the tailings footprint, and produce byproducts (e.g., gypsum, silica) suitable for secondary applications (Cheng and Parsons, 2020).

STOP #2: MONTAGUE GOLD MINES

The Montague Gold District is located in the community of Montague Gold Mines near the urban core of Halifax Regional Municipality (Fig. 2; 44.714949°, -63.521709°). Mining was carried out continuously from 1863 to 1928, then intermittently until 1940, and produced 68,139 troy ounces of gold from 132,158 tonnes of crushed ore (Bates, 1987; Parsons et al. 2012). Most of this gold was mined from narrow quartz veins that occur along the southern limb of a large anticline (a convex-upward fold) in metasandstones and slates of the underlying Goldenville Group. In general, miners used surface trenches to locate these steeply dipping quartz veins, then sunk multiple shafts all along the vein to access the gold ore at depth (Fig. 9; Malcolm, 1929). In most cases, horizontal tunnels called 'drifts' were dug between these shafts underground to mine out as much of the gold-bearing quartz as possible, as well as 'crosscuts' driven perpendicular to bedding to locate and access additional auriferous veins.

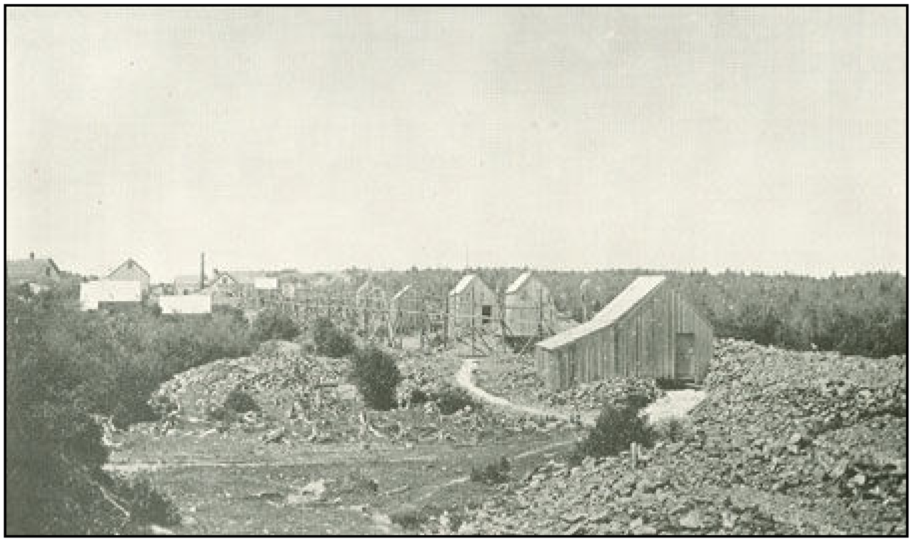


Figure 9. Surface plant of the New Albion gold mine at Montague Gold Mines in 1911, showing headframes over parallel shafts along a quartz vein. Published by the Department of Mines, Canada, 1912 in Wyatt Malcolm's *Gold Fields of Nova Scotia* as Plate XXIV.

One feature that characterizes the Montague district is its very large number of mine openings. Detailed surveying and mapping of the Montague Gold District by the Geological Survey of Canada in 1902 indicated at least 172 individual shafts on the southern limb of the anticline and an additional six on the northern limb (Faribault, 1902). Figure 10 shows a section of this map illustrating multiple shafts up to 150 feet deep developed in the 1880s and 1890s to access ore along the Skerry Lead. Ore from these shafts was crushed at Boyd's Crusher, a 10-stamp mill erected in 1894, and tailings were directed northward into a swamp along Mitchell Brook.

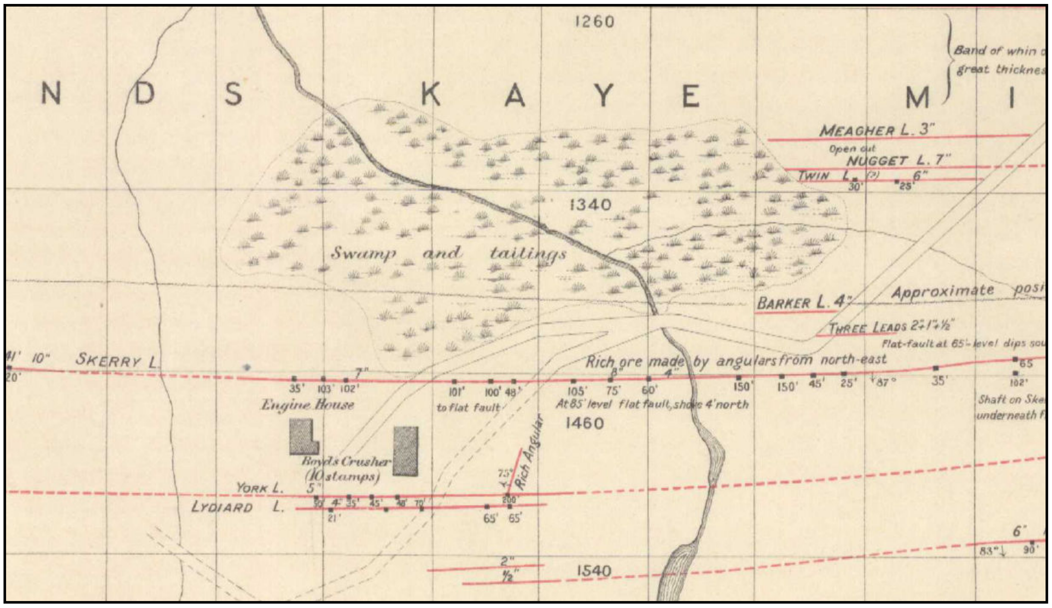


Figure 10. Map of the Symonds Kaye Mine at the Montague Gold District in 1902 (mapped by E.R. Faribault, Geological Survey of Canada, Map #740).

Underground mining at Montague continued until 1940, however, until the 1990s, there was no comprehensive map or database showing the locations of all mine openings that post-dated Faribault's map of the district in 1902. In 1984, the Nova Scotia Department of Mines and Energy (now the Dept. of Natural Resources and Renewables) initiated a program to document and evaluate abandoned mine openings and safeguard the public from these hazards. This program continues to the present day and has resulted in an online Abandoned Mine Openings Database that shows the location of 8,549 shafts, adits, slopes, open cuts, trenches, and associated workings identified at mines in Nova Scotia using modern technologies (GIS, GPS, LiDAR) and on-site risk assessments (Hennick and Poole, 2024a). As of 2021, the program had invested approximately $930,000 to remediate the most hazardous openings on provincially owned (Crown) land using backfilling, fencing, and placement of concrete caps and steel grates.

The most recent version (v. 9) of the Abandoned Mine Openings Database lists 345 individual mine openings in the Montague Gold District, including 219 shafts, 99 pits, 19 open cuts, and 8 trenches. The deepest shaft is the Skerry Shaft—a four-compartment shaft that extends for a total depth of 525 feet (160 m) and accessed multiple veins from different levels (Fig. 11). We will visit the Skerry Shaft during our field trip, which was remediated using steel plates and fencing in the 1990s. Figure 12 shows the locations of most of the mine shafts in this district (represented by red and white symbols), their proximity to local residences, the extent of Crown lands, and the concentrations of As in the top 0-5 cm of forest soil in this area.

a)

b)

Figure 11. (a) Surface plant showing workings on the Skerry lead, circa 1934. The headframe is the tall building on the far left, and the stamp mill is the peaked building in the distance. The wooden trough emanating from the stamp mill towards the lower left corner of this photo is the tailings launder, which was used to direct the tailings to a downstream wetland on Mitchell Brook. **(b)** Close-up of the Skerry Shaft headframe with the mine office on the right (Nova Scotia Archives)**.**

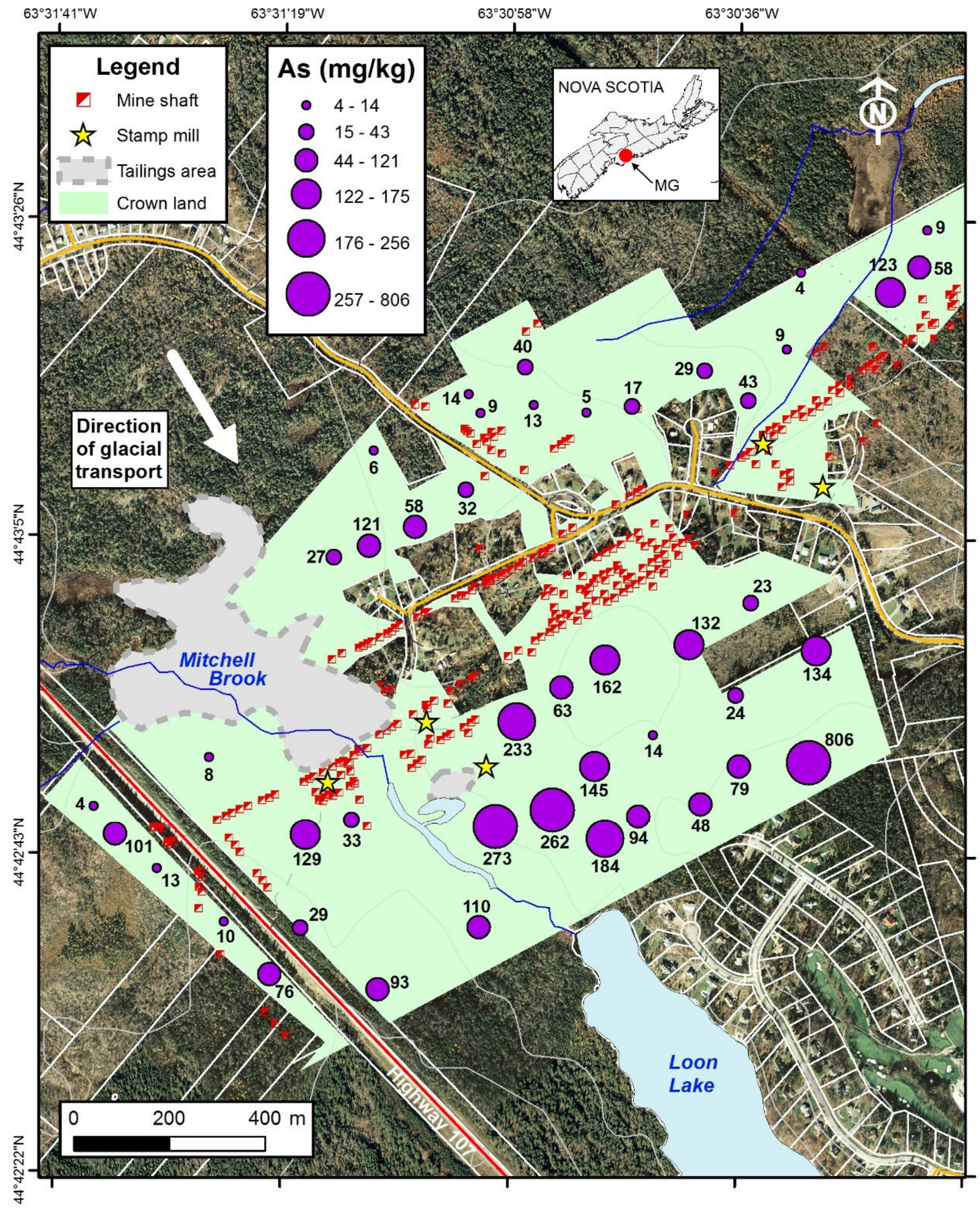


Figure 12: Arsenic concentrations (mg/kg or ppm) in the top 0-5 cm of soil (Public Health Layer) at Montague Gold Mines (< 2 mm size fraction; USEPA 3050B digestion). The extent of Crown Lands is indicated by light green shading. From Parsons and Little (2015).

Mine Tailings in the Montague Gold District

Gold was discovered at Montague in 1862 and the first on-site stamp mill was constructed in 1865. Throughout the history of the mine ore was milled using a variety of 5- to 15-stamp mills and Hg amalgamation (Malcolm 1929). In 1938, a six-ton batch treatment cyanide plant was installed at Montague for the treatment of concentrates from the active stamp mills, as well as stockpiled concentrate (Roach 1940). Most of the tailings from these mills were discharged directly into Mitchell Brook, which originates in Loon Lake and drains into Lake Charles (Fig. 12).

Previous studies in the 1980s and 1990s showed that tailings are present in the various wetland areas along Mitchell Brook, and a layer of fine tailings was found in a sediment core from Lake Charles, approximately 2.5 km downstream of the Montague stamp mills (EPS 1978; Mudroch and Clair 1985). Tailings were also deposited in a wetland along Birch Cove Brook, which drains eastward toward Lake Major (Faribault 1902). Since the 1980s, several companies have investigated the feasibility of extracting gold from the tailings at Montague (Jacques Whitford and Associates, Ltd. 1984; Mills 1997), but these efforts have met with limited success.

For decades, the sandy tailings areas at Montague have been a favourite recreational spot for local off-road vehicle enthusiasts, who frequently race their ATVs, motorbikes, and 4X4 trucks on the tailings (Fig. 13). Unfortunately, the tailings at Montague also contain very high concentrations of arsenic and mercury (Figs. 14, 15). The arsenic is of particular concern to human health, as it is both toxic and carcinogenic if ingested in sufficient quantities.

Figure 13. Children racing dirt bikes on the tailings at Montague Gold Mines in August 2004. The equipment on the right was used to collect airborne particulates and measure wind speed and direction as part of a study of arsenic-rich dusts at the site (Corriveau et al. 2011a).

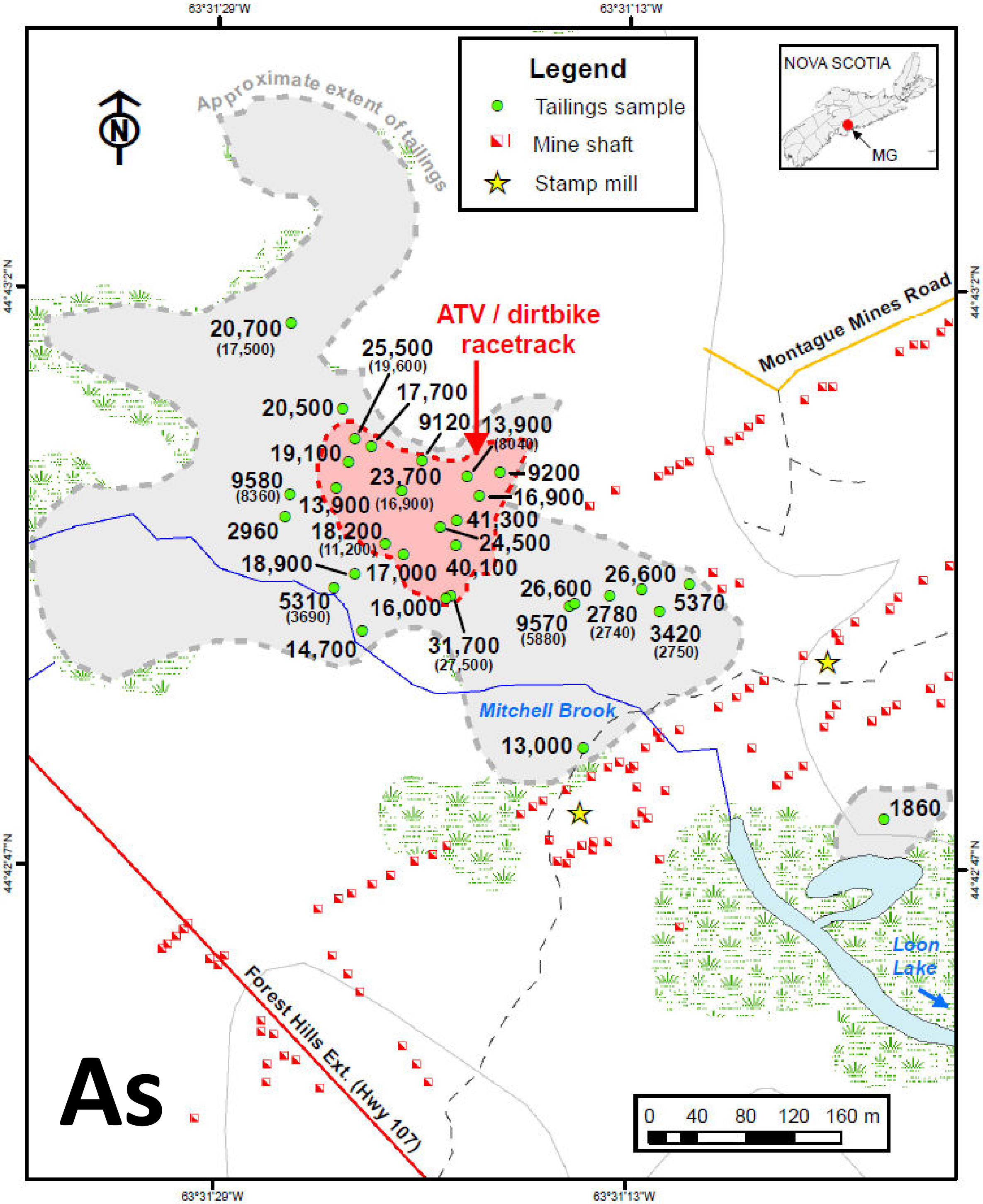


Figure 14. Arsenic (As) concentrations (mg/kg = ppm) in Montague tailings (maximum and (mean) concentrations; <2 mm size fraction) (Parsons et al. 2012).

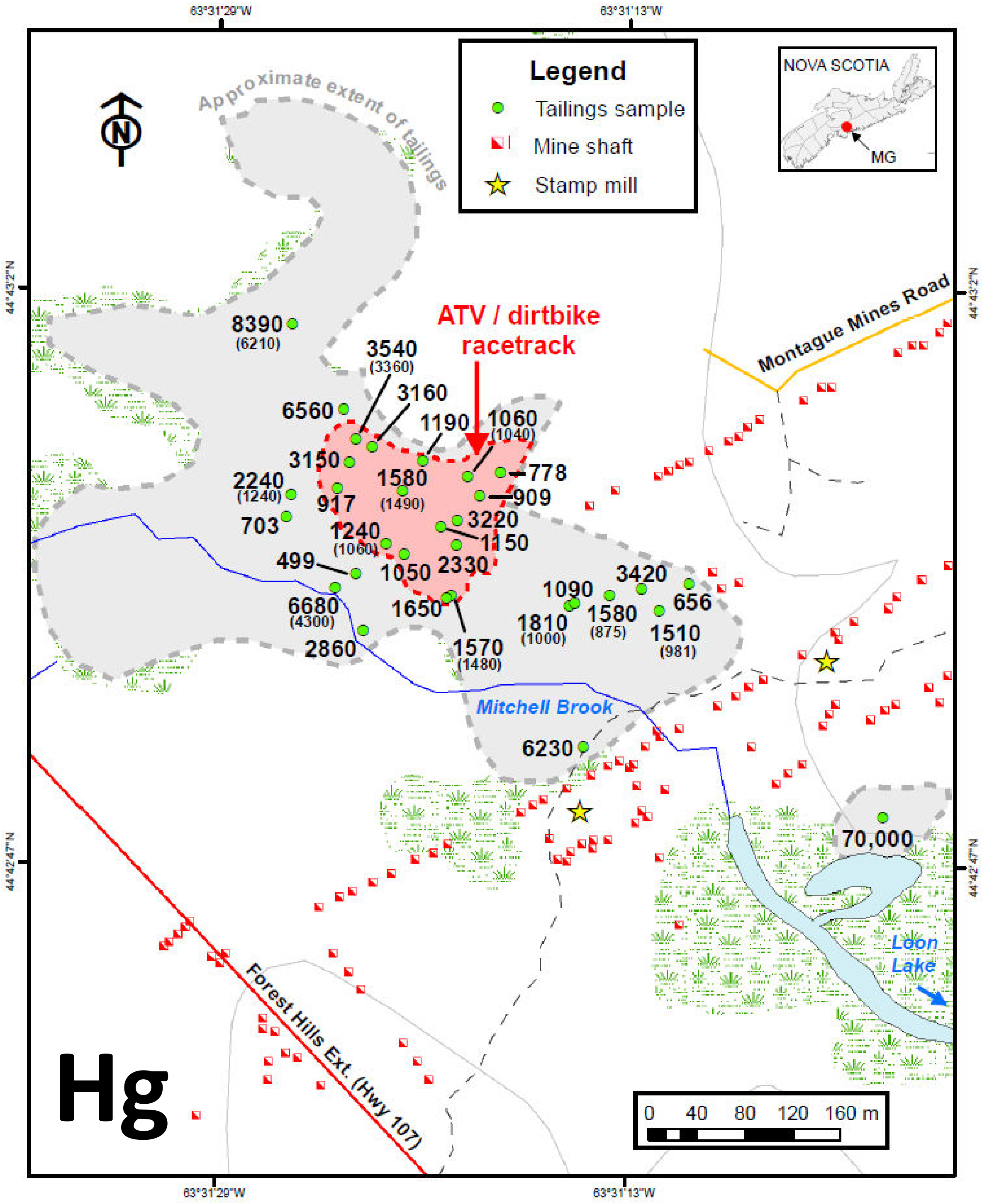


Figure 15. Mercury (Hg) concentrations (µg/kg = ppb) in Montague tailings (maximum and (mean) concentrations; <2 mm size fraction) (Parsons et al. 2012).

From 2004 to 2010, Natural Resources Canada and its research partners evaluated the potential environmental and human health risks associated with the Montague tailings. The tailings at this site are located very close to residential properties, are frequently accessed by the public, and are a source of As and Hg to the surrounding environment via windblown dust and transport of tailings downstream to Lake Charles. Details on the mineralogy and bioaccessibility of As in the tailings can be found in Walker *et al.* (2009), Meunier *et al.* (2010, 2011), Corriveau *et al.* (2011a, 2011b), and DeSisto *et al.* (2011, 2016). Previous field and laboratory studies have identified three main tailings endmembers at Montague: hardpan, oxic, and wetland tailings (Fig. 16). Each of these tailings types is characterized by distinct chemistry and mineralogy reflecting lithological variations in the original gold ore, differences in milling practices, varying depositional conditions, and the effects of weathering reactions over the last 80 to 160 years. The hardpan tailings at Montague represent the oxidized remains of sulphide concentrate (originally consisting mainly of arsenopyrite) that was dumped on top of the tailings following treatment with cyanide in the late 1930s (DeSisto et al. 2011). Over the last 70 to 80 years, most of the arsenopyrite has altered to scorodite ($FeAsO_4{\cdot}2H_2O$) and an intragranular cement consisting mainly of amorphous hydrous ferric arsenate and hydrous ferric oxide. Further details on the Montague tailings can be found in Parsons and Jamieson (2024).

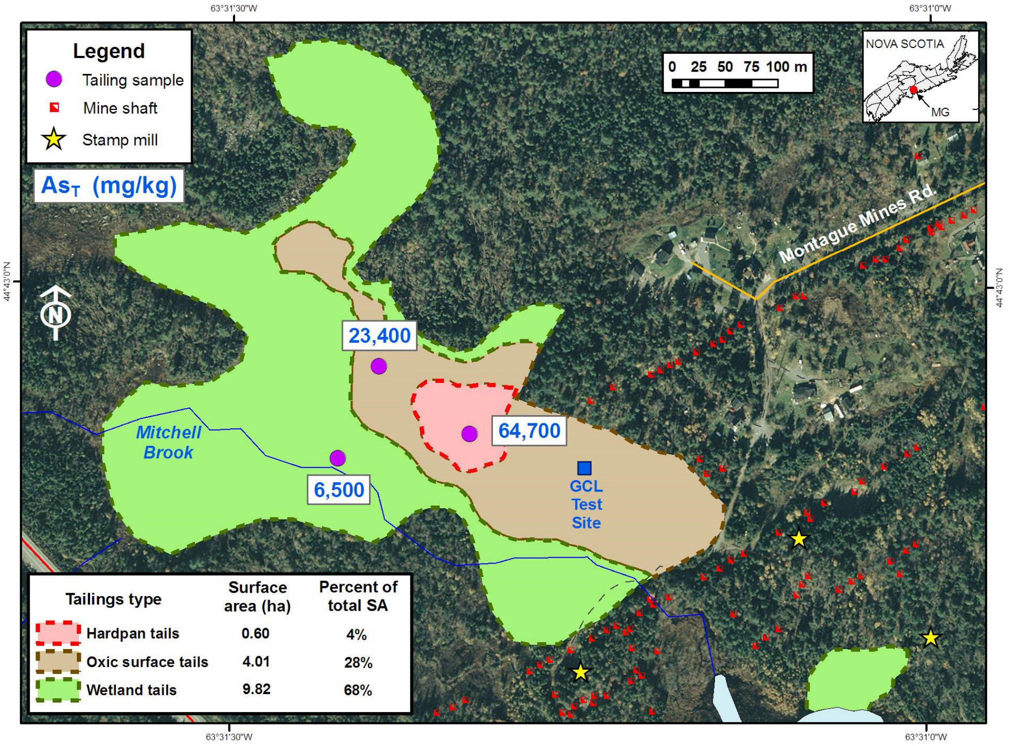


Figure 16. Distribution of three main tailings types at the Montague Gold District.

During the field trip, we will examine each of these tailings types, discuss details of the planned remediation activities, and consider long-term strategies for managing these mine wastes.

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