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Field Trip FT-B6

Structural Geology and Vein Arrays of Gold Deposits of the Meguma Terrane, Nova Scotia.

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Contents

SAFETY

During the five days of this field trip we will visit sea-side cliffs, roadside outcrops and underground mine operations, and safety is of foremost concern. *The field trip leaders will attempt to ensure a safe environment at all time, but individual safety requires the concern of each participant, so please take precaution during field trip activities.* The weather conditions in Nova Scotia are unpredictable. Although mid-May can be pleasant, you should have clothing available for possible cold and wet conditions. A variety of ground conditions will be encountered and boots (preferably safety type) with good traction are essential.

We ask that participants identify any special dietary needs, health risks or physical disabilities that may limit their full participation in the field trip.

This fieldtrip will be conducted using the GAC Field Trip Policy that can be found at https://gac.ca/about/policies-resources/field-trip-policy-documents/ ; it is recommended that each participant familiarize themselves with these policies; in particular the section on participant's responsibility that reads:
are responsible for:

- Following the safety instructions of the field trip leaders or of safety coordinators at industrial sites that may be visited during the trip
- Acting in a manner that is safe for themselves and their co-participants.
- Using PPE when necessary (when recommended by the field trip leader or upon personal identification of a hazard requiring PPE use)
- Informing the field trip leader of any personal health issues or other safety matters of which they have knowledge that may affect their health and safety or that of co-participants

It is *recommended* participants use the following PPE at all planned sites during the fieldtrip.

- Safety boots/shoes
- High visibility safety vests
- Safety glasses, especially if rocks are to be broken using a hammer
- Certified hard hat
- Gloves

At visits to various active mines, including Moose River and Aureus East, participants will be provided specific personal protective equipment and training by the companies specific to the planned activities of the site.

INTRODUCTION

Over sixty Meguma Gold Deposits (MGD) operated at one time or another, mainly during then latter 1800s and early 1900s. These deposits consist of auriferous veins hosted by the Meguma Supergroup, the dominant unit of the Meguma Terrane of southern Nova Scotia (Fig. 1). An important recent paradigm shift for development with MGD deposits has been the development of the low-grade high tonnage Touquoy mine (18 Mt @ 1.1 g/t), and in the future affiliated deposits (Beaver Dam, Fifteen Mile Steam, and Cochrane Hill (i.e., 30+ Mt @ 1.1 g/t), which is referred to as a "disseminated type" of mineralization not previously exploited as part of the historical legacy of MGD.

Several diverse genetic models have been proposed for MGD, which have resulted in much debate regarding their formation; as expected, this has been going on as long as the deposits have been mined. An overview of the principal hypothesis would include: 1) ***syn-sedimentary*** origin; Haynes (1986), among others, considered the veins to represent seafloor hydrothermal hot spring deposits based on the laminated nature of the veins; 2) ***magmatic*** (Newhouse, 1936); 3) ***metamorphic*** (Graves and Zentilli, 1982; Henderson, 1983; Henderson and Henderson, 1986, 1990; Henderson et al., 1986) based on an inferred elevated (supra-lithostatic) fluid pressure during the early stages of regional deformation-metamorphism, which resulted in hydraulic fracturing now seen in the many laminated (crack seal) bedding-concordant veins. Importantly, all these hypotheses considered vein formation to predate regional folding; and lastly 4) **several syn-folding models** which either generally, or specifically, follow a ***saddle-reef type*** model (Faribault, 1899; Mawer, 1987; Keppie, 1976; Kontak et al., 1990; Horne and Culshaw, 2001).

The latter two hypotheses have been given the most recent consideration, with the critical point being whether the veins constituting MGD predated folding or were syn-folding in origin. For the pre-folding hypothesis, the issue is restricted to the interpretation of bedding-concordant veins, which proponents consider the dominant auriferous veins, to predate 'late', unrelated discordant veins. The relative age of bedding-concordant veins to folding is constrained by their relationship to macro- and micro-scale elements of regional folds. This important aspect and inferred relationships will be evaluated during this field trip.

Below is a summary of the regional setting and character of folds hosting the MGD, in addition to a general discussion of the vein arrays that define the ore zones. These features are used to constrain a general model for the deposits. Features of regional folds and vein arrays discussed will be highlighted at the field stops, allowing for observation and discussion of the principal elements that constrain interpretations of a model for the development of MGD.

GEOLOGICAL SETTING

The Meguma Terrane is the most outboard terrane of the Appalachian Orogen and is separated from the northerly Avalon Terrane by the Cobequid Chedabucto Fault System (Fig. 1). The Meguma Terrane is dominated by the Cambrian-Ordovician Meguma Supergroup, which consists of the lower metasandstone-dominated Goldenville Group and overlying slate-dominated Halifax Group; these units are overlain by Early Silurian-Lower Devonian metasedimentary and metavolcanic units (Fig. 1). This sequence was deformed into kilometre-scale folds (Figs. 1, 2) during the Early to Middle Devonian Neoacadian Orogeny. Late Devonian plutons truncate regional folds and related cleavage, but subtle regional structural fabrics within the South Mountain Batholith, the largest of these intrusions, suggest a late syntectonic emplacement (Horne et al., 1992; Benn et al., 1997). A protracted history of post-Acadian deformation of the Meguma Terrane includes: 1) fold tightening (Horne and Culshaw, 2001); 2) Carboniferous shear zones overprinting Acadian fabrics in the southwest Meguma Terrane (Culshaw and Liesa, 1997); 3) shortening of Carboniferous cover rocks; and 4) even late- to post-Cretaceous faulting (Stea and Pullan, 2001).

Regional fold development

The MGD are hosted by regional folds and an understanding of fold development is critical to evaluating the formation of veins.

The Meguma Group is folded into large-scale regional folds, with kilometre-scale wavelengths and axial traces that extend tens to hundreds of kilometres (Fig. 1). Map patterns (Fig. 1) confirm that fold axes are generally horizontal and apparently cylindrical over long distances, although they locally plunge west and east with non-cylindrical geometries. In cross section, folds are characterized by box and chevron geometries which are organized as large-scale anticlinoria and synclinorium (Culshaw and Lee, 2006; Fig. 2). Box folds are characterized by steep (vertical) limbs and gently folded median segments and axial planes with no consistent vergence (Fig. 2). This fold style is characteristic of a folded multilayered sequence (e.g., the Goldenville Group) where there is a high rheological contrast between layers and a low thickness ratio of competent to incompetent layers (i.e., Model F folds of Ramsay and Huber, 1987). Such folds develop with little initial layer-parallel shortening (Ramsay and Huber, 1987), but modeling shows that box and chevron fold development involves shape changes during progression from early box folds to chevrons, during which hinge migration is clearly important (Fig. 2c, e.g., Cobbold et al., 1971; Fowler and Winsor, 1996).

Box and chevron folds develop as flexural folds where strain is accommodated primarily by layer-parallel shear (flexural shear) on fold limbs. Shear strain is largely confined to incompetent layers, where it may be distributed homogeneously across the layer (flexural flow) or be restricted to discrete movement horizons (flexural slip) (Fig. 3a), and results in the development of numerous minor structures (Fig. 3b). The ***rate*** of flexural shear strain increases with increasing limb dip, thus most flexural-shear structures, which become the locus of veins, form only after significant limb dip is achieved (Ramsay, 1974). An array of “accommodation structures” (Ramsay, 1974) may develop in hinge zones because of variation in competent layer thickness, including hinge thrusts and bulbous hinges, and hinge dilatancy; the latter sites may result in saddle reef formation. Veins developed within various structural sites formed during folding produce a family of veins sets which are geometrically related to the fold (Fig. 3b).

Previous studies (Henderson et al., 1986; Horne and Culshaw, 2001, Faribault, 1899; Armstrong, 1937; Keppie, 1976; Horne and Jodrey, 2002) confirm that flexural folding was important in fold development in the Meguma Supergroup with the documentation of many of the structures illustrated in Figure 3b.

Figure 1. Simplified geology map of the Meguma Terrane showing the locations of fieldtrip stops. Note the large pink area in the south, which is the ca.380-375 Ma South Mountain Batholith.

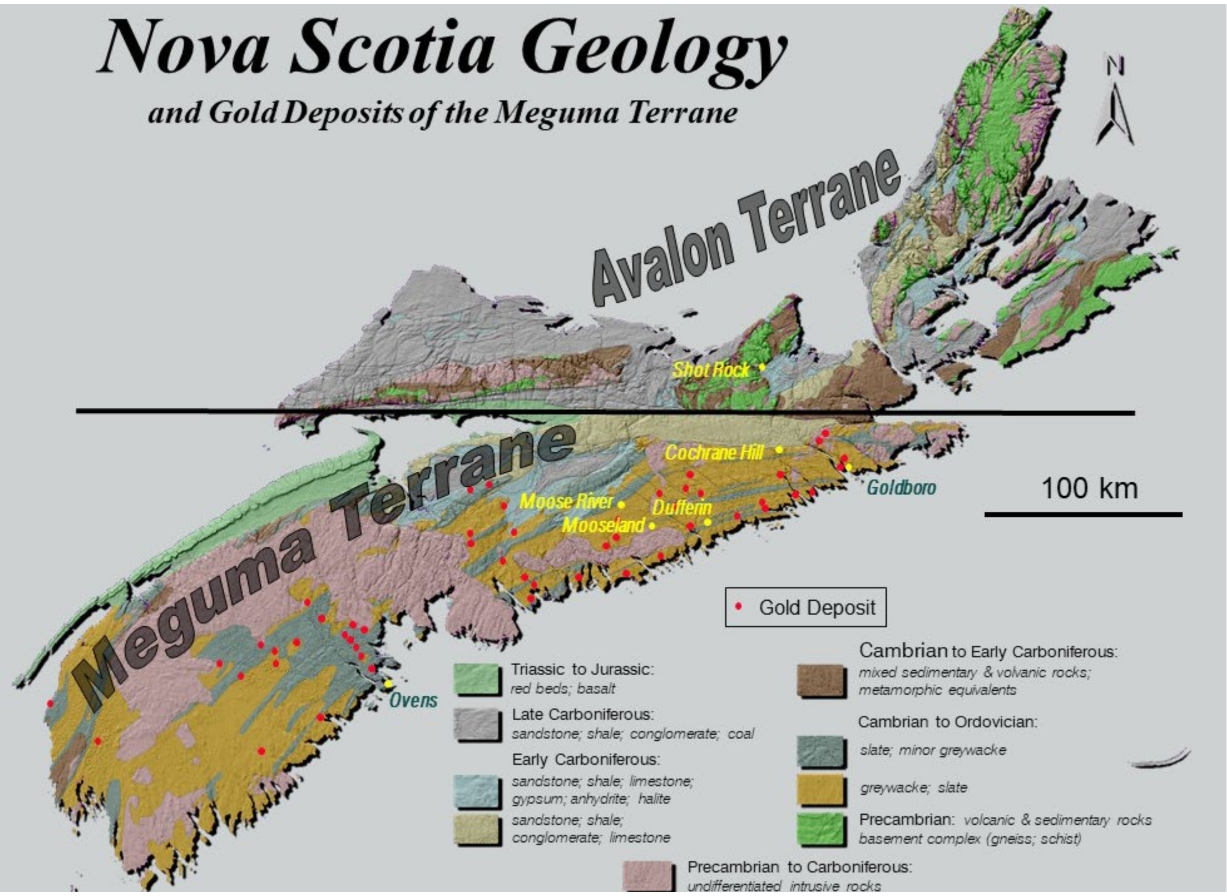


Figure 2. Cross sections of regional folds of the Meguma Supergroup (a) after Fletcher and Faribault (1913) with red dots = gold deposits and (b) after Culshaw and Lee (2006). (c) Model of box fold to chevron evolution involving hinge migration.

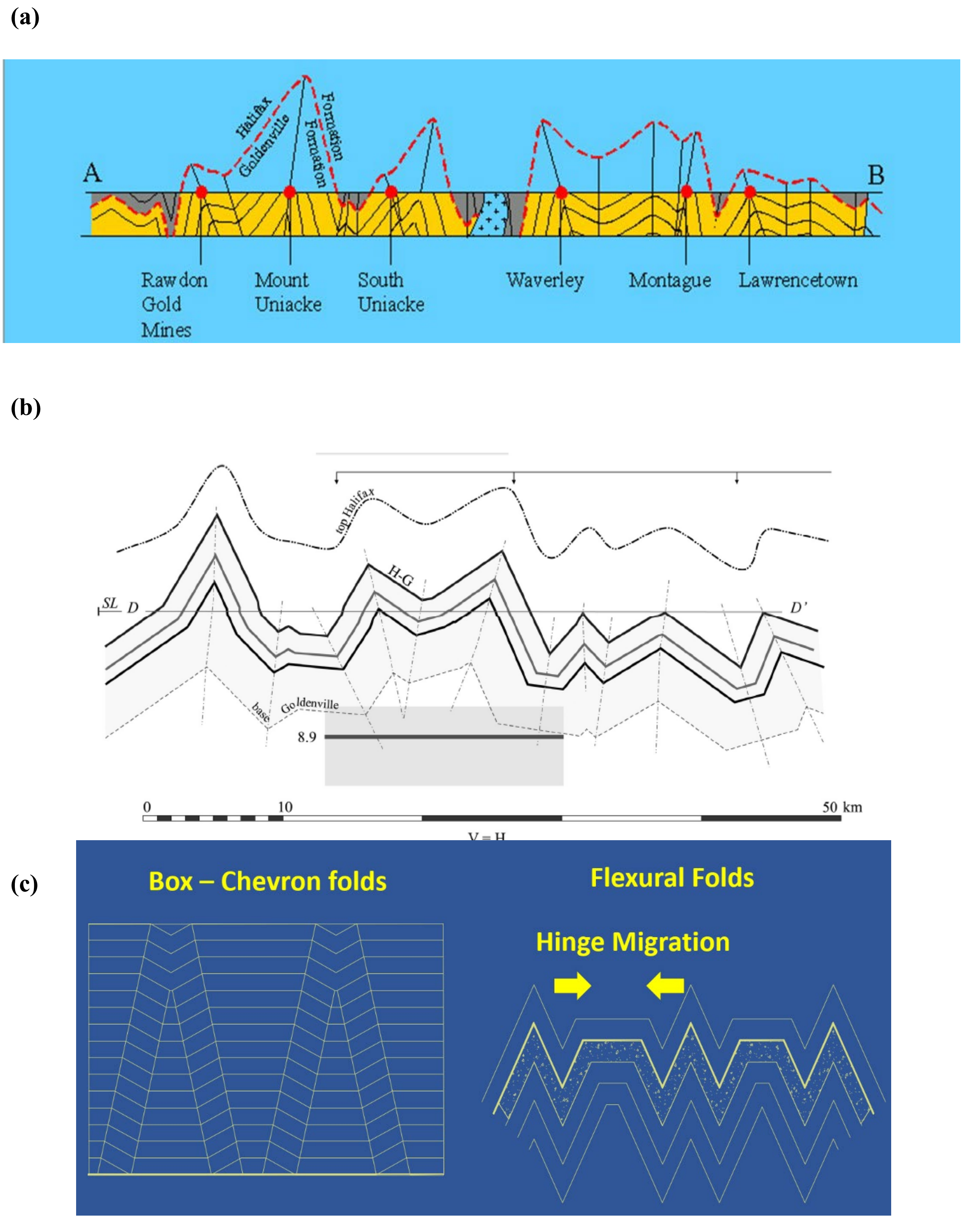
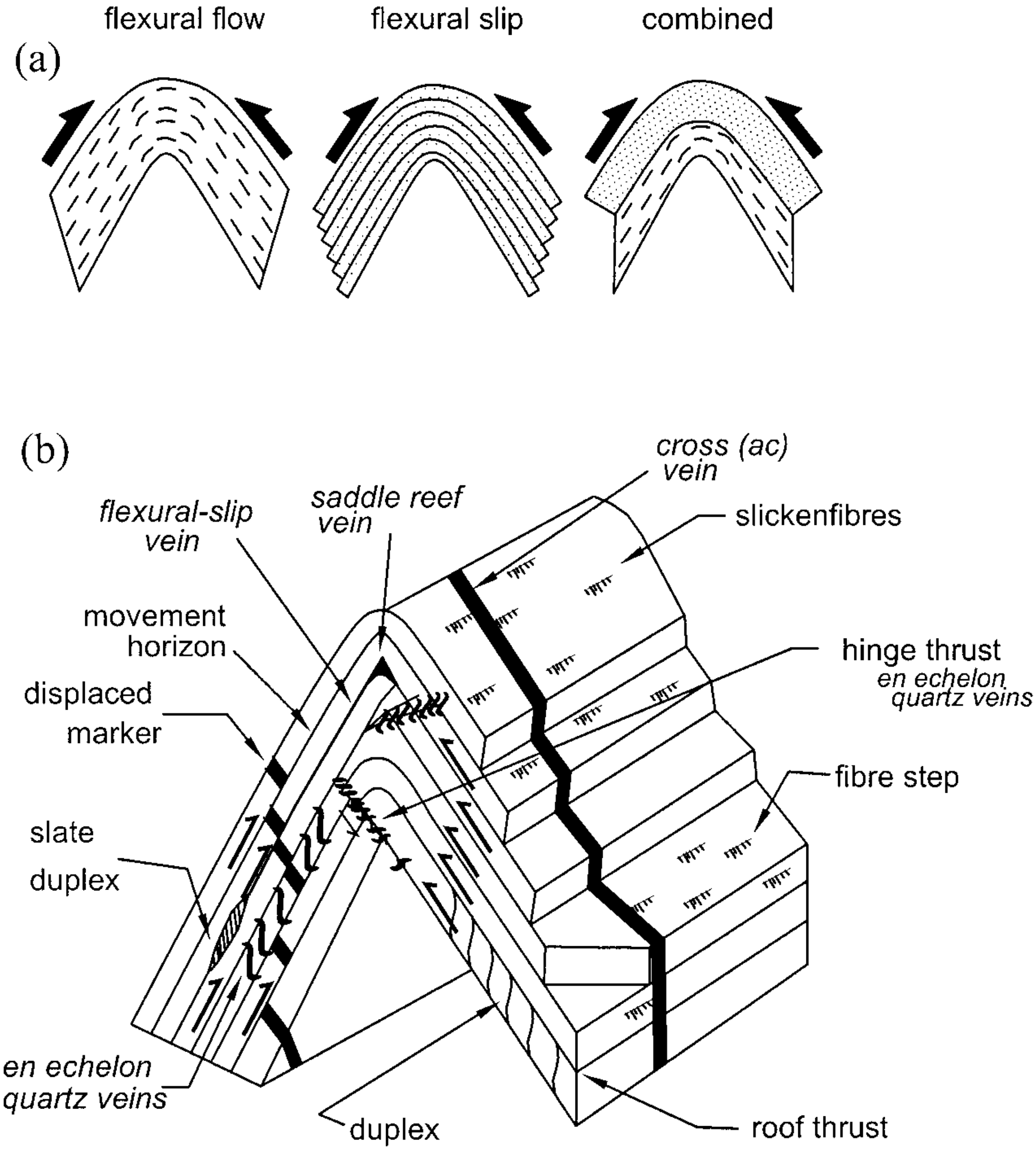


Figure 3. (a) Simplified model of flexural-flow and flexural-slip folding. (b) Diagram showing minor structures and quartz veins developed in flexural folds (after Tanner, 1989).



MEGUMA GOLD DEPOSITS

The MGD comprise highly variable concentrations of auriferous, and also barren, quartz veins. Most of the veins are stratabound with much attention historically given to those bedding-concordant veins with a laminated texture due to the presence of thin septa (mm- to multi-cm scale) of wall-rock material. Although each deposit presents its own unique features, as do all ore systems, in general MGD show remarkable similarities, thus suggesting that a single comprehensive model can best explain their origin. The following section will provide a general review of the principal features of these deposits and is utilized to constrain a general model.

General Setting of Veins Arrays

It has long been recognized (undisputed) that MGD, that is areas of auriferous quartz vein concentration, are primarily localized in the anticlinal hinge zones of regional folds (Fig. 2a; Faribault, 1899; Malcolm, 1912).The distribution of these veins within individual folds shows a systematic relationship with respect to fold geometry. Generally, in tight chevron-type folds where both limbs are steep, veins occur on both limbs and across the hinge, locally with saddle- reef veins (Fig. 4). Where modified box folds defining anticlinoria occur, veins are concentrated on the steep limbs but are rare in the flat median segment of such folds (Fig. 4). This consistent arrangement of vein arrays within folds suggests a structural control on their distribution (i.e., versus pre-folding models), that reflects higher flexural shear strain on steep limbs.

Vein Arrays

Veins within MGD have been variably classified using elements of morphology (e.g., laminated, ribbon, crack seal, massive, bull), mineralogy (e.g., pegmatoid, sulfide poor, silicate bearing, tourmaline), their relationship to folds (stratabound, bedding-parallel, ac, angular, saddle reef, en echelon), and sometimes a combination of features. Additionally, some veins have been referred to with respect to their mechanism of formation (crack seal, replacement, shear) (Smith and Kontak, 1988) and veins of similar type (e.g., ac veins) have been subdivided as early or late (Williams and Hy, 1990). The above list clearly illustrates a variety of vein types are present within MGD.

A review of literature and the many observations of the authors suggest that the most appropriate classification of veins is with respect to their geometric relationship to regional folds, recognizing that veins of various morphology and mineralogy may represent variations on this theme. The principal vein sets of MGD are illustrated in Figure 5 and described below:

- Bedding-Concordant Veins
    - Laminated or massive bedding concordant veins
    - En echelon shear veins
    - Saddle Reef veins
- Discordant (cross)Veins
- Angular Veins

Bedding-Concordant Veins

Stratabound veins are those confined to stratigraphic layers and, but for minor exceptions, are restricted to slate/metasiltstone layers. Several distinct vein types can be recognized and are described here.

Laminated bedding-concordant veins

Bedding-concordant veins with laminations define a distinct class of such veins which are characterized by their laminated nature (see stops below). These veins are typically composite with massive quartz cutting the earlier laminated material (mm to cm in thickness). These veins are typically planar on fold limbs, but may be buckled in fold hinges, and locally it can be demonstrated that they represent the down-dip extension of saddle-reef veins (Horne and Culshaw, 2001; Horne and Jodrey, 2002). These veins commonly occupy flexural-slip horizons defined by the offset of discordant veins that predate the laminated veins (flexural-slip veins of Horne and Culshaw, 2001). The laminations, or septa, within the veins are commonly characterized by the presence of striated slickensides (where vein-laminae planes are visible) oriented perpendicular to the fold hinge. These observations suggest that many laminated veins occupy flexural-slip movement horizons. Importantly, Faribault (1899), who investigated more of these deposits than all those who have since studied these deposits, came to a similar conclusion over 120 years ago! This conclusion therefore suggests that the many features characterizing laminated veins reflect vein formation in once active bedding-parallel flexural-slip movement horizons where progressive vein formation included a combination of shear vein and extensional vein growth during flexural slip (slickenfibres); this also accounts for deformation (shear and buckling) of veins and fabrics in the immediately adjacent wall rock.

Buckled bedding-concordant veins occur locally and have been used to support a pre-folding origin for bedding concordant veins (e.g., Henderson et al. 1986). There has been much debate over the abundance of buckled veins and their continuity down fold and we will see examples of bucked bedding concordant veins at several stops that clearly demonstrates they are restricted to fold hinges (Fig. 5), where layer-parallel shorting occurred concurrent with flexural folding.

Many bedding-concordant veins lack laminations, consisting of massive quartz.

En echelon shear vein arrays

En echelon shear veins within slate or metasiltstone intervals are a common component of many MGD vein systems; they may also occur regionally as isolated veins (Henderson et al., 1986; Sangster, 1990; Horne and Jodrey, 2002). These veins exhibit sigmoidal shapes, with ‘pinned’ ends in competent sandstone and rotated (sheared) median segments within less competent slate or metasiltstone. The veins record significant but variable amounts of shear, and the median segment is commonly boudinaged because of rotation into the extensional field (Fig. 6b). The intersection of individual veins on bedding surfaces is parallel to the fold hinge and the geometry of veins changes across the fold hinge such that they invariably indicate a reverse shear sense perpendicular to the fold hinge. That these veins reflect flexural shear strain seems unequivocal.

Saddle-Reef Veins

It is unclear how prevalent saddle-reef veins are within MGD and their importance has been downplayed by some workers (e.g. Henderson and Henderson, 1987). These veins are documented at several MGD, including those to be visited (i.e., Mooseland and Dufferin).

Saddle-reef veins occupy zones of dilation in fold hinges due to flexural-slip folding and, most importantly, develop only after significant fold development (Ramsay, 1974). This is consistent with the observations made by Malcolm (1912) and Keppie (1976) that such veins are common in MGD districts characterized by tight folds (interlimb angle is <45°). Many of the saddle veins referred to by Faribault on his district maps are characterized by veins that taper gradually down the fold limbs. The amount of dilatancy created in fold hinges is a function of limb dip and the thickness/length ratio of competent and increases markedly with progressing folding (Ramsay, 1974; Ramsay and Huber, 1987). In the Meguma sedimentary rocks the thickness/length ratio is typically very small (much less than 0.02) and therefore does not favour the formation of large saddle reefs. Indeed, the well-developed saddle-reef veins occur in minor folds that have relatively short wavelengths (e.g., Dufferin, Isaacs Harbour). In addition, many of the vein arrays of MGD are found on the steep limb of asymmetric box folds where saddle reefs would not be expected

Discordant Veins

Cross veins are discordant to bedding and are commonly roughly parallel to the ac plane of the fold (Fig. 5). Few studies have presented any systematic structural data on these veins. Abundant cross veins at The Ovens Gold District (Day 3) form a conjugate set with a small acute angle where the poles to the planes bisecting these veins are parallel to the fold hinge (Horne and Culshaw, 2001). Cross veins measured during regional mapping at the east end of the Waverley Gold District parallel the ac plane (Horne et al., 1997). Some previous studies suggested these veins are volumetrically insignificant within gold districts and are instead of regional nature, i.e., not part of the gold-related vein array. However, in some cases observations suggest that concentrations of cross veins are anomalous within MGD (Horne and Culshaw, 2001; Horne et al. 1997; Horne and Jodrey, 2000) and that they formed synchronous with stratabound veins (see field stop at The Ovens below) and can be auriferous. Indeed, cross veins were important gold producers in several deposits (e.g., Brookfield, Leipsigate, Central Rawdon). These veins typically consist of massive quartz with textures suggestive of open space filling and thus record minor extension parallel to the fold hinge. Rarely they have a laminated texture that, as noted above, often typifies the bedding-concordant veins.

Angular Veins

The term ‘angular vein’, or angulars, was applied by early workers (e.g. Faribault, 1899; Malcolm, 1912; Armstrong, 1937) to veins that branch off from bedding-concordant veins (Fig.

5). Their intersection with bedding varies between deposits but is typically consistent within any single deposit (Armstrong, 1937). These veins typically include bedding-concordant and discordant segments (Fig. 5) and where they intersect with earlier bedding-concordant veins they thicken them, and this overlap commonly defines zones of gold enrichment. Angular veins occur at Mooseland (see stop below), although we won't be able to see them as the mine is flooded. Angulars intersect metasandstone beds at a high angle to bedding whereas they cut obliquely, and locally parallel, the slate beds (Malcolm 1912). As noted by Sangster (1990), angular veins resemble en echelon veins which cut across stratigraphy and likely formed in response to bedding-parallel shear. The intersection of angulars with bedding is sometimes parallel to the fold hinge (like pins of en echelon veins).

Discussion

MGD represent anomalous concentrations of auriferous quartz veins localized in the hinges of regional folds. As outlined above, there are several vein types, however bedding-concordant veins, in particular laminated types, have been considered by many as the dominant vein type, or at least the only important vein type, with respect to hosting gold mineralization. We will see on this field trip that:

(1) Concentrations of all vein types are highly anomalous within MGD with respect to regional vein concentrations.
(2) The mutual cross-cutting relationships between stratabound and cross veins indicate a synchronous time of formation.
(3) Bedding-concordant laminated and en echelon vein arrays represent the down-limb extensions of saddle-reef veins and form due to flexural slip.
(4) All vein types can be auriferous and contain similar accessory mineralogy. Furthermore, they have a common fluid signature as revealed from fluid inclusion and stable isotopic (S, C, O) studies (see summary in Kontak et al., 2011).

These observations indicate that MGD are characterized by an array of intimately (temporally and spatially) related vein types with a common origin and, therefore, an explanation of their development must accommodate all vein types. These relationships have been established at the locations of this field trip and will be outlined during our stops.

The relative time of vein development is established with respect to regional deformation (folding). A pre-folding origin for laminated bedding-concordant veins was proposed by Henderson et al. (1986) and Zentilli and Graves (1982), and was based largely on their interpretation that buckling of these veins record layer-parallel shortening prior to regional fold development. However, as discussed above, the layer-parallel shortening represented by the veins is restricted to fold hinges and considered to relate to syn-folding deformation. Notably, proponents of a pre-folding age for MGD do not relate the buckled laminated veins with the development of other vein types and interpret these as separate events. Considering the character of the entire vein array and the constraints imposed by the character of region fold development, we are faced with the following considerations:

- Fold development (box-chevron) involved hinge migration. That MGD are invariably found in fold hinges implies they formed late in the fold history and thus post-date any significant hinge migration. On a deposit scale, kinematics shown by en echelon veins, which clearly record the final increments of fold development, and flexural-slip (laminated) veins, systematically changes across the hinge, confirming the vein array post-dates any hinge migration.

- Bedding-concordant and discordant veins include fragments of cleaved wall rock, thus indicating a post-cleavage age for vein development. Many flexural-slip structures associated with vein formation are brittle.

- The formation of saddle reef veins occurs only after significant fold development. Thus, by inference other related veins must also be late.

- The distribution of veins on steep limbs is consistent with the formation of flexural-shear structures, including veins, resulting from increasing shear strain at high limb dips.

- MGD vein arrays show only moderate deformation. Discordant veins, which show mutual cross-cutting relations with stratabound veins, are largely undeformed and only moderately folded.

These constraints together offer strong support that vein formation was late in the fold history. This late timing is also supported by a number of absolute ages that constrain the absolute timing of hydrothermal vein formation (summaries in Kontak et al. (1998) and Morelli et al. (2006)). Except for a single result, all ages indicate 380-370 Ma, which overlaps with the widespread emplacement of granitoid bodies across the Meguma Terrane (see Fig. 1).

Figure 4. Cross section (generally facing NE) of the South Uniacke, Waverley and Montague gold districts illustrating the distribution of bedding-concordant veins (yellow lines) with respect to the fold. Note presence of veins on both fold limbs of the chevron-type folds on the right versus only on the steep fold limbs on the left.

Bedding-concordant veins restricted to steep limbs

Figure 5. A simple vein classification scheme (top left) based on fold geometry to accommodate vein types in different MGD settings (note vein proportions can vary amongst settings) with images of veins from The Ovens used to illustrate the various vein types. b) View towards NE showing bedding-concordant veins and fold closure (axial trace in white dashed line). Inset is the hinge area with golded (M-type) laminated quartz vein having arsenopryite haloe. c) Hinge area showing bedding-concordant vein with similar thickness. d) Laminated beddng-concordant veins in image c (white box). e) Three discordant quartz veins. Note one of them pre-dates the bedding concordant vein, whereas one offsets the same bedding-concordant veins, thus of different rleative ages for these veins (1, 2, 3). f, g) Bedding-parllel vien with speckled-hen texture.

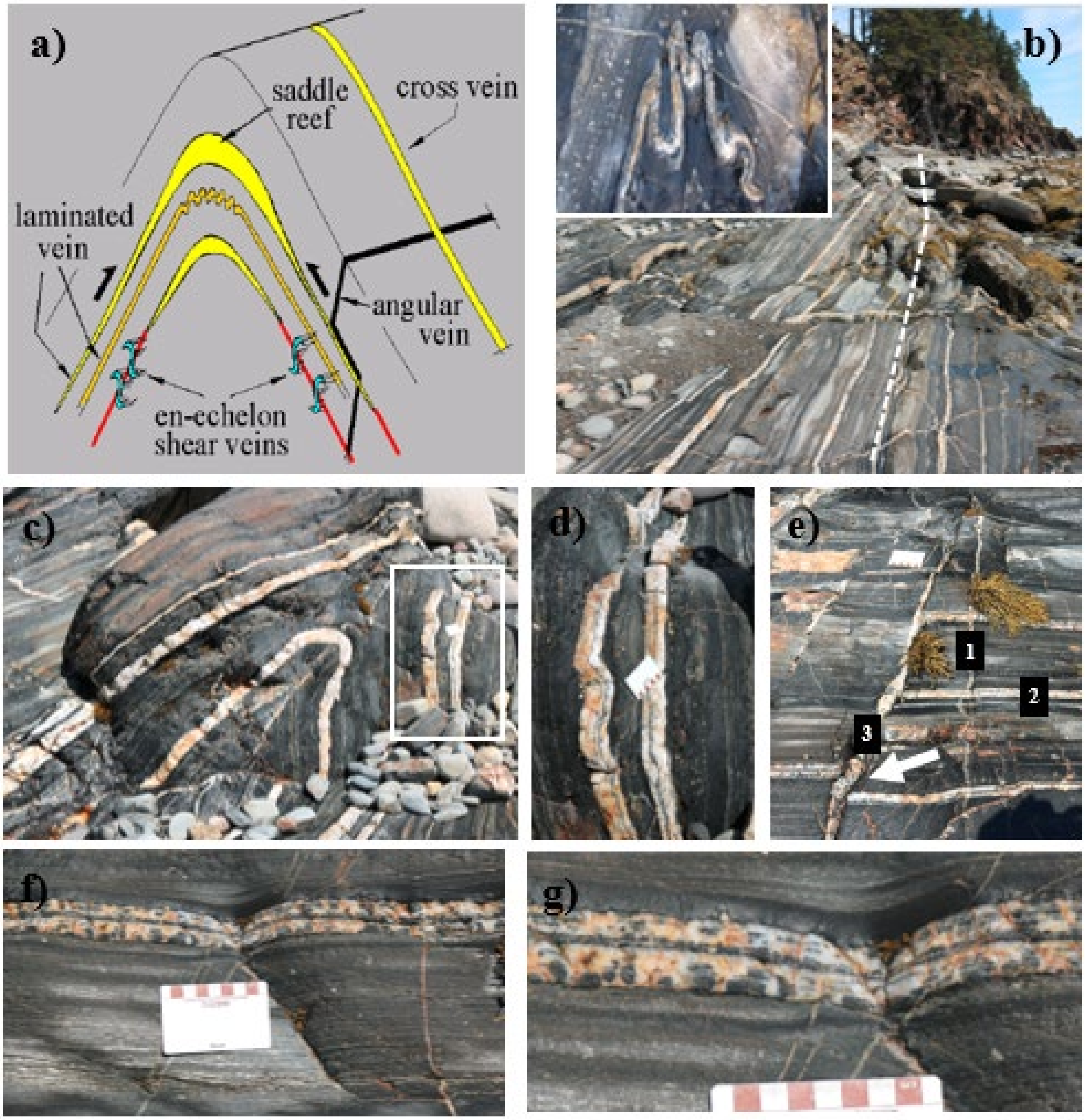
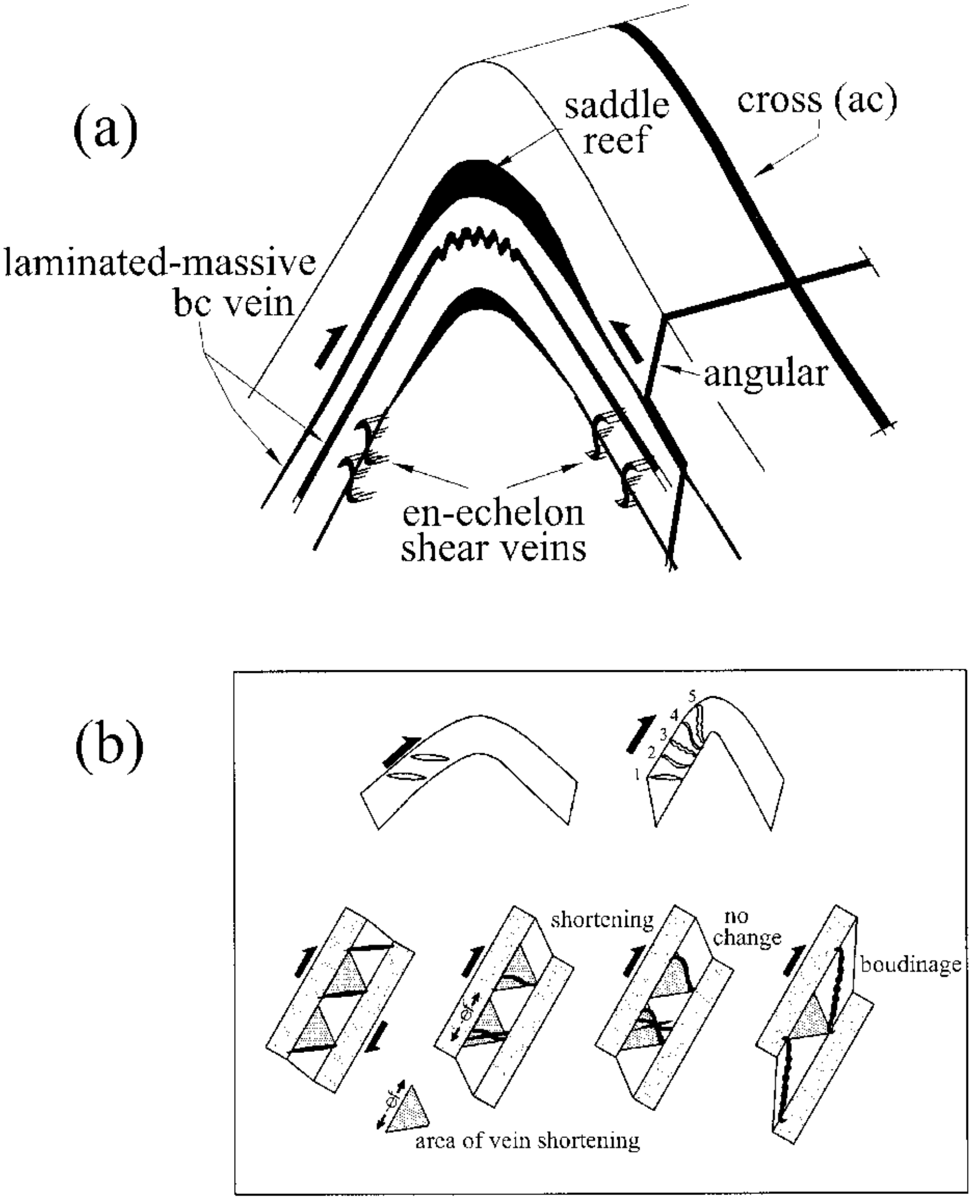


Figure 6. a) Schematic diagram of the principal vein types in MGD. b) Diagram illustrating the formation of en echelon shear vein arrays during fold development. Veins initially are shortened during progressive shear, with significant shear resulting in boudinage of individual veins.



Alteration

Generally, the wall rocks that host veins in MGD only record moderate alteration in comparison to other gold deposit settings or other deposit types (e.g., porphyry, VMS). With regards to the former, we note that cases of intense alteration in gold settings is where the fluid and rock are most of equilibrium, such as potassic basic rocks reacting with an aqueous carbonic fluid to produce widespread sericite-carbonate alteration typical of many Archean lode gold deposits. Although such pervasive widespread alteration is lacking in MGD, which likely reflects the ore fluids being more in equilibrium with the host rocks, as noted in many sedimentary-rock-hosted orogenic gold deposits (Bierlein and Crowe, 2000), variable development of bleaching of host rocks is not uncommon and will be seen in several of the stops.

The only detailed lithogeochemical study of alteration through an ore zone is that done for Moose River (Touquoy) where elevated K_2O/Al_2O_3 ratios (>0.2), reflecting sericite after albite, correlated with Au grade (Bierlein and Smith, 2003). In contrast, our unpublished work at other sites (e.g., Beaver Dam) revealed no correlation between Au mineralization and K_2O or carbonate, but instead with As. We do note, however, that application of modern methods, such as hyperspectral, would likely prove useful in addressing this issue.

The nature of alteration types present in MGD is expanded on below with examples given in Figure 7.

Carbonate:

Carbonate alteration is a pervasive alteration in all MGD, occurring mainly as ankerite and calcite replacement of metasandstone matrix and as carbonate "spots" in slate and metasiltstone. The extent of alteration is often only appreciated on weathered samples, where a distinct brown colour is developed. Lots of carbonate alteration will be seen on the trip.

Sulphide

Sulphides associated with MGD includes pyrite, pyrrhotite, and arsenopyrite, in addition to minor base-metal sulphides (galena, chalcopyrite, sphalerite). In fact, a correlation between the latter, in particular Zn and Pb suphides, with Au mineralization is commonly noted. Pyrite and pyrrhotite occur throughout the Meguma Supergroup, thus relating them to mineralization is not always straightforward. However, arsenopyrite can locally occur in a high abundance as porphyroblasts (Mooseland, Touquoy) or thin beds (The Ovens), is restricted to MGD, and is clearly related to vein emplacement and reflects sulfidation of the wall rocks' related alteration. Although a spatial association with elevated Au is not apparent in most cases, we do note that LA ICP-MS analysis of arsenopyrite shows Au enrichment (as refractory Au) to 100 ppm in arsenopyrite (Gourcerol et al., 2020) and common particular gold.

Oikocrysts

The presence of small (<5 mm) ovoid aggregates in MGD districts was first noted by Smith and Kontak (1986), but in general they have not been evaluated in any detail. Limited studies indicate variable mixtures of quartz (dominant), biotite, chlorite, carbonate, ilmenite, titanite and Fe sulphides (e.g., Kontak et al., 1990, 1993). That they do show a spatial correlation with gold mineralized centres versus barren areas clearly establishes a genetic relationship with these deposits. They are found within slate and metasiltstone and their elongate shapes generally define a strong down dip lineation within axial planar cleavage (see Mooseland stop below), thus supporting a syn-folding origin. Locally, a well-defined, shallow dipping mineral foliation defined by biotite and chlorite within oikocrysts is highly oblique to axial planar cleavage (Horne et al., 2004). A convincing explanation for oikocrysts is yet to be presented, however it would seem any explanation would involve metasomatism related to vein development during fold development.

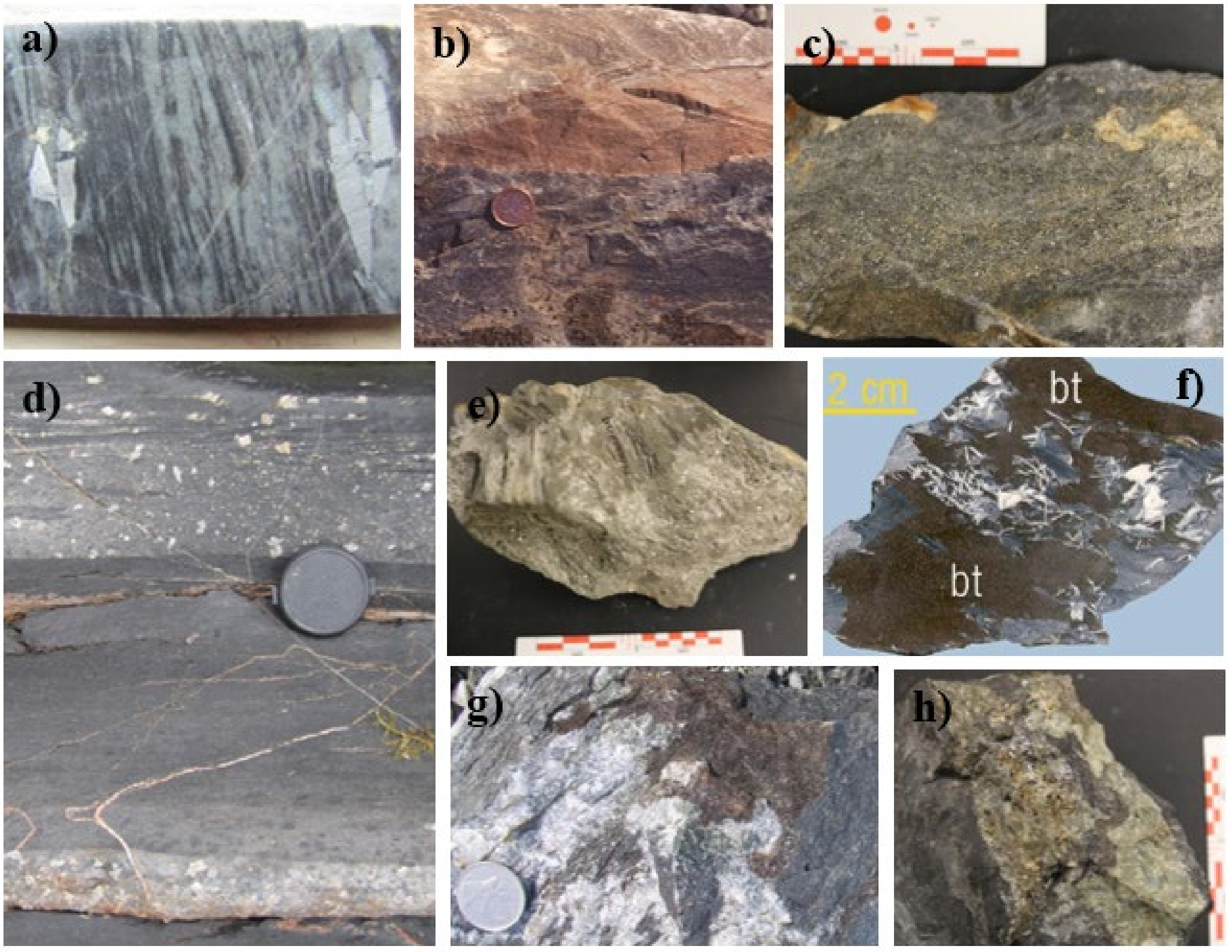
Bleaching

Bleaching refers to local lighting of greywacke units, commonly resulting in a mottled appearance (see Mooseland stop below). There is not much quantitative work to help understand exactly what bleaching records, however it likely reflects formation of leucocratic phases after darker ones, such as occurs when a rock is silicified and carbonatized (e.g., chlorite replaced by carbonate).

Other alteration types

In addition to the above, other wall-rock alteration includes sericite, chlorite, tourmaline, and apatite, but these are not developed on a pervasive scale and are mainly observed petrographically and are thus best described as cryptic. Development of these phases, as also for the aforementioned, relates to fluid flux and thus is coincident with vein emplacement versus part of the regional metamorphic assemblages in the metasedimentary rocks.

Figure 7. Photographs of various alteration types in MGD. a) Drill core showing bleaching of a metasandstone unit with associated coarse arsenopyrite (Beaver Dam). b) Pervasive Fe-carbonate alteration that has weathered brown (Touquoy). c) Disseminated pyrite in metasiltstone unit (Beave Dam). d) Disseminated arsenopyrite in metasiltstone bed (top) and replacive arsenopyrite bed (bottom) (The Ovens). e) Phyllic alteration of slate with pervasive pale green sericite and disseminated pyrite (Dufferin). f) Biotite replacing slate bed with associated calcite (Tangier). This biotite was dated by the ^{40}Ar-^{39}Ar method at 374 Ma (Kontak and Archibald, 2002). g) Biotite replacing slate bed marginal quartz vein (Mooseland). h) Massive calcic plagioclase with some intergrown biotite in slate bed (Beaver Dam).



FIELD STOPS

Day 1 - Moose River-Touquoy and Mooseland Deposits

Moose River-Touquoy Deposit

Safety:

A safety briefing will be provided by Atlantic Gold when we arrive at the site, and they will provide the necessary PPE for the tour. However, personal safety boots would be a benefit for time and sizing. In addition to standard PPE, Atlantic Gold require that long sleeve shirts are worn on site.

Overview

The Moose River (Touquoy) deposit is a low grade – high tonnage open pit mine hosted by argillite and lesser metasandstone of the Moose River Formation (Fig. MR1), which is the lowest exposed unit of the Goldenville Group, as seen in the hinge of the Moose River Anticline (Figs. MR1, MR2, MR3). The Beaver Dam and Fifteen Mile Stream gold deposits also occur within the Moose River Formation and along the same anticline; we will be looking at core from these deposits for comparison. The deposit occurs in the hinge of the Moose River Anticline, which has been locally modified by several cross-cutting and strike-parallel faults (Figs.MR1, 2); relationship of mineralization to faulting is unknown, but the faulting is likely post mineralization as it offsets the ore zone (Bierlein and Smith, 2003). Mineralization at Moose River is commonly referred to as *disseminated*, however the definition of disseminated is rarely quantified. Very little detailed work documents the character of gold at Moose River, and we hope that Atlantic Gold staff will be able to shed some light on this issue during our tour. According to the most recent technical report:

"Gold occurs as native gold, and has been observed in a number of settings, including along shear cleavage, hair line fractures; in pressure shadows; as inclusions; on the margins of sulphide grains; in thin bedding-concordant quartz veins and stringers where it is often associated with pyrite or pyrrhotite and sometimes with base metal sulphides, particularly galena and chalcopyrite; and on the margins of tightly-folded quartz veins, often at, or close to, fold hinges. Gold grain size as indicated by petrographic studies varies from 1 µm to >1 mm and gold grains up to 1.5 mm in size have been observed. Sulphide minerals accompanying the gold mineralization are pyrrhotite, usually aligned along the axial plane cleavage (1–2%), arsenopyrite, often as coarse porphyroblasts (1%), and pyrite (<1%). Other sulphides are rare. At a macro scale, there is typically poor correlation between arsenic and gold content."

Some observations that can be made based on exposures seen in the pit by the authors follow:

- Buckled bedding-concordant veins occur in the hinge of the west face of the pit (Fig, MR4), however these may not be part of the ore zone.
- A high concentration of bedding-concordant and discordant veins occurs on the south wall of the pit (Fig. MR5). The discordant veins are clearly displaced along the

bedding-concordant veins and are thus consistent with the bedding-concordant veins occurring along flexural slip horizons.

- A strike-parallel fault juxtaposing argillite and greywacke units (Fig. MR3).

Tour

Our visit will include a presentation by Atlantic Gold on the operation and a tour of the pit. Access to pit walls will be restricted, but even observations of the general geologic features from a distance will put things in context and samples from various parts of the pit will allow observations of the types of veins, the deformation features (e.g., folds, shearing), mineralization, and alteration.

Figure MR1. Plan map of the geology of Moose River Mine area (from Atlantic Geology) showing that the deposit is located within the Moose River Formation which forms the basal unit of the exposed Goldenville Group.

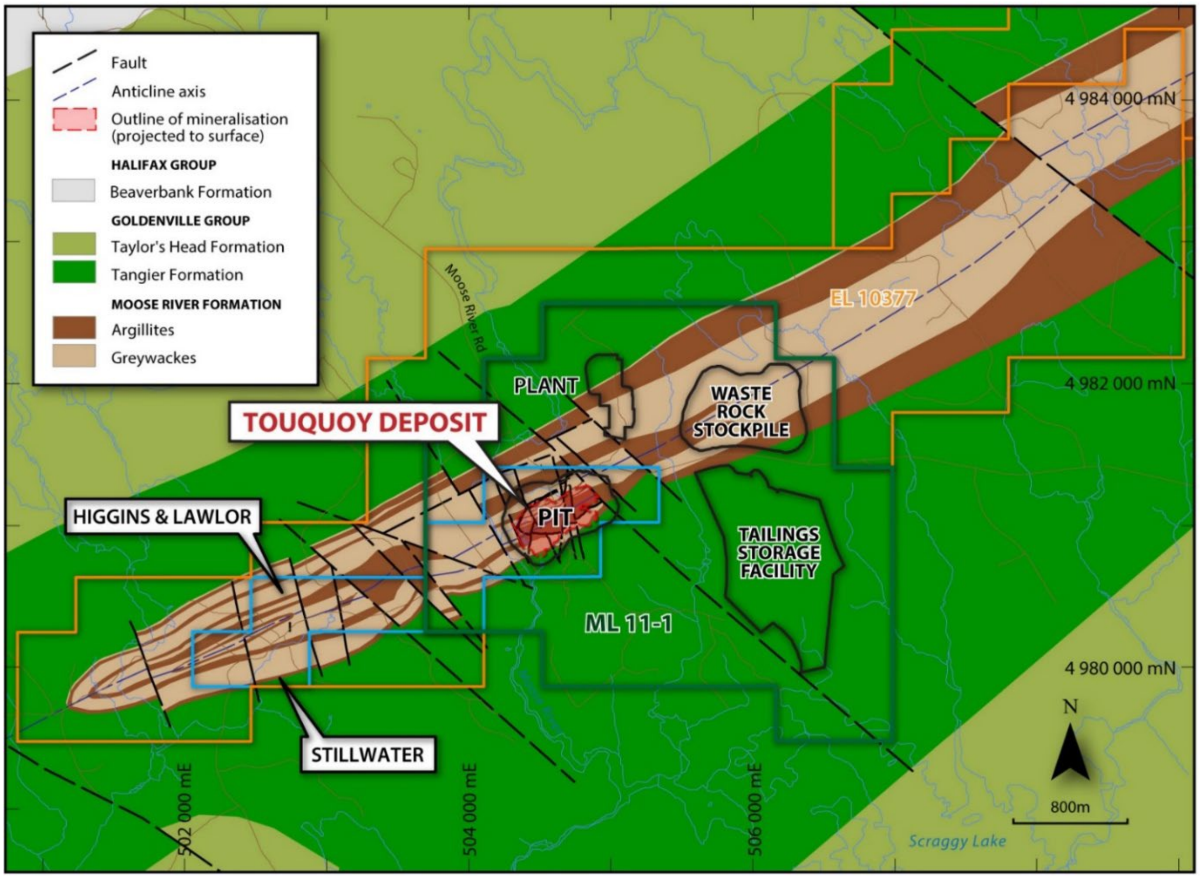


Figure MR2. Cross section of the geology of the Moose River deposit, from Atlantic Gold.

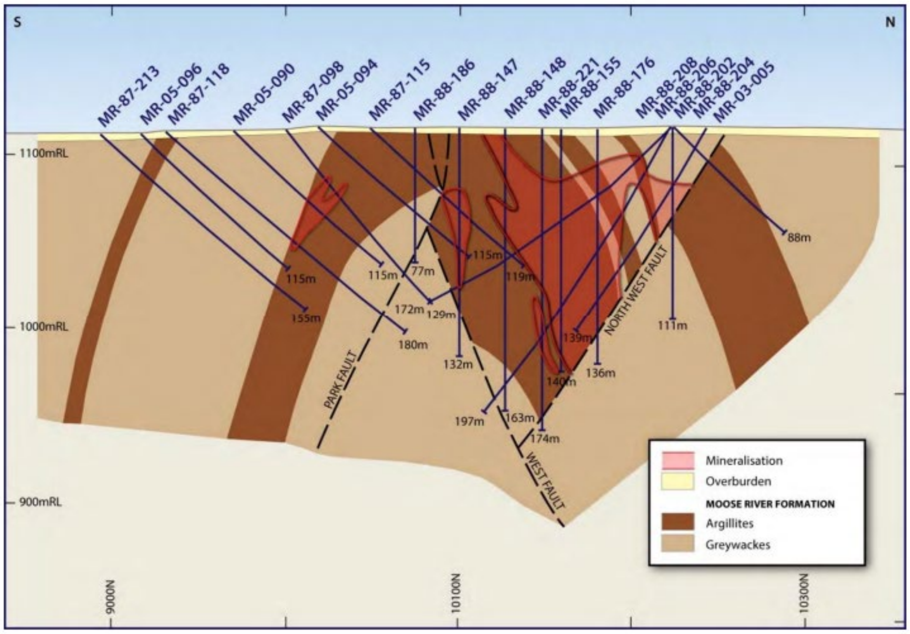


Figure MR3. Photograph of the pit at Moose River (looking southwest) showing the well-defined anticline in the west wall. Note abundant bedding-concordant quartz veins on the south wall. A steep fault juxtaposes an argillite unit with a greywacke unit.

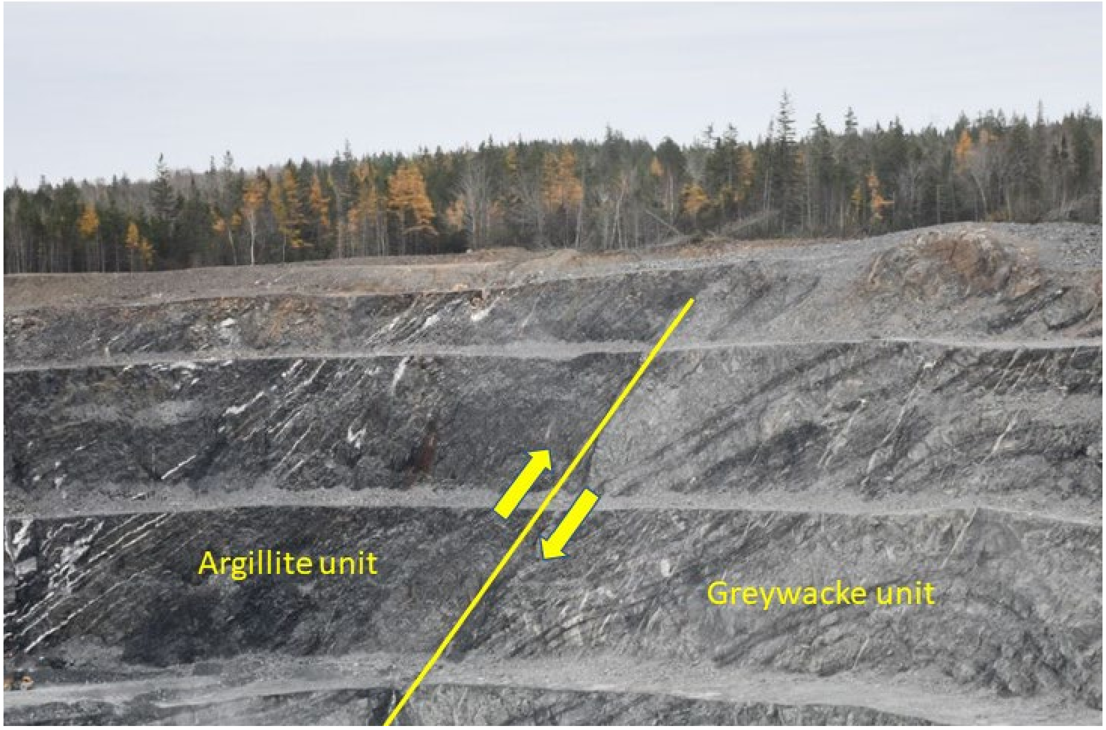
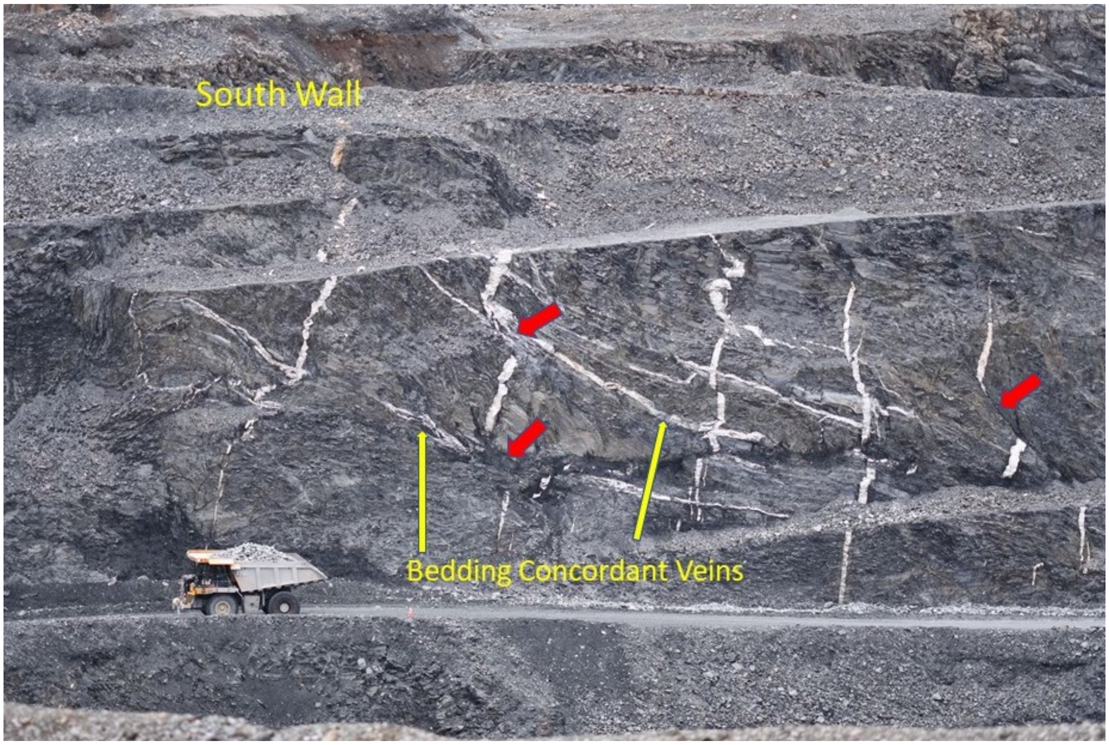


Figure MR4: Close-up photograph of the anticline hinge in the Touquoy deposit showing several strongly buckled bedding-concordant veins (yellow arrows).

Figure MR5: Photograph of the south wall of the open pit (south limb of fold) at Touquoy showing bedding-concordant and -discordant veins. Several discordant veins are clearly offset along bedding-concordant veins (red arrows), which is consistent with the bedding-concordant veins having developed along flexural slip horizons. Some discordant veins cut the bedding-concordant veins, which supports a synchronous timing of formation for both vein sets.



Day 1 - Mooseland Deposit

Safety

Mooseland is an abandoned mine site and we will be visiting outcrop exposures, waste and ore piles, and perhaps looking at some core. Normal safety protocols are applied; note that safety boots are recommended.

Overview

The Mooseland deposit is located to the north of the 380 Ma Musquodoboit peraluminous granitic batholith and possibly within its contact aureole, as suggested by the presence of remnant andalusite in the slate beds. That the andalusite is sheared towards vein margins suggests the veins post-date the granite intrusion (Kontak et al., 1990). The surface veins to be visited are exposed in the hinge of the Mooseland Anticline (Figs. ML1, 2) and conform to bedding-concordant veins. The deposit is typical of a saddle-reef vein setting, although historical work focused on bedding-concordant veins on the fold limbs. A saddle vein is exposed at surface and will be visited (Fig. ML2). Underground mining exposed abundant bedding-concordant veins of both massive and laminated nature, as well as en echelon shear veins exposed on fold limbs (Fig. ML3). Pervasive alteration includes carbonate (Fig. ML5), local bleaching (Fig. ML6), oikocryst development (Fig. ML7) disseminated arsenopyrite (Figure ML8) and hydrothermal biotite, and all of this can be seen in outcrop or in several small ore/waste rock piles on site.

Tour

Outcrop, waste and ore piles, and core are avaliable to examine at the deposit site. A cleared exposure in the hinge zone exposes the legs of a saddle vein (Fig. 2 Bismark vein). Several features of the veins in this area are noteworthy: 1) they are composite veins and represent several stages of vein infill; and 2) in places coarse (2-3 cm) euhedral quartz crystals can be seen indicating that during vein formation fluid pressure created dilatant openings which were lined by the coarse quartz. Alteration to be seen in both drill core and boulders includes dark brown biotie, Fe-rich carbonate, and bleaching of the metasandstones. In addition, lots of arsenopyrite will be seen and it has several modes of occurrence (Fig. ML8): 1) as coarse euhedra in veins and wall rock; 2) as arsenopyrite-rich narrow bedding-concordant veins; and 3) as disseminatoins in the slate beds that locally contain high concentrations of fine-grained euhedral arsenopyrite (Fig. ML8). In addition, local discordant veins are also present in surface outcrops and highly variable degrees of strain will be noted in the outcrops across the deposit site and also drill cores.

Discussion

Our understanding of ore distribution within MGD is not well understood and has been a challenge for historic mining; this issue will be discussed throughout the field trip. Many historic documents, including maps, discuss the importance of “angular” veins with associated localized gold enrichment, although little robust documentation of this exists. Mapping of a recent decline and several drifts that followed bedding-concordant veins documented angular veins that caused (?) enrichment of the bedding-concordant veins where they overlap (Fig. ML4).

Figure ML1. Plan map of the Mooseland deposit. Note the location of the inset map shown in upper left which shows the extent of undreground veins.

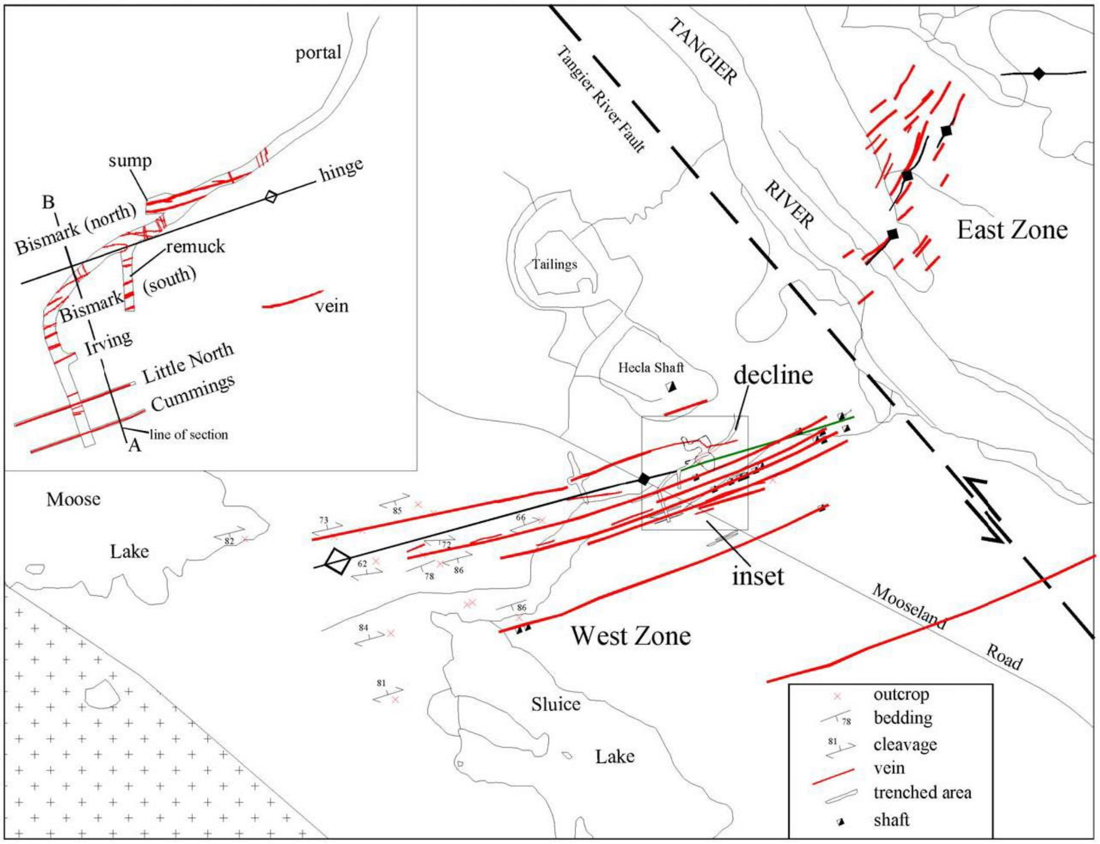


Figure ML2. Photograph of the exposed Bismark saddle-reef vein with cross-section inset. Map of the surface geology of the hinge area at Mooseland.

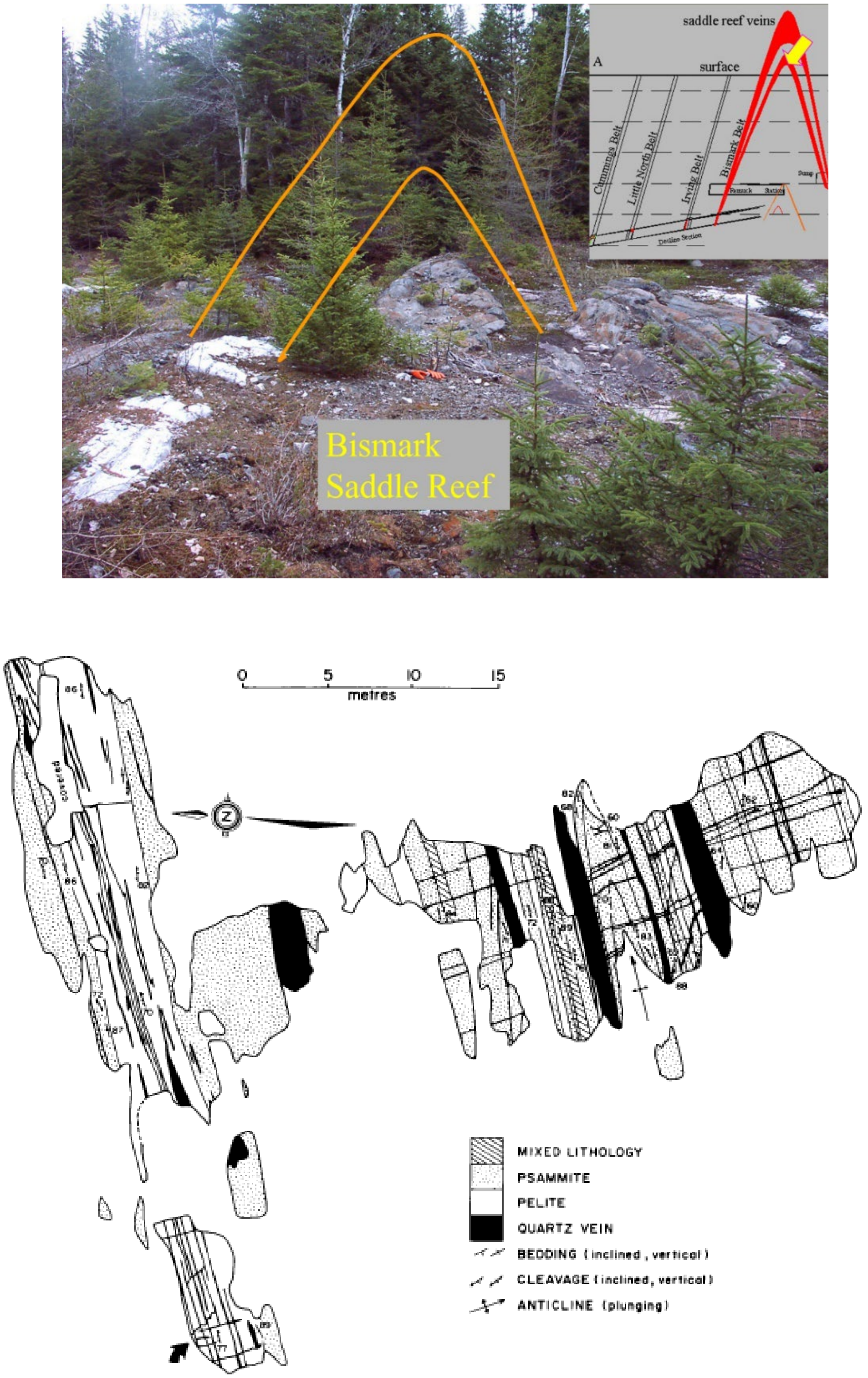


Figure ML3. General cross section and detailed section of the Mooseland Anticline. A) A schematic diagram showing the various structural elements of the Mooseland deposit. Note in particular the stretched oikocrysts. B) General cross section of the deposit showing the saddle-reef vein. C) Detailed section of the underground decline area. D-F) Detailed sections of mineralized zones.

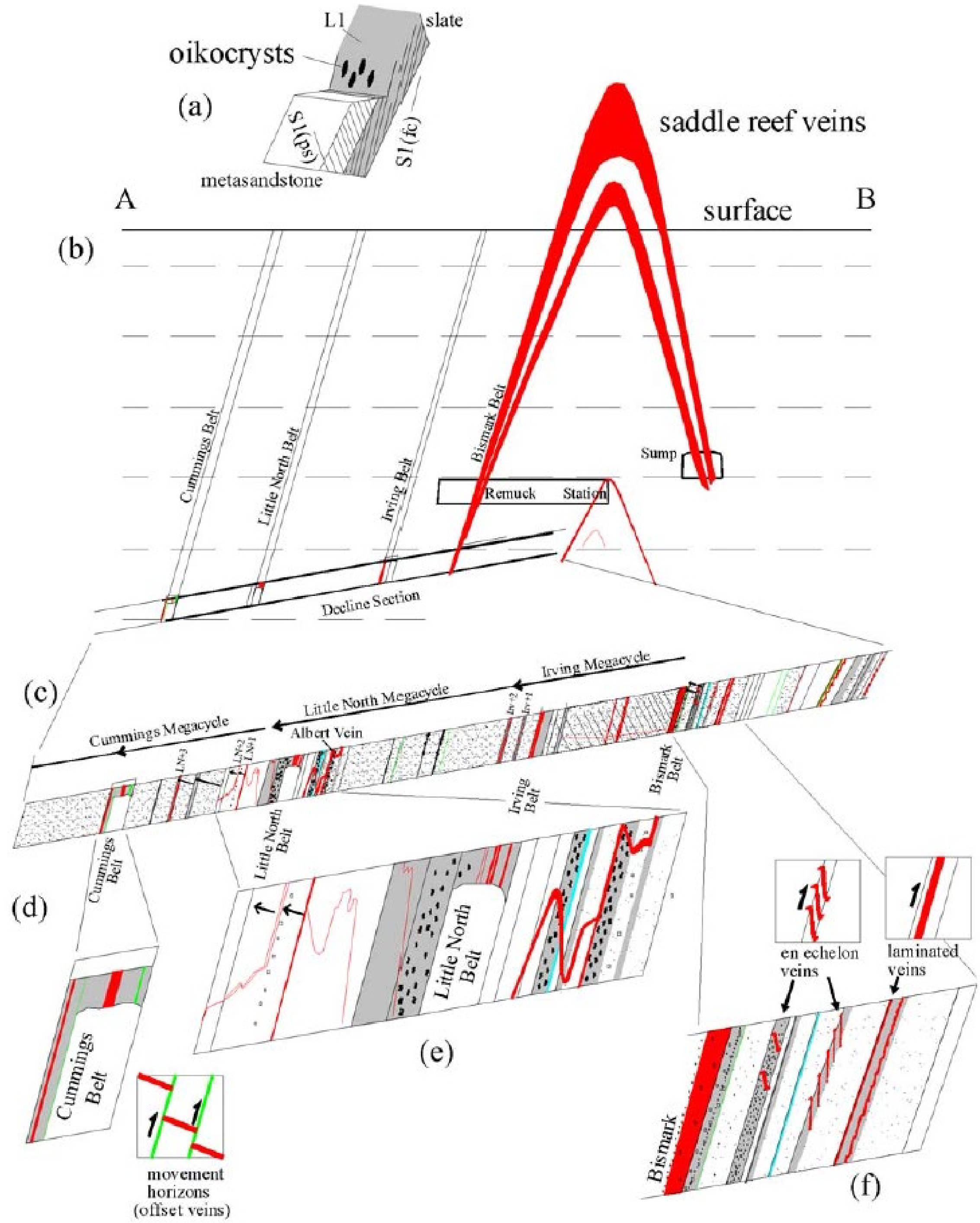


Figure 4. Close up of the Little North belt showing details of angular veins (yellow) and the ore shoots (green arrows) that develop by the overlap of bedding-concordant (red) and angular veins.

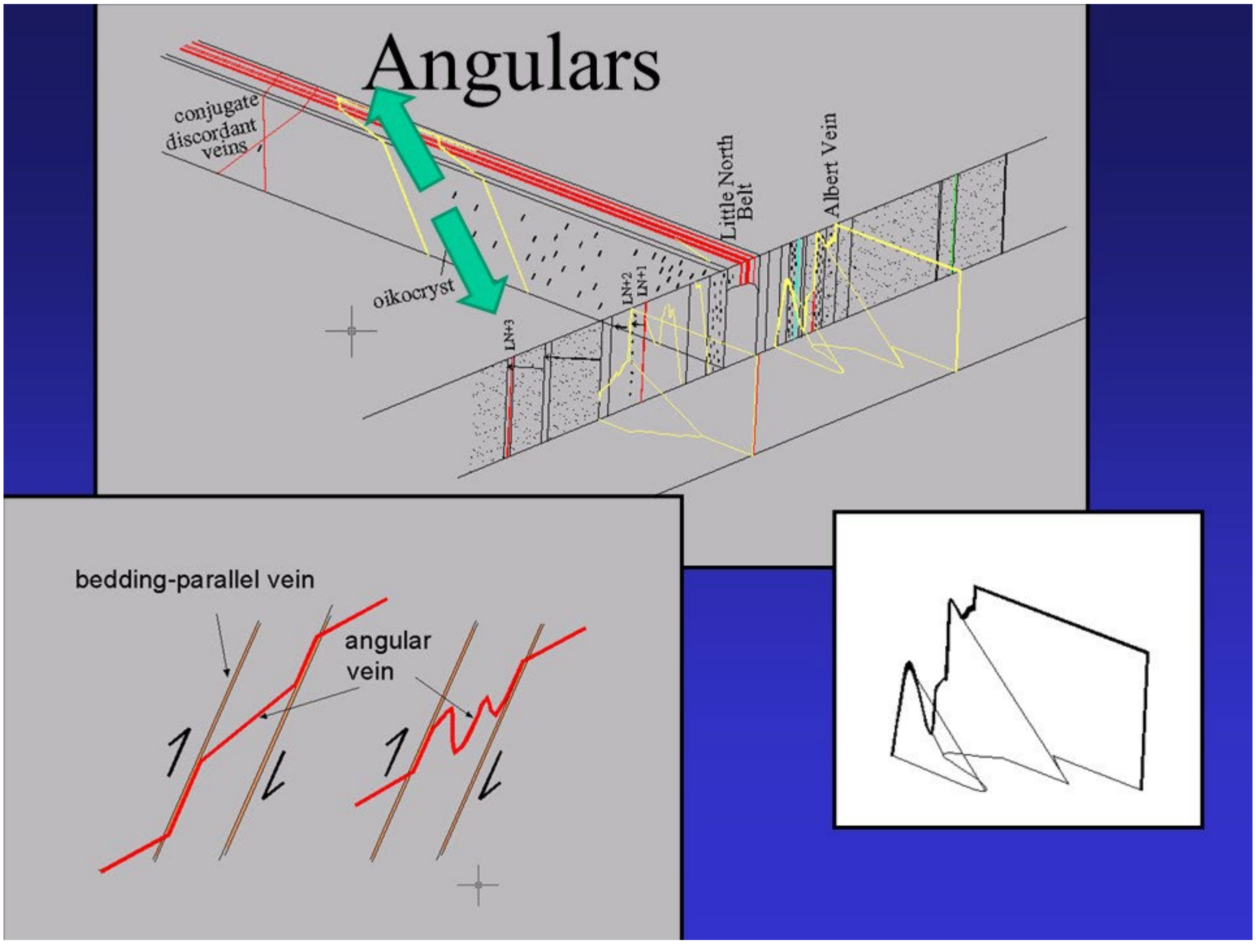


Figure ML5. Photo of core showing Fe-carbonate alteration as seen by the brownish areas.

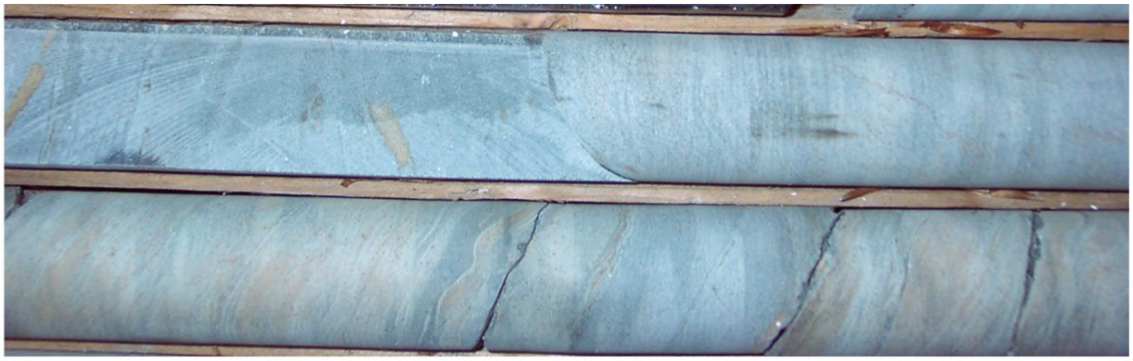
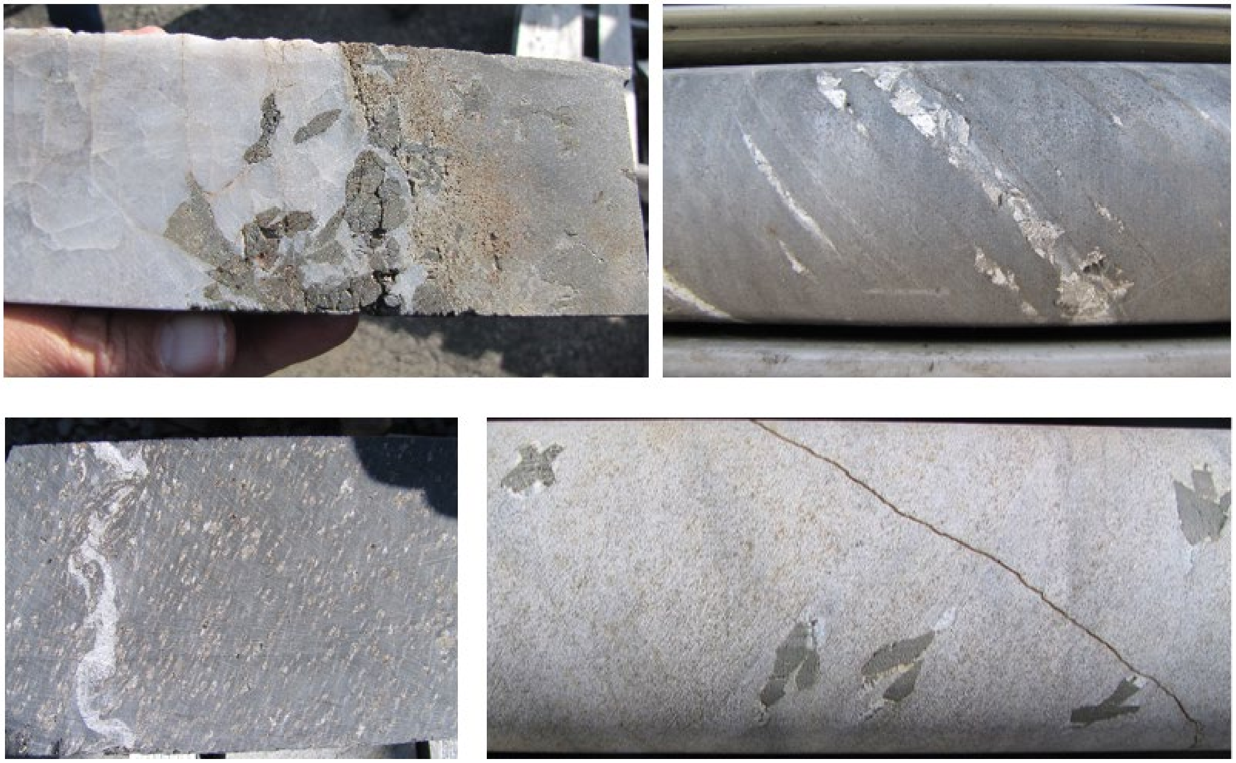


Figure ML6. Underground photo showing local occurrence of bleaching.

Figure ML 7. Photograph of oikocrysts. Note they are elongated perpendicular to the fold axis.

Figure ML8. Different modes of occurrence of arsenopyrite at Mooseland deposits. As coarse euhedral grains in vein and wall rock, forming thin arsenopyrte rich veins ± quartz, and as disseminations in slates,



Day 2 - Aureus East Deposit (the historical Dufferin deposit)

Safety

Our visit will start with safety training to prepare to go underground in addition to a presentation by Aurelius staff on recent developments at the mine. This is an industrial site and safety equipment is always required, including safety boots, hard hats, and goggles. Hard hats and goggles will be provided; however, it is hoped that participants will have safety boots (note that only a limited number of boots will be available in restricted sizes!). Mine lamps and self rescuers will be provided for the underground trip. This site may be operating in some capacity during our visit, and we could encounter moving vehicles. The most important aspect of safety is to stay with the trip leader and to follow his instructions while underground.

Overview

The Aureus deposit, formally known as the Dufferin deposit, is a classic saddle-reef gold deposit consisting of stacked saddle-reef veins and associated veins (leg reefs or bedding-concordant veins and discordant veins) in the hinge of the Crown Reserve Anticline (Fig. A1). Diamond drilling to date has identified numerous saddle veins to a vertical depth of ca 900 metres (Fig. A2). Saddle veins (Fig. A3) vary in size (i.e., up to several metres at their apex) and vary in continuity along strike. Down-dip extensions of saddles are represented by either laminated veins or en echelon shear veins (Fig. A4) which can locally extend for over 60 metres down dip. The saddle veins consist of massive, locally vuggy quartz and contain large inclusions of the laminated quartz vein material. The massive quartz of the saddles invariably crosscuts laminated veins (Fig. A3), consistent with early laminated vein development prior to significant dilation within the fold hinge. Discordant veins are common and record a component of hinge parallel extension. Discordant veins are continuous with saddle veins and are spatially related, hence they are interpreted to be synchronous with saddle development. Several faults displace the saddle veins, the most significant of which is the Harrigan Cove Fault that records >1 km of sinistral strike-slip separation (Fig. A1). Of relevance is that Ar-Ar dating of the wall-rock slates yield a 404 Ma age whereas slate-hosted in the laminated veins yielded a 388 Ma (Kontak et al. 1998) and arsenopyrite from two saddles were dated at 380 ± 3 Ma using the Re-Os method (Morelli et al., 2005).

Tour

The tour will start with a presentation by Aurelius staff on the status of the project. The underground visit will focus on the various vein types (saddle reefs, laminated bedding-concordant, en echelon shear veins, and discordant veins) and the relationship amongst these veins. Discussions on the gold endowment of the various saddle reef veins will be addressed but at present is an outstanding problem as both gold endowment and its distribution remain unexplained. This tour should provide unambiguous evidence that the vein array developed progressively and that all veins were emplaced at the same time.

Figure A1: Plan map of the Aureus East and West deposits (from Aureus).

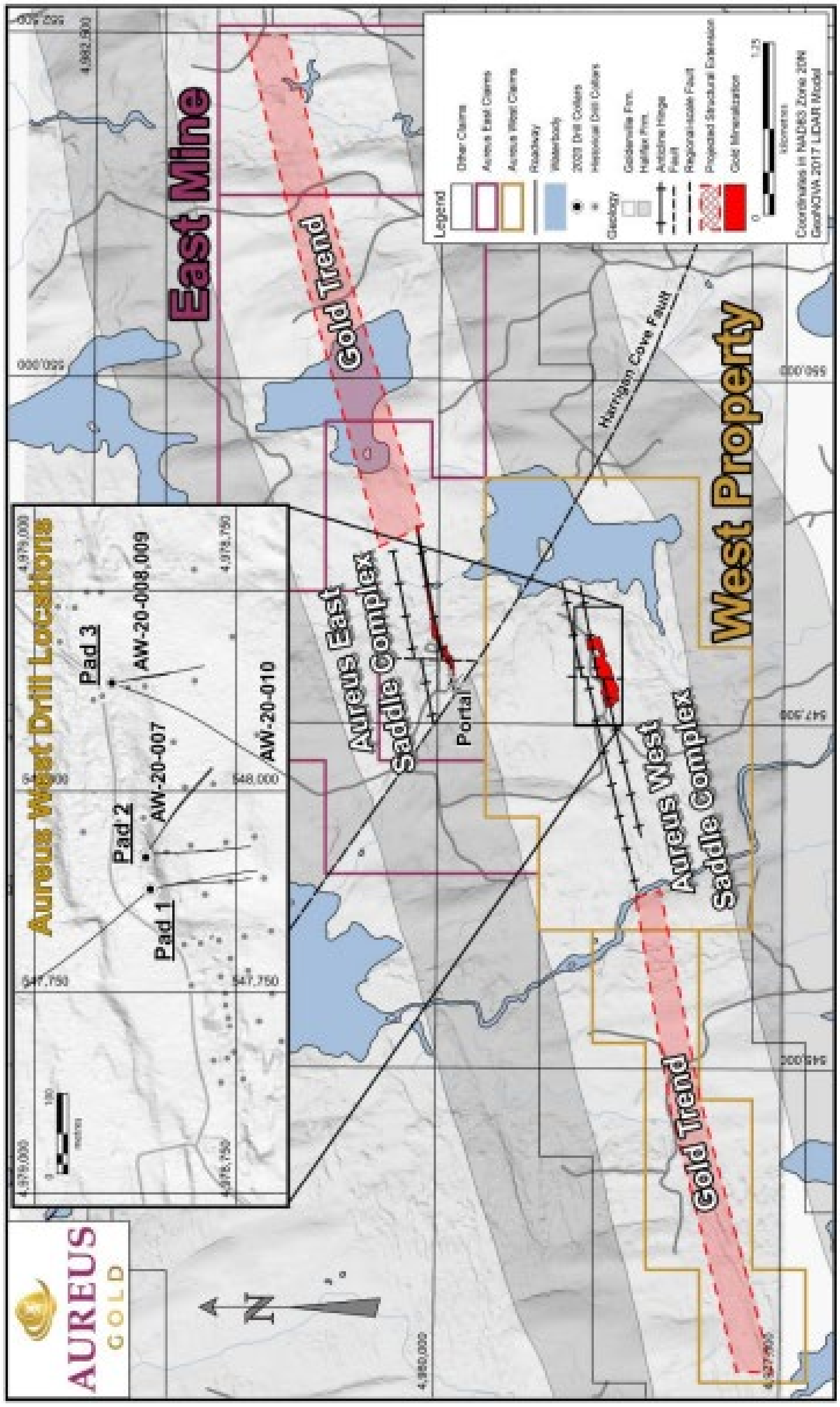


Figure A2. Cross section of the Aureus East deposit showing numerous saddle reef veins in the fold hinge as inferred from deep drilling (from Aureus).

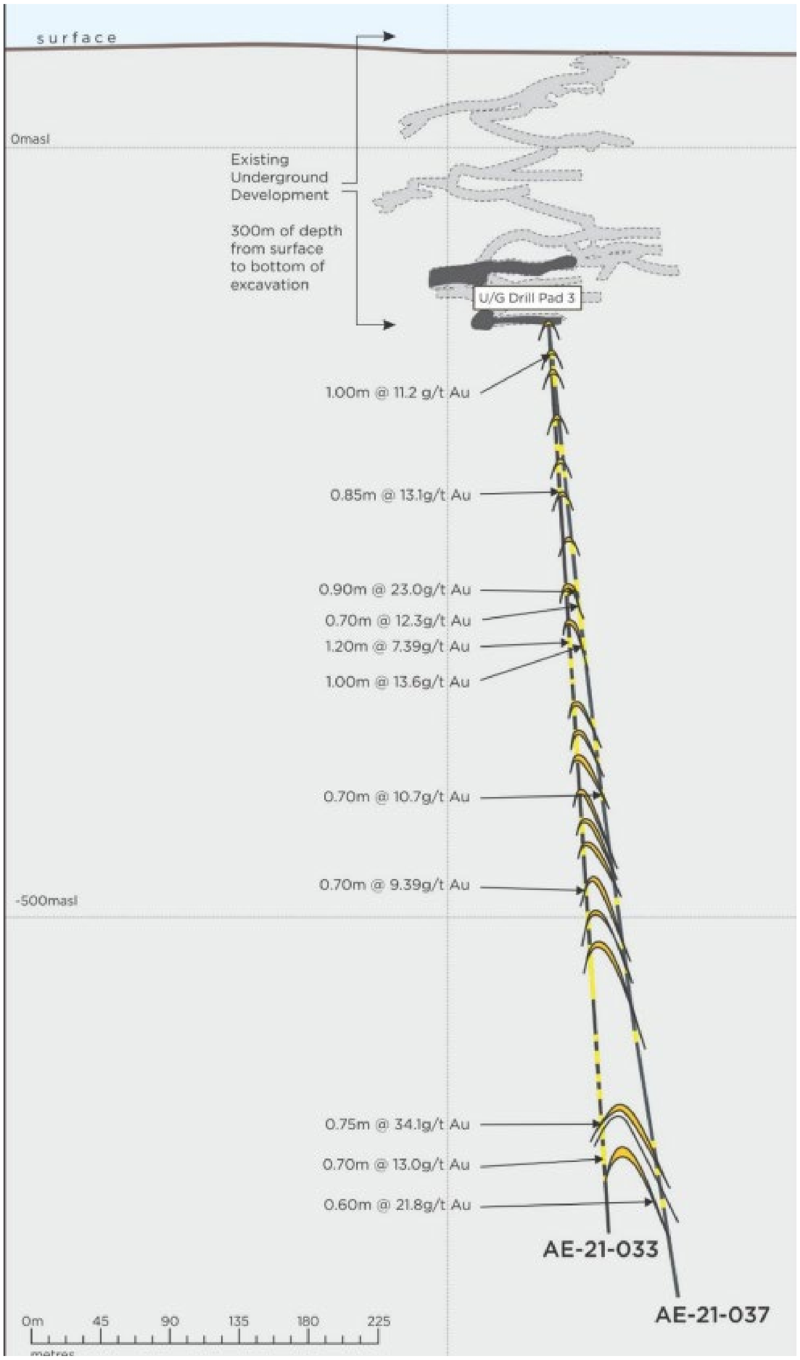


Figure A3. Photograph of Saddle 5 and the immediate leg reef (below). Note inclusions of laminated veins (dark grey) throughout both.

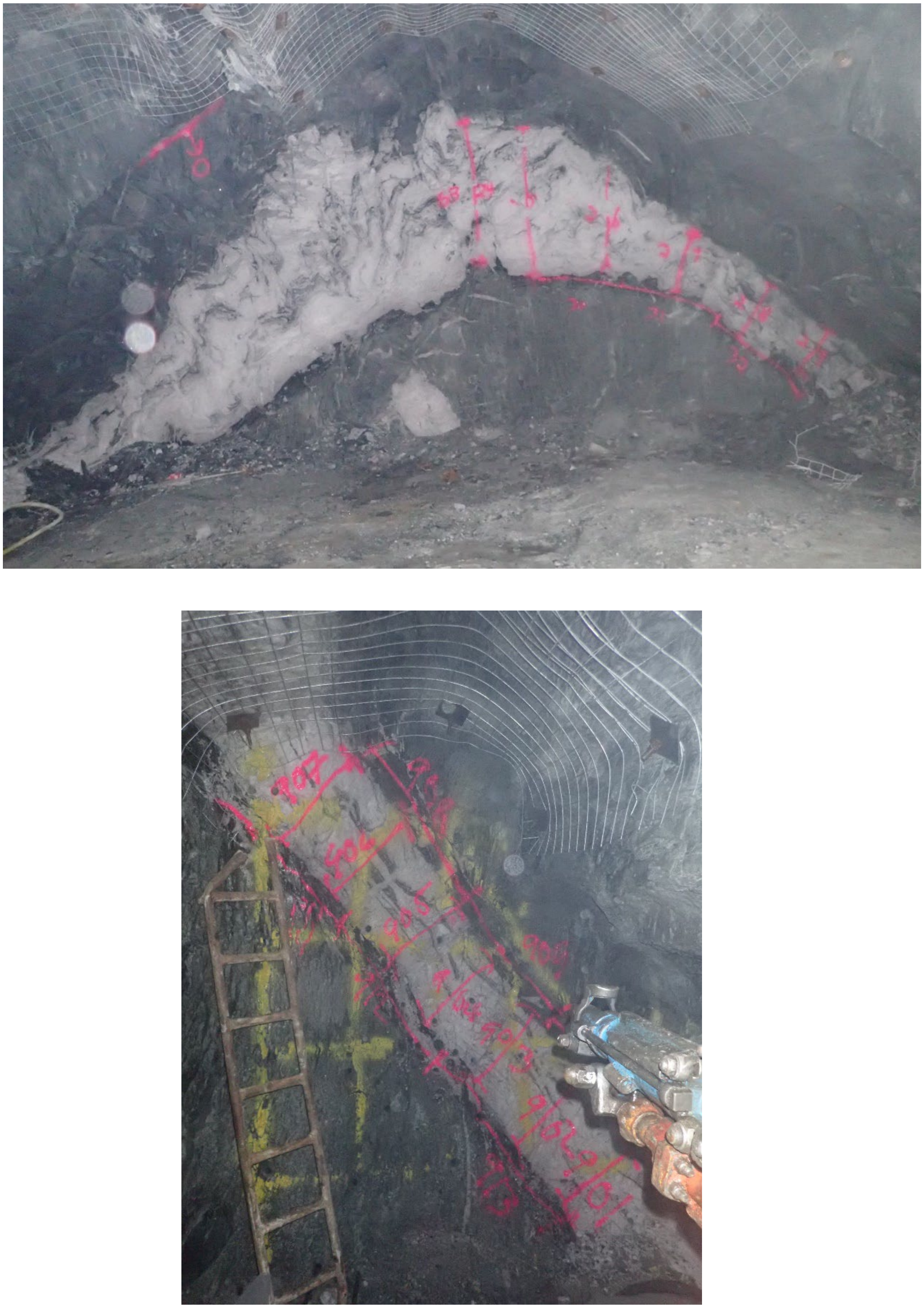


Figure A4. Photograph of leg reefs associated with Saddle 1 (a, b and c) several decametres below the saddles. Leg reefs are represented by laminated bedding-concordant veins and en echelon shear veins confined to slate intervals. Model in lower left illustrates the development of en echelon shear veins.

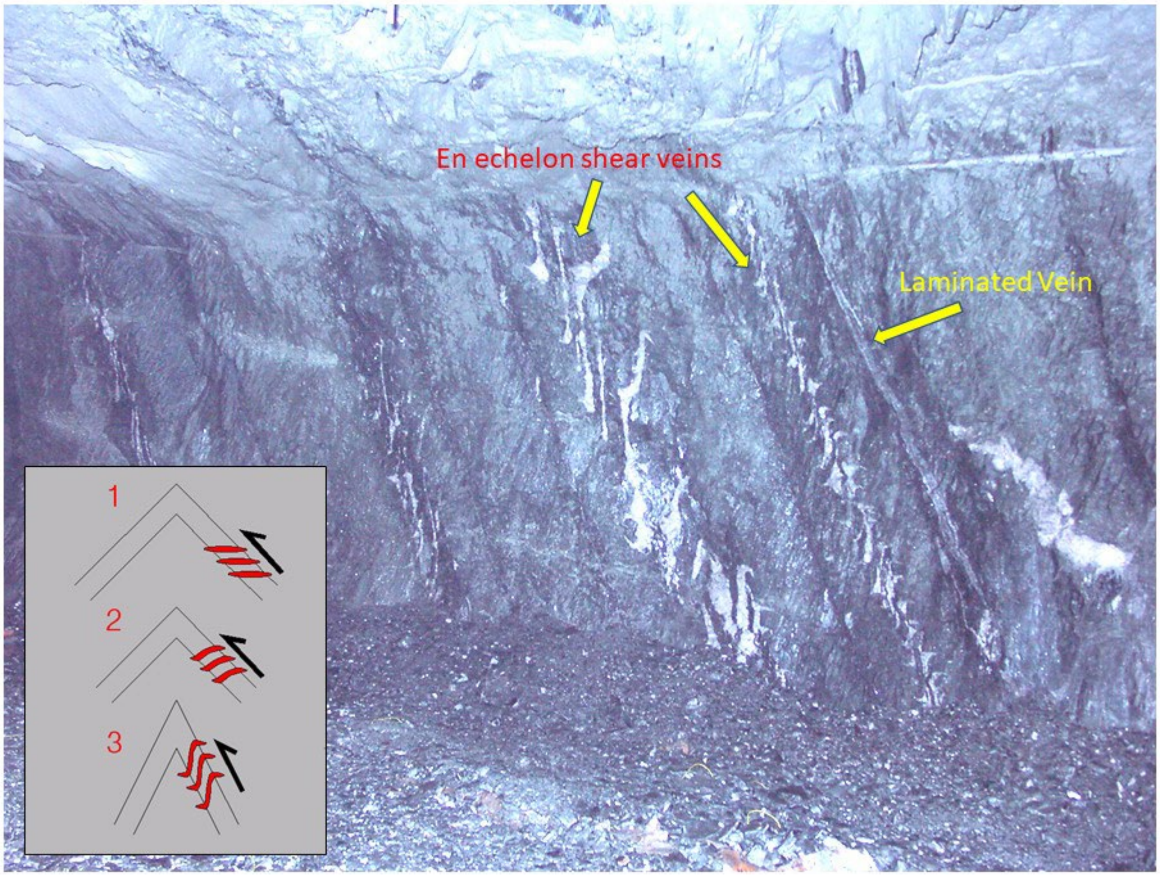
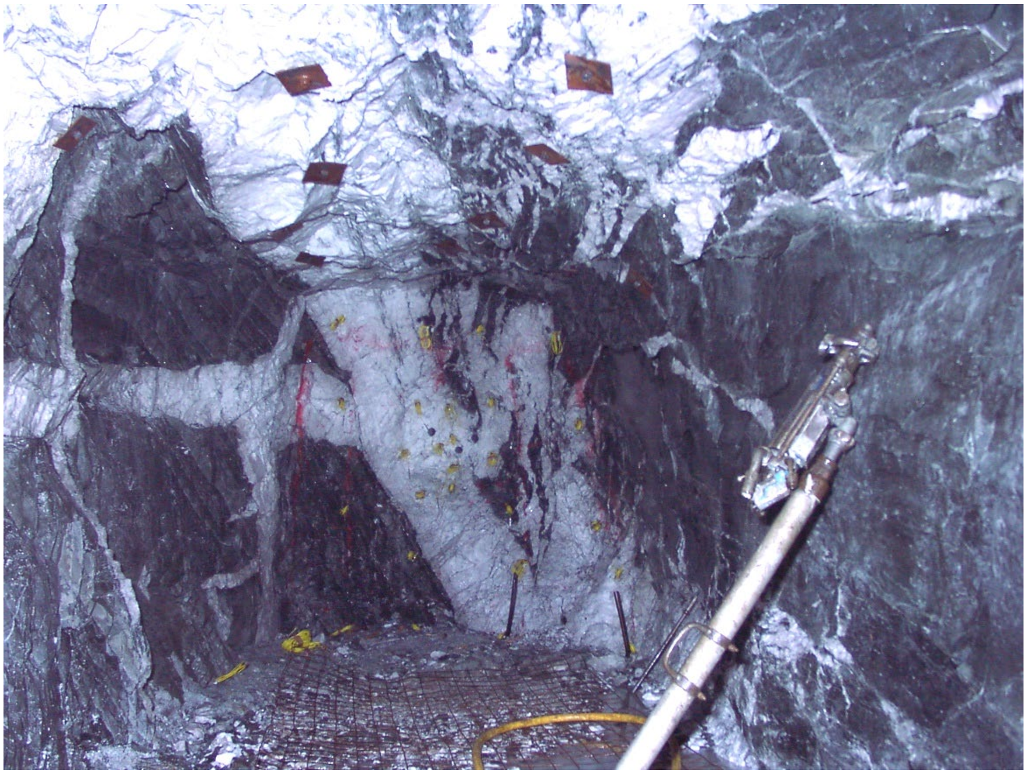


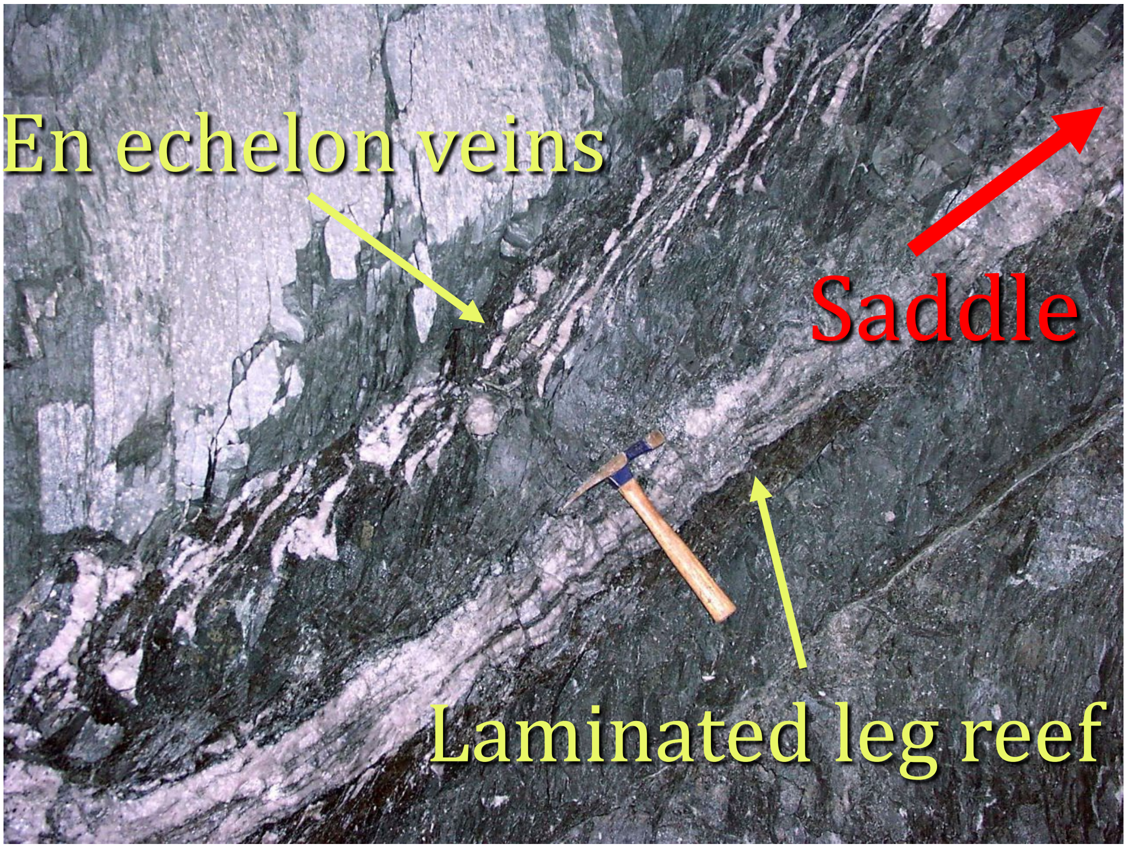
Figure A5. Miscellaneous photos: (a) Saddle 2 saddle (mined out) (b) north leg of saddle 2 with en echelon veins in its hanging wall, flat and discordant veins in the footwall. (c) En echelon and laminated veins. Note spatial association of all vein types.

(a)

(b)



(c)



Day 3 – The Ovens Deposit

Safety

Our visit to The Ovens area will involve traversing along the Atlantic coastline, where wet and seaweed-covered rocks make for slippery conditions. Wear good boots and take caution in these areas; sneakers and shoes will not be permitted. There are cliff exposures and falling rocks are a possibility, so please stay back from these potentially dangerous settings no matter how alluring they appear! Furthermore, though some of the cliffs are low, please do not climb. Many of the exposed outcrops consist largely of slate, which can be more than sharp enough to cut through skin. Access to The Ovens Anticline in Rose Bay is tide dependant, with the western part of the section inaccessible at high tide. Thus, our visit will begin at low tide, with a rising tide during our time on this section and therefore it is critical that participants stay as a group and follow the trip leader to prevent anyone from becoming trapped by the tide.

Overview

The coastal exposure in The Ovens area offers a spectacular view of a chevron fold that hosts a MGD in a vein array - 100s of veins in fact! This excellent exposure provides a unique opportunity to view the relationship of veins to the fold structure, as well as the relationship among vein types, therefore an excellent way to end our trip with a summary of MGD. This stop will focus on the Rose Bay section where an oblique section through the hinge is exposed and the hinge zone exposure within The Ovens Natural Park (Fig. OV1).

It is important to note that gold is found in all vein types here and is most abundant (based on observations over many visits to the site) in discordant veins, which cut thrust sheets (see below). This is consistent with the mutual cross-cutting relationships of bedding-concordant and discordant veins and their inferred synchronous timing of emplacement. Also, of note here is the abundance of arsenopyrite in the hinge area of the structure which is spatially coincident with the presence of quartz veining; this contrasts with its absence away from the gold closure. Locally the disseminated arsenopyrite gives way to beds of massive fine- to medium-grained arsenopyrite that is commonly cored by pyrite based on our microscope studies of select samples. Several coarse arsenopyrite grains extracted from the bedding-concordant and discordant quartz veins yielded identical Re-Os ages of 408 Ma (Morelli et al., 2006), which compare to similar Ar-Ar ages for whole rock slates from within and outside quartz veins (Kontak et al., 1998), but older than an Ar-Ar muscovite age of 376 Ma for mica from pressure shadows around arsenopyrite in the wall rock (Hicks et al., 1999).

Fold Structures

The Ovens Anticline in the area occurs within in the lower Halifax Group (Cunard Formation) which here consists of interbedded black slate and metasandstone/siltstone. Numerous fold-related structures that will be pointed and discussed include (Fig. OV2):

- Extensional veins in the fold hinge; tangential longitudinal strain
- Axial planar cleavage
- Pressure shadows on arsenopyrite (down dip extension)
- Minor folds (restricted to the fold hinge)

- Flexural-slip movement horizons; slickenfibres; displaced discordant veins
- Bulbous hinge
- Hinge thrusts
- Limb thrusts

In addition to the fold related structures, there are a series of thrust sheets on the south limb of the fold exposed along Rose Bay (Fig. OV3). Bedding-cleavage relationships within thrust sheets indicate they originated in regional fold hinges.

Quartz Veins

Quartz veins are abundant in the hinge area of The Ovens Anticline and form an ***array of bedding-concordant and discordant veins***. The anomalous concentration of bedding-concordant and discordant veins is obvious and ***mutual cross-cutting relationships*** between both vein types (Fig. OV4, OV5) illustrates synchronous emplacement of the vein array. Although the common macroscopic sulphides phases are arsenopyrite and pyrite, microscopically rarer sulphides are seen, including pyrrhotite, chalcopyrite, sphalerite, galena; in addition, secondary muscovite, tourmaline, apatite, and rutile are present in the veins and/or wall rocks. The different vein types are discussed below.

Bedding-concordant (flexural-slip) laminated veins: There are abundant bedding-concordant veins on both limbs of the anticline. Individual veins vary in their nature, but include the following features (i.e., rare to common): (1) a laminated- or crack-seal texture (locally speckled-hen texture, Henderson et al., 1990); (2) occupy flexural-slip-movement horizons defined by offset discordant veins (Fig. OV4); (3) striated margins; (4) cut by or cross-cut discordant veins (Fig. OV4); (5) host wall-rock fragments of cleaved slate; (6) pinch and swell; (7) define down-limb extensions of saddle-reef veins.

Buckled bedding-concordant veins: Tightly buckled bedding-concordant veins locally occur, although, as discussed above, they are restricted to the fold hinge and their down-limb extensions are not folded and typical of bedding-concordant flexural-slip veins (Fig. OV4).

Saddle reefs: A classic saddle reef vein occurs in the hinge of The Ovens Anticline at the western end of the Rose Bay section (Fig. OV4). Importantly, the down-dip extension of the saddle reef is represented by a laminated flexural-slip bedding-concordant vein, across which a discordant vein is displaced.

Discordant veins: Abundant discordant veins occur which have mutual cross-cutting relationships with bedding-concordant veins, thus indicating synchronous emplacement (Fig. OV5). Discordant veins consist of a systematic conjugate set with steep and west-dipping veins. The obtuse bisector of the conjugate vein sets is parallel to the fold hinge and their intersection lies dispersed within the ac plane of the fold.

Thrusts

Several ***outcrop-scale thrusts*** occur on the south limb of the anticline in the Rose Bay section (Fig. OV3). Distinction of thrust sheets is apparent by the ***truncation of stratigraphy*** and variation in the orientation of ***structural elements (bedding-cleavage)*** between sheets. Thrusts are characterized by striated fault planes and or laminated veins and show a reverse shear sense. Cleavage is at a high angle (locally near perpendicular) to bedding within the thrusts, thus implying they originated in a fold hinge. Several buckled bedding concordant veins occur within the thrust sheets.

DISCUSSION

Minor folds

Minor folds developed in bedding-concordant veins and/or stratigraphic layers are found in two structural locations in Rose Bay: 1) where accompanied by mullion structures they occur ***within thrust sheets,*** as seen on the south limb of the anticline (Fig. OV3); and 2) in the ***hinge of The Ovens Anticline*** in Rose Bay and Cunard Cove (Fig. OV5). Thus the folded beds and veins are clearly restricted to the hinge region of this major fold, whereas extensions of the folded veins and bedding layers are ***planar features on the limbs*** (Fig. OV5). That the minor folds are spatially restricted to hinge areas of regional folds supports the view that such folds developed in the "flat" hinge area late in the development of the regional folds.

Timing of vein emplacement

The vein array in The Ovens anticline occurs within flexural-slip structures that deform fold-related cleavage; additionally, the veins locally host cleaved slate fragments which indicates a post-cleavage timing, and by inference, must post-date regional metamorphism. Saddle reefs are an essential part of the vein array and implicitly develop late in fold development, as noted above. Mutual cross-cutting relationships with both bedding-concordant and discordant veins, which show only minimal deformation, also support a late timing for vein development.

As noted above, there has been a limited amount of dating for The Ovens which appears to contradict in part the observed field relationships. Thus, whole-rock Ar/Ar dating of slates within and marginal to veins yielded overlapping plateaux ages 397 Ma (Kontak et al., 1998) and are interpreted to reflect cooling through the retention temperature for argon in micas (300 to 350° C). In contrast, muscovite from arsenopyrite pressure shadows gave a plateau age of 376 Ma, thus similar to the granites of the Meguma Terrane, which Hicks et al. (1999) interpreted as the age of flexural-slip deformation and related vein development. We also note local development of hydrothermal sericite in the host rocks marginal bedding-concordant veins at The Ovens based on high-resolution imaging using the SEM (Kontak, 2021). Lastly, we note the anomalously older, but statistically valid, Re-Os arsenopyrite ages for both concordant and discordant vein types of 408 Ma (Morelli et al., 2006). To add to this geochronological quandary, we note a preliminary in situ LA ICP-MS U-Pb age of 390 ± 10 Ma for scheelite from a bedding-concordant vein reported by Kontak et al. (2017). Although we highlight here some discrepancies in the dating, we also note that Re-Os dating of arsenopyrite from other Meguma deposits (i.e., Beaver Dam and Touquoy; Chen et al., 2014) have returned both older (i.e., >400 Ma) and younger (i.e., ca. 380 Ma) ages which may suggest a protracted history for arsenopyrite growth. Thus, there is need for more integrated work to resolve this outstanding but interesting problem.

Figure OV1. Geological map and structural data for The Oven area (from Faribault 1929; Horne and Culshaw, 2001). (a) Simplified geology map of the Lunenburg area showing the location of The Ovens). (b) Geological map and simplified cross section of The Ovens area showing the location of Rose Bay, where the hinge and south limb of The Ovens Anticline are exposed. Stereonets are for selected flexural-slip structural data for The Ovens Anticline.

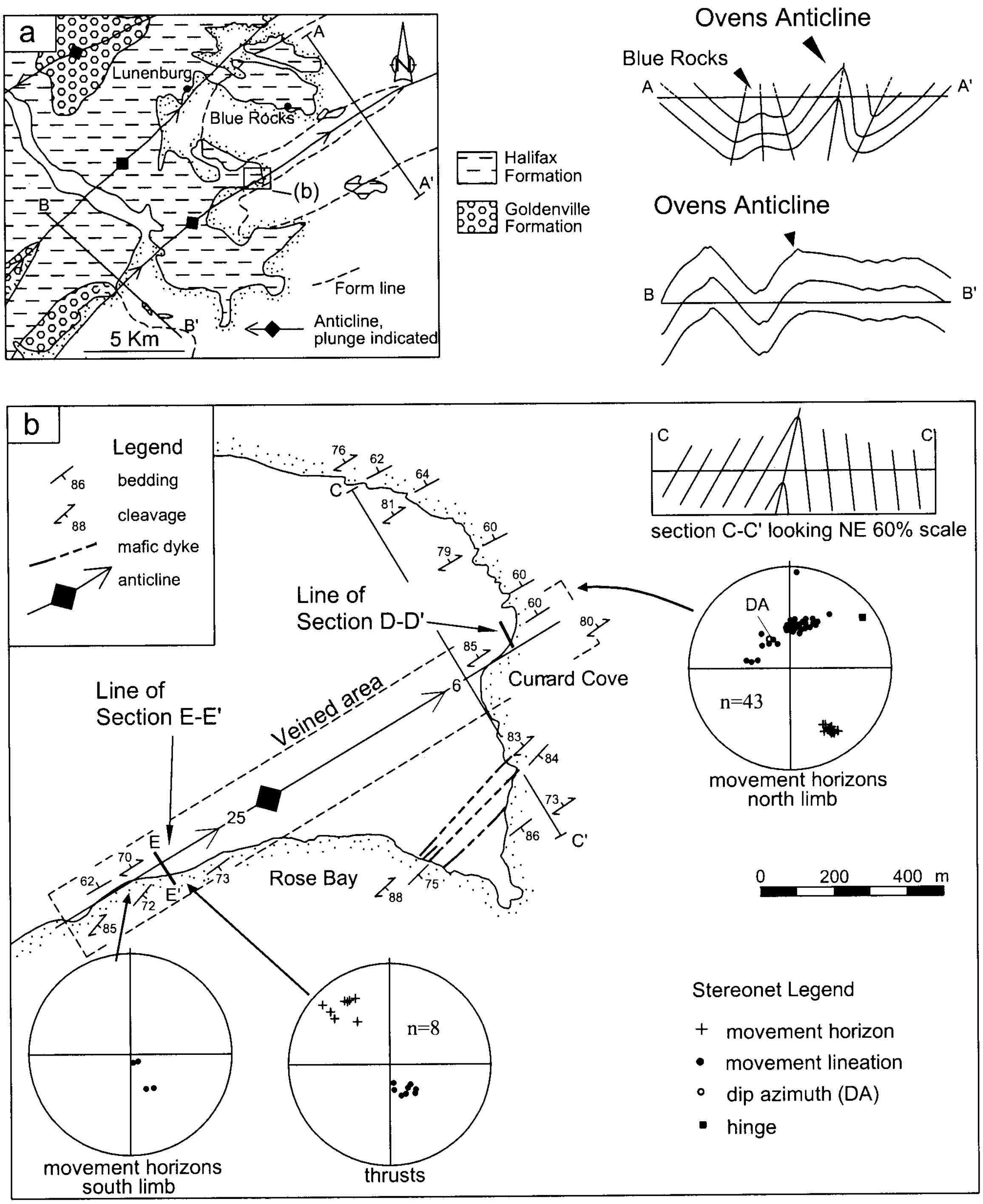


Figure OV2. Sketch of the hinge of The Ovens Anticline exposed in Rose Bay. It shows various structural elements of the fold referred to in the text. In the photograph are shown the following features: BH=bulbous hinge; SR=saddle reef; EV=extensional veins; FH= flat hinge. Note that layering and bedding-concordant veins are buckled in the flat hinge but planar on adjacent limbs.

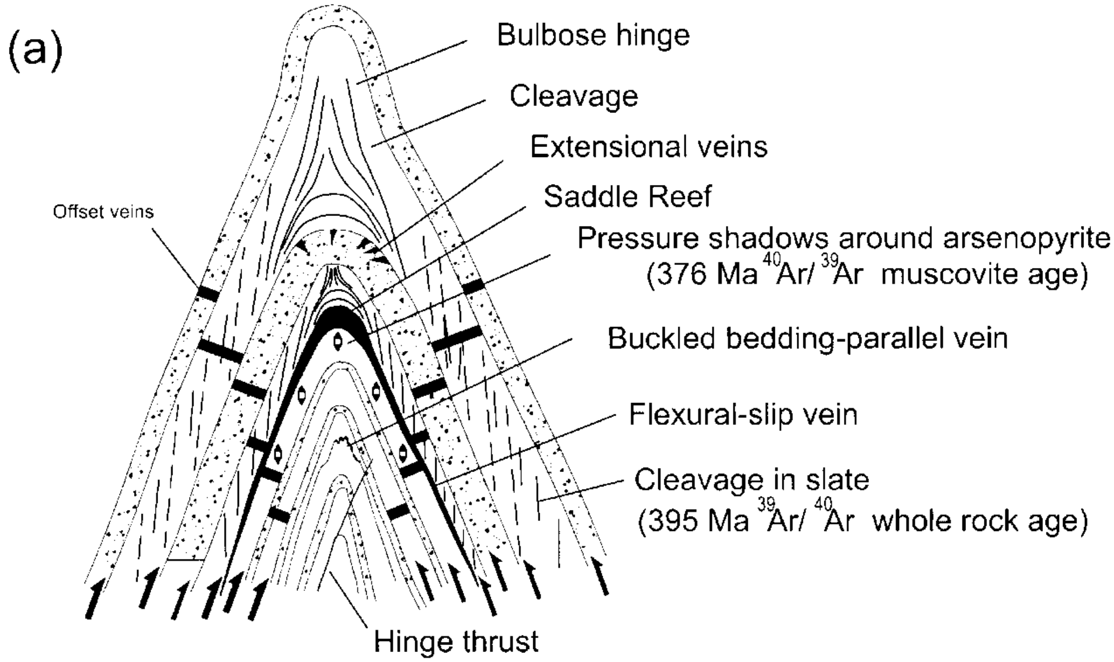


Figure OV3. Cross section of The Ovens Anticline in the Rose Bay area. Location of section is shown in Figure OV1. Zone A illustrates the structural character of The Ovens Anticline whereas Zone B shows the structural character of several thrust sheets emplaced on the south limb of the anticline.

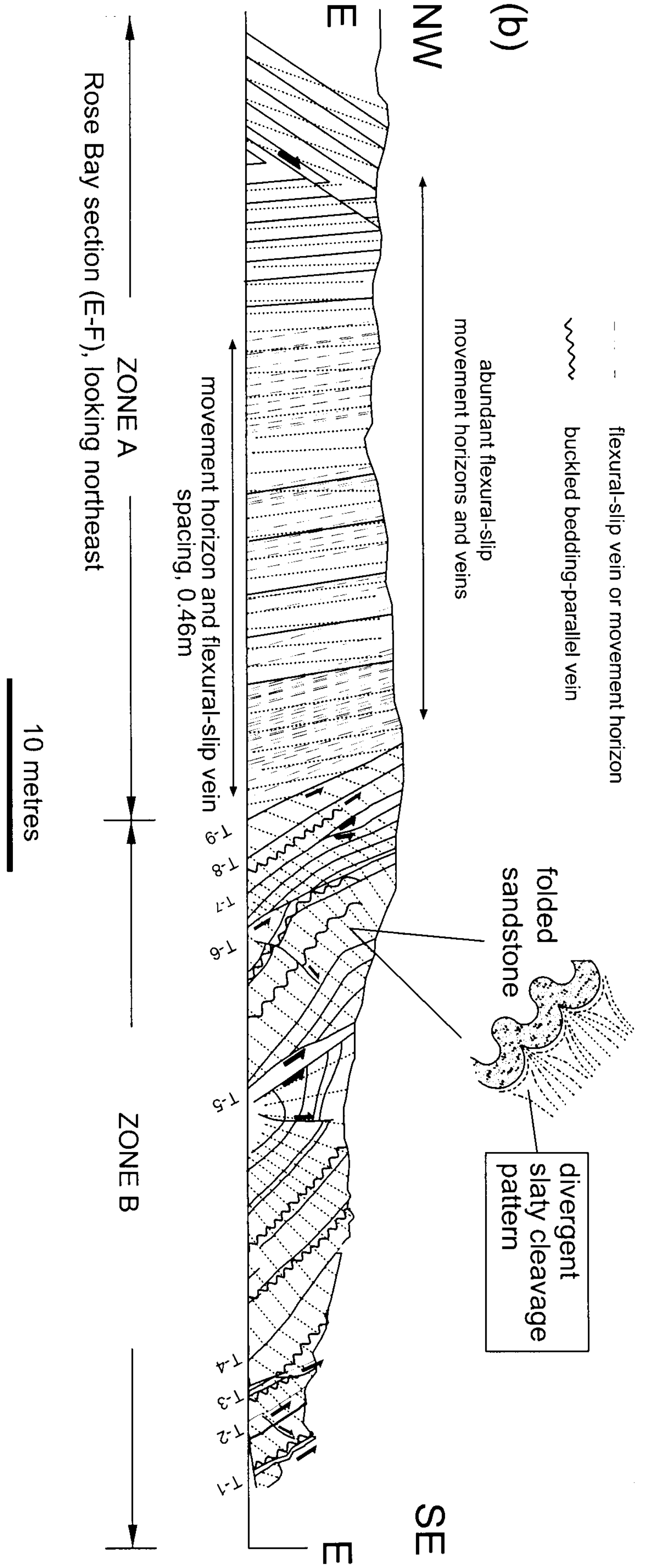


Figure OV4. Photographs of The Ovens Anticline with veins in the hinge zone. Upper row shows buckled-type bedding-concordant veins, whereas the bottom row sows saddle-reef type veins. Note the presence of cleaved wall rock in the saddle vein in lower left and undeformed leg veins in the lower right photo.

Figure OV5. Photograph of The Ovens Anticline with discordant veins and bedding-concordant veins. The conjugate discordant veins in top row show complementary pairs, with arrows used to illustrate this in the middle top picture. Note that these veins may also have the crack-seal texture that is more commonly described in the bedding-concordant veins. The lower photos show evidence of mutually cross-cutting relationships between the discordant and bedding-concordant veins with the latter both predating and post-dating the former.

References

Armstrong, P. 1937. The relationship of ore shoots to structure in the gold deposits of Nova Scotia. Nova Scotia Department of Mines and Energy Open File Report 184.

Bell, L.V., 1948, Caribou mine; *in* Structural geology of Canadian ore deposits: Canadian Institute of Mining and Metallurgy, Jubilee Volume, p. 927-936.

Benn, K, Horne, R.J., Kontak, D.J, Pignotta, G and Evans, N.G. 1997. Syn-Acadian emplacement model for the South Mountain Batholith, Meguma Terrane, Nova Scotia: Magnetic fabric and structural analyses. Geological Society of America Belletin, v, 109, p. 1279-1293.

Bierlein, F.P., and Crowe, D.E. 2000. Phanerozoic orogenic lode gold deposits. *In* Gold in 2000. *Edited by* S.G. Hagemann and P.E. Brown. Society of Economic Geologists, Reviews in Economic Geology, v. 13, p. 103–139.

Chen, L., Creaser, R., and Kontak, D.J. (2014) Further Re-Os arsenopyrite geochronology from selected Meguma Au deposits, Meguma terrane, Nova Scotia: Possible evidence for a protracted gold-forming system. Geological Society America Abstracts with Programs, v. 46.

Cobbold, P.R., Cosgrove, J.W. and Summers, J.M. 1971. Development of internal structures in deformed anisotropic rocks. Tectonophysics, v. 12, p. 23-53. .

Culshaw, N and Lee, S.K.L. 2006. The Acadian fold belt in the Meguma Terrane, Nova Scotia: cross sections, fold mechanics and tectonic implications. Tectonics, Vol. 25.

Culshaw, N. and Liesa, M. 1997. Alleghanian reactivation of the Acadian fold belt, Meguma Zone, southwest Nova Scotia. Canadian Journal of Earth Sciences. v. 34, p. 833-847.

Donnelly B. Archibald, J., Murphy, B., Reddy, S.M., Jourdan, F. Gillespie, J., Glorie, S. 2018: Post-accretionary exhumation of the Meguma terrane relative to the Avalon terrane in the Canadian Appalachians Tectonophysics, 747–748.

Faribault, E.R. 1899. The gold measures of Nova Scotia and deep mining. Journal Canadian Review, v. 18, p. 78-84.

Fowler, T.J. and Winsor, C.N. 1996. Evolution of chevron folds by profile shape changes; comparison between multilayer deformation experiments and folds of the Bendigo-Castlemaine goldfields, Australia. Tectonophysics, v. 258, p. 125-150.

Gourcerol, B., Kontak, D.J., Petrus, J., and Thurston, P.C. (2020): Application of LA ICP-MS analysis of arsenopyrite to gold metallogeny of the Meguma Terrane, Nova Scotia, Canada. Gondwana Research, vl. 80, doi.org/10.1016/j.gr.2019.11.011.

Graves, M.C. and Zentilli, M. 1982. A review of the geology of gold in Nova Scotia. In Geology of Canadian Gold Deposits, ed R.W Holder and K.W. Petruk. Canadian Institute of Mining and Metallurgy, Special Volume 24, p. 133-242.

Henderson, J.R. 1983. Analysis of structure as a factor controlling golf mineralization in Nova Scotia. Current Research, Part B, Geological Survey of Canada, Paper 83-1B, p 13-21.

Henderson, J.R. and Henderson, M.N. 1986. Constraints on the origin of gold in the Meguma Zone, Ecum Secum area, Nova Scotia. Maritime Sediments and Atlantic Geology, v. 22, p. 1-13.
Henderson, J.R, Wright, T.O. and Henderson, M.N. 1988. Mechanics of Vein Formation of gold-bearing quartz veins, Nova Scotia. In Nova Scotia Department of Mines and Energy Report 88-3, p. 221-223.

Henderson, J.R and Henderson, M.N. 1987. Meguma gold deposits; nested saddle reefs or early hydraulic extension fractures. In Nova Scotia Department of Mines and Energy Report 87-1, p. 213-215.

Henderson, J.R. and Henderson, M.N. 1990: Water-sill hypothesis for the origin of certain veins in the Meguma Group, Nova Scotia, Canada. Geology, v. 18, p. 654-657.

Henderson, J.R., Wright, T.O. and Henderson, M.N. 1986. A history of cleavage and folding: An example from the Goldenville Formation, Nova Scotia. Geological Society of America Bulletin, V. 97, p. 1354-1366.

Hicks, R.J., Jamieson, R.A. and Reynolds, P.H. 1999. Detrital and metamorphic 40AR/39AR ages from muscovite and whole-rock samples, Meguma Supergroup, southern Nova Scotia. Canadian Journal of Earth Sciences, v. 36, p. 23-32.

Horne, R.J., Baker, D., Feetham, M. and MacDonald, L. 1997. Preliminary geology of the Waverley-Halifax Airport area, Central Nona Scotia: Some insights on the timing of deformation and vein formation in the Meguma Group.

Horne, R.J., Covey, G. and Albert, C. 2004. Geological report on the early stages of development of the Mooseland Gold District, Halifax County. In Mineral Resources Branch, Report of Activities 2003: Nova Scotia Department of Natural Resources, Report 2004-1, p. 25-39.

Horne, R.J and Culshaw, N.G. 2001. Flexural slip folding in the Meguma Terrane, Nova Scotia, Canada: Fold development, veining and localization of gold deposits. Journal of Structural Geology, v. 23, p. 1631-1652.

Horne, R.J and Jodrey', M. 2002. Geology of the Dufferin Gold Deposit, Halifax County. In Minerals and Energy Branch, Report of Activities 2001: Nova Scotia Departments of Natural Resources, Report 2002-1, p. 51-67.

Horne, R.J., MacDonald, M.A., Corey, M.C. and Ham, L.J. 1992. Structure and Emplacement of the South Mountain Batholith, southwestern Nova Scotia. Atlantic Geology, V28, pp 29-50.

Keppie, J.D. 1976. Structural model for the saddle reef and associated gold veins in the Meguma Group, Nova Scotia. Canadian Institute of Mining and Metallurgy Bulletin.

Kontak, D.J. 2021: Microscopic insight into a Meguma gold deposit setting: Nature of arsenopyrite beds at The Ovens. Annual Atlantic Geoscience Society Meeting, February 5-6, 2021, Program with Abstracts.

Kontak, D.J. and Archibald, D.A. (2002): $^{40}Ar/^{39}Ar$ dating of hydrothermal biotite from high-grade gold mineralization, Tangier gold deposit, Nova Scotia, Canada: Further evidence ca. 370 Ma gold metallogeny in the Meguma Terrane. Economic Geology, v., 97, p. 619-628

Kontak, D.J., Horne, R.J., Sandeman, H. and Archibald, D.A. (1998): $^{40}Ar/^{39}Ar$ dating of whole-rock slates from auriferous veins in the Meguma Group, Nova Scotia: Evidence for post metamorphic timing of vein formation. Canadian Journal of Earth Sciences, v. 35, p. 746-761.

Kontak, D.J., Horne, R.J. and Kyser, K. (2011): A stable isotope ($\delta^{18}O$) study of two saddle-reef vein systems, Meguma gold fields, Nova Scotia, Canada: Evidence for similar isotopic signatures for different age deposits and regional implications. Mineralium Deposita, v. 46, p. 289-304.

Kontak, D.J., McDonald, A.M., Poulin, R., Petrus, J., and McClenaghan, M.B. (2017): Scheelite as a possible ore-deposit discriminator based on luminescence, trace-element chemistry, $\delta^{18}O$ signature, fluid inclusions and U-Pb geochronology. In Applications of indicator mineral methods to bedrock and sediments. Edited by M.B. McClenaghan and D. and Layton-Mathews, Geological Survey of Canada, Open File 8345, 2017, p. 48-59. doi.org/10.4095/306315.

Kontak, D.J., Smith, P.K., Reynolds, P.H. and Taylor, K. (1990): Geological and $^{40}Ar/^{39}Ar$ geochronological constraints on the timing of quartz vein formation in Meguma Group lode-gold deposits, Nova Scotia. Atlantic Geology, v. 26, p. 201-227.

Kontak, D.J., Smith, P.K., Reynolds, P.H. and Taylor, K. (1993): Geology and $^{40}Ar/^{39}Ar$ geochronology of the Beaver Dam gold deposit, Meguma Terrane, Nova Scotia, Canada: Evidence for mineralization at 370 Ma. Economic Geology, vol. 88, p. 137-168.

Malcolm, W. 1912. Gold Fields of Nova Scotia. Canada Department of Mines, Geological Survey Branch, Memoir No 20-4.

Mawer, C.K. 1987. Mechanics of formation of gold-bearing veins, Nova Scotia, Canada. Tectonophysics, v. 135, p. 99-119.

Moncada, D. Mutchler, S., Nieto, A., Reynolds, T.J., Rimstidt, R.D. and Bodnar, R.J. 2012. Mineral textures and fluid inclusion petrography of the epithermal Ag–Au deposits at

Guanajuato, Mexico: Application to exploration. Journal of Geochemical Exploration, v. 114, p. 20-35.

Morelli, R.M., Creaser, R., Selby, D., Kontak, D.J. and Horne, R.J. (2005): Rhenium-Osmium geochronology of arsenopyrite in Meguma Group gold deposits, Meguma Terrane, Nova Scotia, Canada: Evidence for multiple gold-mineralizing events. Economic Geology, v. 100, p. 1229-1242.

Newhouse, W.H. 1936. A zonal gold mineralization in Nova Scotia. Economic Geology, v. 31, p. 805-831.

Ramsay, J.G. 1974. Development of chevron folds. Geological Society of America Bulletin, V. 85, p. 1741-754.

Ramsay, J.G. and Huber, M.I. 1987. The Techniques of Modern Structural Geology, Volume 2: Folding and Fracturing. Academic Press, London.

Sangster, A.L. 1990. Metallogeny of the Meguma Terrane, Nova Scotia. In Mineral Deposits of Nova Scotia, Volume 1, Ed A.L. Sangster. Geological Survey of Canada, Paper 90-8, p. 115-162

Smith, P.K. and Kontak, D.J. 1986. Meguma gold studies: advances in geological insight as an aid to gold exploration. in Department of Mines and Energy Open House, Program and Summaries. Edited by J. Bates, Information Series No. 12, p. 105-113

Smith, P.K. and Kontak, D.J. 1988. Gold studies II: Vein morphology, classification and information, a new interpretation of “crack seal” quartz veins. in Mines and Minerals Branch, Report of Activities 1987, Part B, Nova Scotia Department of Mines and Energy, Report 88-1, p. 61-76.

Stea, R.R. and Pullan, S.E. 1998. Post early Cretaceous faulting in the Musquodoboit Valley, Nova Scotia. In Minerals and Energy Branch, Report of Activities 1997, Nova Scotia Depaertment of Natural Resources, Report 1998-1, p. 135-143.

Szmihelsky, M. Piercey, S, Copeland D. and Tettelaar, T. 2021. Wallrock alteration and gold-bearing vein paragenesis of a Meguma-hosted gold deposit: Goldboro, Nova Scotia. Annual Atlantic Geoscience Society Meeting, February 5-6, 2021, Program with Abstracts.

Williams, P.E. and Hy, C. 1990. Orgin and deformation and metamorphic history of gold - bearing veins on the Eastern Shore of Nova Scotia. In Mineral Deposits of Nova Scotia, Volume 1, Ed A.L. Sangster. Geological Survey of Canada, Paper 90-8, p. 169-194.