Geology of the Halifax Regional Municipality, Central Nova Scotia

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Introduction

With the pressures of growth and development in the Halifax Regional Municipality (HRM), many local construction companies and environmental consulting groups have contacted the Nova Scotia Department of Natural Resources (DNR) in regards to outlining areas in the city where acid rock drainage (ARD) may be an issue in current infrastructure construction projects. To address these concerns, the Geological Mapping, Environmental Geology and Hydrogeology Section initiated a detailed bedrock mapping project in the summer of 2007 on the Halifax map area (NTS 11D/12; Fig. 1), concentrating on the metropolitan Halifax area. It was soon realized, however, that with the increased growth in the area, a need exists for geoscience information beyond just knowing areas of potential ARD. Such information is also needed for regional planning, zoning and regulations by various levels of government. The information also can be used in environmental studies such as waste management, development of regional infrastructure, inventory of natural resources, hydrology, and geological hazards.

For all these reasons the department has initiated a geoscience project in HRM. DNR will compile existing geological information, conduct new bedrock and surficial mapping, and serve as the main repository for the geoscience database for HRM. The department will act as an unbiased expert on issues related to the geological aspects of the rock units and overlying surficial materials. Products of the HRM project will include digital geological maps (printed copies on demand) and related databases. The anticipated users of this information include the three levels of government, geotechnical and environmental consulting firms, educational and research institutions, especially universities, and the public. DNR will not compete with private firms when releasing data as the information released is meant to serve as regional background information. It does not replace site-specific engineering testing, which carries legal implications.

The first phase of the project, begun in 2007, involved detailed geological bedrock mapping of the Halifax map area (NTS 11D/12) at a scale of 1:10 000, using a digital field data collection system. The digital field data collection system consisted of a pocket PC and a Bluetooth® GPS receiver. Software consists of ESRI ArcPad® using Ganfeld, an application developed by the Geological Survey of Canada, on a modified Windows® platform. The use of the GPS-enabled pocket PC as the primary field data collection process should result in observations and measurements being digitally captured by geologists and not digitized later by those who might be unfamiliar with the project. This results in reduced opportunity for transcribing errors and a shorter path from field data collection to release and publication of results. The preliminary results of the bedrock mapping are presented in this report.

Geology

Introduction

The earliest regional mapping in the Halifax area was undertaken by the Canadian Geological Survey Branch between 1896 and 1903 to examine and survey known gold occurrences in the area

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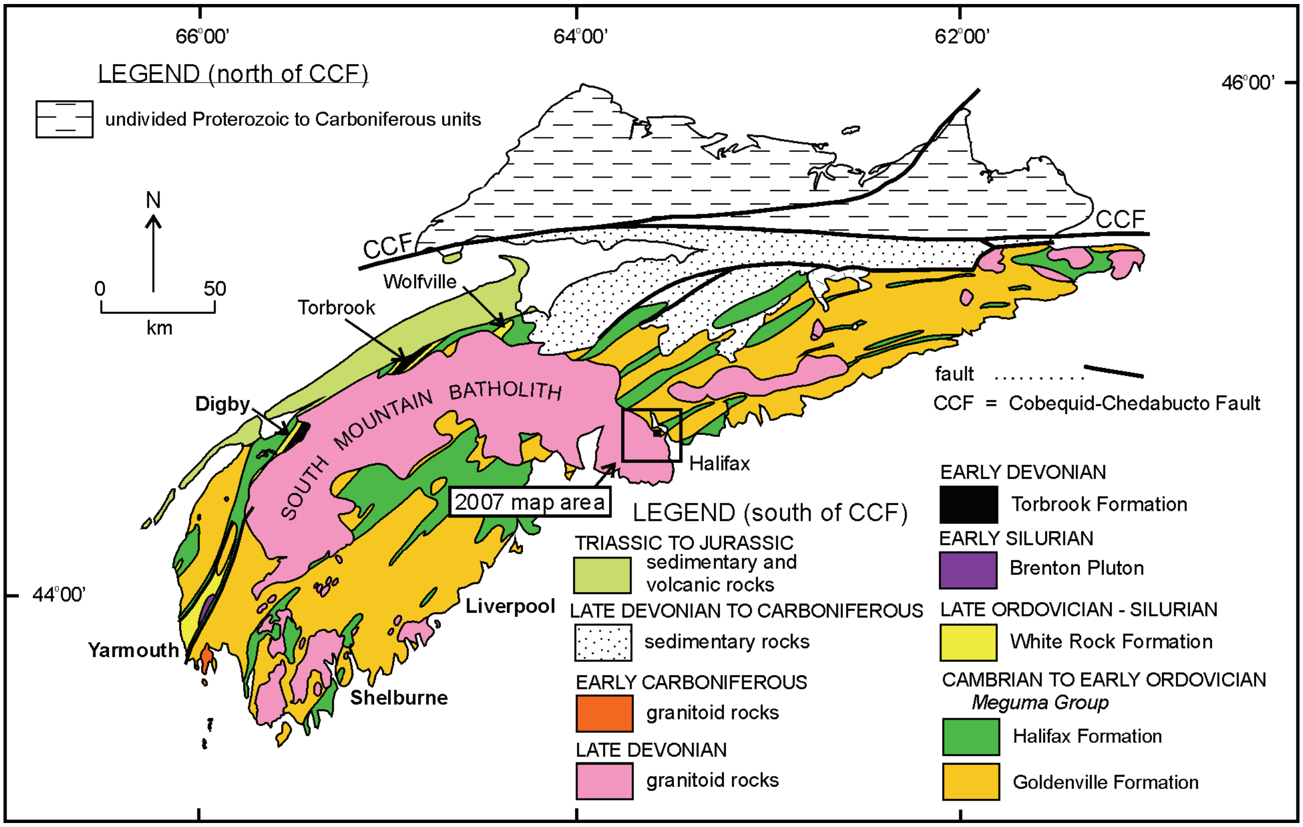


Figure 1. Simplified geological map of the Meguma Terrane, Nova Scotia, showing location of the map area.

(Faribault, 1907). Due to "insufficient help in the office", however, the geological map was not compiled until years later (e.g. Faribault 1908). Faribault (1907, 1908) considered the northeastern half of the map area to belong to the Lower Cambrian 'Gold-Bearing Series' which consisted of the older Quartzite Division and the younger Slate Division, intruded by coarse-grained granite in the southwestern area. The area was not mapped again until the work of MacDonald and Horne (1987); however, their mapping focused primarily on granitic units in the South Mountain Batholith and they only compiled the earlier work of Faribault (1908). MacDonald and Horne (1987) modified the terminology for consistency with modern-day usage by re-assigning the Quartzite and Slate divisions to the Cambrian to Ordovician Goldenville and Halifax formations, respectively, and placing these units in the Meguma Group.

Recent mapping elsewhere has established further subdivisions in the Meguma Group and showed that the traditional two-fold division needs revision (e.g. White, 2007, 2008, this volume; White *et al.,* 2007 a, b; Horne and Pelley, 2007; Horne et al., in press). As a result, new formations have been defined, the Goldenville and Halifax formations have been elevated to 'group' status, the former Meguma Group is now Supergroup (e.g. Schenk, 1995, 1997), and the age is better defined as Late Neoproterozoic to Early Ordovician (White *et al.,* 2007 a, b). This revised terminology is used in this report.

White (2005, 2006, 2007, this volume) established formations in the Meguma Supergroup in the area to the southwest of the present map area (South Shore). Ryan *et al.* (1996), Horne *et al.* (1998), Horne and Pelley (2007) and Horne *et al.* (in press) established similar units in the Meguma Supergroup in central (Central Meguma) and eastern (Eastern Shore) Nova Scotia. The relationship among these various formations and units is described below in the context of the Halifax map area.

Goldenville Group

The Goldenville Group occurs in the northern and eastern parts of the Halifax map area (Fig. 2). It consists of grey to greenish-grey, thickly bedded metasandstone (Fig. 3a), locally interlayered with green to grey, cleaved metasiltstone and rare black slate. Metasandstone beds range from <0.5 m to several metres in thickness, whereas metasiltstone and slate beds are typically <0.5 m thick. Calc-silicate nodules (Fig. 3a) and large (1-2 cm) pyrite cubes are locally common. Sedimentary structures are generally lacking in the metasandstone. Manganese nodules have been reported from this unit (Horne *et al.,* 1998), but their presence was not confirmed during this study. Towards the stratigraphic top of this unit, metasiltstone beds are more abundant and metasandstone beds are thinner. Sedimentary structures, such as ripple marks, cross-bedding, graded-bedding, and fluke/sole marks, are more common (Fig. 3b).

This stratigraphic unit is similar to the Green Harbour Formation to the southwest (e.g. White 2005, 2006, 2007, this volume), the Taylors Head Formation defined by Horne and Pelley (2007) in the northeast, and the Lewis Lake unit in central Nova Scotia (Ryan *et al.,* 1996). Because the present map area is along strike from the area mapped by Horne and Pelley (2007), the map unit in the Halifax area is assigned tentatively to the Taylors Head Formation. The upper part of this formation is lithologically similar to the Government Point Formation exposed to the southwest (White, 2005, 2007, 2007, this volume). Stratigraphically, this upper part is also equivalent to the Steves Road Unit in the Central Meguma area (Ryan *et al.,* 1996); however, the abundant spessartine garnet concentrations characteristic of the Steves Road Unit were not observed. Hence, additional mapping is required to verify the correlation with the Government Point Formation.

Halifax Group

In the Halifax area, the Halifax Group can be subdivided into three formations (from lower to upper): Beaverbank, Cunard and Bluestone. Ryan (1996) introduced the name Beaverbank unit/member (later upgraded to formation status by Horne and Pelley, 2007) to include the package of rocks that is transitional between the metasandstone-dominated Goldenville Group and the overlying slate-dominated Halifax Group in the Central Meguma area, and is used here for the equivalent unit. In the Halifax map area, the contact of the Beaverbank Formation with the underlying Taylors Head Formation is sharp and marked by an abrupt decrease in abundant, thick (>50 cm) metasandstone beds. The Beaverbank Formation consists of grey to green-grey to black, thinly bedded to laminated metasiltstone with minor thin beds (<10 cm) of fine-grained buff metasiltstone and rusty black slate (Fig. 3c). Thin dark brown to black manganese-rich beds and nodules are common and where the metamorphic grade is higher these beds are pink and contain abundant spessartine garnet (coticules) (Fig. 3d). These beds are typically ptygmatically folded. The black slate is locally sulphide-rich (pyrrhotite?) and similar in appearance to sulphide-rich slate in the overlying Cunard Formation.

The presence of manganese-rich beds suggests that the Beaverbank Formation may correlate with the Moshers Island Formation exposed to the southwest, which White (2005, 2007, 2007, this volume) assigned to the top of the Goldenville Group based on the presence of metasandstone beds and the lack of black slate. The abundant black rusty slate and lack of thick metasandstone beds, however, indicates that the Beaverbank Formation in the Halifax area may be more appropriately assigned to the Halifax Group. Further work is planned to investigate this correlation.

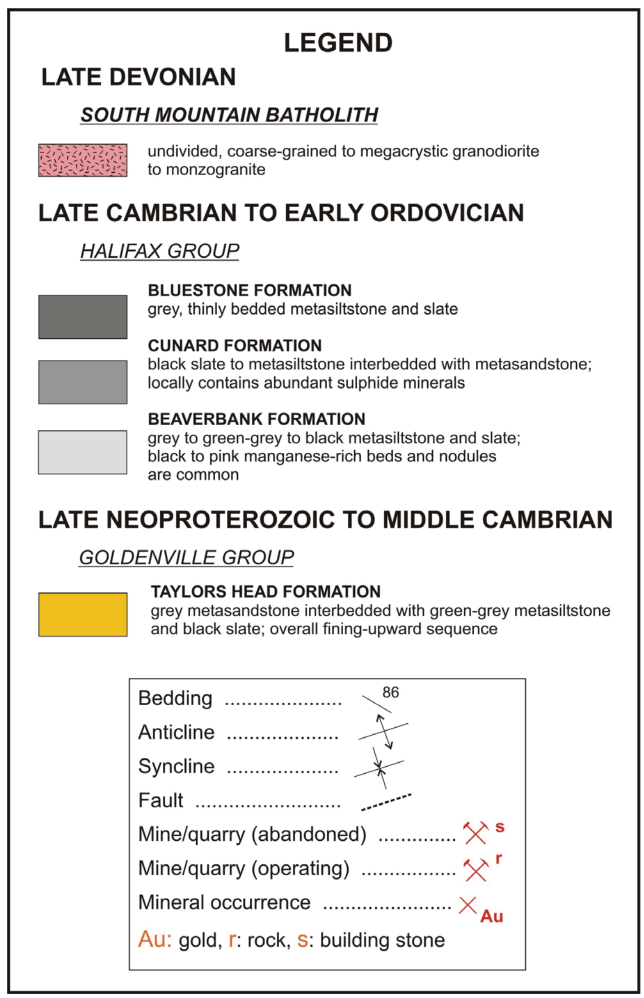
The Cunard Formation conformably overlies the Beaverbank Formation and is characterized by black rusty slate and metasiltstone interbedded with cross-laminated fine-grained metasandstone (Fig. 4). This unit typically contains abundant pyrite, arsenopyrite, and pyrrhotite. Locally the Cunard Formation contains thin, ptygmatically folded beds assumed to be coticule layers, and Mn-rich carbonate concretions have been reported in the Cunard Formation in the Central Meguma area (Ryan *et al.,* 1996); however, additional petrographic and lithogeochemical analysis (in progress) are required to verify the presence of Mn. Manganese-rich carbonate concretions or coticules have not been recognized in the Cunard Formation in southwestern Nova Scotia, and lithogeochemical data have confirmed the absence of elevated Mn in the Cunard Formation (White *et al.,* 2007; unpublished data Nova Scotia Department of Natural Resources). Based on magnetic signatures, distinction between the Beaverbank and Cunard formations is not evident, as also noted by Horne and Pelley (2007) for these units in the Eastern Shore area. The Cunard Formation is equivalent to the Rawdon unit (Horne 1993) in central Nova Scotia.

The conformably overlying Bluestone Formation (Bluestone member of Jamieson *et al.,* 2005a, b) consists of grey thinly bedded metasiltstone and slate, locally containing calcareous concretions. It lacks metasandstone beds and the abundant sulphide minerals observed in the underlying Cunard Formation. Its stratigraphic position above the Cunard Formation suggests that it is correlative with the Glen Brook Formation exposed in the Central Meguma area and the Eastern Shore (Horne and Pelley, 2007; Horne *et al.,* in press), the Feltzen Formation in the South Shore (O'Brien, 1988; White, 2007), and Bear River Formation exposed in the Digby area (White *et al.,* 1999; Horne *et al.,* 2000). All these formations lack abundant sulphide minerals and, therefore, display a distinctive low aeromagnetic response. The difference between the Cunard and Bluestone formations is also evident in the different metamorphic mineral assemblages present in these units (Jamieson *et al.,* 2005 a, b). The Cunard Formation has abundant andalusite, whereas the Bluestone Formation generally lacks andalusite at the same metamorphic grade, suggesting that the Bluestone Formation is less aluminous (Jamieson *et al.,* 2005 a, b). Lithogeochemistry is currently underway to test these differences.

Early Tremadoc specimens of the graptolite *Rhabdinopora flabelliformis* were observed in the Bear River Formation (White *et al.,* 1999) and Feltzen Formation (Cumming 1985), but have not been recognized in the Glen Brook or Bluestone formations.

South Mountain Batholith

The ca. 380-373 Ma South Mountain Batholith in the HRM area was mapped by MacDonald and Horne (1987) and was not systematically remapped during this study. Because of major new construction near the northeastern margins of the batholith and the resulting new exposures, however, systematic remapping was conducted in this zone. As a result, some adjustments have been made to the locations of intrusive contacts shown by MacDonald and Horne (1987). In the map area, the contact between the batholith and the Meguma Supergroup is marked by a narrow (0.5 to 1 km wide) northeast-trending zone of grey, medium-grained, equigranular granodiorite with minor alkali feldspar megacrysts and metasaedimentary xenoliths. Toward the southwest this unit is gradational over an interval of 50 to 100 m with another narrow (~500 m wide) northeast-trending zone of medium- to coarse-grained and megacrystic monzogranite (Sandy Lake Monzogranite of MacDonald and Horne, 1987). This monzogranite grades into the large Halifax Peninsula Leucomonzogranite, which is typically



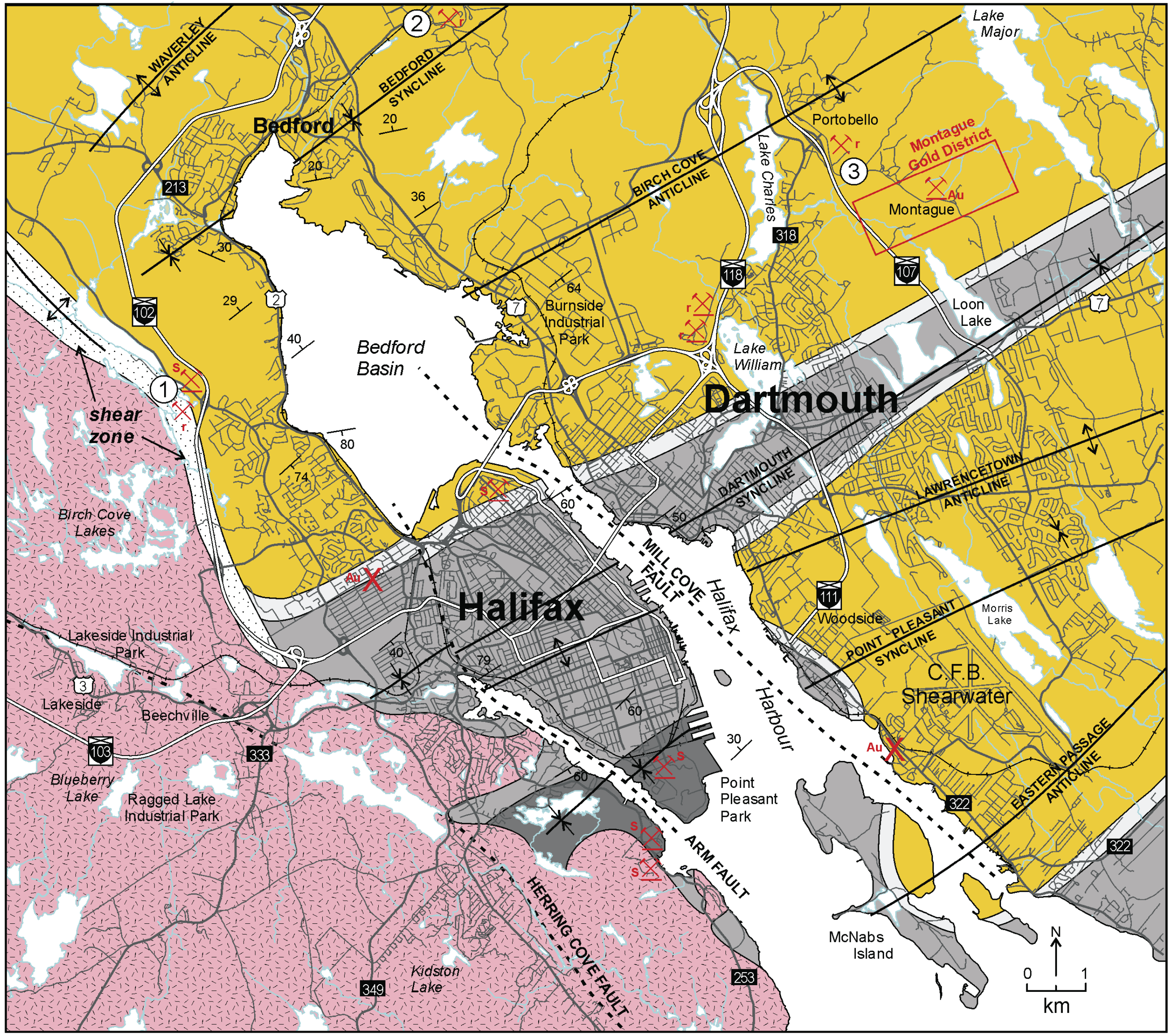


Figure 2. Simplified geological map of the Halifax Regional Municipality map area (NTS 11D/12) based on the present study. Circled numbers refer to quarries described in text; 1 = Gateway Material, 2 = Rocky Lake and 3 = Conrad Brothers. Legend on facing page. For more detail on the shear zone at the Meguma/South Mountain Batholith contact, see page 132.

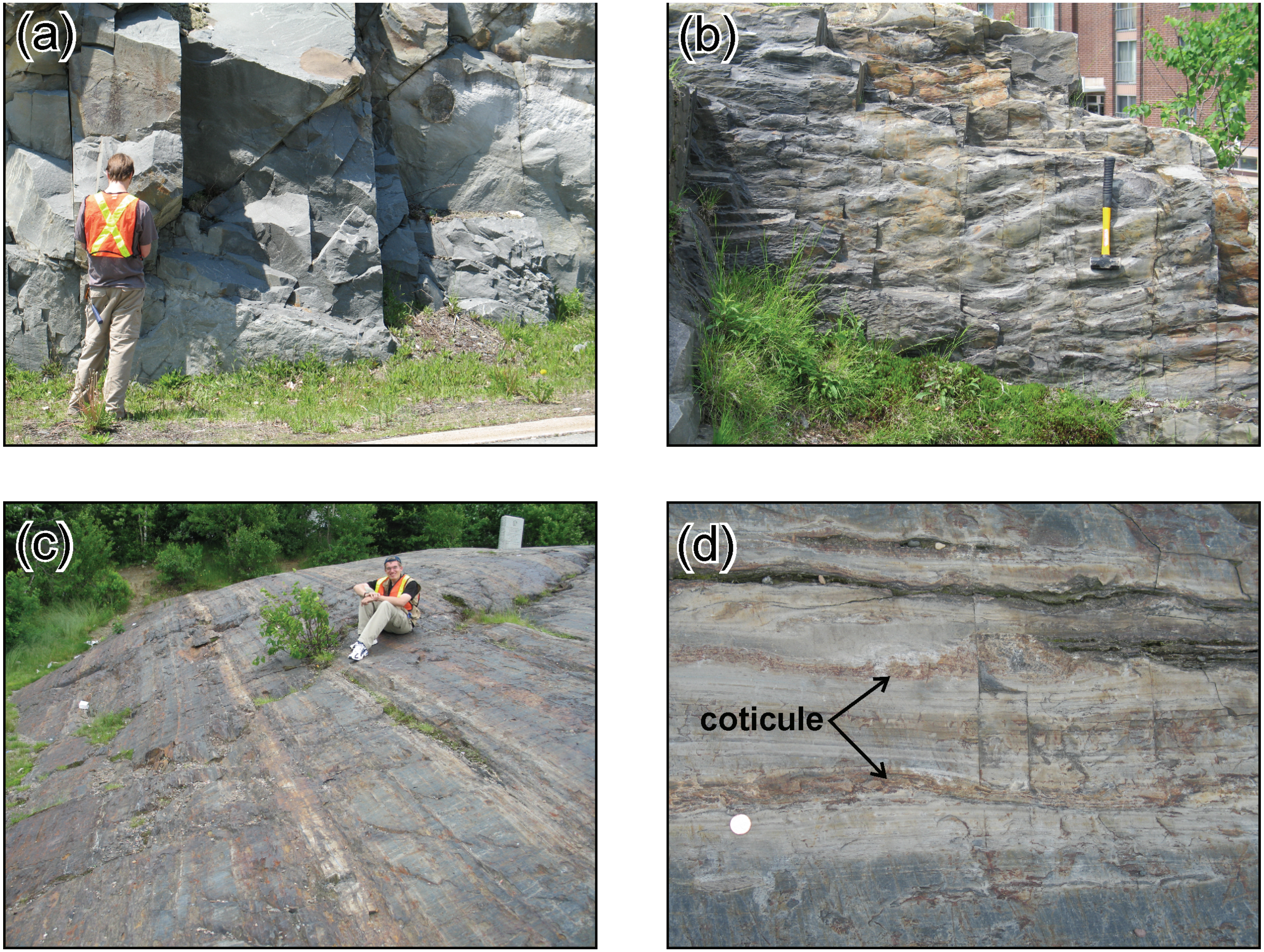


Figure 3. (a) Photograph of thickly bedded metasandstone in the Taylors Head Formation with large brown calc-silicate nodules. (b) Photograph of ripple-marked bedding plane in metasandstone near the top of the Taylors Head Formation (c) Photograph of grey to green-grey to black, thinly bedded to laminated metasiltstone with minor thin beds of metasiltstone and rusty black slate in the Beaverbank Formation. (d) Photograph of folded coticule beds in the Beaverbank Formation.

Figure 4. (a) Photograph of rust-brown cordierite-bearing hornfels of the Cunard Formation adjacent to the South Mountain Batholith. Intersection lineation (L_1) still preserved in contact aureole.

buff to pale pink, predominantly coarse grained, and locally contains up to 4% cordierite. In the southern part of the batholith in the map area, the Sandy Lake Monzogranite grades into a fine- to coarse-grained and megacrystic biotite monzogranite (Harrietsfield Monzogranite of MacDonald and Horne, 1987). These units are intruded by late stage medium-grained two-mica leucomonzogranite (Tantallon Leucomonzogranite of MacDonald and Horne, 1987).

Deformation and Metamorphism

The Meguma Supergroup in the map area, as in most other parts of Nova Scotia, was regionally metamorphosed (greenschist facies) and deformed into northeast-trending, generally upright, tight to open folds with a well developed axial planar cleavage during the ca. 406-388 Ma Neoacadian Orogeny (van Staal, 2007; White *et al.,* 2007c; Moran *et al.,* 2007). The Neoacadian-produced structures are overprinted by hornblende-hornfels facies metamorphism (Yardley, 1989) around the late syntectonic South Mountain Batholith.

Deformation

In the map area, the Meguma Supergroup is folded into a series of upright, shallow northeast- and southwest-plunging F_1 anticlines and synclines (Fig. 2). Contoured poles to bedding define a well developed girdle distribution with a very shallow, northeast-plunging fold axis (Fig. 5a). Contoured poles to foliation are consistent with a steep axial planar foliation that strikes northeast (Fig. 5b).

Minor folds (F_1) are upright and plunge gently to the southwest (Fig. 5a). Intersection lineations (L_1) (bedding/foliation) have shallow northeast and southwest plunges (Fig. 5b), parallel to minor fold axes. The lineation data suggest the occurrence of doubly plunging folds (e.g. Bedford Syncline, Fig. 2).

Contoured poles to joints in the Meguma Supergroup display a prominent, steep, northwest-trending joint set perpendicular to the regional foliation and a second smaller cluster subparallel to the foliation (Fig. 5c). The orientations are similar to joint orientations recorded in the South Mountain Batholith by Lewis *et al.* (1998, Fig. 12). Poles to quartz veins in the Meguma Supergroup appear to form a random distribution (Fig. 5c).

Mapping also confirmed the presence of a major shear zone along the northwestern margin of the South Mountain Batholith in the contact aureole (c.f. Culshaw and Bhatnagar, 2001). In this zone, a northwest-trending, near horizontal anticline trends parallel to the contact with the batholith where bedding is transposed parallel to the mylonitic (S_m) foliation (Fig. 5d). Minor F_2 crenulation axes plunge shallowly to the northwest and southeast (Fig. 5d). The shallow-plunging intersection (L_1) in the low-grade metamorphic rocks becomes increasing steeper towards the granite contact. At the outer zone of the contact aureole, L_1 is subhorizontal and defined by elongate aggregates of metamorphic biotite on the foliation (S_1). Closer to the granite, as metamorphic grade increases, L_1 becomes steeper (Fig. 5d) and is defined by elongate quartz-cordierite-biotite aggregates in pelitic rocks (Gray, 1996) and elongate calc-silicate nodules in the metasandstone (Fig. 6a, b), where it is more properly defined as an L_2. At the contact, in the more pelitic beds, L_2 is near vertical and defined by boudinaged andalusite crystals or elongate aggregates of quartz and biotite (Figs. 6c, d). The L_1 in the contact aureole coincides with this younger L_2 mineral lineation which parallels the stretching lineation and suggests granite side-down sense of shear (Culshaw and Bhatnagar, 2001).

Several northwest-trending faults cut the Meguma Supergroup and South Mountain Batholith in the study area (Fig. 2). The Herring Cove Fault (MacDonald and Horne, 1987) formerly known as the Chain Lakes-Sheehan Cove Fault (Cameron, 1949), is within the South Mountain Batholith and marked by a zone of cataclastic granite and a prominent topographic lineament. The Mill Cove (Halifax Harbour) and Arm (Northwest Arm) faults were interpreted from air photographs (Cameron, 1949) but based on detailed mapping have been shown to exist, but with negligible displacement.

Metamorphism

Regional metamorphism in the map area reached chlorite zone (chlorite + muscovite + albite ± epidote), greenschist facies conditions in the pelitic rocks, similar to most other areas of the Meguma Supergroup (e.g. White 2005, 2006, 2007, this volume). The slaty cleavage is defined by aligned fine-grained muscovite and asymmetric chlorite porphyroblasts. Intrusion of the South Mountain Batholith produced a narrow, well developed contact metamorphic aureole that is superimposed on regional greenschist facies mineral assemblages and textures. The first evidence of contact metamorphism is darkening of the rocks and the presence of biotite (biotite-in isograd). The biotite is decussate and appears to replace chlorite porphyroblasts or was formed within muscovite-chlorite 'stacks' (Jamieson *et al.,* 2005 a, b). As metamorphic grade increases towards the pluton, ovoid, highly poikilitic cordierite appears in the mica-rich layers and biotite content increases. Jamieson *et al.* (2005a, b) noted a difference in andalusite distribution between the Cunard and Bluestone formations. In the less aluminous Bluestone Formation, xenoblastic andalusite is present only in the immediate vicinity of the granite contact, whereas in the Cunard Formation idioblastic chiastolite appears before biotite and gradually increases in size and abundance towards the granite contact. Adjacent to the contact the assemblage andalusite + cordierite + K-feldspar ± fibrolite is developed (Jamieson *et al.,* 2005 a, b). Jamieson *et al.* (2005 a, b) also documented a change in the opaque mineralogy with increasing metamorphic grade where rutile and pyrite in the outer aureole is replaced by ilmenite and pyrrhotite closer to the contact. The distribution of isograds suggests that part of the South Mountain Batholith extends under the South End of Halifax (e.g. Jamieson *et al.,* 2005 a, b).

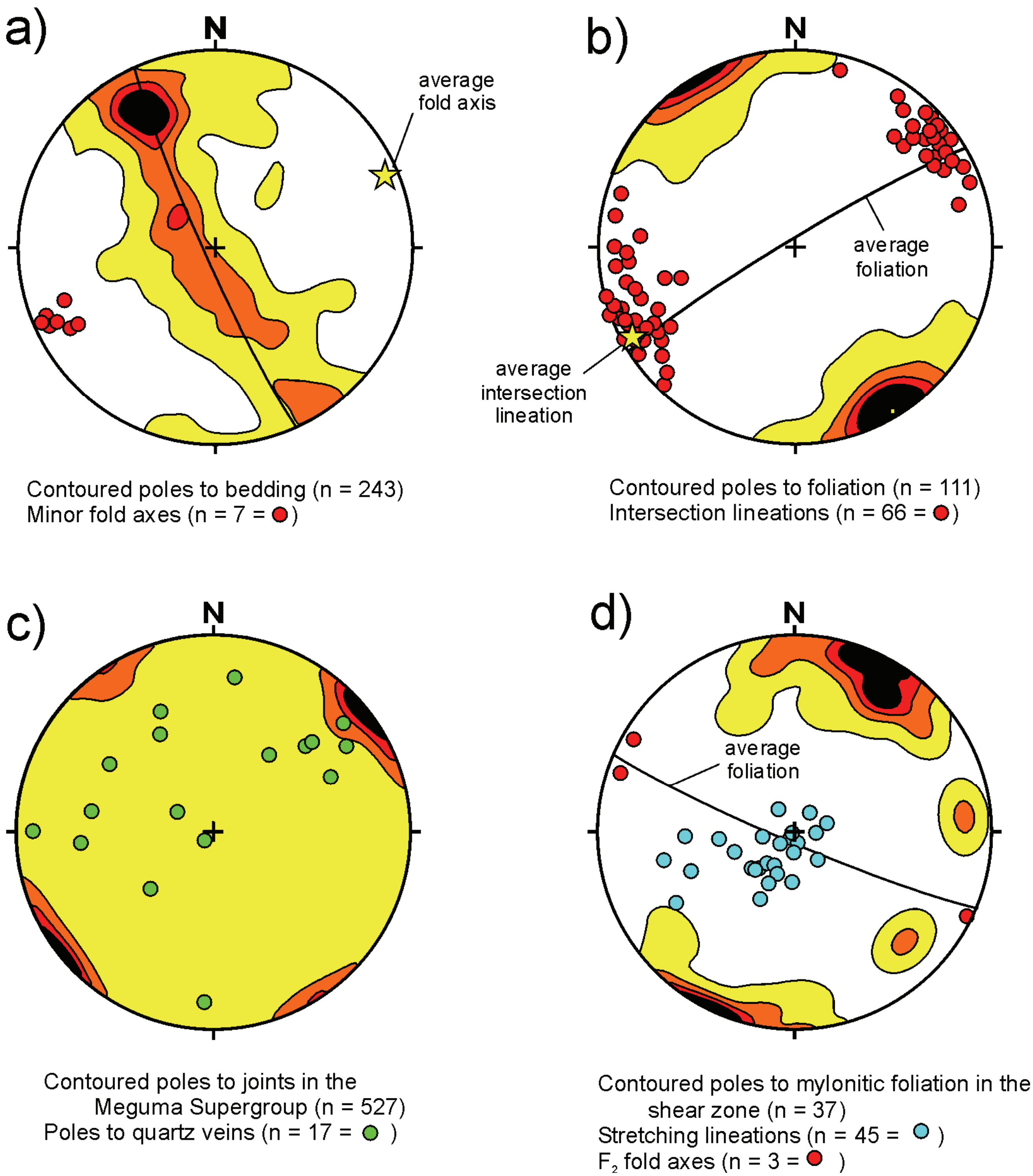


Figure 5. Equal-area stereonets of structural data in the map area. (a) Contoured poles to bedding, and minor F_1 fold axes; solid great circle shows average orientation of S_0 and the star shows the calculated average fold axis. Contours at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area. (b) Contoured poles to foliation and bedding-cleavage intersection lineations (L_1). Contours at 1, 5, 10, and greater than 15% per 1% area; darkest shading indicates highest contour area. (c) Contoured poles to joints, and quartz veins in the Meguma Supergroup. Contours at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area. (d) Contoured poles to mylonitic foliations, F_2 crenulation axes, and L_2 stretching lineations in the shear zone exposed at the contact with the South Mountain Batholith. Contours at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.

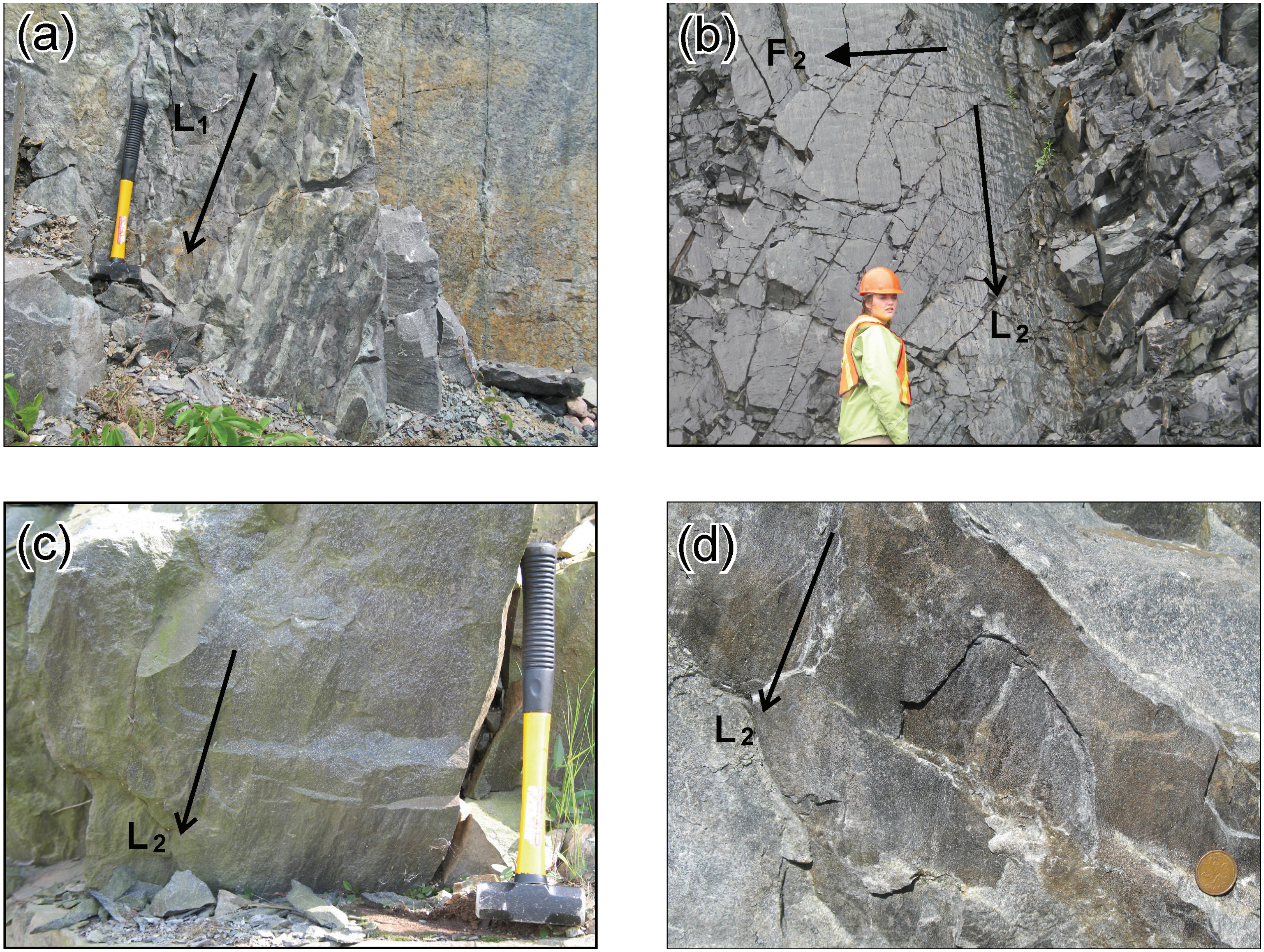


Figure 6. (a) Photograph of elongate calc-silicate nodules defining L_2. (b) Photograph of mylonitic foliation displaying a steep L_2 lineation defined by elongated calc-silicate nodules and near horizontal F_2 folds. (c) Photograph of elongate quartz aggregates that define L_2. (d) Photograph of elongate biotite aggregates that define L_2.

Economic Geology

Gold was discovered at Montague in 1862 (Fig. 2) and a year later the area was proclaimed a 'gold district' (Malcolm, 1976). Gold is located in bedding-parallel quartz veins within thin (<5 m) metasiltstone and slate beds of the Taylors Head Formation. The Montague Gold District had an overall grade of over 1.6 ounces of gold per ton for veins mined in the deposit (Brunton, 1928). The prospect produced 65,196.9 Troy Ounces of gold from 1863-1940 (Bates, 1987). Numerous other gold-bearing veins were noted by Faribault (1907, 1908) in the Halifax area but none of these could be confirmed to exist during the present study. As construction continues in HRM, however, the likelihood that additional gold-bearing veins might be exposed is increased.

As shown in other parts of the Meguma Supergroup, the Goldenville-Halifax Transition (GHT) contains manganese-rich rocks (Beaverbank Formation in HRM) that are anomalous in a variety of elements (e.g. Pb, Zn, W and Sn) and interpreted to be similar to slate-hosted metal deposits elsewhere in the world (Zentilli *et al.,* 1986; Sangster, 1990). Currently, interest in the Beaverbank Formation is concentrated on the Mn content and its use in steel making. In addition to gold and base metal mineralization in the Meguma Supergroup, the South Mountain Batholith in the map area has several areas with anomalous concentrations of U, Sn, W, Cu, and Au (e.g. MacDonald and Horne, 1987).

Between 1800 and 1940, granite from the South Mountain Batholith, metasandstone and slate from the Meguma Supergroup, and hornfels from the contact metamorphic aureole around the South Mountain Batholith were used for building stone in HRM. Many of these old quarries, now abandoned, still exist today (Fig. 2). In recent years, natural stone has again figured in the design of new buildings in HRM, and with this renewed interest contractors and developers may re-explore the potential of local materials.

Sand and gravel deposits in HRM were highly depleted in the early 1970s (Lewis *et al.,* 1998) and since then, gravel from outside HRM and crushed rock from local quarries have been the source for aggregate. Three quarries currently supply the area with the majority of its crushed stone needs, up to 3 Mt each year (Prime and Bonner, 2007). The Rocky Lake and Conrad Brothers quarries are located in metasandstone of the Taylors Head Formation, whereas the Gateway Materials quarry is located in mylontic, contact metamorphosed metasandstone of the Taylors Head Formation along the margin of the South Mountain Batholith (Fig. 2). These three quarries also supply the local building stone market. The Nova Scotia Department of Natural Resources Mineral Occurrences Database for NTS map sheet 11D/12 contains a complete summary of mineral occurrences and former mines in the map area.

Geological Hazards

Like other cities in eastern Canada, Halifax is spared the potentially catastrophic hazards that plague some other cities in Canada, such as the potential for major earthquakes in Vancouver (e.g., Mustard *et al.,* 1998), and the unstable clay foundations of Ottawa (e.g., Bélanger, 1998). But Halifax is not without its problems that should be addressed by decision-makers for urban development. Being on the Atlantic coast, Halifax has been subjected to high sea levels caused by onshore winds and waves, storm surges from hurricanes, and tsunamis (Lewis *et al.,* 1998), and more recently the effects of sea-level rise related to global warming. In the following section, however, only those hazards related to natural substances will be discussed.

Radon and Uranium

Radon is a colourless, odourless radioactive gas that occurs naturally in our environment and is the result of the breakdown of uranium minerals in bedrock. In the map area, radon occurs in areas underlain by the South Mountain Batholith or by tills derived from the granitic bedrock where anomalously high uranium and thorium values exist (see inset map of MacDonald and Horne, 1987). Radon-related health hazards are essentially indoor problems. Radon enters most buildings from the soil and rock beneath foundations or through domestic water supplies. Uranium enters the water supply through the natural weathering of rocks (such as granite in the South Mountain Batholith). Once in the water it does not transfer into the air.

Domestic radon exposure is estimated to result in 10 000-15 000 excess lung cancer deaths per year in North America and is considered to kill more people than any other single environmental hazard (Tilsley, 1992). As a result of this, combined with the recent lowering of the national guidelines for radon from 800 to 200 Becquerels per cubic metre (Bq/m^3), the Government of Nova Scotia is currently testing for radon, not only in HRM but throughout the province (Nova Scotia Department of Environment and Labour, 2008a). Radon tests conducted in various schools across the province has shown that some of the highest concentrations of radon (up to 2737 Bq/m^3) are in buildings sitting on the granite associated with the South Mountain Batholith in HRM (Nova Scotia Department of Environment and Labour, 2008b). To date, the results for public buildings built on metasandstone and slate of the Meguma Supergroup have not been released.

In drinking water, the chemical properties of uranium are of greater concern than its radioactivity. Studies show that elevated levels of uranium in drinking water can affect the kidneys. In Nova Scotia, uranium levels in drinking water are between 0.005 and 0.83 milligrams per litre (mg/L) (Nova Scotia Department of Environment and Labour, 2008c). The interim maximum acceptable concentration (IMAC) of uranium in drinking water in Health Canada's Guidelines for Canadian Drinking Water Quality (2006) is 0.020 mg/L (milligrams per litre).

Arsenic

Arsenopryite is the main natural source of arsenic (As) and is a common mineral in rocks of the Meguma Supergroup and hence it occurs naturally in ground water. Arsenopyrite occurs with gold and many gold areas (e.g., Montague Gold District) have elevated As values. These elevated values are partly due to the concentration in the tailings during historical milling operations where As values are generally two to four orders of magnitude higher than the 12 mg/kg Canadian Soil Quality Guidelines cite as safe (Parsons *et al.,* 2008). In addition, many of these old mine sites have elevated concentrations of mercury (Hg) as this element was used in the milling process. Environmental Site Assessments are ongoing to delineate areas of high risk that are located close to residential properties (Nova Scotia Department of Environment and Labour, 2008d). High concentrations of As (9600 ppm; unpublished NSDNR data) have been reported from elsewhere in the Meguma Supergroup in rocks not associated with known gold districts. It should be noted that additional geological hazards exist in these old gold districts, and include abandoned mine shafts, pits, trenches and tailings.

Acid Rock Drainage

Of particular interest to urban planners in the metropolitan Halifax area is the documentation of the distribution of sulphide-rich units because these units have the potential to produce Acid Rock Drainage (ARD). ARD is the product formed by the atmospheric oxidation of iron-sulphur-bearing minerals such as pyrrhotite (FeS) and pyrite (FeS_2), and to a lesser extent marcasite, chalcopyrite, arsenopyrite, and sphalerite. ARD has adverse effects on engineered infrastructure and the environment. The Cunard Formation is known to contain these sulphide minerals in great abundance and is, therefore, a major ARD producer, with pyrrhotite being the main contributor (Fox *et al.,* 1997). Based on mapping during the current study, the Beaverbank Formation is also shown to locally contain significant sulphide-bearing minerals and as a result may contribute to ARD.

Metamorphic studies (e.g. Jamieson *et al.,* 2005 a, b) have shown that in the contact aureole of the South Mountain Batholith, pyrite has been replaced by phyrrhotite and, therefore, areas around the batholith are more susceptible to ARD. Because these rocks are generally massive hornfels and lack a cleavage, however, fluid access to crystal surfaces is limited and the development of ARD is generally less significant. Disturbances of bedrock by large-scale construction projects may result in ARD.

Concluding Remarks

Decision makers at the federal, provincial and local levels are finding that they need increasing amounts of objective geoscientific information in order to make sound decisions regarding land use, water use, and resource use. A modern digital geologic map and the associated databases often are the best scientific products for providing some of this information. Bedrock mapping has shown that the geology below metropolitan Halifax is both diverse and complex. The area is underlain by folded metasandstone and slate of the Meguma Supergroup and varied granitic rocks of the South Mountain Batholith that intrude them. The area is dissected by several northwest-trending faults that control the orientation of valleys and coastal embayments (e.g. Halifax Harbour).

The geology map can be used to establish linkages between human health and the geographic distribution of hazardous geological materials such as radon and arsenic in HRM. The map will also provide the geological framework for predicting which rocks and areas are susceptible to ARD and concerns about water quality. In general, the geological map is essential in land-use planning throughout HRM.

Acknowledgments

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