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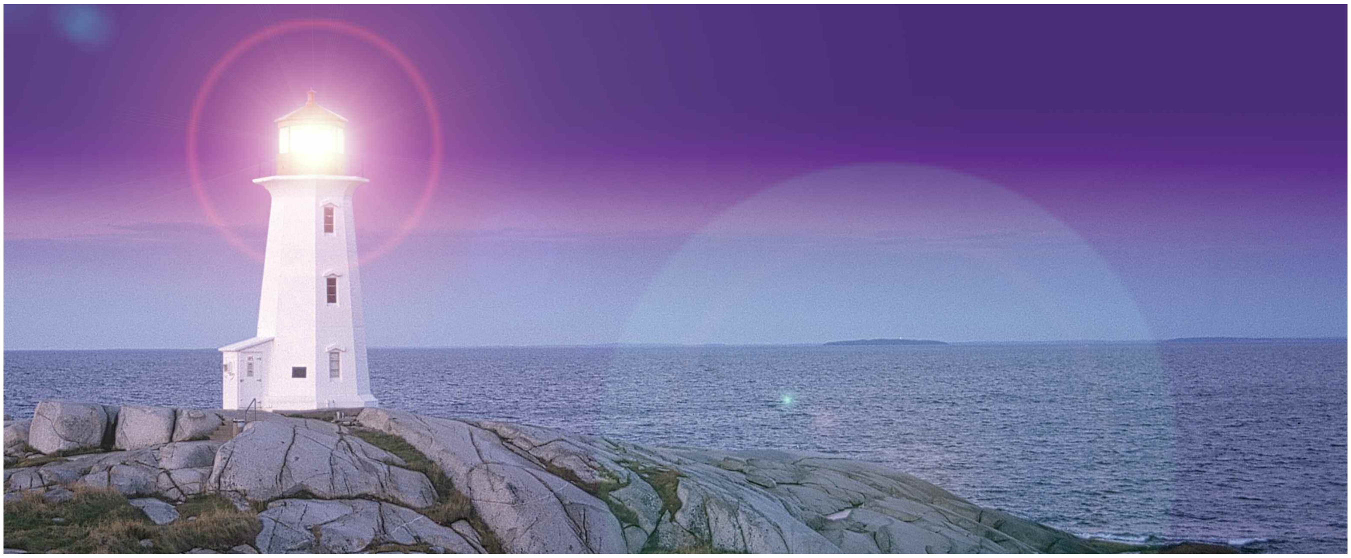

Field Trip A1

Contamination in the South Mountain Batholith and Port Mouton Pluton, southern Nova Scotia

D. Barrie Clarke and Saskia Erdmann

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Contents

Safety

General Considerations

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

Rock Hammers Please use caution when hammering: be aware of people around you, use controlled downward blows, and do not hammer indiscriminately. When hammering, either shield your eyes or wear protective eyewear.

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

Hard Hats Hard hats are recommended anywhere you intend to look at rocks where there are cliff faces or overhangs. Falling rocks are a major hazard on field trips. Avoid unstable waste rock piles or overhanging cliffs, and watch for people below you on slopes.

Roadside Outcrops At roadside exposures, please exercise caution when listening to field trip leaders and when looking at outcrops. Never venture onto the pavement, unless crossing the road at Stop 1.6, and only cross the road with the group to minimize traffic disruption.

Bus While on the bus, please remain seated when the bus is in motion. All knapsacks, rock hammers, rock samples etc. should be safely stowed underneath your seat.

First Aid First Aid kits will be located on the bus.

Emergency **Call 911.**

Stop-Specific Considerations

The more we are aware of possible dangers in the field, the better prepared we are to avoid problems. The following is a list of potential hazards at each of the stops.

Stop Number	**Safety Considerations**
Day 1	
1-1	unpredictable traffic in parking lot
1-2	heavy traffic on busy highway
1-3	heavy traffic on busy highway
1-4	heavy traffic on busy highway, loose rocks on cliff face
1-5	heavy traffic on busy highway, loose rocks on cliff face
1-6	crossing minor highway, slippery rocks, rogue waves
1-7	slippery rocks, rogue waves
1-8	heavy traffic on busy highway, loose rocks on cliff face
Day 2	
2-1	irregular footing on cobble beach, slippery rocks, rogue waves, ticks
2-2	loose boulders, slippery rocks, rogue waves, ticks
2-3	irregular footing on cobble beach, slippery rocks, rogue waves, bears, ticks

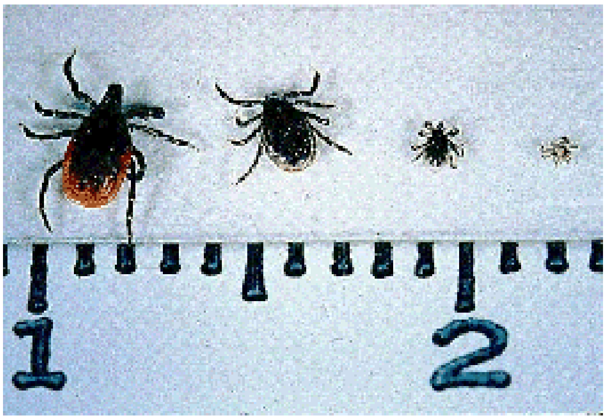
"Bio-Hazard" Considerations

Black Bears Our best defense against a black bear may be our numbers. However, in case you do encounter a black bear in a group or alone (http://www.gov.ns.ca/natr/wildlife/Nuisance/bears.htm):

- Stay calm.
- Try to keep down wind from the bear as you leave the area.
- Speak in a firm authoritative voice and slowly back away. Do not look the bear in the eyes.
- Leave escape routes open for the bear.
- If the bear begins to follow you, drop something - not food - to distract the bear as you move away.
- Do not make threatening gestures or sudden moves unless you are being attacked.
- Never run or climb a tree. Bears excel at both activities.
- If a bear attacks you, fight back with anything and everything you can, and make a lot of noise. Do not 'play dead'. Use pepper spray if you have it.

Ticks The month of May is high tick season, and the Port Mouton area is, unfortunately, the wood tick capital of Nova Scotia. So conditions are never worse than they are right now! Wood ticks are wretched little critters that like to bury their heads in your skin and drink your blood. Elsewhere in eastern North America, ticks are known to transmit Lyme disease, but the number of reported cases of Lyme disease in Nova Scotia is minuscule. The best way to avoid becoming a tick's next meal is as follows:

- Do not walk through grass or low bushes.
- Keep any ticks you do pick up on the outside by tucking your pants into your socks.
- If you do pick up a tick, it will climb until it finds skin.
- At the end of the day, check yourself and have someone else check the parts of your body you can't see.
- If you have a tick partially embedded in you, grab it with a pair of tweezers and pull it out gently – ticks have weak necks, and pulling too fast may leave the head embedded in your skin (a condition deemed undesirable by most victims).
- If you find a tick and don't kill it, it will find you again.
- You can't kill a tick by squeezing it between your fingers or, in some cases, even by stepping on it – squashing ticks between two hard surfaces (e.g., two hammers, or two rocks, or one of each) is par*tick*ularly satisfying from a professional viewpoint.



One minor scale division equals 1 mm.
Source: http://health.gov.on.ca/english/public/pub/disease/lyme.html

General Introduction

Objectives

The objectives of this two-day field trip are to examine how, and to what extent, a granite pluton can become contaminated with externally-derived materials. Because magmatic systems rarely reach chemical equilibrium, restitic (original minerals of the source rocks), refractory (unmelted minerals from the country rocks), and peritectic (new minerals created during melting reactions in the country rocks) solid remnants may exist, in addition to crystallization products of partial melt of xenoliths, all alongside magmatic phases in a granite. Relict phases unique to the source or country rocks should be texturally and chemically distinct in the granite. Relict phases common to the source rocks, country rocks, and granite (= magmatic phases) may be texturally and chemically different, but are we able to recognize/detect those differences?

This trip will provide an opportunity to discuss both the physical-textural inhomogeneities (xenoliths, xenocrysts, fluids) and chemical variation (major elements, trace elements, isotopic ratios of whole rocks and single grains) as evidence for contamination. We expect also to determine the processes involved, to find reliable ways to estimate the percentage of contamination, and to understand the implications of this contamination. Those implications include concepts as diverse as the space required for granite emplacement, various models of crustal evolution, determination of isochron ages for igneous rocks, the origins of certain kinds of mineral deposits, and even the fundamental meaning of granite whole-rock geochemistry (i.e., what does a chemical analysis of a granite signify if granites are just variable mixtures of magma and wall rocks?).

The Meguma Terrane

The Meguma Terrane of southern Nova Scotia is the most outboard terrane of the Canadian Appalachian Orogen (Williams and Hatcher 1982), dominantly comprising:

i) lower crustal felsic (metasedimentary) and mafic (metaigneous) granulites (Avalon basement; e.g., Owen *et al.* 1988; Eberz *et al.* 1991; Greenough *et al.* 1999);
ii) mid to upper crustal, subgreenschist facies to amphibolite facies metapelitic, metapsammitic, and minor calc-silicate rocks of the Cambro-Ordovician Meguma Group (Schenk 1970, 1997; Hicks *et al.* 1999);
iii) middle Ordovician greenschist facies to amphibolite facies metavolcanic and metasedimentary rocks of the Torbrook and White Rock Formations (Keppie *et al.* 1997; MacDonald et al. 2002);
iv) voluminous, late-Devonian granite intrusions (e.g., MacDonald *et al.* 1992; Clarke *et al.* 1997);
v) minor late-Devonian mafic intrusions (Tate 1995; Clarke *et al.* 2000; Keppie and Krogh 1999); and
vi) Carboniferous and younger volcanic and metasedimentary rocks.

The mafic intrusions are likely important sources of heat for the widespread late-Devonian granite magmatism (e.g., Tate 1995; Clarke *et al.* 1997; Keppie and Krogh 1999), metasedimentary rocks of the Avalon basement may be the most important source rocks for the granite intrusions (Eberz *et al.* 1991), and mafic magmas, country-rocks of the Avalon basement, the Meguma Group, and the Torbrook and White Rock Formations are potential contaminants of the granite. The objective of Day 1 is the South Mountain Batholith (SMB), the largest central granite intrusion of the Meguma Terrane; the objective of

Day 2 is the Port Mouton Pluton (PMP), one of several peripheral granite intrusions of the Meguma Terrane (Clarke *et al.* 1997) (Fig. A).

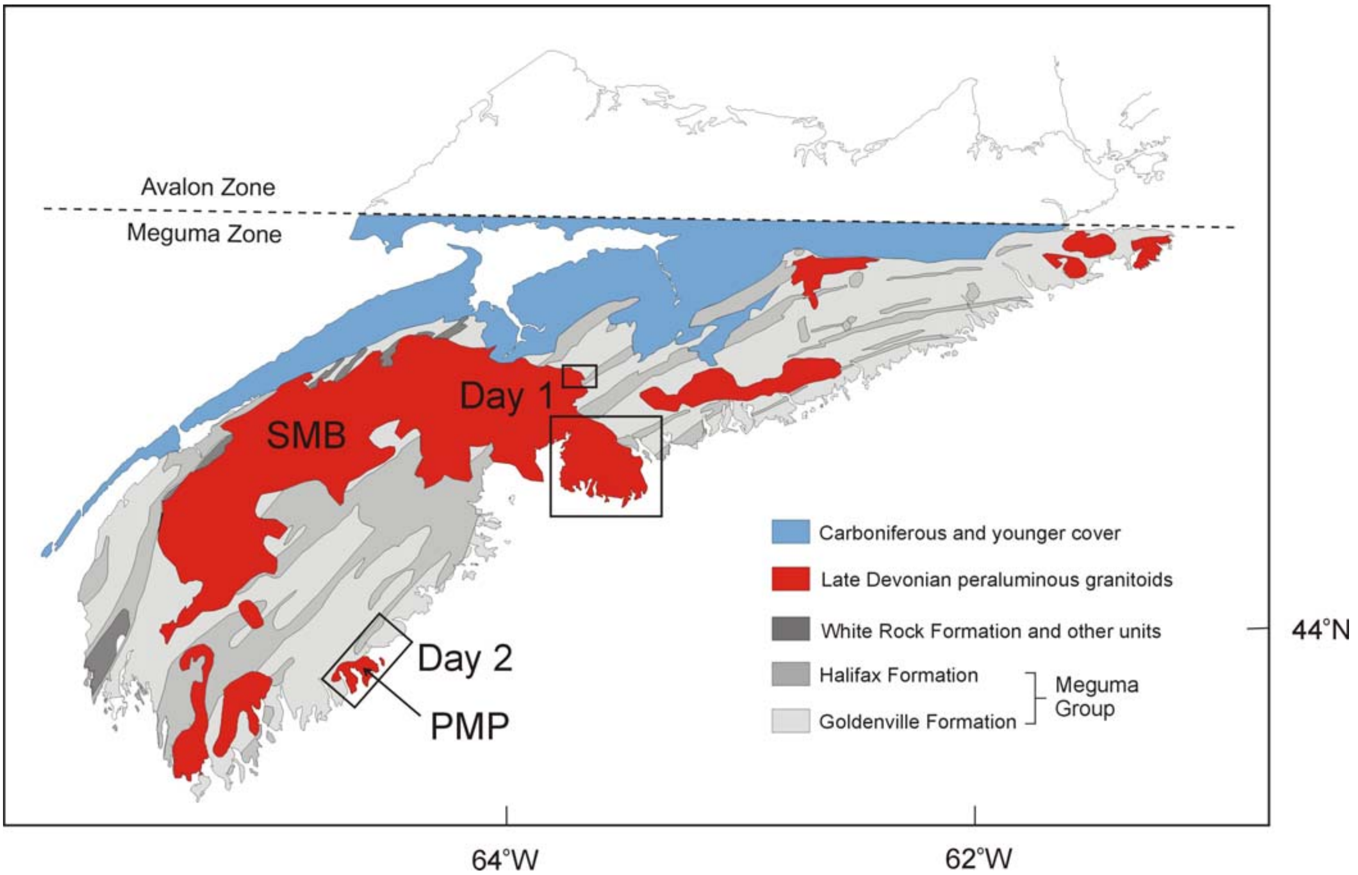


Figure A: Geological map of Nova Scotia, showing the location of the South Mountain Batholith (SMB) and the Port Mouton Pluton (PMP) (modified after Tate 1995).

Previous Studies on Contamination in Meguma Zone Granites

Most of the literature on the granites of the Meguma Zone has dealt with documenting and interpreting their mineralogy, petrology, geochemistry, geochronology, and mineral deposits. We know that the granites, particularly the SMB, have evolved predominantly by a combination of fractional crystallization and fluid partitioning (Clarke and Chatterjee 1988; MacDonald 2001). Not much of the previous work has dealt with the role of contamination in the chemical evolution of the granites; however, Clarke *et al.* (2004) investigated the role of major-element contamination in the variation of A/CNK in the SMB (Fig. B), and Clarke *et al.* (1988) recognized the influence of contamination on the Sr-Nd isotope systematics in the SMB. In addition, Clarke *et al.* (2000) considered a complex three-component mixing model for the Port Mouton Pluton. Recently, a number of mineralogical investigations have focused on the role of contamination, including Erdmann *et al.* (in press) on cordierite, Carruzzo *et al.* (2005) on oxides, Samson and Clarke (2005) on sulphides, and Erdmann *et al.* (2005) on experimental studies.

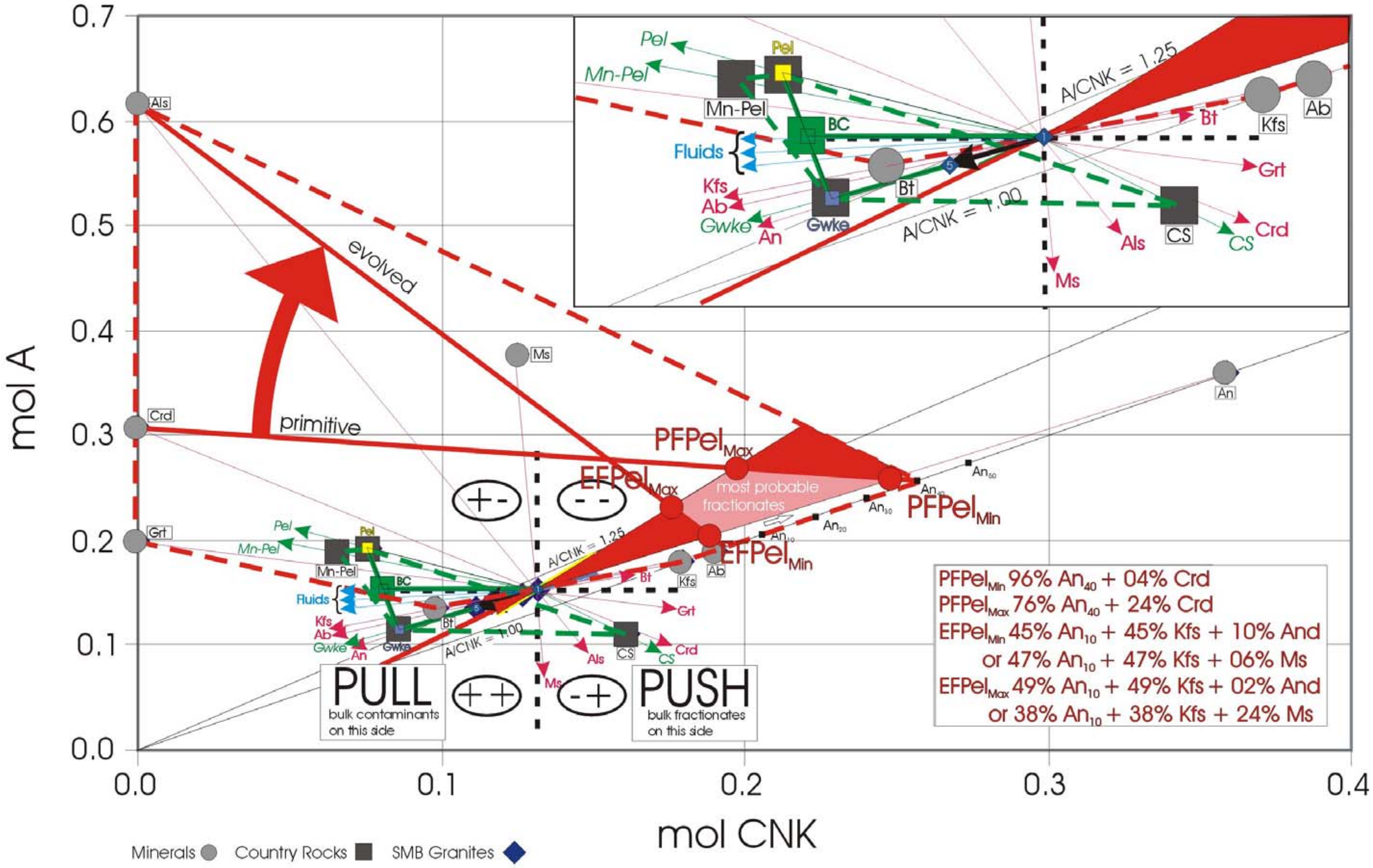


Figure B: Assimilation and fractional crystallization (AFC) processes in the South Mountain Batholith. The SMB evolves from primitive granodiorite (blue diamond 1) to evolved leucogranite (blue diamond 5). The controls for this chemical evolutions can be either fractional crystallization of minerals (grey circles) with a bulk composition lying to the right of granodiorite (red vectors), or contamination by country rocks (black squares) with a bulk composition lying to the left of leucogranite (green vectors), or some combination of the two. [PFPel$_{Max}$ – primitive fractionate with pelite contamination maximized; PFPel$_{Max}$ – primitive fractionate with pelite contamination minimized; EFPel$_{Max}$ – evolved fractionate with pelite contamination maximized; EFPel$_{Min}$ – evolved fractionate with pelite contamination minimized.] (After Clarke *et al.* 2004)

Contamination Processes

Contamination is the process of rendering one material impure by contacting or mixing with another material. The probability that a granite magma has the same composition as its wall rocks is zero. The probability that a granite magma does not react with its wall rocks is also zero. Therefore, all granites are contaminated. The only question is: by how much?

In what ways can the country-rock minerals, either individually or collectively as rocks, interact with the granite magma? They can:

i) **melt, or partially melt,** if their solidus temperatures are below the temperature of the granite magma, and that melting may be:
1) *congruent*, in which case the melt composition is equal to the solid composition
2) *incongruent*, in which case the melt composition and solid composition are different and new (peritectic) solid phases will appear during the melting process
and in either case the new melt may mechanically mix with the granite melt, may to varying degrees diffuse components across the interface with the granite melt, or remain immiscible (mingle) with the granite melt

ii) **dissolve**, if the minerals are currently undersaturated in the silicate melt, and the highly variable rate of dissolution will be a function of solubility (the solubilities may be so low that some phases may appear to be insoluble), and this dissolution may also be:
1) *congruent*, in which case the mineral dissolves completely in the granite melt
2) *incongruent*, in which case the mineral dissolves incompletely in the granite melt, leaving an insoluble ‘residue’ (new mineral)

iii) **undergo ion exchange reactions**, if the phases are saturated in the melt but belong to more refractory members of the solid solution series

iv) **undergo thermal decomposition reactions,** in which the magma temperature is greater than the temperature of the decomposition reaction (e.g., calcite or chlorite)

v) **undergo redox reactions,** if the phase contains significant concentrations of elements with variable valencies such as Fe, C, and S

vi) **remain as refractory, incompletely reacted, insoluble minerals** to become xenocrysts that may range from a readily distinguishable phase physically and chemically if not a normal member of the mineralogy of the granite (e.g., country rock hornblende in a peraluminous granite), to highly an indistinguishable phase physically and chemically if a normal member of the mineralogy of the granite (e.g., country rock quartz compared with granite quartz).

If all granites are contaminated, and if we want to determine qualitatively how much contamination has occurred, then we have to be able to recognize the contaminants either physically or chemically, or both. Some physical evidence (e.g., partial melt of xenoliths hybridized with the main magma) will have disappeared. Other physical evidence (e.g., xenocrysts, peritectic reaction products resulting from a reaction between country rocks and main magma) may remain. The recognition of xenoliths is straightforward, but it is only through some combination of texture and chemistry that we can recognize xenocrysts and other grain-scale contaminants. Table 1 covers the spectrum of attempts by a xenocryst to reach textural and compositional equilibrium. If the xenocryst retains its metamorphic texture and composition, the confidence we have in its recognition is high. On the other hand, if the xenocryst completely equilibrates texturally and chemically with the granite melt, the confidence we have in its recognition is low. Most cases for real xenocrysts fall between these extremes.

A GRAIN OCCURRING IN GRANITE WITH THE GIVEN CHARACTERISTICS IS:	**Igneous Texture**	**Intermediate or Transitional Texture**	**Metamorphic Texture**
Igneous Composition	a primary magmatic grain PROB OCCUR HIGH CONFID IDENT HIGH **or** a peritectic grain consisting of foreign elements growing in an incongruent melting reaction PROB OCCUR MODERATE CONFID IDENT MODERATE **or** a perfectly equilibrated metamorphic grain PROB OCCUR LOW? CONFID IDENT LOW	a metamorphic grain that has fully equilibrated chemically, but still retains some of its metamorphic texture (size, shape, inclusions, zoning) PROB OCCUR LOW-MODERATE CONFID IDENT MODERATE	a metamorphic grain that has completely retained its textural characteristics, but has fully equilibrated chemically with the granite melt PROB OCCUR LOW CONFID IDENT HIGH
Intermediate or Transitional Composition	a fully recrystallized metamorphic grain that has partially chemically equilibrated with the granite magma PROB OCCUR MODERATE CONFID IDENT MODERATE	a partially equilibrated metamorphic grain that has a composition and texture that are not clearly either metamorphic or igneous PROB OCCUR HIGH CONFID IDENT LOW	a metamorphic grain that has fully retained its textural characteristics, but has partially chemically equilibrated with the granite melt PROB OCCUR MODERATE CONFID IDENT HIGH
Metamorphic Composition	a fully recrystallized metamorphic grain that has behaved like a chemically closed system and has completely retained its metamorphic composition PROB OCCUR LOW CONFID IDENT HIGH	a partially recrystallized metamorphic grain that has completely retained its metamorphic composition PROB OCCUR MODERATE? CONFID IDENT MODERATE?	**a metamorphic grain that has retained all of its textural and chemical characteristics** **PROB OCCUR VARIABLE** **CONFID IDENT HIGH**

Table 1: Physical and chemical characteristics of xenocrysts in granite magma.

Our initial contact with a sample of granite, contaminated or not, is visual. We see the rock with our eyes and we are, therefore, initially sensitive to textural features, not chemical features. All grains in the upper left cell of Table 1 look igneous and nothing stands out as being anything but magmatic, even though there could be many fully equilibrated xenocrysts there masquerading as igneous. Likewise in the lower left cell, everything looks magmatic, so we are not inclined to do any chemical analyses. In summary, everything in the left column passes texturally as magmatic and, therefore, apparently no contamination has occurred. Conversely, in the upper right cell, it may be possible for some foreign grains to reach chemical equilibration without totally surrendering their metamorphic textural features, so a casual inspection of a thin section with grains in the upper right cell picks out grains that look suspicious texturally, but they turn out to be “magmatic” chemically (and then we *trust* the chemistry). Grains in the lower right cell may not have been in the granite magma for very long, otherwise they should have lost some of their distinctive textural and chemical characteristics (admittedly, depending on the mineral species). These grains look metamorphic texturally, and they can be readily confirmed chemically as metamorphic in origin. The white and black cells are relatively straightforward. Unfortunately most cases are grey. The dark grey cell is probably the place where most xenocrysts lie. The overall conclusion is that grains retaining at least some vestiges of their metamorphic textures have a greater probability of being identified as xenocrysts than those retaining only their metamorphic compositions, simply because the eye is faster and cheaper than the microprobe.

Assimilation of Country Rocks

Assimilation is the process of conversion/incorporation of one material into another substance by changing the nature of the former into the nature of the latter (Fig. C). Figure D illustrates the problem of recognizing and quantifying contamination with progressive disintegration and assimilation of the country-rock material. Contaminants in the form of xenoliths are easily recognizable, but typically make up < 1-3 vol% in most plutons. Furthermore, xenoliths are easy to avoid in whole-rock geochemical analysis, and will therefore have no effect, or only a minor effect, on geochemical trends and variations. However, with progressive disintegration and assimilation, the identification of the foreign material becomes more and more challenging, and any whole-rock geochemical analysis of a granite may be an analysis of a random mixture of cognate magmatic and foreign phases. Such random mixtures of cognate magmatic and foreign material may result in non-systematic major and trace element, and isotopic variations, as well as a component of “noise” in the whole-rock geochemical data of many plutons. To evaluate if these geochemical variations are a result of country-rock contamination, the amount and the nature of micro-scale contaminants need to be determined for mineralogically, texturally, and compositionally variable rocks, and these findings have to be compared to the whole-rock geochemical signature.

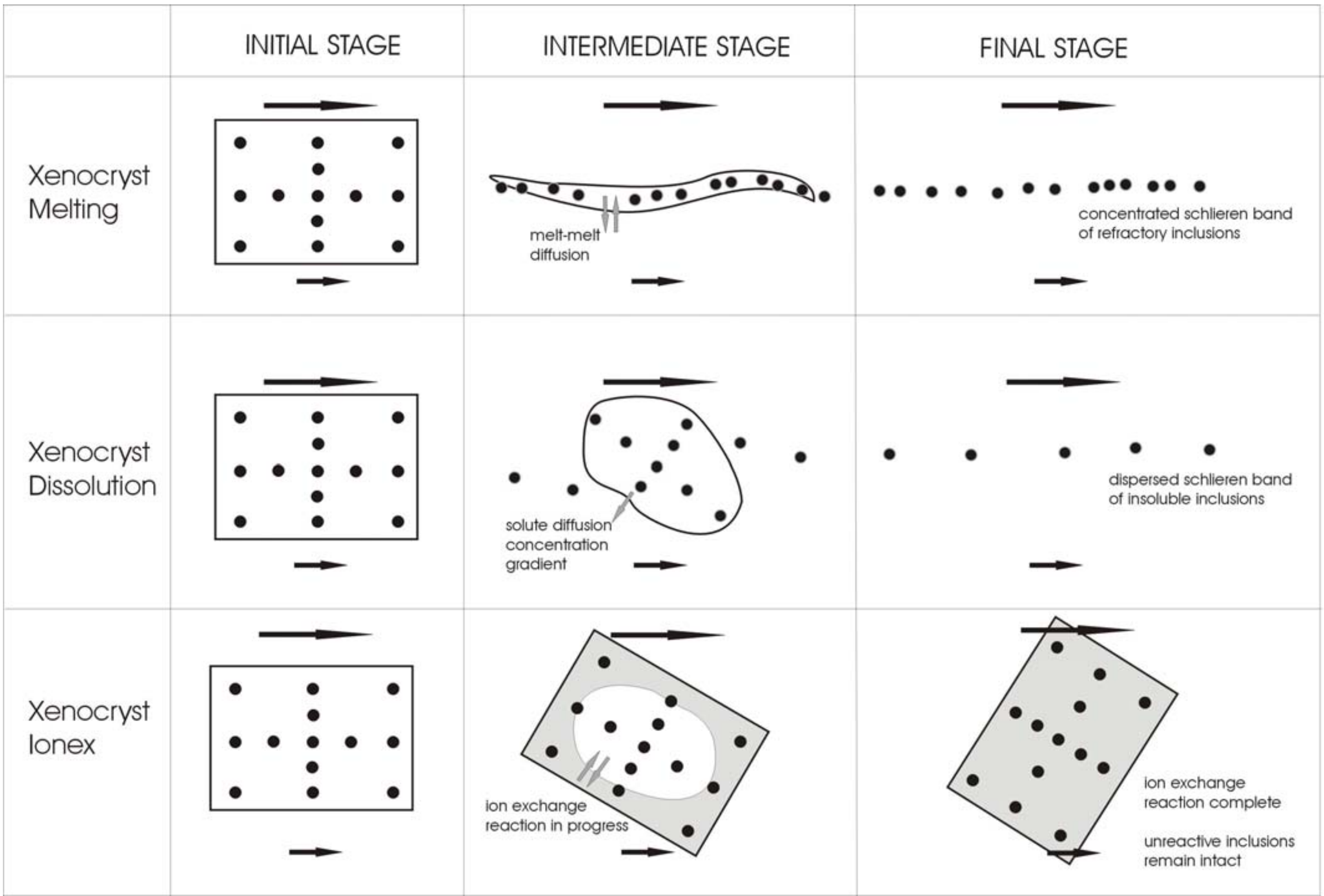


Figure C: Graphic Illustration of the Differences among Melted, Dissolved, and Ion Exchanged Xenocrysts. Illustration of the response of an identical xenocryst with inclusions (black dots) in a magma undergoing shear flow (arrows) in response to three different assimilation reactions: melting, dissolution, and ion exchange. The final products of melting and dissolution are similar (although the intermediate stages and rates of reaction may be different). The products of the ion exchange reaction at all stages are distinct. The three final stages are not reached at the same time.

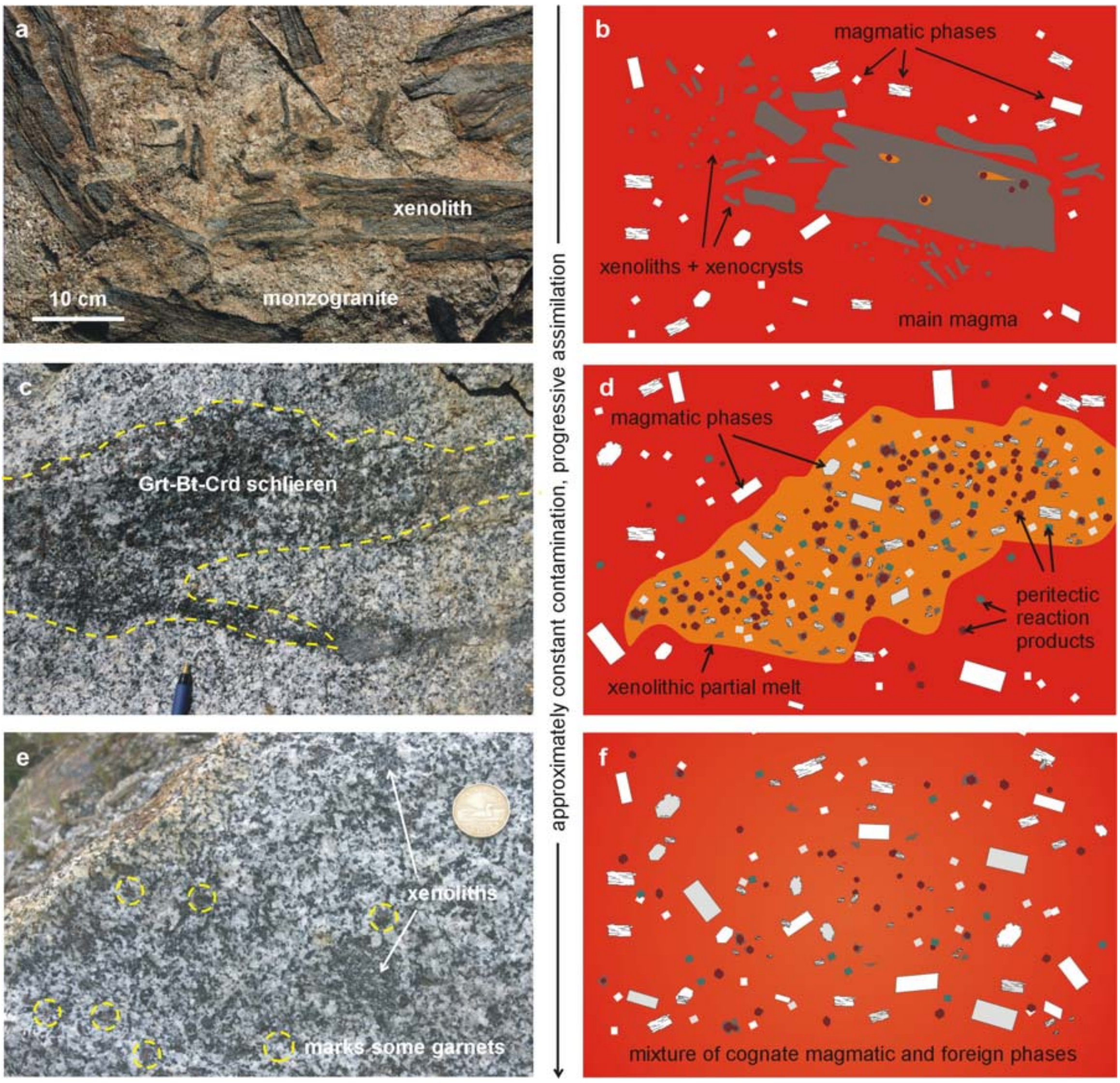


Figure D: Photographs from the South Mountain Batholith and comparable sketches showing approximately constant contamination of granites by country-rock material, but progressive assimilation of the foreign material from a and b to e and f. Disintegration and assimilation of country-rock material may occur by partial melting and fracturing of xenoliths, as well as melting and dissolution of xenocrysts and intermediate reaction products (peritectic reaction products). The case made here considers disintegration and assimilation through partial melting. (a,b) ~ 30 vol% contamination, imperceptible assimilation; (c,d) ~ 30 vol% contamination, ~ 10 vol% assimilation; (e,f) ~ 30 vol% contamination, and ~ 25 vol% assimilation. If xenoliths are raised to temperatures above the solidus, they partially melt. Solids within the partial melt are refractory xenocrysts and peritectic reaction products such as garnet and cordierite (d). Once the system starts to cool, the xenolithic partial melt and the main magma crystallize, forming minerals such as quartz, plagioclase, K-feldspar, and biotite (c). In cases where the foreign partial melt and solids mix only slightly with the main magma, it is easy to recognize the foreign material (e.g., in the form of garnet-biotite-cordierite schlieren) (c). However, if mixing of the xenolithic and the cognate magmatic melt phases, and the dispersal of xenocrysts and peritectic reaction products is well advanced, it is challenging to determine the amount of foreign material present (e,f), where small xenoliths and garnet or cordierite may be the most visible foreign constituents (e). Moreover, if disintegration, dispersal, and assimilation of the foreign material proceeds to a more advanced stage than shown in (f), the presence of foreign material may not be any longer recognizable on the macro-scale, but may be expressed in mineralogical, textural, and chemical variations of a pluton.

Day 1 -- Contamination in the South Mountain Batholith

Date/Time

Meet at Dalhousie University, Studley Campus, Dunn Building, Howe Hall parking lot, 8:00 am on Saturday May 14, 2005 (enter campus from Coburg Road gate).

Itinerary

08:00 Meet at Dalhousie University, Stop 1.1
08:30 Depart Stop 1.1
09:00 Arrive Stop 1.2, Hwy 101
09:45 Depart Stop 1.2
09:50 Arrive Stop 1.3, Hwy 101
10:30 Depart Stop 1.3
10:35 Arrive Stop 1.4, Hwy 101
11:45 Depart Stop 1.4
12:10 Arrive Stop 1.5, Hwy 101
12:40 Depart Stop 1.5
13:05 Arrive Tim Hortons
13:50 Depart Tim Hortons
14:10 Arrive Stop 1.6, Portuguese Cove
15:10 Depart Stop 1.6
16:10 Arrive Stop 1.7, Peggys Cove
17:10 Depart Stop 1.7
17:40 Arrive Stop 1.8 (or former location thereof)
18:10 Depart Stop 1.8
19:00 Arrive Lunenburg

Lunch – en route
Dinner – in Lunenburg

Geological Overview and Objective

The Late-Devonian South Mountain Batholith (SMB) is the largest intrusion of the Meguma Lithotectonic Zone, dominantly comprising biotite granodiorites, biotite monzogranites, biotite-muscovite monzogranites, and leucomonzogranites (e.g., McKenzie and Clarke 1975; MacDonald *et al.* 1992; MacDonald 2001). Less than 10% of the > 500 km perimeter of the SMB is in contact with rocks other than the metasedimentary rocks of the Meguma Group, which is up to 10 km thick (Schenk 1997; Richardson 2000). In other words, the batholith is in contact with a large surface of material with limited lithological and chemical variation. Country-rock xenoliths in the granites, and irregular and relatively sharp contacts between country rocks and the SMB, suggest that stoping played, at least temporarily, a role for the emplacement of the SMB, and for the incorporation of country-rock material into the emplaced magma. Evidence for country-rock contamination in the form of xenoliths is present throughout most units of the batholith, but most common in the marginal facies of granodiorites and monzogranites. Further macro-scale evidence for country-rock contamination exists locally in the form of xenocrysts, peritectic reaction products (cordierite, garnet, possibly biotite), and minerals representing former partial melt (dominantly quartz, plagioclase, K-feldspar).

The objective of Day 1 of this field trip is to examine:

i) metasedimentary rocks of the Meguma Group (Stop 1.1);
ii) compositionally and texturally variable granodiorites of the SMB (Stop 1.2, 1.3, 1.5);
iii) contact relations and material exchange between granodiorites and metasedimentary rocks (Stop 1.4);
iv) the physical disintegration of a large xenolith (Stop 1.6); and
v) enclave-rich monzogranites of the SMB close to the contact with the Meguma Group (Stop 1.7); and
vi) a cordierite-rich monzogranite (Stop 1.8).

Stop 1.1 to Stop 1.8 will thereby provide the opportunity to explore potential country-rock contaminants, as well as macroscopically relatively uncontaminated to macroscopically highly contaminated granodiorites and monzogranites. Figure 1.0 shows locations of the stops.
UTM coordinates for outcrops described in this field guide use the WGS 84 datum.

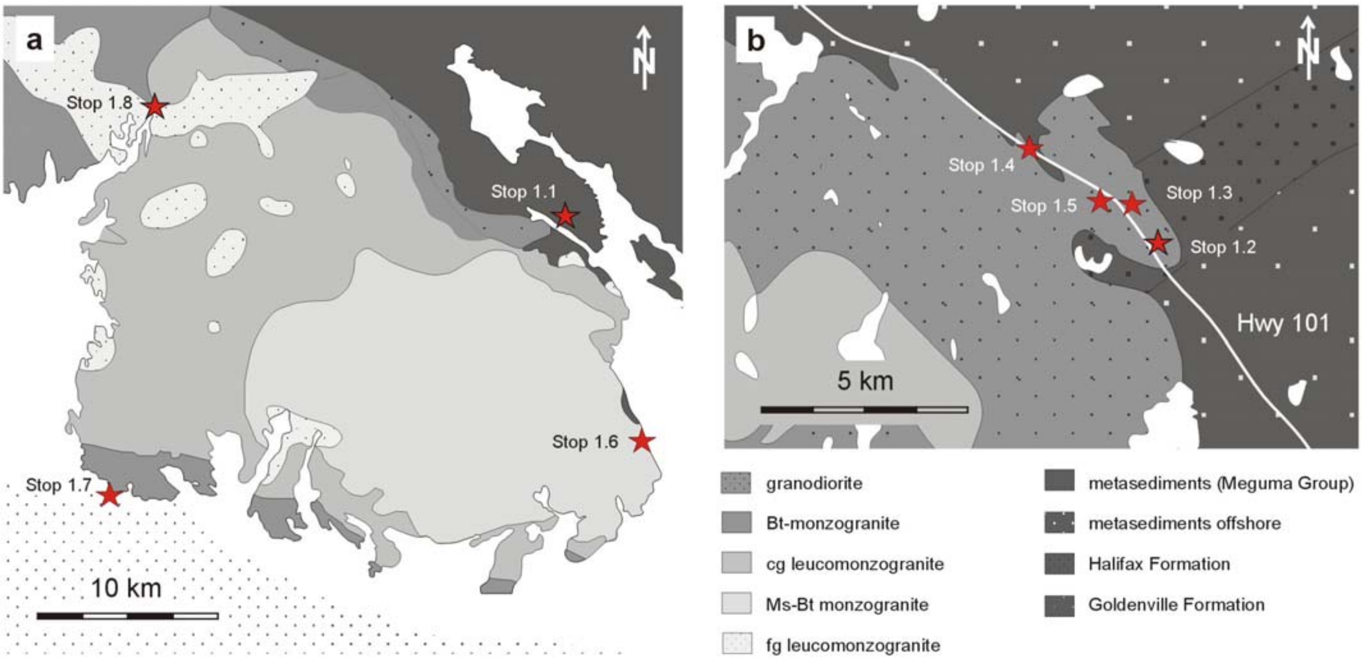


Figure 1.0: Locations of Stops 1.1 – 1.8. (a) Detailed map of the Halifax Pluton. (b) Detailed map of the northern contact between the South Mountain Batholith and the Meguma Group along Highway 101 (modified after MacDonald 2001).

Stop 1.1 -- Meguma Group, Dalhousie University

Dalhousie University, Studley Campus; 20T E452954, N4942901

Abstract – The Meguma Group dominantly consists of greenschist to amphibolite facies metapelitic and metapsammitic rocks.

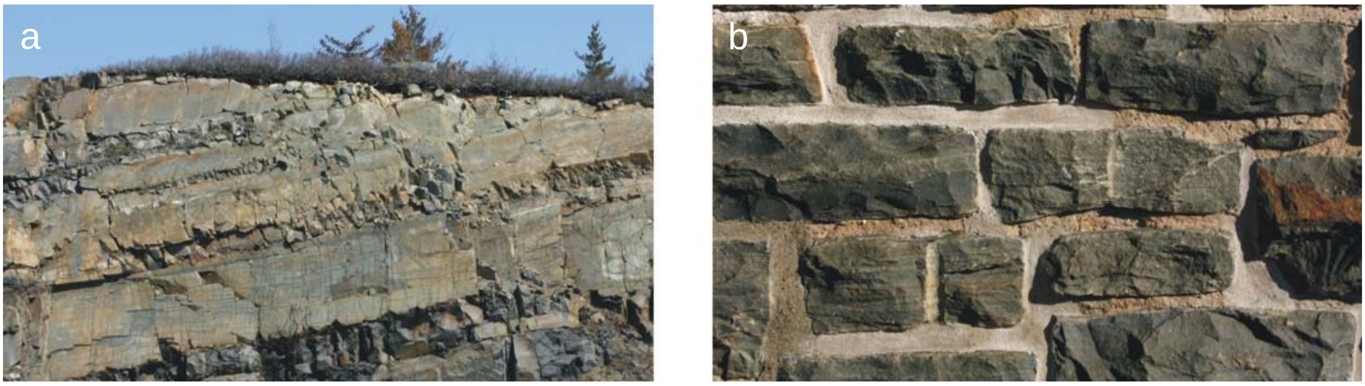


Figure 1.1.1: (a) Outcrop of the Meguma Group (Goldenville Formation), dominated by metapsammitic rocks and interbedded metapelitic rocks (Hwy 102). The gently dipping layers mark the hinge of an anticline. (b) Cladding of the Sir James Dunn Building, Dalhousie University, consisting of metapsammitic and metapsammopelitic rocks of the Meguma Group. The meta-sedimentary rocks show thin laminations, gradational layering, and crossbedding.

Figure 1.1.2: (a) Outcrop of metapelitic rocks of the Meguma Group (Halifax Formation) on the Dalhousie Campus. (b) Metapelitic rocks of the Meguma Group also form the "dry stane dyke" surrounding the campus.

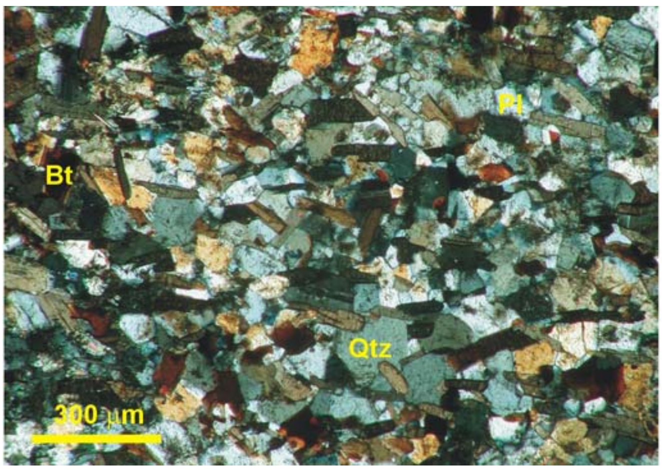


Figure 1.1.3: Fine-grained, metapsammitic rock (sample from Hwy 101). Quartz, plagioclase, and biotite dominate the assemblage; K-feldspar, muscovite, cordierite, and sulphides are minor constituents. The abundances of quartz, plagioclase, and biotite vary considerably between layers.

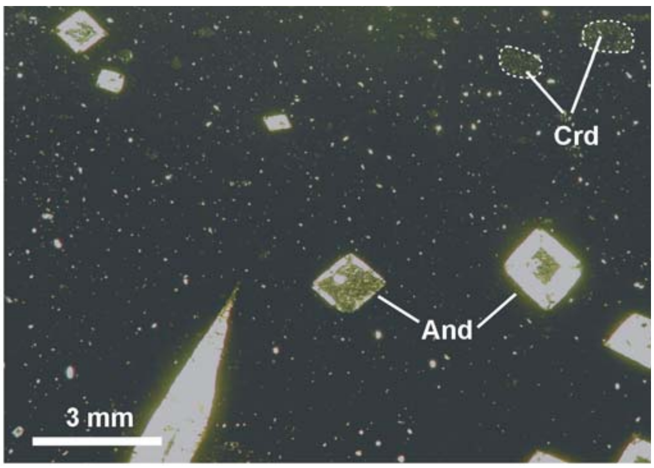


Figure 1.1.4: Very fine-grained metapelitic rock (sample from the Aspotogan Peninsula). The dominant assemblage is muscovite, chlorite, quartz, plagioclase, K-feldspar, andalusite, biotite, graphite, and sulphides. Pinite replaces ellipsoidal cordierite.

Stop 1.1 - Key Observations and Discussion

Less than 10% of the > 500 km perimeter of the South Mountain Batholith is in contact with rocks other than metapelitic to metapsammitic rocks of the Meguma Group. In the vicinity of the South Mountain Batholith, the Meguma Group is ~10 km thick (Schenk 1997; Richardson 2000). In other words, the batholith is in contact with a large surface of material with limited lithological and chemical variation. However, lithology and composition of metapelites and metapsammites are variable (e.g., A/CNK varies from 1.3 for metapsammitic rocks to 3.5 for metapelitic rocks), and thus provide contaminants of different composition, placing major uncertainties on geochemical AFC models (in addition to other uncertainties). Moreover, various xenolith lithologies have had variable physical and chemical properties. Metapelitic rocks as well as metagreywackes of the Meguma Group may have reacted with the magma more readily than quartzitic metapsammites, resulting in abundant xenoliths with quartz-rich lithologies, and a higher degree of assimilation of metapelite and metagreywackes. Xenoliths of the Meguma Group, dominantly metapsammitic rocks, occur throughout all units of the South Mountain Batholith (typically between ≤ 1 and 3 vol%), but are most abundant in granodiorites and biotite monzogranites close to the contact with the Meguma Group (locally up to 15 vol%). The scarcity of xenoliths away from the contact with the country rocks may be explained either by only minor contamination or efficient assimilation.

Subsequent stops within the South Mountain Batholith (Stops 1.2 – 1.8) will give us the opportunity to look at the nature of contaminants, and their macro-scale abundance. The stops will also serve as the basis for discussing the likely degree of contamination by country-rock material in the South Mountain Batholith, and the strategies to reliably quantify the overall amount of contamination, including the amount of contamination that may not be visible on the macro-scale.

Stop 1.2 -- Relatively Homogeneous Granodiorite

Roadside outcrop, north side of Hwy 101; 20T E0435354, N4967265

Abstract - Medium-grained biotite granodiorite, showing < 5% of clearly foreign material in the form of various enclaves; however, mineralogical variations within the outcrop suggest that a higher percentage of partly assimilated foreign material is present.

Figure 1.2.1: Texturally and mineralogically relatively homogeneous granodiorite. Although there is evidence for macro-scale and micro-scale contamination, this outcrop seems to expose the apparently most uncontaminated grano-diorite we will see in the South Mountain Batholith (SMB).

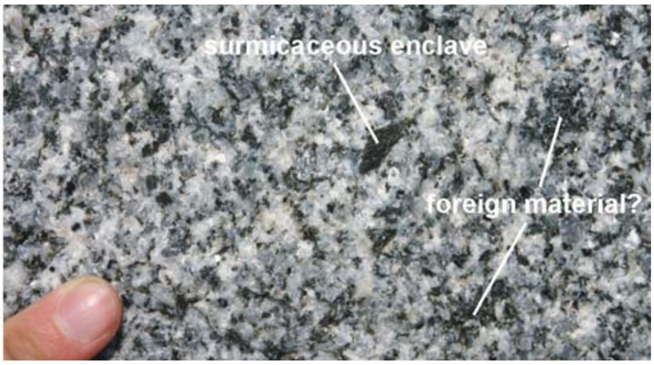


Figure 1.2.2: Foreign material is present in various sizes (dm to < 1 cm), where small enclaves and xenocrysts may easily be overlooked. Surmicaceous enclaves are relatively rare; they most likely represent refractory residues of otherwise assimilated country-rock material.

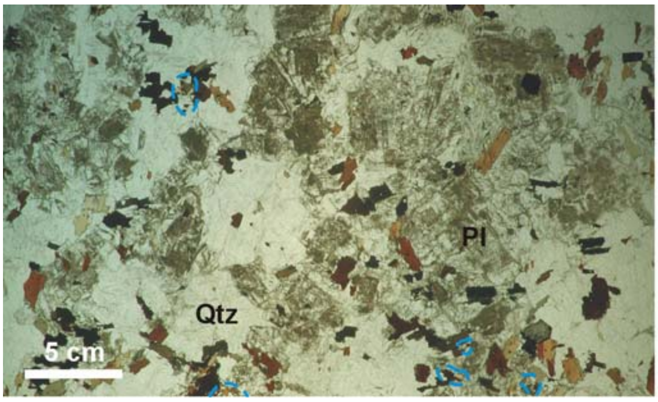


Figure 1.2.3: Photomicrograph (crossed polarizers) of the granodiorite shown in Fig. 1.2.1. Most grains have a magmatic texture, but some crystals have textural characteristics similar to those of the equivalent minerals in the rocks of the Meguma Group (; detail Fig. 1.2.4).

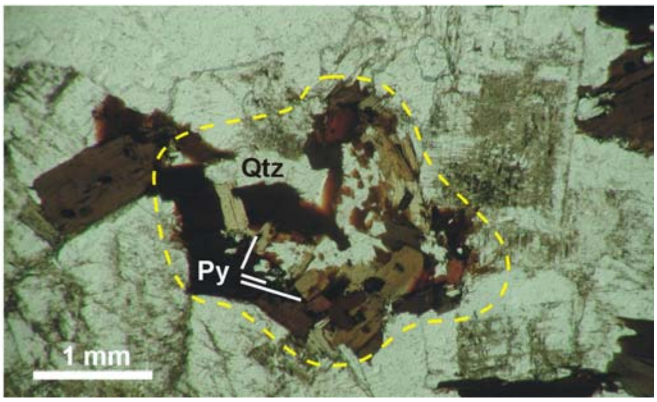


Figure 1.2.4: Photomicrograph (plane polarized light) of a biotite clot in the granodiorite. Enclosed in the biotite are quartz grains of a similar shape and texture as quartz grains of the metasedimentary host rocks. Thus, are the quartz crystals xenocrysts?

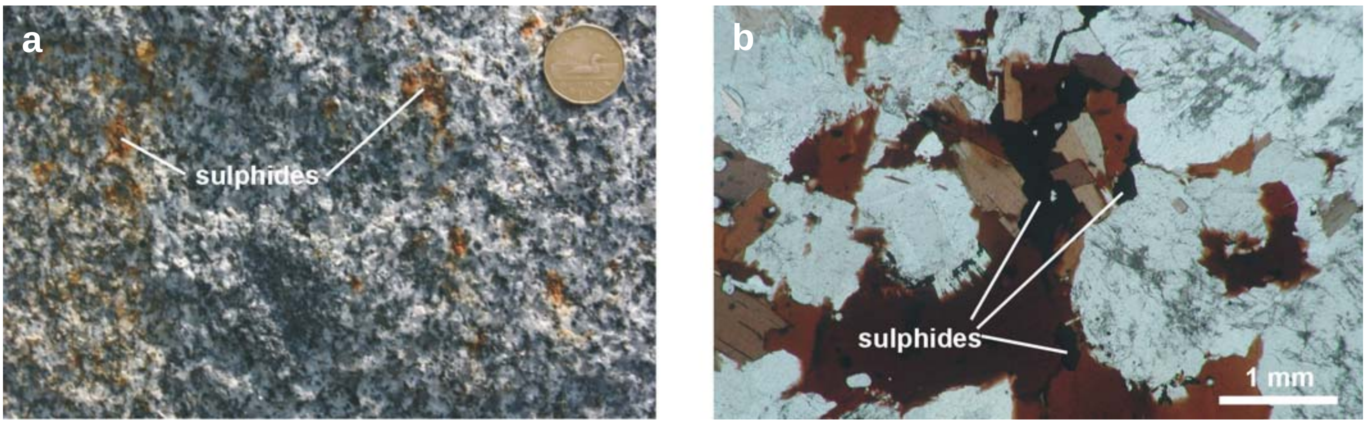


Figure 1.2.5: Disseminated sulphides. (a) Outcrop photograph. (b) Photomicrograph (transmitted light). Disseminated sulphides are locally abundant in the granodiorites, probably representing country-rock contaminants. The question is: are the sulphides xenocrysts, or are they crystallized immiscible sulphide melts? (Samson and Clarke 2005)

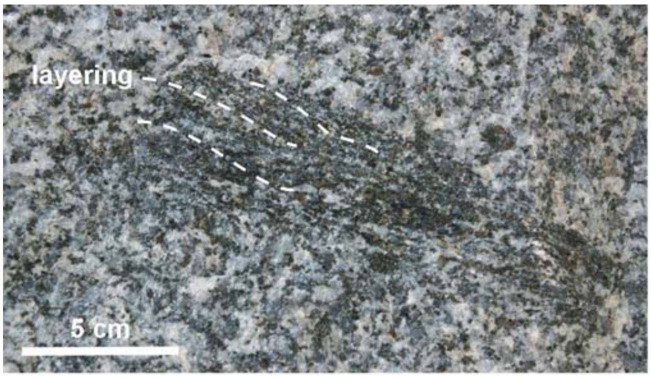


Figure 1.2.6: Foreign or cognate enclave? From the layering, we interpret the enclave as a xenolith at an advanced stage of assimilation. If reaction had progressed further, and if disintegration had taken place, it would have been difficult to distinguish the disintegration products from minerals of the granodiorite host.

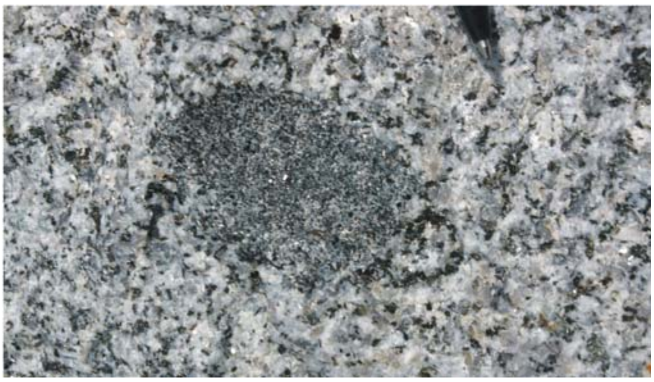


Figure 1.2.7: Equigranular enclaves in the SMB may have one of two origins: they may be magmatic, or they may be xenoliths affected by grain coarsening and partial melting. A detailed microstructural analysis is essential to detect their origin, because magmatic enclaves and formerly partially molten xenoliths may both exhibit magmatic textures.

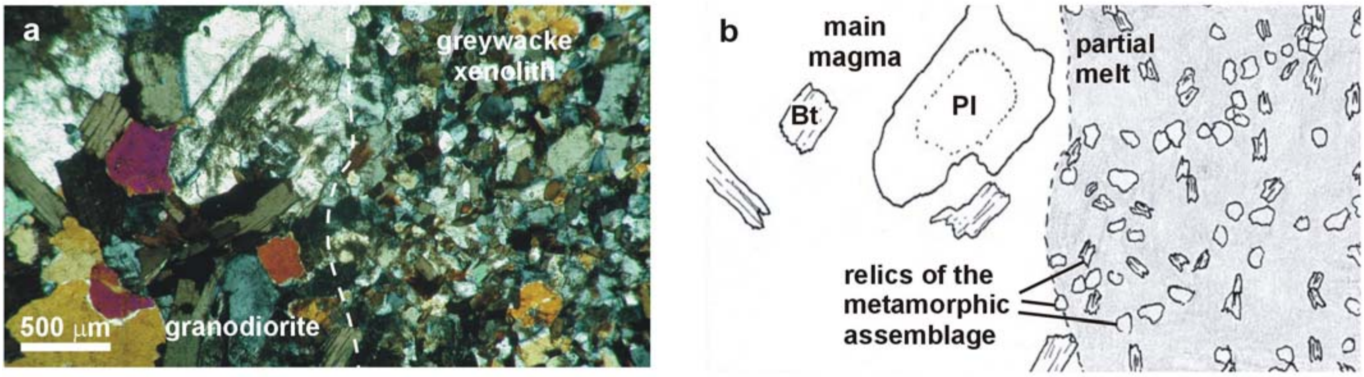


Figure 1.2.8: A xenolith as a possible origin of an equigranular enclave. (a) Unreacted greywacke xenolith. (b) If such a xenolith had partially melted, the original metamorphic texture and mineralogy may have been modified to a microgranitoid texture if significant amounts of partial melt were present (Fig. 1.2.9).

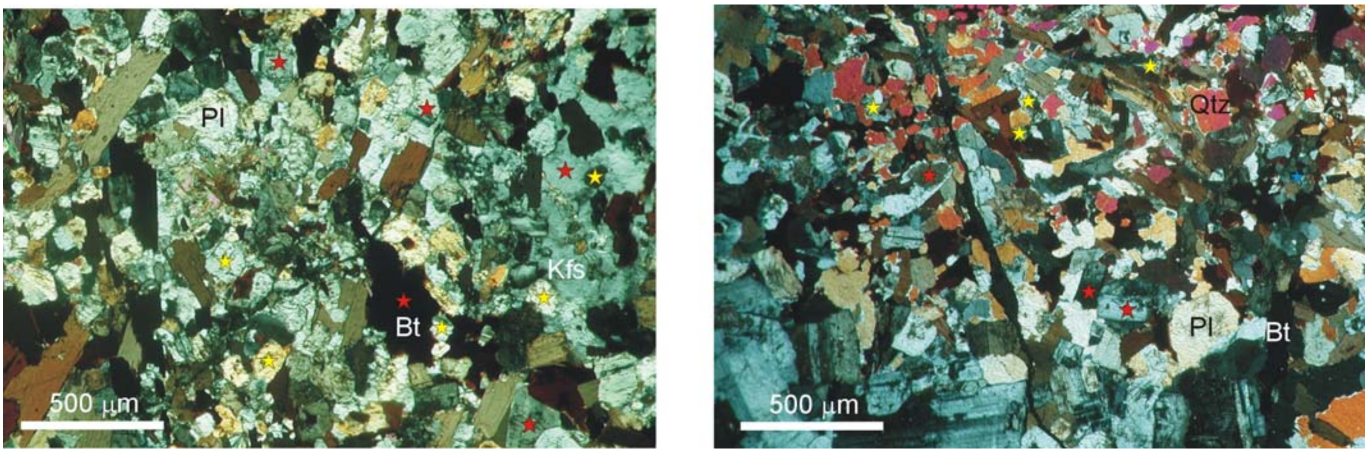


Figure 1.2.9: Two examples of enclaves, where crystallization of partial melt (+/- infiltrating melt) may have allowed growth of magmatic crystals, or at least magmatic overgrowths, on the metamorphic assemblage of a xenolith, and thus, resulted in the formation of a magmatic texture characteristic of "microgranitoid" enclaves. ☆ marks what we interpret as relict metamorphic minerals, ★ mark what we believe to be new magmatic crystals, interpreted based on textural criteria (such as grain size, grain shape, inclusion relations, and optical zoning).

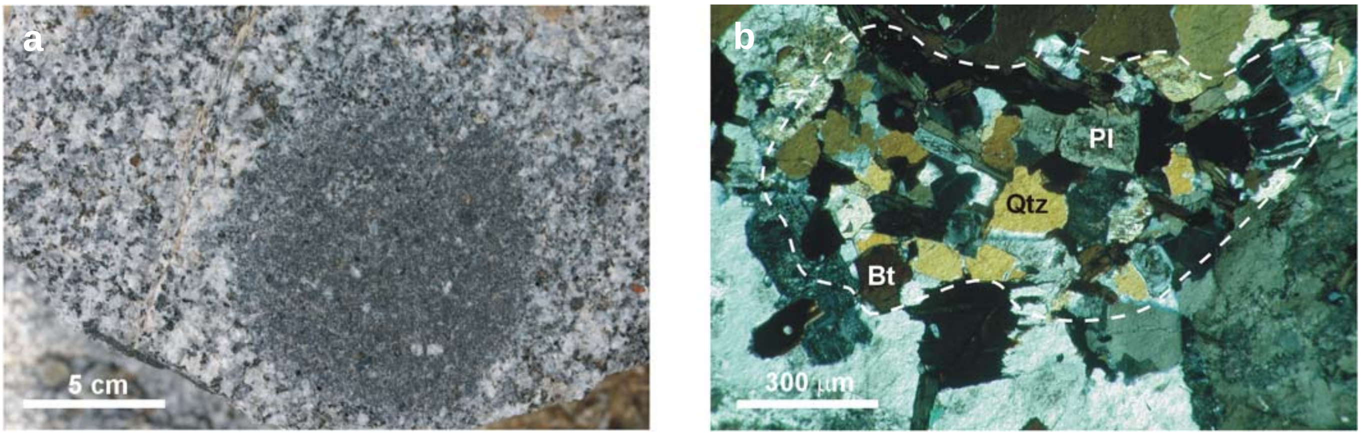


Figure 1.2.10: Porphyritic, microgranitoid enclaves are usually easily distinguished from xenoliths. However, the difficulty may be to distinguish material derived from microgranitoid enclaves if it is well mixed/mingled with the main magma from the disintegration products of country-rock material, on the macro-scale, as well as on the micro-scale. (a) Hand specimen photograph. (b) Photomicrograph (crossed polarizers) showing the fine-grained matrix of a porphyritic microgranitoid enclave (enclosed by dashed line).

Stop 1.2 - Key Observations and Discussion

The relatively homogeneous texture and mineralogy of the granodiorite, and the scarcity of macro-scale contaminants suggests that no major contamination by the metasedimentary host rocks occurred in this part of the former magma chamber, once magma movement ceased. However, during earlier stages of the magma chamber evolution, while the magma was still relatively hot (allowing for partial melting of xenoliths and/or partial dissolution of the xenolithic assemblage), less viscous, and convecting, xenolithic material (solids and partial melt) may have been easily dispersed and assimilated (Fig. C, D). Evidence for contamination during an early stage of the magma evolution appears to be present in the form of disseminated sulphides, slight variations in biotite content, and quartz versus plagioclase and K-feldspar abundance. To test if the observed mineralogical variation is a result of contamination, and whether the contamination occurred at the emplacement level, or during ascent, it is important to evaluate the patterns of those inhomogeneities within a pluton/batholith/unit in respect to contacts with the country rocks (the potential emplacement level contaminants).

In this outcrop, evidence for an intermediate stage of country rock assimilation may exist in the form of at least some of the equigranular enclaves present (Fig. 1.2.6, 1.2.7, and 1.2.9). To test this hypothesis, a careful examination of microtextures and mineralogy seems to be most amenable. The question is: do minerals characteristic of the metasedimentary country rocks, but not characteristic of the magmatic rocks, occur? Whereas certain minerals may help to unequivocally determine the origin of the enclaves, the interpretation of microtextures is challenging, given the difficulty to distinguish textures resulting from thermal and compositional disequilibrium between country-rock material and magma, from disequilibrium textures resulting from the interaction of two magmas (Table 1).

Stop 1.3 -- Mafic and Intermediate Biotite Granodiorite

Roadside outcrop, north side of Hwy 101; 20T E0434562, N4968313

Abstract - Two mineralogically and texturally variable biotite granodiorites in contact. The differences in composition, mineral assemblage, modal abundance, and texture appear to be the result of various degrees of contamination and/or accumulation of early fractionates (biotite).

Figure 1.3.1: Biotite-rich and enclave-rich granodiorite. Locally, coarse-grained andalusite occurs. The unusual mineralogy may be a result of contamination by country-rock material, fractional crystallization, or both.

Figure 1.3.2: Clotty granodiorite with a biotite content of ~ 15 vol%. Enclaves do occur, but they are less common than in the mafic granodiorite of this outcrop. Biotite clots make up ≤ 5 % of the mode.

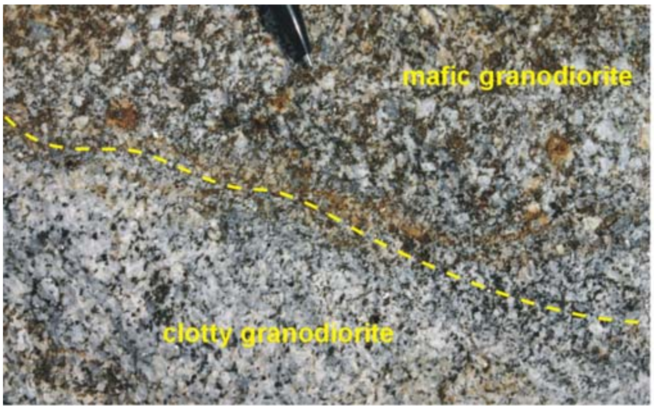


Figure 1.3.3: Irregular contact between the mafic and the intermediate clotty granodiorite.

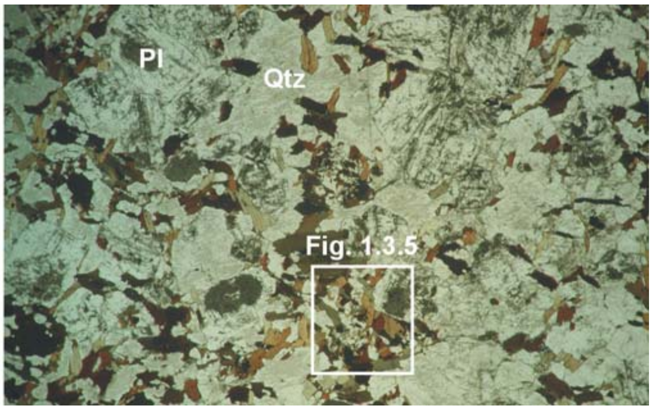


Figure 1.3.4: Contaminated or uncontaminated (mafic) granodiorite?

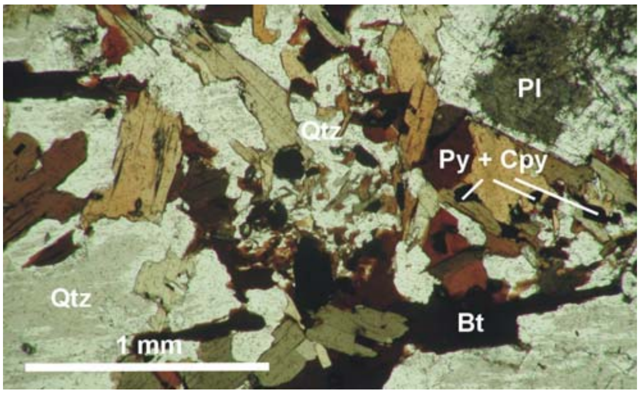


Figure 1.3.5: Biotite-quartz-pyrite-chalcopyrite clot. The origin of quartz, pyrite, and ± chalcopyrite is most likely foreign; however, is the coarse-grained biotite also foreign (e.g., a peritectic reaction product of xenolithic material and main magma), or did the biotite grains nucleate from the granite magma on the foreign solids?

Stop 1.3 - Key Observations and Discussion

The granodiorite in this outcrop appears to be more contaminated than the granodiorite at Stop 1.2. Undoubtedly foreign material, such as sulphides, are present, but the question is whether the granodiorite magma was selectively contaminated, or bulk contamination prevailed. To constrain the importance of contamination on the macro-scale, determining the origin of biotite, and particularly the origin of the biotite clots, is most critical. If all biotite clots have a foreign origin, they may suggest that > 10 vol%, possibly up to 30 vol% foreign material is present; however, if they crystallized from the main magma, the amount of foreign material is likely to be < 3 vol%.

Stop 1.4 -- Contact Granodiorite / Meguma Group

Roadside outcrop, north side of Hwy 101; 20T E0430386, N4971237

Abstract - Granodiorite and dominantly metapsammitic host rocks in contact. The granodiorite is contaminated with xenoliths, xenocrysts, peritectic reaction products, and partial melt.

Figure 1.4.1: Lit-par-lit contact between granodiorite, metapsammitic, metapelitic, and calc-silicate rocks. Abundant xenoliths, mineralogical and textural heterogeneities of the granodiorite, diffuse contacts, and reaction rims along the contact are all evidence for the contamination of the granodiorite. The question is, how much contamination occurred, and how much of the contamination is still visible on the macro-scale?

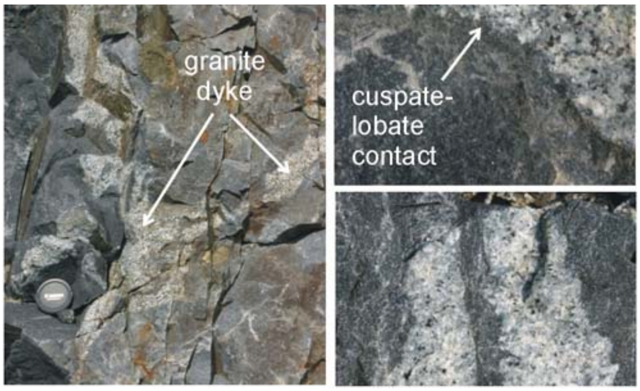


Figure 1.4.2: Metasediments irregularly intruded by a granite dyke. The contacts are sharp, and cuspate-lobate on a cm to mm-scale.

Figure 1.4.3: Diffuse contacts are characterized by a mixture of fine-grained country-rock and granitic material, or medium-grained biotite, garnet, and cordierite.

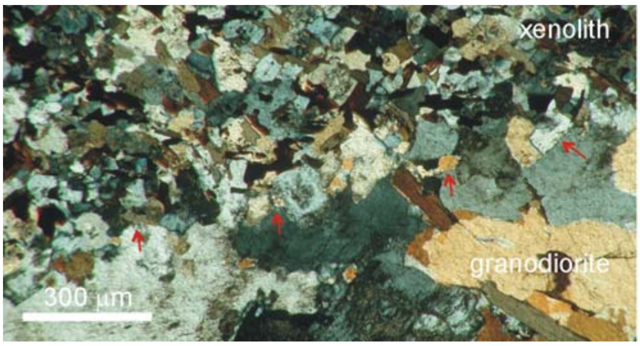


Figure 1.4.4: Photomicrograph (crossed polarizers). Contact between a xenolith and granodiorite. The boundary is irregular on the grain-scale, but sharp. Minerals of the xenolith along the interface show straight to rounded grain boundaries, where the latter suggest partial assimilation through dissolution or partial melting.

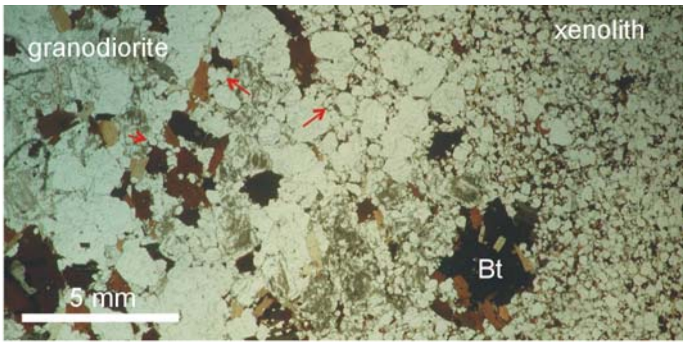


Figure 1.4.5: Photomicrograph (plane polarized light). Diffuse contact between a xenolith and granodiorite with magmatic minerals in a xenolithic matrix, and xenocrysts in the granodiorite (arrows). The xenolith did undergo partial melting, where evidence for partial melting is preserved in the form of thin epitactic overgrowths of xenocrystic plagioclase.

Figure 1.4.6: Irregular layer of garnet, cordierite, quartz, biotite, plagioclase, sulphides (e.g., pyrite), and accessories, representing peritectic reaction products (Grt, Crd), and former partial melt (Qtz, Bt, Pl, Py). Enclosed in this layer are xenoliths with an equigranular texture that appear to be the refractory remnants of the metasedimentary material.

Figure 1.4.7: Xenoliths with diffuse reaction rims of biotite, quartz, K-feldspar, plagioclase, cordierite, sulphides, chalcopyrite, apatite, and accessories. In places, the rims seem to have detached, resulting in the formation of coarse-grained biotite clusters/clots in the surrounding granodiorite. Hence, did other biotite clusters form in a similar way?

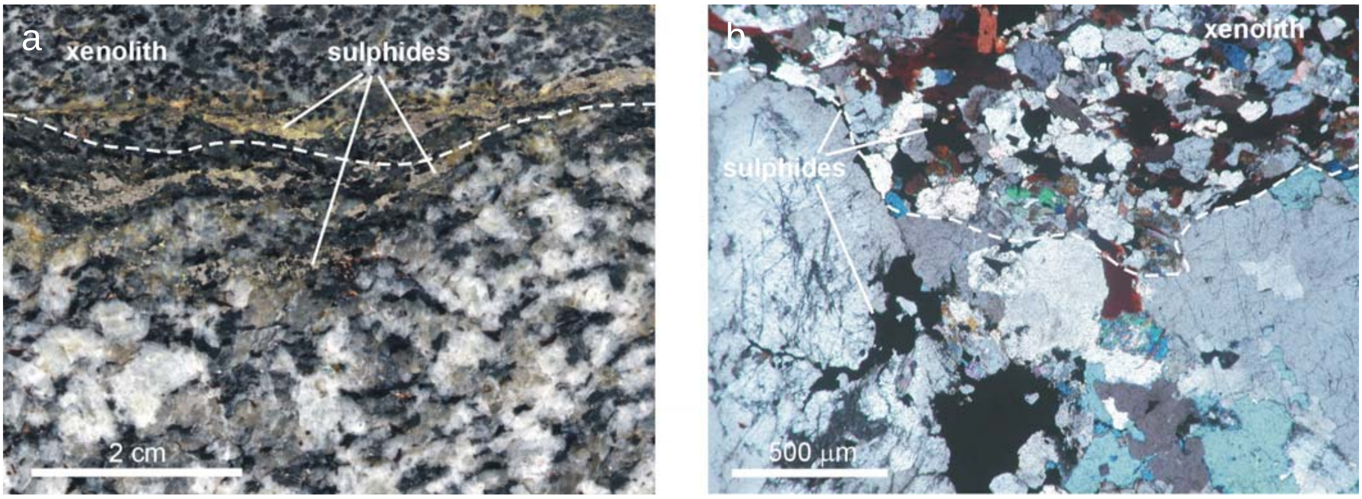


Figure 1.4.8: Contamination of granodiorite by sulphides from a Meguma Group xenolith. (a) Hand specimen photograph. (b) Photomicrograph (partly oblique polarizers) of a sulphide-rich xenolith in contact with granodiorite. The sulphides within the granodiorite occur as fine-grained and coarse-grained inclusions in, and along grain boundaries and microcracks of magmatic minerals (note the sulphide-filled crack in the large plagioclase crystal). Their occurrence in thin films along grain boundaries and microcracks show that at least some of the sulphides entered the granodiorite magma as an immiscible sulphide melt.

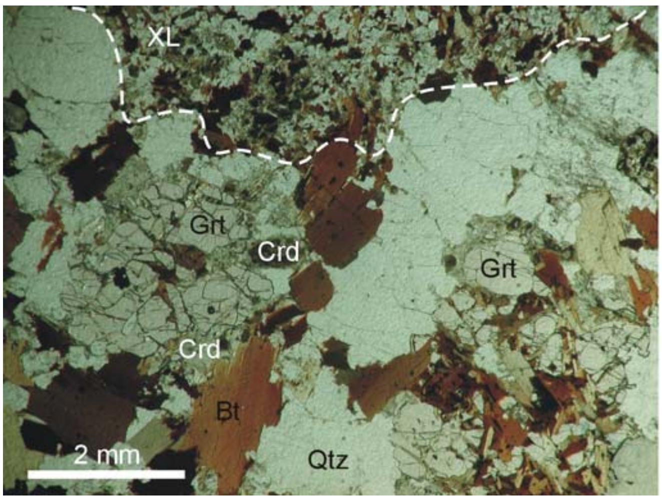


Figure 1.4.9: Photomicrograph (plane polarized light) showing a reaction rim of coarse-grained garnet, cordierite, quartz, and biotite around a xenolith (XL).

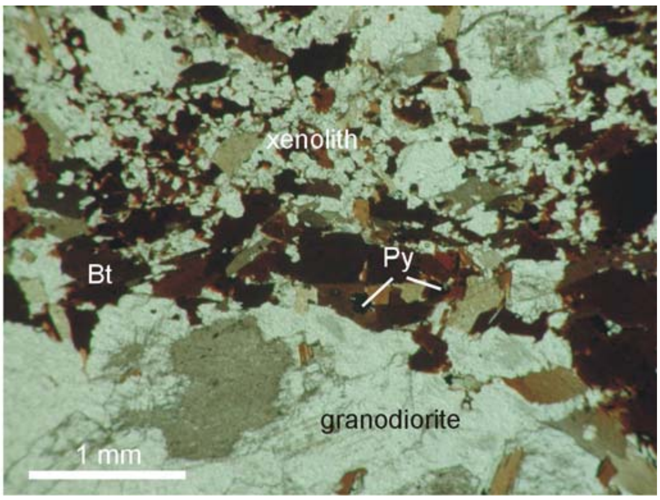


Figure 1.4.10: Photomicrograph (plane polarized light) showing coarse-grained biotite with inclusions of pyrite at the interface between a xenolith and granodiorite.

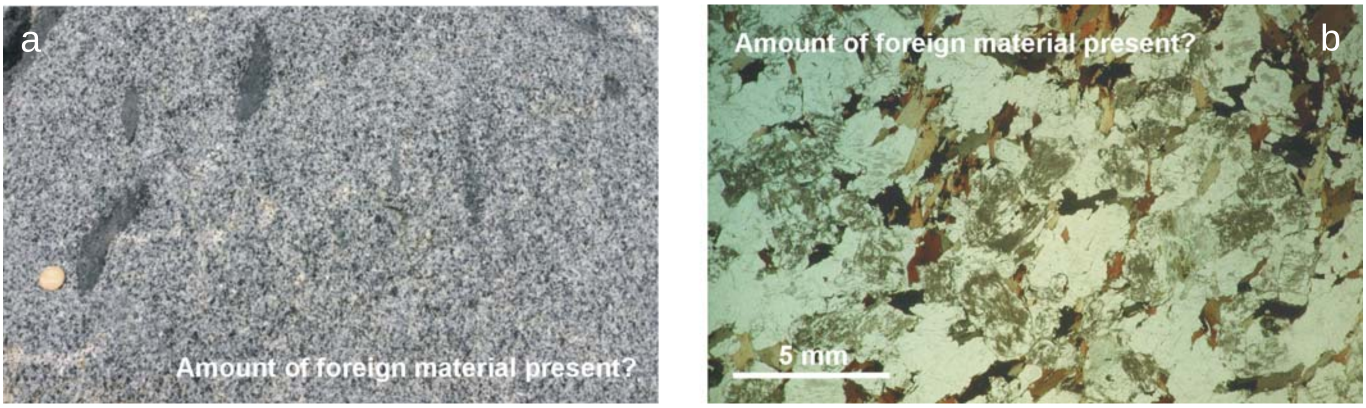


Figure 1.4.11: Heterogeneous, clotty granodiorite comprising rounded to irregularly shaped xenoliths. It is straightforward to determine the percentage of xenolithic contaminants (a), but an estimate of the grain-scale contaminants in the granodiorite is much more challenging (b).

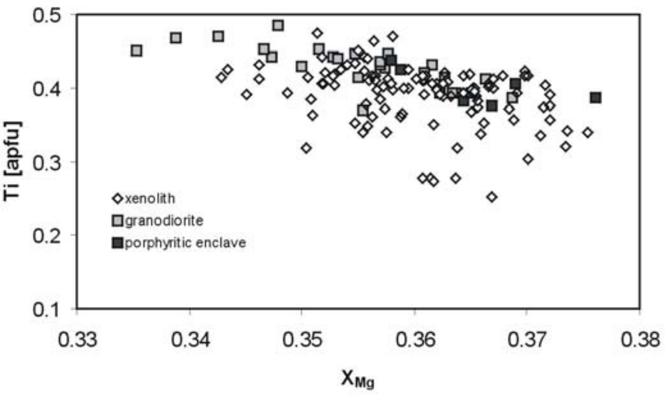


Figure 1.4.12: Biotite compositions determined by electron microprobe analysis (EMPA). Biotite from xenoliths, the granodiorite, and a porphyritic enclave show considerable overlap in X_{Mg} and Ti (apfu), and also in other elements. Discrimination of biotite grains of various origins in the granodiorite based on major element composition is thus not possible.

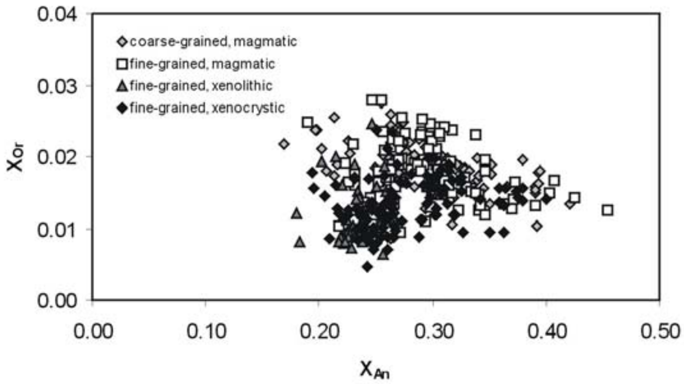


Figure 1.4.13: Plagioclase compositions determined by EMPA. Plagioclase is grouped based on textural criteria (size, shape, inclusion relations, and zoning). Although compositions overlap, xenolithic plagioclase is relatively low in X_{An} and X_{Or}, and magmatic plagioclase high in X_{An} and X_{Or}. Potential xenocrysts show compositions similar to those of xenolithic and magmatic crystals.

Stop 1.4 - Key Observations and Discussion

The irregular contact between the rocks of the Meguma Group and the granodiorites, as well as the abundant xenoliths, are evidence that stoping of wall rocks occurred, at least during the final stage of emplacement. Country-rock xenoliths and *in situ* country rocks in direct contact with the granodiorites (within a < 30 cm wide zone away from the contact) show various stages of disintegration/reaction. Disintegration products are xenocrysts, peritectic reaction products, and partial melt (silicate melt ± a sulphide melt). Xenocrysts possibly comprise quartz, biotite, minor plagioclase and K-feldspar, and accessories such as zircon, monazite, and xenotime. Peritectic reaction products of the country rocks are garnet and cordierite, and possibly apatite. The origin of the abundant biotite clots is not yet clear; they may represent xenocrystic biotite with magmatic overgrowths, peritectic magmatic biotite, as well as cotectic magmatic biotite that nucleated on foreign solids. Criteria to unequivocally determine the origin of each biotite grain in question may not exist, but a combined characterization of various minerals (e.g., quartz, plagioclase, biotite, and apatite) may constrain the amount of foreign versus magmatic biotite at least semi-quantitatively. Criteria most amenable to distinguish between foreign and magmatic versions of quartz, plagioclase, and K-feldspar appear to be grain size, grain shape, and zoning patterns.

Stop 1.5 -- Contaminated Granodiorite

Roadside outcrop, south side of Hwy 101; 20T E0433396, N4969268

Abstract - Remote from the contact with the metasedimentary rocks, xenoliths become less abundant in the granodiorite, but foreign material on the grain-scale may still be present in significant amounts.

Figure 1.5.1: Inhomogeneous granodiorite with xenoliths, garnet-rich and biotite-rich schlieren, as well as abundant biotite clots and sulphides.

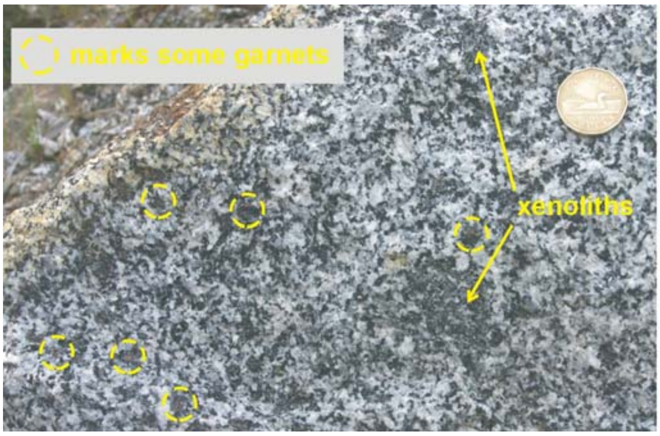


Figure 1.5.2: Garnet-rich schlieren, characterized by abundant coarse-grained, biotite-rimmed garnet, abundant biotite, cordierite, quartz, sulphides, and apatite (as in Fig. 1.4.6). Xenoliths within the schlieren have a relatively refractory composition, and probably represent remnants of an otherwise disintegrated xenolith.

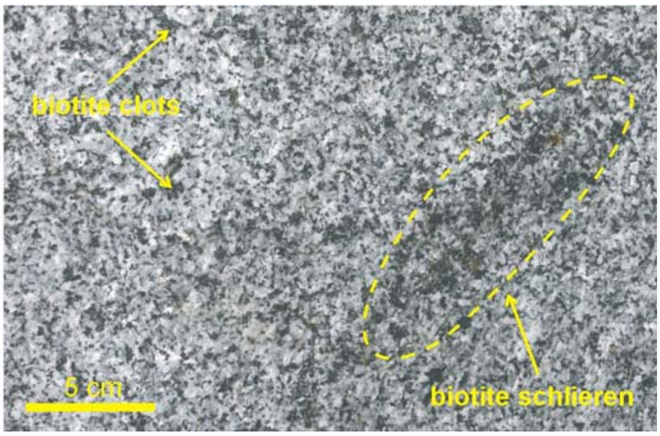


Figure 1.5.3: Granodiorite with biotite-rich schlieren and abundant biotite clots. Do the xenoliths, biotite-rich schlieren, and garnet-rich schlieren represent a late increment of magma contamination by country-rock material, and biotite clots an earlier contamination event? How can we test this hypothesis?

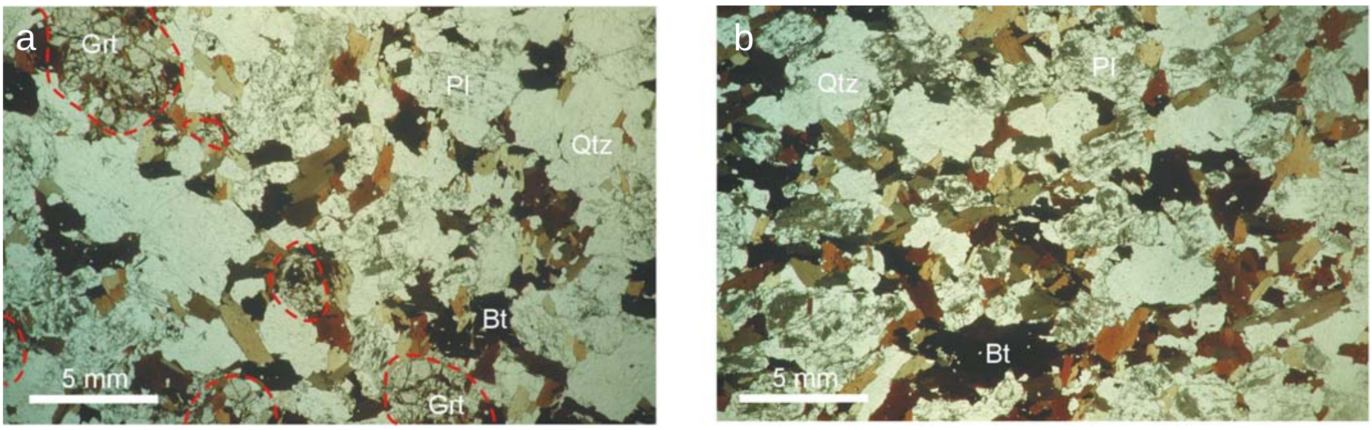


Fig. 1.5.4: (a) Garnet-rich schlieren appear to be the disintegration products of xenoliths. The question is, how much of the garnet is preserved throughout the evolution of the batholith, and how much is consumed in subsequent reactions? (b) Biotite schlieren may have a similar origin to garnet schlieren, but the unequivocal designation of an origin is much more challenging.

Stop 1.5 - Key Observations and Discussion

Although evidence for contamination at this outcrop is present in the form of xenoliths, and in the form of contaminants on the grain-scale, it is difficult to estimate the overall amount of contamination by country-rock material. For how much of the contamination do the observed contaminants account? For all the contamination during ascent and emplacement, or only for the last increment of contamination at the emplacement level? What are the “survival” times, and “survival” chances of country-rock material enclosed in a magma? In the case of the South Mountain Batholith: what are the chances that quartz, plagioclase, K-feldspar, biotite, muscovite, chlorite, and several accessories – the mineral assemblage of the metasedimentary country rocks – survive the incorporation into the magma in a texturally and/or chemically recognizable form (Table 1, Fig. C, D)? Will the minerals partly dissolve, will they develop epitactic overgrowths, and therefore lose their textural characteristics, or will they preserve their original textural and chemical identity? Reactivity and reaction rates depend on a combination of: (i) the temperature of contaminants and main magma, and the thermal contrast between both; (ii) the mineralogy and composition of contaminants and main magma, as well as the compositional contrast; (iii) fluid presence or absence, and fluid composition; (iv) size, surface properties, and grain size of the contaminants; and (v) time. Although qualitatively known, the parameters are quantitatively poorly understood. For example: how long does it take to dissolve or partially melt a xenocrystic plagioclase that is not in equilibrium with the magma - hours, days, years, thousands of years? In experiments, plagioclase in disequilibrium with a melt reacts rapidly, where the crystal marginally dissolves or melts, and recrystallizes in the equilibrium composition (e.g., Johannes 1989). Xenocrystic plagioclase showing spongy, skeletal rims has been found in many volcanic rocks (e.g., Kaczor *et al.* 1988; Green 1994); however, to our knowledge, xenocrystic plagioclase with spongy, skeletal rims has never been reported from granites. The question is: Does xenocrystic plagioclase derived from the country-rocks completely lose its original identity in such a reaction (Table 1), if magma residence times are long-lasting, or will a grain only react and crystallize with a different composition on its margin, and thus effectively insulate the core of the grain from any further reaction?

Stop 1.6 -- Exploding Xenolith, Portuguese Cove

Hwy 349, coastal outcrop, private land; 20T E0457622, N4930098

Abstract - A large xenolith caught in the act of disintegrating, possibly by thermal stress fracturing, showing that extensive stoping can take place without producing elephants' graveyards.

Figure 1.6.1 Stoping Analogue. Disintegration of the Lowell Glacier in Kluane National Park, Yukon Territory, into Lowell Lake is a good analogue for the stoping of country rocks into a granite magma chamber. In both cases, large solid blocks separate, translate, rotate, and react in the liquid medium. (Philip Giles photo)

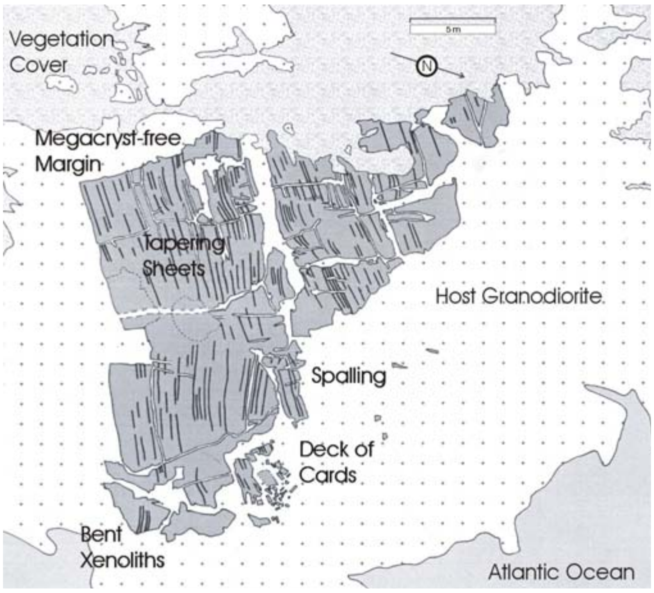


Figure 1.6.2: Sketch map of the xenolith at Portuguese Cove.

Figure 1.6.3: House-sized xenolith (with a house for scale!), completely surrounded by granite in two-dimensions. The attitude of the bedding in the xenolith is approximately the same as the regional attitude of the Meguma Group country rocks. If so, either the xenolith has not rotated about a vertical axis, or the "xenolith" is really a small roof pendant. If this block is a "free-swimming"/sinking xenolith, why did it stop descending here? If it is a roof pendant, the story about fragmentation and contamination does not change.

Figure 1.6.4: Granite-xenolith contact parallel to bedding in xenolith. Little or no penetration of the xenolith by the granite magma.

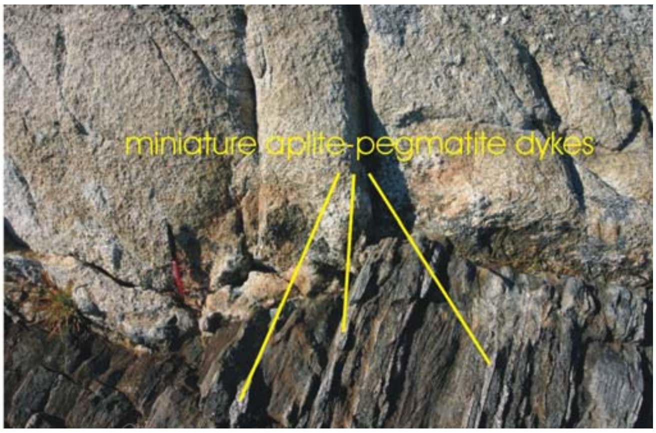


Figure 1.6.5: Granite-xenolith contact perpendicular to bedding in xenolith. Note miniature aplite-pegmatite dykes originating in granite and tapering in width with distance into the xenolith. Note also the mysterious absence of K-feldspar megacrysts adjacent to the xenolith.

Figure 1.6.6: Disintegration of psammitic bands into fragments down to the millimetre scale.

Figure 1.6.7: Fragmentation of more pelitic bands to produce a "deck of cards".

Figure 1.6.8: Remarkable survival of high surface area/volume ratio xenolith. Why did this xenolith not melt or bend or both?

Figure 1.6.9: Moderately advanced assimilation of what appears to have been a pelitic xenolith.

Figure 1.6.10: Apparent local ductile deformation of xenolith at its margin. Were these rocks bent prior to, or during, fragmentation?

Figure 1.6.11: More bent fragments.

Figure 1.6.12: Apparent removal of spalled material from the main xenolith by flow in the granite magma. If this process of fragmentation-spallation-dispersion of xenolithic material is generally what happens to xenolithic blocks, there need be no “elephants’ graveyards” at the bottoms of batholiths as evidence of stoping.

Stop 1.6 - Key Observations and Discussion

The Portuguese Cove xenolith was clearly in the process of active disintegration at the time the granite magma reached its mechanical solidus. Whether the fragmentation was thermal stress fracturing, release of stored elastic strain energy, or explosive release of volatiles, the chaotic dispersal patterns of xenolithic shrapnel suggest explosive disintegration (Clarke *et al.* 1998). The large aspect ratio of the aplite-pegmatite microdykes in the xenolith suggests that the granite magma was inexorably drawn into the xenolith by the high vacuum created by the fracturing process, rather than by the granite magma's forcing the xenolith apart by magmatostatic(?) pressure. The fractures were probably led by water vapour at the crack tip, and they likely propagated at the speed of sound. If this block is a stoped "elephant", then its rapid disintegration suggests that there may be no "elephants' graveyard" at the bottom of this batholith. Instead, the entire batholith will be strewn with elephants' body parts, undergoing further disintegration theoretically down to the single grain level (recall the individual andalusite crystal at Stop 1.3 and the individual garnet crystals at Stop 1.5). As a result, the batholith can become highly contaminated without the enormous thermal energy cost of the latent heat of fusion. The thermal energy used to heat the xenoliths and xenocrysts to ambient magma temperature is heat that the batholith was going to lose to the surroundings anyway, and it merely promoted more rapid crystallization. Such xenocrysts are subject to possible melting, dissolution, and ion exchange to complete the assimilation.

Stop 1.7 -- Peggys Cove Biotite Monzogranite

Peggys Cove Lighthouse, coastal outcrop; 20T E427123, N4926812

Abstract - This monzogranite is < 1 km away from the contact with country rocks of the Meguma Group at the currently exposed level of erosion. It contains ~ 3-4 % enclaves and xenoliths (~ 1 % of country-rock material) of typically < 20 cm, and most commonly between 0.5 and 5 cm in size.

Figure 1.7.1: Peggys Cove biotite monzogranite (photo J. H. Kruhl).

Figure 1.7.2: Biotite monzogranite containing abundant enclaves.

Figure 1.7.3: Xenolith derived from the Meguma Group. Macroscopically, there is no evidence for material exchange between the xenolith and the main magma. Given that partial melt was apparently not present, only slow solid (xenolith) - liquid (main magma) ion exchange could have taken place.

Figure 1.7.4: Enclave, possibly representing a partially melted xenolith. Whatever the origin of the enclave is, if it contained a melt phase, diffusive exchange of alkalies and other elements between enclave and main magma probably occurred. How much did that exchange affect the major, trace, and isotopic signature of the granite magma?

Figure 1.7.5: Weakly layered xenolith? The texture is similar to the texture of many equigranular enclaves.

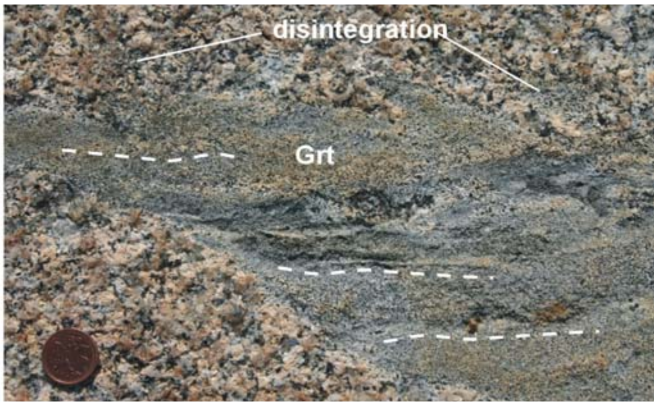


Figure 1.7.6: Marginally disintegrating, weakly layered, garnet-bearing xenolith.

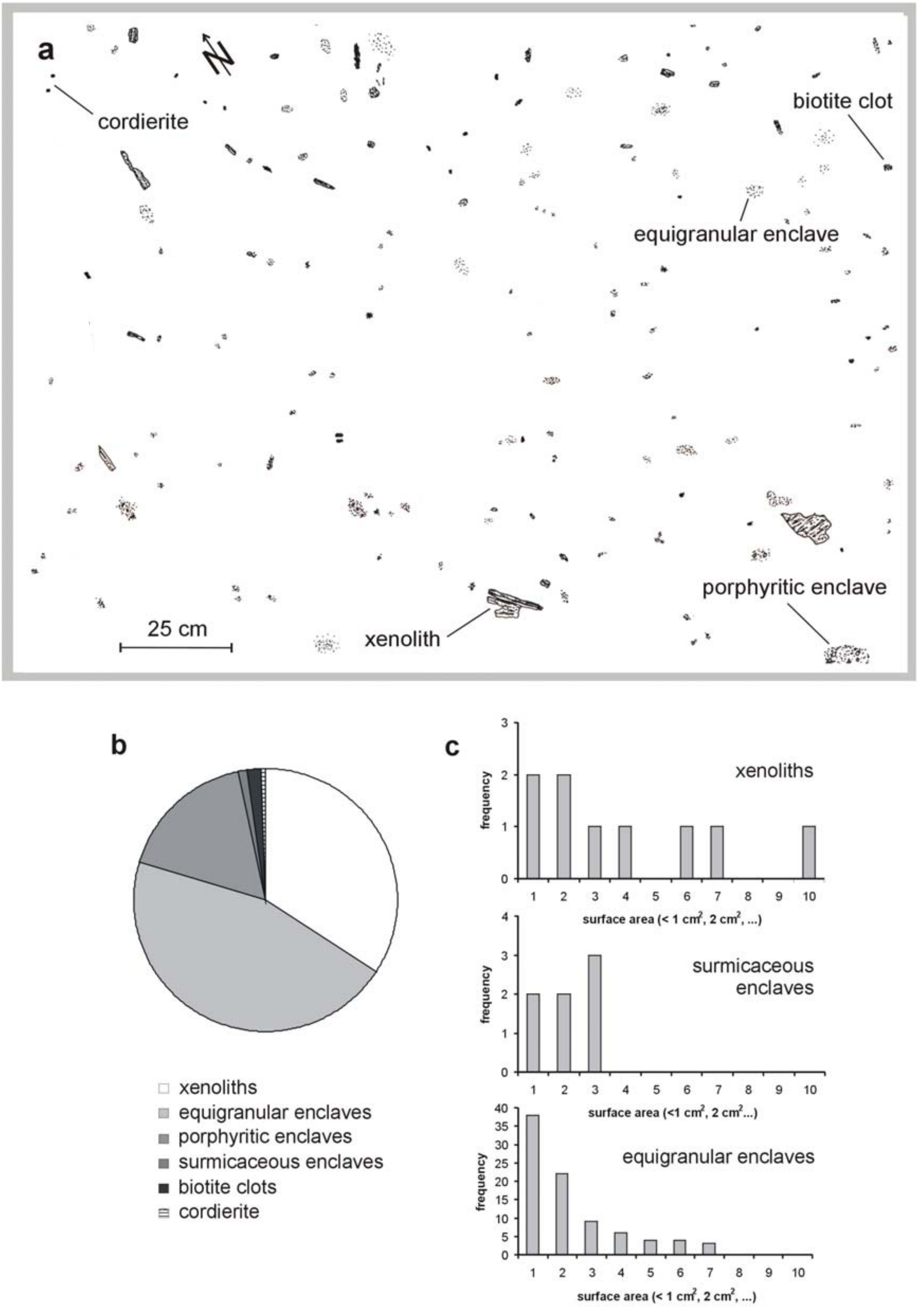


Figure 1.7.7: (a) Grid map of ~ 3 m^2 of outcrop at Peggys Cove showing 'foreign' material such as country-rock xenoliths, equigranular enclaves, porphyritic enclaves, surmicaceous enclaves, and cordierite (the latter may be a disintegration product of the xenoliths). The macroscopically visible contaminants are more or less homogeneously distributed; they comprise about 3 to 4 % in the mapped area at Peggys Cove. Outcrops further inland, away from the contact with the Meguma Group, show significantly less foreign material on the macro-scale, typically ≤ 1 %. The question is: does the abundance of macro-scale contaminants reflect the amount of foreign material present reasonably well? (b) Relative abundance of various enclaves, biotite clots, and cordierite in the area mapped. Enclaves grouped as "equigranular", "porphyritic", and "surmicaceous", respectively, may be variable in modal mineralogy, and may comprise enclaves characterized by sharp, as well as diffuse, margins. Relative abundances of the foreign materials vary over a larger area at Peggys Cove, but not drastically, although porphyritic enclaves are locally much more abundant, and tend to cluster. (c) 2-D sizes and their relative frequency for xenoliths, surmicaceous enclaves, and equigranular enclaves.

Stop 1.7 - Key Observations and Discussion

The monzogranite at Peggys Cove is less than a kilometre away from the contact with the country-rocks of the Meguma Group at the currently exposed level of erosion. The amount of material in the monzogranite of unquestionably Meguma Group origin (xenoliths) is low, approximately 1 vol%. The amount of material that may represent enclosed Meguma Group rocks (equigranular enclaves) is higher, ~ 3 vol%. Hence, are we now looking at a more advanced stage of disintegration (elephant body parts) of the country-rock material than at Stop 1.6 (the elephant)? Critical is whether the foreign material visible on the macro-scale represents most of the foreign material present, or if it represents only relatively refractory remnants. If the contamination visible on the macro-scale accounts for most of the contaminants present, the contamination of the South Mountain Batholith is insignificant; if, however, the macroscopically visible contaminants reflect only the last increment of contamination, contamination by country-rock material may be more important than commonly assumed. In any case, material must have been exchanged by liquid-liquid diffusion between enclaves and main magma, selectively affecting the geochemical signature of the monzogranite, but this effect is negligible, if only ~ 3 vol% foreign material is present.

Stop 1.8 -- Cordierite-rich Monzogranite

Hwy 103, north side, 900 m west of Exit 5 overpass; 20T E431062, N4950207

Abstract - A cordierite-rich monzogranite, about which we ask the question: are the abundant large euhedral cordierites in this rock magmatic, peritectic, or xenocrystic in origin?

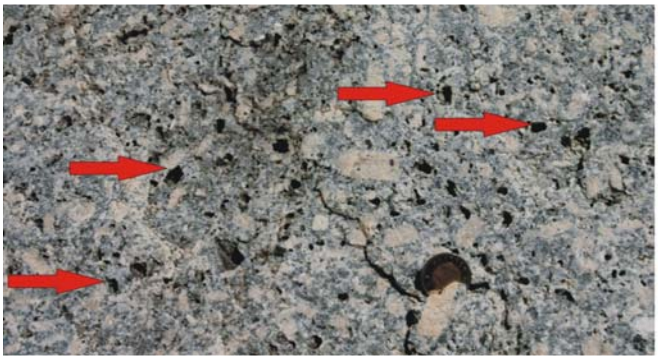


Figure 1.8.1: Weathered surface of the outcrop showing a large number of euhedral holes.

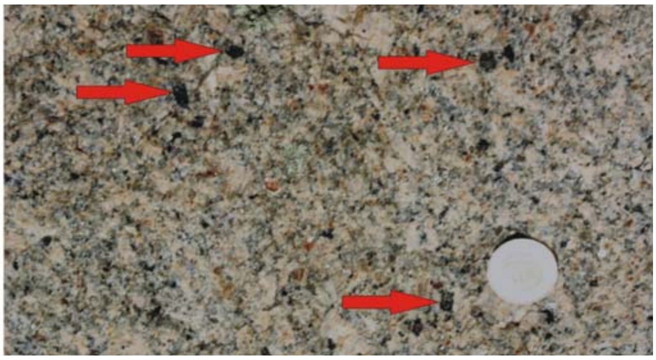


Figure 1.8.2: Freshly broken surface of the outcrop showing blocky dark cordierites corresponding in size and shape to the euhedral holes.

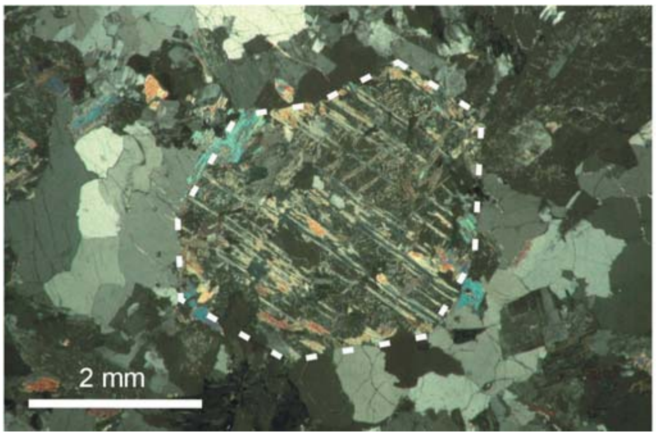


Figure 1.8.3: Thin section (crossed polarizers) revealing that the dark euhedral cordierites are completely pinitized.

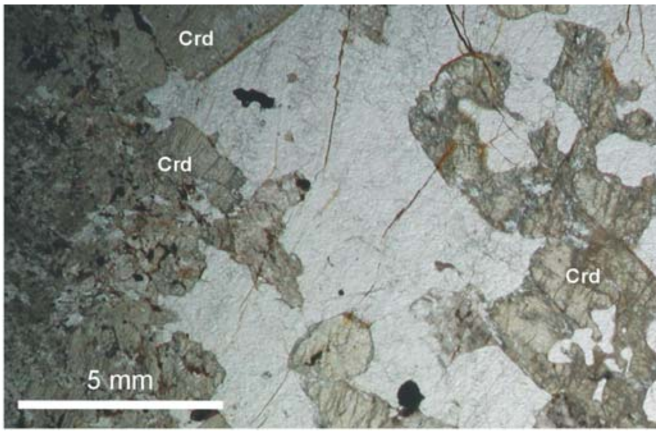


Figure 1.8.4: Thin section (plane polarized light) showing large euhedral cordierites growing at the contact between a xenolith (left) and granite (right). Such cordierites appear to be the products of incongruent melting of biotite or chlorite in the xenolith, but they masquerade as euhedral magmatic grains when released into the granite magma.

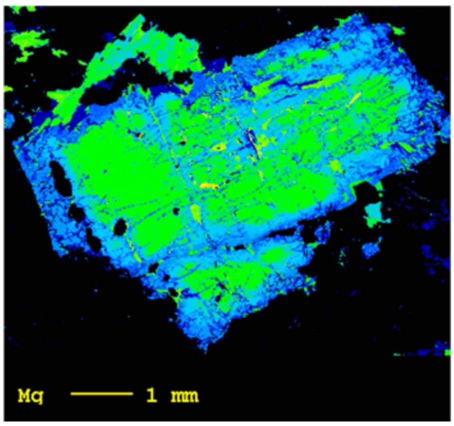


Figure 1.8.5: Magnesium X-ray map of a cordierite in granite from sample 304 iiii. The grain shows weak normal zoning from an Mg-rich core to an Mg-poorer rim (some of which is alteration).

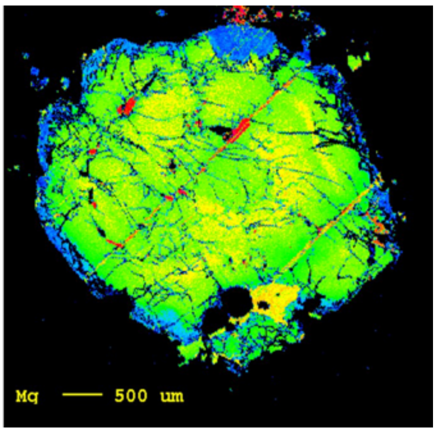


Figure 1.8.6: Magnesium X-ray map of a cordierite in granite from sample D15-304i. The grain shows well-developed oscillatory zoning that must be explained in any model for the origin of cordierite in granite.

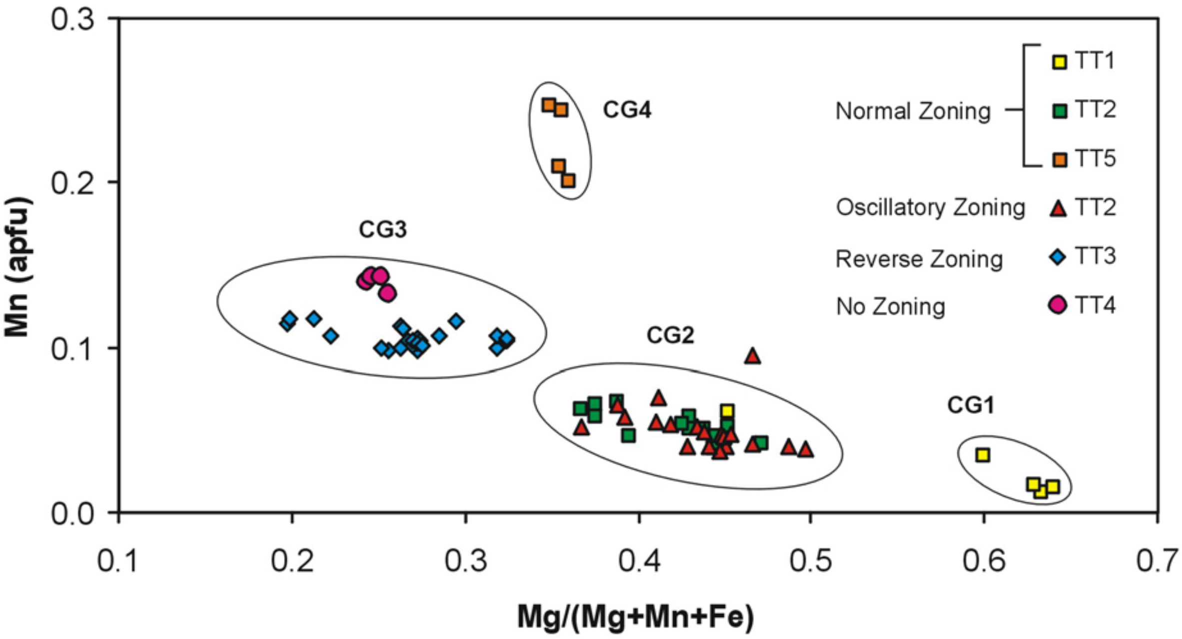


Figure 1.8.7: Chemical compositions of cordierites in the SMB and neighbouring Musquodoboit Batholith (Erdmann *et al.* in press). So far, we are able to recognize four chemical groups: CG1 - high X_{Mg} and low Mn with normal zoning; CG2 - intermediate X_{Mg} and Mn with normal and oscillatory zoning; CG3 - low X_{Mg} and high Mn with reverse zoning or no zoning; and CG4 - intermediate X_{Mg} and very high Mn with normal zoning. We tentatively suggest that (i) type CG1/TT1 and CG2a/TT2 cordierite grew in a peritectic reaction between country rocks and melt; and (ii) type CG2b/TT2, CG3a/TT3, CG3b/TT4, and CG4/TT5 cordierite crystallized in a cotectic reaction from the main magma.

Stop 1.8 - Key Observations and Discussion

Some peraluminous granites contain cordierite, even to the point where cordierite is the principal mineral of the rock (good references on such “cordierities” including those by Ugidos and Recio 1993, and Rapela *et al.* 2002). Where does all the cordierite come from? Either it is a primary magmatic phase (in which case the granite magma must have had high Al_2O_3 and (Mg,Fe)O contents, or these cordierites are xenocrysts from the country rock (but the cordierites of the Meguma Group are ellipsoidal and full of inclusions), or the cordierites form as the result of a peritectic melting reaction when the xenoliths enter the granite magma (in which case the cordierites are, paradoxically, new minerals made of old country rock material - they are country-rock contaminants in magmatic disguise). The cordierites at this outcrop are nearly completely pinitized (converted to muscovite and chlorite), but some other cordierites in the SMB and Musquodoboit Batholith show normal and oscillatory zoning that suggest, along with the euhedral shape, that they grew uninhibitedly in a melt, perhaps along the margins of pelitic xenoliths. That they appear to occur in bands parallel to the contact of the SMB with the country rock (MacDonald 2001) suggests that they may be mega-schlieren (c.f. Stop 1.5).

Obituary for Stop 1.8 (RIP)

The rocks of Stop 1.8 have occupied the same spatial co-ordinates in the Earth from 379,997,995 BCE until this year when the evil agents of Dexter Construction Ltd. are scheduled to blow the most magnificent outcrop on Highway 103 to smithereens. (Road-building may only be considered as progressive when it creates outcrops, not when it destroys them.) Whether we will find Stop 1.8 near death, smithereened to death, or utterly dead and buried on May 14, 2005 is highly uncertain. If the latter, your field trip leaders will attempt to provide sacred relics.

Day 1 – Summary and Implications

Metapsammites, metapelites, and minor calc-silicates of the Meguma Group are the major contaminants in the South Mountain Batholith. Disintegration and assimilation of the metasediments in the granites through fracturing, partial melting, and subsequent peritectic reactions and dissolution, is evident in the form of progressive reaction series from *in situ* country rocks to partially molten xenoliths with Bt±Grt±Crd reaction rims, Bt±Grt schlieren, and dispersed minerals of foreign origin (e.g., cordierite, and possibly clotty biotite). If contaminants in the form of xenoliths or schlieren represent most of the foreign material present, the degree of contamination by country rocks in the South Mountain Batholith is low. However, mineralogical and textural variations within the granodiorites of the South Mountain Batholith suggest that at least locally the amount of grain-scale contaminants (xenocrysts, peritectic reaction products, and crystallization products of a xenolithic partial melt) is significant, accounting for up to ~ 30 vol% of the granodiorite. If such a degree of partly assimilated country-rock material is the rule rather than the exception in plutons intruding low-grade metasediments, contamination may be more important to explain geochemical trends and variations than commonly assumed.

Day 2 -- Contamination in the Port Mouton Pluton

Date/Time

Depart from Lunenburg at 8:00 am on Sunday May 15, 2005, rain or shine.

Itinerary

Time	Activity	Logistics
08:00	Leave Lunenburg	
09:15	Arrive Stop 2.1 Mersey Point	10-minute walk, easy terrain
10:15	Depart Stop 2.1 Mersey Point	
10:30	Arrive Tim Hortons	
11:00	Depart Tim Hortons	
11:15	Arrive Stop 2.2 Summerville	roadside/coastline
12:15	Depart Stop 2.2 Summerville	
12:45	Arrive Stop 2.3 Kejimkujic	*NO HAMMERS!* – 45-minute hike over easy terrain to first outcrop (enjoy the wind-swept barrens as we walk) / lengthy traverse along a cobble beach / out of the bus for ~ 3-4 hours, so take all the protection and sustenance you may need
16:15	Depart Stop 2.3 Kejimkujic	
18:00	Arrive Halifax	back in time for getting settled into your hotels, cleaning up, eating, registering, and attending the social function

Objective

The Port Mouton Pluton (PMP, pronounced locally as “Port M’toon”) has an age of ~373 Ma (Fallon 1998), and is one of several small “Peripheral” or satellite plutons occurring around the margin of the large “Central” South Mountain Batholith. The PMP is a highly differentiated granitoid complex that shows considerable variation in its mineralogy, texture, and chemical composition from early tonalite to late leucogranite (Douma 1988). Its location appears to be spatially related to a major crustal-scale shear zone (Fig. 2.0; Clarke *et al.* 2002).

The Peripheral Plutons differ in several important ways from the Central Plutons:

i) they contain a wider range of rock types (from tonalite to monzogranite)
ii) some appear to show synplutonic deformation
iii) they are less peraluminous than the central plutons
iv) some have synplutonic intrusions of mafic magma
v) they generally have lower $\delta^{18}O$, lower $^{87}Sr/^{86}Sr_i$, and higher εNd_i values.

We need a petrogenetic model to explain why the small peripheral plutons are different from the main masses of granitoid rocks in the Meguma Zone. Think contamination. The principal purpose of this part of the excursion is to walk through the broad contact zone of the PMP to observe the progressive assimilation of the Meguma country rocks. These rocks are the same lithologies as we observed on Day 1, but the regional metamorphic grade is amphibolite facies, rather than greenschist facies. The first two stops are to introduce the petrological players: Stop 2.1 is to look at a Late Devonian Mafic Intrusion, and

Stop 2.2 is to catch a glimpse of the contact migmatite on the northern contact of the PMP. Then at Stop 2.3 we will walk through the southern contact zone of the PMP.
UTM coordinates for outcrops described in this field guide use the WGS 84 datum.

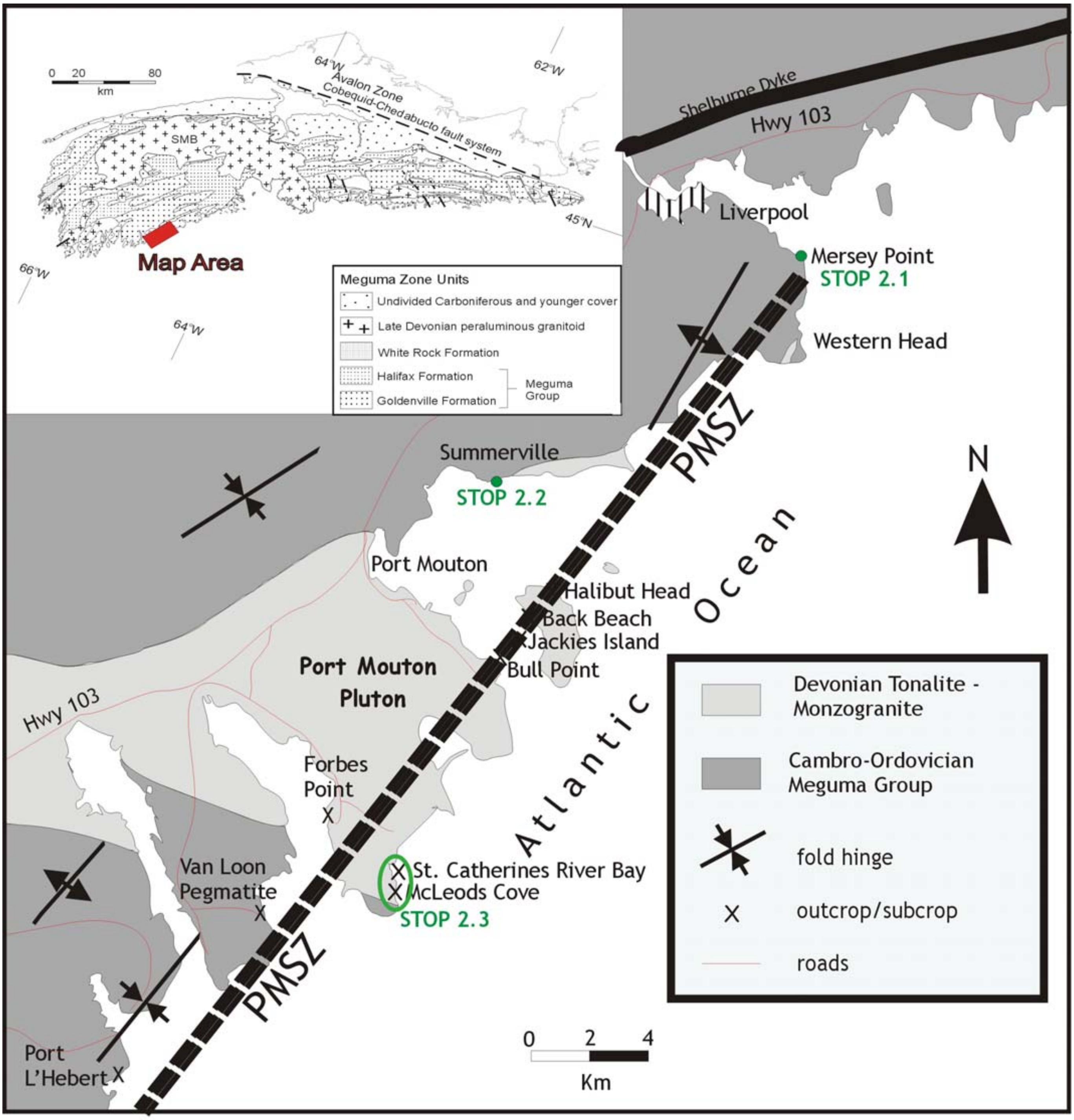


Figure 2.0: Day 2 – Stop Location Map. Locations of several disparate, but possibly related, geological features in the Port Mouton area. A narrow, strongly foliated zone in the granite defines the Port Mouton Shear Zone (PMSZ). Outcrops of LDMIs at Mersey Point (Stop 2.1) and at McLeods Cove (Stop 2.3) are approximately colinear with the PMSZ.

Brief Overview of the Igneous Features

Stop 2.1 - Mersey Point Sill: The Mersey Point sill is one of approximately twenty Late Devonian (377-368 Ma) Mafic Intrusions (LDMIs) in the Meguma Zone (Tate and Clarke 1995). The Mersey Point sill is a pristine olivine-rich norite containing abundant olivine and orthopyroxene enclosed by huge poikilitic hornblende and phlogopite. It shows subhorizontal leucocratic patches and weak layering. These LDMI bodies are virtually the same age as the granites in the Meguma Zone, so it is at least possible that they are related in some way to those much more abundant peraluminous granites, but does a temporal and spatial association necessarily imply a genetic relationship?

Stop 2.2 – Summerville Migmatite: At this locality, we are in the Goldenville Formation of the Meguma Group, and the PMP lies out in the water to the south of us. Some of the granitoid material in this outcrop has intruded from the PMP; but the rest of it was created right here as a result of melting the Goldenville Formation (Merrett 1987).

Stop 2.3 – Traverse from Port Joli Head to St. Catherines River Beach: *This locality is inside the Seaside Adjunct to Kejimkujik National Park, so leave your hammer in the vehicle.* We are going to walk along the coast from the Meguma country rock into the Port Mouton Pluton. We begin in ~100% country rock and end in ~100% granite, but the transition zone is very wide. We will see not only progressive disintegration of the country rock into hundreds of slabs into the granite, but also a large breccia pipe and a disaggregated *synplutonic* mafic dyke that in places has broken up to become irregular pillows in the granite. The dyke is technically a kersantite-spessartite lamprophyre, and probably related to the Mersey Point olivine-rich norite.

Stop 2.1 -- Mersey Point Late-Devonian Mafic Intrusion

Mersey Point Road, private land; 20T E0365686, N4876421

Abstract - The Late-Devonian Mafic Intrusions (LDMI) of the Meguma Lithotectonic Zone are small calc-alkaline gabbros and lamprophyric bodies that are coeval with, and therefore potential contaminants of, the granites.

Figure 2.1.1: Typical rather non-descript LDMI outcrop. Contact relations with the Meguma Group are uncertain, but some sub-horizontal layering suggests that the body may be sill-like.

Figure 2.1.2: Appearance of freshly broken olivine-rich norite. Note reflection of light off the large poikilitic grains of magnesio-hornblende and phlogopite.

Figure 2.1.3: Appearance of weathered norite. Poikilitic magesio-hornblende and phlogopite appear as large brown patches. Note the leucocratic patch.

Figure 2.1.4: Detail of more leucocratic patches. Are these largely sub-horizontal leucocratic patches: (i) disrupted felsic cumulates; (ii) late differentiates; (iii) granite xenoliths; or (iv) melted country rock? If either of the latter two, the norite itself is contaminated.

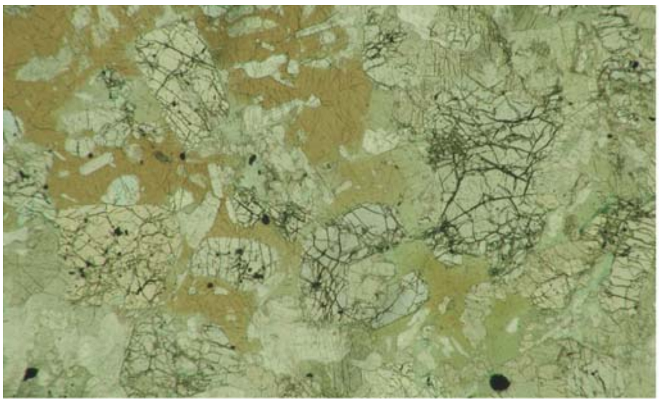


Figure 2.1.5: Mersey Point olivine-rich norite (plane polarized light). Sample contains Ol + Opx ± Cpx + Mg Hbl + Bt, and is excellent for illustrating Bowen's Discontinuous Reaction Series. It's a great undergraduate petrology test rock. Take a sample!

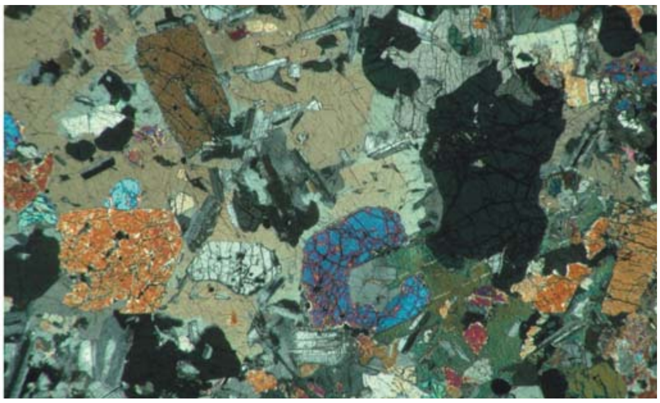


Figure 2.1.6: Mersey Point olivine-rich norite (crossed polarizers).

Figure 2.1.7: Leucocratic patch (plane polarized light) below and normal olivine-rich norite above. Patch is plagioclase-rich and fine-grained along the contact, suggesting that it may just be a late differentiate (gabbroic pegmatite) of the Mersey Point mafic magma injected along subhorizontal planes of weakness.

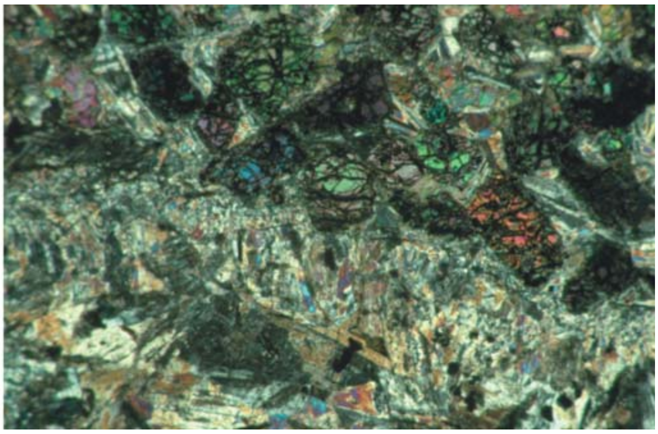


Figure 2.1.8: Leucocratic patch (crossed polarizers) below and normal olivine-rich norite above.

Stop 2.1 - Key Observations and Discussion

The Mersey Point sill, together with the nearby Western Head granite dyke (not visited), establish the northeastern end of the Port Mouton Shear Zone. The main purpose of this stop is to observe the freshest and most mafic of all the LDMIs. As is the case here at Mersey Point, most LDMIs occur as small intrusive bodies and dykes in the Meguma Group without any granite in the vicinity, but some are synplutonic with respect to the granites (Stop 2.3). Tectonomagmatic indicators suggest that these mafic rocks are related to a continental arc magmatic environment in which old oceanic crust was subducted beneath the Meguma Terrane (Tate and Clarke 1995). These mafic intrusions, with the same radiogenic isotopic ages as the granites, raise the possibility that the mantle-derived LDMI magmas could at least have provided heat for partial melting of the crust and/or could represent a possible contaminant for the granite magmas. The table below shows the compositions of the Mersey Point LDMI and the synplutonic McLeods Cove LDMI, with some significant differences highlighted (Tate and Clarke 1995).

	Mersey Point	**McLeods Cove**
SiO_2	45.71	53.13
TiO_2	0.52	1.25
Al_2O_3	9.75	12.34
FeO^T	10.62	7.26
MnO	0.18	0.12
MgO	23.99	13.27
CaO	6.96	6.05
Na_2O	0.91	1.32
K_2O	0.82	4.39
P_2O_5	0.13	0.86
LOI	1.10	1.29

Stop 2.2 -- Summerville, Injection and Anatectic Migmatites

Hwy 3, coastline east of Summerville Beach; 20T E0355604, N4867833

Abstract - The northern contact of the Port Mouton Pluton showing a complex injection and anatectic migmatite. Reaction between the PMP magma and the country rock is extensive.

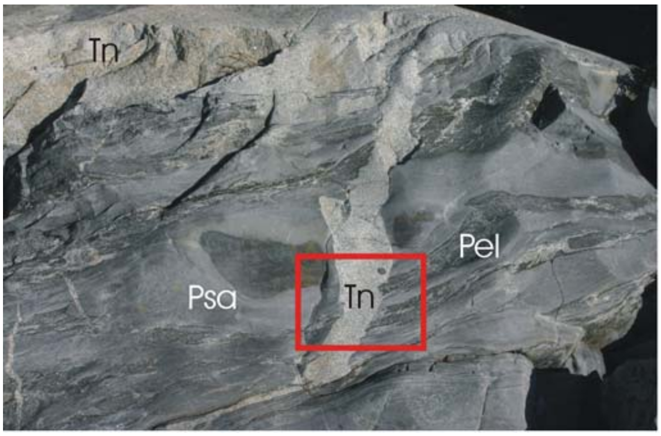


Figure 2.2.1: Contact migmatite (Pel = pelite, Psa = psammite, Tn = tonalite). The tonalite dyke injected from the Port Mouton Pluton is clearly discordant. The pelite bands show leucosomes and melansomes as evidence of anatexis.

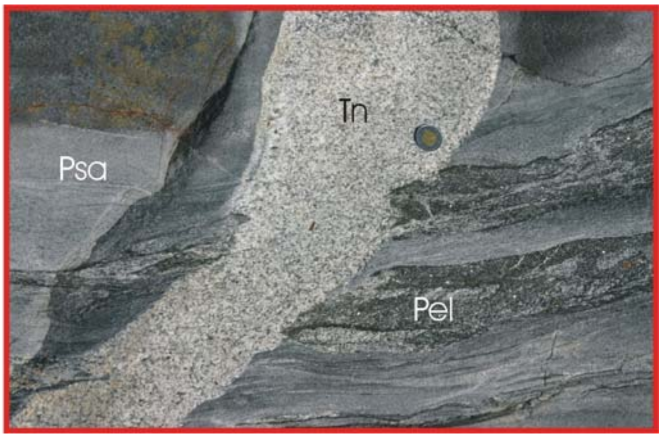
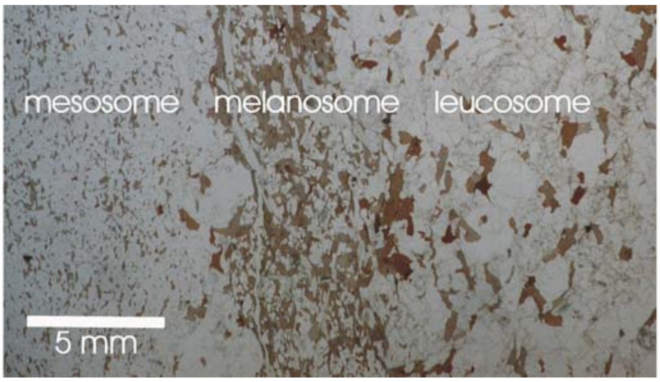


Figure 2.2.2: Contact migmatite (detail). Small-scale mixing and hybridization of the injected tonalite and anatectic granite must have taken place.

Figure 2.2.3: Predominantly pelitic band, enclosed in intruding tonalite, showing extensive development of melanosomes. Complementary partial melt (leucosomes) may have hybridized with the tonalite. This xenolith is a microcosm for Stop 2.3.

Figure 2.2.4: Further disintegration of the country rock material. Pelitic horizons are reduced to biotite-rich schlieren. Disaggregated biotite from these schlieren might be indistinguishable from magmatic biotite.



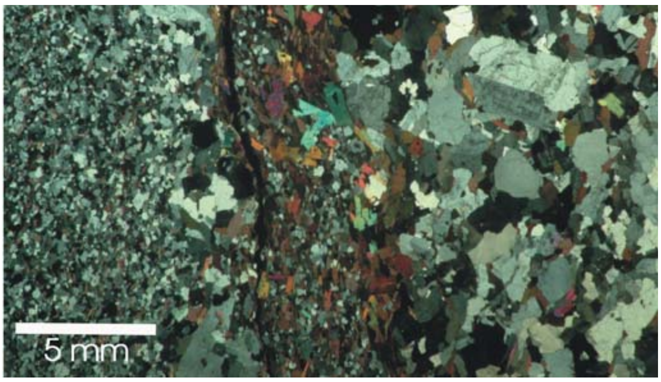


Figure 2.2.5: Thin sections across the Summerville mesosome-melanosome-leucosome (plane polarized light on left and crossed polarizers on right). The principal differences between the “somes” are mineral proportions and grain size, but not mineral assemblage. What is the origin of the biotites in the leucosome? Is there more than one type of biotite and more than one type of origin?

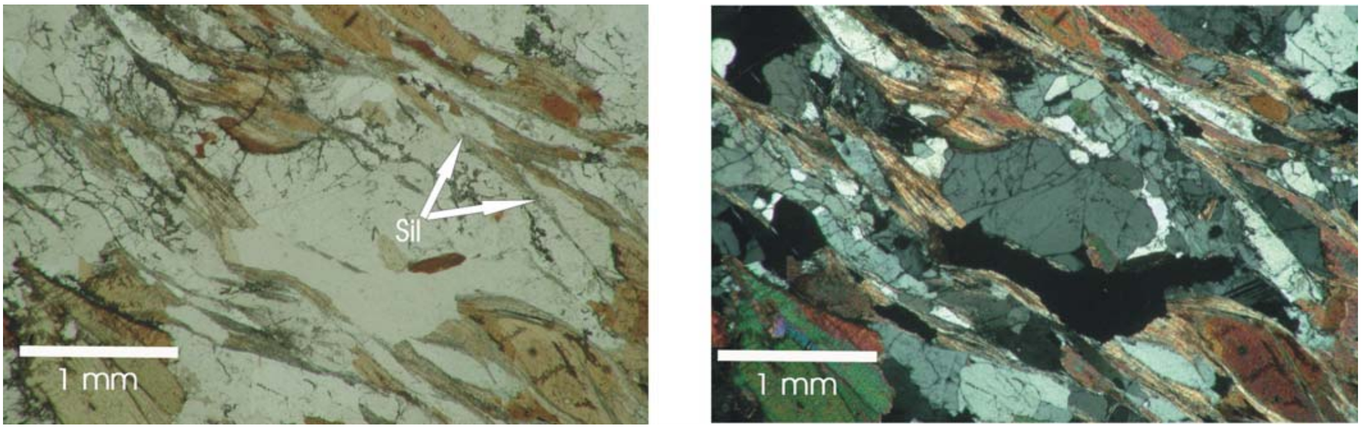


Figure 2.2.6: Thin section (plane polarized light on left and crossed polarizers on right) of a sheared leucosome from this contact migmatite zone showing extensive development of sillimanite on the biotite grains during partial melting.

Stop 2.2 - Key Observations and Discussion

This outcrop is a prelude for Stop 2.3. It demonstrates an intimate zone of contact between the Port Mouton tonalite and the Meguma Group. The psammitic and calc-silicate rocks are highly refractory and do not show much evidence of reaction with the intruding tonalitic melt. The pelites are less refractory and show considerable evidence of anatexis (leucosome-melanosome relationship). In some places, the disproportionate amount of melanosome suggests that the leucosome has already been assimilated into the PMP marginal tonalite. If so, the intruding tonalite is contaminated with both the solid (visible) and molten (now completely assimilated and, therefore, invisible) material from the country rocks.

Stop 2.3 -- Kejimkujic Seaside Adjunct, Contamination Zone

Port Joli Head to St. Catherines River Beach, coastline traverse;
from 20T N0352532, E4853126 to 20T E0352357, N4854491

Abstract - An oblique traverse across a wide contact zone in the Port Mouton Pluton shows strong evidence of interaction with, and contamination by, LDMIs and Meguma Group country rocks.

Figure 2.3.1: Location of the traverse, beginning at the contact in the south and working into the interior of the Port Mouton Pluton in the north. This traverse takes us progressively from ~100% country rock to ~100% "granite".

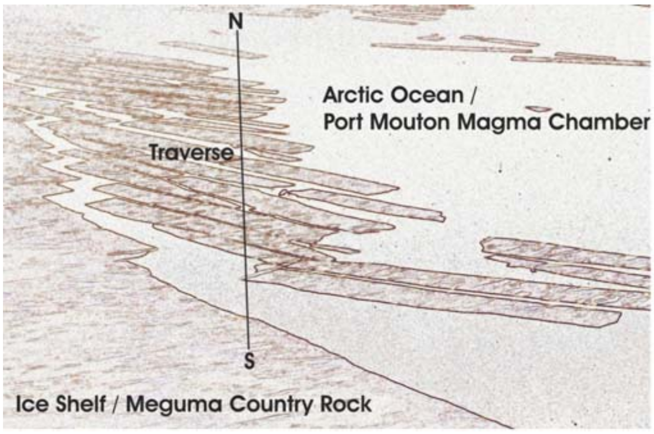


Figure 2.3.2: Disintegrating ice-shelf analogue for the fragmentation of the Meguma Group country rocks into the Port Mouton Pluton (the large slabs are ca. 1 km long). Our current south-to north traverse is comparable to the line S-N.

Figure 2.3.3: Southern contact of the Port Mouton Pluton. Bedding-parallel sheets of granite intrude the Meguma Group country rock. Pre-intrusion horizon dismembered by steep lineation (arrow).

Figure 2.3.4: Mafic pillows at McLeods Cove and nearby Forbes Point help to pin SW end of Port Mouton shear zone. These mafic rocks are higher in K_2O and H_2O than the Mersey Point olivine norite. At the very least, the mafic magma appears to have become contaminated by components from the granite magma.

Figure 2.3.5: Mafic pillows (detail). Note the fractal shapes resulting in high surface area to volume ratio, conducive to chemical exchange across the interface. Compare the bulk chemical composition of this synplutonic LDMI with the Mersey Point LDMI (p. 35).

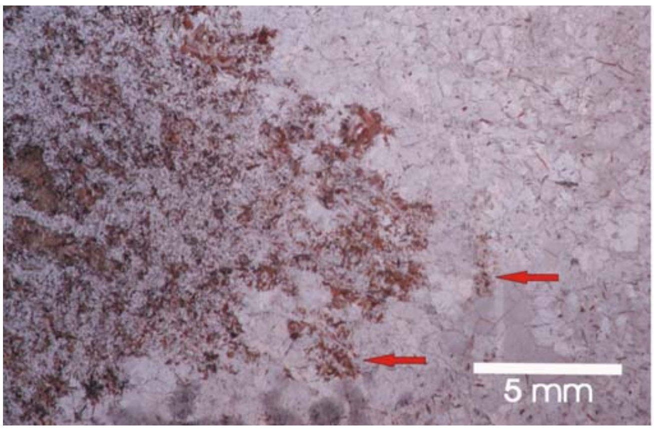


Figure 2.3.6: Fractally shaped contact between mafic pillow (left) and granite (right) in plane polarized light. The granite contains acicular apatite, reverse zoning in plagioclase, and dislodged fragments of the LDMI (arrows).

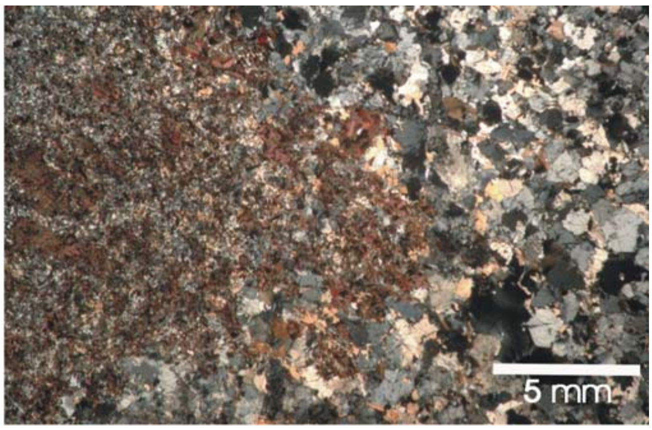


Figure 2.3.7: Same subject in crossed polarizers.

Figure 2.3.8: Breccia pipe showing a variety of sizes and shapes of country rock fragmaents in a matrix of "granite". Contact with surrounding granite is irregular, so the host may have been a crystal-melt mush. System was probably fluidized at the time of emplacement. Many xenoliths contain garnet, not present in the aureole rocks. Recall the appearance of garnet associated with xenoliths at Stops 1.4 and 1.5.

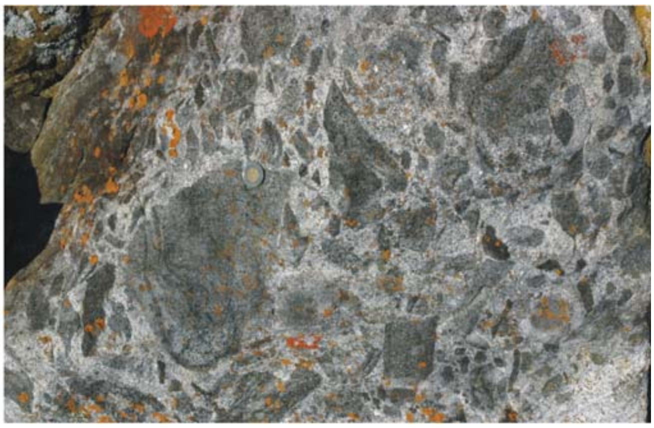


Figure 2.3.9: Breccia pipe showing fragmentation and weak foliation of country rock fragments. Apparently mechanical disintegration of the country rock was a process in this pipe. Orange material is lichen.

Figure 2.3.10: Granitic pipe structures, typical of those developed through mafic 'flows' on the floors of felsic magma chambers, so well described from many plutons in coastal Maine (Wiebe 1993; Wiebe and Collins 1998). Bob Wiebe himself for scale. Scott Johnson photo.

Figure 2.3.11: Note the approximately circular shapes and regular spacing of the granitic pipe structures in cross section. Scott Johnson photo.

Figure 2.3.12: Example from the wide zone of alternating slabs of country rock and sheets of granite (Gr = granite; Pel = pelite; Psa = psammite).

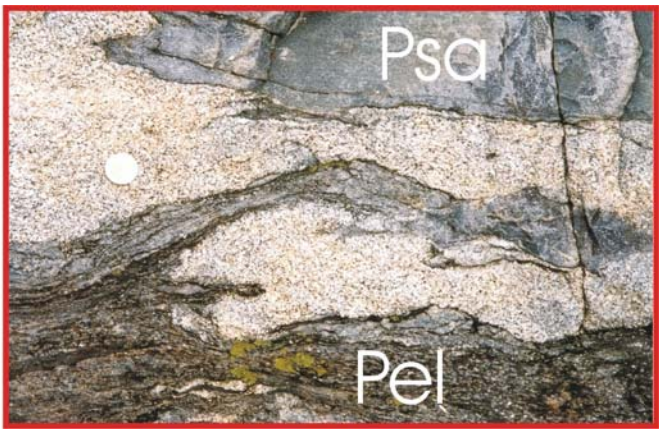


Figure 2.3.13: Detail of red rectangle above (rotated 90° counter-clockwise). Note conversion of pelite to leucosome and melansome (cf. Stop 2.2, Fig. 2.2.3), and the incipient development of biotite-rich schlieren.

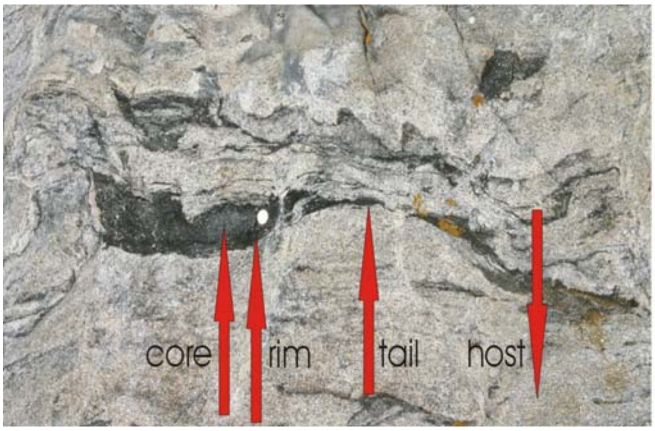


Figure 2.3.14: The last stages of conversion of pelitic bands to biotite-rich schlieren and dispersed refractory phases. For whatever reason, the massive psammite horizons are absent.

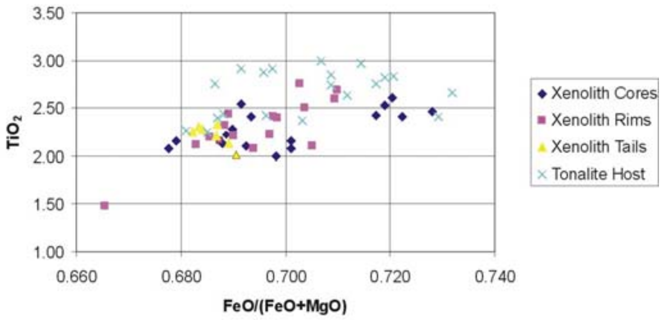


Figure 2.3.15: Chemical compositions of biotites from the cores, rims, and tails of xenoliths such as that shown in Fig. 2.3.14. Also included are biotite compositions in the host tonalite remote from the xenoliths. Are cognate and foreign biotites distinguishable chemically?

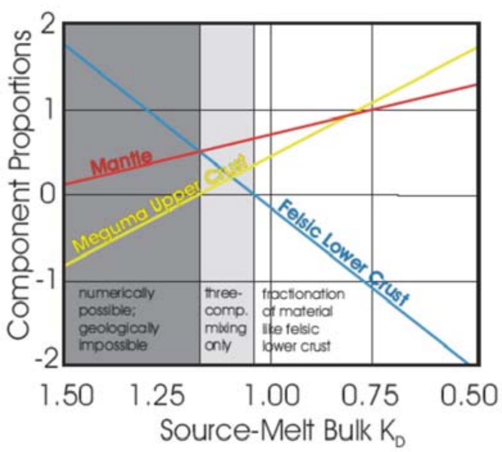


Figure 2.3.16: Results of mixing equations to produce early stage PMP tonalite. The sum of all three components is, for all K_D values for Sr and Nd, equal to 1.000.

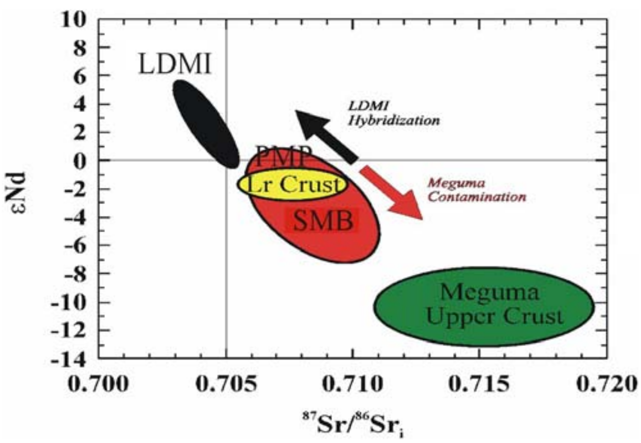


Figure 2.3.17: Strontium-neodymium isotopic compositions of major rock types in the Meguma Zone. Relative to the putative lower crustal source, the SMB shows a net effect of Meguma > LDMI contamination and the PMP shows a net effect of LDMI > Meguma contamination.

Stop 2.3 - Key Observations and Discussion

We have obliquely traversed a wide contact zone, ranging from ~100% country rock to ~100% granitoid rock. The country rock has disintegrated into slabs parallel to bedding planes, analogous to the breakup of an ice shelf. Such fragmentation greatly increases the surface area of contact between the country rocks and the granite magma, and significantly increases the opportunity for chemical reaction and chemical contamination of the granite magma. Where present near the southern contact of the PMP, the highly refractory psammitic horizons remain largely unmodified. Farther into the pluton, the psammites are absent, either because they have been removed, presumably by mechanical means (gravity settling?) rather than chemical ones, or they were never part of the stratigraphic sequence. The pelitic horizons, however, show increasing tendency to melt, producing residual refractory biotite schlieren. The melt fraction hybridizes with the PMP magma, and the refractory schlieren eventually disperse to become individual biotite crystals that are difficult to distinguish from magmatic biotite.

The mingled mafic pillows at McLeods Cove show evidence of coexistence of mafic and felsic magmas, and even some evidence of mixing, but their small volumes might suggest only a minor role to play in changing the composition of the PMP. The mafic boulders containing felsic pipes, however, indicate that much larger volumes of mafic magma intruded the PMP magma chamber, and that the process of sieving or straining the felsic magma through the mafic magma (e.g., D’Lemos 1992), again greatly increasing the surface area of contact between the PMP magma and contaminant, provided an effective mechanism for chemical exchange.

Day 2 – Summary and Implications

Thus, to summarize contamination of the Port Mouton Pluton: the psammitic and calc-silicate rocks are minor players, perhaps ending up as chemically inert “elephants’ graveyards” on the floor of the pluton; the pelitic rocks contribute two components to the PMP - partial melt that mixes with the PMP magma, and refractory biotite that disperses in the PMP magma - effectively meaning that something approaching bulk contamination with pelite has taken place; and the Late Devonian Mafic Intrusions appear to mingle, mix, and sieve with the PMP magma at this level of the intrusion, and radiogenic and stable isotopic evidence clearly shows a shift of the PMP composition toward the LDMIs; therefore, effective mixing and homogenization with mafic magma has taken place elsewhere in the magmatic plumbing system, possibly in the mafic-felsic ‘sieves’. Clarke *et al.* (2000) concluded that the PMP tonalite could be a hybrid of magma from lower felsic crust, mantle-derived LDMI magma, and upper crustal Meguma contaminant.

If this broad and complex contact zone is an anomalously well-preserved example of what happens during the emplacement of other granite plutons, then most granites may be more contaminated than previously believed. Both contaminants (Meguma and LDMI) have greatly expanded surface areas of contact that promote a two-way chemical exchange across the interfaces.

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Pre-conference Field Trips

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

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

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

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

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

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

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

Post-conference Field Trips

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

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

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

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

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

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

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

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

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