PROTOLITH RECOGNITION OF METAMORPHOSED FELSIC VOLCANIC/ VOLCANICLASTIC ROCKS, WITH SPECIAL REFERENCE TO THE GRENVILLE PROVINCE IN SOUTHEAST LABRADOR

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ABSTRACT

The apparent lack of rocks in metamorphic terrains having a felsic volcanic/volcaniclastic or quartzofeldspathic clastic sedimentary protolith is argued to be an artifact of difficulties in recognition rather than in their absence. Even when rocks are in a highly deformed state, experienced geoscientists have never had serious problems in recognizing texturally distinctive units such as conglomerates, volcanic breccias or pillow lavas, or compositionally distinct rocks, such as quartzite, marble or banded iron formation. In contrast, felsic volcanic rocks lacking fragmental fabrics and quartzofeldspathic clastic sediments of arenitic texture have always been difficult to identify in amphibolite- or granulite-facies metamorphic state.

Although challenging, identification of such rocks is not impossible. Field spatial association with rocks more obviously derived from a supracrustal protolith remains one of the most viable methods, but recognition can be immensely facilitated by awareness of relatively subtle features manifest in petrographic thin sections. The following grouped criteria are suggested to be of value, i) slight compositional deviations from those expected in most quartzofeldspathic intrusive rocks, ii) quality and nature of banding, when not attributable to deformation, iii) grain size, and heterogeneity of grain size, iv) grain shape, v) nature and arrangement of phyllosilicates, calcium-bearing mafic minerals, and opaque/heavy/accessory minerals, and vi) abnormal features, such as clasts or pebbles at former sediment interfaces. None of these characteristics is uniquely diagnostic.

The criteria have been applied to fine-grained quartzofeldspathic gneisses in the Pinware terrane in the Grenville Province in southeast Labrador. As a result, the extent of rocks now interpreted to have been derived from felsic volcanic/volcaniclastic or clastic sedimentary protoliths has been modified. Revised interpretation has considerable economic significance both in the immediate region, as well as farther afield, in that the target area for felsic-volcanic-hosted mineralization – especially for Cu, U, Mo, Ag and Au – is now more focused. These elements are known from lake-sediment geochemical surveys to be anomalous in the region.

The location of the best-preserved felsic volcanic/volcaniclastic rocks can be related to a Neoproterozoic–Paleozoic basin, the formation of which is linked to a change in orientation of late-stage, brittle faults.

INTRODUCTION

If one examines geological maps of gneissic terranes, among the vast tracts of quartzofeldspathic orthogneiss generally depicted, remnants of supracrustal rocks such as mafic volcanic sequences (especially pillow lavas), pelitic gneisses, quartzites, calc-silicate rocks, meta-conglomerates, and perhaps felsic agglomerates/breccias are commonly shown. The recognition of these rock types as having a supracrustal protolith hinges on them having one of two characteristics, namely i) either a distinctive texture that has survived the ravages of metamorphism, or ii) an anomalous composition that is outside the normal spectrum of igneous rocks.

In contrast, supracrustal rock types without distinctive textures or compositions (such as felsic volcaniclastic rocks or arenites) are rarely identified as protoliths. Why not? These rocks are a major component of the supracrustal record in unmetamorphosed regions, so surely they are just as likely to be present in high-grade terranes as their other, more easily recognizable, supracrustal counterparts. The essential problem in the identification of felsic volcanic rocks in an advanced metamorphic state is, on one hand, to

distinguish them from metamorphosed magmatic intrusive equivalents (namely granite and felsic hypabyssal rocks), and, on the other hand, to discriminate them from metamorphosed arkosic sediments derived from weathering of these intrusive and extrusive rocks. Composition will not assist in making the distinction as this could be identical in felsic volcanic rocks and granites, in which case the only feature that will separate the two is whether or not the magma reached the surface. Similarly, composition will not help to distinguish highly metamorphosed felsic volcanic rocks from similarly metamorphosed arkosic sediments, if the arkoses were derived from the immediately surrounding volcanic rocks. The problem resolves itself into establishing criteria that reflect the environment of formation.

The intent of this communication is to advocate that some rocks that might have been traditionally mapped as orthogneiss do, in fact, have a supracrustal protolith, being either derived from arenaceous sediments or felsic volcaniclastic rocks. The criteria advanced to support this position are mostly petrographic (*see below*), and, inevitably, still rely on texture or composition. These criteria are extrapolated to a more subtle level, however – such that those unfamiliar in detail with quartzofeldspathic gneisses might be skeptical of their validity. Note that no attempt is made to distinguish between a felsic volcanic rock versus one derived from a volcaniclastic or arenaceous sediment – even when the rocks are unmetamorphosed that can be problematic enough!

In addition to texture and composition, the third element that comes into play is close, and repeated, spatial proximity of quartzofeldspathic gneisses of equivocal parentage (to which the criteria offered here must be applied) with gneissic rocks having a more readily interpretable supracrustal protolith. This introduces a, guilt-(of a supracrustal protolith)-by-association argument. Because inferring the protolith of an ambiguous rock by recognizing less equivocal siblings is an important first step, after these introductory comments, a brief review is made of some of the more readily identifiable supracrustal rock types found in high-grade terrains.

Why should one attempt to distinguish the protoliths of such troublesome rocks in the first place? The most valid scientific answer is to enhance ones understanding of gneissic terranes. Beyond that, however, there are sound economic justifications. Felsic (sub-)volcanic rocks, volcaniclastic sediments and psammitic rocks are important hosts for various types of mineralization. Included among these are porphyry Cu–Mo–Au–W deposits, volcanic massive sulphide (VMS) deposits (Cu–Pb–Zn–Ag–Au), Olympic Dam-type deposits (Fe–Cu–U–Mo), Besshi-type deposits (Zn–Cu–Pb)
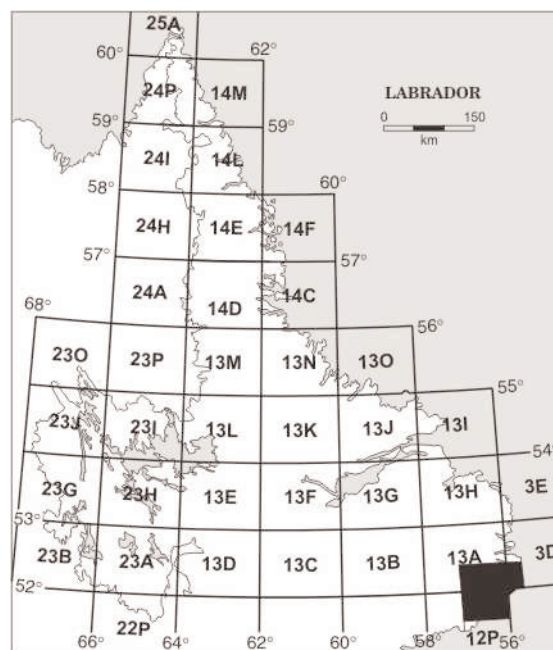

Figure 1. *Location map showing area from which samples used in this study were drawn and the conclusions applied.*

and sedimentary exhalative (Sedex) deposits (Pb–Zn–Ag). Each of these environments represents as much a continuum from a magmatic to a sedimentary setting as do the metamorphosed felsic volcanic/volcaniclastic rocks discussed here.

In a reconnaissance geological mapping context, all that one can generally hope to achieve is the recognition of regions where felsic volcanic and related rocks are present in a high-grade metamorphic state. Identifying specific economic targets will still require other techniques; geophysical, geochemical and geological. Among the latter will be a search for alteration haloes, remembering that these will also be metamorphosed.

The specific impetus for this study stems from mapping in the coastal region of the Pinware terrane in southeasternmost Labrador (Figure 1). Most of the rocks were mapped in either 1987 or 1993 (St. Lewis and Pinware map regions, respectively; Gower *et al.*, 1988a; 1994). On first seeing the rocks in 1987, it was realized that these fine- to medium-grained, quartzofeldspathic gneisses constitute a different assemblage from quartzofeldspathic gneiss encountered farther north (Lake Melville, Hawke River and Groswater Bay terranes). Their significance beyond that was uncertain, although it was suggested that they might have a felsic volcanic/volcanoclastic protolith. During petrographic studies following the completion of mapping it was concluded that if this is the case, a set of criteria is needed to facilitate better their recognition.

RECOGNITION OF SUPRACRUSTAL PROTOLITH BY TEXTURE OR COMPOSITION (OR BOTH)

TEXTURES

Generally, the larger and more obvious the primary feature in the supracrustal rock, the more likely it is to be preserved in a high-grade metamorphosed state; pillows in mafic volcanic rocks are an obvious example. Even when severely deformed, they are still comparatively easy to identify, although they may have been stretched (and thinned) greatly from their original dimensions. The pillow is preserved because of grain-size and compositional differences between various parts of the structure. These features include chilled margins versus coarser grained interiors, the presence of amygdules and, especially, calcic mesostasis (derived from lime-rich mud) commonly found as interpillow material. Other commonly recognized protoliths in high-grade terranes are conglomerates and volcanic fragmental rocks. Again, it is textural and compositional differences that provide the evidence, but, in these rocks, reliance is placed on contrasts between types of clasts, rather than differences within a single textural entity (such as, in a pillow). As one moves from a polymictic to monomictic association, and, as clast size decreases, then protolith recognition becomes progressively more challenging.

In addition to pillows and clasts, evidence such as crossbedding, graded bedding, volcanic flow banding and other features indicative of supracrustal deposition may provide clues as to the original protolith. If such characteristics are preserved, the rocks probably have not been metamorphosed to grades requiring application of the criteria offered here. Generally, the more subtle the original sedimentary or volcanic feature, then the less likely it is to be preserved as grade of metamorphism increases.

COMPOSITION

The type of differentiation that occurs in supracrustal settings contrasts with that in deep-seated magmatic environments. Is it a valid generalization that magmas tend, initially, to homogenize things (although not denying that igneous fractionation may take place later), whereas sedimentary environments tend to separate them? In the sedimentary environment, any of the major-element oxides present in igneous rocks may be concentrated to produce a distinctive sedimentary rock. The most abundant oxides in most igneous rocks, namely SiO_2, Al_2O_3, $Fe_2O_3^{total}$ and CaO, differentiate to produce, when metamorphosed, quartzites, pelites, meta-iron formation, and marble–calc-silicate rocks, respectively. Granted, similar separation can occur under igneous conditions (*e.g.*, SiO_2 differentiation to produce quartz veins), but takes place under rather different physiochemical conditions and produces very different-looking rocks, so there should be little likelihood of confusion. Concentration of other oxides, for example TiO_2 in heavy-mineral deposits, P_2O_5 in phosphatic sediments, Na_2O and K_2O in evaporates, are not sufficiently commonplace to be of routine significance in protolith recognition in high-grade metamorphic terranes, although of considerable interest if discovered. The key point is that if a rock that has an unusual composition is found in a high-grade terrane, then the choice commonly comes down to deciding whether it formed through an anomalous igneous process or by a commonplace sedimentary one.

CRITERIA FOR THE IDENTIFICATION OF QUARTZOFELDSPATHIC ROCKS OF SUPRACRUSTAL ORIGIN

The criteria offered are summarized below and include some points mentioned previously; special attention has been given to illustrations. It should be kept in mind that these criteria were developed specifically from study of rocks in southeast Labrador (Figure 2). The reader is cautioned that, in keeping with the generally rather non-descript nature of the rocks, the illustrations are not compelling. Nevertheless, those facing similar challenges to the author will, perhaps, find them of interest and practical applicability.

LITHOLOGICAL ASSOCIATION

A useful starting point for considering any specific quartzofeldspathic gneiss to be of supracrustal origin is its association with rocks of less equivocal sedimentary parentage, such as quartzite, calc-silicate rocks and pelites. If the quartzofeldspathic gneiss is interlayered in a regular, concordant manner with such rocks (or, simply, regionally associated), then it is reasonable to suspect that both have a common depositional origin, rather than the quartzofeldspathic rocks being (for example) later, injected granitic sheets. Whilst not denying that concordant intrusion is a viable process, it is probably safe to claim that the more intimate the interlayering, the greater the probability of a supracrustal protolith. Even concordant intrusions locally transgress layers, and the resultant discordance is not easily destroyed during high-grade metamorphism. The nature of the rocks must also be considered. One might be rather suspicious of a sequence of alternating marble and K-rich quartzofeldspathic gneiss claimed to be derived from limestone and arkose, given the contrasting conditions under which these two rocks commonly form.
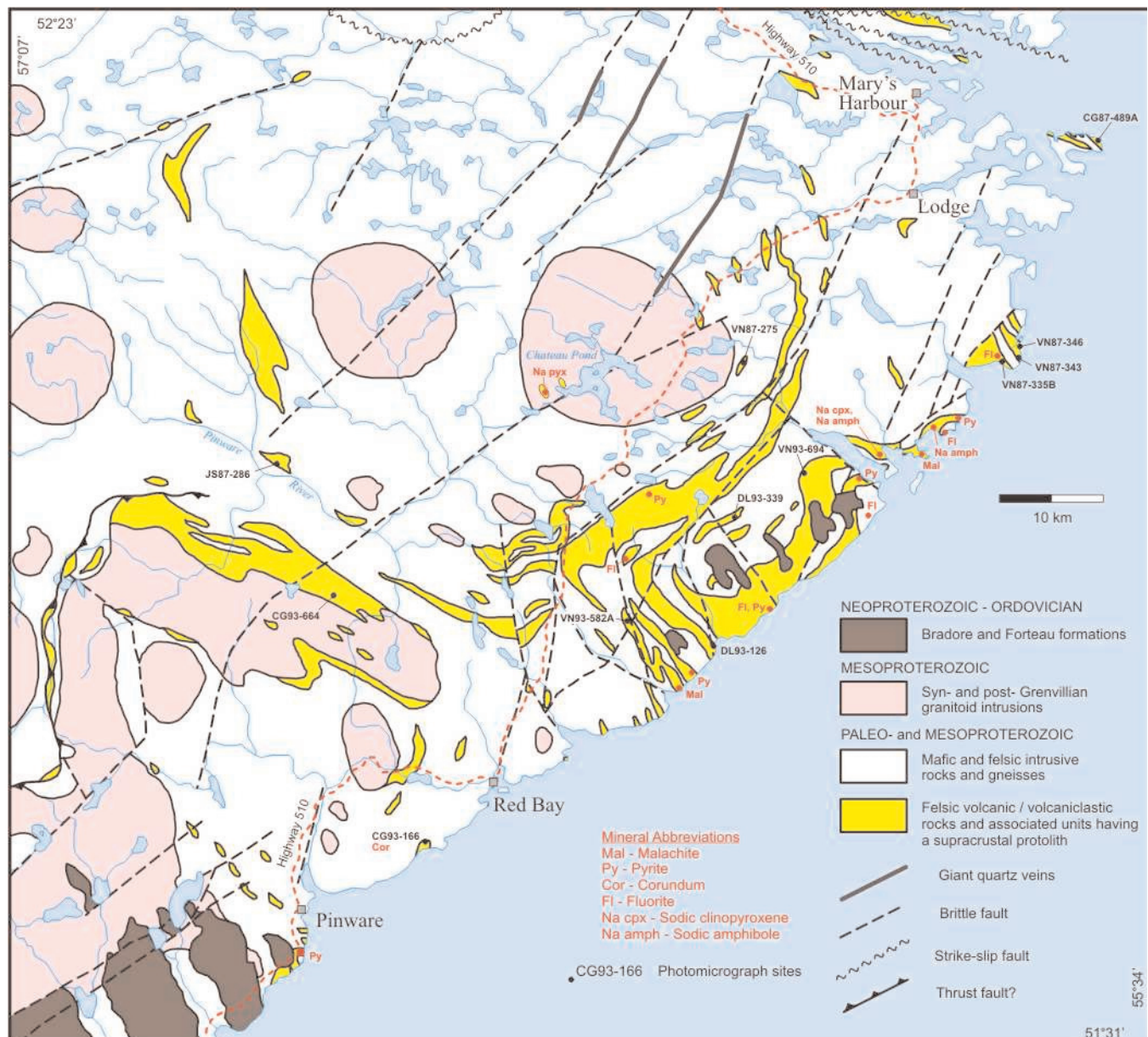
Figure 2. *Map showing the extent of rocks interpreted to have felsic volcanic/volcaniclastic protoliths (Pitts Harbour Group), incorporating conclusions derived from petrographic analysis and additional data gathered from roadcuts along Highway 510, newly opened in 2003. Locations are shown for the samples used to illustrate the interpretations made in this study (Plates 1 to 12), and sites where atypical minerals were found within the inferred felsic volcanic/volcaniclastic rocks.*

COMPOSITION

Numerous geochemical criteria have been proposed that purport to distinguish gneiss derived from a supracrustal protolith from that having an igneous intrusive origin. Undeniably, compositional criteria are extremely valuable, but in my experience, they only perform consistently and convincingly when the compositional contrast between the supracrustal and intrusive rock is sufficiently distinct, such that the protolith of the rock can be reasonably

inferred without recourse to geochemical analysis. Even if the composition is not sufficiently extreme so as to exclude normal igneous rocks, mildly abnormally high or low proportions of specific minerals (especially quartz and muscovite) may hint at a sedimentary protolith (*cf.,* Plate 1). An example of this is illustrated by compositions reported in the literature for arkose, which is characterized by lower Na_2O and K_2O than in rhyolite. This can be explained as due to dilution of feldspar by other minerals (mostly more robust quartz) during weathering and transportation. It is also
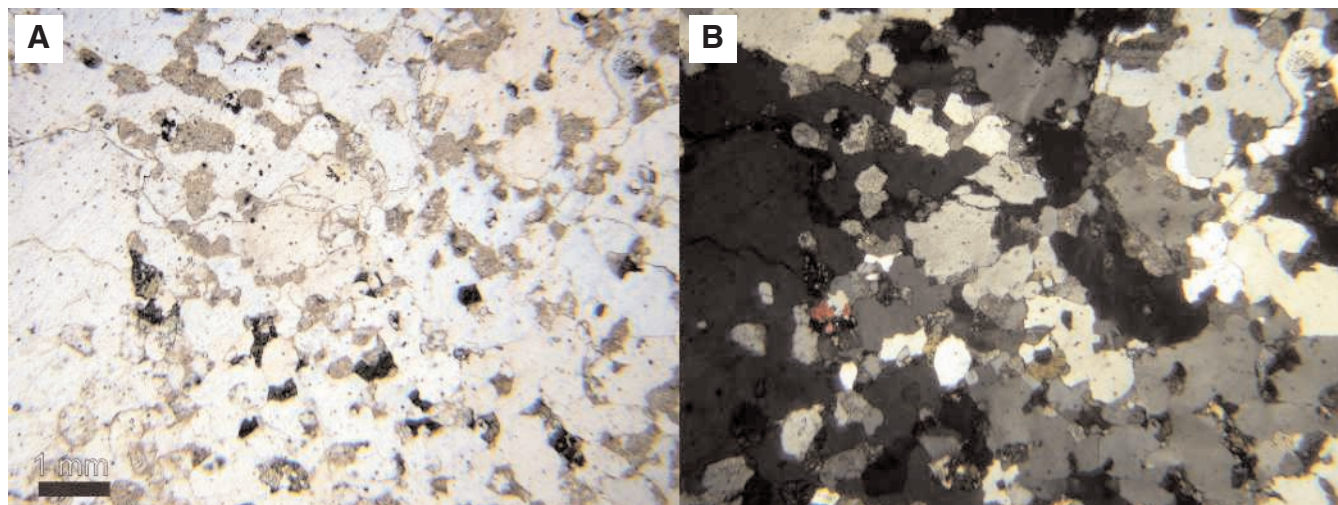
Plate 1a, b. *A simple example of use of compositional criteria. The colourless mineral in plane-polarized light (left in this, and subsequent images; right is crossed polars) is quartz; the rough-textured buff-brown mineral is altered plagioclase and the dark mineral is mostly amphibole. Given this much quartz, interpretation of protolith requires choosing between an igneous rock of anomalous composition or a commonplace sedimentary rock (in this case some form of impure quartzite, such as calcareous feldspathic quartz arenite). The latter option is favoured here. Data station VN87-275.*

worth remembering that minor igneous intrusions having atypical compositions commonly reflect their immediate host rocks – or more distant precursors. Muscovite-bearing pegmatite intruding pelitic gneiss is a good example.

The main purpose of this communication, however, is to address situations where the near-total compositional overlap between supracrustal and igneous intrusive rocks calls for an alternative approach.

QUALITY OF BANDING

The dearth of clastic supracrustal rocks depicted on geological maps of high-grade terranes is in marked contrast to a few decades ago, when almost any well-banded high-grade metamorphic rock would have been interpreted as paragneiss. Advances in structural geology have demanded reinterpretation of many well-banded gneisses as the product of high-strain, and, quite correctly, rendered obsolete the viewpoint that all banded rocks (excluding those derived from igneous layering) were once necessarily bedded supracrustal rocks. Banding, of course, may also be formed post-depositionally, by various alteration/replacement processes.

Nevertheless, quality of banding remains a helpful, albeit far from diagnostic criterion. It seems axiomatic that rocks having good banding to start with are more likely to end up having the best-developed banding in a high-grade metamorphic state. In quartzofeldspathic gneiss derived from sediment, banding, if present, is generally more continuous and regular than that seen in compositionally equiv-

alent orthogneiss. Banding/bedding reflects compositional heterogeneities between individual layers, some of which will have lower minimum melting temperatures than others, so partial melting is more likely to emphasize original structure, rather than obliterate it, at least during early melt stages. In homogeneous rocks, such as granitoid intrusions, initial partial melting produces irregular melt patches, although these may be crudely oriented parallel to the regional structural trend, in keeping with the stress field operative at the time.

GRAIN SIZE

There are numerous examples in the literature interpreting grain-size reversal as a result of recrystallization (particularly in the upper, pelitic parts of graded beds, where aluminous metamorphic minerals may grow abnormally large relative to the grain size of the original protolith). In general, however, a fine-grained protolith (especially quartzofeldspathic rocks) will produce fine-grained, high-grade metamorphic rocks, and coarse-grained rocks will retain vestiges of their former coarse-grained state. Even if large grains experience grain-size reduction through recrystallization, primary grain outline is still generally evident (Plate 2).

Primary grain-size contrasts commonly exist between individual layers in rocks of supracrustal origin, whereas in quartzofeldspathic igneous rocks these are typically induced by partial melting. Heterogeneity in the grain size of particular minerals (if it cannot be explained in terms of an igneous crystallization sequence) may be a useful criterion, especially in the case of those derived from a volcaniclastic
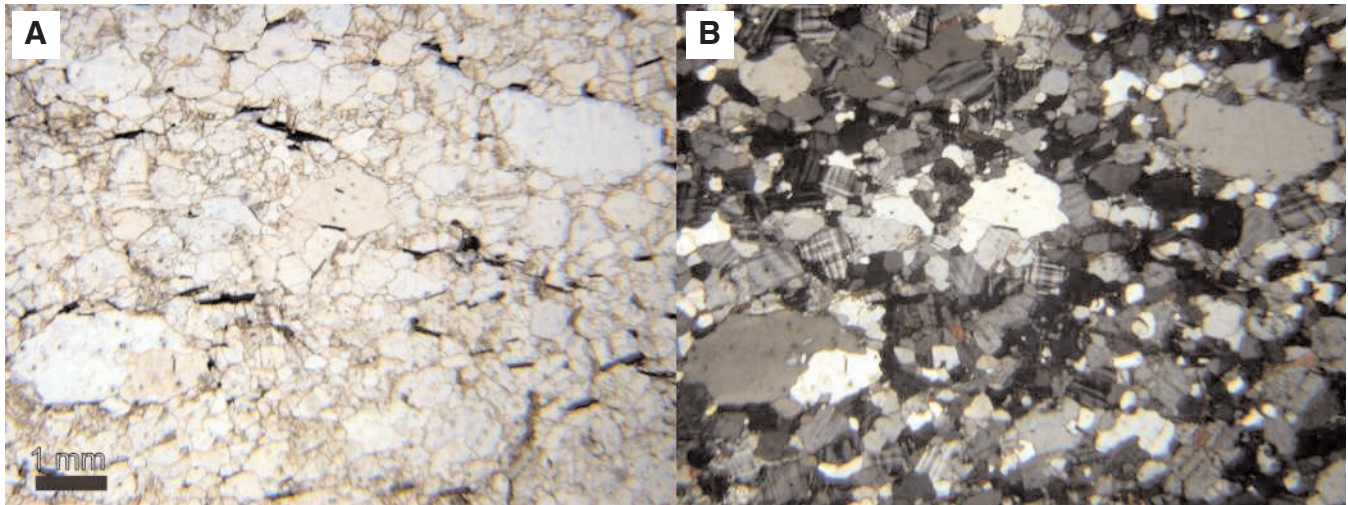
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Plate 2a, b. *The very heterogeneous grain-size variation shown by this rock (note especially the large, but slightly polygonized quartz grains in the lower left and upper right) is, despite its recrystallized state, suggestive of a protolith that was poorly sorted and immature, such as a felsic volcaniclastic rock. Data station DL93-339.*
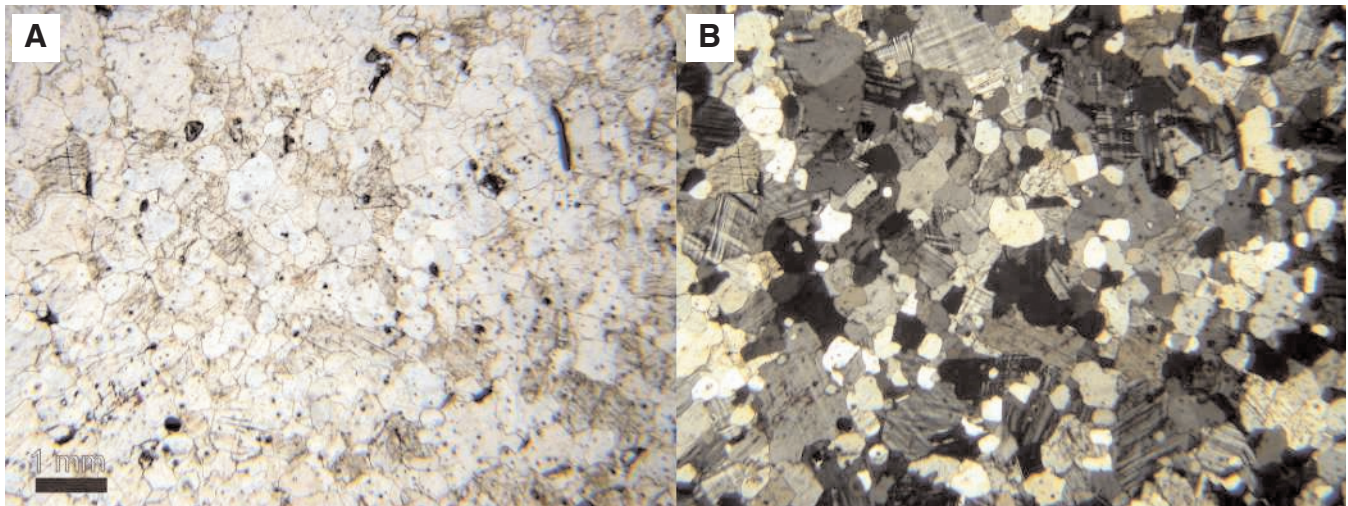

Plate 3a, b. *A common feature seen in this package of quartzofeldspathic rocks is the presence of rounded grains, especially quartz (for example, the white grains in crossed polars). Although other explanations can be advanced to explain their form, one possibility is that these represent original clastic grains. Note also the small, equant, very dispersed opaque grains (a feature addressed in a subsequent part of the text; see similar texture in Plate 6a, b). Data station VN93-582A.*

protolith. Bimodal grain size may imply that the protolith was a porphyry.

GRAIN SHAPE

In thin section, quartzofeldspathic rocks derived from clastic metasedimentary rocks may be seen to retain vestiges of rounded grains, the outlines of which can commonly still be discerned despite fairly extensive recrystallization (Plates 3, 4). Quartz grains tend to show less strain than in their igneous counterparts (strain being accommodated intergranularly?) and feldspars sporadically show embayed grain boundaries. As an aside, plagioclase is typically more heav-

ily sericitized and less well twinned, and K-feldspar seems to be most commonly microcline, rather than perthite. Why the microcline/perthite observation should apply is difficult to explain, unless it is due to failure to recognize felsic volcanic/volcaniclastic protoliths in granulite-facies terranes, where perthite typically dominates.

PHYLLOSILICATES, AMPHIBOLE, EPIDOTE

Phyllosilicates, in thin section, are seen to be more abundant in some psammitic gneisses than in their igneous compositional counterparts; especially to include more muscovite and chlorite. The flakes commonly occur as intersti-
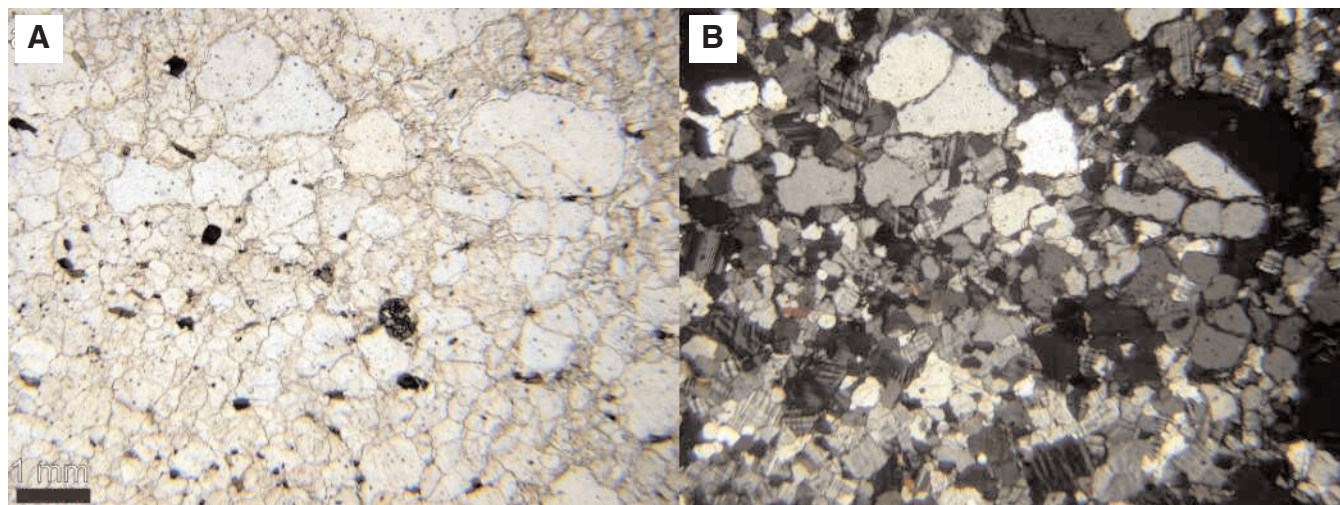
Plate 4a, b. *Although this rock is extensively recrystallized, hints of rounded grains, coupled with an overall 'clastic' appearance, the presence of garnet (right of, and slightly below, centre) and dispersed mafic/opaque grains are taken as suggestive of a volcaniclastic protolith. Data station VN93-694.*
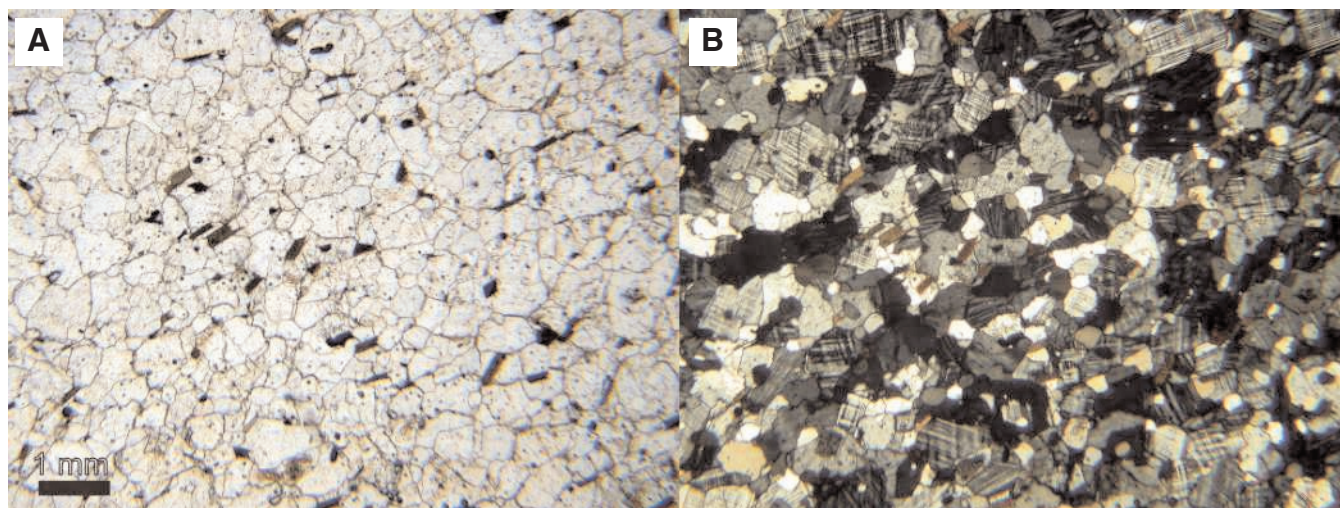

Plate 5a, b. *The feature shown in this rock, namely stubby biotite flakes (dark green-brown and aligned from bottom left to top right) that are similar in length to the grains on either side, is typical of these rocks. Possibly, the biotite is the product of metamorphism of an iron-rich intergranular mud. Data station JS87-286.*

tial material at boundaries between rounded quartz or feldspar grains, and/or concentrated into particular layers. Typically, the flakes are of similar length to the felsic grains on either side (Plates 5, 6). These minerals may represent former muddy cementing material between felsic grains (Al_2O_3-rich-yielding muscovite; Al_2O_3- and $Fe_2O_3{}^{total}$- rich-producing biotite indicating incomplete sorting of sand and mud in the original sediment – which would explain why the flakes are similar in length to their neighbouring felsic grains).

Interstitial material may also include amphibole and epidote, which generally have a rather ragged habit, and show a tendency to be concentrated into particular layers.

Commonly, this material is too fine grained to allow identification of individual minerals and simply has a 'grungy' appearance. In these cases, it is postulated that the protolith would have been a calcareous sandstone. In some instances, amphibole poikiloblasts occur within quartz-rich rocks. These are interpreted to have grown within the quartzofeldspathic matrix during metamorphism from an intergranular calcareous cement (Plate 7).

OPAQUE/HEAVY MINERALS

A wide range of opaque minerals may be present and include magnetite, ilmenite, pyrite, hematite and leucoxene. Hematite (a common cementing material in sandstones),
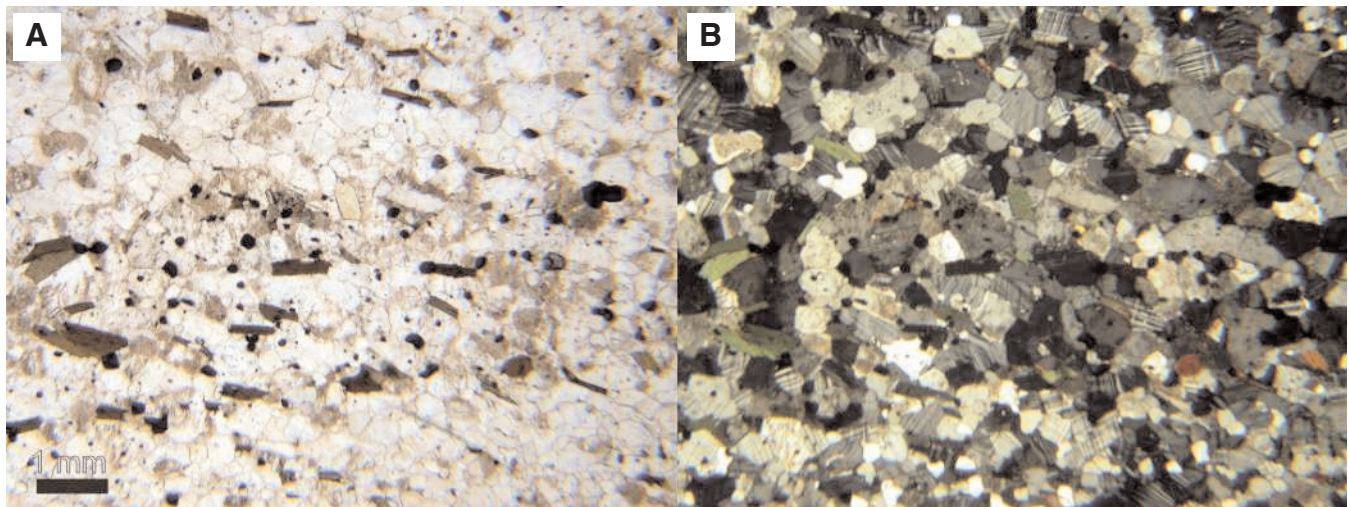
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Plate 6a, b. *This is another example of stubby biotite flakes at quartz and feldspar grain boundaries. The image also shows dispersed, equant oxide grains, lacking any spatial association with biotite - in contrast to their habit in intrusive igneous rocks of similar composition. Data station VN87-346.*
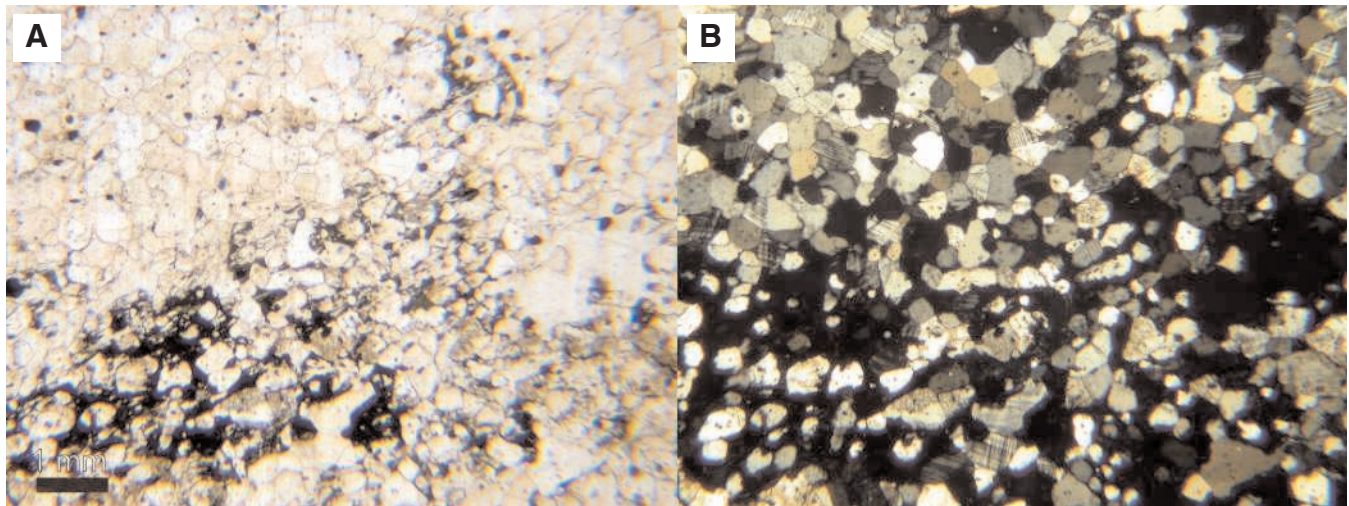

Plate 7a, b. *Much of the darker material in the lower half of the plane-polarized light image is a single sodic amphibole porphyroblast (albeit partially replaced by iron oxide). The porphyroblast is interpreted as having formed from intergranular mud matrix and calcareous cement during metamorphism. Data station CG87-489A.*

typically occurs as a coating to quartz grains and serves to emphasize clastic grain boundaries in thin section (Plate 8). Magnetite/ilmenite may be concentrated into heavy mineral layers, and, rarely, is associated with other durable minerals such as zircon. Large, euhedral pyrite is more evident in metamorphosed, semipelitic supracrustal rocks than in igneous compositional equivalents. Garnet and more unusual minerals (*e.g.*, tourmaline, or corundum; Plate 9) with other heavy minerals are indicative of a sedimentary protolith, but are not often found.

ACCESSORY MINERALS

Accessory minerals, such as titanite, apatite and zircon,

characteristically occur as dispersed single grains (Plate 10), rather than occurring in clumps associated with mafic silicate minerals as they do in granitoid rocks. In most granitoid rocks (with caveats applied regarding composition and grade of metamorphism) a fairly standard suite of accessory phases is usually present (zircon, apatite, opaque phase(s), titanite, allanite ± monazite) whereas in quartzofeldspathic rocks derived from psammitic supracrustal rocks, members of the suite may be absent or present in atypical proportions. Roundness of accessory minerals, traditionally cited as a strong criterion for a sedimentary protolith, although not diagnostic, is not to be dismissed. Delicate, skeletal or amoeboid grains, or those with abundant inclusions, are less likely to withstand the rigours of fluvial or aeolian transport
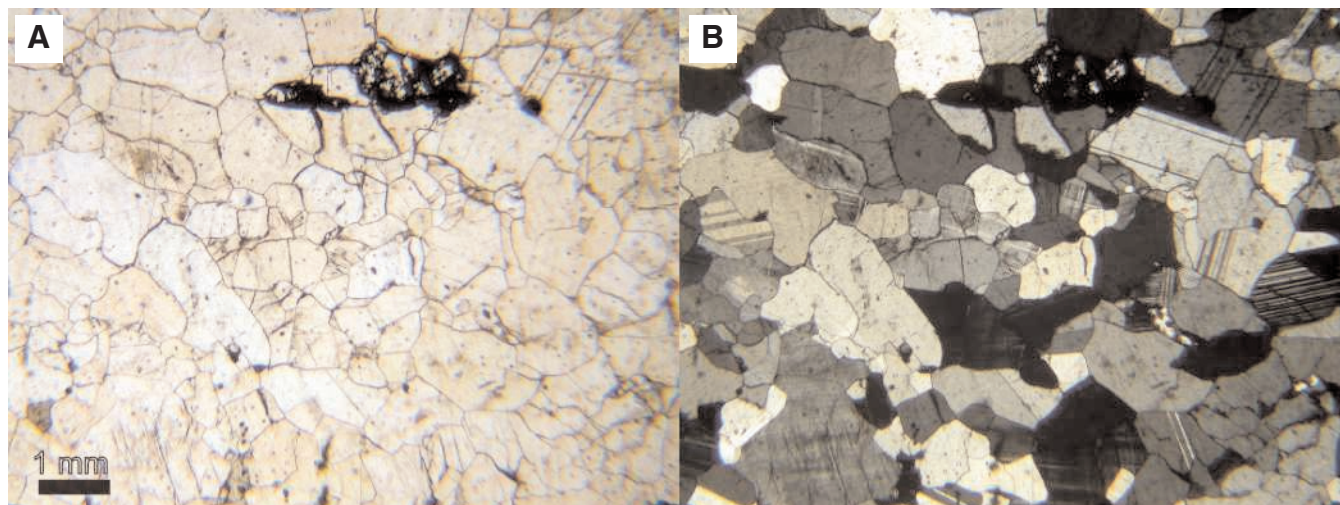
Plate 8a, b. *The sharply defined grain boundaries of quartz and feldspar seen in plane-polarized light is due to thin rinds of iron oxide (especially hematite). Regardless of whether one interprets the feature as relict-primary or secondary, it is a ubiquitous and characteristic feature of these rocks. Note the obvious 120° triple junctions, which attest to the extensive recrystallization this rock has experienced. Data station VN87-335B.*
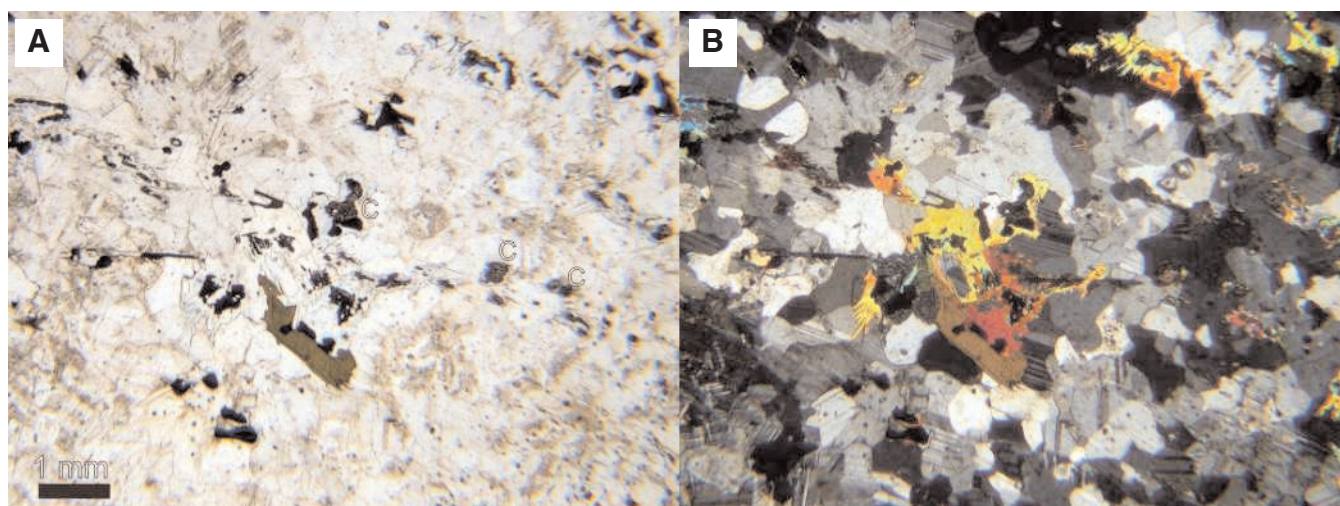

Plate 9a, b. *Relict corundum ('C' in plane-polarized light image) enveloped by muscovite in this sample raises questions regarding a metamorphic versus detrital origin. Coupled with muscovite and minor sillimanite (not shown), an aluminous protolith is indicated, which is deemed here most likely to have been sedimentary. Pelitic rocks are not abundant in the region, but their sporadic presence endorses a supracrustal protolith for the generally rather non-descript quartzofeldspathic rocks with which they are associated. Data station CG93-166.*

and, if present, decrease the probability of a sedimentary origin. Nevertheless, in metasedimentary rocks, one must be alert to branching secondary minerals that were formed during subsequent metamorphism. Titanite is a common culprit, forming in those rocks having common chlorite (both minerals being products of biotite breakdown).

If the geoscientist is fortunate enough to have U–Pb geochronological data available then inferences may be made from the shape of zircon, and perhaps other separated minerals. For example, those within a fine-grained felsic rock from southeast Labrador, provisionally mapped as a probable supracrustal rock, were separated and dated by Tucker and Gower (1994). The zircons have a short-prismatic habit, a form typically found in felsic volcanic rocks.

OTHER FEATURES

Anomalous features (to those expected in a granitoid intrusive rock) may be helpful. Two examples were seen in thin sections from southeast Labrador of large, rounded grains (quartz in one instance, microcline in the other) in a
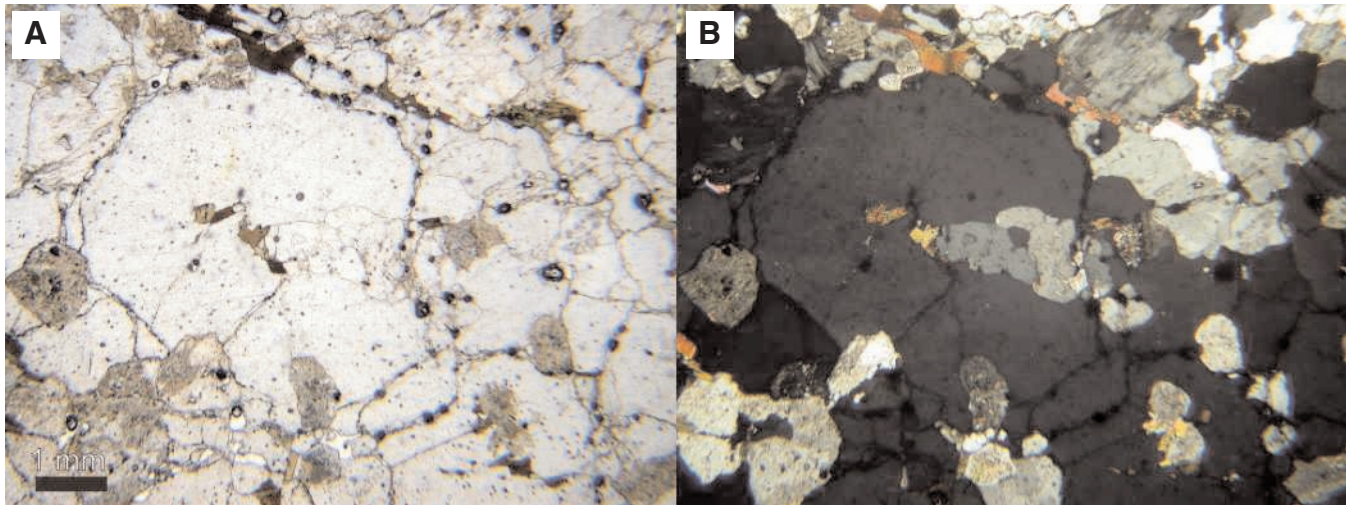
Plate 10a, b. *The purpose of showing these images is to draw attention to the tiny dark blebs at quartz and feldspar grain boundaries. These are accessory minerals, such as titanite, apatite, allanite, epidote and opaque minerals. This habit contrasts to that seen in most igneous intrusive rocks where they tend to be closely associated with mafic silicate phases. Data station CG93-664.*
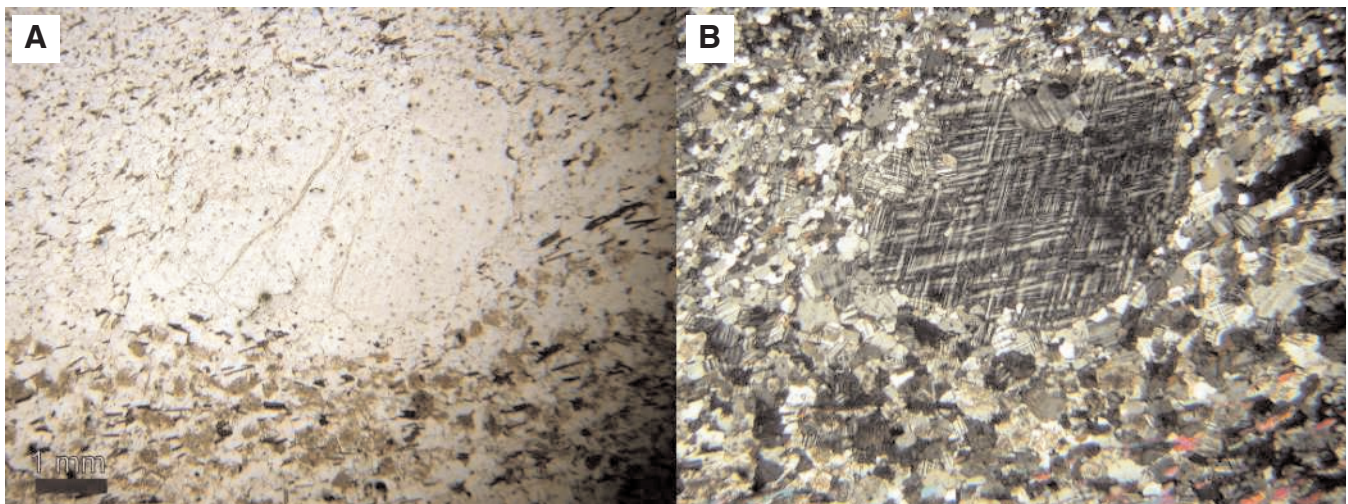

Plate 11a, b. *In this image a large, rounded microcline grain is situated at the boundary between finer grained biotite-bearing quartzofeldspathic material above and coarser grained muscovite-bearing quartzofeldspathic material below (with which buff-brown altered plagioclase is associated). The microcline grain is interpreted to be a pebble redeposited on the coarser grained sediment, which was subsequently covered by finer grained clastic material. Data station DL93-126.*

fine-grained matrix, located at a compositional boundary between two layers (*e.g.*, Plate 11). These are interpreted as small pebbles resting on sediment, subsequently covered by another layer of sediment.

One should also be alert to composite grain clusters, especially those showing well-defined outer margins, as, for example, those shown in Plate 12. These might represent former clasts, although, alternatively, the 'clasts' could be pseudomorphs of a mafic silicate mineral.

Note that little mention has been made of alteration haloes around ore deposits as a criterion for recognizing highly metamorphosed felsic volcanic rocks. That would be rather akin to concluding the straw (halo) around a needle (orebody) belongs to a haystack (host rock). That is not the issue here – the problem is first recognizing the haystack after it has been flattened, then trampled over by farm animals!
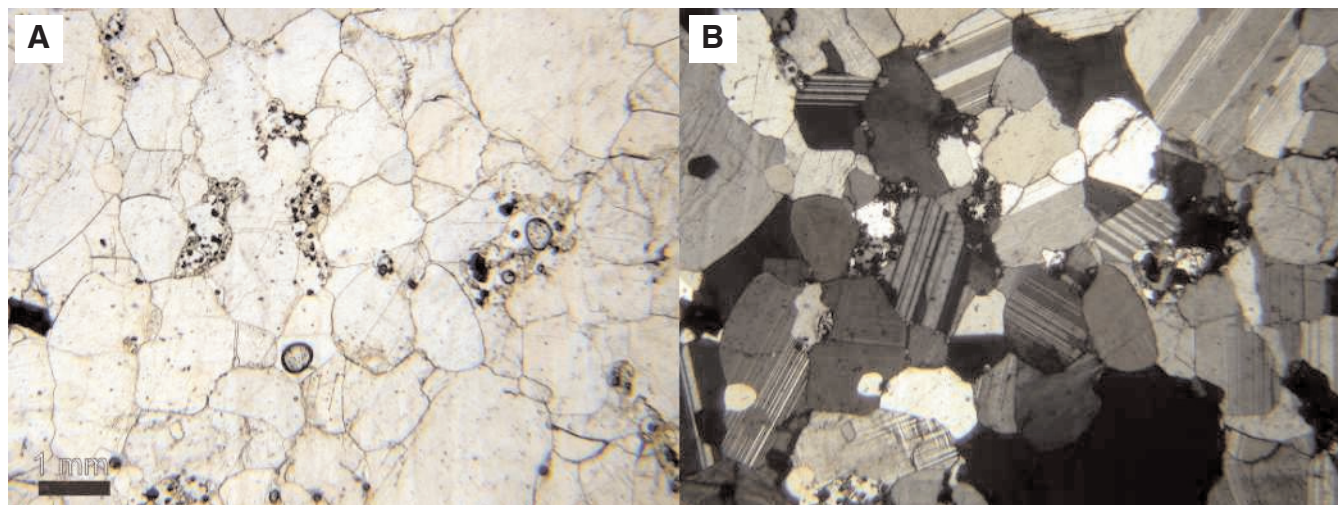
Plate 12a, b. *Note the two green and spotty black, kidney-like patches (left of centre), and less-well-developed examples elsewhere. As an alternative to a pseudomorphed mafic silicate origin, might they represent foreign, composite clastic grains? Data station VN87-343.*

APPLICATION OF CRITERIA TO ROCKS IN SOUTHEAST LABRADOR

The rocks from which the criteria described above are derived have been termed the Pitts Harbour Group (Gower *et al.*, 1988b). Despite the confidence implied in naming the rocks, considerable uncertainly existed at the time as to which rocks should be included. This study goes some way to alleviating this problem.

The supracrustal rocks can be classified into six groups. These are; i) banded amphibolite interpreted to have been derived mainly from a mafic volcanic protolith, ii) quartzofeldspathic rocks thought to have a felsic volcanic/volcanoclastic protolith, iii) quartzofeldspathic rocks considered to have been derived from medium-grained quartzofeldspathic clastic metasediments, iv) quartzite and quartz-rich meta-arkose (including one outcrop where cross-bedding is preserved), v) pelitic rocks, and vi) calc-silicate rocks. The focus of this article is on groups (ii) and (iii), but, had they not been in spatial association with the other rock types listed, somewhat different conclusions may have been reached.

The correlation of Cu–U–Mo–Ag–Au–As lake-sediment anomalies with some of the fine-grained quartzofeldspathic gneisses in southeasternmost Labrador (Gower *et al.*, 1995), also encouraged the supposition that these rocks are genetically distinct from other felsic gneisses in eastern Labrador (where comparable correlation is not evident). The anomalies perhaps reinforce the notion of a felsic volcanic/volcaniclastic protolith as mineralization embodying the anomalous elements is more characteristic of felsic volcanic and hypabyssal rocks than mid-crustal granitoid rocks prevalent elsewhere in eastern Labrador. Partly because of this background, in 2006, the Geological Survey of Newfoundland and Labrador completed a lake-sediment sampling program to augment existing data for the region (McConnell and Ricketts, 2006). The survey region was designed to include most occurrences of the Pitts Harbour Group. A total of 782 samples were collected, but at time of writing this article, analytical results have not been released.

Figure 2 shows the re-interpreted extent of the Pitts Harbour Group in the Pinware terrane, revised from that shown by Gower *et al.* (1988a, b; 1994). In addition to embodying the results of this petrographic study, the map also includes information gathered from road cuts along Highway 510, newly opened in 2003. Areas inferred to be underlain by rocks derived from felsic volcanic/volcaniclastic and clastic quartzofeldspathic protoliths are expanded in two areas; in the upper Pinware River district and east of Chateau Pond. It is stressed that rocks of felsic volcanic/volcaniclastic origin are *not* the only protolith type to be found in these expanded areas, but, rather, the supracrustal rocks occur as rafts, remnants, and slivers associated with granitoid orthogneiss, which, itself, is probably of several ages.

In the vicinity of the eastern upper Pinware River, a 1- to 4-km-wide, north-northwest-trending swath of terrain was mapped as fine-grained biotite granite and alkali-feldspar granite (Gower *et al.*, 1988b, Unit 5f). Re-examination of samples has not resulted in revision of this label for most of the rocks in the area. On the other hand, some significance may be attached to their presence; perhaps representing hypabyssal intrusive rocks linked to supracrustal remnants identified farther north-northwest and south-southeast.

East of Chateau Pond, supracrustal rocks were previously mapped by Gower *et al.* (1988b, Units 1q and 2q) as thin slivers of quartz-rich gneiss, quartzite or meta-arkose, in places, associated with calc-silicate rocks. The main change introduced is to re-assign various slivers of the enveloping granitoid gneiss as having a supracrustal origin, rather than being intrusive. New exposures of quartzofeldspathic rocks derived from supracrustal rocks (and identifiable without the use of the petrographic criteria described here), are identified in roadcuts along Highway 510 south of Lodge, and between Mary's Harbour and St. Lewis Inlet.

The best-preserved and most extensive areas of quartzofeldspathic rocks derived from supracrustal protoliths are in coastal districts. The previously mapped extent (Gower *et al.*, 1988b) has not been greatly modified, but mineralogical detail has been augmented as a result of petrographic studies. Gower *et al.* (1988a) mentioned the presence of sodic amphibole and rare corundum in these rocks, to which may now be added sodic clinopyroxene and fluorite. None of these 'anomalous' minerals are abundant, but, collectively, they could be taken as an indication of felsic volcanism having alkalic leanings (with a link to intrusive magmatism, as these minerals are also found in spatially associated granite).

IMPLICATIONS FOR NEOPROTERO-ZOIC–PALEOZOIC TECTONICS

The location of the most extensive areas of supracrustal rocks can be readily explained in terms of basin formation related to the opening of the Iapetus Ocean. Note that the late-stage faults trend northeast in the southwestern part of area depicted in Figure 2, whereas they trend north-northeast in the northeastern part of the area. These are brittle, normal faults, downthrown to the east. Assuming the fault surfaces have a southeast/east-southeast dip, then, in the simplest situation, a wedge-shaped gap would develop where the change in fault trend occurs (Figure 3a). Obviously, in reality, this does not happen. Instead, the 'gap' is accommodated by subsidiary faults developing both parallel to, and at a high angle to the major northeast and north-northeast systems (Figure 3b). As a result, a rhomb-shaped basin develops on the convex side of the change in orientation of the fault systems. In Figure 3b, this basin is depicted as having developed on the southwest side of the 'gap', as this seems to be more in keeping with the situation in the region but, presumably, it could form on the opposite, or both, sides. The basin facilitates preservation of shallower level crustal rocks, which would include the supracrustal felsic volcanic/volcaniclastic units described here. This model is consistent with the lower grade of metamorphism present in the rhomb-shaped basin and also explains why outliers of Bradore Formation are preserved in that region.

Furthermore, the giant quartz veins associated with late-stage faults and located at the change in fault trend (north of Chateau Pond, Figure 2), are a manifestation of a similar, but much less advanced process. Comparable changes in the trend of late-stage faults exist elsewhere at the margin of the St. Lawrence rift system (*e.g.*, east of La Romaine in eastern Quebec in the vicinity of Archipel de Ste. Marie).
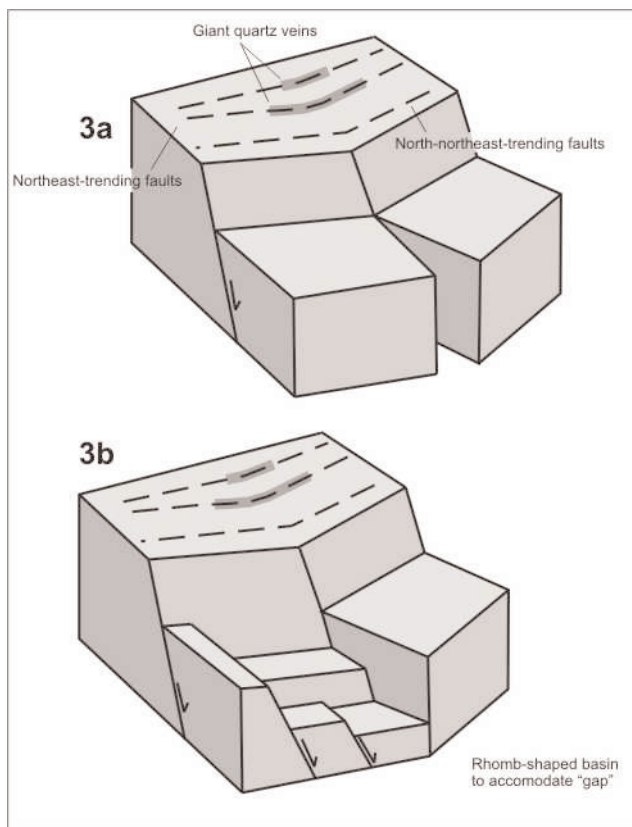

Figure 3. *Diagrams explaining why the felsic volcanic/volcaniclastic rocks are preserved where they are. a) Simple block diagram to illustrate how a wedge-shaped gap develops at the point where two normal fault systems have a change in trend (in this instance, related to the opening of Iapetus Ocean). b) In reality, the gap does not develop being accommodated by subsidiary normal faults, both parallel and normal to the major fault systems. The best-preserved felsic volcanic/volcaniclastic rocks are contained within the basin.*

CONCLUSIONS

It is argued that discrimination can be made, even in relatively non-descript, fine- to medium-grained quartzofeldspathic gneisses, between those having a felsic volcanic/volcaniclastic or quartzofeldspathic clastic sedimentary protolith versus those of similar composition having an igneous intrusive protolith. Distinguishing the two relies on field association with more easily recognizable rocks, slight com-

positional departures from igneous norms, and petrographic textural features. None of these criteria is diagnostic individually, so interpretation of protolith must rely on their collective application.

This study was carried out to draw attention to what must surely be an artificial imbalance (in favour of igneous intrusive rocks versus compositionally equivalent supracrustal rocks) in the representation of quartzofeldspathic protoliths in high-grade terranes. The economic implications of refined protolith discrimination are enormous, given the very high mineralization potential of felsic volcanic rocks.

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REFERENCES

Gower, C.F., McConnell, J.W. and van Nostrand, T.
    1995: New mineral exploration targets in the Pinware terrane, Grenville Province, southeast Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 95-1, pages 15-24.

Gower, C.F., van Nostrand, T. and Evans-Lamswood, D.
    1994: Geology of the Pinware River region, southeast Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 94-1, pages 347-369.

Gower, C.F., van Nostrand, T. and Smyth, J.
    1988: Geology of the St. Lewis River map region, Grenville Province, eastern Labrador. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 59-73.

    1988: St. Lewis River map region. Newfoundland Department of Mines, Mineral Development Division, Map 8887.

McConnell, J., and Ricketts, J.
    2006: A detailed lake sediment and water survey in three areas of Labrador. Newfoundland and Labrador Department of Natural Resources, Mines Branch, Report of Activities, page 43.

Tucker, R.D., and Gower, C.F.
    1994: A U–Pb geochronological framework for the Pinware terrane, Grenville Province, southeast Labrador, Journal of Geology, Volume 102, pages 67-78.