REPORT ON
THIN SECTIONS FROM
DDH WM-1, SPRUCE ROAD CU-NI DEPOSIT,
SOUTH KAWISHIWI INTRUSION,
DULUTH COMPLEX

By

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PREAMBLE

General Petrographic Characteristics of the Giants Range Batholith (GRB)

The GRB is a large composite, calc-alkaline batholith comprising plutons ranging in composition from diorite, tonalite, granodiorite, quartz monzonite to hornblende syenite. However, two-mica quartz monzonite appears to be the most abundant rock type (Prince and Hanson, 1972; Sims & Viswanathan, 1972). Biotite and hornblende are the two principal ferromagnesian minerals in the batholith, but in some of the more mafic rocks and a few hornblende granites, the hornblendes have cores of clinopyroxene (Sims & Viswanathan, 1972). Some two-mica granites and aplites contain garnet; probably reflecting their very fractionated compositions.

Although graywacke and greenstone sequences to the north are contact metamorphed up to the middle amphibolite facies by intrusion of the batholith, petrographic reports of the GRB rocks from west of Babbitt consistently describe primary igneous mineral assemblages. Typically, plagioclase + K-feldspar + quartz + biotite, and either hornblende or muscovite. Commonly described secondary minerals are, chlorite, epidote and muscovite, e.g., Sims & Viswanathan (1972), and this suggests that the original, igneous crystallization mineral assemblages have been partially retrogressed by no more than low grade (maximum of greenschist facies) regional metamorphism.

Another commonly reported characteristic of the GRB is that the rocks are foliated, and the textures are variously described as “granulated”, “cataclastic” or “mortar-textured”. Typically, the foliation is subvertical and trends to the SE and, consequently, has been related to the same regional deformation event active in the country rocks at the time of pluton emplacement, or shortly afterwards, since it is generally parallel to the foliation in the older Archaean rocks to the north. In some places this SE-trending foliation in the GRB may have formed in the magmatic or submagmatic state. However, a subvertical, NE-trending foliation in some of the GRB rocks developed after the batholith rocks had crystallized; this foliation is related to faulting at relatively low temperatures. Some of these faults now place batholith rocks directly in contact with older Archaean rocks to the north, cutting out rocks of the contact metamorphic aureole.

Green (quoted in Sims and Viswanathan, 1972) reported that rocks of the GRB east of Babbitt are thermally metamorphosed by the Duluth Igneous Complex. Textures there are recrystallized and new mineral assemblages, e.g., hornblende + augite + hypersthene + biotite + magnetite, replace the original igneous mineral assemblages typically found in the GRB farther to the west. Hypersthene has exsolution lamellae, suggesting inversion from pigeonite. Green observed that in some rocks hypersthene was retrograded to biotite + actinolite and that copper sulphides were introduced in some rocks. Green attributed the low variance mineral assemblages east of Babbitt as resulting from partial equilibration between the original igneous assemblage and the amphibolite, hornblende amphibolite or pyroxene-hornfels facies assemblages formed by contact metamorphism. He suggested that thermal metamorphism of the GRB caused by intrusion of the Duluth Igneous Complex reached temperatures of 600 to 675°C, at an assumed pressure of 1 to 2.5 kbars.

THE WALLBRIDGE THIN SECTIONS

Samples for this project come from borehole WM-1 drilled by Wallbridge American in the Spruce Road Cu-Ni Deposit (Figure 1). None of the felsic rocks rocks belonging to the Giants Range Batholith from the borehole contain hornblende or primary muscovite, e.g., samples W990762, W990763, W990764, W990764, W990766, W990768 (felsic part of the thin section), W990771 (felsic part of the thin section), W990772, W990775 (felsic part only), W990776, and W990777. The principal difference between the samples, as far as the silicate mineralogy is concerned, is variation in modal proportions; notably some rocks have much lower quartz contents than others. The thin sections have many characteristics in common.

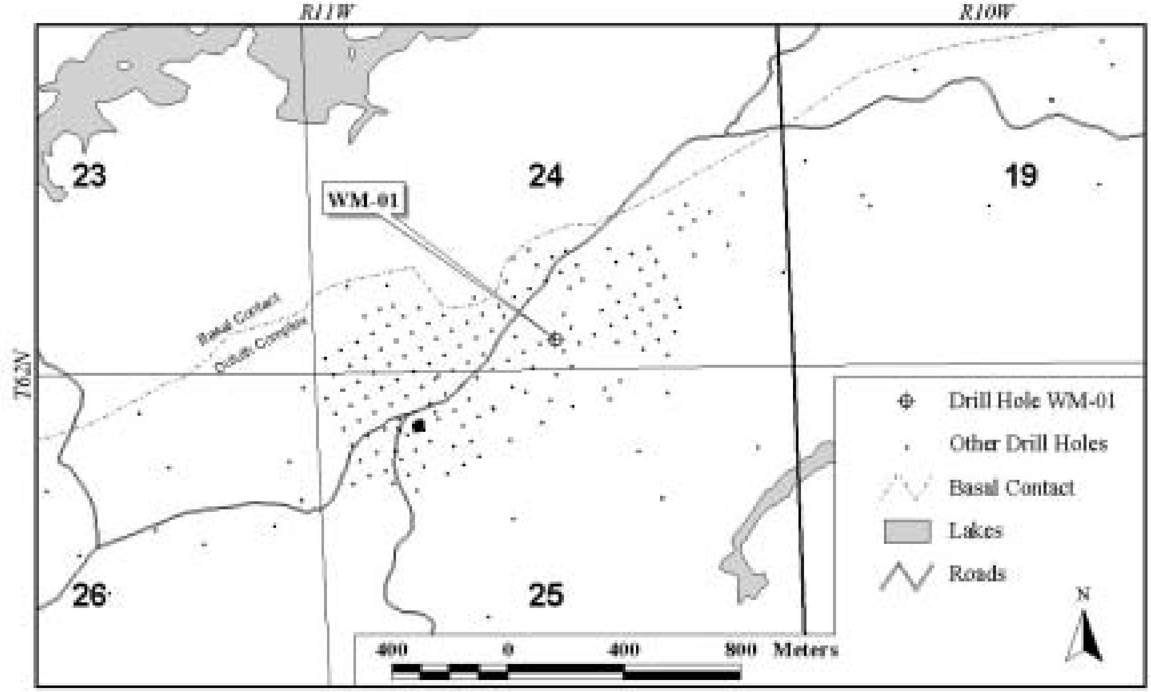

Figure 1. Location map of drill hole WM-1 in the Spruce Road Cu-Ni deposit.

Evidence for High Temperature Deformation from the Feldspars

The principal textural feature of all the GRB rocks is that they are strongly deformed. Typically, large (2 to 7 mm), strained grains of plagioclase and K-feldspar are embedded in a matrix of much smaller (0.1 to 0.2 mm), polygonal, and generally strain-free, quartz, plagioclase and K-feldspar. In all cases the domains of fine-grained, polygonal matrix define a planar fabric in the rock, i.e. the rocks are protomylonitic or mylonitic; thus, the large feldspar grains are porphyroclasts **Figure 2**. Typical deformation features in the porphyroclasts include (in order of increasing lattice strain), undulose extinction, deformation bands, offset twins, and polygonal subgrains. At low temperatures, plagioclase tends to respond to increasing strain of the lattice by, bending, kinking and fracturing; the development of polygonal subgrains in plagioclase is generally a high-temperature response to lattice strain. **Figure 2** shows that the small grains form a mortar texture around the feldspar porphyroclasts, but that the matrix grains are generally rather coarser grained (0.1 to 0.2 mm) than the subgrain structure in the porphyroclasts. Commonly, the matrix feldspar grains show evidence for grain boundary migration; some grains have rounded, bulged grain boundaries giving them a more granoblastic texture **Figure 3**. The recrystallization began in order to reduce the total strain energy in the lattice resulting from a high density of dislocations, but the last stage of recrystallization, which lead to the formation of straight or slightly curved grain boundaries (i.e. an equilibrium, or polygonal texture, **Figure 4**), was driven by need to reduce the total surface energy in the rock. In some rocks the porphyroclasts also show evidence of grain growth; 1) irregular boundaries have lobes enclosing polygonal matrix grains of different optical orientations, 2) the outer rims of some porphyroclasts are strain-free (no undulose extinction) and contain inclusions of other minerals notably orthopyroxene **Figure 5**, and 3) locally the strain-free rims on the porphyroclasts have crystallographic faces.

Descriptions of GRB rocks far to the west of the Duluth Igneous Complex also mention cataclastic or granulated textures, thus the possibility exists that some of the textures observed in the Wallbridge slides are inherited from their earlier, late-Archaean, pre-Duluth Igneous Complex history. However, the textural evidence appears to suggest that the deformation was younger, most likely synchronous with contact metamorphism and the emplacement of the Duluth Igneous Complex. The evidence includes:

1. Grain growth by grain boundary migration of some plagioclase crystals has trapped orthopyroxene inclusions (**Figure 6**), and orthopyroxene is not a mineral reported in the

Archaean mineral paragenesis of the GRB, it is recorded only from the contact aureole of the Duluth Igneous Complex.

2. Some orthopyroxene-bearing mafic rocks (norites W990768 and W990771) in the borehole may be part of the Duluth Igneous Complex injected into the GRB. These rocks have textures in which the plagioclase grains that locally form a cumulate framework are strained. They show undulose extinction and have smaller, strain-free, polygonal-shaped grains at their borders, indicating that these rocks underwent deformation and recorded the strain increments which occurred after a solid framework of plagioclase had formed.

The textures in norite W990771, and the degree of grain boundary adjustments shown by the feldspar porphyroclasts in the granitic rocks suggests that some, if not all, of the strain in these rocks occurred at high temperatures and, therefore, they are most likely related to emplacement of the Duluth Igneous Complex.

Evidence of High Temperatures from Orthopyroxene and Melt Textures

All the felsic/granitic rocks contain orthopyroxene (except sample W990767 which is extensively retrogressed and contains a greenschist facies mineral paragenesis) that is located in the finer-grained quartzofeldspathic matrix between the porphyroclasts. The orthopyroxene occurs three principal forms. In some rocks it occurs as isolated, relatively large (up to 1 mm), clear, subidioblastic to idioblastic grains with well developed crystal faces (**Figure 5**); some of these orthopyroxene grains contain small rounded inclusions of reddish brown biotite (**Figures 6 and 7**). Generally, orthopyroxene in the matrix occurs in association with biotite, and these textures are critical in interpreting the origin of the orthopyroxene. Some of the rocks contain skeletal porphyroblasts of orthopyroxene, or domains of fine-grained, xenoblastic orthopyroxene that are intergrown with polygonal-shaped, matrix quartz and plagioclase, although biotite may be nearby it is not in contact with both the quartz (or plagioclase) and the orthopyroxene. In many samples, e.g., **Figure 8** from sample W990776, biotite in surrounded by a rim of orthopyroxene. Collectively, these textures and the general observation that the orthopyroxene occurs interstitially to the feldspar porphyroclasts (exactly like biotite does in the GRB rocks farther west) suggests that orthopyroxene is the product of a biotite-breakdown reaction involving plagioclase and quartz. A key observation is that these metagranites do not contain cordierite, sillimanite or muscovite, probably indicating that the rocks are metaluminous, rather than strongly peraluminous. This limits the range of possible orthopyroxene-producing reactions. One possible reaction is:

biotite+quartz+plagioclase = orthopyroxene+K-feldspar+water (R1)

The subsolidus reaction (R1) occurs at temperatures of between 600 and 675°C in the pressure range 1 to 2.5 kbar (Hoffer and Grant, 1980), or 710 to 780°C (Vielzeuf and Holloway, 1988). However, temperatures would have been much higher if orthopyroxene was formed by a melt-producing reaction.

Evidence for Partial Melting in the Wallbridge Samples

Textures derived from partial melting are found in some contact aureoles and in the quenched products of partial melting experiments. These typically show corroded reactant minerals enclosed in a glass, which is the quenched melt. In incongruent melting, the solid reaction products may develop crystal facies where they have grown into the melt, but are xenoblastic where grown into the solid matrix. Pools of melt formed during melting have characteristic rounded or scalloped edges, which result from the partial dissolution of the reactant phases into the melt. More slowly cooled melts crystallize of course, and in this case the pools of melt have blocky outlines because coherent homogeneous nucleation results in euhedral overgrowths crystallized from the melt onto the solid phases surrounding the melt pools (see references in Sawyer, 1999). Crystallization of the pool of melt, or linked melt pools, means that upon solidification part of the former melt pool may be preserved by the shape of just one mineral, e.g., quartz, which crystallized from the melt. This is easy to understand. Imagine a fixed point inside a completely molten pluton, if the pluton were to freeze instantly the point would be in glass and so have exactly the same composition as the melt. However, if the pluton crystallized slowly, then the point would likely lie inside one of the minerals that crystallized from the melt and, therefore the composition of the point is no longer that of the melt, but most likely either quartz, plagioclase or K-feldspar. Furthermore, if cooling is slow, then another characteristic type of microstructure can develop as the melt trapped in grain boundaries reacts with the adjacent solid residual phases; typically, the anhydrous ferromagnesian minerals are replaced by a symplectic intergrowth of plagioclase, or quartz, and biotite. Examples of all these textures can be found in the Wallbridge samples.

Figure 9 shows an example of a partial melting texture; a corroded grain of biotite is surrounded by a fringe of quartz, which crystallized from the melt. The cuspate form of the quartz at the corners between plagioclase grains is typical of melting textures produced in experiments, and indicates the former presence of a pool, or film, of anatectic melt. Orthopyroxene occupies a concave grain boundary on the biotite, which is interpreted to be the corroded edge of the reactant biotite grain.

Figure 5 shows a texture indicating crystallization of orthopyroxene in the presence of melt. A large orthopyroxene crystal has well-developed crystal facies against quartz; this texture is interpreted to indicate that the orthopyroxene grew into a melt, and that the quartz was the last phase to crystallize from the melt in that part of the slide.

Most GRB samples contain orthopyroxene that is partially replaced by biotite; there are two types of replacement. In the first, the melt has reacted with the orthopyroxene during cooling and generated new biotite grains. **Figure 7** shows that the new biotite forms very small elongate needles that lie in deep embayments (site of corrosion, or reaction) in the orthopyroxene. This photomicrograph also shows overgrowths of plagioclase crystallized from the melt on cores of strained plagioclase porphyroclasts; the overgrowths have inclusions of rounded biotite which presumably were in the melt as it crystallized. Melt-solid reaction can also form large, reddish-brown, strain-free biotite grains at the edges of orthopyroxene **Figure 10**. In a second type of replacement texture, mats of small, randomly oriented brown biotite (possibly indicating a lower TiO_2 content, and hence lower temperature of formation) crystals enclose orthopyroxene crystals; this type of replacement does not appear to be associated with melt textures (**Figure 11**) and may, therefore, represent a subsolidus replacement.

Figure 12 shows a large reddish-brown biotite grain with crystal facies against quartz which has a shape interpreted to be a melt pocket; this biotite is not associated with orthopyroxene, and indicates that some biotite crystallized directly from melt (not as a replacement of orthopyroxene) after deformation had ended. The size and colour of the biotite is very similar to that replacing orthopyroxene in **Figure 10**, suggesting that they might have formed at similar temperatures.

Since melt textures and back reaction textures (i.e. textures indicating reaction between melt trapped in the grain boundaries and adjacent residual minerals, such as orthopyroxene) are common in the GRB thin sections, the borehole samples between W990762 and W990777 are interpreted to have been partially melted during contact metamorphism. Possible melt-producing reactions are:

biotite+plagioclase+quartz+vapour = melt+orthopyroxene+/- K-feldspar (R2)

and

biotite+plagioclase+quartz = melt+orthopyroxene+/- K-feldspar (R3)

According to Vielzeuf and Holloway (1988), the vapour-present reaction (R3) starts at about 770ºC for pressures below 2.5 kbars; the vapour-absent melting reaction (R4) starts at around 800ºC in the pressure range 1 to 3 kbars (Montel and Vielzeuf, 1997).

In most of the granitic rocks orthopyroxene is replaced by biotite, but in the orthopyroxene-rich mafic rocks (norites W990769, W990771, W770773 and W770774) it is replaced by clinoamphibole. However, this orthopyroxene is not of anatectic origin; it appears be an early cumulate phase and in some norite samples the plagioclase is also cumulate, but generally plagioclase is an intercumulus phase (**Figure 13**), along with biotite and amphibole. In some of the norites the last mineral to crystallize was quartz; this may be indicative of a mafic magma contaminated by felsic material.

Location and Orientation of the Silicate Anatectic Melt in the Granite Samples

Examination of the core shows that in most cases the foliation trace in the granites is close to the core axis, i.e. the foliation was subvertical to steeply dipping - assuming a vertical borehole. At the thin section scale the foliation is marked by domains of fine-grained polygonal quartz, feldspar, biotite and orthopyroxene which anastomose around the elongate feldpar porphyroclasts, **Figure 2**. Textures indicating the former presence are anatectic melt occur in this fine-grained matrix, typically along the sides of the porphyroclasts, but the largest concentrations of trapped melt occur at the ends of the porphyroclasts, in a position that corresponds to a pressure shadow, **Figure 14**. Thus, the melt in the GRB samples was located in the matrix between feldspar porphyroclasts and, therefore, had a principally subvertical orientation. The subvertical orientation of anatectic melt films and pools in the GRB samples is consistent with the orientation of melt-filled fractures seen elsewhere. Steeply-dipping, melt-filled extension fractures in the Peter Mitchell mine and at Dunka Pit, together with the conjugate sets of melt-filled shears present at Linwood Lake, support a broadly subhorizontal (layer-parallel in the Biwabik and Virginia Formations) extension and subvertical (layer-normal) shortening in the footwall of the Duluth Igneous Complex. However, there does not appear to be a steeply-dipping protomylonitic or mylonitic foliation in the metasedimentary rocks lying under the intrusion. The protomylonitic/mylonitic foliation in the Wallbridge GRB samples might be related to faults formed in the footwall during emplacement of the Duluth Igneous Complex.

Location of Sulphides and Oxides in GRB Samples

Many of the granites contain both sulphide and oxide minerals. Typically, ilmenite occurs as blebby exsolutions intergrown with pyrhottite. In some samples another sulphide, possibly arsenopyrite, is also present. Magnetite blebs occur in some of the sulphides.

Sulphides and oxides are located in the fine-grained, quartz-feldspar matrix between the plagioclase porphyroclasts. They occur as small (0.05mm) grains and aggregates and as much larger (10 mm) lenses and veins in the matrix. In some samples, e.g., W770763 and W990776 sulphides; W990777 sulphides and oxides, and in the core, the sulphide (or oxide) veinlets are partially linked into a more extensive array **Figure 15**, that appears to have been better connected in the vertical direction, rather than laterally. That is, the distribution and linking of the sulphide veinlets may be the vestige of a former permeability that was strongest in the vertical direction.

Some inclusions of feldspar and orthopyroxene in the sulphides in samples W990763 and W990776 have well developed crystal faces, suggesting that they might have grown in a melt rather than a solid. If the sulphides (and/or oxides) occupy a fracture that formed in an already solidified granite, then one might expect the feldspar and orthopyroxene crystals to have been broken before being incorporated. Thus, it may have been that plagioclase and orthopyroxene were growing in a silicate melt which coexisted with, or was displaced by, a sulphide/oxide melt. In some cases sulphide has penetrated along the cleavage planes of plagioclase inclusions and in the host wallrock. Some orthopyroxene grains in the sulphides (W990763) are rounded and have rims of quartz and feldspar (relic of silicate melt?), whereas other orthopyroxene grains are corroded and have narrow alteration rims of clinoamphibole.

In the norite sample W990774, the sulphide and oxide patches have the same relationship to the orthopyroxene as the plagioclase, biotite and amphibole, i.e. they are intercumulate, **Figure 16.** Sample W990772 (**Figure 3**) is interesting, it has small grains of oxide dispersed throughout the fine-grained quartz-feldspar matrix. Some oxides occur as a fine-grained dust, and around these patches the matrix is especially fine-grained, i.e. grain growth has been inhibited. Elsewhere, the oxides form large patches, up to 3mm long, although 0.2mm is typical; these larger patches occur with biotite, orthopyroxene, quartz and plagioclase, and can be linked together by trains of oxides in the matrix. The overall distribution of oxides in W990772 (**Figure 3**) is similar to that in W990763 (**Figure 15**) although not connected as well. The trains and patches of sulphides and oxides define a net-like pattern that is parallel to the foliation and distributed relics of silicate melt in the rock. Possibly the disseminated and larger patches of opaques indicate where an oxide or sulphide melt moved through the rock. Or alternatively, are the disseminated sulphides and oxides places where the oxide/sulphide melt did not pass and sweep out the interstitial oxides?

CONCLUSIONS

The feldspar textures indicate that the GRB rocks, and some of the norites, in the borehole were deformed and recrystallized principally by crystal-plastic processes (dislocation creep and recovery) at high temperatures. The streaked-out, fine-grained biotite aggregates in W990776 located in the polygonal-textured, quartz-feldspar matrix indicates that biotite was also deformed and recrystallized. However, textural relationships between biotite and orthopyroxene indicate that biotite was unstable during the non-coaxial shearing. The widespread presence of relict melt textures indicates that the biotite breakdown reaction produced melt, comparison with recent melting experiments suggests that contact metamorphism and deformation occurred at temperatures that could have been as high as 800°C. Silicate partial melt formed by contact metamorphism was located in the fine-grained matrix between the feldspar porphyroclasts. Melting started during the deformation, but final stages of crystallization of the melt occurred after the deformation. The distribution of sulphide and oxide minerals is very similar to that of the anatectic silicate melt, and some textures could indicate that the rocks contained silicate and sulphide/oxide melts at the same time.

REFERENCES

Hoffer, E. & Grant, J.A. 1980. Experimental investigation of the formation of cordierite-orthopyroxene paragenesis in pelitic rocks. Contributions to Mineralogy and Petrology 73: 15-22.

Montel, J.-M. & Vielzeuf, D. 1997. Partial melting of metagreywackes, Part II. Compositions of minerals and melts. Contributions to Mineralogy and Petrology 128: 176-196.

Prince, L.A. & Hanson, G.N. 1972. Rb-Sr isochron ages for the Giants Range granite northeastern Minnesota. Geol. Soc. Amer. Mem. 135: 217-225.

Sawyer, E.W. 1999. Criteria for the recognition of partial melting. Phys. Chem. Earth (A) 24: 269-279.

Sims. P.K. & Viswanathan, S. 1972. Giants Range Batholith. In: *Geology of Minnesota: A Centennial Volume* (Eds; Sims, P.K. & Morey, G.B.) Pp120-139. Minnesota Geol. Surv.

Vielzeuf, D. & Holloway, J.R. 1988. Experimental determination of the fluid-absent melting relations in the pelitic system. Contributions to Mineralogy and Petrology 98: 257-276.

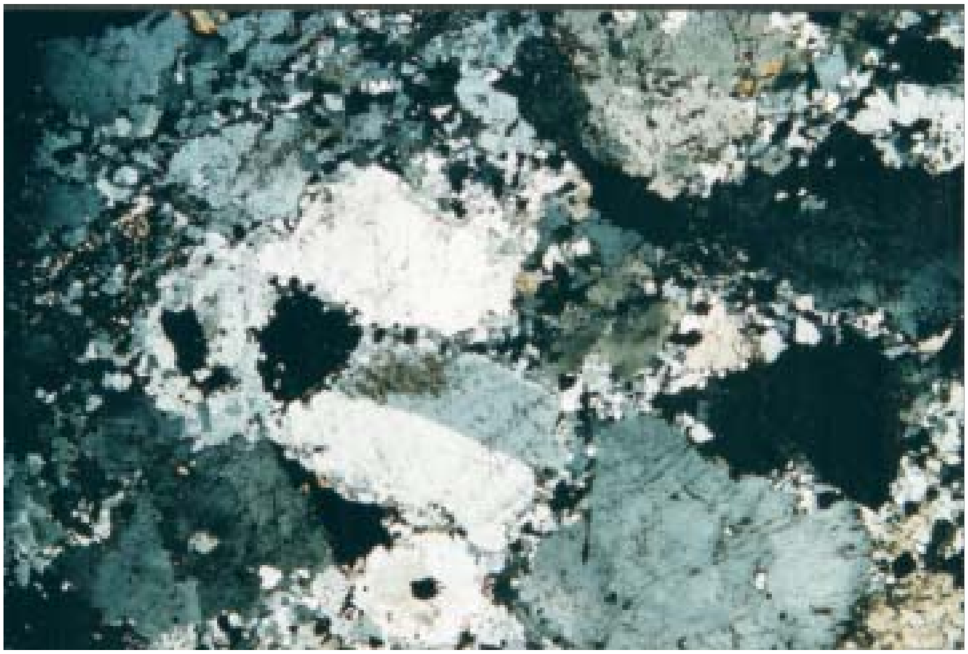

Figure 2. Typical protomylonitic or mylonitic texture of the Giants Range Batholith samples. Porphyroclasts of plagioclase showing strain features such as, undulose extinction, bent twin planes and subgrains, occur in a matrix of fine-grained, polygonal, strain-free quartz and feldspar. Biotite and orthopyroxene are in the fine-grained matrix. Sample W990777.

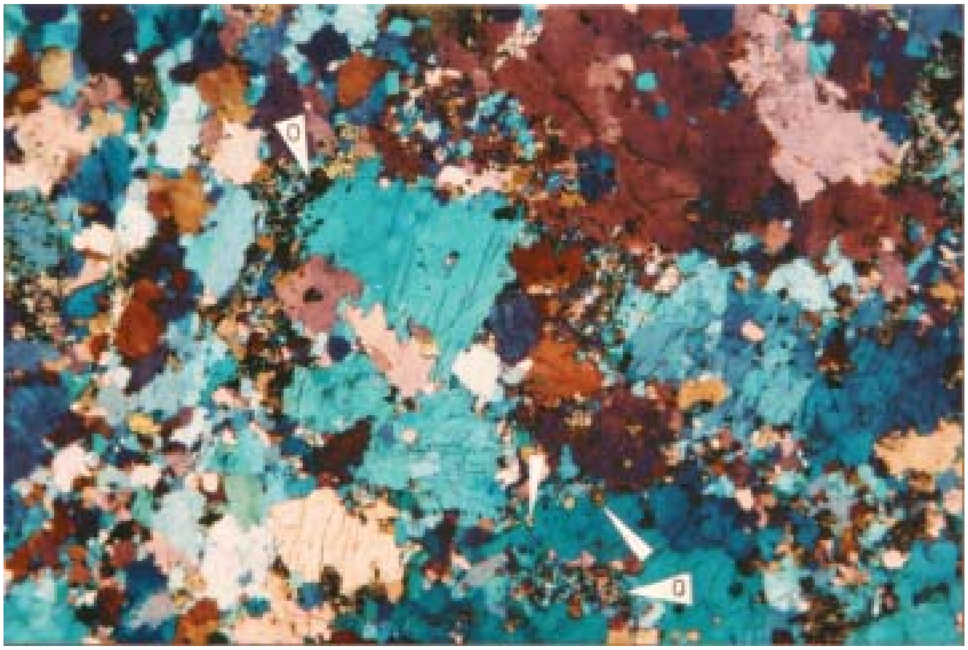

Figure 3. Porphyroclasts of feldspar in a fine-grained, granoblastic matrix of quartz and feldspar. Orthopyroxene inclusions (arrowed) occur in the rims of some plagioclase porphyroclasts and indicate porphyroclast growth into the matrix. Fine-grained opaque minerals (O) are locally abundant and have inhibited growth of the matrix grains. Sample W990772; one wave plate.

Figure 4. Well developed polygonal texture in the quartz-plagioclase matrix. Orthopyroxene (O) crystals in the matrix are subidioblastic. The matrix texture indicates recrystallization and textural equilibration, but the porphyroclasts still retain strain features. Sample W990760.

Figure 5. Recrystallization of matrix grains and growth of strain-free rims containing orthopyroxene and biotite on strained porphyroclast cores (A). Some orthopyroxene (O) and plagioclase crystals (C) have straight crystal faces against quartz (D). The quartz shape indicates that it was a late crystallizing phase, hence orthopyroxene and plagioclase developed crystal faces because they grew into a melt pocket. Sample W990763; one wave plate.

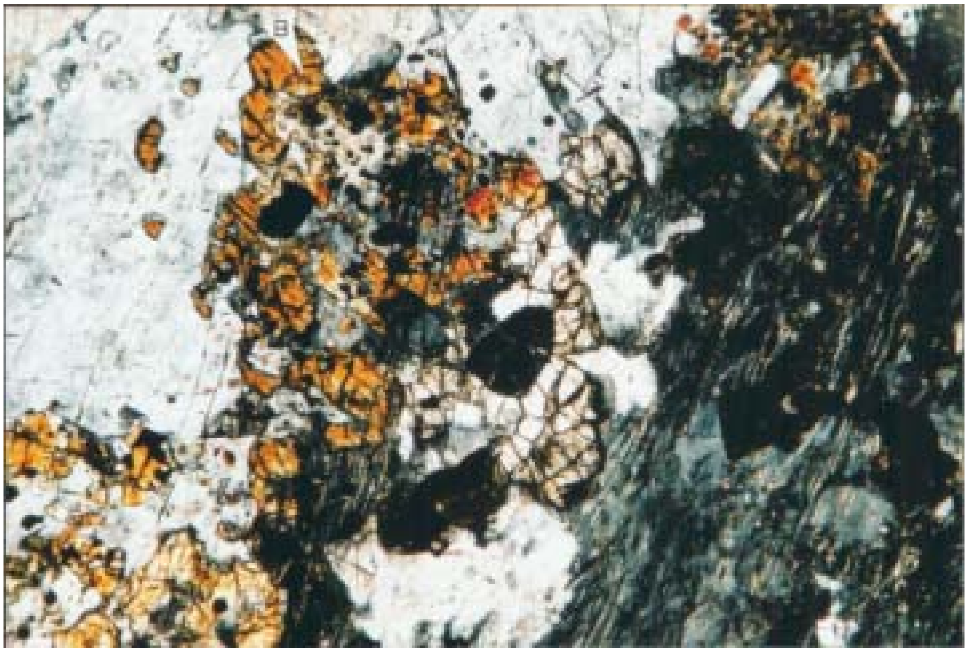

Figure 6. Clear orthopyroxene poikiloblast containing scattered, round inclusions of reddish biotite (arrow). The orthopyroxene and adjacent rounded biotite grains are inclusions in the outer, strain-free part of a large plagioclase porphyroblast. Sample W990769.

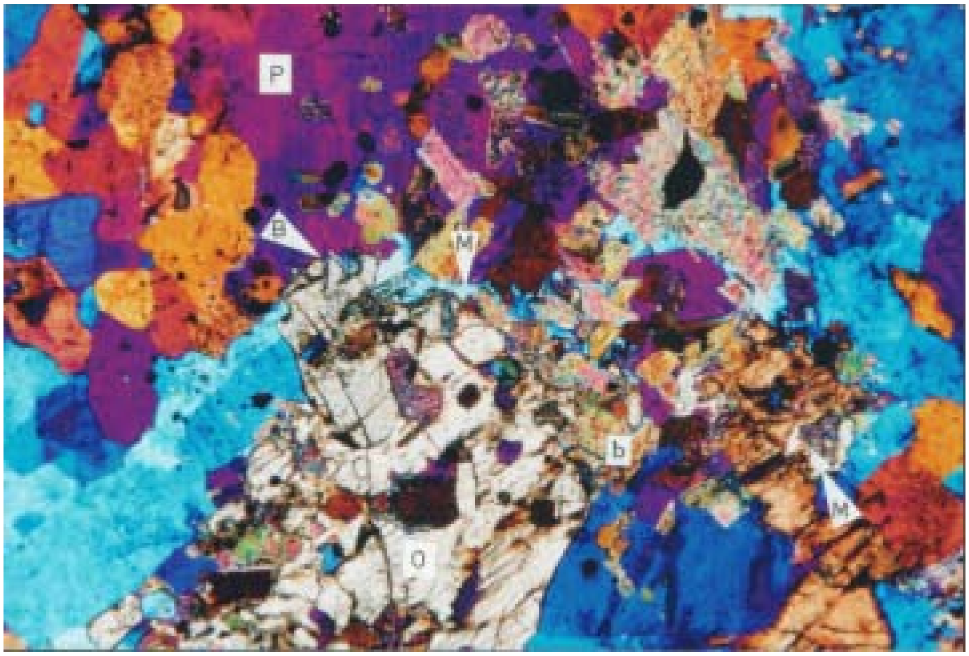

Figure 7. A large orthopyroxene (O) crystal containing corroded inclusions of biotite is partially surrounded by film of quartz and plagioclase (M) which preserves the shape of a melt pool. The orthopyroxene partly reacted with the melt and is replaced by biotite blades (B) that penetrate deeply into the crystal, and by a fringe of larger biotite crystals (b). The rim of plagioclase porphyroclast (P) contains orthopyroxene and biotite inclusions. Sample W990764; one wave plate.

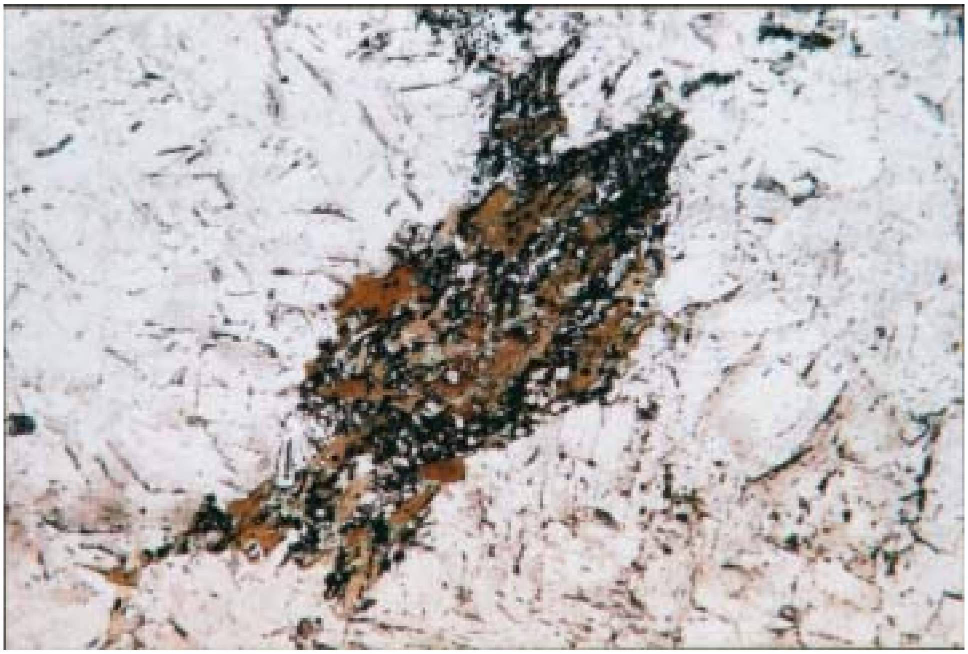

Figure 8. Biotite in the fine-grained, quartz-feldspar matrix partially replaced by orthopyroxene, suggesting that orthopyroxene formed by the breakdown of biotite+plagioclase+quartz. Sample W990776.

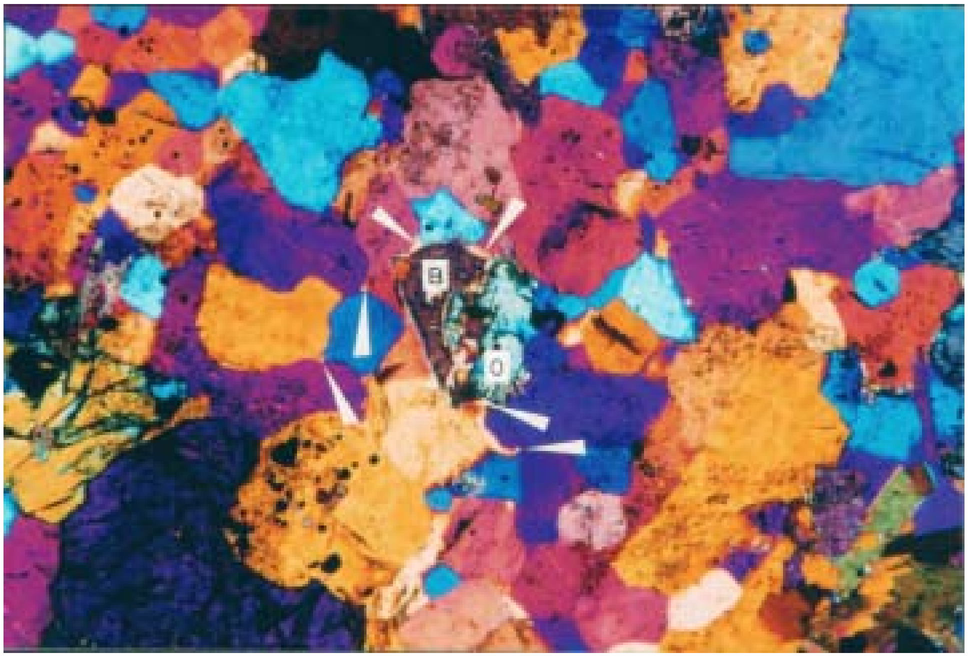

Figure 9. Textural evidence for a melt-producing reaction such as, biotite+plagioclase+quartz = orthopyroxene+melt. Corroded biotite (B) is separated from orthopyroxene (O) by a thin film of quartz (arrowed) which extends to nearby biotite-plagioclase, plagioclase-quartz and plagioclase-plagioclase grain boundaries. Note the cuspate shape of the quartz at multigrain contacts. Sample W990764; one wave plate.

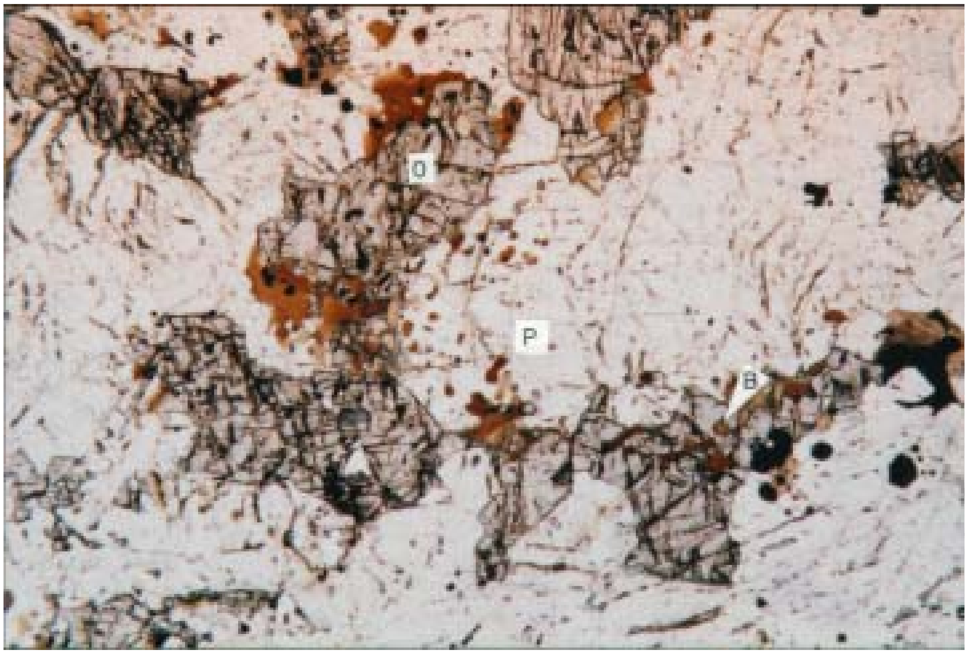

Figure 10. Large subidioblastic orthopyroxene crystal (O) replaced at the edges by large strain-free biotite grains, interpreted to result from reaction between trapped melt and the residual orthopyroxene. Inclusions of corroded biotite occur in the orthopyroxene and adjacent feldspar crystals. Felsic part of sample W990768.

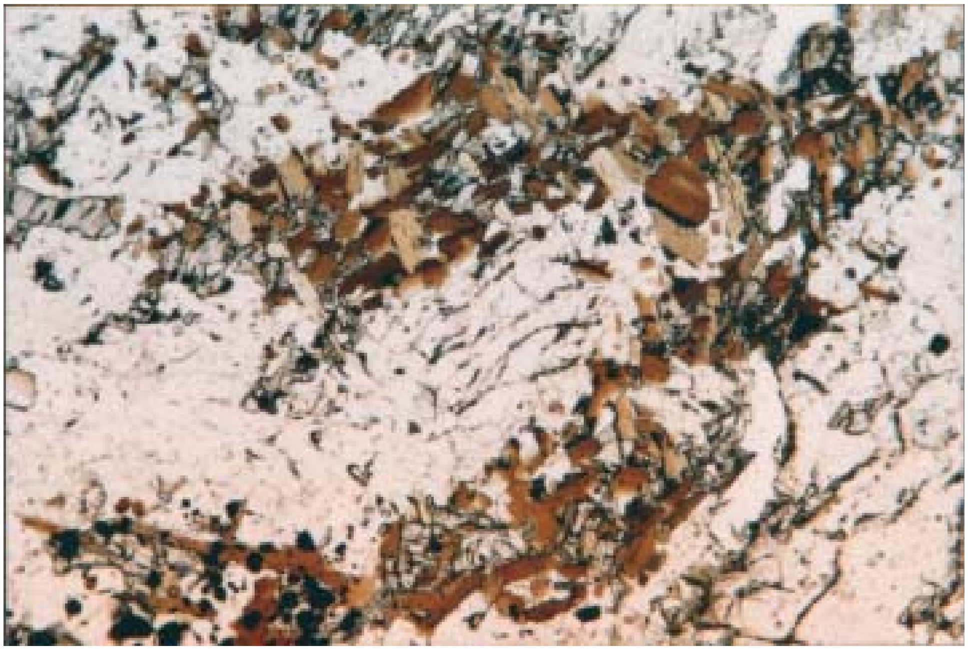

Figure 11. Orthopyroxene replaced by a mat of small, brownish biotite crystals. This may be a recrystallized melt-orthopyroxene texture, or it may be a subsolidus replacement of orthopyroxene. Felsic part of sample W990768.

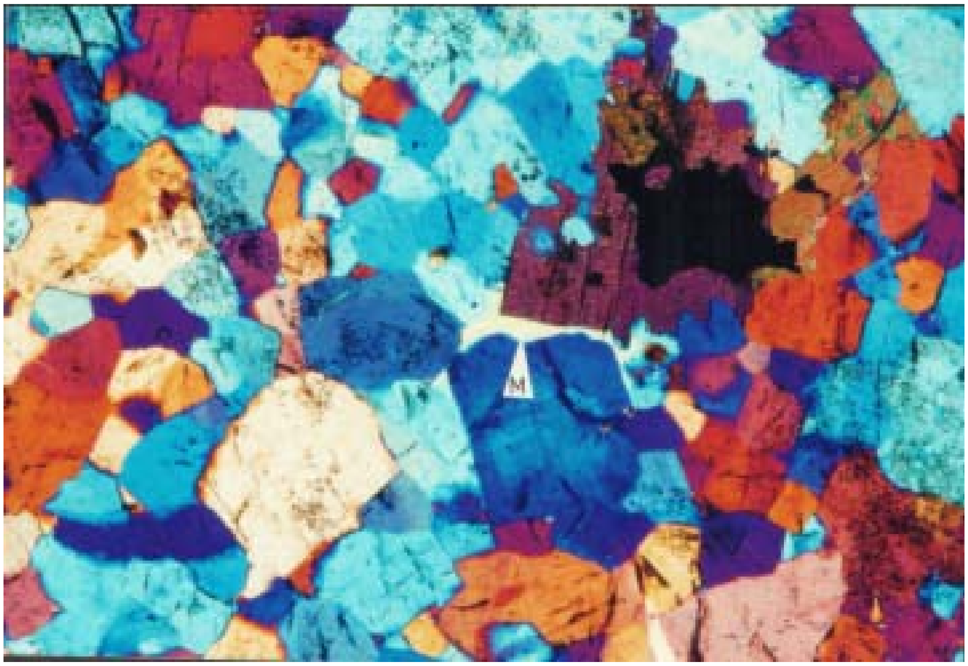

Figure 12. Melt pocket (M) outlined by the shape of infilling quartz. Note the straight sides to the biotite crystal projecting into the melt pocket may indicate that the biotite grew from the melt. Sample W990764; one wave plate.

Figure 13. Norite with cumulate orthopyroxene (O) and intercumulate plagioclase (P) and amphibole (A). Sample W990768.

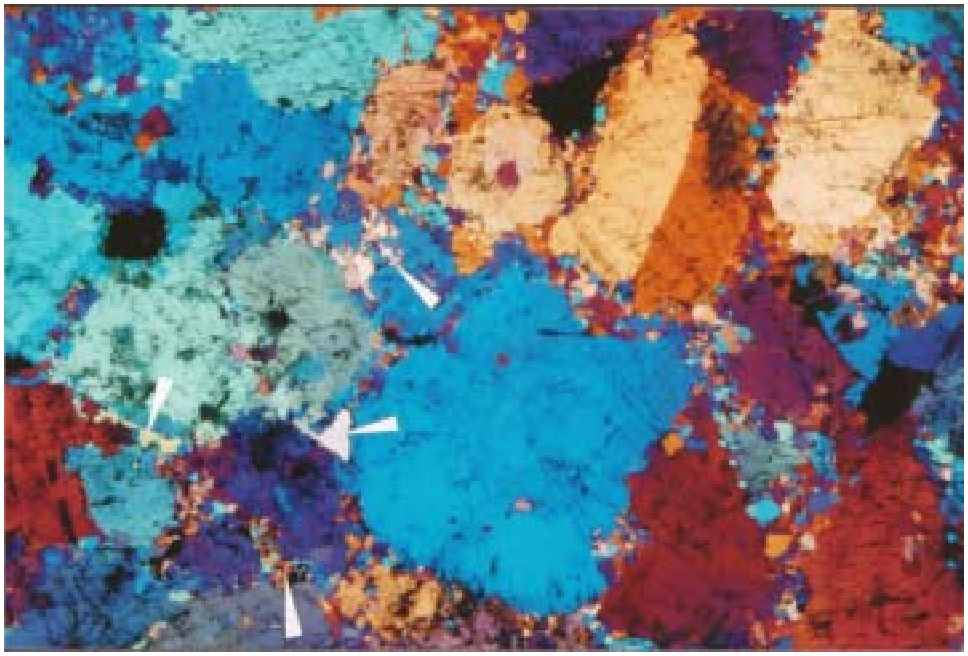

Figure 14. Tightly packed plagioclase porphyroclasts with narrow rims of polygonal quartz-feldspar matrix (mortar texture). Larger quartz grains (arrowed) outline blocky melt pockets in the matrix. The distribution of these melt pockets in the thin section shows that they occur along the edges of the porphyroclasts, but the largest are located at the corners, or junctions, of three or more porphyroclasts, i.e., in the pressure shadow regions. Sample W990777; one wave plate.

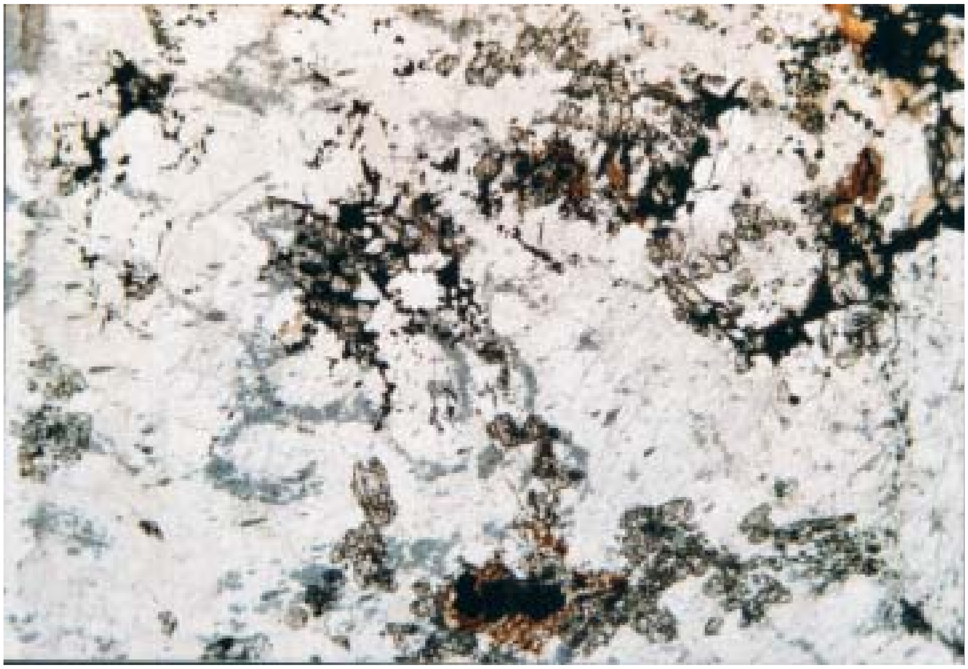

Figure 15. Distribution of sulphide minerals in a typical Giants Range Batholith sample follows the fine-grained quartz-feldspar matrix around the feldspar porphyroclasts. The distribution of sulphides and oxides is similar to that of the silicate melt in the GRB Sample W990763.

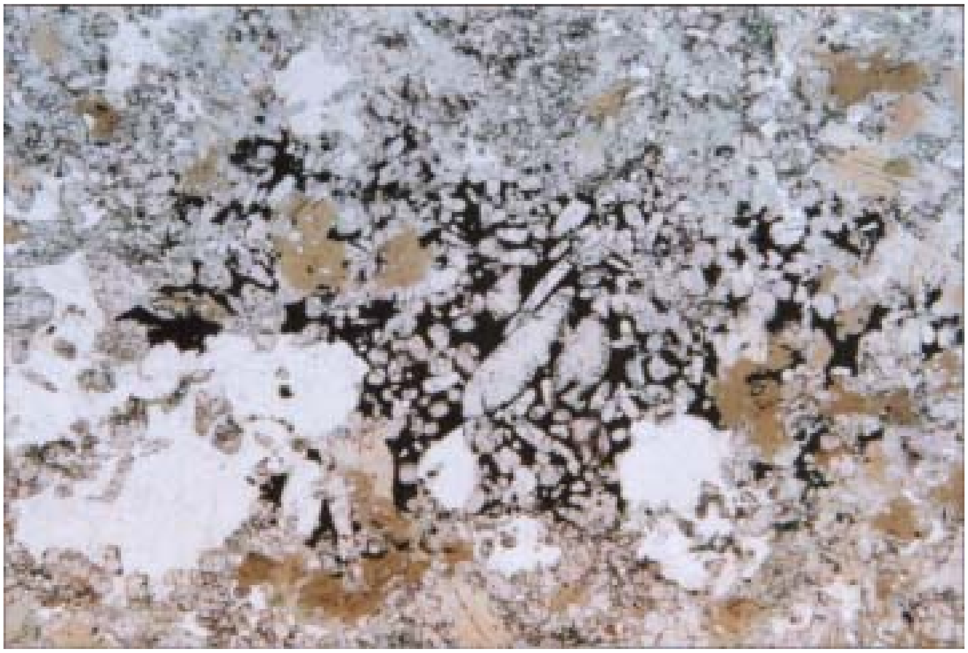

Figure 16. Norite with interstitial sulphides containing orthopyroxene inclusions. Sample W990774.