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Petrology of the metamorphic rocks exposed in the Assynt area, Sutherland, NW Scotland

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) and described the mineralogy and petrology of a suite of meta-igneous and metasedimentary rocks exposed in the Assynt district, Sutherland, northwest Scotland.

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Summary

This report describes the mineralogy and petrology of a suite of metamorphic rocks exposed in the Assynt area of Sutherland, northwest Scotland. The work forms part of the Moine Thrust Project and utilised the British Geological Survey's extensive collection of Scottish rocks and thin sections.

1 Introduction

This report describes the mineralogy and petrology of a suite of metamorphic rocks exposed in the Assynt area of Sutherland, northwest Scotland. Approximately 250 thin sections were examined during this study with the work forming part of the Moine Thrust Project of the British Geological Survey's Integrated Geological Survey (North) Programme.

2 Thin Section Descriptions

2.1 META-IGNEOUS ROCKS

2.1.1 Hornblende schistose metabasic rock

The hornblende schistose metabasic rocks (Plate 1) are, in general, fine- to very fine-grained, moderately to highly foliated rocks (S2750a; S2750b; S2751a; S2751b; S2752a; S2755a; S2741; S9776; S9763; S8388; S2932; S2952) which comprise an inequigranular assemblage of hornblende, plagioclase and quartz with minor to trace amounts of epidote, clinozoisite, titanite and opaque minerals. Secondary alteration/retrogression of this amphibolite facies metamorphic assemblage resulted in the development of very fine-grained chlorite, sericite, clay minerals, carbonate and actinolitic amphibole.

The tectonic fabric developed within these rocks is defined by elongate to lenticular aggregates or ribbons of quartz and plagioclase enclosed within anastomosing domains of granular to shape aligned amphibole (Plate 1a and b). Both quartz and plagioclase are granular in appearance and exhibit very little evidence of intracrystalline deformation, possibly due to the annealing of the schistosity after deformation had ceased. In some samples the schistosity is weakly domainal in nature. The asymmetry and locally developed SC-geometry of this schistose foliation yields an apparent sinistral sense of shear (S2750b; S2751b; S2752a). However, all the thin sections of hornblende schist examined during this present study are not orientated so the overall geographical sense of shear recorded by these rocks is unknown. Both the S and C components of the fabric are defined by variably aligned, fine-grained amphibole. In sample S9763, the schistosity is deformed by a weakly developed, open crenulation cleavage. No obvious new mineral growth has been recognised associated with the imposition of this crenulation cleavage.

Hornblende is the dominant mineral phase forming up to 75 to 85% of the total rock. It is strongly pleochroic and ranges from yellow-green, through moderate green to dark blue green in colour. Three textural varieties of amphibole have been recognised within these schistose rocks: (1) larger (up to 1.5 mm in size), anhedral, subhedral to irregular relict crystals; (2) fine- to very fine-grained, granular looking amphibole which is the dominant textural form and was observed enclosing the larger relict crystals; and (3) later, subhedral to euhedral, elongate to lozenge-shaped randomly orientated crystals which post-date and cross cut the schistosity. It is possible that the growth of the later (type 3) amphibole crystals accompanied the annealing of the earlier developed tectonic fabric. In some rocks (S2750b; S2751a) the early formed hornblende porphyroblasts or porphyroclasts are wrapped by the schistosity. This microtextural relationship suggests that growth of these porphyroblasts either pre-dated or was synchronous with the imposition of the main foliation. However, in sample S2755a, the margins of the porphyroblasts were observed clearly cross cutting the enveloping matrix foliation, suggesting that hornblende porphyroblastesis continued after deformation had ceased (possibly accompanying the annealing of the foliation). The porphyroblast may locally possess a dusty looking (in plane polarised light) core containing numerous very fine-grained inclusions of an opaque mineral. In sample S2755a the hornblende porphyroblasts are enclosed within weakly developed pressure shadows composed of quartz and plagioclase. The porphyroblasts may also show some evidence of intracrystalline deformation (kinking, undulose extinction) and microboudinage (S9776).

In contrast to the majority of the hornblende schistose metabasic rocks, sample S9763 contains rounded to elliptical porphyroblasts or porphyroclasts of plagioclase. These porphyroblasts are wrapped by the matrix foliation and variably replaced by secondary carbonate. Minor patchy alteration or retrogression (greenschist facies) of the hornblende schists led to the variable replacement of amphibole to chlorite and carbonate. In sample S9776, the hornblende porphyroblasts are locally enclosed within a fine-grained reaction rim of chlorite and/or actinolitic amphibole. Trace to minor amounts of very fine-grained, granular to rod-shaped clinozoisite and epidote are present included within plagioclase. Titanite is a minor accessory phase and may be absent in some rocks (S2751a).

2.1.2 Coarse-grained epidote-hornblende-actinolite schistose metabasic rock

A thin section (S2950) of a coarse-grained schistose metabasic rock (Plate 2a and b) was examined during this present study. It comprises an inequigranular assemblage of actinolitic amphibole, hornblende, diopside, epidote and plagioclase with minor amounts of carbonate, quartz and biotite.

Approximately 70% to 80% of the total rock is composed of amphibole forming large 2.5 to 3.5 mm long relict, zoned hornblende porphyroblasts which are wrapped by the matrix foliation (Plate 2a and b). The hornblende porphyroblasts are rounded to elliptical in shape and possess a green-brown core grading into a pale green rim, possibly reflecting their partial recrystallisation to actinolitic amphibole. The porphyroblasts possess a shadowy to undulose extinction and are enclosed within variably developed asymmetrical pressure shadows. The pressure shadows are composed of elongate, aligned to randomly orientated actinolite with minor amounts of granular to cryptocrystalline plagioclase and quartz. Minor, rounded to irregular, relict diopsidic clinopyroxene crystals and rare biotite flakes were noted included within the cores of these hornblende porphyroblasts. Relict diopside porphyroclasts were also noted, wrapped by the matrix foliation.

The well developed schistosity present within the matrix of this metabasite is defined by shape aligned actinolitic amphibole crystals and granular to rod shaped epidote. The asymmetry of this foliation and asymmetrical pressure shadows developed upon the hornblende porphyroblasts yields an apparent sinistral sense of shear. Actinolite forms anhedral to irregular, elongate crystals which exhibit a weakly developed pleochroism ranging from colourless to very pale green. Intracrystalline deformation of actinolite resulted in the variable development of a sweeping to undulose extinction. Actinolite was also noted forming pseudomorphs after the hornblende porphyroblasts. The original hornblende appears to have initially been replaced by several large actinolite crystals which are themselves progressively recrystallised to a finer grained aggregate of actinolitic amphibole.

Epidote forms anhedral to irregular, equant to elongate crystals which are variably aligned within the plane of the schistosity (Plate 2a). Epidote is weakly pleochroic ranging from pale yellow to colourless. Traces of secondary carbonate, probably replacing plagioclase, are present within the pressure shadows.

2.1.3 Plagioclase-hornblende schistose metabasic or calc-silicate rock

In thin section the plagioclase-hornblende schistose rocks (Plates 2c, 2d, 3a and 3b) are, in general, fine-, very fine- to rarely medium-grained, quartzose metabasic or calc-silicate rocks (S2748; S2747; S3050a; S48157; S8408a; S2754a; S4452) which comprise an inequigranular assemblage of plagioclase, amphibole, quartz and epidote or clinozoisite. Minor to accessory phases present include biotite, opaque minerals, titanite, apatite and allanite.

These weakly to highly foliated rocks are mainly composed of very fine-grained to cryptocrystalline plagioclase and quartz with elongate to lenticular aggregates or clusters of slightly coarser grained amphibole (Plate 2 c and d). Quartz is strained to unstrained with a variably developed undulose extinction. Quartz was also noted forming narrow ribbons aligned within the plane of the schistosity. The foliation present within these rocks is defined by the shape alignment of hornblende crystals and aggregates of finer grained amphibole. A variably developed compositional banding within these rocks is defined or preserved by alternating amphibole and plagioclase-rich layers or domains (S3050a; S48157; S4452). The main foliation developed within these rocks is developed parallel to this compositional banding. Amphibole is pale green to blue green in colour and forms anhedral to weakly subhedral granular crystals with a variably developed pleochroism. Elongate to occasionally lozenge shaped amphibole crystals were also noted in some samples (S2747). In sample S2754a, hornblende was also noted forming asymmetrical porphyroblasts or porphyroclasts up to 1.0 mm in length which are wrapped by a well developed schistosity (Plate 3 a and b). The margins of these porphyroblasts locally overgrow the enveloping foliation indicating that metamorphism and porphyroblastesis continued after deformation had ceased; this probably accompanied the annealing of the fabric. The asymmetry of the foliation and hornblende porphyroblasts yields an apparent sinistral sense of shear.

Rounded to lenticular aggregates of very fine-grained, granular to rod-shaped zoisite/clinozoisite crystals are developed in some rocks (S2747) and may represent pseudomorphs after plagioclase porphyroblasts/porphyroclasts. In sample S48157, elliptical to lenticular augen or porphyroblasts of plagioclase are preserved. These porphyroblasts are wrapped by the hornblende foliation (Plate 2c and d). Secondary alteration or retrogression resulted in the patchy replacement of this amphibolite facies assemblage by dusty fine-grained carbonate and sericitic white mica. Trace amounts of titanite was noted forming irregular rims upon opaque minerals. Both titanite and the opaque minerals are spatially related to amphibole.

Sample S8408a is distinguished from the other rocks included within this lithological group by the presence of green biotite. Biotite is associated with irregular, rounded to elliptical aggregates of slightly coarser grained hornblende. These aggregates appear to represent pseudomorphs after a pre-existing ferromagnesian mineral. The outer margins of the aggregates are composed of finer grained granular amphibole which contains small inclusions of granular epidote (± opaque minerals). In sample S3050a the compositional banding is deformed by a small scale (2.0 to 3.0 mm in amplitude), tight to isoclinal intra-folial fold, with the fold axial surface parallel to the undeformed layering. A weakly developed axial planar foliation is developed within the hinge area of this microfold. Small scale (off-set of *c*. 1.0 to 1.5 mm), late brittle microfaults (S3050a) and/or veinlets of cataclasite (S48157) have been noted in some rocks. Trace amounts of carbonate may be present, replacing plagioclase.

2.1.4 Quartz-bearing metagabbro or melanocratic metadiorite

In thin section these metagabbros to metadiorites (Plate 3 c and d) are, in general, fine- to coarse-grained, massive, variably recrystallised rocks (S2744; S2743; S8414; S2746; S3907; S8387; S2935; S2760; S55257; S2951) which comprise an inequigranular assemblage of plagioclase, hornblende and clinopyroxene with minor amounts of quartz. Other minor to accessory phases present include epidote, biotite, K-feldspar, opaque minerals and apatite. Alteration resulted in the development of a fine-grained secondary assemblage dominated by sericitic white mica, clinozoisite, muscovite, zeolite and chlorite.

Although metamorphosed the original igneous texture can be clearly recognised in some rocks, comprising an open crystal framework of randomly orientated plagioclase laths with intergranular, locally ophitic clinopyroxene (Plate 3 c and d). In contrast, in the most intensely recrystallised/metamorphosed rocks this primary igneous texture has been largely overprinted. Although typically massive, a weak to well-developed pre-full crystallisation fabric (PFC) is developed in some samples (S8387; S2760). This primary igneous foliation is defined by the variable shape alignment of plagioclase laths (Plate 4a). Interstitial quartz within these foliated rocks exhibits very little, or no evidence of intracrystalline deformation. The intensity of the fabric may vary due to the variable collapse of the primary crystal framework which formed prior to full crystallisation of these gabbroic to dioritic rocks. Deformation resulting in the collapse of this framework may have resulted in the curved nature of some of the plagioclase laths as they were bent around neighbouring more rigid pyroxene crystals (S2760); the latter now replaced by an aggregate of amphibole.

Pyroxene is variably replaced or completely pseudomorphed by either single crystals or an aggregate of fine-grained amphibole (Plate 3 c and d). Amphibole forms anhedral to occasionally subhedral, twinned (simple) and untwinned crystals which possess a moderately developed pleochroism ranging from yellow-green-brown, through moderate green to blue green. The larger hornblende crystals locally possess a sieve textured core composed of intergrown amphibole and plagioclase (Plate 4b and c). These cores may represent pseudomorphs after relict pyroxene, with the mimetic growth of hornblende locally preserving the original ophitic nature of clinopyroxene. Early formed green to green brown hornblende crystals are variably recrystallised to a finer grained aggregate of paler green actinolitic amphibole. A locally developed darker coloured margin to these amphibole aggregates may preserve an earlier developed reaction rim on pyroxene (S8387) (Plate 4b and c). The original planar crystals faces of hornblende and/or clinopyroxene are locally preserved by the mimetic growth of this secondary amphibole. However, in general, the boundaries between these amphibole aggregates and the surrounding plagioclase are irregular with amphibole having grown into the adjacent feldspar. In sample S2746 the primary ferromagnesian mineral (probably pyroxene) has been replaced by an aggregate of medium- to fine-grained, sieve textured, anhedral amphibole crystals which contain rounded inclusions of plagioclase.

Plagioclase forms anhedral to subhedral, zoned, twinned and untwinned, prismatic and lath-shaped crystals (range up to *c*. 3.0 mm in length) which exhibit preferential alteration of their cores to sericitic white mica. In some cases, plagioclase crystals possess a distinct anhedral to subhedral core indicating the possible two stage growth of feldspar. In sample S2743, plagioclase is very highly altered (sassuratised) and contains small granular to rod-shaped crystals of clinozoisite and amphibole. This rock also contains trace amounts of white mica and a zeolite mineral infilling some of the interstitial to intersertal spaces between plagioclase and amphibole.

The remaining intergranular areas are filled by plagioclase and minor to accessory quartz. Quartz apparently developed as a primary igneous phase and typically occurs filling wedge shaped interstitial areas between plagioclase laths. In contrast, in samples S3907 and S8387, quartz was note forming anhedral, intergranular poikilitic crystals. The presence of apparently primary quartz suggests that the protolith was a quartz-bearing gabbro or melanocratic diorite; if the latter is correct then some of the hornblende may also be primary igneous in origin. However, trace amounts of K-feldspar is only apparent in a small number of the samples examined; for example sample S8414 contains trace amounts of microcline. Sample S8414 is distinguished from the other metagabbroic to dioritic rocks by the presence of 1.0 to 2.0 mm in size, poikilitic or poikiloblastic green coloured biotite flakes. These poikiloblasts locally include or overgrow the actinolitic amphibole pseudomorphs after pyroxene. Traces of brown biotite was noted within samples forming rims upon opaque minerals (S8387) and as inclusions within relict pyroxene (S2760).

Minor to trace opaque minerals are present within these melanocratic rocks and may locally form irregular skeletal crystals. Trace titanite present in some rocks forms skeletal to lozenge-shaped crystals.

2.1.5 Plagioclase-hornblende schistose metabasic rock

A small number of thin sections of a highly foliated, fine-grained plagioclase-hornblende metabasic rock have been examined (S2749a; S2749b). These highly schistose rocks are composed of an inequigranular assemblage of hornblende, plagioclase and quartz with accessory titanite and opaque minerals. Alteration and hydration of these metabasic rocks resulted in the development of a fine-grained secondary assemblage dominated by sericitic white mica, carbonate and epidote or clinozoisite.

The well developed foliation is defined by aligned amphibole crystals as well as lenticles and ribbons of very fine-grained plagioclase and quartz. Lenticular aggregates and chains of granular looking titanite are aligned within the plane of the schistosity. This possibly mylonitic fabric wraps around lenticular porphyroblasts or aggregates of slightly coarser grained plagioclase. The plagioclase porphyroblasts or porphyroclasts (up to 1.5 mm in size) are highly altered to, or pseudomorphed by sericite and/or single crystals of white mica. These pseudomorphs may also contain anhedral, granular, very fine-grained epidote or clinozoisite. The mimetic growth of these alteration products locally preserves multiple and simple twins developed within the original plagioclase. Replacement of plagioclase by white mica clearly post-dated deformation as these unstable pseudomorphs are undeformed. The plagioclase porphyroblasts are enclosed within variably developed asymmetrical pressure shadows. Hornblende forms anhedral, elongate crystals which possess a weakly to moderately developed pleochroism ranging from pale green, through green to blue green.

2.1.6 Two-pyroxene metaperidotite

In thin section the metaperidotites are coarse-grained, granoblastic rocks (S3307a; S8123a) which comprise an inequigranular assemblage of olivine, clinopyroxene, orthopyroxene and plagioclase (Plate 5). Minor to accessory phases present include opaque minerals, biotite, tremolite and talc. Hydration of this high-grade (granulite facies) metamorphic assemblage resulted in the development of serpentine, chlorite, sericite, carbonate and clay minerals.

These granulite facies metamorphic rocks are mainly composed of rounded, anhedral to occasionally subhedral fractured olivine (up to 1.3 mm in size) enclosed within laths (up to *c*. 4.0 mm in size) poikilitic clinopyroxene or orthopyroxene (Plate 5). The pyroxenes are typically anhedral; however, planar crystal faces are locally developed/preserved. Orthopyroxene is distinguished from clinopyroxene by its straight extinction, overall lower birefringence colours and the presence of very fine exsolution lamellae. Clinopyroxene is very pale brown to grey-brown in colour and rarely contains exsolution lamellae of orthopyroxene. Both pyroxenes are strained with a variably developed undulose to shadowy extinction. Dislocations within pyroxene crystals were observed off-setting cleavage planes and, in the case of orthopyroxene, exsolution lamellae.

Olivine forms colourless anhedral, rounded to occasionally elongate, fractured crystals in which the fractures are filled by opaque minerals, serpentine and chlorite (Plate 5a and b). More altered crystals may be enclosed within a fibrous or granular reaction rim composed of fine-grained colourless serpentine and/or tremolitic amphibole. Radiating fractures developed during hydration of olivine may deform adjacent pyroxene and plagioclase crystals. In some rocks (S8123a) olivine occurs in poorly defined clusters associate with finer grained pyroxene. The remaining interstitial areas within these olivine-rich pockets are filled by plagioclase and minor pale brown to orange-brown (possibly phlogopitic) biotite. Plagioclase occurs intergranular to both olivine and pyroxene. It forms twinned, anhedral crystals which locally possess a sweeping extinction and dislocations which off-set the twin composition planes. Plagioclase may possess a slightly dusty appearance in plane polarised light due to minor alteration to sericitic white mica and/or clay minerals.

Traces of red-brown biotite may be present associated with the alteration of olivine. These metaperidotites may be deformed by narrow zones of cataclasite. Minor carbonate and sericite alteration associated with these fractures.

2.1.7 Metadunite

One thin section of a fine- to medium-grained, weakly to moderately serpentinised metadunite has been examined (S22026). This rock is mainly composed of rounded, fractured and variably serpentinised olivine and minor plate-like crystals of talc (Plate 6 a and b). Colourless olivine is probably Mg-rich (forsterite) as there is very little opaque oxides developed associated with the breakdown of olivine. Talc forms large, up to 3.5 mm in size, crystals which exhibit a pronounced change in relief under plane polarised light as the microscope stage is rotated. These anhedral porphyroblasts may locally internal possess angular kinks and an undulose extinction due to intracrystalline deformation. Talc probably formed at the expense of serpentine in response to the introduction of a CO_2–bearing fluid phase during hydration. Serpentine is colourless to very pale green in colour and is locally associated with trace amounts of carbonate.

2.1.8 Hornblende-pyroxene metaperidotite

In thin section these metaperidotites (Plate 6 c and d) are coarse-grained, anhedral granoblastic rocks (S2934; S3946) which comprise an inequigranular assemblage of clinopyroxene, orthopyroxene, olivine and hornblende. Orthopyroxene is very weakly pleochroic ranging from colourless to very pale pinky brown. This pyroxene is also distinguished from clinopyroxene by its straight extinction and overall lower birefringence colours. Olivine is variably replaced and locally pseudomorphed by mesh-textured, pale green serpentine and/or chlorite. Fractures within olivine and the serpentine pseudomorphs after this ferromagnesian mineral are lined by opaque oxide. Fracturing of olivine during serpentinisation locally effected the adjacent pyroxene and hornblende crystals. Olivine is much finer grained (typically $\leq$ 0.4 mm) than the associated pyroxene which range up to 2.0 mm in size. These smaller olivine crystals are, in some instances, partially included within pyroxene.

The presence of green to green-brown hornblende is a characteristic feature of these metaperidotites and indicates that granulite facies metamorphism did not occur under totally anhydrous conditions. Hornblende is intergranular to pyroxene and forms anhedral weakly strained crystals which possess a variably developed undulose extinction. Amphibole also exhibits minor alteration to chlorite, carbonate and trace amounts of possible tremolite. In sample S3946, hornblende forms large (up to 4.5 mm in length), anhedral, elongate crystals which possess cuspate grain boundaries against adjacent olivine (Plate 7 a and b). These elongate crystals are shape aligned and define a weakly foliation or layering. Opaque minerals are common within these rocks are appear to be partially derived from the breakdown of olivine and, to a lesser extent, pyroxene. Trace amounts of dark green coloured spinel are present forming rims upon primary opaque minerals (probably magnetite).

2.1.9 Serpentinite

A small number of thin sections of highly altered serpentinite (S3947; S21979) were examined during this petrographic study. These coarse-grained, anhedral granoblastic metaperidotites (ranging from dunite to lherzolite in composition) were originally composed of an assemblage dominated by pyroxene and olivine. This primary assemblage has been completely replaced by serpentine, opaque minerals, tremolite, talc and carbonate (Plate 7 c and d). Large, 2.0 to 3.0 mm long, pyroxene crystals are pseudomorphed by plate-like crystals of Mg-rich chlorite or bastite. The mimetic growth of these alteration products preserves the original cleavage relationships and fractures within pyroxene. Olivine has been completely pseudomorphed by mesh-textured colourless to pale green serpentine with opaque oxides preserving fractures within the pre-existing relict olivine crystals.

Dusty looking pseudomorphs after a second pyroxene have also been recognised within these serpentinites. This second pyroxene apparently formed large (4.0 to 5.0 mm in size) intergranular poikilitic crystals which enclosed finer grained olivine. During the initial stages of serpentinisation both olivine and pyroxene appear to have been enclosed within a reaction rim of fibrous serpentine and/or tremolite. Traces of tremolite and/or talc have been noted replacing the pseudomorphs after pyroxene. In sample S21979, the serpentine and chlorite have been partially replaced by dusty looking (in plane polarised light) carbonate. This sample also contains large (up to 5.0 to 6.0 mm in size), anhedral to irregular, sieve textured plates of talc. Talc is strained with a well developed undulose extinction as well as kinks and dislocations in some crystals.

2.1.10 Diopside-talc-serpentine rock

One thin section (S8407) of a fine-grained, diopside-talc-serpentine rock has been examined during this study. This originally olivine-rich rock has been completely replaced by mesh textured serpentine and chlorite. Although altered the rock does contain clusters of small (≤ 0.35 mm in diameter), rounded, anhedral crystals of colourless diopsidic pyroxene. The pyroxene appears to have been unaffected by the serpentinisation of olivine. Carbonate pseudomorphs after olivine were also noted, with diopside being spatially related to areas of carbonate alteration. The original crystal shape and fractures developed within olivine during the early stages of hydration are preserved by thin veinlets of opaque oxide. Olivine apparently formed anhedral to rounded crystals.

Serpentine is preferentially replaced by later carbonate as well as aggregates or clusters of randomly orientated, anhedral to irregular crystals of talc (up to 1.0 mm in length). Talc is colourless with a low relief and variably developed sweeping to undulose extinction due to intracrystalline deformation. A weakly developed banding present within this rock is defined by a slight variation in the modal proportions of serpentine, talc and carbonate.

2.1.11 Tremolite-rich metamorphosed ultramafic rock

This fine- to medium-grained highly altered/metamorphosed ultramafic rock (S55256) is composed of an inequigranular assemblage of tremolite, chlorite, serpentine and sericite (plate 8 a and b). Minor to trace amounts of quartz and opaque minerals are also present. Although altered the original anhedral granular, holocrystalline igneous texture can still be recognised due to the mimetic growth of the secondary tremolite dominated mineral assemblage. Tremolite, serpentine and chlorite (± sericite) locally form pseudomorphs after 3.0 to 4.0 mm long, anhedral to subhedral pyroxene crystals. Tremolite is colourless with a moderate to low relief and forms anhedral to irregular grains, as well as subhedral elongate to lozenge shaped crystals. Tremolite was also noted forming fibrous reaction rims upon the pseudomorphs after pyroxene. These reaction rims probably formed during the early stages of alteration. Mg-chlorite is colourless and possesses well developed multiple twins. A fine grained chloritic assemblage was noted replacing the original interstital phases within this meta-igneous rock. No obvious pseudomorphs after olivine have been recognised within this thin section.

2.1.12 Spinel-pyroxene-amphibole metamorphosed ultrabasic rock

A small number of thin sections (S8382; S8381) of a coarse-grained, anhedral granoblastic, altered, spinel-pyroxene-amphibole metamorphosed ultrabasic rock have been examined. These rocks comprise an inequigranular assemblage of diopsidic clinopyroxene and amphibole with minor amounts of spinel and opaque minerals. Olivine, which was present within the original mineral assemblage, has been replaced by a very fine-grained talc, chlorite and/or serpentine. These pseudomorphs after olivine are variably replaced by later carbonate. Fractures and the overall shape of the olivine crystals is preserved by veinlets or stringers of dusty looking opaque oxides. Diopsidic clinopyroxene is colourless and forms anhedral, fractured crystals. Pale green to colourless, weakly pleochroic amphibole forms anhedral crystals which are intergranular to, and locally enclosed pyroxene. Amphibole may also contain inclusions of biotite and opaque oxide. Dark green coloured spinel is a common minor component within sample S8382, forming anhedral to irregular crystals which are rimmed by opaque oxide. Sample S8381 is cut by a number of weakly sheared chlorite and serpentine veinlets which may also contain minor colourless tremolite along the margins of these features.

2.1.13 Metadiorite

The metadiorites are, in general, medium- to coarse-grained (average grain size 2.0 to 3.0 mm), holocrystalline, massive to weakly foliated, anhedral granular, weakly metamorphosed rocks (S2933; S2933a; S30671; S30670; S3041; S3040; S1821) which comprise an inequigranular assemblage of plagioclase, hornblende and quartz with minor amounts of K-feldspar and actinolitic amphibole. Other minor to accessory phases include biotite, opaque minerals and apatite. Alteration resulted in the development of the assemblage clinozoisite/epidote, carbonate and sericite. Metamorphism resulted in the variable recrystallisation of the rock and replacement of plagioclase by granular looking epidote and/or clinozoisite. Although metamorphosed the original igneous texture of the rock can still be recognised. It is possible that this low-grade (?greenschist/sub-greenschist facies) metamorphic event may have accompanied the final stages of crystallisation of these igneous rocks.

The bulk of the rock is composed of a framework of plagioclase and amphibole with the intergranular areas filled by intergranular poikilitic quartz. Quartz is strained with a variably developed undulose extinction. Plagioclase forms anhedral to irregular, twinned and untwinned, zoned crystals which locally exhibit preferential alteration of their cores to fine-grained sericitic white mica. In some rocks, plagioclase is strained with a variably developed undulose to shadowy extinction and may be ‘intergrown’ with quartz. This coarse intergrowth may have developed during recrystallisation and metamorphism. Large, poikilitic plagioclase crystals, up to 6.0 mm in length (S2933a), may also be present and contain inclusions of acicular to lozenge shaped amphibole. In sample S30671, closely packed anhedral to subhedral, variably shape aligned plagioclase laths define a moderately developed pre-full crystallisation fabric.

Amphibole is strongly pleochroic and ranges from green, through green-brown to blue-green in colour. It forms anhedral to irregular crystals which locally possess sieve textured cores or patches containing numerous small, rounded inclusions of quartz and plagioclase. The original hornblende and, within the more melanocratic rocks, pyroxene have been replaced by single crystals or an aggregate of pale green to blue green, secondary actinolitic amphibole. These pseudomorphs locally preserve the original subhedral to euhedral shape of the original minerals. In some cases, the actinolite aggregates posses a paler coloured, dusty looking core which may represent relict fragments of amphibole and/or pyroxene.

Trace amounts of biotite and interstitial K-feldspar were noted in some rocks. Equant to rod shaped apatite is a common accessory within these metadioritic rocks. Minor to accessory opaque minerals are typically associated with amphibole and locally form anhedral, skeletal crystals.

2.1.14 Hornblende-biotite schistose metabasic rock

In thin section (S2757a; S2757b) these hornblende-biotite metabasic schists are fine- to very fine-grained, weakly banded rocks which comprise an inequigranular assemblage of amphibole, plagioclase, biotite, quartz and clinozoisite. Accessory phases present include opaque minerals and apatite. The bulk of this metabasic rock is composed of granular, fine-grained pale green to blue-green amphibole with subordinate plagioclase and minor biotite and quartz. Plagioclase was also noted forming occasional/rare, anhedral to subhedral, simple twinned crystals which range up to 0.5 mm in length. These larger plagioclase crystals may contain inclusions of very fine-grained clinozoisite. A weakly to moderately developed tectonic fabric is defined by shape aligned biotite, elongate sieve textured aggregates of plagioclase and amphibole, as well as plagioclase crystals. Weakly to moderately pleochroic biotite is orange-brown in colour and forms anhedral flakes. The variation in the modal proportions of biotite defines and/or preserves a weakly developed compositional banding. Opaque minerals form very fine-grained, anhedral, granular crystals which are disseminated throughout the rock. In sample S2757a, the rock is cut by a deformed and recrystallised granitic veinlet.

2.1.15 Amphibolite

The amphibolites (S2071; S38687; S936) are massive, medium- to coarse-grained, non foliated, anhedral granoblastic rocks which comprise an inequigranular assemblage of hornblende and plagioclase with minor to accessory opaque minerals and quartz. Secondary alteration and hydration of these metabasic igneous rocks resulted in the development of a fine-grained assemblage dominated by sericitic white mica, chlorite and carbonate. Amphibole is pale green to green-brown in colour and forms anhedral crystals which locally exhibits a shadowy to undulose extinction. Hornblende exhibits variable alteration to, and is locally pseudomorphed by chlorite. In sample S2936, hornblende possesses a distinct sieve texture core which contains rounded, fine-grained inclusions of plagioclase and quartz. Plagioclase is variably altered to sericite. Quartz occurs intergranular to both plagioclase and amphibole.

2.1.16 Biotite-bearing hornblende metabasic rock

In thin section these hornblende-rich metabasites (S17562; S2753; S17563) are fine- to medium-grained, anhedral granoblastic, massive to weakly foliated rocks which comprise an inequigranular assemblage of hornblende, plagioclase and biotite with minor quartz and clinozoisite. Minor to accessory phase include opaque minerals, titanite and possible rutile.

Although metamorphosed, relicts of the original igneous texture can still be recognised. The protolith appears to have been dioritic in composition and is now mainly composed of amphibole and plagioclase with minor quartz. Quartz forms anhedral, strained and unstrained crystals which appear to have originally been intergranular to both amphibole and plagioclase. Two textural varieties of a pale green to blue-green amphibole have been recognised: (1) larger (up to 2.5 mm in length), anhedral to irregular hornblende crystals; and (2) small (≤ 0.4 mm in size), anhedral to subhedral and occasionally euhedral, elongate or lozenge shaped crystals. A weakly developed foliation, where present, is defined by the shape alignment of the larger amphibole blades. Anhedral, pale brown biotite forms anhedral flakes which are closely associated with amphibole. In sample S17563, biotite appears to be replacing amphibole. Plagioclase is intergranular to amphibole and forms anhedral to irregular, twinned and untwinned crystals. Larger poikilitic plagioclase crystals contain inclusions of finer grained amphibole and rod-shaped crystals of clinozoisite. Trace amounts of micrographic intergrowth have been noted within sample S17562.

2.1.17 Garnet-pyroxene metagabbroic gneiss

One thin section (S3306) of a fine- to medium-grained, anhedral granoblastic, garnet-pyroxene metagabbroic gneiss was examined during this petrographic study. This high-grade (granulite facies) metamorphic rock comprises an equigranular to weakly inequigranular assemblage of plagioclase, clinopyroxene, orthopyroxene and garnet (Plate 8 c and d). Accessory phases present include opaque minerals and apatite. Subsequent retrogression and/or alteration resulted in the development of the fine-grained assemblage sericite, chlorite, carbonate, amphibole and biotite.

The bulk of the rock is composed of anhedral plagioclase with clusters, chains or aggregates of granular looking clinopyroxene. Plagioclase is fresh and forms twinned and untwinned, anhedral crystals which exhibit only minor amounts of alteration to sericitic white mica. Green to yellow-green clinopyroxene is the dominant ferromagnesian mineral within this gneiss and forms anhedral, weakly pleochroic crystals with fine-grained opaque oxides occurring along inter-pyroxene grain boundaries. A weakly developed compositional banding or gneissose foliation is defined by elongate chains of clinopyroxene. Orthopyroxene is pale pinky brown in colour and is distinguished from clinopyroxene by its overall lower birefringence colours and straight extinction. Orthopyroxene may be rimmed by granular clinopyroxene and locally exhibits limited retrogression to amphibole.

Two textural varieties of garnet have been recognised within this metagabbroic gneiss: (1) anhedral, relict garnet porphyroblasts which are enclosed within a corona/reaction rim which is mainly composed of plagioclase (± orthopyroxene, opaque minerals) (Plate 8 c and d); and (2) minor, late garnet which forms a fine, irregular rim upon opaque minerals and, in some cases, orthopyroxene. The earlier porphyroblasts are locally pseudomorphed by an aggregate of granular plagioclase. Breakdown of the garnet porphyroblasts and/or the formation of the later garnet rims may have accompanied retrogression and localised replacement of clinopyroxene and orthopyroxene by amphibole. Amphibole is green to blue-green in colour and was noted forming reaction rims upon, as well as occasional pseudomorphs after, pyroxene. Continued retrogression and the introduction of a K^+ bearing fluid phase resulted in the localised replacement of amphibole by biotite. Biotite is dark orange-brown in colour and was also noted forming rims upon opaque minerals.

2.1.18 Retrogressed meta-tonalitic gneiss

In thin section (S2315; S2988; S3416; S8722; S30676; S55002; S30674; S2993; S30675) the meta-tonalitic gneisses are medium- to coarse-grained, anhedral granoblastic rocks which are composed of an inequigranular assemblage of plagioclase, quartz, clinopyroxene and amphibole. Minor to accessory phases present include biotite, opaque minerals and apatite. Late alteration resulted in the variable development of a fine-grained assemblage of chlorite, carbonate and sericitic white mica.

The bulk of these originally high-grade (granulite facies) metamorphic rocks is composed of anhedral granoblastic plagioclase with subordinate to minor quartz. Plagioclase forms twinned and untwinned crystals which exhibit a dusty appearance in plane polarised light due to minor alteration to sericite. Intracrystalline deformation within plagioclase resulted in the local development of as weeping to undulose extinction and distortion of twin composition planes. In some rocks plagioclase is antiperthitic containing elongate to possibly rod-shaped K-feldspar exsolution lamellae. Quartz (up to 6.0 mm in size) is variably strained and possesses an undulose extinction, with sub-grains and deformation bands occurring within the more deformed crystals. In sample S3416, a weakly developed foliation is defined by the shape alignment of quartz and plagioclase.

Clinopyroxene originally formed discrete clusters or aggregates of 3 to 4 crystals which have subsequently been replaced by a mat or aggregate of pale green amphibole. These amphibole mats contain rounded inclusions of quartz.. In some rocks the amphibole aggregates preserve an earlier, weakly developed gneissose foliation (S3416) or compositional banding (S8722; S30676). Where present, relict clinopyroxene is pale green in colour and formed anhedral crystals which range up to 2.0 mm in size. The mimetic growth of amphibole locally preserve the original shape and cleavage relationships within the pyroxene crystals. The pseudomorphs after pyroxene may be texturally zoned preserving an earlier stage of retrogression where anhedral relict clinopyroxene was enclosed within a irregular amphibole reaction rim. The pyroxene relicts may be pseudomorphed by amphibole or later, fine-grained carbonate and chlorite.

Biotite, where present, is pale brown to orange-brown in colour and exhibits variable alteration to chlorite (± carbonate, opaque oxide). Biotite typically occurs replacing earlier formed amphibole, suggesting that there was a change in fluid composition (introduction of K^+) during retrogression from granulite to amphibolite facies. However, in sample S8722, biotite was also noted forming anhedral to irregular poikilitic intergranular flakes which may have form part of the high-grade granulite facies mineral assemblage. Sample S55002 is cut by a narrow veinlet of clinozoisite.

2.1.19 Retrogressed garnet-pyroxene metagabbroic gneiss

The garnet-bearing metagabbros (S4465; S4464; S7842) are medium- to coarse-grained, anhedral granoblastic, originally pyroxene-rich rocks and are composed of an inequigranular assemblage of amphibole, plagioclase, clinopyroxene and garnet (Plate 9 a and b). Minor to accessory phases present include quartz, actinolite, spinel, opaque minerals and apatite. Later alteration resulted in the development of a fine-grained assemblage of carbonate, sericitic white mica and chlorite. A compositional banding present within some of these metagabbroic rocks is defined by the variation in modal plagioclase and pyroxene.

These originally high-grade (granulite facies) gneisses have been retrogressed under amphibolite facies conditions which resulted in the variable replacement of clinopyroxene by amphibole (Plate 9a and b). Pyroxene is rimmed or pseudomorphed by an aggregate or mat of fine-grained, pale green to blue-green amphibole. Minor amounts of very pale green actinolitic amphibole has been noted within the centre of some of the amphibole aggregates (S7842). In some rocks (S7842), amphibole is locally being replaced by biotite indicating that there was an introduction of K^+ in the fluid phase during retrogression. The amphibole aggregates may also possess a distinctly darker coloured rim or margin. The latter may represent an earlier formed reaction rim upon pyroxene. Relict, pale green to colourless clinopyroxene is present within the core of some of the amphibole aggregates. Clinopyroxene appears to have formed an irregular network of crystals which enclose irregular to elongate patches of plagioclase.

Plagioclase forms anhedral, twinned and untwinned crystals which appear to be intergranular to pyroxene. In some rocks (S4464) plagioclase exhibits patchy alteration to sericitic white mica. In sample S7842, plagioclase is locally antiperthitic to mesoperthitic in nature. Garnet occurs rounded, anhedral relict porphyroblasts which are enclosed within a reaction rim or corona of granular looking plagioclase. In sample S7842, two textural varieties of garnet have been recognised: (1) rounded relict porphyroblasts enclosed within a corona of plagioclase; and (2) irregular garnet rims developed upon opaque minerals (Plate 9 a and b). The larger garnet porphyroblasts range up to 6.0 mm in diameter. Minor quartz is present in some rocks and possesses a variably developed undulose extinction and sub-grain textures.

2.1.20 Biotite-plagioclase gneiss

One thin section (S55001) of a coarse- to very coarse-grained, anhedral granoblastic biotite-plagioclase gneiss was examined as part of this petrographic study. This massive gneissose rock comprises an inequigranular assemblage of plagioclase, quartz and biotite with minor opaque minerals. Subsequent alteration resulted in the development of a fine-grained assemblage of sericitic white mica, chlorite, carbonate and clinozoisite/epidote.

The rock is mainly composed of anhedral granoblastic plagioclase (approximately 80% of the total rock) within subordinate quartz and minor biotite. Plagioclase forms twinned and untwinned crystal which range up to 2.2 mm in size and exhibit a dusty appearance under plane polarised light due to minor alteration to sericitic white mica. Occasional, small muscovite flakes have been noted associated with the alteration of plagioclase. Plagioclase also exhibits minor alteration to carbonate and clinozoisite/epidote. Quartz is coarser grained than feldspar and forms anhedral to irregular crystals which range up to 6.0 mm in size. Intracrystalline deformation within quartz resulted in the development of an undulose extinction, deformation bands and sub-grain textures.

Biotite is strongly pleochroic ranging from pale brown to dark brown in colour. It forms anhedral flakes and plates which are up to 2.0 mm in size. Biotite occurs in clusters of 3 to 4 flakes which may also show evidence of intracrystalline deformation, in particular the formation of a sweeping to undulose extinction and kinking of the basal (010) cleavage. Both quartz and biotite have locally been recrystallised to a fine- to very fine-grained, granular aggregate. Biotite exhibits minor alteration to chlorite.

2.1.21 Hornblende-pyroxene metagabbroic gneiss

A thin section (S30677) of a medium-grained, anhedral granoblastic, hornblende-pyroxene metagabbroic gneiss has been examined during this study. This weakly foliated rock is composed of an inequigranular assemblage of plagioclase, hornblende and clinopyroxene (Plate 9 c and d) with minor to accessory actinolitic amphibole, biotite, epidote, opaque minerals and apatite. The weakly developed foliation is defined by the localised shape alignment of hornblende.

Clinopyroxene and hornblende form an open framework/network with the remaining 'intergranular' areas being filled by plagioclase (Plate 9 c and d). Plagioclase forms anhedral, weakly zoned, twinned and untwinned crystals which locally possess a sweeping to shadowy extinction and curved twin composition planes. Plagioclase is fresh and shows very little alteration to sericitic white mica. Hornblende forms anhedral, elongate to equant crystals which possess a well developed pleochroism ranging from pale green to dark green in colour. Thin foils or seams of an opaque mineral have been noted along the cleavage planes within amphibole. Minor to trace dark green-brown to brown biotite was noted associated with and may be included within hornblende. Hornblende and biotite appear to be part of the primary granulite facies mineral assemblage, indicating that the high grade metamorphic event recorded by this gneiss did not occur under totally anhydrous conditions.

Clinopyroxene is spatially related to hornblende and has largely been replaced by an aggregate or mat of fine-grained, pale green actinolitic amphibole. These pseudomorphs are locally texturally zoned and comprise an darker coloured rim or margin enclosing acicular, finer grained actinolite. These zoned pseudomorphs may represent an earlier stage of retrogression in which relict clinopyroxene was enclosed within a amphibole reaction rim. The darker coloured amphibole has itself locally been replaced by granular epidote and/or clinozoisite.

2.2 METASEDIMENTARY ROCKS

2.2.1 Plagioclase-biotite schistose rock

One thin section of a fine- to very fine-grained, highly foliated plagioclase-biotite schistose rock (Plate 10 a and b) has been examined during this study (S9769). It is composed of a very fine-grained assemblage of biotite, plagioclase, quartz and muscovite with minor to trace amounts of opaque oxide. Later alteration resulted in the development of the secondary assemblage dominated by chlorite and sericite.

The well developed homogenous to very weakly domainal schistosity is defined by shape aligned green coloured (chloritised) biotite flakes and minor muscovite (Plate 10 a and b). This fabric wraps around small (up to 0.25 mm in size), rounded plagioclase porphyroblasts. These rounded, anhedral to slightly elliptical porphyroblasts possess a shadowy extinction and contain very fine-grained inclusions of opaque minerals and biotite. Plagioclase is untwinned and exhibits only minor alteration to sericite. The porphyroblasts are enclosed within variably developed pressure shadows composed of either cryptocrystalline quartz and feldspar or slightly coarser grained, granular looking biotite. These plagioclase porphyroblasts are located within the remnants of earlier developed quartz domains. This microtextural relationship suggests that porphyroblastesis occurred earlier in the deformation history of the rock, prior to homogenisation of the foliation. The relict quartz domains also preserve a sigmoidal (S-shaped) earlier (S1) foliation. The relationship of this S1 fabric to the plagioclase porphyroblasts is unknown. The asymmetry of the pressure shadows, enveloping fabric and geometry of locally developed narrow shear bands yields a sinistral (top to left) sense of shear in this plane of section. However, none of the thin sections of the metasedimentary rocks are orientated so the geographical sense of displacement/shear is unknown.

2.2.2 Meta-quartz arenite

The meta-quartz arenites (quartzites) are typically fine- to medium-grained (average grain size 0.3 to 0.4 mm) rocks (S8406; S15032; S15028; S15029; S65963) which are largely composed of inequigranular quartz with minor to accessory opaque minerals, white mica, chlorite, tourmaline, monazite and zircon. Quartz ranges up to 0.6 mm in size and forms irregular, anhedral crystals which possess serrated or sutured grain boundaries and variably developed undulose extinction. Although recrystallised, a relict the original clastic texture may still be recognised in some rocks (S8406; S15029). This takes the form of irregular to rounded quartz grains (relict detrital grains) set within a matrix of fine-grained, granular quartz.

In the more deformed rocks intracrystalline deformation within quartz resulted in the development of deformation bands, sub-grains and dislocations. A preferred shape alignment of quartz may define a weakly developed foliation. In sample S15028, a well developed, possibly mylonitic, foliation is defined by highly flattened, elongate (up to 1.5 mm in length) single quartz crystals and polycrystalline ribbons. Dynamically recrystallised quartz within the matrix to this rock possesses a well developed crystallographic/c-axis orientation. In sample S65963, a mylonitic fabric is defined by fine-scale (≤ 0.2 mm in width), white mica-rich domains.

2.2.3 Biotite hornfels

The biotite hornfelsed rocks are, in general, fine- to very fine-grained, massive, granular looking rocks (S22043; S8409) which comprise the assemblage quartz, biotite, plagioclase, clinozoisite and muscovite. Minor to accessory phases present include opaque minerals, chlorite, tourmaline and zircon. The rock is mainly composed of fine- to very fine-grained granular quartz, biotite and plagioclase. Biotite is pale orange-brown in colour and forms anhedral to rounded crystals which exhibit traces of chloritic alteration. Biotite is the dominant phyllosilicate within the contact metamorphosed rocks which were originally siltstones. The biotite hornfelses are locally cut by granitic veinlets (S8409) or thin (≤ 0.15 mm wide) quartz and clinozoisite veins (S22043). Clinozoisite may also occur within the matrix of the rock.

2.2.4 Quartzite

One thin section of a quartzite (S32760) has been examined during this study. This medium-grained, highly recrystallised, anhedral granoblastic rock comprises an inequigranular assemblage dominated by quartz with minor to accessory plagioclase, muscovite, K-feldspar and opaque minerals. Recrystallisation during metamorphism resulted in the complete overprinting of the original sedimentary texture of this rock. Quartz forms anhedral rounded crystals with slightly irregular to interlocking grain boundaries. Intracrystalline deformation within quartz resulted in the variable development of a sweeping to undulose extinction and, in some cases, deformation bands. The rock is massive and lacks any obvious tectonic fabric. Trace muscovite is pale yellow in colour and possesses a sweeping to undulose extinction.

2.2.5 Garnet-biotite-schistose pelite

In thin section (S21934; S21933; S17566) the garnet-biotite schistose pelites or semipelites are, in general, fine-grained, moderately to well foliated rocks which comprise an inequigranular assemblage of quartz, biotite, garnet, plagioclase and muscovite. Minor to accessory phases present include opaque minerals, apatite and zircon.

These schistose rocks are mainly composed of anhedral granular to locally interlocking quartz and biotite. Biotite is brown to dark brown in colour and forma anhedral to granular looking flakes. These locally contain dusty looking inclusions of opaque oxide as well as zircon. Biotite is the dominant phyllosilicate within these pelitic to semipelitic rocks, which contain only minor amounts of muscovite. In sample S21933, biotite was also noted forming 0.3 to 1.5 mm long porphyroblasts which are aligned within, but also overgrow the main schistosity developed within this rock.

Two tectonic fabrics have been identified within these schists, both of which are defined by shape and optically aligned biotite flakes. In samples S2934 and S21933, the first fabric (S1) is preserved as hinges of a crenulation within the weakly defined quartz domains of a later schistosity (S2). Muscovite present within these rocks mainly occurs within the mica-rich domains of this second fabric. These mica domains were observed wrapping around anhedral, pre- to syn-kinematic (S2) garnet porphyroblasts. The porphyroblasts range up to 2.0 mm in diameter and contain small rounded inclusions of quartz, opaque oxide and rare biotite. Garnet porphyroblasts are, in general, located within the quartz domains of the S2 fabric. Some of the garnet porphyroblasts possess an inclusion-rich core enclosed within a relatively inclusion-free rim. In sample S17566, the texturally zoned garnet porphyroblasts show evidence of a compositional distinct pinky, subhedral to square-shaped core enclosed within a pink-grey coloured rim. These microtextural relationships suggests that there may have been two stages of garnet porphyroblastesis. In sample S21933, the garnet porphyroblasts possess weakly to moderately developed, curved to crenulated inclusion trails which preserve S1 and the earlier stages of the development of the later S2 fabric. The garnets within this sample are locally enclosed within a reaction rim of biotite and plagioclase, with garnet breakdown possibly accompanying the annealing of the S2 schistosity and late (post S2) biotite porphyroblastesis.

Minor retrogression resulted in the localised replacement of garnet and biotite by pale green chlorite.

2.2.6 Epidote-biotite schistose psammite

The epidote-biotite schistose psammites (S2948; S4449; S17564) are typically fine-grained, moderately to well foliated rocks which comprise an inequigranular assemblage of quartz, biotite and epidote with minor amounts of plagioclase and muscovite. Other minor to accessory phases present include garnet, opaque minerals, allanite, titanite and apatite. The domainal to weakly homogenous schistosity is defined by length and optically aligned biotite, muscovite and quartz. Pale brown to dark brown biotite is the dominant phyllosilicate and forms anhedral elongate flakes as well as more equant, granular looking crystals. In sample S4449, the schistosity is defined by elongate aggregates or impersistant foliae of biotite as well as lenticular quartz ribbons.

Pale yellow to colourless epidote forms granular crystals which are spatially related to biotite. The larger epidote crystals may exhibit a weakly developed pleochroism. Anhedral granular quartz is strained with a variably developed undulose extinction. Adjacent to the biotite-rich schistosity, quartz is variably replaced by a mosaic of sub-grains and/or new grains. Occasional larger (≤ 1.0 mm long) flakes of muscovite are aligned parallel to the biotite fabric and exhibit a distinctive pale pink colouration under plane polarised light.

2.2.7 Garnet-plagioclase-mica schistose pelite

A small number of thin sections (S2947; S17580) of a distinctive garnet-plagioclase-mica schist have been examined during this study. These fine- to occasionally coarse-grained, highly foliated rocks comprise an inequigranular assemblage of muscovite, quartz, biotite, plagioclase and garnet. Minor to accessory phases present include opaque minerals, titanite, apatite and zircon.

The homogenous to domainal schistosity is defined by shape and optically aligned muscovite and biotite flakes and wraps around pre- to syn-kinematic plagioclase and garnet porphyroblasts. Muscovite is the dominant phyllosilicate. Moderately pleochroic biotite varies from pale brown to dark brown in colour and forms granular to elongate flakes. Occasional rounded biotite crystals were noted included within the plagioclase porphyroblasts. In sample S17580, a well developed coarse schistosity is defined by narrow muscovite-rich domains (± biotite). This fabric is overgrown by later, pale green to yellow epidote.

Anhedral to very weakly subhedral garnet porphyroblasts range up to 0.7 mm in diameter and contain dusty looking inclusions of opaque oxide. Plagioclase forms anhedral, rounded to elliptical, twinned and untwinned crystals (typically 1.0 mm in size) which may exhibit a weak zonation and sweeping to undulose extinction. These porphyroblasts are enclosed within weakly developed pressure shadows and contain small rounded inclusions of quartz which are similar in grain size to the external matrix. In sample S17580, plagioclase forms large, up to 3.0 mm in length, poikiloblasts which contain inclusions of biotite, muscovite and quartz. In sample S2947, the plagioclase poikiloblasts contain straight inclusion fabrics which preserve an earlier developed (S1) foliation. The parallel alignment of the inclusion fabrics within all the plagioclase poikiloblasts indicates there was very little if any rotation of the porphyroblasts during deformation and the imposition of the S2 schistosity. This S1 fabric is also preserved as inclusion trails within garnet, but has been completely overprinted within the matrix of the rock.

2.2.8 Garnet-mica schistose pelite

The garnet-mica schists (S938; S56164) are fine-grained, highly foliated, pelitic to semipelitic rocks which are composed of the assemblage quartz, muscovite, biotite and garnet. Accessory phases include opaque minerals and tourmaline, with retrogression and/or alteration resulting in chloritisation of biotite and garnet.

A well developed schistosity is defined by narrow, alternating quartz- and muscovite-rich foliae. This domainal schistosity wraps around small (≤ 0.7 mm in diameter) garnet porphyroblasts. An earlier developed S1 foliation preserved within the quartz-domains results in an SC-fabric geometry which yields a possible dextral sense of shear within this plane of section. Anhedral to subhedral garnet porphyroblasts contain sigmoidal to possibly snowball-like inclusion trails (quartz, opaque oxide) within their cores enclosed within a relatively inclusion-free rim. This microtextural relationship suggests that their were two stages of garnet growth, with the earlier phase of porphyroblastesis being accompanied by high shear strains resulting in porphyroblast rotation and the development of snowball inclusion trails. The development of the later inclusion-free rim may have accompanied the annealing of the matrix foliation.

2.3 METALIMESTONES, SKARNS AND CALC-SILICATE ROCKS

2.3.1 Silicified limestone

One thin section (S890) of a silicified limestone has been examined during this study. This originally coarse-grained, bioclastic limestone has been totally replaced by very finely microcrystalline to cryptocrystalline quartz. Although highly altered, pseudomorphs after arcuate/curved shell fragments (up to *c*. 6.0 mm in length) and rounded ooids or peloids have been recognised. The internal concentric structure developed within the ooids may be preserved within some of the pseudomorphs. Small patches of slightly coarser grained quartz were noted replacing the matrix and/or original cavity fills within the limestone. The mimetic growth of quartz locally preserves an isopachous rim cement.

2.3.2 Garnet-hornblende calc-silicate rock

One thin section (S21932) of a medium-grained, garnet-hornblende calc-silicate rock has been examined during the present study. This weakly to moderately foliated rock is composed of an inequigranular assemblage of plagioclase, quartz, amphibole, garnet and zoisite/clinozoisite. Accessory phases present include opaque minerals, titanite, biotite and apatite. Alteration and hydration of this amphibolite facies minerals assemblage resulted in the development of chlorite and sericitic white mica.

The rock is mainly composed of anhedral granular, twinned and untwinned plagioclase with subordinate amounts of quartz. Plagioclase possesses a dusty appearance under plane polarised light due to minor alteration to sericite. Small granular, anhedral crystals of zoisite/clinozoisite are a common minor component within this calc-silicate rock and occur both in the matrix and included within plagioclase. Quartz forms strained and unstrained, anhedral crystals which possess a variably developed undulose extinction. Anhedral, elongate to lozenge shaped hornblende porphyroblasts or poikiloblasts range up to 3.5 to 4.0 mm in length. These amphibole porphyroblasts are pseudomorphed by a cryptocrystalline, yellow-green chloritic assemblage. The randomly orientated to shape aligned amphibole crystals define the weakly developed foliation present within this rock. Inclusions within amphibole are mainly composed of rounded quartz ± opaque minerals, plagioclase and zoisite. These inclusions are similar in grain size to the surrounding matrix suggesting that amphibole porphyroblastesis occurred during the later stages of metamorphism.

Garnet forms anhedral to weakly euhedral, fractured porphyroblasts with contain straight, curved and sigmoidal inclusion trails preserving an earlier developed foliation. This fine-scale schistosity has been completely overprinted within the matrix. The uniform alignment of the inclusion trails within the porphyroblasts suggests that there was very little, if any rotation of garnet during deformation. Some of the porphyroblasts are texturally zoned with an inclusion-rich core, surrounded by a relatively inclusion-free rim; indicative of two stages of garnet growth. The fine-grained nature of the inclusion fabrics indicates that the matrix has been annealed/recrystallised probably during the development of the later amphibole poikiloblasts which post-dated garnet porphyroblastesis.

2.3.3 Diopside-rich rock

In thin section this suite of 'marbles' or skarns (S21998; S21999; S21997; S22011; S22003; S22004; S22028) are fine- to coarse-grained rocks which are mainly composed of anhedral to subhedral diopsidic clinopyroxene. These rocks also contain minor amounts or quartz, tremolite and carbonate with accessory zoisite, opaque minerals and biotite. Clinopyroxene is pale green to colourless and forms equant to prismatic, simply twinned crystals which range up to 1.5 mm in size. In some rocks (S21998) these diopsidic pyroxene crystals exhibit a weakly developed zonation represented by the presence of a slightly darker green to blue green core or rim. The remainder of these diopsidic rocks is composed of fine-grained colourless to pale green tremolite, dusty looking carbonate (under plane polarised light) and/or quartz. In sample S21998, quartz is intergranular to pyroxene and forms a fine-grained granular aggregate or clusters of accicular, radiating crystals. Sample S21997, contains trace amounts of a pale brown, possibly phlogopitic, biotite. Carbonate may locally form intergranular poikiloblastic crystals which contain inclusions of finer grained pyroxene. In general these rocks are undeformed. However, in sample S22003 a weakly to moderately developed tectonic fabric is defined by anastomosing foliae of tremolite. This fabric wraps around broken/cataclased diopside cleavage fragments.

2.3.4 Metalimestone

The metalimestones (S22021; S22025; S8411; S8410; S14999; S887; S886; S1735; S1736; S9916; S35797; S9914; S9906; S11150; S11148; S9908; S888; S1332; S9907) are typically fine- to medium-grained, massive to weakly banded, crystalline rocks which are mainly composed of carbonate with minor to accessory plagioclase, quartz phlogopitic biotite, Mg-chlorite and opaque minerals.

The composition of the carbonate minerals present within these rocks is, in general, uncertain as the thin sections examined during this study were largely unstained. However, samples which have been stained (S8410) contain both non ferroan dolomite and ferroan calcite. Carbonate forms anhedral, rounded to irregular, dusty looking (under plane polarised light) crystals which may possess a sweeping to undulose extinction (Plate 10 c and d). Intracrystalline deformation may have also resulted in the distortion of cleavage and/or twin composition planes. The presence of plagioclase, quartz and biotite within these rocks suggests that the protolith was an impure (muddy) limestone. Plagioclase forms twinned and untwinned, anhedral crystals which appear intergranular to carbonate. Pale brown biotite is locally a common minor phase within these metalimestones and occurs in clusters of 3 to 4 crystals. Biotite be partially replaced by or altered to chlorite. Quartz occurs in small pockets of variably strained crystals.

A compositional banding present in some samples (S8411) is defined by the variation in the grain size of the carbonate minerals and by the presence of dusty looking partings containing trace amounts of biotite. Some of the metalimestones (S9914; S9906) are composed of rounded to lenticular crystals of carbonate (ranging from 0.3 to 1.3 mm in size) set within a fine- to very fine-grained matrix. These larger crystals possess irregular to serrate grain boundaries which developed due to the recrystallisation of the matrix (Plate 10 c and d). In sample S9906, these larger crystals rarely preserve radiating structures which may represent septa of a coral. Primary sedimentary features are rarely preserved present in these rocks, however, pseudomorphs after ooids containing weak concentric structure are present in sample S3095.

The majority of these rocks are undeformed, however, sample S8410 is cut by a sheared serpentine/M-chlorite veinlet and narrow, planar to anastomosing shear bands which result in the dynamic recrystallisation of the carbonate minerals. In samples S1735, S9908 and S1736, brittle deformation resulted in localised fracturing and cataclasis, the fractures being filled by clear crystalline, sparry carbonate. The more highly deformed lithologies (S11150; S11148) may possess a mylonitic to schistose fabric. These rocks also contain rounded to rhomb-shaped carbonate porphyroblasts/porphyroclasts (≤ 1.0 mm in size) with the individual cleavage rhombs locally being stacked en-echelon. Rare serpentine pseudomorphs after olivine may also be present in some of the metalimestones (S11150).

2.3.5 Plagioclase calcareous schistose rock

The plagioclase calcareous schists (S3449; S15036; S9770) are fine- to very fine-grained, highly deformed rocks which are composed of an inequigranular assemblage of carbonate, white mica and plagioclase. Minor to accessory phases present include opaque minerals, quartz and chlorite.

The rock is mainly composed of shape and optically aligned, very fine-grained to cryptocrystalline carbonate and white mica which defined a well developed tectonic fabric. This homogeneous to domainal foliation wraps around pseudomorphs after anhedral plagioclase porphyroblasts (up to 2.0 mm in size). These pseudomorphs are rounded to elliptical in shape and composed of very fine-grained sericite quartz and carbonate. The mimetic growth of the alteration products locally preserves the original plagioclase twins and fractures associated with microboudinage of feldspar. Traces of relict plagioclase are present within some of the pseudomorphs. Sericitisation of plagioclase post-dated ductile deformation and foliation development within these schists, as the pseudomorphs show no evidence of deformation. The porphyroblasts are enclosed within weakly to very weakly developed pressure shadows.

Rare chloritised (± opaque oxides) biotite flakes have been noted in some rocks. The schistosity is overgrown by anhedral to euhedral opaque minerals. In sample S15036, the domainal schistosity is partially overprinted/annealed due to later recrystallisation resulting in a slight increase in the grain size of carbonate. This fabric is defined by narrow, alternating quartzose- and white mica-rich foliae, with carbonate typically occurring within the mica domains. The quartzose domains are composed of very fine-grained to cryptocrystalline quartz and plagioclase.

2.3.6 Diopside-biotite rock

A small number of thin sections (S8413; S8412a) of a medium- to coarse-grained, weakly to moderately foliated diopside-biotite rock or skarn have been examined during this petrographic study. The rock is dominated by an inequigranular assemblage of diopside and biotite with minor to trace amounts of plagioclase, aegirine augite chlorite, quartz, Na-amphibole, titanite, apatite and carbonate. Colourless to pale green diopside is the dominant mineral phase and forms anhedral, equant to prismatic crystals. Green-brown biotite occurs intergranular to diopside and may posses a sweeping to undulose extinction. Intracrystalline deformation within biotite also resulted in the kinking of the basal (010) cleavage. Both biotite and clinopyroxene may exhibit a weak shape alignment defining a poorly developed fabric. Minor amounts of a bright green, possibly aegirine-rich, clinopyroxene are also present. In sample S8413, this Na-bearing pyroxene is locally partially replaced or overgrown by a sodic blue amphibole (crossite/glaucophane).

2.3.7 Diopside marble

In thin section (S9210; S9205; S9204) the diopside marbles (Plate 11) are medium- to coarse-grained, massive to moderately foliated rocks which are composed of an inequigranular assemblage of carbonate (including ferroan calcite), diopside and subordinate aegirine augite. Minor to accessory phases present within these rocks include opaque minerals, talc, plagioclase, K-feldspar, biotite and tremolite.

These marbles are mainly composed of anhedral to irregular carbonate crystals which range up to 3.0 to 4.0 mm in size. Samples S9210 and S9204 are stained showing that carbonate dominated mineralogy includes ferroan calcite. Intracrystalline deformation within calcite resulted in the development of an undulose to sweeping extinction and localised distortion of cleavage and/or twin composition planes. Deformation also resulted in localised patches and bands of dynamic recrystallisation of larger calcite crystals. These are partially replaced by a fine- to very fine-grained aggregate of new carbonate grains. In sample S9204, anastomosing bands or foliae of very fine-grained carbonate define a weakly to moderately developed foliation which wraps around elongate to rounded, larger relict carbonate porphyroclasts.

Diopside is colourless to pale yellow and forms anhedral to subhedral, fractured or broken crystals (up to 1.6 mm in size) with the fractures filled by carbonate (Plate 11 a and b). Pyroxene occurs in clusters of several crystals and possesses a sweeping extinction and localised kinking/distortion of cleavage planes. In some rocks (S9205), subhedral to occasionally euhedral diopside is enclosed within a irregular rim of grass green, possibly aegirine-rich, augite. These is a pronounced compositional break between the two types of pyroxene clearly indicating a marked change in fluid composition and the introduction of Na during metamorphism/metasomatism. The aegirine augite rim may contain inclusions of green-brown biotite.

Trace amounts of anhedral flakes of white mica or talc are present in some rocks. These possess a sweeping to undulose extinction. Sample S9205 contains irregular poikiloblasts of untwinned K-feldspar which possess a distinctive shadowy extinction.

2.3.8 Aegirine augite-bearing marble

The aegirine augite-bearing marbles (S9203; S9206; S9909; S9204a; S22041) are medium- to coarse-grained, variably deformed rocks which comprise an inequigranular assemblage of carbonate (including ferroan calcite) and clinopyroxene (Plate 11 c and d) with minor to accessory opaque minerals, K-feldspar, Na-amphibole, tremolite and Mg-chlorite. These skarns/marbles are mainly composed of variably shape aligned carbonate crystals which range up to *c*. 5.0 mm in size. Intracrystalline deformation of calcite resulted in the development of a sweeping to undulose extinction and distortion of cleavage and/or twin composition planes. Localised dynamic recrystallisation led to a reduction in grain size of the carbonate and the development of fine-grained new grains along calcite grain boundaries.

Clinopyroxene forms anhedral to subhedral, fractured crystals which are grass green in colour and possess a very weakly developed pleochroism (Plate 11 c and d). This possibly aegirine-rich augite occurs in clusters of several crystals (ranging up to 4.0 mm in size) which may possess a moderate to well developed zonation. Pyroxene has locally undergone cataclasis (fractures filled by carbonate) with the associated intracrystalline deformation resulting in the development of an undulose extinction and sub-grain textures.

In sample S9206, trace amounts of K-feldspar were noted forming large (up to 2.0 mm in size) perthitic crystals which possess a distinctive shadowy extinction. Tremolite is a minor to accessory phase within these marbles and forms elongate, rod like to lozenge shaped crystals. In sample S9909, tremolite is aligned and, along with carbonate, defines a locally well developed foliation. Localised microboudinage of the tremolite crystals were noted due to extension apparently occurring within the plane of the foliation. Traces of Na-amphibole were noted in some rocks replacing tremolite and/or pyroxene. Sample S2204, also contains a 6.0 to 7.0 mm long aggregate or mat of pale green, fibrous Mg-chlorite.

2.3.9 Forsterite Marble

These olivine-bearing marbles (S22032; S9913; S9910; S9211; S9912; S10005; S3099; S10006; S15037; S34440) are fine- to medium-grained, massive to weakly foliated rocks which are composed of an inequigranular assemblage of carbonate, forsterite and/or serpentine with minor to trace amounts of opaque minerals and brucite (Plate 12 a and b). The rock is mainly composed of fine- to medium-grained (average grain size ≤ 1.2 mm), anhedral carbonate (including ferroan calcite) crystals which locally possess a sweeping to undulose extinction and distorted cleavage and/or twin composition planes. Rare, large (up to *c*. 6.0 mm in length) poikiloblastic carbonate crystals may also be present, containing inclusions of finer-grained carbonate and forsterite. Olivine forms small, rounded, anhedral crystals (≤ 1.3 mm in diameter) which are fractured and variably altered to, or pseudomorphed by mesh-textured serpentine. Dusty looking carbonate rims are locally developed upon olivine. Olivine typically occurs in clusters or as granular aggregates of crystals (Plate 12 a and b). In some rocks these crystals are optically aligned suggesting that they represent a single poorly formed crystal which is intergrown with the matrix carbonate. Sample S3099 is extremely olivine-rich, with forsterite forming approximately 80% of the total rock. Trace amounts of colourless brucite has been noted in some samples (SS9912).

2.3.10 Phlogopite-diopside marble

In thin section (S21980; S22037; S9207) these marbles are fine- to medium-grained rocks which comprise an inequigranular assemblage of diopside, carbonate (including ferroan calcite), phlogopite and tremolite (Plate 12 c and d). Minor to accessory phases present include opaque minerals and Mg-chlorite. The rock is mainly composed of complete or broken cleavage fragments of diopside set within a fine- to very fine-grained matrix of carbonate (± Mg-chlorite). Diopside is colourless and originally formed equant to prismatic crystals which were up to 2.0 mm in size. In sample S9207, a moderate to well developed foliation is defined by wispy looking, anastomosing carbonate foliae as well as the asymmetry of larger (*c*. 0.7 mm in size) deformed carbonate crystals. These deformed crystals are shape aligned and possess a sweeping to undulose extinction, as well as curved to sigmoidal twins and/or cleavage planes. This foliation wraps around diopside crystals.

Elongate to lozenge shape crystals (up to *c*. 1.0 mm in size) of colourless tremolite may be present as a minor component within these marbles. In sample S21980, tremolite forms occasional plate like to elongate crystals associated with the margin of a deformed carbonate vein. Phlogopite is colourless to pale brown or green-brown and forms single isolates plates or clusters of several anhedral flakes. Intracrystalline deformation within phlogopite resulted in the development of a sweeping to undulose extinction. Phlogopite is typically intergranular to diopside and was locally observed forming larger poikiloblastic crystals which contain inclusions of rounded diopside (S21980).

2.3.11 Brucite Marble

In thin section the brucite marbles (S37403, S37402; S3098; S9208; S9208b; S9911; S11146; S36957) are fine- to medium-grained, equigranular to inequigranular, massive to weakly foliated rocks which are composed of an assemblage dominated by carbonate and brucite (Plate 13 a and

b) with minor to accessory forsterite, opaque minerals and sericite. These marbles are mainly composed of anhedral granoblastic, dusty looking (under plane polarised light), twinned carbonate crystals which include ferroan and non-ferroan dolomite as well as ferroan calcite. A weakly developed foliation may be present defined by the variable shape alignment of carbonate crystals. Colourless brucite occurs within mesh-textured pseudomorphs (≤ 0.3 mm in diameter) after possible periclase. It forms fine- to very fine-grained (cryptocrystalline) accicular to fibrous crystals which exhibit a low relief and low first order birefringence colours (Plate 13 a and b). Trace amounts of small rounded olivine (forsterite) crystals were noted in some rocks (S3098). In sample S9911 minor olivine is pseudomorphed by serpentine.

2.3.12 Forsterite-brucite marble

The forsterite-brucite marbles (S3096; S9208; S9843; S9915; S11147; S11149; S44815) are typically medium- to coarse-grained, anhedral granoblastic, massive to weakly foliated rocks which are composed of the assemblage carbonate (including ferroan calcite, non-ferroan dolomite), brucite and serpentine with minor to trace amounts of opaque minerals (Plate 13 c and d). Rounded, anhedral olivine crystals present within these marbles have been pseudomorphed by mesh-textured serpentine. Olivine originally formed single isolated grains (≤ 0.8 mm in size) as well as clusters or aggregates of 2 to 5 crystals. In sample S9843, the pseudomorphs after olivine are enclosed within an isopachous rim of granular carbonate. Patches or mats and pseudomorphs after possible periclase are composed of fine- to very fine-grained, fibrous to accicular brucite. The mats and aggregates are locally shape aligned and define a weakly developed foliation (S3096).

2.4 MYLONITIC ROCKS AND RELATED LITHOLOGIES

2.4.1 Carbonate-rich phyllonitic schist

One thin section (S2307) of a very fine grained, highly deformed carbonate-rich phyllonitic schist has been examined during this petrographic study. This highly foliated and banded rock is mainly composed of an inequigranular assemblage of quartz and carbonate with minor to trace amounts of opaque minerals, biotite, spinel and zircon (Plate 14 a and b). The compositional banding is highlighted by the variation in modal quartz and carbonate. The carbonate dominated layers are highly foliated and contain very fine granules of opaque oxide. The quartzose domains or bands are deformed by at least two foliations resulting in an SC-like fabric geometry yielding a sinistral (top to left) sense of shear in this plane of section. The main foliation within these quartzose domains occurs parallel to the compositional banding. This fabric is deformed by a number of narrow shear bands (sinistral sense of off-set) which are developed antithetic to the main shear direction. Other kinematic indicators present within this apparently phyllonitic rock include asymmetrical shear folds and poorly developed quartz porphyroclast systems. Quartz porphyroclasts are lenticular in shape with intracrystalline deformation resulting in the variable development of a sweeping extinction and deformation bands. Tails and/or pressure shadows developed upon these porphyroclasts are composed of very fine-grained to cryptocrystalline quartz. Small lenticular pods or aggregates of cryptocrystalline quartz (≤ 0.3 mm in length) present within this sample may represent dynamically recrystallised quartz porphyroclasts.

2.4.2 Tremolite schistose rock

In thin section (S8404) this highly foliated schistose to phyllonitic rock is composed of a very fine-grained, inequigranular assemblage of tremolite, quartz, biotite and plagioclase (Plate 14 c and d). Minor to trace amounts of chlorite and opaque minerals are also present. The rock is mainly composed of accicular to occasionally lozenge shaped tremolitic amphibole. Tremolite is colourless and possesses a sweeping to shadowy extinction due to intracrystalline deformation. The shape alignment of tremolite defines the well developed, weakly domainal possibly mylonitic foliation. A SC-like fabric geometry and tight crenulation-style folds are locally preserved within the narrow quartzose domains of the schistosity. This fabric is deformed by a number of shear bands which result in the variable development of an extensional crenulation cleavage (ECC) orientated oblique to the main foliation. The shear bands and SC-like geometry present within the main schistosity yield an apparent dextral sense of shear in this plane of section. Slightly coarser grained tremolite (± chlorite, biotite, quartz) was also noted forming lenticular augen which are wrapped by the matrix foliation. Biotite is pale green to green-brown in colour.

2.4.3 Plagioclase-white mica schistose/phyllonitic rock

In thin section (S3087a; S3087; S8301) these phyllonitic schists are fine- to very fine-grained and comprise an inequigranular assemblage of quartz, plagioclase, white mica and carbonate. Minor to trace amounts of chlorite and opaque minerals are also present. The rock is mainly composed of a cryptocrystalline quartzofeldspathic mosaic.

An anastomosing, well developed mylonitic foliation is defined by wispy looking, lenticular foliae composed of very fine-grained, acicular white mica, carbonate and minor chlorite. This fabric encloses lenticular quartzofeldspathic domains and wraps around rounded to elliptical plagioclase and quartz porphyroclasts (porphyroclasts form approximately 20% to 30% of the total rock). These porphyroclasts are variably shape aligned parallel to the mylonitic matrix foliation. This fabric is deformed by a set of narrow shear bands which are orientated antithetic to the main shear direction and may define a weakly developed extensional crenulation cleavage (S3087). In sample S8391, the wispy mica foliae appear to have nucleated upon the margins of the plagioclase porphyroclasts.

The quartz porphyroclasts are irregular in shape with dynamic recrystallisation resulting in the development of increasingly serrated grain boundaries. These relict quartz porphyroclasts possess an undulose to sweeping extinction and are enclosed within an aggregate of very fine-grained, unstrained new grains. Plagioclase forms anhedral crystals which are variably altered to sericitic white mica. Plagioclase was apparently more rigid during ductile deformation resulting in localised cataclasis and microboudinage with fragmentation occurring along pre-existing fractures and twin composition planes. Broken, angular fragments of plagioclase may locally possess a weakly developed undulose extinction, but overall plagioclase appears to have been more resistant to intracrystalline deformation than the associated quartz porphyroclasts. Minor carbonate and sericitic white mica occur along the fractures within some plagioclase porphyroclasts. Both quartz and plagioclase porphyroclasts are enclosed within asymmetrical to symmetrical pressure shadows.

Fine-grained, granular opaque oxides locally overgrowth the mylonitic foliation and are typically associated with the presence of chlorite within the mica foliae.

2.4.4 Quartz-white mica schistose/phyllonitic rock

In thin section (S8389) this highly foliated schistose rock is composed of a fine- to very fine-grained, inequigranular assemblage of white mica and quartz with minor to trace amounts of opaque minerals and tourmaline. The homogeneous mylonitic foliation is defined by shape aligned white mica flakes and wraps around rounded to irregular quartz porphyroclasts. These porphyroclasts are enclosed within variably developed pressure shadows denoted by a marked change in orientation of the white micas immediately adjacent to quartz. The quartz porphyroclasts occur in discrete clusters and may represent deformed fragments of a single much larger grain. Quartz forms anhedral crystals which have undergone localised cataclasis and/or intracrystalline deformation; the latter resulting in the development of an undulose to sweeping extinction, deformation bands and dislocations. The fractures within quartz are filled by sericite. Quartz may possess serrated grain boundaries with localised dynamic recrystallisation resulting in minor sub-grain and new grain growth. The preservation of quartz porphyroclasts within this rock may, at least in part, due to the partitioning of deformation into its white mica-rich matrix.

Very fine-grained, dusty looking opaque mineral grains occur in discrete aggregates or clusters. The mylonitic foliation is overgrown by small, radiating fans, aggregates and rosettes of blue to blue-green tourmaline.

2.4.5 Phyllite

The phyllites (S15035; S15034) are fine- to very fine-grained, highly foliated rocks which comprise and inequigranular assemblage of white mica, quartz and plagioclase. Minor to accessory phases present include opaque minerals, biotite, tourmaline and epidote. The foliation is homogenous and defined by shape and optically aligned white mica flakes. Both quartz and plagioclase form very small, rounded to elliptical grains which possess a low to moderate sphericity and give the appearance of being relict detrital grains (speculative). Rare lenticles of slightly coarser grained quartz, biotite and opaque oxide are present in sample S15035. In sample S15034, the opaques (probably pyrite) form small, syn- and apparently post-kinematic porphyroblasts. The former are enclosed within locally well developed quartz-fibre pressure shadows. In contrast, the post-kinematic opaque crystals clearly overgrow the matrix foliation.

2.4.6 Muscovite porphyroblastic mylonitic schist

In thin section (S38691) this highly deformed to mylonitic schist is composed of a fine- to very fine-grained assemblage of quartz, plagioclase, biotite, muscovite and epidote. Minor to accessory phases present include opaque minerals, chlorite and sericite. It is characterised by the presence of deformed muscovite porphyroblasts which form distinctive asymmetrical to lenticular foliation fish. Muscovite is deformed with intracrystalline deformation resulting the development of a sweeping to undulose extinction, kinking and distortion of the basal (010) cleavage and displacement along these cleavage planes. The asymmetry of these foliation fish yield a dextral (top to right) sense of shear in this plane of section.

The matrix of the rock is granular in appearance and mainly composed of cryptocrystalline quartz and feldspar with wispy aggregates or foliae of green coloured biotite and granular epidote. The biotite aggregates define a weakly developed foliation which wraps around the muscovite porphyroblasts.

2.4.7 Quartzofeldspathic ultramylonite

In thin section (S8396; S8395; S9765; S3093; S9766; S9773; S9774) the quartzofeldspathic ultramylonites are highly deformed, extremely fine-grained, finely banded, streaky-looking rocks which comprise the assemblage quartz, feldspar, white mica and opaque minerals. The foliation is define by thin chains of very fine-grained, granular opaque oxide and a streaky looking banding defined by stringers of very slightly coarser grained quartz. In some rocks (S9765; S3093), this mylonitic foliation is also defined by shape and optically aligned, very fine-grained white mica flakes. These rocks have largely been completely recrystallised (dynamic recrystallisation) during deformation, however, small (≤ 0.2 mm in size), elliptical to rounded quartz and feldspar porphyroclasts may be present (forming ≤ 1% of the total rock). These porphyroclasts are wrapped by the matrix foliation. Both quartz and feldspar which form the bulk of the matrix of the rock possesses a well developed preferred c-axis/crystallographic orientation. Sample S9765 is cut by a number of apparently syn-kinematic quartz veinlets which are internally deformed. Rare muscovite porphyroblasts or foliation fish have been noted in some of these ultramylonitic rocks (S9766; S9773).

2.4.8 Quartzofeldspathic mylonite

These mylonitic rocks probably represent a less intensely deformed equivalent of the previously described ultramylonites. In thin section (S8415; S9758; S9764; S2949) they are composed of a fine-grained, inequigranular assemblage of quartz, plagioclase and K-feldspar with minor to accessory opaque minerals, biotite, epidote, white mica, monazite and titanite. However, the rock is mainly composed of anhedral variably strained quartz and plagioclase. The well developed mylonitic foliation is defined by narrow zones or foliae of intensely deformed, very fine-grained to cryptocrystalline quartz and feldspar. Elsewhere a fine-scale mylonitic fabric is defined by granular to elongate quartz and very small needles or flakes of biotite and white mica. In sample S8415, this finer scale mylonitic fabric is partially overprinted by the development of late (?post-kinematic), fine-grained, replacive carbonate. Both mylonitic fabrics wrap around relict feldspar and quartz porphyroclasts. In sample S9764, deformation resulted in the development of a weakly to moderately developed SC fabric, with the C planes defined by wispy looking mica-foliae. The corresponding S-surfaces are defined by dynamically recrystallised, optically and shape aligned quartz.

Plagioclase is typically more resistant to deformation forming larger, rounded to elliptical porphyroclasts which range from < 0.2 mm up to 4.0 mm in size. Plagioclase is twinned and possesses a variably developed undulose to sweeping extinction. Intracrystalline deformation within plagioclase may also result in the kinking of twin composition planes and localised sub-grain and new-grain growth. The feldspar porphyroclasts occur in discrete bands accompanied by the presence of variably chloritised biotite within the matrix. The porphyroclasts are locally enclosed within variably developed pressure shadows which are composed of fine-grained quartz. Sample S9758 also contains rare microcline porphyroclasts and elongate quartz ribbons. In sample S9764, rounded to lenticular microcline porphyroclasts are common.

Opaque minerals form anhedral to subhedral crystals which apparently post-date the ductile deformation and the imposition of the mylonitic fabric. Samples S9758 and S2949 also contain traces of post-kinematic, yellow coloured epidote and titanite.

2.5 CLASTIC SEDIMENTARY ROCKS

2.5.1 Feldspathic sandstone

In thin section the feldspathic sandstones (S15023; S41011; S15024; S15025; S15026) are medium- to coarse-grained, immature, matrix-poor rocks which possess a closely to very closely packed, clast supported texture. Detrital grains are subrounded to rounded in shape with a low to moderate sphericity, Although typically rounded in shape, rare subangular clasts have also been recorded. Elongate grains may exhibit a preferred shape alignment, possibly parallel to bedding. The shape of some grains has been modified during the recrystallisation of the matrix and as a result of pressure solution between adjacent clasts; the latter leading to the localised development of interlocking grain boundaries.

The clast assemblage is dominated by monocrystalline quartz, K-feldspar and plagioclase. Quartz and feldspar are internally deformed with a locally well developed undulose to shadowy extinction, deformation bands and sub-grain textures. Plagioclase may also exhibit variable alteration to sericitic white mica. Other minor to accessory detrital components include perthite, cryptocrystalline felsic rock or chert, polycrystalline quartz, biotite, apatite, titanite, allanite, opaque minerals, polycrystalline epidote, clinozoisite, muscovite, garnet and chlorite. This clast assemblage suggests that the sandstones were derived from a granitic to syenitic continental provenance, a conclusion supported by the presence of granule sized granitic lithic clasts within sample S15025.

The matrix to these immature sandstones is composed of a very fine-grained to cryptocrystalline mosaic of quartz. Patchy of secondary carbonate were noted replacing this quartzose matrix/cement. Carbonate was also noted replacing detrital feldspar grains. In sample S15025, a sedimentary lamination is preserved by thin (≤ 0.4 mm thick), siltstone and/or mudstone partings. This sample also contains heavy minerals bands which are mainly composed of opaque oxide. Some of the sandstone have undergone limited low-grade (possibly sub-greenschist facies) metamorphism (S41011; S15026). This led to the recrystallisation of the matrix and growth of accicular chlorite/mica beards or fringes upon detrital grains. Patches of very fine-grained chlorite (± dusty opaque minerals) were noted within the matrix of these rocks, possibly replacing an original clay cement. However, although metamorphosed the original clastic texture of the rock is well preserved. A weak tectonic fabric may be developed defined by aligned chlorite flakes (S15026).

2.5.2 Calcareous siltstone

A thin section (S889) of a fine-grained, laminated siltstone has been examined during this study. The original clastic rocks has largely been replaced by fine- to very fine-grained, granular looking carbonate (the type of carbonate minerals present is uncertain as the rock is unstained). The original sedimentary lamination within the siltstone is preserved by a variation in the intensity of carbonate replacement, with the most altered laminae representing the mud-rich partings. Relict, fine- to medium-silt grade detrital quartz grains can still be recognised within some of the less intensely altered laminae. Other relict accessory detrital grains present include opaque minerals, biotite, muscovite, chlorite, K-feldspar and plagioclase. Thin wispy looking seams of opaque oxide occur parallel to bedding and possibly represent pressure solution seams (styolites).

2.5.3 *Salterella*-bearing quartz arenite

In thin section (S54621; S54622; S35825; S35826) these quartz arenites are typically medium- to coarse-grained, moderately to poorly sorted, compositionally mature, weakly recrystallised rocks which possess a closely to very closely packed, grain supported texture. These quartzose sandstones are characterised by the presence of the fossil *Salterella*. The fossil fragments are roughly rounded to cone shaped and composed of a dusty grey-brown, cryptocrystalline, isotropic material. The shape of these fragments of Salterella have been locally modified due to embayment against neighbouring more rigid quartzose clasts.

Detrital grains are subrounded to rounded in shape with a high to moderate sphericity. However, occasional to rare low to moderate sphericity grains are also present. The shape of these clastic grains has been variably modified due to pressure solution and during the recrystallisation of the matrix. Pressure solution appears to have resulted in the main mode of cementation within these sandstones. The bulk of the clast assemblage is dominated by monocrystalline quartz. The quartz clasts are locally enclosed within variably developed quartz rim cement. The sandstone also contain elongate to irregular mudstone and siltstone lithic clasts which have been distorted during compaction. These lithic clasts are composed of a dusty looking, grey coloured argillaceous material containing angular to subangular quartz grains.

Glossary

Amphibolite – A metamorphosed basic igneous rock with a mineral assemblage comprised largely of amphibole and plagioclase, usually with quartz and epidote.

Atoll structure – A structure consisting of a core of one mineral entirely surrounded by a rim of another mineral. For example garnet forming a core entirely surrounded by plagioclase.

Augen gneiss – a gneissose rock with abundant ***augen*** (eyes) represented by porphyroblasts (typically K-feldspar) enveloped by the foliation.

Bow-tie structure – Aggregates of elongate prismatic and acicular crystals that are arranged to give the appearance of a bow-tie. Commonly exhibited by amphiboles in ***garbenschiefer*** that have grown in the foliation plane under low stress.

Calc-silicate rock – a rock with a chemistry dominated by calcium and silica (e.g. a metamorphosed calcareous mudstone, marl), consisting of the hydrous or anhydrous calc-silicate minerals such as tremolite, diopside and grossular garnet. Carbonate minerals may also be present.

Cleavage – A sub-parallel set of closely spaced approximately planar surfaces produced during rock deformation. Defined by the preferred alignment of platy or elongate mineral grains (usually phyllosilicate minerals such as muscovite, biotite, chlorite).

Corona or reaction rim – A monomineralic or polymineralic rim totally surrounding a core of another mineral phase. It typically represents an arrested reaction between the core phase and other components within the rock.

Decussate structure – A term used to describe interlocking, randomly orientated, elongate, prismatic or subhedral crystals, generally of one mineral phase.

Gneiss – A coarsely banded high-grade metamorphic rock consisting of alternating, mineralogically distinct layers.

Granoblastic texture – An aggregate consisting of equidimensional, typically rounded to anhedral crystals of approximately equal size.

Granulite – A high-grade metamorphic rock typically with a granoblastic texture and with an assemblage containing pyroxene and anorthite-rich plagioclase.

Greenschist – A low-grade metamorphosed basaltic rock consisting of the assemblage actinolite, chlorite, epidote, albite, quartz and accessory titanite (sphene).

Hornfels – A hard, fine- to medium-grained granoblastic rock produced by high-grade contact metamorphism.

Phyllite – A well-cleaved metamorphosed mudstone characterised by a distinctive sheen on foliation surfaces; generally of intermediate grain size and metamorphic grade between slate and schist.

Poikiloblast – A term used to describe porphyroblasts with abundant mineral inclusions.

Porphyroblast – A metamorphic mineral (e.g. garnet) that has grown to much larger size than the minerals of the surrounding matrix.

Porphyroblastic – A term used to describe a metamorphic rock containing large porphyroblasts within a finer grained matrix.

Porphyroclast – A large relict crystal, or crystal fragment in a fine-grained matrix of a deformed rock.

Post-tectonic growth – Growth of minerals or parts of a mineral which occurred after deformation had ceased.

Pressure shadow – A region of low strain developed immediately adjacent to a rigid or competent object in a rock (e.g. a garnet porphyroblast).

Pre-tectonic growth – Mineral growth before deformation has occurred.

Pseudomorph – A mineral or aggregate of minerals having taken the form/shape of another mineral phase that it/they have replaced.

Schist – A metamorphic rock of broadly pelitic composition (i.e. a metamorphosed mudstone) with a well-developed schistosity.

Schistosity – A planar structure defined by the alignment of elongate minerals such as micas and amphibole.

Plates

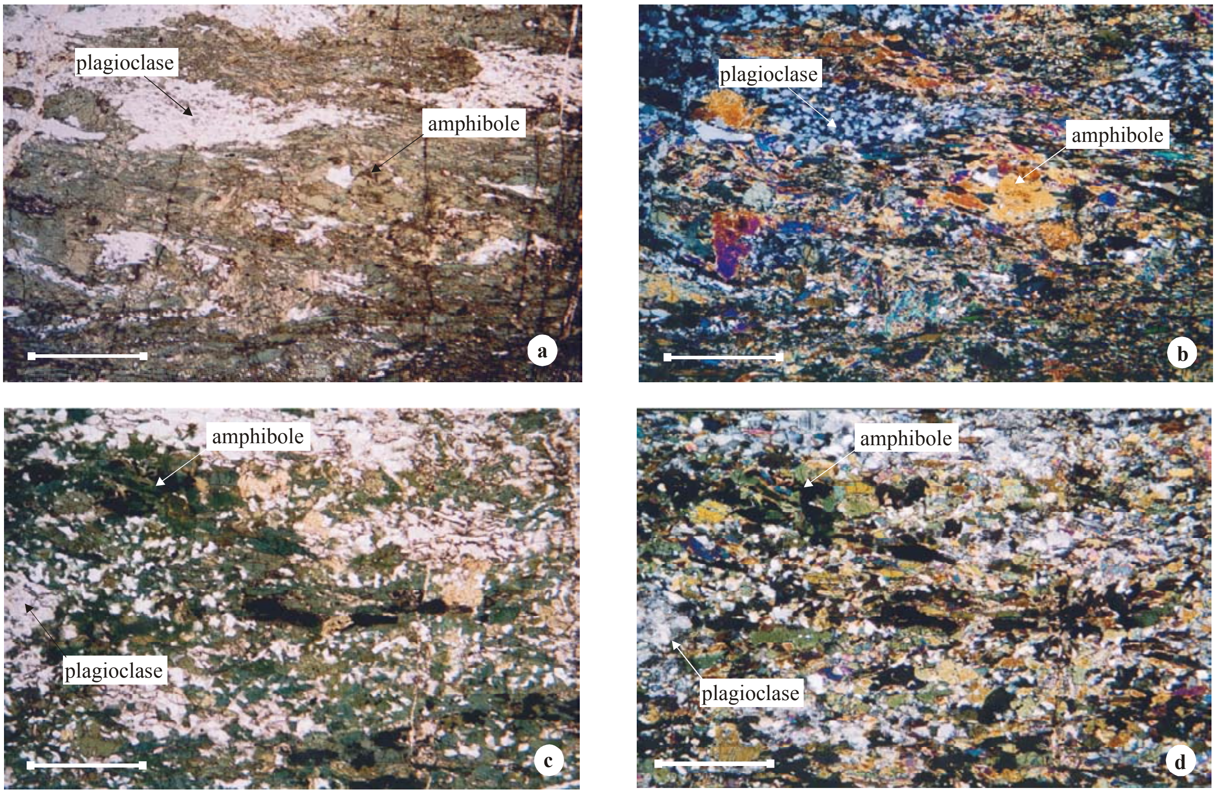

Plate 1. (a) and **(b)** Moderately foliated hornblende schistose metabasic rock (plane and crossed polarised light. Sample 2750). **(c)** and **(d)** Weakly foliated hornblende schistose metabasic rock (plane and crossed polarised light. Sample S2932). Scale bar = 1 mm

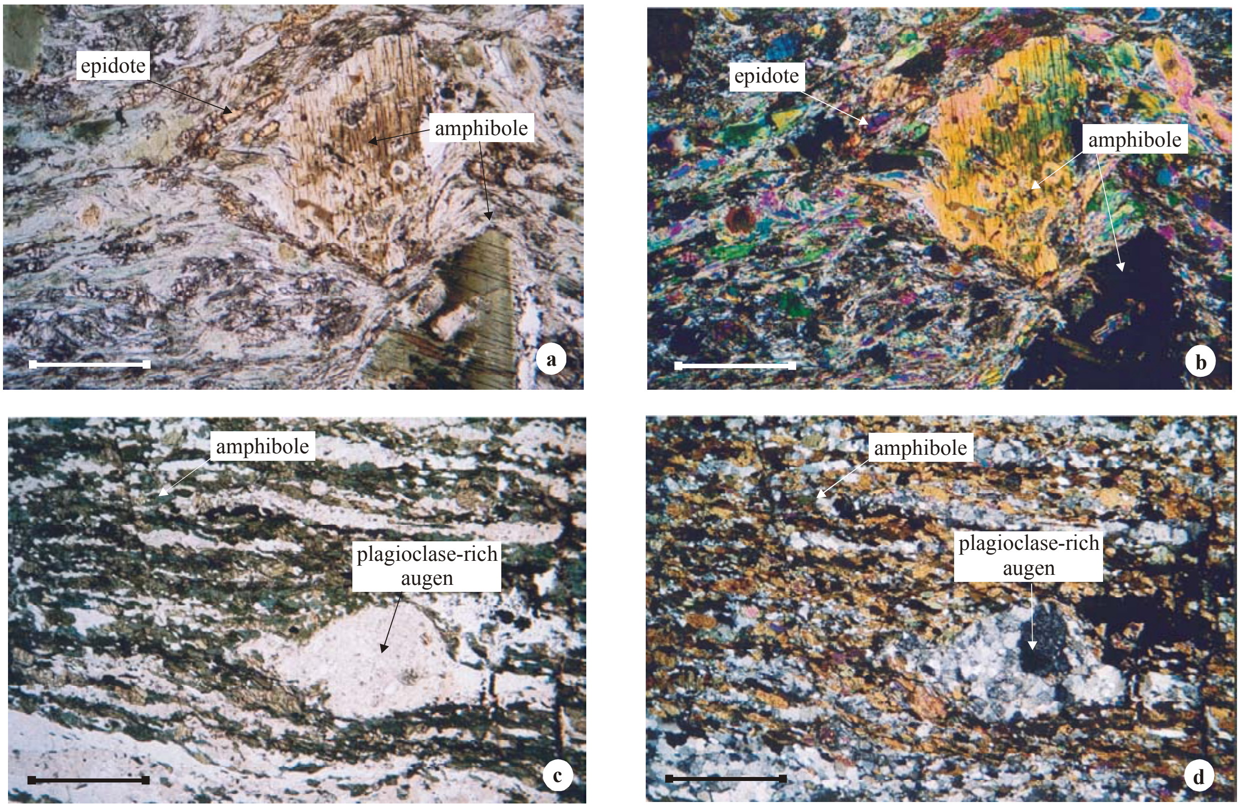

Plate 2. (a) and **(b)** Coarse-grained epidote-hornblende-actinolite metabasic rock containing large amphibole porphyroclasts wrapped by the matrix foliation (plane and crossed polarised light. Sample S2950). **(c)** and **(d)** Highly foliated plagioclase-hornblende schistose metabasic rock (plane and crossed polarised light. Sample S48157). Scale bar = 1 mm

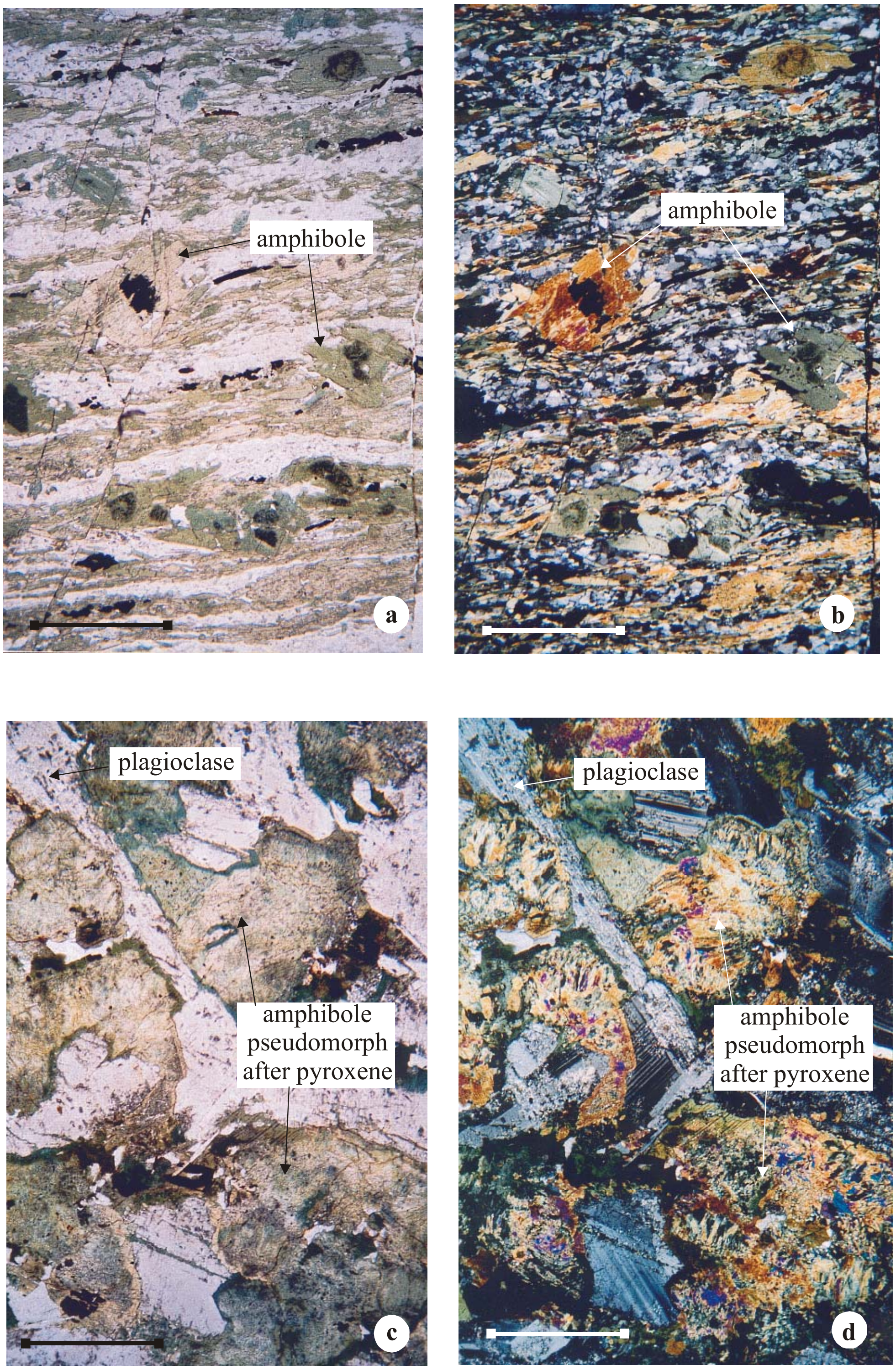

Plate 3. **(a)** and **(b)** Plagioclase-hornblende schistose metabasic rock containing amphibole porphyroblasts wrapped by the matrix foliation (plane and crossed polarised light. Sample S2754a). **(c)** and **(d)** Quartz-bearing metagabbroic rock containing amphibole pseudomorphs after intergranular ophitic pyroxene (plane and crossed polarised light. Sample S8387). Scale bar = 1 mm

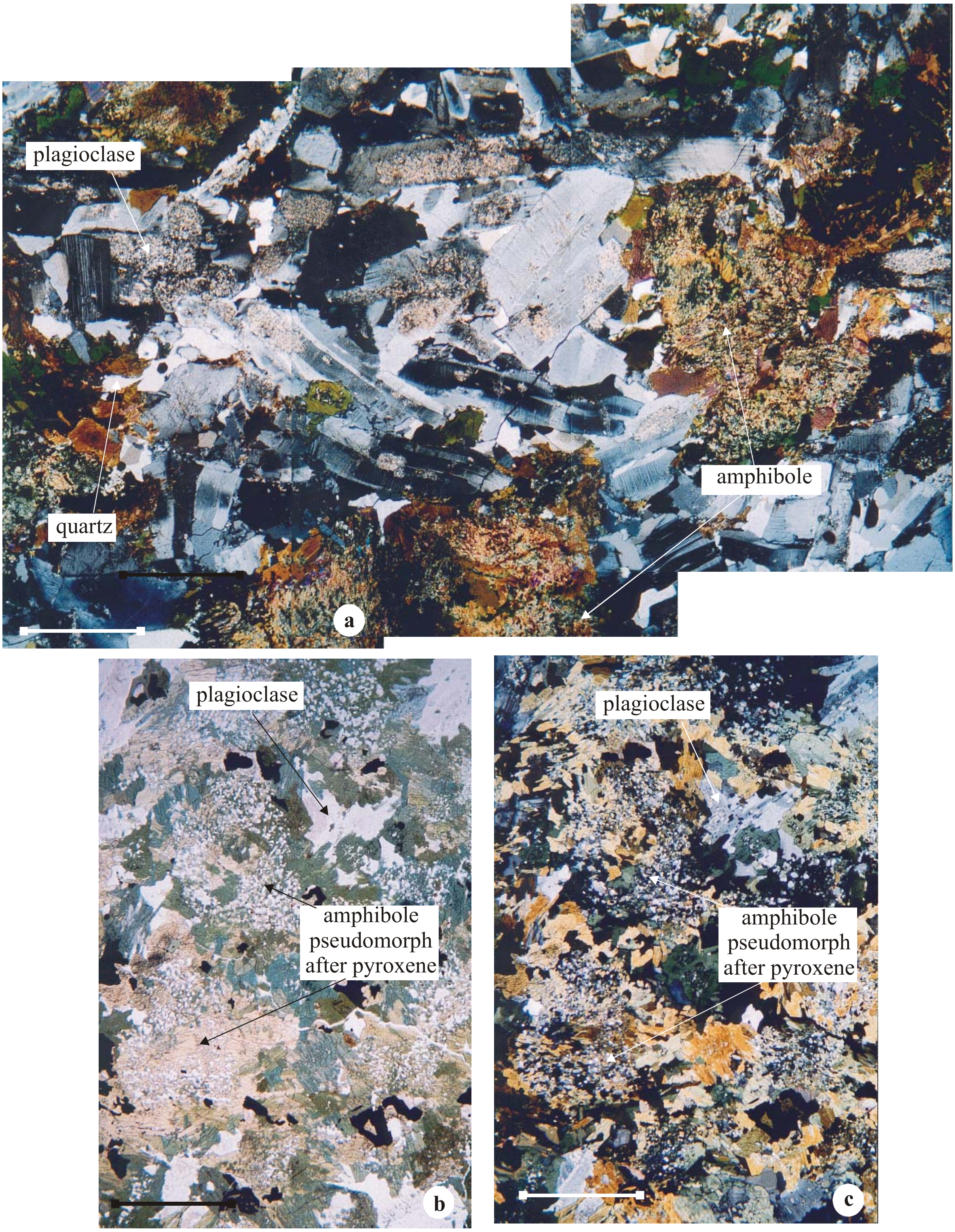

Plate 4. (a) and **(b)** Quartz-bearing metagabbro or melanocratic metadiorite with a well developed pre-full crystallisation fabric (plane and crossed polarised light. Sample S2760). **(c)** and **(d)** Quartz-bearing metagabbroic rock containing sieve textured pseudomorphs after pyroxene (plane and crossed polarised light. Sample S8387). Scale bar = 1 mm

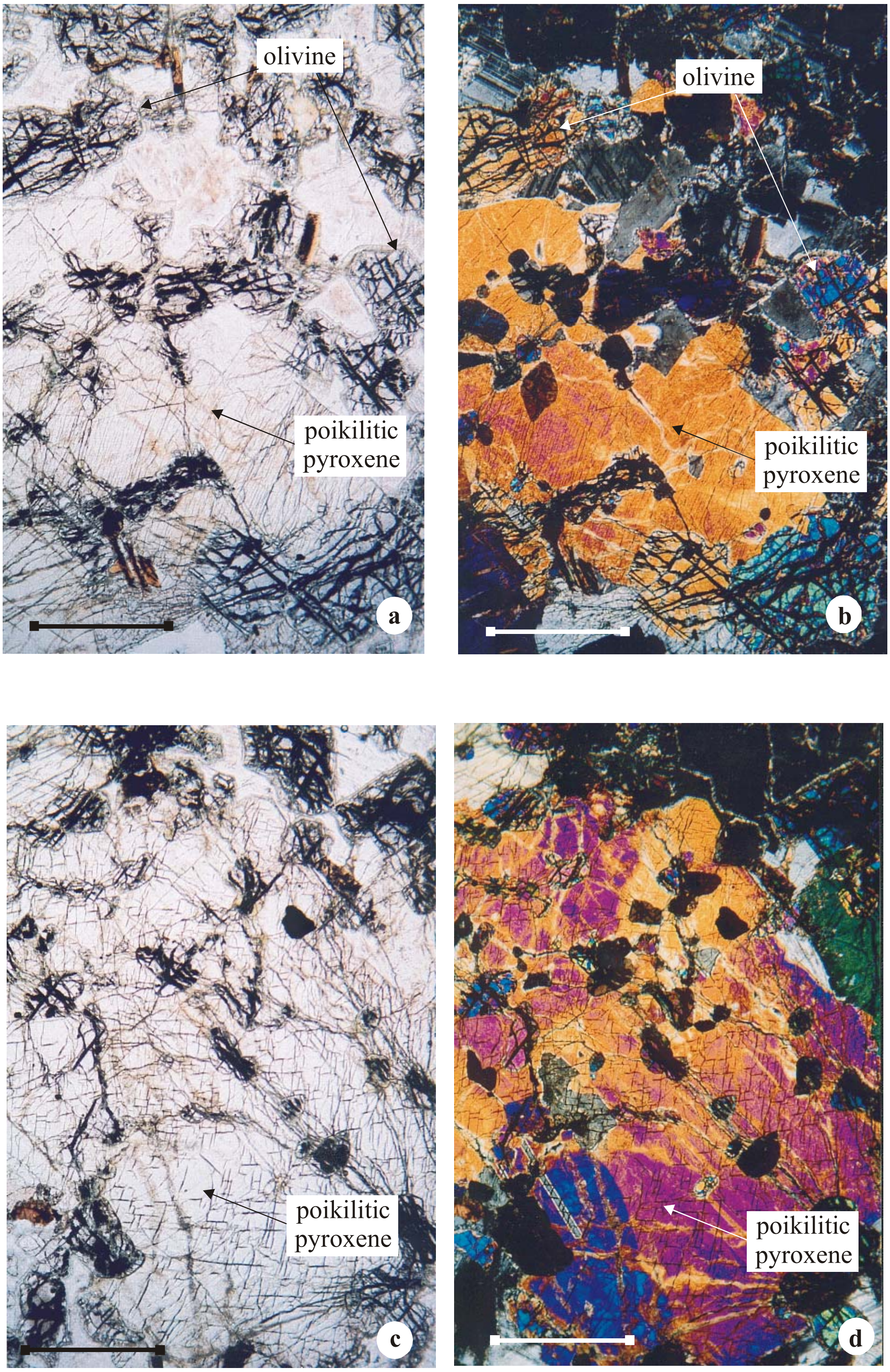

Plate 5. (a) and **(b)** Coarse-grained two-pyroxene metaperidotite with poikilitic intergranular pyroxene (plane and crossed polarised light. Sample S3307a). **(c)** and **(d)** Large poikilitic intergranular pyroxene containing rounded inclusions of olivine (plane and crossed polarised light. Sample S3307). Scale bar = 1 mm

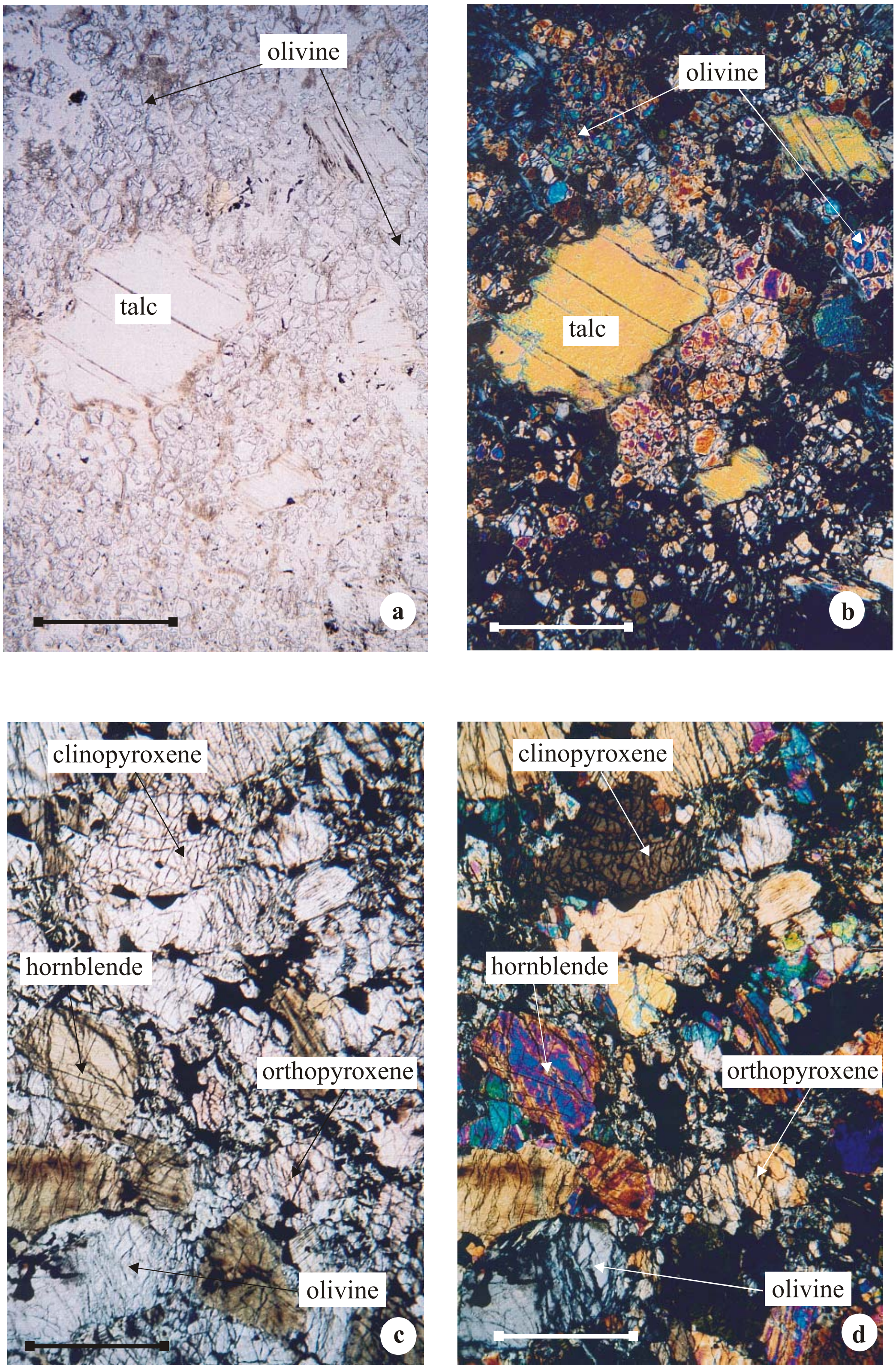

Plate 6. (a) and **(b)** Fine- to medium-grained metadunite containing anhedral crystals of talc (plane and crossed polarised light. Sample S22026). **(c)** and **(d)** Hornblende metaperidotite containing both clinopyroxene and orthopyroxene (plane and crossed polarised light. Sample S2934). Scale bar = 1 mm

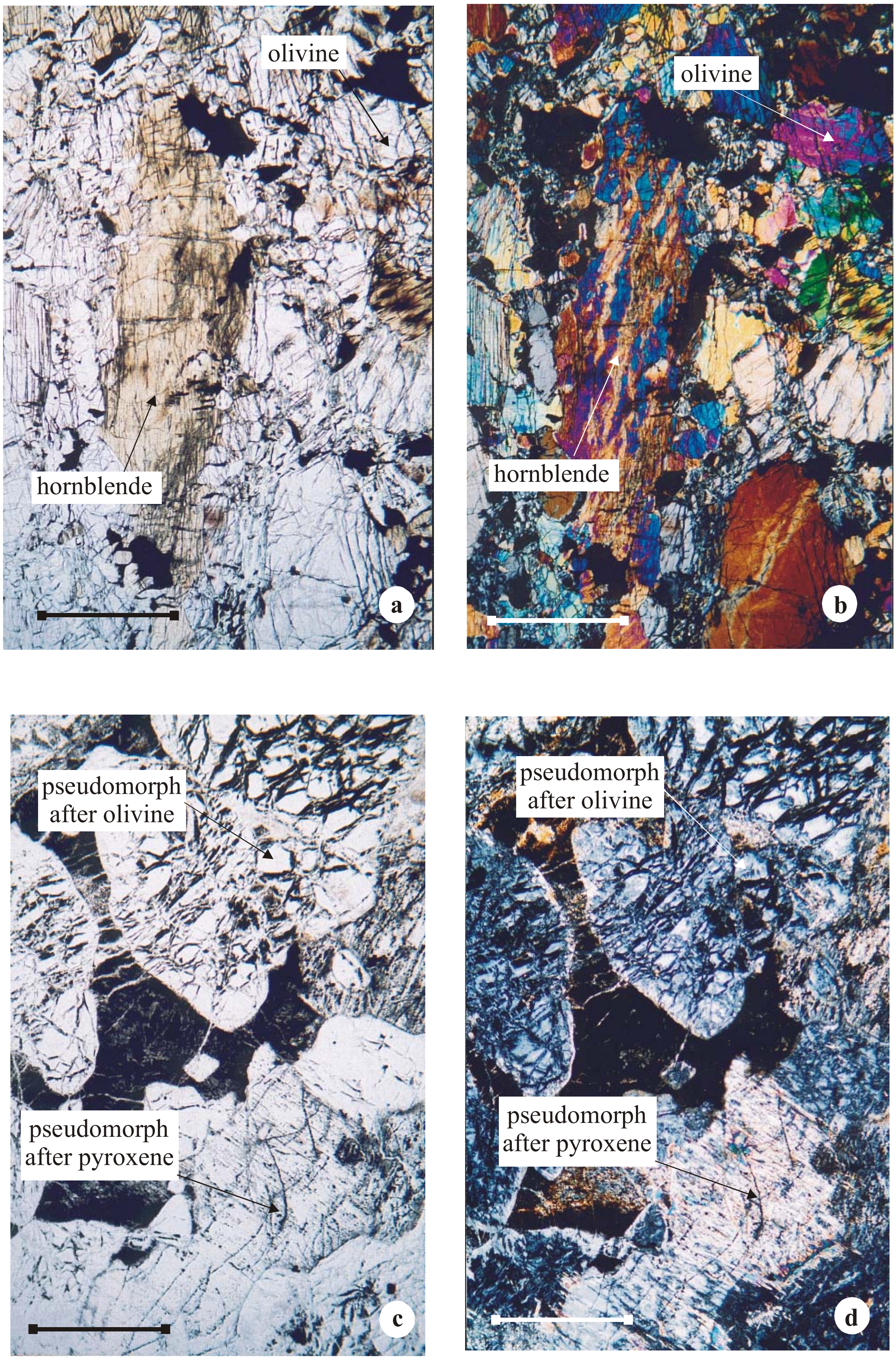

Plate 7. (a) and **(b)** Hornblende-pyroxene metaperidotite containing elongate crystals of amphibole (plane and crossed polarised light. Sample S3946). **(c)** and **(d)** Serpentinite containing pseudomorphs after olivine and pyroxene (plane and crossed polarised light. Sample S3947). Scale bar = 1 mm

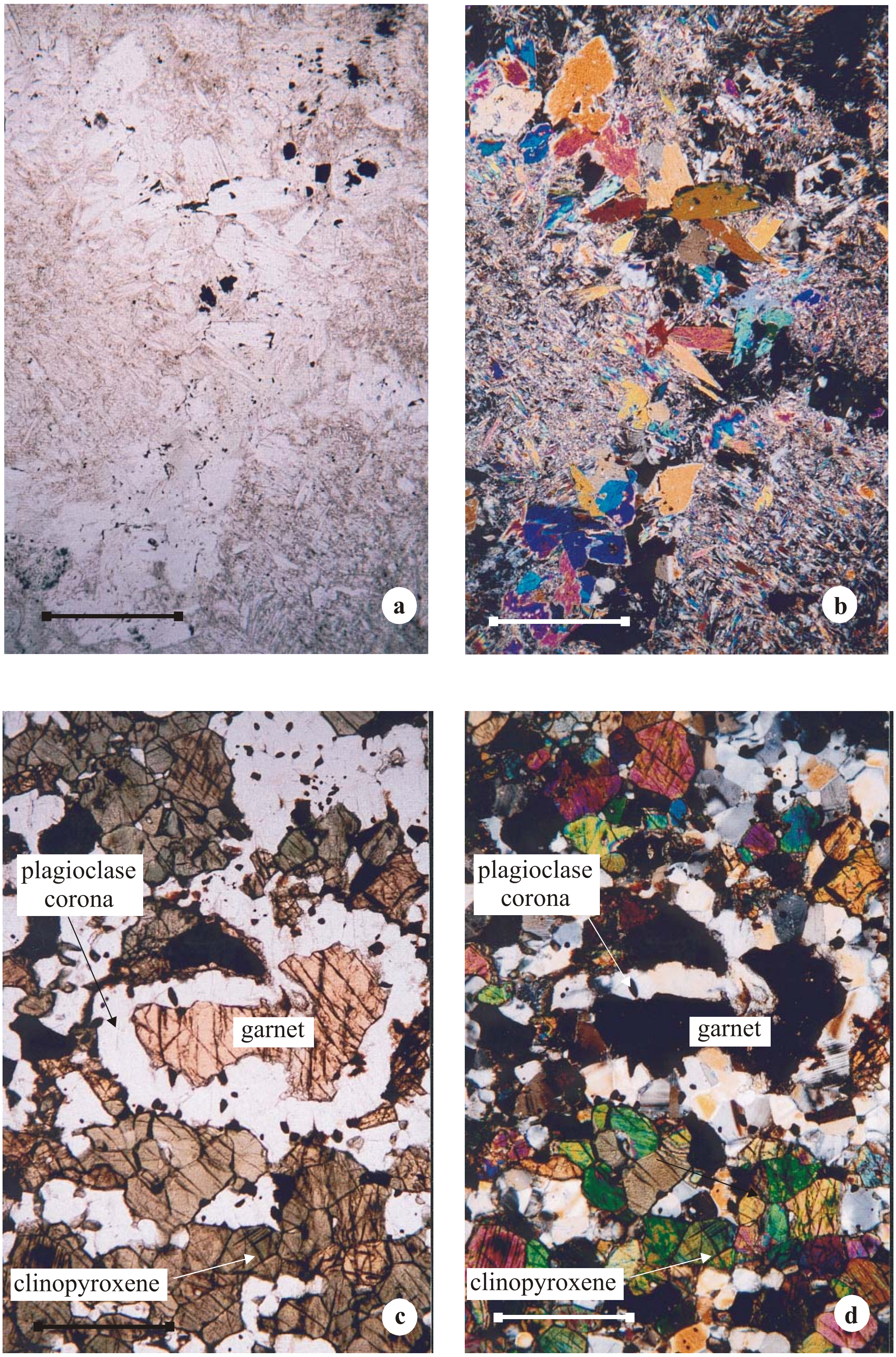

Plate 8. (a) and **(b)** Tremolite-rich metamorphosed ultramafic rock (plane and crossed polarised light. Sample S55256). **(c)** and **(d)** garnet-pyroxene metagabbroic gneiss with anhedral garnet porphyroblasts surrounded by a granular looking plagioclase corona (plane and crossed polarised light. Sample S3306). Scale bar = 1 mm

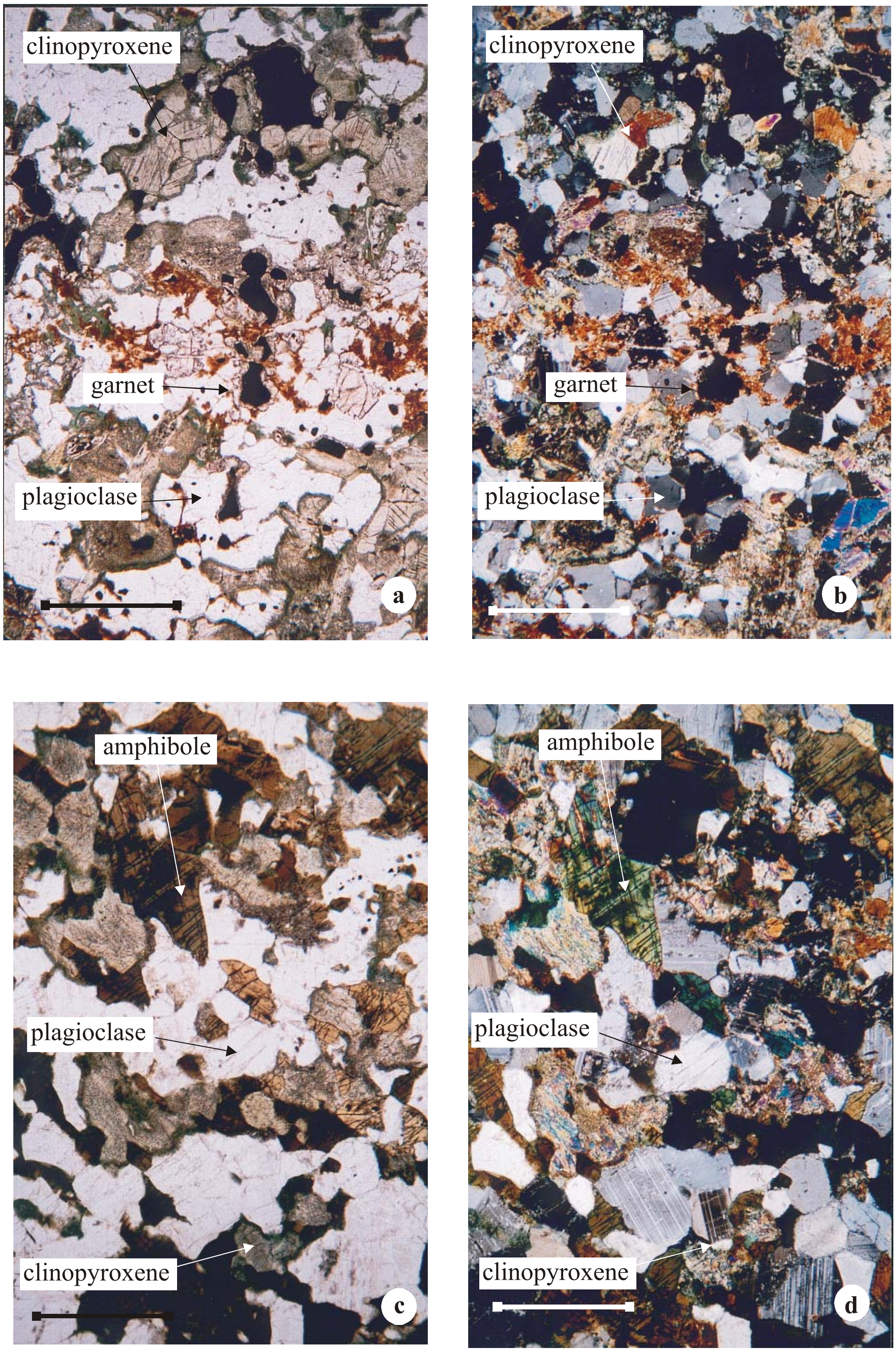

Plate 9. (a) and **(b)** Retrogressed garnet-pyroxene metagabbroic gneiss with amphibole reaction rims upon clinopyroxene and garnet rims upon opaque minerals (plane and crossed polarised light. Sample S7842). **(c)** and **(d)** Hornblende-pyroxene metagabbroic gneiss (plane and crossed polarised light. Sample S30677). Scale bar = 1 mm

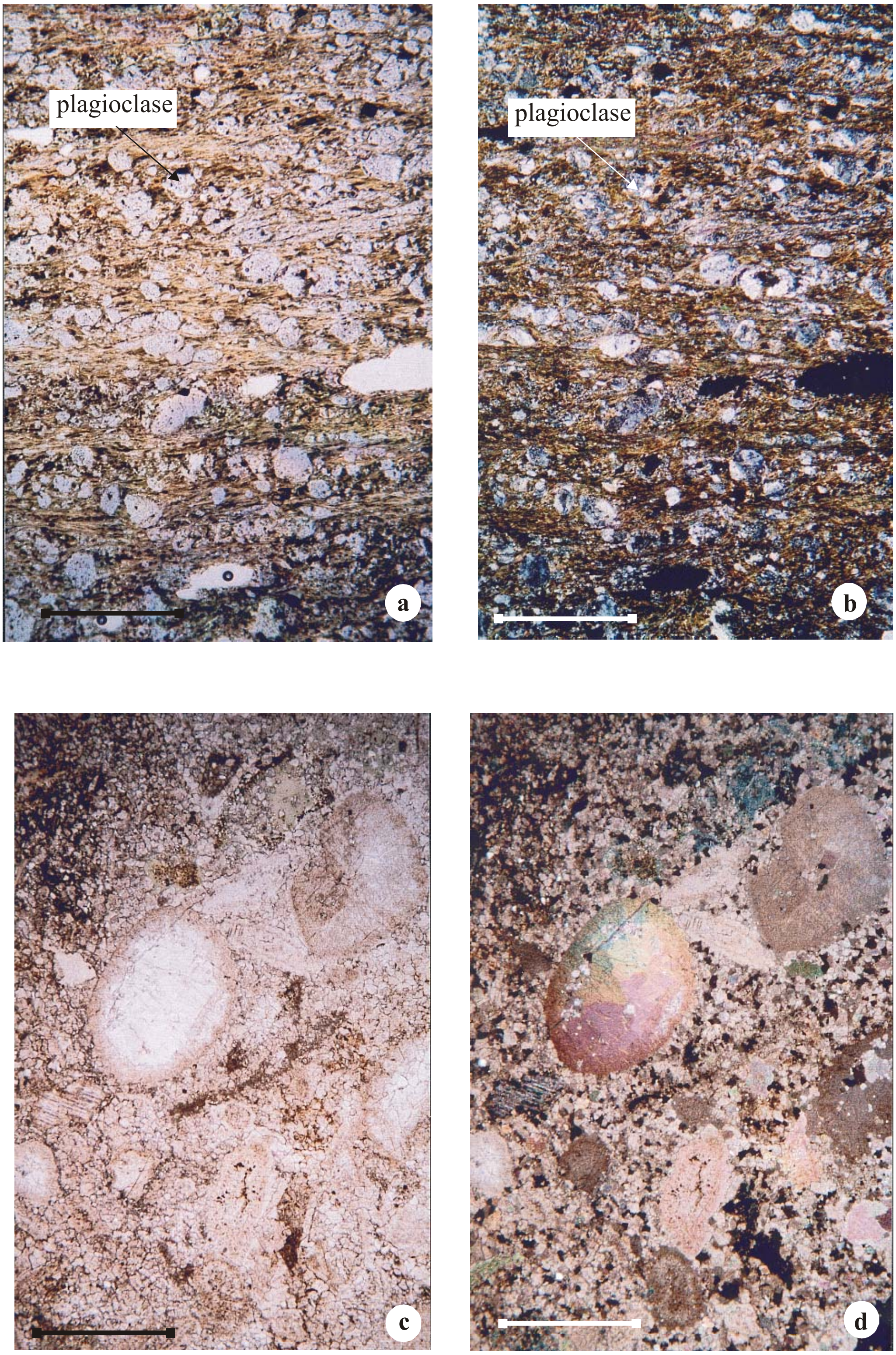

Plate 10. (a) and **(b)** Highly foliated plagioclase-biotite schistose rock containing small plagioclase porphyroblasts (plane and crossed polarised light. Sample S9769). **(c)** and **(d)** Metalimestone containing possible bioclastic fragments (plane and crossed polarised light. Sample S9906). Scale bar = 1 mm

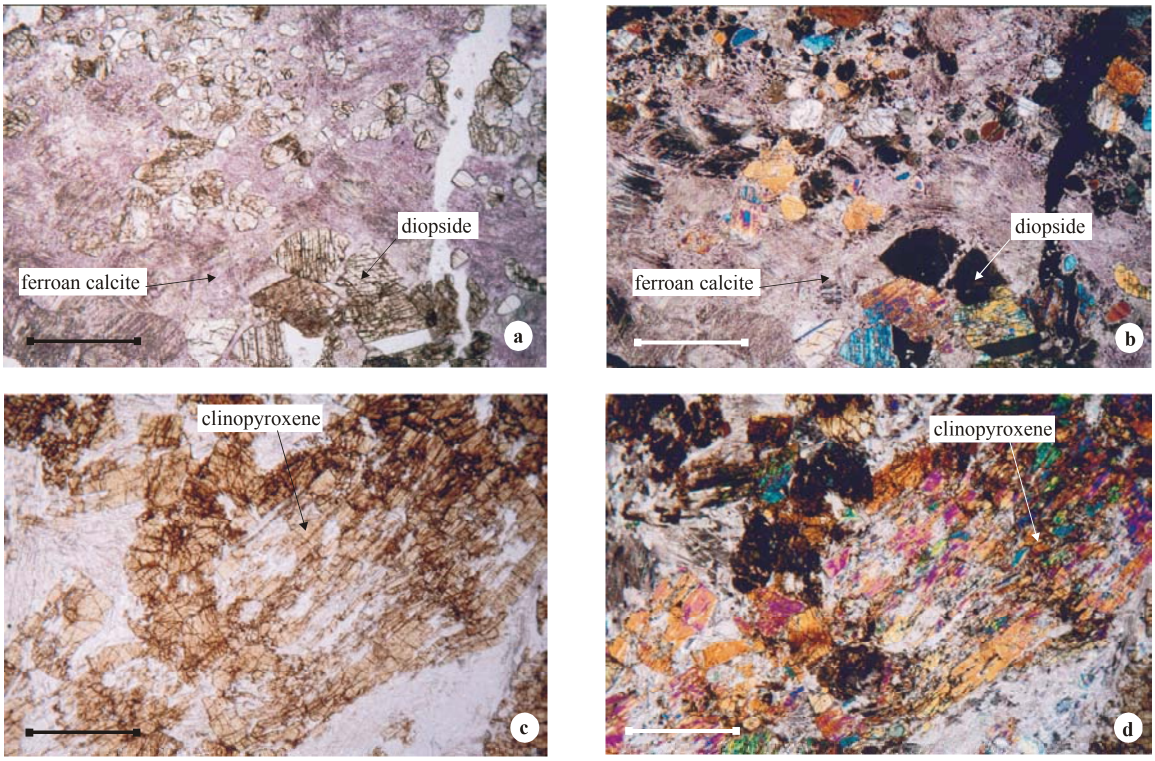

Plate 11. (a) and **(b)** Medium- to coarse-grained diopside marble (plane and crossed polarised light. Sample S9210). **(c)** and **(d)** Larger aegirine augite crystals within marble (plane and crossed polarised light. Sample S9204a). Scale bar = 1 mm

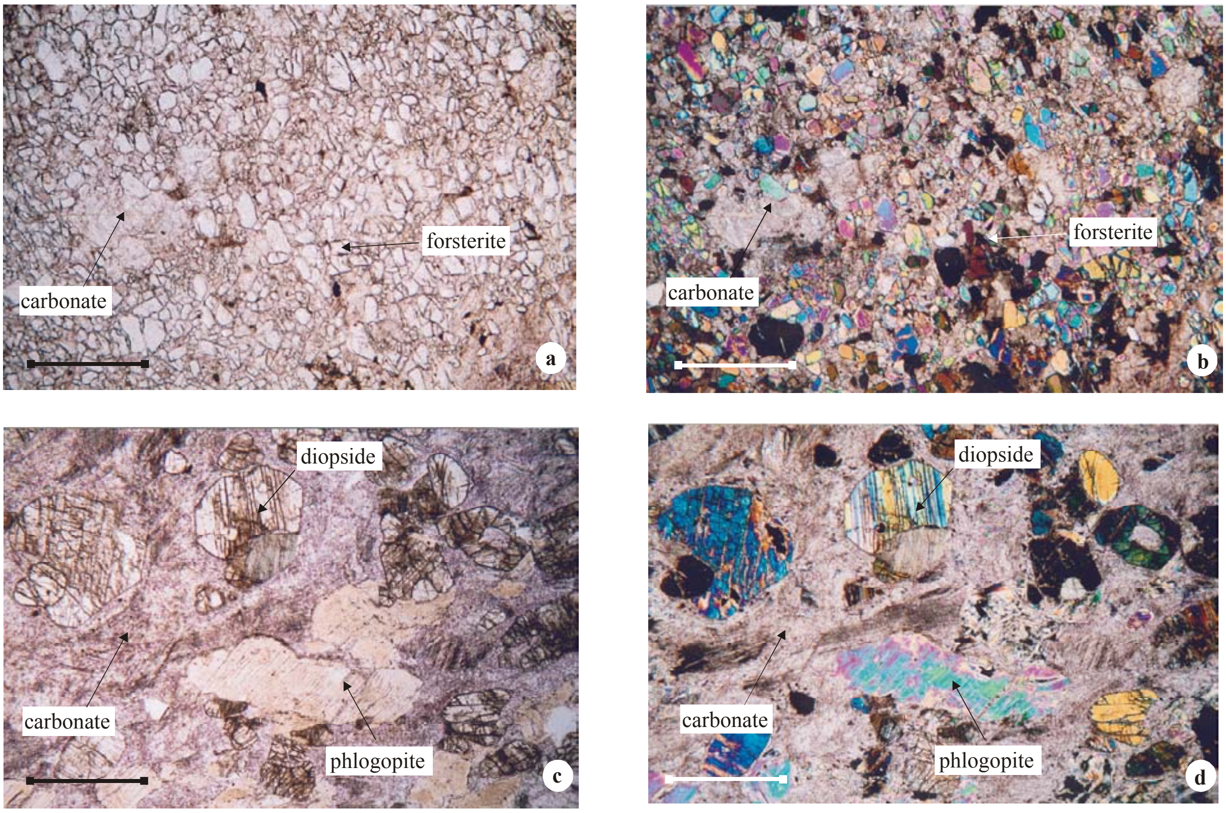

Plate 12. (a) and **(b)** Fine- to medium-grained forsterite marble (plane and crossed polarised light. Sample S3099). **(c)** and **(d)** Foliated phlogopite-diopside marble (plane and crossed polarised light. Sample S9207). Scale bar = 1 mm

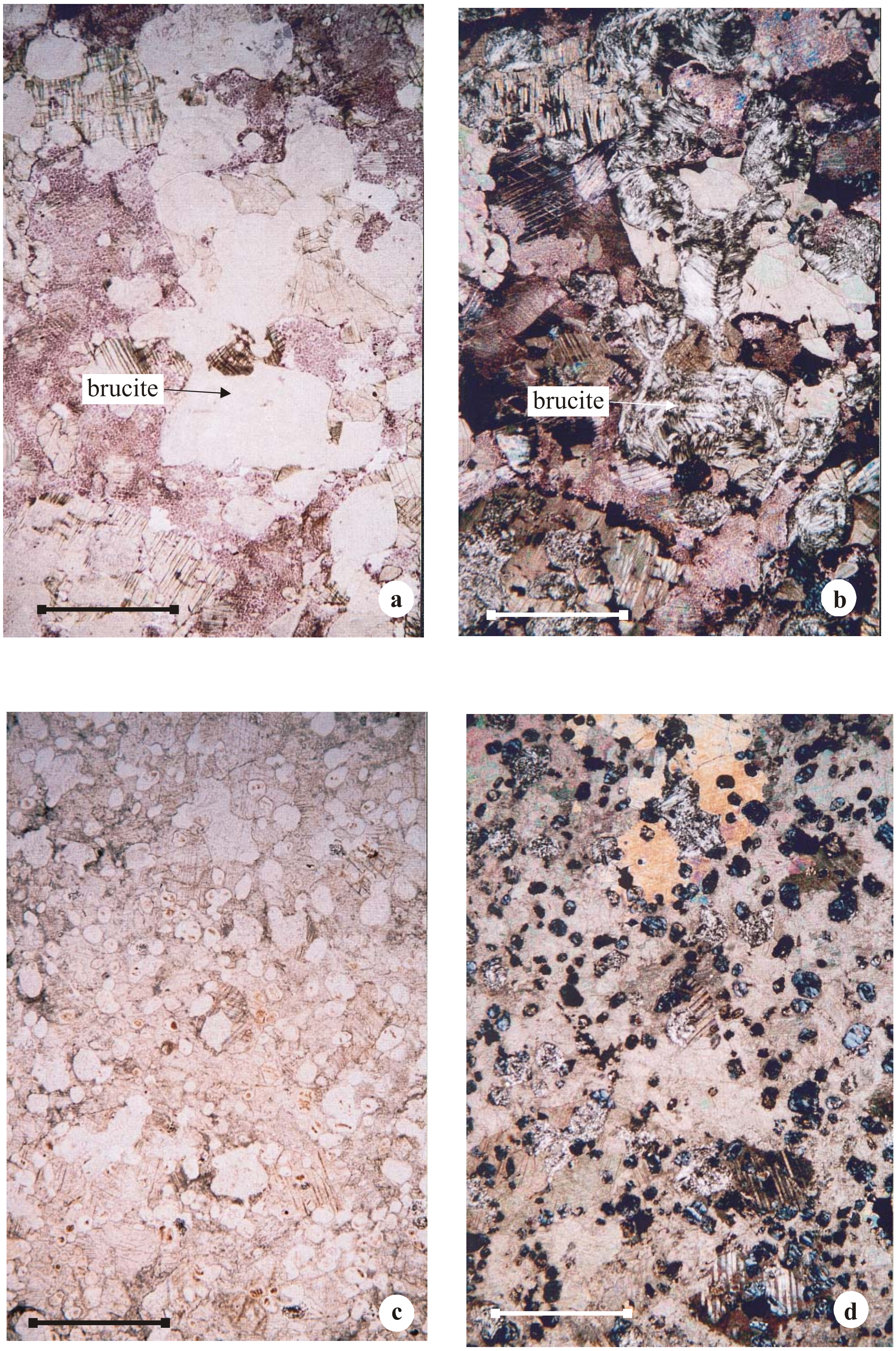

Plate 13. (a) and **(b)** Brucite marble (plane and crossed polarised light. Sample S9208). **(c)** and **(d)** Forsterite-brucite marble in which all the olivine has been replaced by serpentine (plane and crossed polarised light. Sample S9843). Scale bar = 1 mm

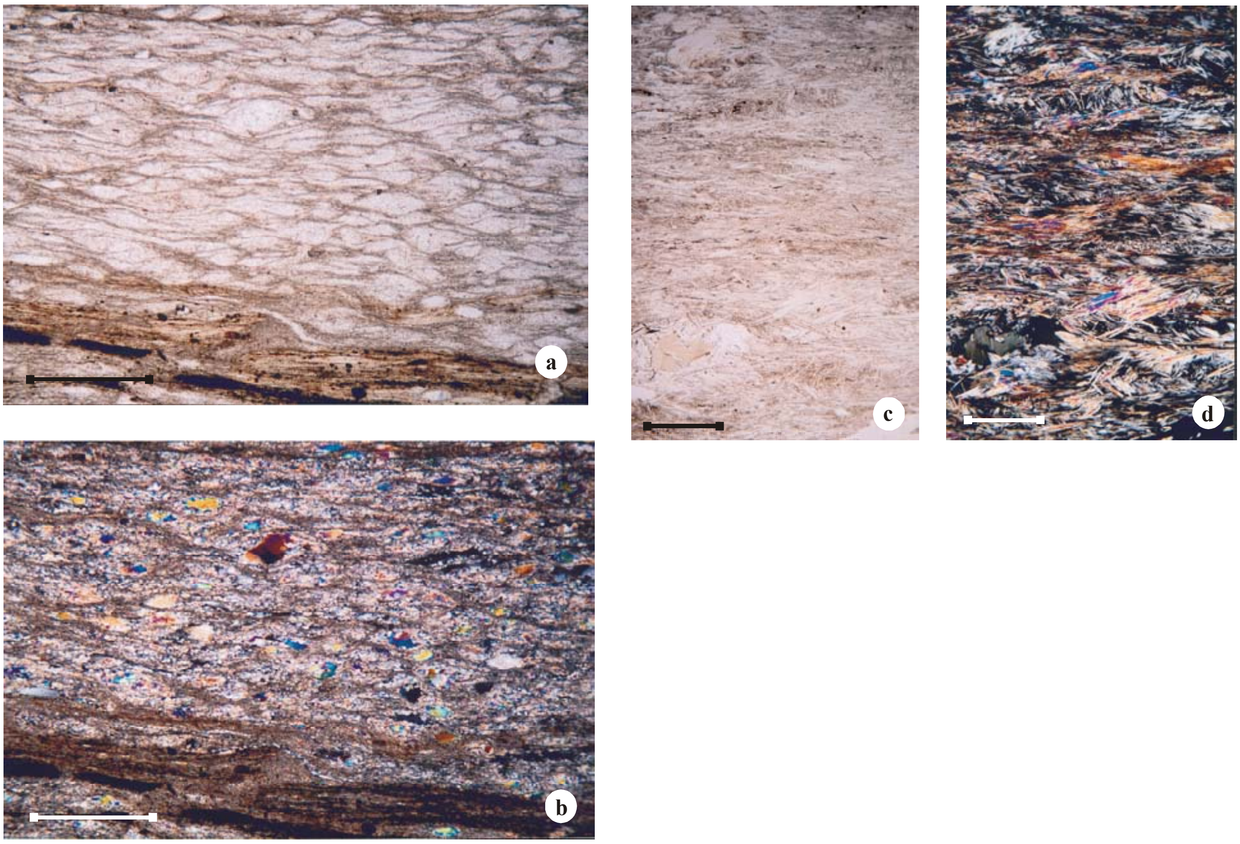

Plate 14. (a) and **(b)** Very fine-grained carbonate-rich phyllonitic schist (plane and crossed polarised light. Sample S2307). **(c)** and **(d)** Fine-grained tremolite schistose rock (plane and crossed polarised light. Sample S8404). Scale bar = 1 mm