Mason Geoscience Pty Ltd

Petrological Services for the
Minerals Exploration and Mining Industry

ABN 64 140 231 481 ACN 063 539 686

Postal: PO Box 78 Glenside SA 5065 Australia
Delivery: 141 Yarrabee Rd Greenhill SA 5140 Australia
Ph: +61-8-8390-1507 Fax: +61-8-8390-1194
e-mail: masongeo@ozemail.com.au

Petrographic Descriptions and Interpretations for Five Rock Samples from the Koolendong Project (EL8040, Northern Territory)

REPORT # **2790**

CLIENT **Centrex Resources NL**

ORDER NO **Office Visit and Request, R. Bluck**

CONTACT **Mr Russ Bluck**

REPORT BY **Dr Douglas R Mason**

SIGNED

for Mason Geoscience Pty Ltd

DATE **17 October 2002**

CONTENTS

Petrographic Descriptions and Interpretations for Five Rock Samples from the Koolendong Project (EL8040, Northern Territory)

SUMMARY

1. Rock Samples

- Five rock samples from the Koolendong Project (Northern Territory) have been studied using routine petrographic and mineragraphic methods.

2. Brief Results

- *A summary of rock names and mineralogy* is provided in TABLE 1.

- *Primary rock types*

  - **Gabbroic intrusive igneous rocks** were initially composed of plagioclase, clinopyroxene (augite) and orthopyroxene (hypersthene), with minor amounts of hornblende, biotite, ilmenite, magnetite, quartz and apatite. Trace amounts of primary sulphide (pyrrhotite, ?maucherite = $Ni_{11}S_8$) formed as tiny inclusions in ilmenite and magnetite grains. Positive identification of these tiny grains could be obtained by future electron-probe microanalysis, if required. Primary igneous mineralogical layering is defined by lenses rich in plagioclase, and local variable concentrations of apatite and Fe-Ti oxides. The rocks are interpreted to have formed in a differentiated mafic intrusion of tholeiitic magmatic affinity.

  - **Granitoid intrusive igneous rocks** are represented by biotite-hornblende tonalite and biotite monzogranite (Fig. 1). The massive medium-grained tonalite is composed of plagioclase, quartz, K-feldspar, and biotite, accompanied by accessory apatite, zircon, ilmenite and magnetite. The monzogranite is finer-grained, equigranular in texture, and composed of K-feldspar, quartz, plagioclase, biotite, and accessory allanite, zircon and apatite. The granitoids are of calc-alkaline magmatic affinity, and the biotite monzogranite may have formed by normal igneous fractionation mechanisms from the tonalite.

- *Metamorphism and alteration*

  - **Greenschist facies metamorphism** has partly affected the gabbroic rocks, producing new replacement assemblages of actinolite, chlorite, biotite, and traces of magnetite, pyrite and chalcopyrite. The presence of biotite intergrown with actinolite in the assemblage confirms that the alteration occurred at moderate temperature and pressure. In contrast, the granitoids have suffered only mild deformational effects (shadowy strain extinction in quartz, mild kinking of biotite plates), suggesting that the granitoids were emplaced subsequent to the gabbroic rocks and their partial metamorphic overprint.

  - **High-intensity chlorite-albite-illite-pyrite alteration** has severely affected some of the gabbroic rocks (sample 01CX6, 21.0m). Thin fractures were filled by veinlet assemblages of quartz, chlorite, calcite and K-feldspar (adularia), and gabbroic host rock suffered severe replacement by chlorite, albite, illitic clay, leucoxene/rutile, pyrite, marcasite and chalcopyrite. A relatively low P-T environment for the alteration is confirmed by the presence of illitic clay and marcasite in the assemblage.

- *Potential Mineralisation Styles*

  - **The gabbroic rocks** have potential for PGE sulphide mineralisation, because they were able to crystallise sulphide minerals as part of their primary igneous assemblage. Further, they also have potential for unconformity-related Au-U-PGE mineralisation in relation to their intense low-temperature hydrothermal alteration.

  - **The granitoid rocks** appear to have limited potential for mineralisation, owing to their relatively reduced primary magmatic compositions.

TABLE 1: SUMMARY OF ROCK NAMES AND MINERALOGY

SAMPLE	ROCK NAME	MINERALOGY*			
		Primary**	**Metamorphism /Alteration**	**Veins*****	**Weathering**
CX1	Meta-gabbro	Pla, ilm, mt, apa, hbl, bio, sulp(?py,?mau)	Act, chl, bio, mt, py, cpy	-	Cla(?ill)
CX7	Weakly altered two-pyroxene gabbro	Pla, cpx, opx, hbl, ilm, bio, mt, qtz, po, ?mau, zir	Act, py, chl, mt, cpy	Act	-
CX9	Biotite-hornblende tonalite	Pla, qtz, bio, Kf, hbl, apa, zir, ilm, mt	Chl, py, mrc, cpy	-	Cla(?ill)
01CX3, 20.4m	Biotite monzogranite	Kf, qtz, pla, bio, all, zir, apa	Chl, ser, epi, py, sph	Chl	-
01CX6, 21.0m	Veined and medium- to high-intensity chlorite-albite-illite-pyrite altered gabbroic rock	Bio, apa, mt	Alb, chl, cla(?ill), leu/rut, py, mrc, cpy	Kf; Qtz, Kf; Qtz, chl, cal	-

NOTES:
*: Minerals are listed in each paragenesis according to approximate decreasing abundance.
**: Only primary minerals currently present in the rock are listed. Others may have been present, but are altered.
***: Earlier parageneses are separated from later parageneses by a semicolon.

Mineral abbreviations:
Act = actinolite; alb = albite; all = allanite; apa = apatite; bio = biotite; chl = chlorite; cla = undifferentiated clays (possible mineral in brackets); cpx = clinopyroxene (augite); cpy = chalcopyrite; epi = epidote; hbl = hornblende; ill = illitic clay; ilm = ilmenite; Kf = K-feldspar (microcline); leu = leucoxene (very fine-grained TiO_2 phase); mau = maucherite ($Ni_{11}S_8$); mt = magnetite; mrc = marcasite; opx = orthopyroxene (hypersthene); pla = plagioclase; po = pyrrhotite; py = pyrite; qtz = quartz; rut = rutile; ser = sericite; sph = sphalerite; sulp = undifferentiated sulphides (possible mineral in brackets); zir = zircon; ?min = uncertain mineral identification.

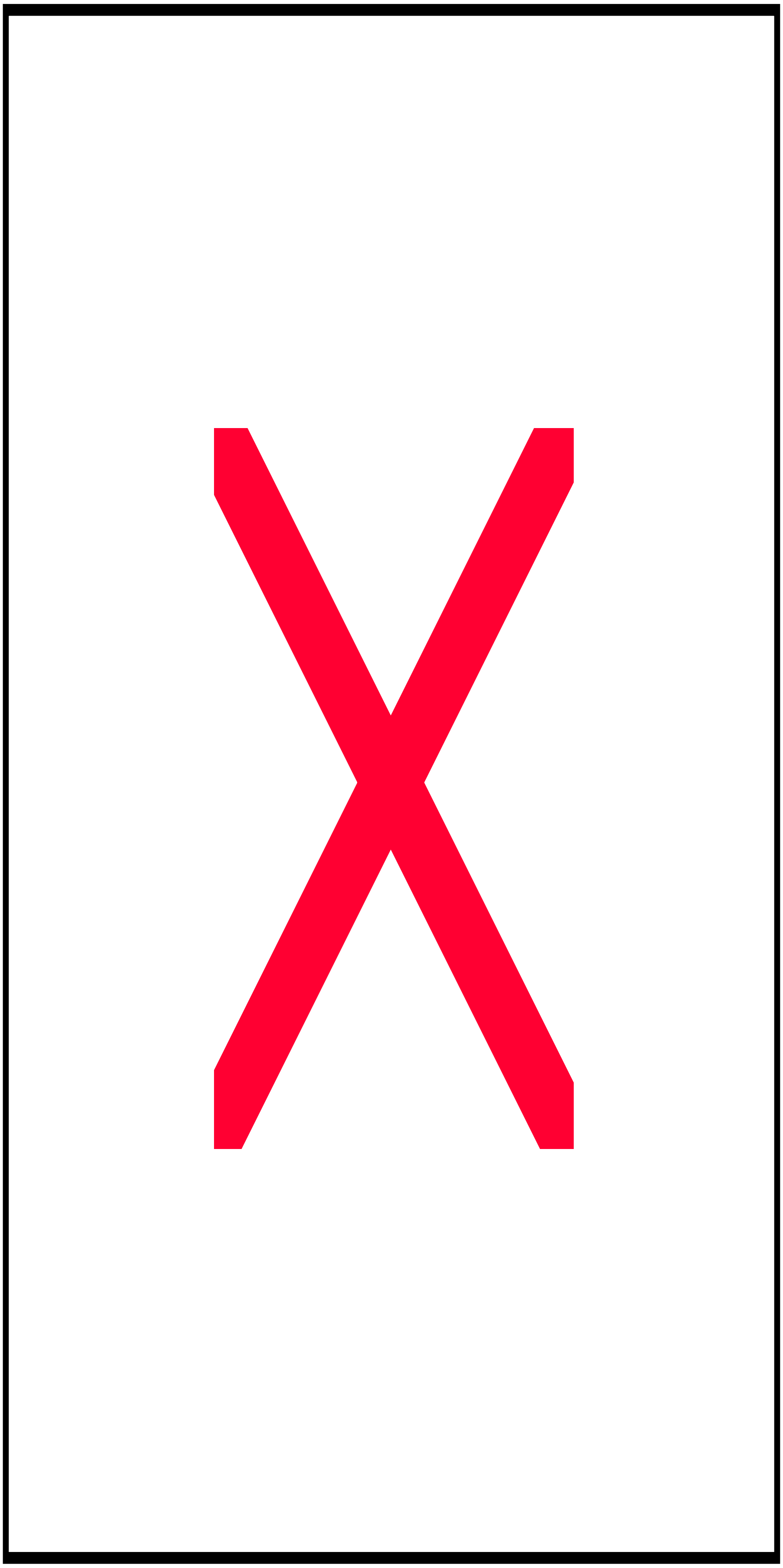

Fig. 1: Quartz(Q) – alkali feldspar(A) – plagioclase(P) ternary plot of modal primary minerals in Koolendong Granitoids

1 INTRODUCTION

A suite of five drill core rock samples was provided by Mr Russel Bluck (acting for Centrex Resources NL, Hove, South Australia) on 4 October 2002.

It was indicated that the samples originate from the Koolendong Prospect in the Northern Territory, located approximately 300 km southwest of Darwin. The geological setting has been described previously (Earthrowl 2002), as follows:

‘The project area is situated within the Fitzmaurice Mobile Zone, a crustal suture which links the Halls Creek Mobile Zone in the East Kimberly Region of Western Australia with the Pine Creek Inlier of the Northern Territory.

The regional geology is dominated by Upper Proterozoic sediments of the Aubergne and Fitzmaurice Groups which are separated by a major regional fault which is probably an extension of the Giant’s Reef Fault further north. These sediments, predominantly flat-lying undeformed sandstone, have been selectively eroded along the regional structure to form a window into the underlying Lower Proterozoic rocks. The Lower Proterozoic rocks exposed in the window belong to the Finniss River Group, and consist of Noltenius Formation amphibolitic metasediments and the highly deformed Meeway Volcanics. These Lower Proterozoic sequences have been intruded by later Lower Proterozoic post-tectonic granites, with two stocks of Koolendong Granite mapped with the project area.

The dominant feature of the southern block of EL 8040, and the target of the 2001 field program, is a circular air magnetic anomaly approximately 1 km in diameter.

The detailed geophysical signature of this feature has been described from the airborne data and the ground data collated by Centrex, and is documented in earlier annual reports. ...

Centrex Resources Ltd has over the life of its tenement tested the air magnetic anomaly in various ways:

- interpretation of the air magnetic anomaly in two and three dimensions
- ground magnetic traversing and interpretation
- conventional soil geochemistry and analysis
- partial digest, ionic, soil geochemistry and assaying
- thin section petrology of surface rubble samples.’

A field program in 2001 resulted in nine vertical drill holes (Earthrowl 2002), from which five core samples were despatched for petrological study (Radke 2001).

Together with the rock samples and thin sections, the client provided the 2002 Annual Report (Earthrowl 2002) and the previous petrology report (Radke 2001). The particular request was to review the petrology of the samples, with emphasis on possible relationships to mineralisation.

The results were briefly discussed by telephone with Mr Bluck on 15 October 2002. This report contains the full results of this work.

2 METHODS

At Mason Geoscience Pty Ltd conventional transmitted and reflected polarised light microscopy was used to prepare the combined petrographic and mineragraphic descriptions. A selection of colour photomicrographs has been included to illustrate particular mineralogical and microtextural aspects of the gabbroic rocks (Appendix 1).

A single sample (01CX6, 21.0m) was submitted for confirmation of presence or absence of K-feldspar. A vein-free area of the section offcut (stained yellow for K-feldspar in a previous study; Radke 2001) was circled in black felt-tipped pen, and this preferred area was drilled and studied by X-ray diffraction methods to determine the mineralogy, especially to determine the presence or absence of K-feldspar. The full report is provided in Appendix 2.

3 PETROGRAPHIC DESCRIPTIONS

The combined petrographic and mineragraphic descriptions are provided in the following pages.

SAMPLE : CX1 (Koolendong Project, Northern Territory)

SECTION NO : CX1

HAND SPECIMEN : The drill core sample represents a medium-grained massive mafic grey crystalline rock, with readily distinguished prismatic dull paler grey feldspar crystals. Rare small lustrous sulphide grains (?pyrite) are evident under the hand lens.

The sample responds positively to the hand magnet, suggesting a significant amount of magnetite is present.

Examination of the section with the unaided eye and under the binocular microscope suggests that indistinct mineralogical layering is present.

ROCK NAME : Meta-gabbro

PETROGRAPHY AND MINERAGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	**Vol %**	**Origin**
Plagioclase	58	Relict igneous
Ilmenite	3	Igneous
Magnetite	2	Igneous
Apatite	2	Igneous
Hornblende	<1	Igneous
Biotite (plates)	Tr	Igneous
Sulphide (?pyrite, ?maucherite)	Tr	Igneous
Actinolite	30	Metamorphic
Biotite (very fine-grained)	<1	Metamorphic
Chlorite	<1	Metamorphic
Magnetite	Tr	Metamorphic
Pyrite	Tr	Metamorphic alteration
Chalcopyrite	Tr	Metamorphic alteration
Illitic clay	2	Weathering (after plagioclase)

In polished thin section, this sample displays a well-preserved gabbroic igneous texture, modified by selective pervasive metamorphic alteration and weak subsequent weathering effects. Mafic and felsic minerals vary in abundance across the section (mineralogical layering), but the average mode across the whole section is given above.

Plagioclase is abundant, occurring as randomly oriented prismatic crystals ~1-3 mm in size. All display well-developed primary twinning and weak compositional zoning. Tiny ragged flecks and small patches of colourless phyllosilicate forms small replacement patches in most crystals, and appears to be a clay: its low birefringence suggests an illite.

Amphiboles are abundant, and three types are distinguished:

i) Most occurs as very pale green pleochroic to almost colourless replacements of precursor anhedral angular ferromagnesian grains mostly ~1-2 mm in size (pyroxene(s), but none is preserved). These replacements are variably optically continuous to fibrous, and clearly have formed by complete replacement of the precursor pyroxene(s).

ii) Some actinolite occurs as fine-grained to fibrous pleochroic bluish green to green rims around the paler actinolite-altered pyroxene grains. This amphibole also is of alteration origin.

iii) A small amount of pleochroic dark brownish green hornblende occurs as small blocky to subhedral grains, moulded on larger pyroxene grains (now altered to actinolite). The darker colour (ie regular Al- and Ti-bearing hornblende), grain size and shape confirm that this hornblende represents a relict primary igneous phase.

Magnetite occurs in significant amount, and two types are distinguished:

i) Most occurs as equant subhedral to anhedral grains intimately associated with ilmenite (see below). These grains clearly represent a relict primary igneous phase.

ii) Some magnetite occurs as minute granules peppered through the pale actinolite after pyroxene grains. This magnetite clearly is of metamorphic alteration origin.

Ilmenite forms subhedral to anhedral grains ~0.2-1.0 mm in size. They are distributed throughout the rock, but are more abundant in some indistinct pyroxene-rich layers on the millimetre scale observed in thin section by the unaided eye. The ilmenite displays its typical brownish grey colour with strong anisotropism. Many of the ilmenite grains display cuspate shapes, moulded on blocky pyroxene crystals, suggesting they formed as interstitial grains during final crystallisation of the igneous rock.

Biotite occurs in minor amount, and two types are distinguished:

i) Some biotite occurs as well-shaped plates ~0.3-0.6 mm in size. Their pleochroism from reddish brown to pale yellow suggests a relatively reduced composition, which is consistent with the abundance of ilmenite. These flakes commonly are moulded on margins of ilmenite grains. The size, shape and occurrence of this biotite confirms it formed as part of the late-forming igneous assemblage.

ii) A trace of biotite occurs as tiny flakes intergrown with actinolite in mantles around some altered pyroxene grains. This biotite clearly formed as part of the metamorphic alteration assemblage. A trace of biotite also occurs as tiny flakes in dense replacement patches within some altered pyroxene grain sites.

Chlorite is present in minor amount as aggregates of small pleochroic pale green flakes, located in patches in limited areas.

Apatite occurs as well-shaped small stumpy colourless prisms ~0.2-0.4 mm in size. They tend to be intergrown with the primary pyroxene, Fe-Ti oxide and biotite crystals.

Sulphides occur in trace amount, and different forms are distinguished:

i) Most sulphide occurs as fine-grained ragged alteration patches of pyrite that tend to be intergrown with actinolite around altered pyroxene grain sites. This pyrite clearly formed as part of the metamorphic alteration assemblage.

ii) Uncommon small sulphide grains (?pyrite, ?maucherite) occur as tiny inclusions ~50 µm in size in larger ilmenite grains. The subrounded to euhedral blocky crystal shapes of these inclusions suggest that they formed as primary igneous inclusions within the ilmenite. Some have suffered partial to complete replacement by microgranular alteration pyrite, but it is possible that some of the primary phase is preserved. Positive optical identification is not possible with such small grains.

Chalcopyrite occurs as rare tiny ragged grains intergrown with actinolite with the alteration pyrite.

INTERPRETATION :

This sample represents a gabbroic igneous rock, originally composed of plagioclase and pyroxene, with lesser ilmenite, magnetite, apatite, biotite and trace sulphide(s). Indistinct mineralogical layering developed during crystallisation, with some layers richer in pyroxene(s) and Fe-Ti oxides, and other layers richer in plagioclase. The relatively fractionated composition of the gabbro is indicated by the relatively low abundance of total ferromagnesians, the relatively high abundance of Fe-Ti oxides, the presence of minor primary biotite, and the presence of a significant amount of apatite for an accessory phase.

The observation that small inclusions of sulphide(s) developed within the ilmenite during crystallisation confirms that the basic magma became saturated with respect to sulphide(s) at a relatively late stage during its crystallisation.

At a later time, the rock suffered a low-grade metamorphic overprint. This generated actinolite + chlorite + trace magnetite + biotite + pyrite + chalcopyrite. The mineral assemblage, particularly the presence of actinolite and biotite, suggests P-T conditions in the lower to middle greenschist facies. Sulphides developed as part of this event, forming fine-grained aggregates of pyrite and chalcopyrite in close association with actinolite. It is possible that the sulphide components represent remobilised sulphide components from the precursor igneous sulphide.

A small amount of illitic clay developed as patchy replacements of plagioclase, possibly in response to circulation of near-surface meteoric waters (weathering).

SAMPLE : CX7 (Koolendong Project, Northern Territory)

SECTION NO : CX7

HAND SPECIMEN : The drill core sample represents a medium-grained mafic grey crystalline rock, composed of white feldspar grains distributed through darker greenish black ferromagnesian grains. Local lenticular patches richer in white feldspar contribute to definition of indistinct mineralogical layering.

The sample responds positively to the hand magnet, suggesting magnetite is present in minor amount.

ROCK NAME : Weakly altered two-pyroxene gabbro

PLATE 1: SAMPLE CX7. Macrophotograph of sawn surface, wet, 4 cm left to right across sample. Note the white feldspar-rich lens which represents a section through primary igneous layering oriented NE-SW.

PETROGRAPHY AND MINERAGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
Plagioclase	50	Relict igneous
Clinopyroxene (augite)	20	Igneous
Orthopyroxene (hypersthene)	10	Igneous
Hornblende	5	Igneous
Biotite	3	Igneous
Ilmenite	4	Igneous
Magnetite	1	Igneous
Quartz	Tr	Igneous
Pyrrhotite	Tr	Igneous
Sulphide (?maucherite)	Tr	Igneous
Zircon	Tr	Igneous
Pyrite	<1	Alteration (?metamorphic)
Actinolite	2	Alteration (?metamorphic)
Chlorite	Tr	Alteration (?metamorphic)
Magnetite	Tr	Alteration (?metamorphic)
Chalcopyrite	Tr	Alteration (?metamorphic)
Clay (?illite)	2	Alteration (low-temperature)
Zoisite	1	Alteration (low-temperature

In polished thin section, this sample displays a well-preserved gabbroic igneous texture, modified by local alteration which, in binocular examination of the thin section, is concentrated in the margins of thin irregularly oriented fractures.

Plagioclase is moderately abundant, occurring as stumpy subhedral prisms ~1-2 mm long. A significant number appear to display a preferred orientation which is interpreted as a primary cumulate texture (lamination). This lamination lies subparallel to the indistinct concentration of feldspar observed in the hand sample. The plagioclase crystals display their well-developed primary twinning and weak normal compositional zoning. Minute acicular crystals (?rutile, ?hematite) just microns wide thinly lace the plagioclase crystals along crystallographic planes: they appear to be of exsolution origin, and confirm the relatively slow cooling of the host gabbroic rock. Small ragged patches of colourless phyllosilicate flakes (clay of ?illitic composition) form replacement patches in most plagioclase crystals, and minute poorly-formed epidote-group mineral (probably zoisite) occurs intimately with the ?illitic clay.

Two pyroxenes are distinguished:

i) Clinopyroxene (inferred to be augite) is moderately abundant, occurring as small subhedral blocky crystals ~0.4-1.0 mm in size. Most are quite fresh. All contain thin spaced exsolution lamellae of orthopyroxene, confirming that the igneous rock enjoyed slow cooling.

ii) Orthopyroxene forms larger anhedral grains ~1-2 mm in size, with a tendency to partly enclose smaller plagioclase prisms in typical subophitic texture. Most of the orthopyroxene is fresh, except for local very fine fibrous replacements patches of actinolite. Pleochroism of the orthopyroxene, from pale pink to very pale green or colourless, suggests it has a hypersthenic composition.

Two types of amphibole are distinguished:

i) Pleochroic dark green to brownish green hornblende occurs as mantles which overgrow pyroxene grains, and as anhedral angular interstitial grains. The textures clearly indicate that the hornblende formed as a late magmatic phase, not by replacement of pyroxene but by overgrowth and interstitial filling.

ii) Pleochroic pale green actinolite occurs as granular mosaics which have replaced pyroxene grains in the vicinity of thin actinolite-filled fractures. The actinolite is confined to the fractures and their vicinity, and is absent elsewhere in the rock.

Biotite occurs as local large plates ~1-2 mm in size which have poikilitically enclosed smaller ferromagnesian and plagioclase crystals. Pleochroism of the biotite from reddish brown to pale yellow suggests a relatively reduced composition (consistent with presence of ilmenite).

Ilmenite is moderately abundant, forming lobate to cuspate grains ~0.4-1.0 mm in size that tend to be moulded on pyroxene crystals. This suggests that the ilmenite formed late in the crystallisation of the rock.

Magnetite is present in minor amount as subhedral grains that tend to be closely associated with ilmenite. Thin exsolution lamellae of ilmenite locally cut the magnetite grains. Rare tiny magnetite granules in actinolite aggregates after pyroxene are of secondary origin.

Quartz is present in trace amount as uncommon clear interstitial angular grains.

Sulphides of different types are identified:

i) Most suphide is pyrite, which occurs as fine-grained granular aggregates irregularly scattered through the rock. Some appear to be physically associated with thin microcracks filled by actinolite. The alteration origin of the pyrite is evident.

ii) A trace of pyrrhotite occurs as larger subhedral grains, located at margins of some ilmenite grains. This pyrrhotite forms equilibrium boundaries with the adjacent ilmenite, and is considered to be of primary igneous origin.

iii) Uncommon small euhedral to rounded sulphide grains ~7-30 µm in size occur as inclusions within ilmenite and magnetite grains. Some of these inclusions display equant euhedral prismatic crystal forms, with moderately strong anisotropy: they may be pyrrhotite, but some appear to be whiter than pyrrhotite and may therefore be ?maucherite ($Ni_{11}S_8$).

iv) Rare small ragged grains of chalcopyrite occur in association with other alteration phases.

Chlorite forms tiny ragged pleochroic green flakes which are concentrated in uncommon thin discontinuous fractures.

Zircon occurs as rare small euhedral growth-zoned crystals.

INTERPRETATION :

This sample represents a gabbroic igneous rock, originally composed mainly of plagioclase and two pyroxenes (clinopyroxene and orthopyroxene), with lesser hornblende, biotite, ilmenite, magnetite, quartz and trace sulphide(s) and zircon. The rock is considered to have formed by slow cooling of basic magma in an intrusive body, allowing early crystallisation of plagioclase and pyroxenes, followed by interstitial hornblende, Fe-Ti oxides (with small inclusions of sulphides), biotite, quartz and trace zircon. A weak preferred orientation of plagioclase prisms, and indistinct concentration of plagioclase in plagioclase-rich lenticular patches, suggests that weak mineralogical layering developed during crystallisation of the intrusion. The slow cooling of the intrusion is confirmed by exsolution features in clinopyroxene (orthopyroxene lamellae), magnetite (ilmenite lamellae) and plagioclase (acicular ?rutile or ?hematite crystals).

Subsequent weak fracturing and invasion by very small amounts of fluid resulted in filling of the thin fractures by actinolite, and replacement of nearby pyroxenes by actinolite. A small amount of secondary sulphides (pyrite, chalcopyrite) formed during this event. The S may have been derived in part from the precursor primary igneous sulphides that were present in trace amount. Elsewhere the rock remained quite fresh.

At a later time, circulation of small amounts of low-temperature ?meteoric waters through the body generated a minor amount of illitic clay and zoisite after plagioclase. This event most likely was the same event which generated much more intense low-temperature alteration in the gabbro sample 01CX6, 21.0m.

SAMPLE : CX9 (Koolendong Project, Northern Territory)

SECTION NO : CX9

HAND SPECIMEN : The drill core sample represents a massive to weakly foliated medium-grained granitoid composed of white to grey felsic grains and dark green to black ferromagnesian grains. Although mostly massive, a weak foliation is defined by local alignment of the ferromagnesian grains.

The sample fails to respond to the hand magnet, suggesting magnetite is absent.

The section offcut, previously stained for K-feldspar (Radke 2001), accepted a positive yellow stain for K-feldspar indicating it occurs in minor amount as scattered ragged grains.

ROCK NAME : Biotite-hornblende tonalite

PETROGRAPHY AND MINERAGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	**Vol %**	**Origin**
Plagioclase	50	Igneous
Quartz	25	Igneous
Biotite	15	Igneous
K-feldspar (microcline)	5	Igneous
Hornblende	2	Igneous
Apatite	Tr	Igneous
Zircon	Tr	Igneous
Ilmenite	Tr	Igneous
Magnetite	Tr	Igneous
Chlorite	Tr	Alteration / microcrack fillings
Pyrite	Tr	Alteration
Marcasite	Tr	Alteration
Chalcopyrite	Tr	Alteration
Clay (?illite)	1	Alteration (?weathering)

In polished thin section, this sample displays a well-preserved granitoid igneous texture, with only limited modification.

Plagioclase is abundant, occurring as subhedral blocky twinned crystals mostly ~1-2 mm in size but ranging up to ~3 mm. All have suffered weak replacement by tiny flecks of phyllosilicate (clay of possible illitic composition).

Quartz occurs as clear anhedral interstitial grains mostly ~1-2 mm in size. All display shadowy strain extinction indicating mild strain has affected the rock subsequent to crystallisation, but no recrystallisation of the grains has occurred. Small fluid inclusions occur along indistinct sealed microcracks in the quartz, and different types are distinguished: two-phase type with small vapour bubble in colourless liquid (probably H_2O-rich composition); two- or three-phase types with dark large bubble in liquid (probably CO_2-rich composition); and uncommon multi-phase types with small vapour bubble and small colourless daughter crystal in colourless liquid (possibly high-salinity aqueous type). The fluid inclusions appear to be of primary origin (possibly ‘pseudo-secondary’ as per their concentration along sealed microcracks).

K-feldspar is present in minor amount as clear ragged grains associated with quartz. They display the combined albite and pericline twinning (‘tartan’ twinning) that is characteristic of microcline, which probably formed by inversion during slow cooling after primary orthoclase.

Biotite is moderately abundant, occurring as aggregates of randomly oriented plates. Their pleochroism from fox red to very pale yellow suggests a reduced composition (consistent with very low abundance of Fe-Ti oxides and dominance of ilmenite among the Fe-Ti oxides). Weak kinking of the biotite flakes is consistent with the mild deformation observed in quartz.

Hornblende is present in minor amount as pleochroic dark green subhedral to anhedral grains intergrown with biotite and quartz.

Apatite occurs as small euhedral prisms ~0.1 mm in size, commonly enclosed within the biotite aggregates. Small terminated and growth-zoned zircon crystals also tend to occur in the biotite aggregates.

Ilmenite occurs in tiny trace amount as minute grains that tend to occur as inclusions in plagioclase grains. They are readily identified in reflected light by their colour and anisotropism. Rare small magnetite grains may be closely associated with the ilmenite.

Chlorite occurs in trace amount as fine-grained pleochroic green aggregates that occur as replacements of some small hornblende grains, and also as fillings in very thin discontinuous microcracks.

Pyrite is uncommon, forming small ragged microgranular aggregates. One small ragged aggregate is composed of marcasite and chalcopyrite closely associated with the pyrite.

INTERPRETATION :

This sample represents a granitoid which crystallised early plagioclase, biotite, hornblende, accessory apatite, zircon and ilmenite, accompanied by late-formed quartz and K-feldspar. A tonalitic composition is indicated by the relatively low abundance of K-feldspar in comparison with quartz and plagioclase (Fig. 1). The primary mineralogy indicates that the rock is calc-alkaline in magmatic affinity. The magma was metaluminous rather than peraluminous, and the magma was relatively reduced as indicated by the presence of ilmenite, virtual absence of magnetite, and red pleochroism of the biotite.

Post-crystallisation processes have affected the rock:

i) Mild pervasive deformation affected the intrusion, causing shadowy strain extinction in the quartz and mild kinking of biotite flakes. The deformation was not sufficiently strong to cause recrystallisation.

ii) Primary K-feldspar (probably orthoclase) inverted to microcline in response to slow cooling.

iii) A small amount of chlorite formed by replacement of some hornblende grains, and as fillings in thin discontinuous microcracks. Uncommon small grains of pyrite, marcasite and chalcopyrite formed through the rock. These effects were very weak, and of unknown origin.

iv) A trace amount of phyllosilicate (?illitic clay) formed by incipient replacement of plagioclase. It remains uncertain whether this occurred as part of the alteration referred to in iii) above, or whether it occurred during later near-surface processes (ie weathering).

SAMPLE : 01CX3, 20.4m (Koolendong Project, Northern Territory)

SECTION NO : 01CX3, 20.4m

HAND SPECIMEN : The drill core sample represents a compositionally uniform, fine- to medium-grained granitoid rock in which an overall pale pinkish cream hue arises from incipient alteration of feldspar grains.

The section offcut accepted a strong positive yellow stain (previous staining by Radke, 2001), indicating that K-feldspar occurs abundantly throughout the rock as uniformly distributed ragged grains.

ROCK NAME : Biotite monzogranite

PETROGRAPHY AND MINERAGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
K-feldspar (microcline microperthite)	40	Igneous (inverted from ?orthoclase)
Quartz	30	Igneous
Plagioclase (incl. myrmekite)	23	Igneous (incl. subsolidus alteration)
Biotite	5	Igneous
Allanite (incl. turbid alteration products)	Tr	Igneous (metamict)
Zircon	Tr	Igneous
Apatite	Tr	Igneous
Chlorite	<1	Alteration / fracture fillings
Sericite	Tr	Alteration
Epidote	Tr	Alteration
Pyrite	Tr	Alteration
Sphalerite	Tr	Alteration

In polished thin section, this sample displays a well-preserved massive granitoid texture, modified by weak selective pervasive alteration.

K-feldspar is abundant, occurring as anhedral grains mostly ~0.4-1.0 mm in size. Some larger subhedral blocky crystals display simple twinning, and all display combined albite and pericline twinning (‘tartan’ twinning) that is characteristic of microcline. Some grains contain thin trails of exsolved albite (microcline microperthite).

Quartz is abundant, forming anhedral grains that display a moderate degree of shadowy strain extinction but no evidence of recrystallisation.

Plagioclase occurs in lesser amount as subhedral crystals and anhedral grains distributed throughout the rock. Most are rendered slightly turbid from tiny phyllosilicate flecks (sericite).

Biotite is present in moderate amount as small randomly oriented flakes ~0.2-0.6 mm in size, distributed more-or-less uniformly through the rock. Where fresh they display their primary pleochroism from reddish brown to very pale yellow. Some have suffered partial replacement around flake margins by fine sericite, and others have suffered partial to severe replacement by very fine-grained aggregates of pleochroic drab green chlorite.

Allanite occurs as small stumpy prismatic crystals, now rendered turbid by metamict alteration.

Epidote is present in trace amount as small turbid microgranular aggregates, locally at margins of biotite flakes. The anomalous interference colours of the epidote aid in its recognition.

Chlorite occurs as local replacements of some biotite flakes, but it also occurs as fillings in uncommon thin discontinuous fractures. In places, the thin fractures pass through quartz grains where they are sealed and filled by trails of small fluid inclusions.

Zircon occurs in trace amount as rare small stumpy crystals with growth zoning.

Apatite forms tiny accessory colourless prisms.

Pyrite occurs as rare small crystals very sparsely and irregularly scattered through the rock. Rare small grains of sphalerite also are observed, locally in association with pyrite. The very pale colour of the sphalerite suggests it has a low Fe content.

INTERPRETATION :

This sample represents a massive fine- to medium-grained granitoid of monzogranitic composition (Fig. 1). Early crystallisation of plagioclase and biotite was quickly followed by crystallisation of K-feldspar, and quartz, with accessory allanite, apatite and zircon. The mineralogy indicates a calc-alkaline magmatic affinity, and a somewhat fractionated composition is supported by the high abundance of felsic minerals and relatively low abundance of ferromagnesian phases.

The mineralogy is consistent with fractionation from a less-evolved granitoid magma, such as that represented by sample CX9. Features that link the two samples include presence of reddish biotite, inferred relatively reduced composition for both samples, and similar post-crystallisation mild deformational effects.

Mild alteration effects have affected the rock, with the following consequences:

i) Mild deformation caused shadowy strain in all quartz grains.

ii) Trace amounts of alteration chlorite, epidote, sericite, pyrite and sphalerite were formed in response to invasion by very small amounts of hydrothermal fluid. A trace amount of chlorite filled uncommon thin discontinuous fractures. It is possible that this occurred as a deuteric phenomenon (ie alteration in response to natural evolution of fluid from the crystallising magma).

SAMPLE : 01CX6, 21.0m (Koolendong Project, Northern Territory)

SECTION NO : 01CX6, 21.0m

HAND SPECIMEN : The drill core sample represents a dark green altered massive mafic rock, cut by minor thin fractures and veinlets. Small spots of alteration leucoxene are sprinkled uniformly throughout.

The section offcut accepted a strong yellow stain for K-feldspar in blocky to ragged patches throughout the rock (Radke 2001). Under binocular microscope, the stain is observed to be irregular in strength and locally quite patchy. In conjunction with thin section observations, this is considered to be a 'false' stain for K-feldspar: that is absorption of the sodium cobaltinitrite stain into the cleavages of tiny phyllosilicate flecks that are developed abundantly in many of the altered feldspar grains.

ROCK NAME : Veined and medium- to high-intensity chlorite-albite-illite-pyrite altered gabbroic rock

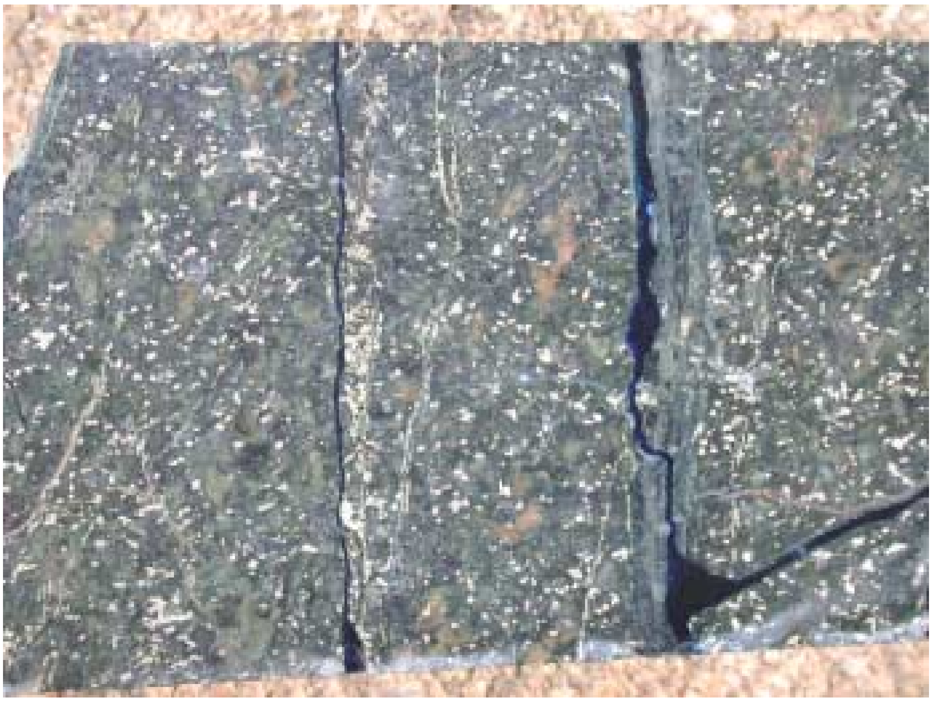

PLATE 2: SAMPLE 01CX6, 21.0m. Sawn drill core, wet, width of core 4.2 cm. Note the thin veinlets and pervasive dull greenish grey altered appearance. Small white disseminated grains are leucoxene/rutile after primary Fe-Ti oxide grains.

PETROGRAPHY AND MINERAGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
Medium- to high-intensity chlorite-albite-illite-pyrite altered gabbroic rock		
Biotite	2 (0-5)	Relict igneous / alteration 1
Apatite	Tr	Relict igneous
Magnetite	Tr	Relict igneous
Albite	32	Alteration 2 (after plagioclase crystals)
Phyllosilicate (?illitic clay)	20	Alteration 2 (after plagioclase crystals)
Chlorite	40	Alteration 2 (after ?ferromag. crystals)
Leucoxene/rutile	4	Alteration 2
Carbonate (dolomitic)	<1	Alteration 2
Pyrite	Tr	Alteration 2
Marcasite	Tr	Alteration 2
Chalcopyrite	Tr	Alteration 2
[N.B: XRD confirms presence of dominant amorphous materials, chlorite, rutile, and anatase]		
Quartz-chlorite-adularia veinlets		
Quartz	78	Fracture fillings 2
Chlorite	20 (0-50)	Fracture fillings 2
K-feldspar (?adularia)	2 (0-20)	Fracture fillings 2

In polished thin section, this sample displays a partly-preserved massive gabbroic igneous texture that has suffered severe modification by fracturing, veining and strong selective pervasive alteration.

Medium- to high-intensity chlorite-albite-illite-pyrite altered gabbroic rock retains its primary igneous texture. Randomly oriented plagioclase prisms and subhedral grains ~1-2 mm in size have suffered complete replacement by optically continuous albite, some of which retain indistinct multiple twin lamellae, peppered by minute phyllosilicate flecks (probably an illitic clay). Locally, some plagioclase crystals have suffered complete replacement by the phyllosilicate mats, and these mats have absorbed the stain to produce a false K-feldspar stain. Ragged grains of carbonate (inferred to be dolomite from relatively high double refraction and lack of reaction of sample with dilute HCl) locally occur in the altered plagioclase crystal sites.

Blocky ferromagnesian grains (probably pyroxene but none is preserved) were subequal in abundance to primary plagioclase, but have suffered complete replacement by fine-grained dense mats of pleochroic pale green chlorite.

Biotite occurs in different forms:

i) Some occurs as pleochroic orange-brown flakes that fill interstices between plagioclase and ferromagnesian grains (now completely altered). In places the biotite is undeformed, but elsewhere it displays severe kinking and recrystallisation. The biotite is preserved in parts of the rock that are distant from the thickest veins, but biotite is completely replaced by chlorite proximal to the veins.

ii) A small amount of biotite occurs as small ragged flakes that are concentrated along discontinuous fractures through the rock.

Leucoxene/rutile occurs as fine-grained dense pseudomorphous replacements of anhedral, lobate and cuspate grains ~0.4-1.0 mm in size scattered uniformly through the rock. The shapes of the grains suggests that they formed as interstitial igneous grains of ?ilmenite, moulded on earlier-formed plagioclase and ?pyroxene. In many of the altered aggregates, small elongate rutile crystals are distinguishable. Similar rutile occurs as fine granular aggregates locally concentrated along margins of veinlets.

Rare magnetite occurs in close association with the leucoxene/rutile altered ?ilmenite grains. The magnetite formed grains intergrown with the ?ilmenite, but has suffered partial replacement along miocrocracks by fine-grained green chlorite and minor quartz.

Apatite is present in trace amount as small blocky subhedral grains with typical lack of colour, high relief, and low birefringence.

A small amount of pyrite occurs as fine-grained microgranular fillings in thin discontinuous veinlets (locally associated with K-feldspar), and as sparsely disseminated small crystals and microgranular aggregates. Rare small chalcopyrite grains occur independently.

Quartz-chlorite-adularia veinlets vary in thickness. Thinnest veinlets are present locally and are discontinuous; they are filled entirely by anhedral K-feldspar grains. Slightly thicker, more continuous veinlets are filled by zoned assemblages of fine-grained quartz and fine-grained to sparry K-feldspar (adularia). Thickest veins are filled by elongate terminated quartz crystals, fine-grained dense aggregates of pleochroic pale green chlorite, and anhedral central concentrations of calcite.

INTERPRETATION :

This sample represents a gabbroic igneous rock, originally composed of a massive medium-grained granular assemblage of plagioclase, ?pyroxene, minor interstitial biotite and Fe-Ti oxides (ilmenite >> magnetite), and trace accessory apatite. The rock most likely was comparable with other gabbroic rocks described elsewhere in this report.

Mild deformation of the rock generated kinking in biotite and local recrystallisation of some of the biotite plates. A small amount of replacement by fine biotite flakes formed in small trails through the rock. This event most likely occurred at moderate temperature, probably under lower to middle greenschist facies P-T conditions, but without significant invasion by fluids.

At a much later time, fracturing and invasion by low-temperature hydrothermal fluid severely modified the rock. Particular effects included the following:

i) Open fractures were filled, with increasing thickness, by assemblages of K-feldspar, K-feldspar + quartz, and quartz + chlorite + calcite. The assemblages and their textures confirm that the conditions during this event were low P-T conditions, that is subgreenschist conditions. The nature of the vein-filling assemblages confirms that the hydrothermal fluid(s) were capable of transporting significant amounts of Si, Al, K, Fe, Mg, Ca, S, CO_2 and H_2O.

ii) Gabbroic wallrock suffered severe replacement by albite + chlorite + illitic clay + dolomite + leucoxene/rutile + pyrite + marcasite + chalcopyrite. Alteration was most severe in the selvedges of thicker quartz-chlorite-calcite veins, and alteration was less intense distal from the veins where some primary biotite survived. XRD of the wallrock confirms that amorphous materials are dominant (see Appendix 1).

This alteration event is reminiscent of intense hydrothermal alteration known to occur associated with unconformities in the NT region.

4 DISCUSSION

4.1 The Gabbroic Rocks

4.1.1 Primary mineralogy and magmatic affinity of the gabbroic rocks

Three of the available samples represent intrusive basic igneous rocks of gabbroic texture and mineralogy. When initially crystallised, they were composed mainly of plagioclase, clinopyroxene (augite) and orthopyroxene (hypersthene), with minor amounts of hornblende, biotite, ilmenite, magnetite, apatite, quartz and trace sulphide(s). The significant amount of accessory magnetite in the rocks, in contrast with magnetite-poor nearby granitoids, confirms that the magnetite-bearing gabbros are the source of the magnetic anomaly in the region.

A normal tholeiitic magmatic affinity is indicated by the presence of two pyroxenes in the ferromagnesian assemblage, the development of hornblende and biotite as late-forming ferromagnesian minerals, and the presence of late-forming quartz in one of the samples. Other magmatic affinities are discounted: thus the rocks do not belong to an alkalic, ultrapotassic, or kimberlitic magmatic suite.

Particular observations indicate that the gabbroic rocks formed in a differentiated mafic intrusion of substantial size:

i) Textural evidence of a relatively slow cooling rate (viz. medium-grained textures in all samples; presence of exsolution textures in clinopyroxenes) suggest uniformly slow rates of crystallisation in a relatively large intrusive body, rather than in a small intrusive body. This is consistent with the kilometre-scale size of the magnetic anomaly in the Koolendong area.

ii) Indistinct preferred orientation of plagioclase prisms is consistent with accumulation processes in a differentiated intrusion.

iii) Mineralogical layering is evident in some samples, defined by indistinct lenses richer in feldspar (macro-inspection of sample CX7), and varied abundances of plagioclase and ferromagnesian minerals in the thin section (sample CX7).

iv) Mineral abundances vary from sample to sample (eg relatively high abundance of accessory apatite in sample CX1; presence of accessory quartz in sample CX7).

Although the textures of the rocks are consistent with formation in a layered mafic intrusion, there is no firm evidence where the present rocks might be located with respect to primary igneous stratigraphy of the intrusion. The observation that all samples are gabbroic suggests either that the samples were taken from the central part of a layered intrusion with possible ultramafic cumulates below and felsic fractionates above, or else it suggests that the intrusion is only of sufficient size to have developed weakly expressed layering with limited development of ultramafic and felsic fractionates. There is some meagre evidence that the gabbroic rocks might belong to a somewhat fractionated upper gabbroic part of the intrusion, as suggested by the relatively high abundance of primary Fe-Ti oxide minerals (consistently ~3-5%), and by the presence of relatively high abundance of apatite in sample CX1.

Initial impressions gained by the writer were that the Koolendong mafic body may have formed synchronous with, and interlayered in annular manner with, the granitoid plutonic rocks. Mingling of coexisting basic and acid magmas in the plutonic environment is well-documented, and particularly good examples are recorded in well-exposed mobile belts (eg MacColl 1964; Furman & Spera 1985). Particular observations which lead to this initial interpretation were the location of the mafic intrusion at the margin of, or partly enclosed within the granitoid pluton, and the annular geochemical anomalies which might have been interpreted as upward funnelling of mingled basic and acid magmas. However, fine-grained igneous quench textures are invariably developed in such mafic rocks, and these textures are notably absent from the Koolendong mafic rocks. A magma mingling origin is therefore discounted. Further, there is evidence that the mafic rocks have suffered a metamorphic overprinting event which the granitoids have not experienced, as discussed next.

There is evidence that the gabbroic rocks have been partly modified by greenschist facies regional metamorphism subsequent to their initial crystallisation:

i) In sample CX1, all primary pyroxene grains have been replaced by actinolite ± magnetite, and minor new biotite is intergrown with the actinolite.

ii) In sample CX7, thin fractures are filled by actinolite and pyroxene grains in the veinlet selvedges have been replaced by actinolite. Plagioclase crystals contain tiny acicular ?hematite or ?rutile crystals which might have formed in response to this event.

iii) In sample 01CX6, 21.0m, fine-gained alteration biotite forms small discontinuous replacement veinlets that cut plagioclase grains. This biotite formed after the primary minerals (including some primary biotite), but formed prior to the subsequent low-temperature pervasive alteration which locally destroyed both biotite generations and other minerals as well.

These observations confirm that the gabbros have suffered mineralogical modification under moderate P-T conditions, with temperature sufficiently high to stabilise biotite (ie T>330-350°, in the middle greenschist facies). The effects were not developed everywhere through the intrusion, possibly owing to limited ability of small volumes of metamorphic fluid to migrate through the massive igneous body.

4.1.2 Potential primary mineralisation styles of the gabbroic rocks

Layered mafic/ultramafic intrusions may contain associated mineralisation of different styles, including chromite and/or platinum-group element (PGE) deposits associated with ultramafic layers usually in the stratigraphically lower part of the intrusions (eg Bushveld Intrusion, Stillwater Intrusion), and localised Ni-sulphide deposits at structural contacts with wall rocks (eg Voisey's Bay NiS).

The development of metal-rich sulphide concentrations in layered intrusions depends entirely on the ability of the magma to crystallise sulphide minerals. If the basic magma was depleted in sulphide and chalcophile elements prior to emplacement (eg at the site of magma generation or during uprise), then there is no possibility of precipitating sulphides subsequently during their crystallisation. In the Koolendong gabbroic rocks, there is mineralogical and microtextural evidence that these magmas were capable of crystallising sulphide minerals at a relatively late stage during their crystallisation. The evidence is observed as small sulphide inclusions in primary ilmenite and magnetite grains. Although present in only trace amount, their presence confirms that the magmas had not been previously stripped of all S and related metals. Note that it is important in these rocks to distinguish between these igneous sulphides, and subsequent alteration sulphides which are present in greater abundance than the primary sulphides.

The primary sulphide minerals are difficult to optically identify owing to their very small size. One small grain of pyrrhotite has been confirmed in sample O1CX6, 21.0m. Other tiny grains just tens of microns in size are considered not to be pyrite or pyrrhotite, owing to their whitish colour and anisotropic optical behaviour. They may be a Ni-sulphide such as ?maucherite ($Ni_{11}S_8$), or another phase entirely. Positive identification can only be obtained by electron-probe microanalytical methods which can readily be performed if required.

A note of caution should be expressed in regard to relationships between the gabbroic rocks and the granitoid rocks. If the granitoid rocks (see below) were intruded after the gabbroic rocks, as is considered by the writer to be the case, then it is possible that a significant amount of the layered intrusion has been stoped out by the granites, with reduction of the potential size of any ore deposit in the layered intrusion.

4.1.3 Potential secondary mineralisation styles in the gabbroic rocks

Gabbro sample 01CX6, 21.0m displays thin veining and high-intensity alteration. Fracturing of the rock allowed invasion by significant volumes of hydrothermal fluid which generated the high-intensity pervasive alteration assemblage of albite + chlorite + illitic clay + minor leucoxene/rutile + trace pyrite + marcasite + chalcopyrite. The open fractures were filled by assemblages of K-feldspar in the thinnest discontinuous fractures, K-feldspar + quartz in slightly thicker veinlets, and quartz + chlorite + calcite in thickest veins. Note that K-feldspar has been positively identified in the veinlets, but is absent from the host rock (see mineralogy by XRD, Appendix 1).

The alteration event occurred under quite low conditions of pressure and temperature, as indicated by the development of an illitic clay as the K-silicate phase (instead of sericite at higher temperatures), by the presence of marcasite as part of the sulphide assemblage, and by the identification of adularia as the K-silicate phase in the veinlets.

Such alteration is known to occur in the vicinity of unconformity-related Au-U-PGE deposits in the Northern Territory. The presence of such alteration in the Koolendong area is consistent with the presence of the mapped unconformity between the Lower-Mid Proterozoic Meeway Volcanics and the Mid-Upper Proterozoic Moyle River Formation.

4.2 The Granitoid Rocks

4.2.1 Mineralogy and petrogenesis of the granitoids

Two samples of acid intrusive igneous (granitoid) rocks have been identified in this suite: sample CX9 and sample 01CX3, 20.4m.

Sample CX9 represents a biotite-hornblende tonalite composed of plagioclase, quartz, minor K-feldspar, biotite, hornblende, and accessory apatite, zircon, ilmenite and magnetite. This metaluminous (hornblende-bearing, muscovite-free) granitoid magma was relatively reduced, as indicated by the reddish colour of the biotite and by the nature of the Fe-Ti oxides (ie the very tiny amounts of total Fe-Ti oxides, and dominance of ilmenite over magnetite).

Sample 01CX3, 20.4m represents a biotite monzogranite composed of K-feldspar, quartz, plagioclase, biotite and accessory allanite, zircon and apatite. No primary Fe-Ti oxides have been identified. The reddish brown pleochroism of the biotite and the absence of Fe-Ti oxides confirms that the magma was relatively reduced.

It is considered likely that samples CX9 and 01CX3, 20.4m are related through normal igneous differentiation mechanisms, possibly crystal fractionation. Observations that support this conclusion are: both samples are calc-alkaline granitoids, they crystallised from reduced magmas, and sample 01CX3, 20.4m is finer-grained and more felsic. It may represent a fractionated silicate liquid from the magma which crystallised to form CX9, which intruded CX9 or the gabbroic rocks. Similar felsic fractionated granitoid rock may occupy areas to the south and southeast identified by air photograph interpretation as ‘colour pattern in granite – alteration? or alkali phase?’ (R. Bluck, pers. comm. and map showing air photo lineaments and colour patterns).

Note that there is no likelihood of any genetic relationship between the gabbroic rocks and the granitoid rocks. Whereas the gabbroic rocks formed by crystallisation of a mantle-derived basic magma, the granitoid rocks formed by crystallisation of a relatively Si-rich crustal-derived granitoid magma.

4.2.2 Potential mineralisation related to the granitoids

Reduced granitoid magmas may lose S by crystallisation of early-formed sulphide minerals (eg pyrrhotite). Fractionates will therefore be poor in S and associated chalcophile elements, but enriched in Sn and W. If a final hydrothermal fluid is evolved, it may generate Sn-W deposits poor in S (Ishihara 1981; Blevin and Chappell 1992).

Rare tiny grains of pyrite and sphalerite appear to indicate that trace amounts of S and metals were fractionated into the magma which crystallised to form this phase. However, there is no indication in sample 01CX3, 20.4m that there has been any significant enrichment of an appropriate volatile phase, so that Sn-W mineralisation may not be associated with this granitoid body.

5 REFERENCES

Blevin P.L. and Chappell B.W. (1992): The role of magma sources, oxidation states and fractionation in determining the granite metallogeny of eastern Australia. Trans. Roy Soc. Edinburgh: Earth Scis. 83, 305-316.

Earthrowl J.A. (2002): EL 8040, Koolendong, Northern Territory. Eighth Annual Report. Internal report for Centrex Resources Limited.

Furman T. & Spera F.J. (1985): Co-mingling of acid and basic magma with implications for the origin of mafic I-type xenoliths: Field and petrochemical relations of an unusual dike complex at Eagle Lake Sequoia National Park California USA. Jl. Volc. Geotherm. Res. 24, 151-178.

Ishihara S. 1981): The granitoid series and mineralisation. Econ. Geol. 75th Anniversary Vol., 458-484.

MacColl R.S. (1964): Geochemical And Structural Studies in Batholithic Rocks Of Southern California: Part I Structural Geology Of Rattlesnake Mountain Pluton. Geol. Soc. Amer. Bull. 75, 805-822.

Radke F. (2001): Petrology of five samples. Amdel Report No. G175PE01, 12 November 2001.

APPENDIX 1: PHOTOMICROGRAPHS

A selection of colour photomicrographs is provided to illustrate particular themes in the gabbroic rocks (Table 2).

TABLE 2: THEMES FOR PHOTOMICROGRAPHS

PLATE(-S)	THEME
3–9	Gabbroic rocks: primary and metamorphic mineralogy and textures
10–14	Gabbroic rocks: low-temperature alteration

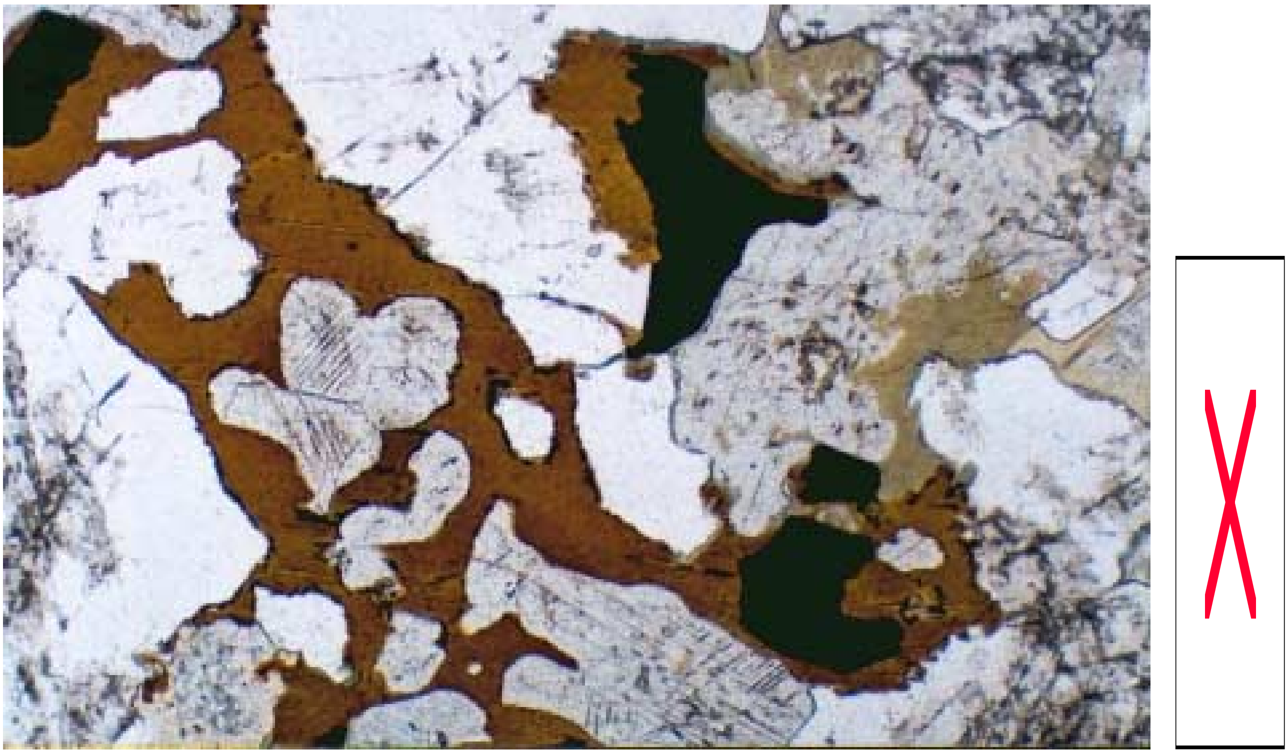

PLATE 3: SAMPLE CX7 (Transmitted plane polarised light, x5, Film 1 / Frame 7)
This view of fresh gabbro shows a large poikilitic plate of biotite (dark brown) which encloses pyroxene grains (equant, colourless, cleaved), plagioclase grains (colourless, top, left, centre), and opaques (ilmenite, magnetite). A small amount of primary hornblende (green, right) forms mantles on some pyroxene grains.

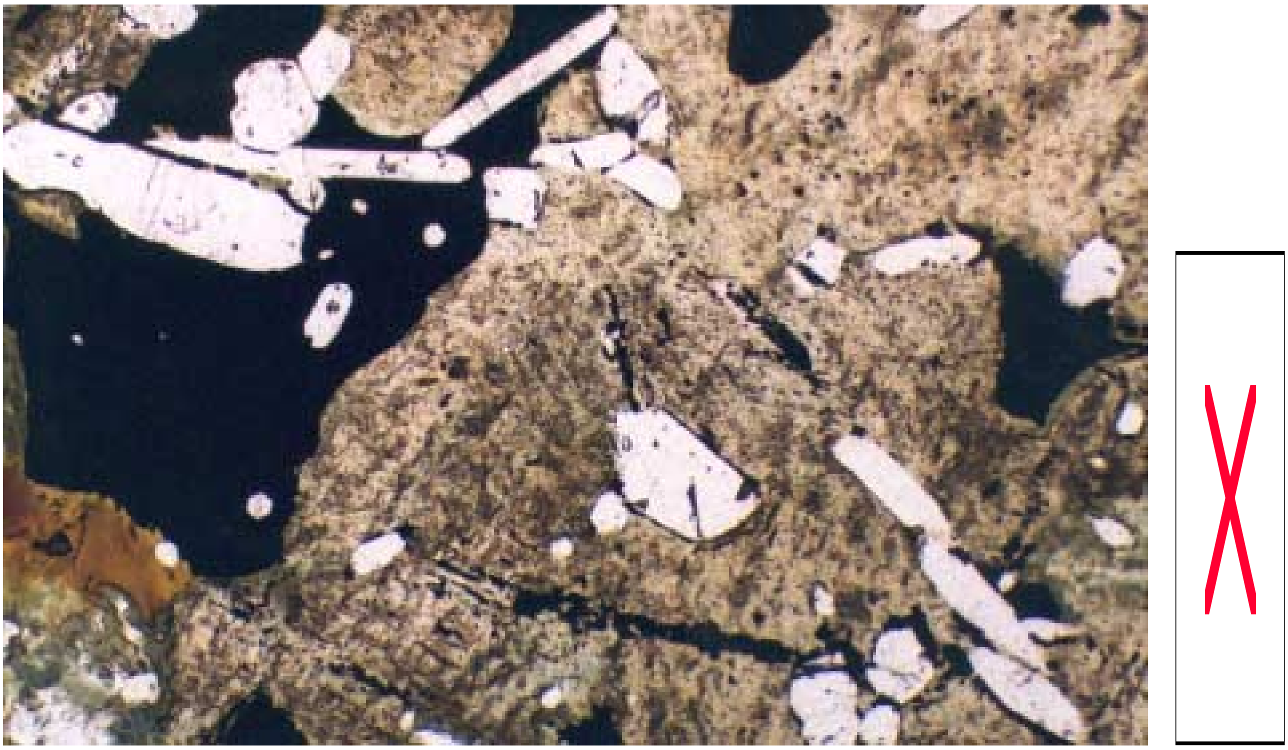

PLATE 4: SAMPLE CX1 (Transmitted plane polarised light, x5, Film 1 / Frame 3)
This sample contains a significant amount of apatite (colourless prisms) with associated primary opaques (ilmenite, magnetite) and biotite (brown, bottom left). Fine-grained actinolite (dull pale green) has completely replaced primary pyroxene grains.

PLATE 5: SAMPLE CX7 (Reflected plane polarised light, x20, Film 1 / Frame 12)
This view captures a single grain of primary pyrrhotite (centre, cream) which lies in textural equilibrium with a larger grain of primary ilmenite (pale grey).

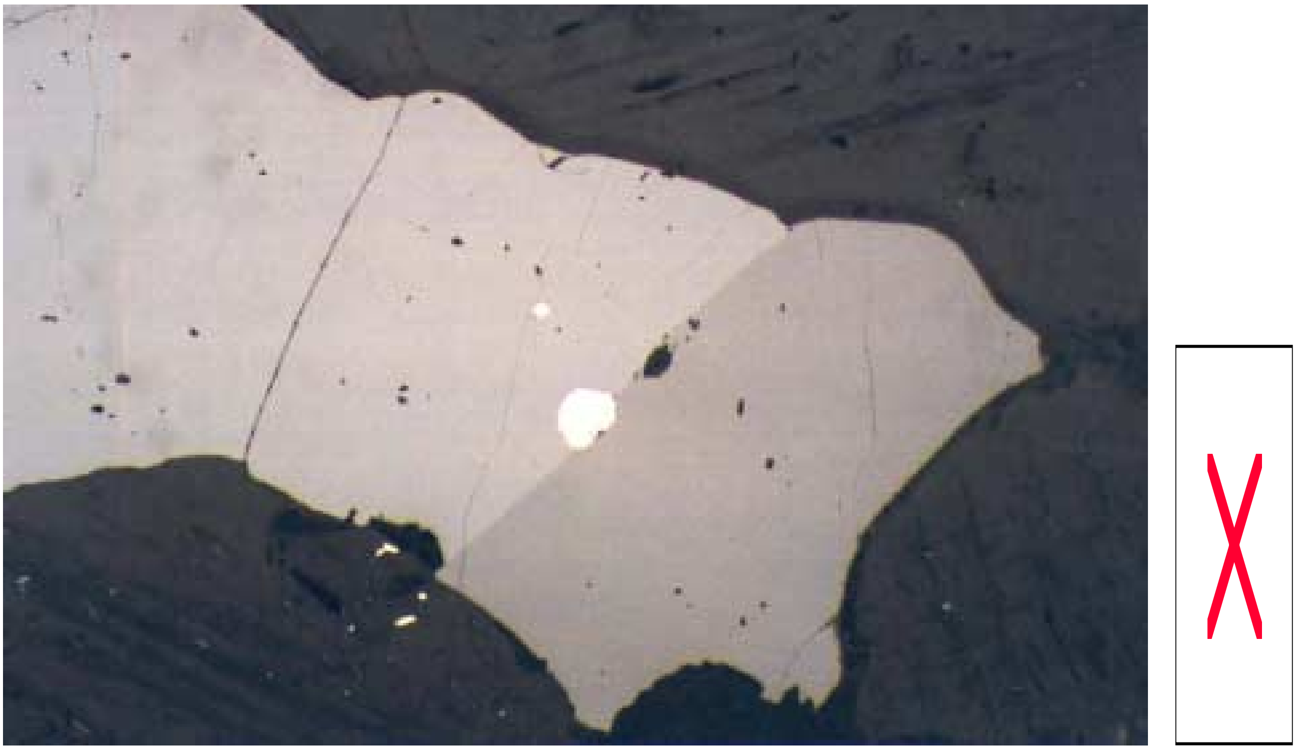

PLATE 6: SAMPLE CX7 (Reflected plane polarised light, x20, Film 1 / Frame 11)
Small equant grains of primary sulphide (off-white, centre) lie in primary ilmenite grains. Note the cuspate shapes of the ilmenite, confirming it formed after pyroxene grains on which it is moulded. The sulphide grains therefore also formed relatively late in the crystallisation of the gabbro.

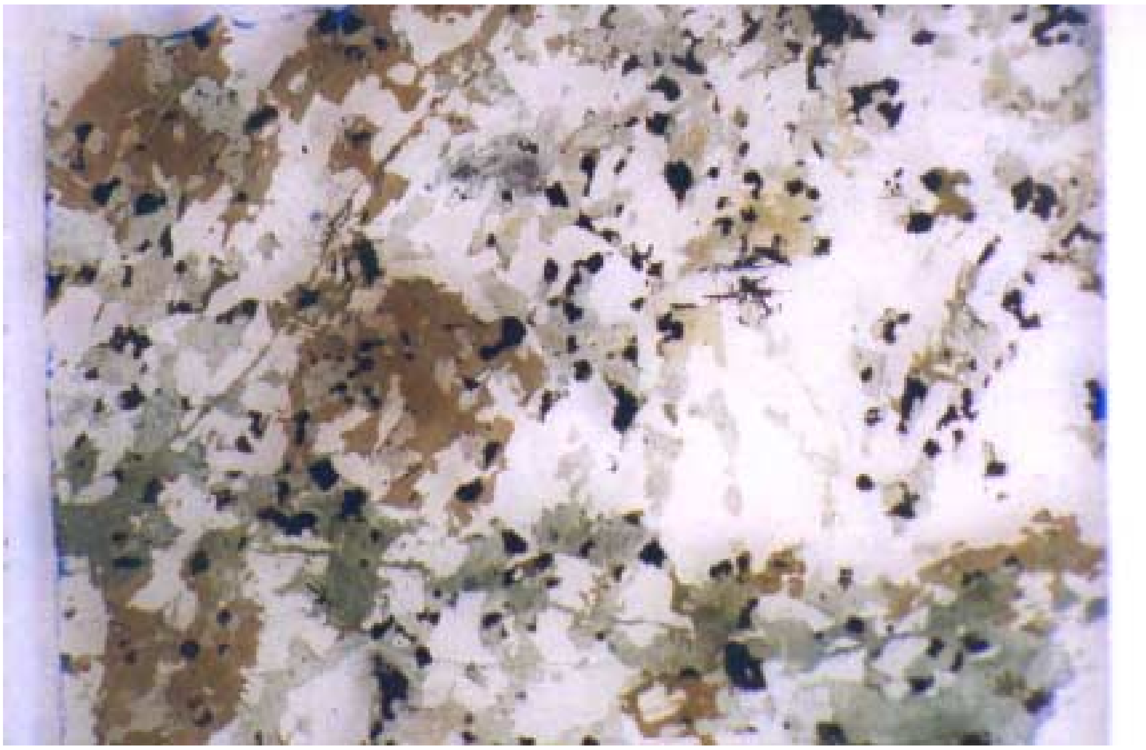

PLATE 7: SAMPLE CX7 (Macrophotograph of thin section, 2.5 cm left to right, Film 1 / Frame 6)
This view illustrates the development of metamorphic actinolite (green) as fillings in thin fractures (near bottom, and at upper left) and as replacements of pyroxene grains marginal to the fractures. Elsewhere, primary pyroxene (pale grains) remain fresh, biotite (brown) is fresh, plagioclase prisms (colourless) remain fresh, and opaque grains are preserved (ilmenite, magnetite).

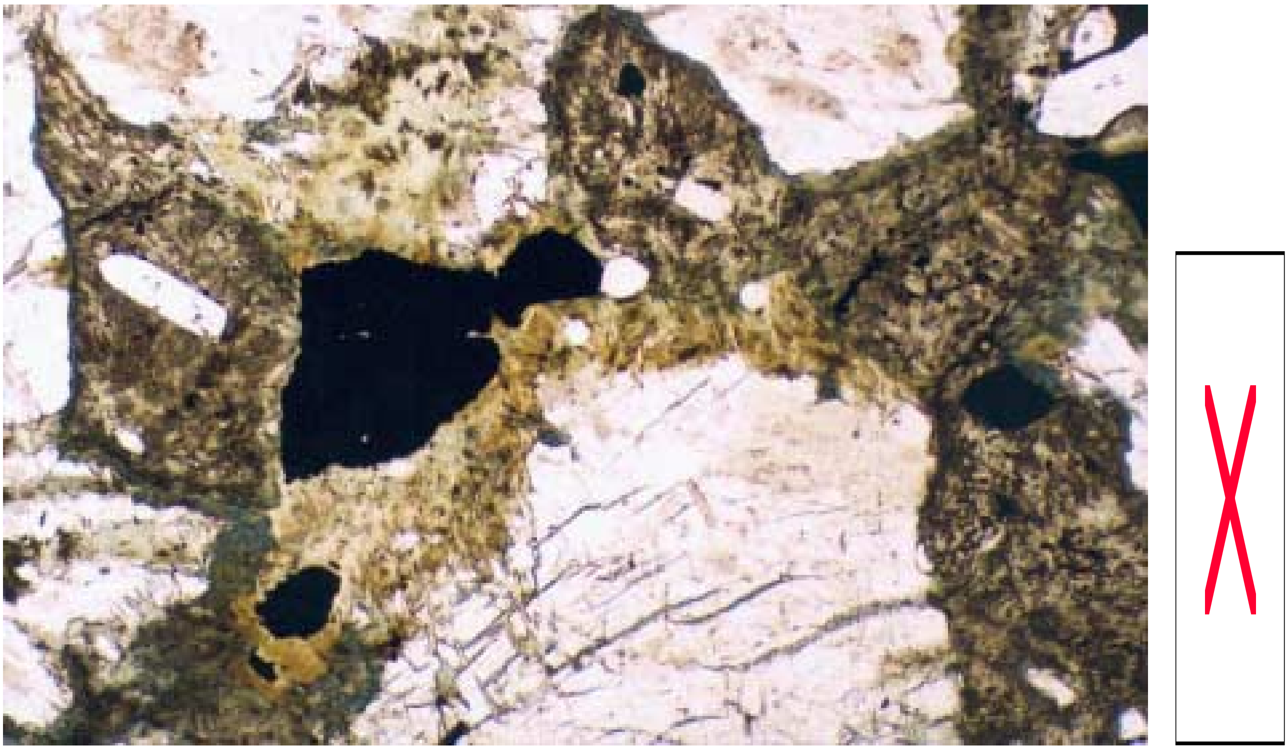

PLATE 8: SAMPLE CX1 (Transmitted plane polarised light, x5, Film 1 / Frame 1)
Metamorphic actinolite has completely replaced blocky grains of pyroxene (left, upper right, bottom right), and small metamorphic biotite flakes (brown) are intimately intergrown with the actinolite around the margin of the ferromagnesian grains. Most of the plagioclase is relatively well preserved (colourless).

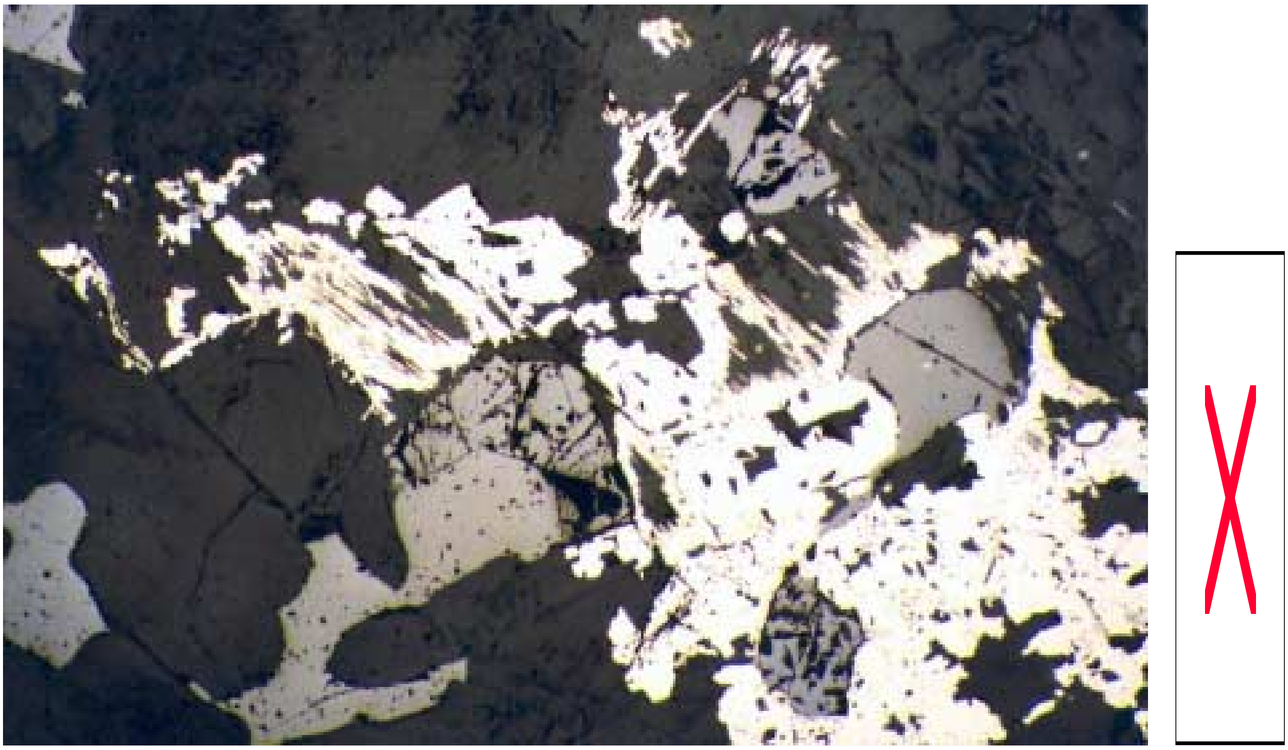

PLATE 9: SAMPLE CX7 (Reflected plane polarised light, x5, Film 1 / Frame 10)
Alteration pyrite (white) forms fine-grained ragged replacement aggregates irregularly scattered through the rock.

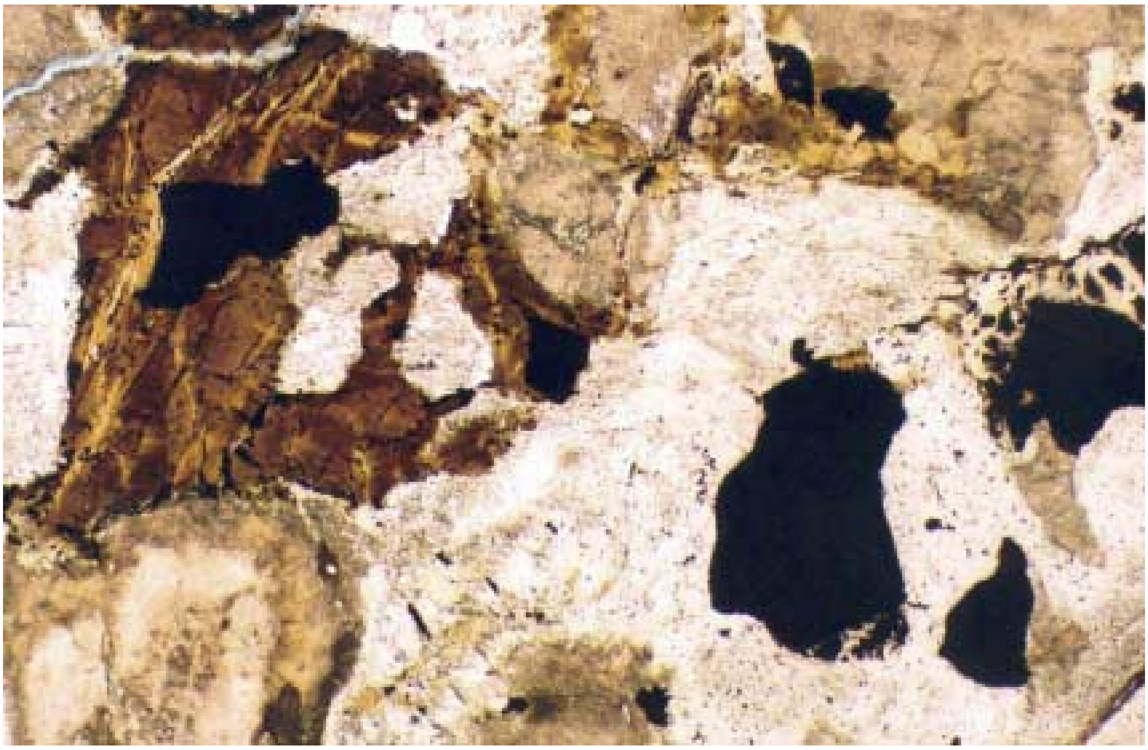

PLATE 10: SAMPLE 01CX6 (Transmitted plane polarised light, x5, Film 1 / Frame 23)
This view captures some preserved primary biotite (poikilitic reddish brown plate, top left) and some metamorphic biotite (small ragged reddish flakes, top right), but all other primary minerals have been destroyed. Plagioclase has been replaced by turbid pale brownish clays and albite (bottom left, top right), and ferromagnesians have been replaced by chlorite (almost white, centre right). Primary opaques have been replaced by leucoxene/rutile (lower right).

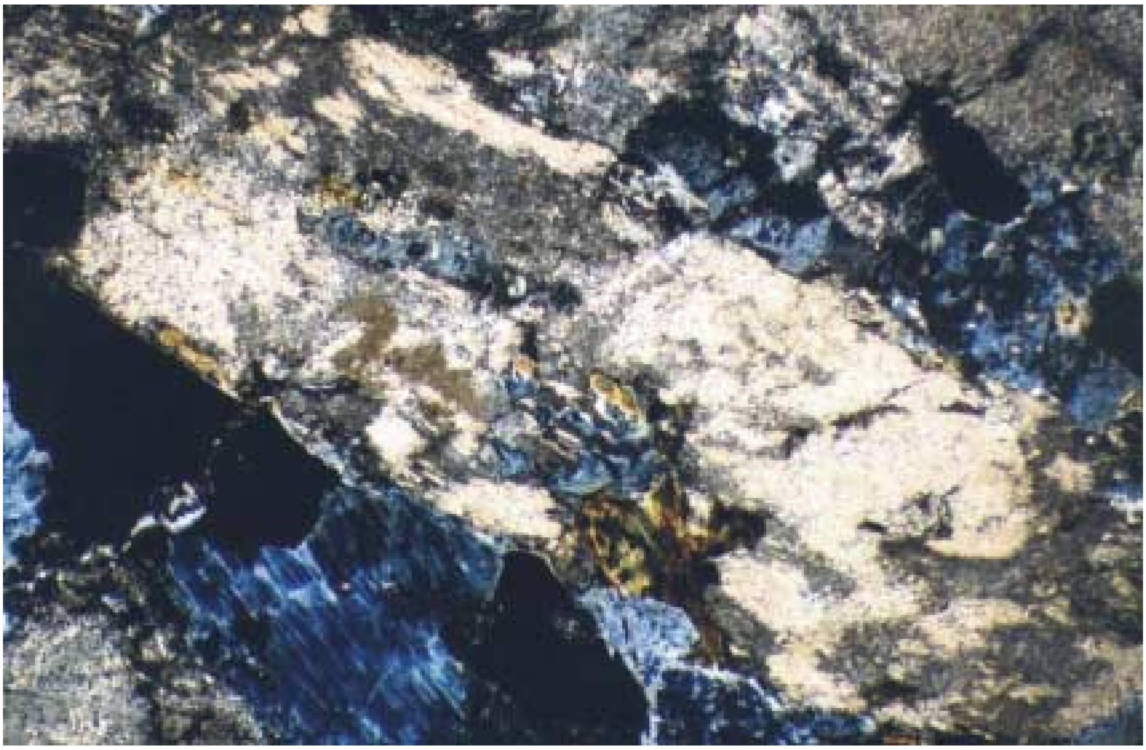

PLATE 11: SAMPLE 01CX6 (Transmitted light, crossed polarisers with condenser, x5, Film 1 / Frame 18).
A prismatic plagioclase crystal (oriented NW-SE) has been replaced mostly by a fine mat of illitic clay (bright pale yellow colours), and chlorite (blue, bottom left) has replaced pyroxene.

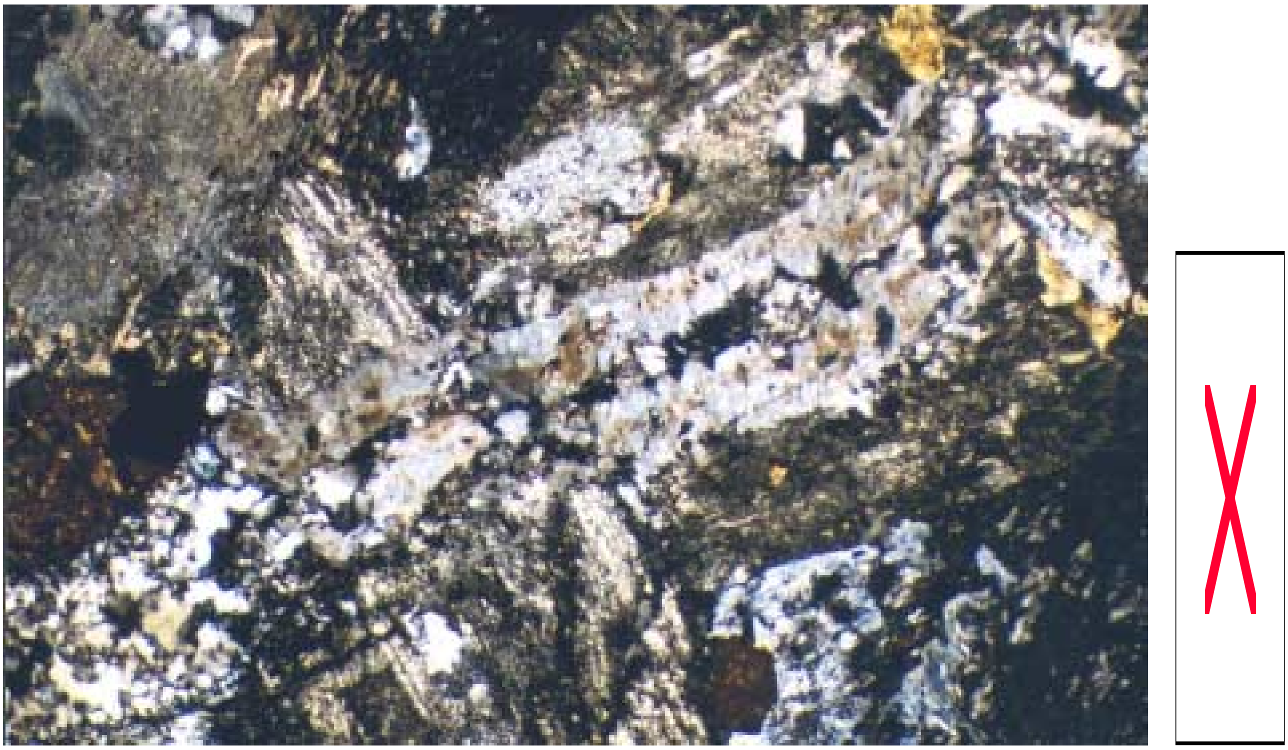

PLATE 12: SAMPLE 01CX6 (Transmitted light, crossed polarisers with condenser, x5, Film 1 / Frame 24)
A thin veinlet (oriented NE-SW) is filled by K-feldspar (adularia, medium grey in optical continuity) and minor fine-grained quartz (bottom left, top right). K-feldspar is observed in the thinner veinlets, but not in the altered host rock (top left, bottom right).

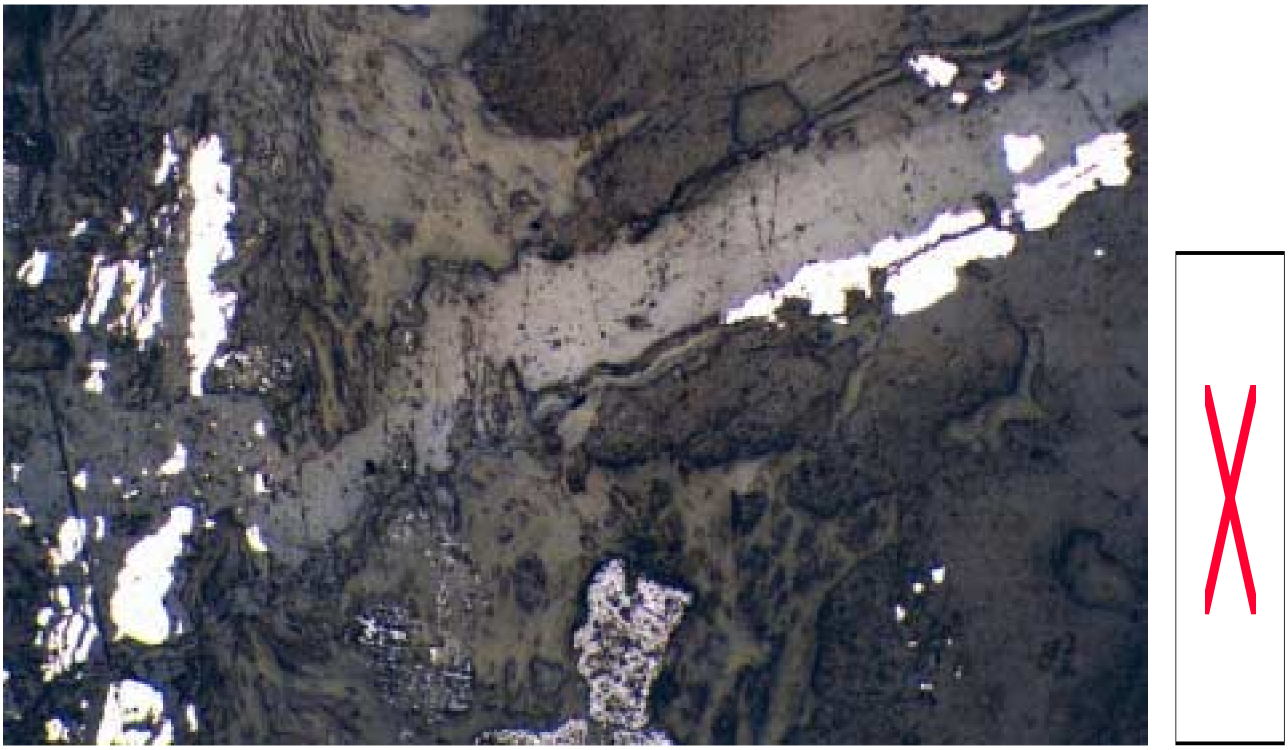

PLATE 13: SAMPLE 01CX6 (Reflected plane polarised light, x5, Film 1 / Frame 22)
Pyrite (white) forms fine-grained aggregates which locally form within and along margins of the thin veinlets (one is oriented NE-SW, and one is oriented N-S at left). Locally, marcasite (not shown) is intergrown with the pyrite, confirming the low-temperature nature of the alteration.

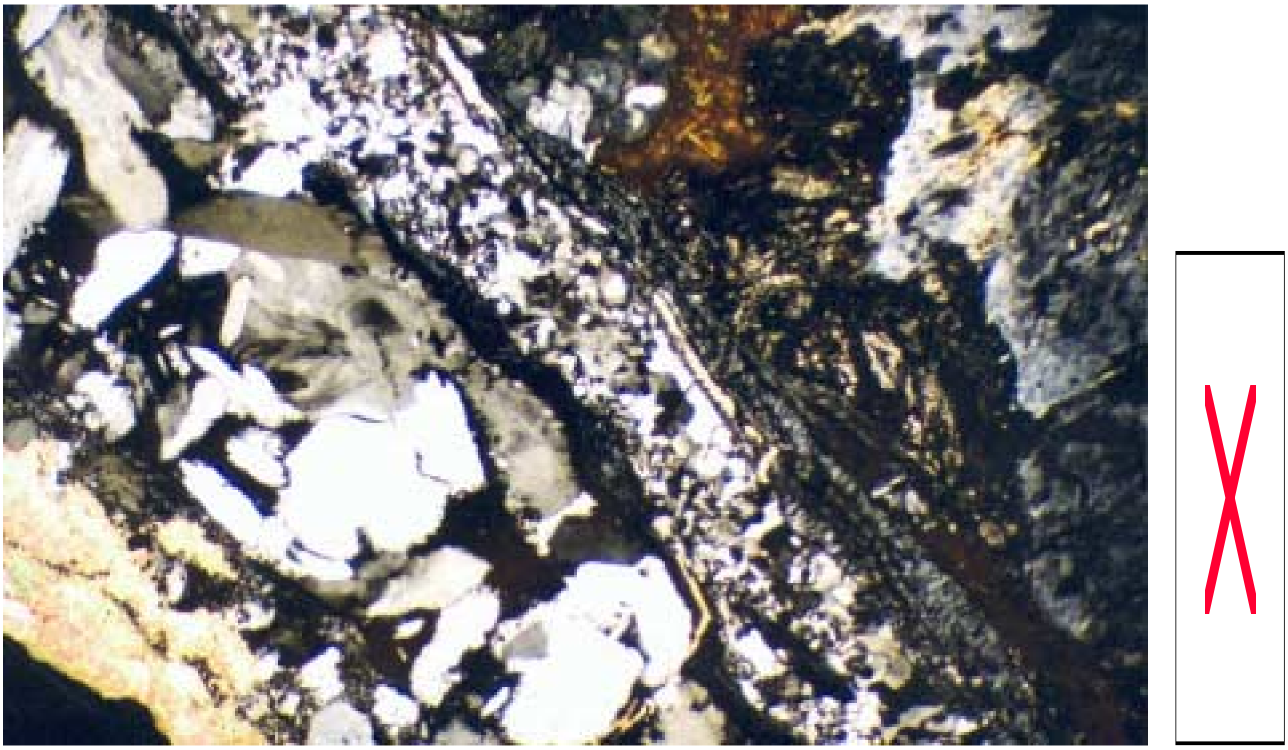

PLATE 14: SAMPLE 01CX6 (Transmitted light, crossed polarisers, x5, Film 1 / Frame 19)
This view captures one of the thicker veins (left, oriented NW-SE). Note the banding in the vein, from fine-grained microcrystalline quartz at the vein margin, through coarser-grained quartz with elongate prismatic crystals, to calcite in the vein centre (bottom left). The vein texture is consistent with a low-temperature origin. Altered gabbroic wall rock (upper right) contains fine-grained dense leucoxene/rutile (dense reddish aggregate, top right) after primary Fe-Ti oxide grains.

APPENDIX 2: MINERALOGY OF SAMPLE 01CX6, 21.0m BY X-RAY DIFFRACTION