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A blue amphibole occurrence from the Flowerdale River, northern Arthur Lineament

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Abstract

An isolated outcrop of weakly foliated amphibolite in the Flowerdale River near Lapoinya lies within a belt of schist, close to the most northerly exposure of the Arthur Metamorphic Complex. The amphibolite, which was derived from a strongly fractionated tholeiitic basaltic protolith, has been completely recrystallised to a mainly greenschist facies assemblage of albite-epidote-actinolite-chlorite-biotite-sphene-magnetite-(quartz-tourmaline-pyrite). The sodic composition of relict blue amphibole (winchite/ferrowinchite) suggests an earlier high pressure (≥ 560 MPa) blueschist facies phase of metamorphism, implying burial to depths of ≥ 20 km. These conditions were attained widely throughout the Arthur Metamorphic Complex, as very similar metamorphic assemblages in chemically similar amphibolites have been previously reported from its southern part, up to 90 km from Lapoinya. The relationship of the blueschist facies rocks to the remainder of the complex, and to Proterozoic mafic rocks elsewhere in northwest Tasmania, remains problematical.

Introduction

Metamorphic amphiboles with blue-grey pleochroism and high sodium/calcium ratios in the B sites are usually considered to have formed at relatively high pressure/low temperature (blueschist facies) conditions (e.g. Winkler, 1979, p.175–176). They have been reported from northwest Tasmania as rare relict phases in largely retrogressed greenschist facies amphibolites within the Arthur Metamorphic Complex (AMC). Localities include the present site of Reece Dam (Spry, 1964; Turner and Bottrill, 1993, 2001), Savage River mine (Green and Spiller, 1977) and Main Creek (about 5 km southwest of Savage River township) (Turner and Bottrill, 1993, 2001). All of these previously described occurrences are from the southern part of the AMC and are from the Bowry Formation, a unit lying near the eastern edge of the AMC.

The purpose of this report is to document blue amphibole within an amphibolite outcrop in the Flowerdale River, about 10 km WSW of Wynyard, near the northernmost exposure of the AMC and more than 60 km from the nearest occurrence to the south.

Regional Setting

The oldest rocks in far northwest Tasmania belong to a multiply deformed, relatively unmetamorphosed Proterozoic shelf sequence of siltstone, quartzarenite and minor carbonate (the Rocky Cape Group). This sequence is disconformably to unconformably overlain by a similarly deformed Neoproterozoic volcanosedimentary sequence of basal siliciclastic rocks, dolomite, diamictite, tholeiitic basalt and associated volcaniclastic rocks (the Togari and Ahrberg Groups). The region is separated from the rest of Tasmania by the Arthur Lineament, a southwest-trending belt, more than 100 km long (onshore) and up to 15 km wide, of more intense deformation and higher grade metamorphism. The rocks which comprise the Arthur Lineament are referred to as the Arthur Metamorphic Complex.

The AMC is best known in its southern segment from the Savage River mine to Ahrberg Bay (Turner *et al*., 1991), and in a smaller part of its northern segment between the Lyons and Arthur rivers (Everard *et al*., 1996). In both segments the deformation and metamorphism in the Rocky Cape and Ahrberg Groups to the west, and in the dominantly quartzwacke turbidite Burnie and Oonah Formations to the east, increase in intensity and grade towards the complex. The central core of the AMC in both segments is dominated by strongly deformed mafic volcaniclastic to pelitic rocks with intercalated amphibolite.

Little geological work has been done near the northern end of the AMC since the original mapping of the Burnie quadrangle (Gee *et al*., 1967; Gee, 1977). These authors showed that, in the northwest corner of this sheet, the AMC (which they termed the Keith Metamorphics) consists of a belt of "pelitic, calcic and basic schists", flanked to the northwest by a narrower belt of "phyllite– marginal to metamorphics" intercalated with units of "schistose quartzite"(fig. 1). Four small northeasterly-trending units of amphibolite, not fully mapped along strike, were shown within the former unit, apparently from exposures in the Flowerdale River and Inglis River. Permo–Carboniferous sedimentary rocks and Tertiary basalt conceal the relationships of the AMC in this area with the less metamorphosed Burnie Formation to the east.

The phyllite and intercalated schistose quartzite appear to be continuous with a similar unit, provisionally termed the Bird Phyllite, which occurs in the Arthur River area, about 25 km to the southwest (Everard *et al*., 1996; unit Pap). This unit appears to have a transitional metamorphic relationship to the less metamorphosed Rocky Cape Group to the northwest. The "pelitic, calcic and basic schists" of Gee *et al*. (1967) may be partly equivalent to a unit of chlorite schist, minor phyllite and carbonate, and intercalated amphibolite, provisionally termed the Champion Schist, in the Arthur River area (Everard *et al*., 1996; unit Pac). In the Arthur River, the Champion Schist has an apparent gradational lithological relationship with the Bird Phyllite, although exposure is not continuous and a faulted contact is also possible. To the southeast the Champion Schist is partly concealed by Permo–Carboniferous sedimentary rocks, which are faulted against an un-named unit of strongly deformed but low metamorphic grade, mainly sedimentary rocks including phyllitic mudstone, dolomite and magnesite in the Keith–Lyons River area (unit Pam; also shown green in fig. 1). In turn this unit is faulted against the pelitic Keith Schist (unit Pak), which decreases in metamorphic grade southeastward and passes transitionally into the Oonah Formation (unit Pob; equivalent to the Burnie Formation).

Field relationships

Preliminary efforts were made in early 1996 to relocate and sample the four amphibolite units mapped by Gee *et al*. (1967) in the Flowerdale River–Inglis River area.

The northernmost of these units is represented by a small outcrop on the right (east) bank of the Flowerdale River, about 2.4 km ESE of Lapoinya (382 320 mE, 5 458 220 mN; Australian Map Grid, Zone 55, AGD66). A sample (FR4, Reg. No. R005492) of amphibolite was collected and is described in detail below. Exposure is poor and contacts are not exposed. Strongly foliated grey-green mafic schist, with possible small albite porphyroblasts, crops out in the river to the northeast, about 300 m downstream (382 400 mE, 5 458 480 mN).

The more southerly amphibolite unit in the Flowerdale River (depicted near 382 410 mE, 5 455 520 mN by Gee *et al*., 1967) has so far not been relocated, although a sample (FR1, R005489) of coarse-grained albite-biotite-chlorite-calcite schist, without obvious quartz, was collected near this locality.

A further two amphibolite units were depicted by Gee *et al*. (1967) in the Inglis River, about one kilometre north of the confluence with the Calder River. A traverse in this area located several small river outcrops. Unfoliated but well jointed, grey-green possible amphibolite, sometimes with pink albite veinlets, occurs as a mid-river outcrop (583 060 mE, 5 453 450 mN). Gee (1977) described similar "albite-rich amphibolite, showing remnant doleritic textures" in this area and suggested that several near-vertical tabular bodies are present. Other rock types noted include grey-green, brown-weathering foliated (020W85) mafic schist (e.g. 583 030 mE, 5 453 490 mN), platy quartzite and strongly foliated quartz-mica schist (e.g. 383 000 mE, 5 453 500 mN). Although samples were collected, the rocks are too weathered for detailed petrology.

Petrography

In hand specimen the amphibolite (sample FR4) is a tough, nearly massive, dark blue-grey to greenish-grey dense rock with a mean grain size of 0.5–1 mm. Albite porphyroblasts (1–2 mm) occur in some coarser-grained variants. There is a weak foliation defined by the elongation of dark blue-green diffuse clots of amphibole (up to 2–5 mm long × 1 mm across) and a very weakly developed compositional banding. Fresh surfaces sparkle in strong light due to crystal faces of small magnetite euhedra, and there are also a few small granular pyrite grains (<1 mm).

The rock is highly magnetic with an apparent susceptibility of about 46×10^{-3} SI (mean of 20 measurements taken in the field, range 24.2–75.2). A measurement of 95×10^{-3} SI, taken from a flat cut surface of a large, fresh hand specimen, may be more accurate.

In thin sections (plates 1, 2, 3) the rock is seen to be thoroughly recrystallised, with no vestige of primary igneous texture or mineralogy. It is crudely porphyroblastic and consists of abundant ragged xenoblastic aggregates of amphibole, up to one millimetre across, in an uneven-grained mosaic of albite, epidote, amphibole, chlorite, sphene, quartz and magnetite. Minor biotite and tourmaline are also present. In places the texture of the groundmass grades to poikiloblastic, with very abundant inclusions, particularly of epidote, enclosed by albite.

The bulk of the amphibole is fibrous, length slow and has birefringence up to lower second order, with

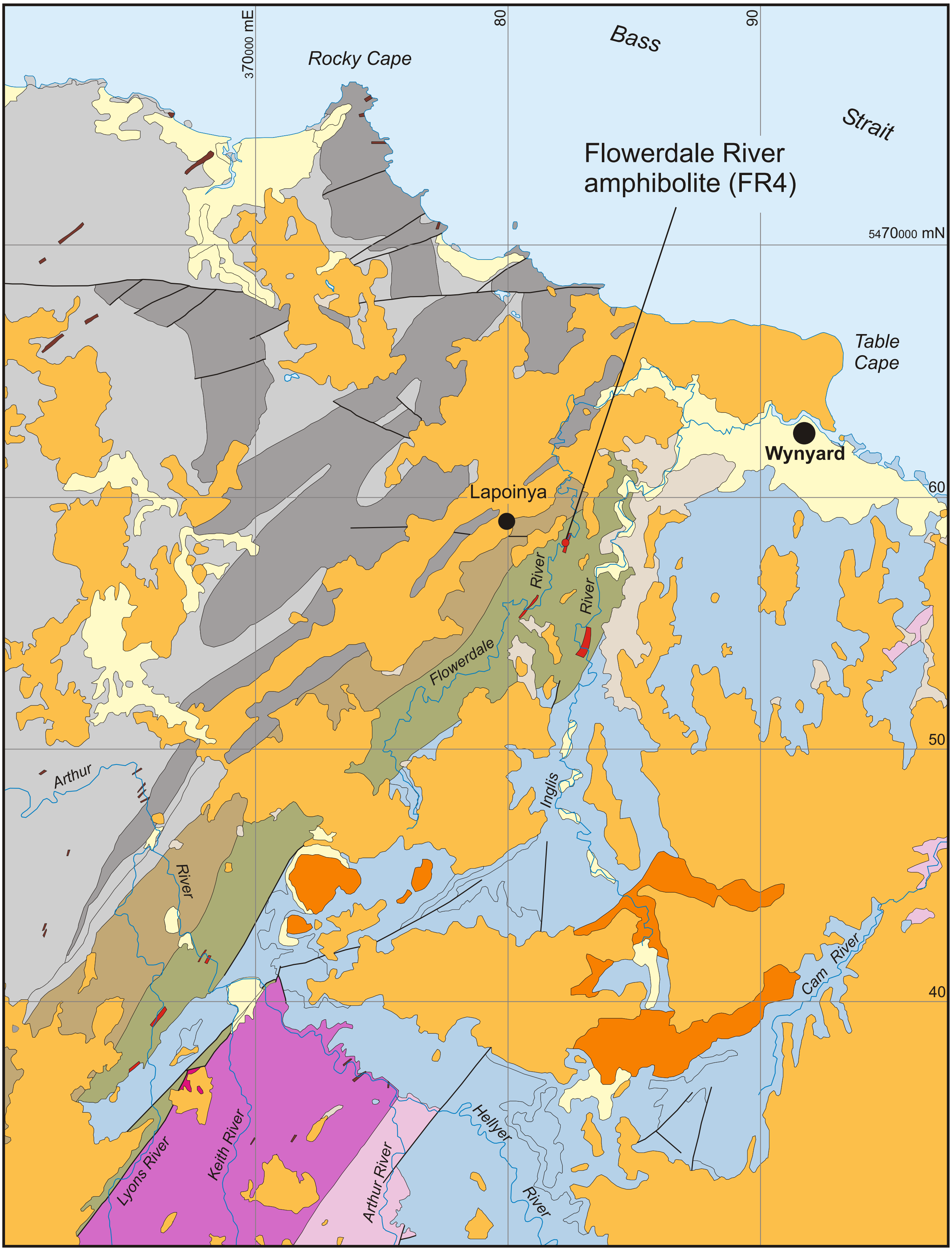

Figure 1

Simplified geology of the northern Arthur Metamorphic Complex, adapted from MRT 1:250 000 scale digital data. The AMC in this area consists of the Keith Schist (dark purple), Bird Phyllite (dark brown) and Champion Schist (dark green) with amphibolite units (red). To the west the Rocky Cape Group includes pelite units (light grey) and quartzite units (dark grey); the Burnie Formation (light purple) lies to the east. 10 km grid also shown. See page 4 for a detailed legend.

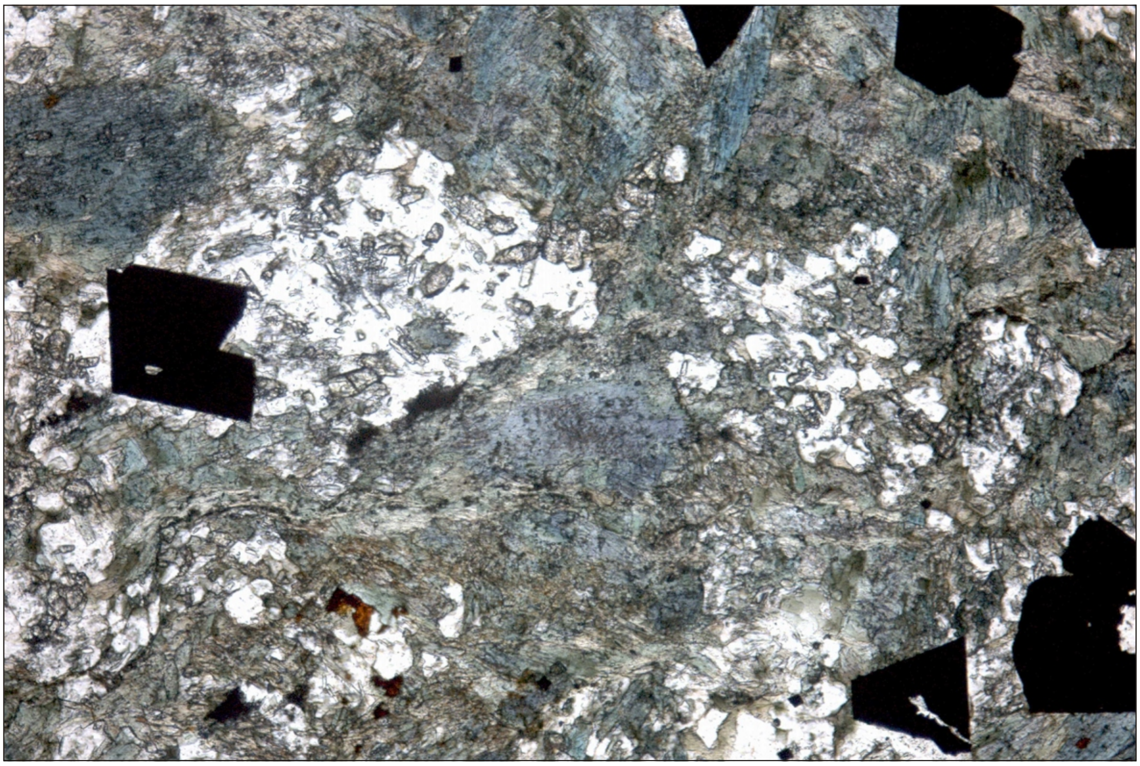

Plate 1

Photomicrograph of Flowerdale River amphibolite (sample FR4) showing winchite amphibole (blue-grey), actinolite and chlorite (green), albite (clear, low relief), epidote (colourless, high relief) and magnetite (opaque). Plane polarised light, field of view 1.8 × 1.3 mm.

Quaternary		🟨	*Alluvium and slope deposits*
Tertiary		🟧	*Basalt*
		⬜	*Marine and non-marine sediments*
Jurassic		🟧	*Dolerite*
Permian–Carboniferous		🟦	*Tillite and siltstone*
Proterozoic	Rocky Cape Group	⬛	*Quartzarenite*
		⬜	*Siltstone with tholeiitic dolerite dykes (brown)*
	Arthur Metamorphic Complex (Including Keith Metamorphics)	🟫	*Phyllite and schistose quartzite (Bird Phyllite)*
		🟩	*Pelitic, calcic and basic schist (Champion Schist)*
		🟥	*Amphibolite*
		🟪	*Dominantly quartz-mica schist (Keith Schist)*
		🟪	*Quartzwacke and slaty mudstone (Burnie Formation)*

Legend for Figure 1

pleochroism (α straw yellow, β pale yellow-green, γ blue-green) typical of actinolite. Some material, particularly in the cores of the aggregates, is less fibrous, has lower birefringence, different pleochroism (α pale yellow, β pale grey-blue, γ blue-green) and a low optic axial angle (nearly uniaxial, negative), suggesting more sodic 'blue' amphibole. These identifications are confirmed by electron microprobe analyses (Table 1 and below). It should be noted that the more sodic 'blue amphibole' is diagnosed in part by the pale grey-blue 'lavender' pleochroism of the β vibration direction, not the darker blue-green colour of the γ vibration direction which may also be seen in actinolite.

Chlorite is present as small ragged fragments intergrown with other groundmass minerals. Despite similar pleochroism (pale green to pale yellow) to actinolite, chlorite is distinguished by its very low birefringence, occasionally with anomalous interference colours.

A small amount of biotite is present as ragged, often elongate, length-slow shreds (<100 μm) finely intergrown with amphibole, from which it is distinguished by its pleochroism (dark khaki greenish-brown to nearly colourless) and much higher birefringence.

Epidote is abundant as clear, colourless to pale yellow subhedral to euhedral equant granules, mostly less than 50 μm across, and elongate tabular grains

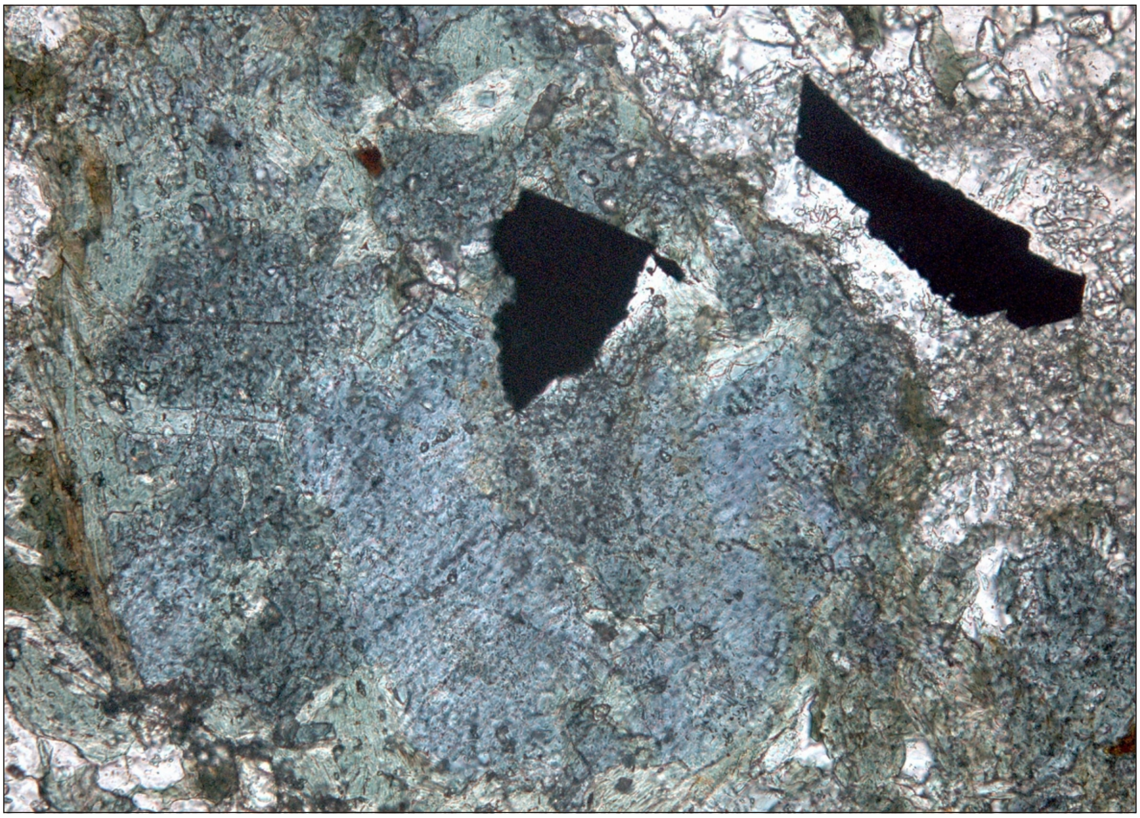

Plate 2

Photomicrograph of Flowerdale River amphibolite (sample FR4) showing winchite amphibole (blue-grey, approximately in β orientation) surrounded by retrograde actinolite (blue-green, approximately in γ orientation). Albite, epidote, biotite (brown, at left) also present. Plane polarised light, field of view 730 × 520 μm.

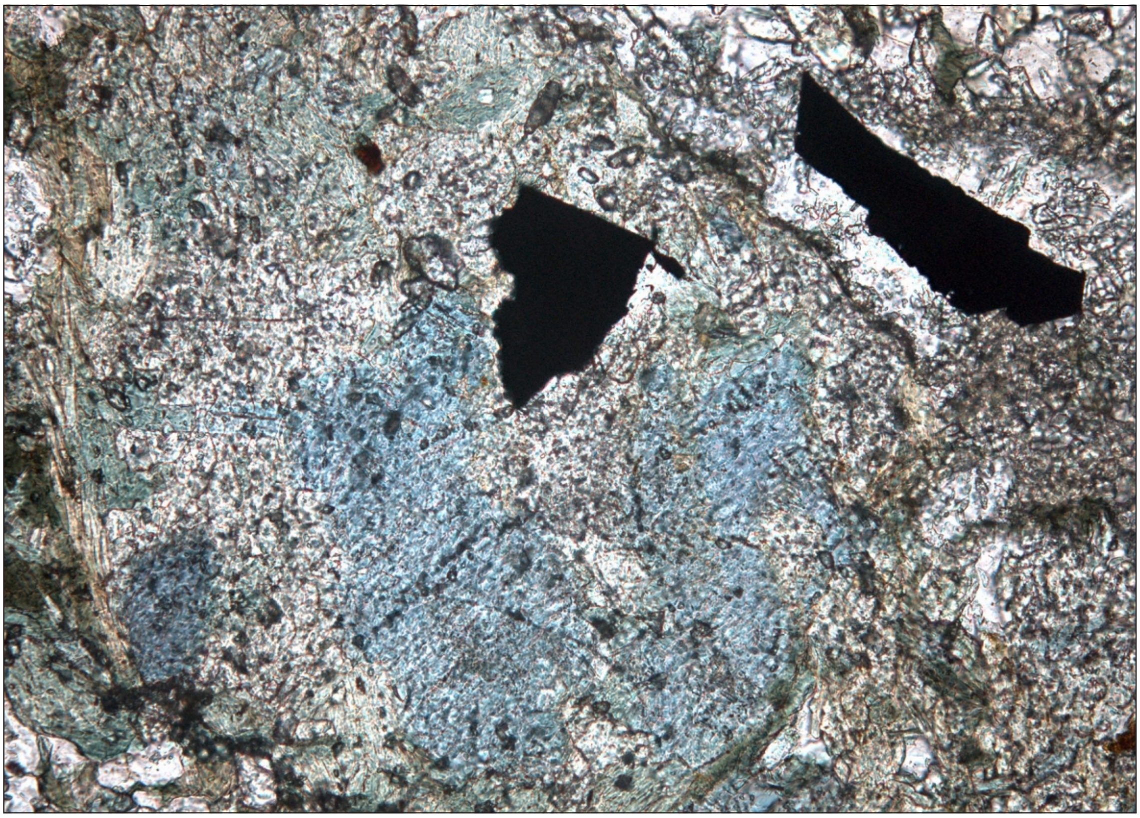

Plate 3

Same view as above but with polariser rotated by 90°. Winchite (blue-green) now in γ orientation, actinolite (pale yellow-green) in β orientation.

occasionally up to 250 mm long. It has the high relief and birefringence (to lower third order with anomalous brilliant greens) and negative optic sign of iron-rich varieties (as opposed to clinozoisite).

Albite forms a mosaic of interlocking clear equant anhedra, rarely more than 200 µm across, together with, or enclosing, epidote granules. Extinction is sometimes slightly undulose, suggesting either strain or compositional zoning, but twinning is rarely seen.

Although x-ray diffraction indicates that a few per cent quartz is also present, it is difficult to find in thin section. Quartz may be finely intergrown with albite, from which it is difficult to distinguish. All grains examined that were large enough to give an interference figure proved to be biaxial positive, consistent with albite.

The magnetite grains are typically equant, angular and euhedral to subhedral and mostly 200–400 µm across. They are commonly partly or wholly surrounded by large (≤1.5 mm) irregularly anhedral or apparently angular subhedral grains of sphene. These are dark except under strong illumination, have very high birefringence but do not show extinction, and are probably fine-grained cryptocrystalline aggregates.

There are also rare small euhedral prisms (e.g. 110 × 35 µm) of strongly pleochroic tourmaline (ε pale pink, ϖ almost opaque).

Although most of the sections are fresh, there is locally some oxidation with minor secondary dark orange-red iron oxide.

Mineral chemistry

The mineral chemistry of sample FR4 was investigated using the Cameca SX-50 electron microprobe at the Central Science Laboratory, University of Tasmania. The primary object was to determine the composition of amphibole (Table 1), but reconnaissance analyses were made of most other mineral phases (Table 2).

Amphiboles

The seven amphibole analyses (Table 1) have, allowing for H_2O which was not determined, good totals (97.0–98.5%) and appear to be essentially uncontaminated by other phases. However the mineral is compositionally quite variable (e.g. Na_2O 0.70–3.54%, CaO 5.8–12.0%).

The analyses were converted to the standard amphibole formula $AB_2C_5T_8O_{22}(OH,F,Cl)_2$ and classified according to the procedure described by Schumacher (in Leake *et al.*, 1997). This involves the initial assumption that all iron is in the ferrous state (Fe^{II}). Constraints imposed by site occupancy limitations for specific cations are then applied to calculate the minimum and maximum permissible ferric iron (Fe^{III}).

For six of the seven analyses, acceptable amphibole formulae result if all iron is ferrous; there is no requirement that any ferric iron be present, and the 'minimum Fe^{III} formulae' are the same as the 'all ferrous formula'. For analysis R4/1A the 'all ferrous' formula violates the requirement that (Si + Al + Ti + Cr + Mg + Ni + Fe + Mn + Ca) < 15; i.e. that Ca does not enter the A sites. In this case, the minimum Fe^{III} formula is given by the '15eNK' method, by which cations are renormalised so that those other than Na and K sum to 15. A small amount of Fe (0.1156 cations/formula unit) is then allocated to Fe^{III} to maintain a total cation charge of 46.

'Maximum Fe^{III} formulae' are also calculated using the most restrictive constraint demanded by site occupancy considerations. (Note: there is a small error in Leake *et al.*, 1997; the cation sums must be divided by the stoichiometric limits before determining which constraint is most restrictive, and renormalising). For five analyses, this is the requirement that (Si + Al + Ti + Cr + Mg + Ni + Fe + Mn + Ca + Na) >15 (i.e. that K does enter the B sites), and the resultant are '15eK' formulae. For the other two analyses it is the requirement that (Si + Al + Ti + Cr + Mg + Ni + Fe + Mn) >13 (i.e. that Ca does not enter the C sites) and the resultant maximum estimates of Fe^{III} are '13eCNK' formulae.

Two analyses (R3/2 and R7/1) contain Na_B > 0.50, in their minimum Fe^{III} formulae, and thus qualify as sodic-calcic amphiboles. As $(Na + K)_A$ < 0.50, they are assigned to the winchite group. Although the analyses are very similar, a small difference in $Mg/(Mg + Fe^{II})$ causes them to classify as ferrowinchite (0.4923) and winchite (0.5050) respectively. Of the other five analyses, four are actinolites whilst R3/5, with $Mg/(Mg + Fe^{II})$ of 0.4977, marginally qualifies as ferroactinolite.

The maximum Fe^{III} formulae are very variable in the amount of Fe^{III} (0.1137 to 0.8807 cations), and are considered less realistic than the minimum Fe^{III} formulae. They have more Na in the B sites and less in the A sites, resulting in a further two analyses (R3/3 and R3/5) being classified as winchites.

Amphiboles with essentially vacant A sites may be plotted in the ternary system tremolite-glaucophane-tschermakite, with ideal winchite being regarded as a 50:50 solid solution of tremolite and glaucophane (fig. 2). Hornblende and barroisite are similarly intermediates between tremolite and tschermakite, and tschermakite and glaucophane, respectively. (In this scheme, Fe^{II} and Mn are grouped with Mg, and Fe^{III} and Cr with Al). Because of several possible multiply-coupled substitutions, there is no unique or even satisfactory way of projecting compositions with substantial Na and K in the A sites on to this system. For these amphiboles, the maximum Fe^{III} formulae are used, because they have much lower A site occupancies. The small amounts of Na and K in the A sites are regarded as due to an edenite [$Na.Ca_2.(Mg, Fe^{II}, Mn)_5.AlSi_7O_{22}(OH,F)_2$ component (plotted

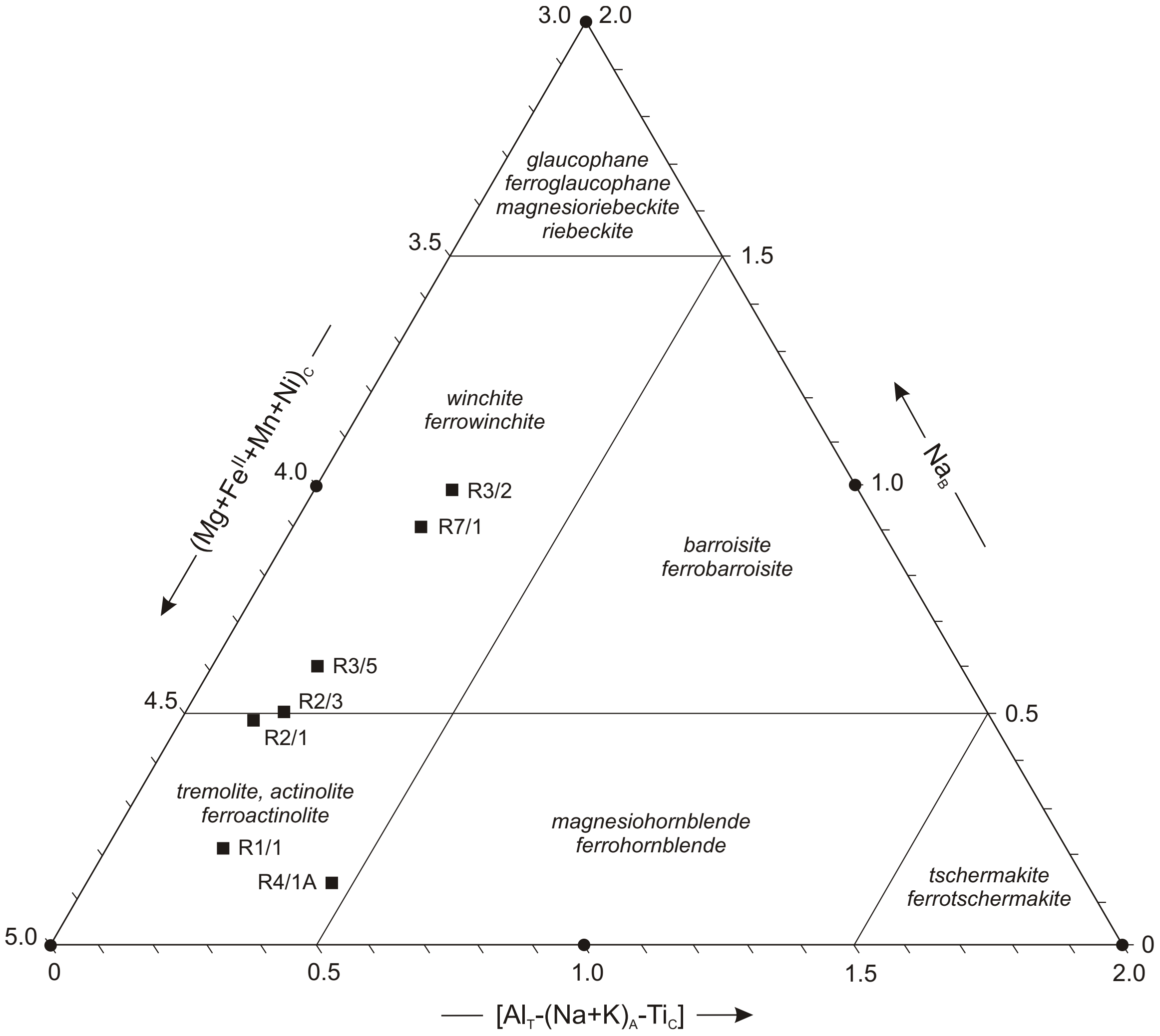

Figure 2

Amphibole compositions, Flowerdale River amphibolite: maximum Fe^{III} *formulae plotted in the glaucophane/riebeckite (gl)-tremolite/actinolite (tr)-tschermakite (ts) ternary system. Amphibole nomenclature shown is consistent with Leake et al. (1997), providing Ti and* $(Na+K)_A$ *are both negligible. End-member compositions including winchite, barroisite and hornblende also shown. See text for further explanation.*

with tremolite), and tetrahedral Al and Si adjusted accordingly ($Na_AAl_T \leftrightarrow \square_ASiT$). Similarly Ti is regarded as due to the hypothetical component $Ca_2.(Mg,\ Fe^{II})_4Ti.Al_2Si_6O_{22}(OH,F)_2$ (plotted with hornblende), and Al_T and Si are likewise adjusted ($Al_CSi_T \leftrightarrow Ti_CAl_T$). Thus the analyses can be reduced to the parameters:

C site parameter = $(Mg + Fe^{II} + Mn + Ni)_C$
B site parameter = Na_B
T site parameter = $Al_T - (Na + K)_A - Ti_C$.

The results are plotted on Figure 2, together with the compositions of ideal amphibole end-members. This shows that the two most sodic analyses (R3/2 and R7/1) lie intermediate between tremolite/actinolite and glaucophane, and close to ideal winchite/ferrowinchite [$NaCa.(Mg,\ Fe,\ Mn)_4Al.AlSi_7O_{22}(OH,\ F)_2$]. The other five analyses lie closer to tremolite/actinolite, with R4/1A plotting almost half way to ideal hornblende.

The minimum Fe^{III} formulae are less suited to this diagram, particularly as three out of seven contain insufficient tetrahedral Al to account for the A site cations, resulting in negative values for the T site parameter.

Plagioclase

Both analyses are apparently albite ($An_{0.3,\ 5.3}$ with negligible Or). Although small amounts of iron are common in plagioclase analyses, the higher FeO (0.52%) reported in the second analysis (R2/2) suggests slight contamination, possibly by epidote. This may also account for the higher CaO, and plagioclase may be very close to the pure albite end-member. Turner and Bottrill (1993, 2001) analysed albite ($An_{0.3\text{–}2.9}$, $FeO_t \leq 0.28\%$) coexisting with blue amphibole at the Reece Dam localities.

Epidote

The sole analysis is nearly stoichiometric and fairly close to the maximum permissible Fe^{III} content, with Mn being the only other significant element (approximately 84% pistacite, 12% clinozoisite, 4% piedmontite). The analysis generally lies within the compositional range of epidote that coexists with blue amphibole in the southern part of the Arthur Metamorphic Complex (six microprobe analyses, Turner and Bottrill, 1993, 2001), apart from MnO (0.57% vs. 0.16–0.48%).

Chlorite

The sole analysis is a moderately aluminous clinochlore (classification of Gaines *et al.*, 1997, p.1496–1503), and is slightly more magnesian (Mg# 53.5) than the associated biotite. Extraneous elements such as Ca and K are very low and there is no evidence for appreciable Fe^{III}. In the classification of Hey (1954) it is probably a pycnochlorite variety, but is close to the arbitrarily defined boundaries of both the more iron-rich brunsvigite variety (Mg# <50) and the more aluminous ripidolite variety (Si <2.8 cation/formula unit). By comparison, chlorites that coexist with blue amphibole near Reece Dam have similar Si and Al contents but higher Mg# (55.4–68.4) (Turner and Bottrill, 1993, 2001).

Mica (biotite)

All three analyses are deficient in K (0.55–0.88 cations/formulae unit), possibly due to incipient alteration to chlorite. The Mg# varies within a narrow range (46.4–48.3) and is probably indicative of primary compositions. They are trioctahedral micas, low in octahedral aluminium (Al^{vi}) (0.2618–0.3792) and may be described as moderately Mg-rich biotites.

Sphene (titanite)

The sole analysis is fairly close to stoichiometric $CaTiSiO_5$, with Al_2O_3 (1.19%) and total FeO (0.85%) being the only other significant components.

Tourmaline

The analysis has slightly excessive Si (>6 cations/formulae unit) and slightly low Na, but is moderately close to the ideal composition, given that B_2O_3 has not been determined. It is dominated by the Mg-rich end member (dravite), with Mg# of 55.0. This contrasts with the mainly iron-rich tourmaline (schorl) typical of granites.

Magnetite

The magnetite is nearly pure end-member Fe_3O_4, and in particular has a negligible ulvospinel component (TiO_2 only 0.06%). It is likely to be metamorphic in origin (consistent with its habit), and does not preserve a relict igneous composition.

Metamorphism

The main mineral assemblage of the rock, albite-epidote-actinolite-chlorite-biotite-sphene-magnetite-(quartz-tourmaline-pyrite), is consistent with the low temperature subdivision of low grade (i.e. greenschist facies) metamorphism. Chlorite is considered diagnostic of low grade, as opposed to medium grade, or amphibolite facies (Winkler, 1979, p.173). The presence of albite ($An_{<5}$) and epidote, rather than oligoclase ($An_{>17}$), also places an upper limit on metamorphic grade. On the other hand, pumpellyite and prehnite, minerals characteristic of very low grade metamorphism, are absent, although (iron-rich) epidote is not especially diagnostic and is also known in sub-greenschist facies rocks (e.g. Deer *et al.*, 1997, p. 91–100; Winkler, 1979, p.175).

The additional presence of sodic amphibole, probably as a relict phase, suggests an earlier episode of higher P/T, blueschist facies metamorphism.

Very similar assemblages occur in the southern part of the Arthur Metamorphic Complex, near Reece Dam and Main Creek (Turner and Bottrill, 1993, 2001). Amphibolites at Reece Dam contain both 'blue prograde' and 'green retrograde' amphibole, together with albite, epidote, chlorite, quartz, sphene and magnetite. Hematite is an additional phase whilst biotite and microcline were only found in one sample. At Main Creek, a mafic schist interbedded with magnesite and dolomite contains relict blue amphibole in a similar assemblage containing also calcite and rare tourmaline.

Amphibole analyses from the Flowerdale River amphibolite are plotted on the Al^{iv}- Na_B diagram (fig. 3), which has been tentatively contoured for pressure by Brown (1977). Data from Reece Dam and Main Creek (Turner and Bottrill, 1993, 2001) and Savage River mine (Green and Spiller, 1977) are also shown for comparison. The Flowerdale River amphibole is not as sodic (Na_2O ≤3.54%) as some of those from the southern localities (Na_2O ≤6.12%), suggesting that the maximum pressure of metamorphism was either less, or is not preserved. Nevertheless, the most sodic amphibole (analysis R3/2) contains at least 0.72 cations of Na/formula unit in its B sites (Table 1, minimum Fe^{III} formula). According to the geobarometer of Brown (1977) this implies a peak pressure of metamorphism about 560 MPa (5.6 kb). Similar conditions of metamorphism are implied by analysis R7/1. If the maximum Fe^{III} formulae, which contain appreciably more Na_B, are used, the implied pressure is somewhat over 600 MPa. The remaining amphibole analyses from the Flowerdale River are probably actinolites (based on their minimum Fe^{III} formulae), but three contain appreciable Na_B and may have equilibrated at 400–500 MPa.

Although most amphiboles from the southern part of the AMC are appreciably more sodic, their estimated peak pressures of metamorphism are only slightly higher (600–700 MPa) because of the high sensitivity of Na_B to pressures in this range. It should be noted that this data (Turner and Bottrill, 1993, 2001) is based on the average of the minimum and maximum Fe^{III} formulae.

Application of the Maruyama *et al.* (1986) geobarometer, based on Al_2O_3 in sodic amphibole and

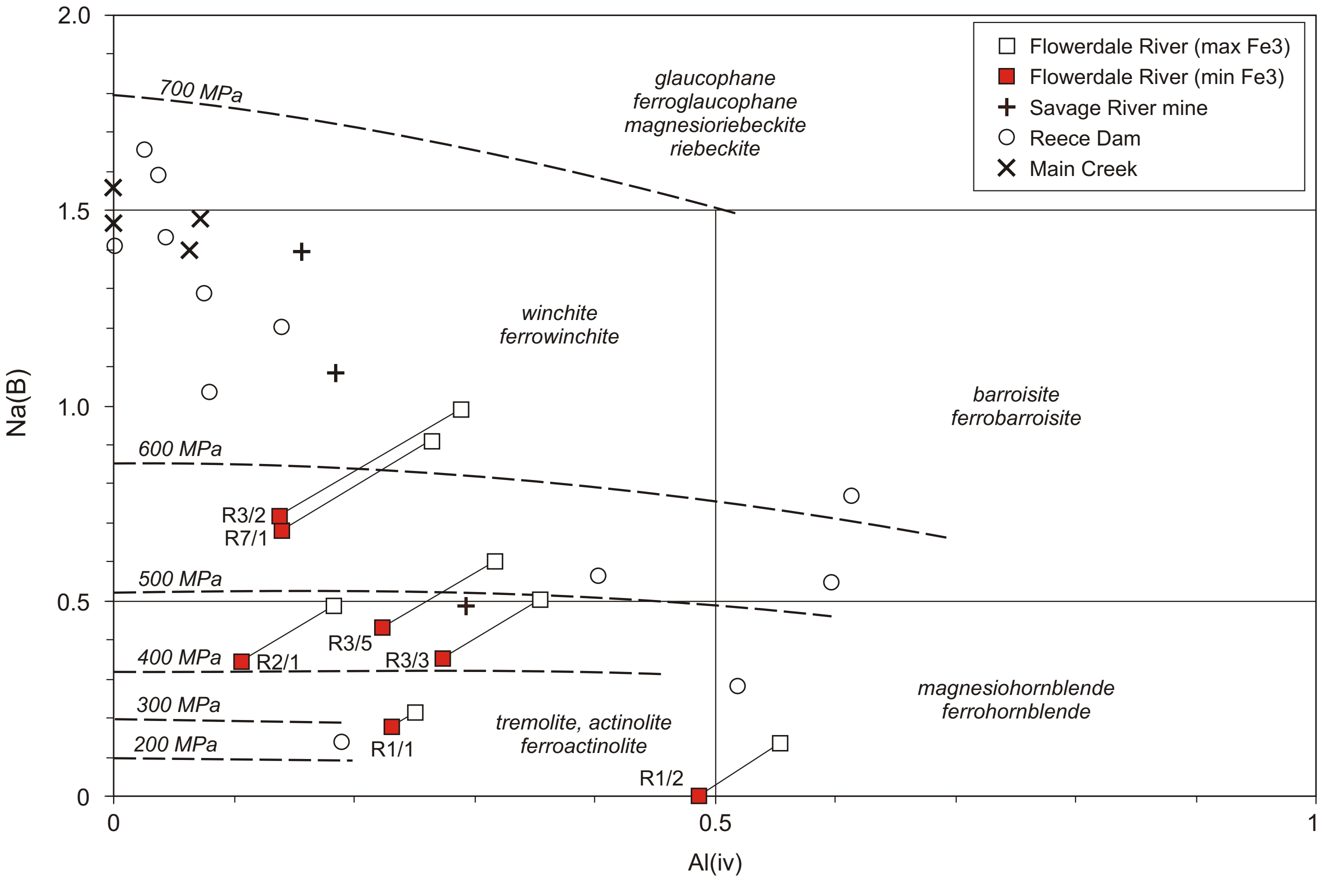

Figure 3

Amphibole compositions: plot of Na in B sites (Na_B) versus tetrahedrally co-ordinated Al in T sites (Al^{iv}). Tie-lines join minimum Fe^{III} and maximum Fe^{III} formulae for each analysis (Table 1) from Flowerdale River amphibolite (sample FR4). Data (average of minimum and maximum Fe^{III} formulae) from Reece Dam area, Main Creek and Savage River mine (Turner and Bottrill, 1993, 2001; Green and Spiller, 1977) also shown for comparison. Isobars refer to geobarometer of Brown (1977). Amphibole nomenclature is consistent with Leake et al. (1997).

X_{Fe} in chlorite, is more problematic as only a single chlorite grain was analysed and it is uncertain to what extent the prograde composition is preserved. The maximum Al_2O_3 in amphibole (3.84%, analysis R7/1; 3.73%, analysis R3/2) and observed X_{Fe} in chlorite (0.465, analysis R3/4, Table 3) imply a pressure of about 460 MPa (fig. 4). Again, this pressure estimate is lower than those obtained by Turner and Bottrill (1993, 2001) by this method from the Reece Dam and Main Creek assemblages (500–750 MPa), although it is comparable to that from Savage River mine, even though the chlorite is considerably more magnesian at that location.

At these pressures (c. 450–600 MPa) the absence of pumpellyite and the presence of quartz and chlorite suggest a minimum temperature of 360–370°C (Nitsch, 1971; Liou *et al.*, 1987). Lawsonite, a mineral often accompanying blue amphiboles in very low grade, relatively high pressure assemblages, is also absent in this rock (and apparently elsewhere in the Arthur Metamorphic Complex). This is probably because the geothermal gradient (P/T) was insufficiently high; the chemically similar mineral epidote forms instead. Some blueschist terrains, notably those of New Caledonia (e.g. Brothers, 1974; Black, 1977) and the Sambagawa Belt of Japan (e.g. Miyashiro and Seki, 1958) have been subdivided into a lower temperature lawsonite zone and a higher temperature epidote zone. Ernst (1972) noted that epidote-bearing terrains, like the Arthur Metamorphic Complex, are generally older (commonly Palaeozoic, rarely Proterozoic) than lawsonite-bearing terrains (commonly Mesozoic to Cainozoic).

Whole-rock chemistry

The Flowerdale River amphibolite was analysed by XRF for major and trace elements (sample FR4, Table 3) at Mineral Resources Tasmania laboratories using standard techniques. FeO was determined by titration with $KMnO_4$, and CO_2 was determined gravimetrically using an induction furnace.

Both the major and trace element chemistry of sample FR4 are broadly consistent with a tholeiitic basalt protolith. Relatively low MgO, Mg#, Ni and Cr also suggest that the sample was quite strongly fractionated.

Thirteen previously unpublished analyses of amphibolites from the Arthur Metamorphic Complex in the Arthur River–Lyons River area, 21 to 28 km southwest of the Flowerdale River locality, are also presented in Table 3 for comparison. Although the

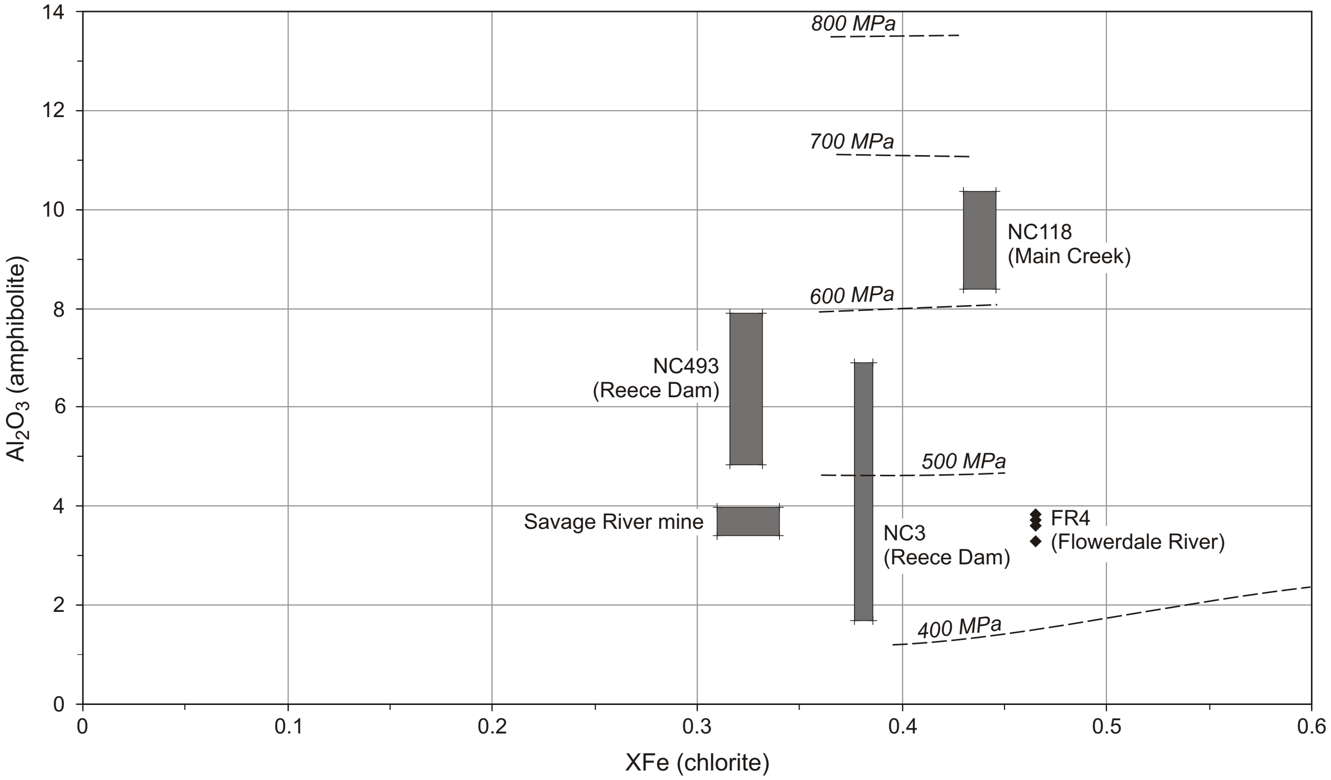

Figure 4

Plot of Al_2O_3 (wt%) of amphibole versus molar Fe/(Fe+Mg) in coexisting chlorite, for amphibolites from Flowerdale River (Tables 1, 2) and southern Arthur Metamorphic Complex (data from Turner and Bottrill, 1993, 2001). Isobars extracted from Maruyama et al. (1986).

petrology of these rocks will be discussed in greater detail elsewhere, they are also strongly fractionated tholeiites, broadly similar to sample FR4. Good mutual correlations (e.g. fig. 5*a*) between high field strength elements (e.g. P, Nb, Ti, Zr, Y and Ce), which are relatively immobile during metamorphism and alteration, suggest that the amphibolites can be considered as a single suite and original magmatic ratios are preserved. The variation within the suite is small and for the most part can be explained by variable amounts of crystal fractionation of the original basaltic protoliths. In particular, the high field strength elements, which behave incompatibly during crystal fractionation, correlate negatively with Mg# (e.g. fig. 5*b*), whilst Ni and Cr, which are strongly compatible in olivine and/or pyroxene during magmatic processes, correlate positively with Mg# (e.g. fig. 5*c*).

Slightly unusual features of sample FR4 are the relatively high K_2O (0.90%) and Rb (39 ppm) values, which are expressed mineralogically by the presence of biotite. By comparison the next highest K_2O value is 0.71% (with Rb 27 ppm) in sample KJ355 from the Lyons River. Although these are not high values for tholeiitic rocks, the remaining twelve amphibolites have ≤ 0.30% K_2O (with ≤ 17 ppm Rb) (fig. 5*d*). The more potassic nature of samples FR4 and KJ355 may be of primary magmatic origin, ultimately reflecting some variation in mantle sources. Two analyses of the mafic schist unit (Champion Schist) that encloses the amphibolites are also more potassic but this may reflect a subordinate detrital pelitic component.

Available analyses of amphibolites from the southern part of the Arthur Metamorphic Complex (including those assigned to the Nancy, Lucy and Bowry formations, within the Timbs Group) generally display the same characteristics of low Mg# and low K_2O (e.g. data of Wilson, 1991; Turner and Crawford, 1993; Turner and Bottrill, 1993).

Discussion and Conclusions

The Na content of relict blue amphibole (winchite) in the Flowerdale River amphibolite suggests that peak metamorphism occurred at a pressure of at least 560 MPa, implying a minimum depth of burial of perhaps 20 km (assuming a local mean crustal density of 2900 kg/m^3). This locality extends the known extent of high P/T metamorphism in the AMC from Reece Dam and Savage River mine, in the south, to almost the full exposed extent of the complex. However samples of amphibolite, collected by the author from the AMC in the Lyons River–Arthur River area, 21–28 km to the southwest, contain only green amphibole (probably actinolite) and may be more thoroughly retrogressed.

Throughout the Arthur Metamorphic Complex, amphibolite bodies are enclosed by a wider central zone of mainly mafic (chloritic) schist and phyllite, termed the Timbs Group in the south (Turner *et al.*, 1991) and tentatively termed the Champion Schist in the Arthur River–Lyons River area (unit Pac of

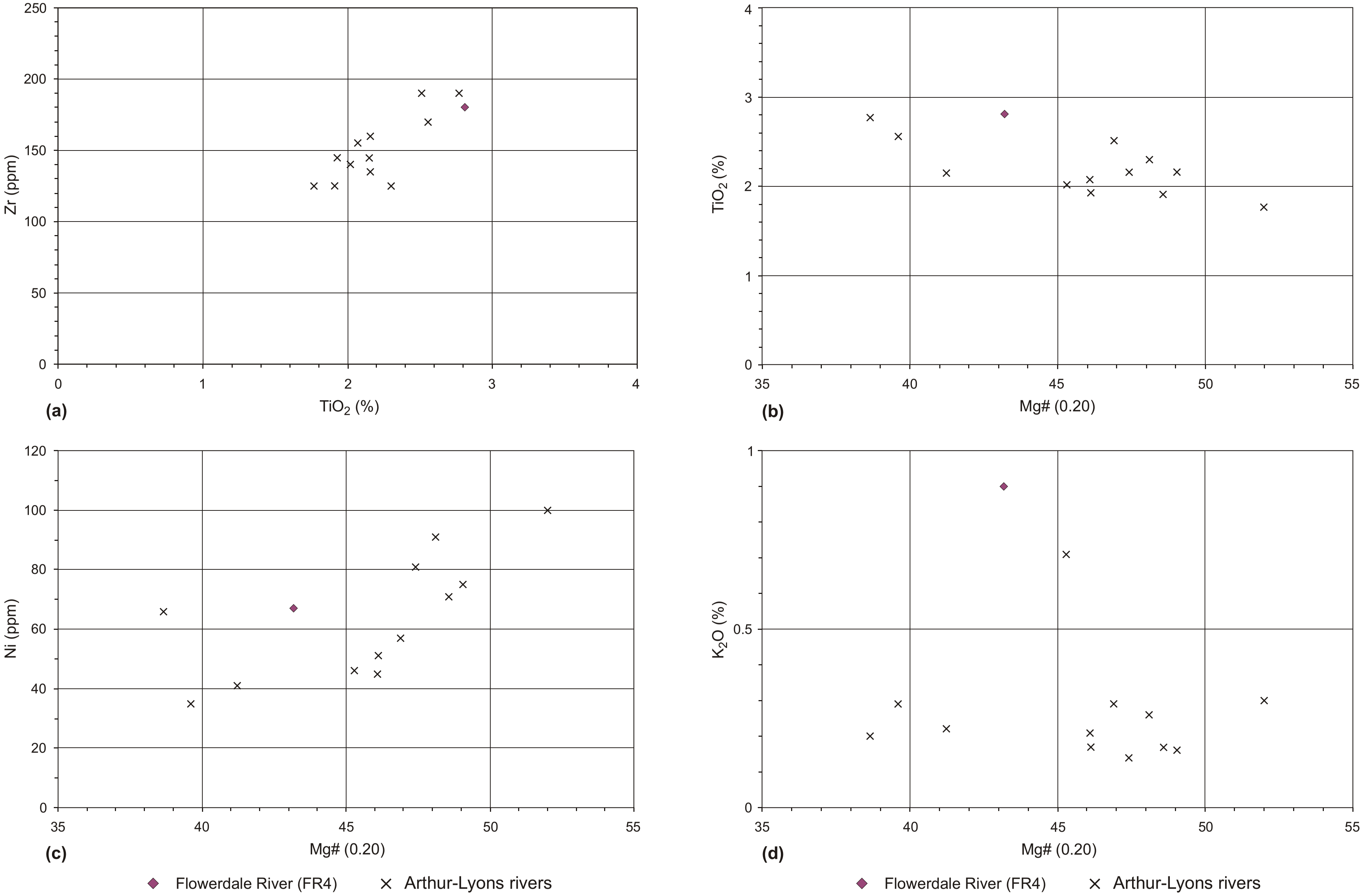

Figure 5

Whole-rock geochemical plots of amphibolites from the northern Arthur Metamorphic Complex (data from Table 3): (a) Zr against TiO_2*; (b)* TiO_2 *against Mg# ; (c) Ni against Mg#; (d)* K_2O *against Mg#.*

Everard *et al*., 1996). All known blue amphibole-bearing amphibolites in the south lie within the Bowry Formation, which is the distinctive, easternmost unit of the Timbs Group. Blue amphibole has not been reported from elsewhere in the Timbs Group, for example not from the Nancy and Lucy amphibolites near Corinna.

The age of the metamorphism in a Bowry Formation amphibolite has been determined at 494 ±10, 499 ±10 and 510 ±4 Ma (Middle–Late Cambrian) by K/Ar dating of hornblende (A. W. Webb in Turner, 1993), and may be applicable to the remainder of the AMC. The age and relationships of the protolith is controversial.

Several authors correlate the protolith of the Timbs Group with the less metamorphosed Ahrberg Group, immediately to its west, which unconformably overlies the Rocky Cape Group at Mt Donaldson. The Ahrberg Group is in turn correlated with the Togari Group near Smithton, which has a similar relationship to the Rocky Cape Group. The Togari Group is younger than 750 Ma, and its mafic volcanic component, the Kanunnah Subgroup, is probably c. 650–580 Ma (Calver, 1998).

The Bowry Formation, supposedly part of the Timbs Group, is intruded by minor bodies of granitoid, one of which has been dated by the SHRIMP U/Pb method on contained zircons at 777 ±7 Ma (Turner *et al*., 1998). This apparent contradiction has led Holm and Berry (2002) to suggest that the Bowry Formation is a separate older allochthonous unit, unrelated to the remainder of the Timbs Group (which they term the 'eastern Ahrberg Group').

It is clear that much further work, commencing with more detailed regional mapping, is required to elucidate the relationship of the 'Keith Metamorphics' in the Flowerdale River–Inglis River area to the rest of the Arthur Metamorphic Complex. The Flowerdale River amphibolite contains evidence for high pressure metamorphism in the form of blue amphibole, suggesting that it represents an extension of the Bowry Formation. However it lies toward the western side of the Champion Schist (fig. 1), whilst the Bowry Formation is the narrow easternmost unit of the Timbs Group, the probable southern equivalent of the Champion Schist. The amphibolites from the Arthur River–Lyons River appear to occur in the central to western part of the Champion Schist (fig. 1).

Turner and Bottrill (2001) suggested that the Bowry Formation represents a subducted ductile wedge of continental mafic rocks that was buried to about 20 km in a west-dipping subduction zone (at 514–510 Ma) and then rapidly 'extruded' back to the surface by east-directed thrusting, to be emplaced as subhorizontal nappes. It seems possible that the nappes were disrupted by subsequent south-directed and/or west-directed thrusting episodes (Holm and Berry, 2002), which also emplaced the western Tasmanian allochthonous mafic-ultramafic complexes (Berry and Crawford, 1988) prior to about 506 Ma, leaving them tectonically interleaved with the unrelated remainder of the Timbs Group. Alternatively, as neither the Flowerdale River amphibolite nor those in the Bowry Formation appear to be chemically very different from amphibolites elsewhere in the Timbs Group, the distinction may be purely one of metamorphic grade, and the conclusion of Holm and Berry (2002) may be incorrect. In that case either the correlation of the Timbs Group with the Ahrberg and Togari groups is also incorrect, or the 777 ±7 Ma granitoid age has been misinterpreted.

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[20 October 2002]

Table 1

Electron microprobe analyses, amphiboles, sample FR4, amphibolite, Flowerdale River

Analysis (%)	R1/1	R2/1	R3/2	R3/3	R3/5	R4/1A	R7/1
SiO_2	53.532	54.329	53.458	52.147	52.053	51.351	53.470
TiO_2	0.080	0.254	0.123	1.342	0.837	0.043	0.070
Al_2O_3	3.280	1.902	3.734	2.359	2.736	3.619	3.840
Cr_2O_3	0.002	0.096	0.037	0.058	0.042	0.002	0.160
FeO	16.155	14.642	19.592	18.021	19.123	17.166	19.220
MnO	0.493	0.651	0.727	0.579	0.650	0.539	0.450
NiO	0.055	0.066	0.014	0.034	0.002	0.031	nd
MgO	12.326	14.194	10.656	11.697	10.630	12.866	11.000
CaO	11.531	9.366	5.827	9.212	8.598	12.005	5.960
Na_2O	0.775	1.745	3.537	1.776	2.106	0.700	3.240
K_2O	0.091	0.094	0.106	0.101	0.115	0.142	0.100
F	0.004	nd	0.031	0.023	0.069	0.028	0.010
Cl	0.001	nd	0.015	0.017	0.019	0.004	0.010
Total	**98.323**	**97.337**	**97.858**	**97.368**	96.977	98.496	97.550

ions calculated on the basis of 22 oxygen, 2 (OH, F, Cl)

	method	min Fe3	max Fe3	min Fe3	max Fe3	min Fe3	max Fe3	min Fe3	max Fe3	min Fe3	max Fe3	min Fe3	max Fe3	min Fe3	max Fe3
	site	all Fe2	13eCNK	all Fe2	15eK	all Fe2	15eK	all Fe2	15eK	all Fe2	15eK	15eNK	13eCNK	all Fe2	15ek
Si	T	7.7683	7.7491	7.8932	7.8161	7.8622	7.7117	7.7262	7.6444	7.7757	7.6831	7.5127	7.4449	7.8598	7.7346
$Al^{(iv)}$	T	0.2317	0.2509	0.1068	0.1839	0.1378	0.2883	0.2738	0.3556	0.2243	0.3169	0.4873	0.5551	0.1402	0.2654
$Al^{(vi)}$	C	0.3293	0.3087	0.2188	0.1386	0.5094	0.3465	0.1382	0.0520	0.2574	0.1590	0.1366	0.0633	0.5251	0.3893
Ti	C	0.0087	0.0087	0.0277	0.0274	0.0136	0.0134	0.1495	0.1479	0.0940	0.0929	0.0047	0.0046	0.0077	0.0076
Cr	C	0.0002	0.0002	0.0110	0.0109	0.0043	0.0043	0.0068	0.0067	0.0049	0.0049	0.0002	0.0002	0.0186	0.0183
Fe3	C	0.0000	0.1137	0.0000	0.4489	0.0000	0.8807	0.0000	0.4870	0.0000	0.5481	0.1156	0.5297	0.0000	0.7328
Mg	C	2.6665	2.6599	3.0741	3.0441	2.3364	2.2917	2.5837	2.5563	2.3672	2.3390	2.8061	2.7808	2.4105	2.3721
Ni	C	0.0064	0.0064	0.0077	0.0076	0.0017	0.0016	0.0041	0.0040	0.0002	0.0002	0.0037	0.0036	0.0000	0.0000
Fe2	C	1.9606	1.8421	1.6607	1.3127	2.1345	1.4619	2.1177	1.7223	2.2762	1.8124	1.9332	1.5516	2.0380	1.4798
Fe2	B	0.0000	0.0000	0.1183	0.0000	0.2753	0.0211	0.1153	0.0000	0.1128	0.0000	0.0514	0.0000	0.3247	0.1125
Mn	C	0.0283	0.0604	0.0000	0.0096	0.0000	0.0000	0.0000	0.0236	0.0000	0.0435	0.0000	0.0662	0.0000	0.0000
Mn	B	0.0322	0.0000	0.0801	0.0697	0.0906	0.0889	0.0726	0.0483	0.0822	0.0377	0.0669	0.0000	0.0560	0.0551
Ca	B	1.7929	1.7884	1.4579	1.4436	0.9182	0.9007	1.4624	1.4469	1.3761	1.3597	1.8817	1.8648	0.9387	0.9237
Na	B	0.1749	0.2116	0.3437	0.4867	0.7159	0.9893	0.3497	0.5048	0.4289	0.6026	0.0000	0.1352	0.6806	0.9087
Na	A	0.0430	0.0058	0.1478	0.0000	0.2928	0.0000	0.1605	0.0000	0.1809	0.0000	0.1987	0.0617	0.2428	0.0000
K	A	0.0168	0.0167	0.0175	0.0173	0.0198	0.0195	0.0190	0.0188	0.0219	0.0216	0.0265	0.0263	0.0188	0.0185
F		0.0018	0.0018	nd	nd	0.0146	0.0143	0.0109	0.0108	0.0326	0.0322	0.0131	0.0130	0.0046	0.0046
Cl		0.0003	0.0003	nd	nd	0.0036	0.0035	0.0043	0.0043	0.0047	0.0047	0.0011	0.0011	0.0025	0.0025
sum to Mn		13.0322	13.0000	13.1985	13.0697	13.3659	13.1100	13.1879	13.0483	13.1950	13.0377	13.1184	13.0000	13.3807	13.1676
sum to Ca		14.8251	14.7884	14.6563	14.5133	14.2841	14.0107	14.6503	14.4952	14.5711	14.3974	15.0002	14.8648	14.3194	14.0913
sum to Na		15.0430	15.0058	15.1478	15.0000	15.2928	15.0000	15.1605	15.0000	15.1809	15.0000	15.1988	15.0616	15.2428	15.0000
sum to K		15.0598	15.0225	15.1653	15.0173	15.3126	15.0195	15.1795	15.0188	15.2028	15.0216	15.2254	15.0879	15.2616	15.0185
Mg/(Mg+Fe2)		0.5763	0.5908	0.6334	0.6987	0.4923	0.6071	0.5364	0.5975	0.4977	0.5634	0.5857	0.6419	0.5050	0.5984
Name		actinolite	actinolite	actinolite	actinolite	ferrowinchite	winchite	actinolite	winchite	ferroactinolite	winchite	actinolite	magnesio-hornblende	winchite	winchite

Table 2

Electron microprobe analyses, other minerals — Sample FR4, amphibolite, Flowerdale River

	plagioclase	plagioclase	biotite	biotite	biotite	chlorite	epidote	tourmaline	sphene	magnetite
Analysis	R3/1	R2/2	R1/3	R1/4	R1/5	R3/4	R2	R8/2	R2/3	R9/1
SiO_2	72.624	67.800	39.341	36.239	33.433	26.695	37.375	36.551	30.154	0.308
TiO_2	0.008	0.006	1.506	1.471	1.357	0.056	0.047	0.187	38.483	0.060
ZrO_2	na	na	na	na	na	na	na	na	na	0.038
Al_2O_3	21.461	20.245	14.938	15.193	14.698	19.054	22.877	29.332	1.191	0.038
Cr_2O_3	0.013	-	0.002	0.028	0.092	0.116	0.020	0.051	0.002	0.002
La_2O_3	na	na	na	na	na	na	na	0.032	na	na
Ce_2O_3	na	na	na	na	na	na	na	0.033	na	na
Y_2O_3	na	na	na	na	na	na	na	0.026	na	na
FeO	0.075	0.523	19.605	20.511	17.804	24.761	13.292	9.709	0.844	91.836
MnO	0.002	0.021	0.337	0.428	0.218	0.628	0.574	0.013	0.032	0.089
NiO	0.010	-	0.046	0.011	0.002	0.080	0.002	na	0.002	-
MgO	0.003	0.012	9.904	9.943	9.336	15.989	0.003	6.660	0.003	0.002
SrO	-	0.030	na	na	na	na	na	0.080	na	na
CaO	0.067	1.116	0.181	0.157	0.243	0.047	22.717	0.194	29.296	-
Na_2O	11.684	10.888	0.065	0.075	0.056	0.012	0.016	2.741	0.003	na
K_2O	0.036	0.046	7.939	8.749	4.996	0.022	0.026	0.024	0.001	na
F	0.035	na	na	na	na	0.020	na	0.054	na	na
Cl	0.003	na	na	na	na	0.010	na	0.004	na	na
(O)=F, Cl	-	na	na	na	na	-0.002	na	-0.024	na	na
Total	**106.021**	**100.687**	**93.863**	**92.804**	**82.234**	**87.488**	**96.948**	**85.666**	**100.010**	**92.065**
Ions calculated on basis of oxygens =										
	8	8	11	11	11	14	12.5	24.5	5	4
Si	2.9838	2.9531	3.0019	2.8524	2.8846	2.8204	2.9790	6.1193	0.9891	excl
Al (iv)	1.0392	1.0393	0.9981	1.1476	1.1154	1.1796	0.0210	-	-	0.0017
Al (vi)	-	-	0.3453	0.2618	0.3792	1.1930	2.1281	5.7877	0.0461	-
Ti	0.0003	0.0002	0.0864	0.0871	0.0880	0.0044	0.0028	0.0235	0.9493	0.0018
Zr	na	na	na	na	na	na	na	na	na	0.0007
Cr	0.0004	-	0.0001	0.0017	0.0063	0.0097	0.0013	0.0067	0.0000	0.0001
La	na	na	na	na	na	na	na	0.0020	na	na
Ce	na	na	na	na	na	na	na	0.0020	na	na
Y	na	na	na	na	na	na	na	0.0023	na	na
Fe^{III}	-	-	-	-	-	-	0.8860	-	-	1.9932
Fe^{II}	0.0026	0.0190	1.2510	1.3501	1.2846	2.1878	-	1.3594	0.0231	0.9995
Mn	0.0001	0.0008	0.0218	0.0285	0.0160	0.0562	0.0388	0.0019	0.0009	0.0029
Ni	0.0003		0.0028	0.0007	0.0001	0.0068	0.0001	na	0.0000	-
Mg	0.0002	0.0008	1.1266	1.1667	1.2008	2.5182	0.0003	1.6621	0.0001	0.0001
Sr	na	0.0008	na	na	na	na	na	0.0077	na	na
Ca	0.0030	0.0521	0.0148	0.0132	0.0225	0.0053	1.9400	0.0348	1.0296	-
Na	0.9308	0.9195	0.0097	0.0115	0.0093	0.0024	0.0025	0.8897	0.0002	na
K	0.0019	0.0026	0.7728	0.8785	0.5499	0.0030	0.0026	0.0051	0.0001	na
cations	4.9624	4.9881	7.6312	7.7999	7.5566	9.9868	8.0025	15.9043	3.0386	3.0000
F	0.0045	na	na	na	na	0.0066	na	0.0286	na	na
Cl	0.0002	na	na	na	na	0.0018	na	0.0012	na	na
(OH)	-	-	-	-	-	-	-	3.9702	-	-
Mg#	-	-	47.4	46.4	48.3	53.5	-	55.0	-	-

Table 3

Chemical analyses of amphibolites and associated rocks from the northern part of the Arthur Metamorphic Complex (Burnie and Trowutta quadrangles)

Field No.	FR4	AR460	AR472	AR477	AR480	AR483	KJ120	KJ120A
Reg. No.	R005492	R004991	R004993	R004995	R004996	R004997	R005413	R005414
Anal. No.	961108	930548	930549	930550	930551	930552	930648	930649
AMG (mE)	382320	368070	368450	368020	367960	367820	365850	365850
AMG (mN)	5458220	5440270	5441450	5441610	5441920	5441720	5437570	5437570
Locality	Flowerdale R	Arthur R Tiger Bend	Arthur R	Arthur R	Arthur R	Arthur R	Lyons R bridge	Lyons R bridge
Rock type	amphibolite	amphibolite	amphibolite	amphibolite	amphibolite	amphibolite	amphibolite	amphibolite*
SiO_2 (wt %)	48.23	48.97	46.06	46.88	48.64	45.72	49.30	41.37
TiO_2	2.81	2.77	2.30	2.16	1.91	2.16	1.93	1.42
Al_2O_3	12.26	12.92	12.73	13.51	13.13	13.44	12.34	13.18
Fe_2O_3	7.13	7.68	4.61	5.98	4.15	4.87	4.91	14.21
FeO	8.41	9.71	10.17	9.71	9.18	9.38	9.58	8.52
MnO	0.28	0.18	0.22	0.22	0.21	0.23	0.26	0.28
MgO	5.36	4.98	6.31	6.47	5.80	6.30	5.70	3.84
CaO	8.18	2.52	10.32	5.78	10.45	11.85	9.87	10.57
Na_2O	3.30	3.87	3.22	4.96	3.96	3.29	2.08	3.21
K_2O	0.90	0.20	0.26	0.14	0.17	0.16	0.17	0.18
P_2O_5	0.31	0.27	0.38	0.25	0.26	0.27	0.24	0.24
SO_3	0.08	0.01	0.04	0.00	0.00	0.03	0.14	0.15
CO_2	0.07	1.07	0.04	0.00	0.01	0.00	0.13	0.22
$H2O^+$	2.27	5.19	3.37	3.18	2.41	2.95	2.84	2.27
Total	**99.54**	**100.34**	**100.03**	**99.24**	**100.28**	**100.65**	**99.49**	**99.66**
Sc (ppm)	39	53	38	44	38	43	43	38
V	470	480	440	450	400	400	419	357
Cr	53	115	88	120	110	115	48	58
Co	41	45	52	46	37	41	54	39
Ni	67	66	91	81	71	75	51	44
Cu	140	220	260	190	115	330	187	6525
Zn	185	340	175	150	115	135	219	265
Ga	25	26	22	22	21	22	19	16
As	<20	<20	<20	<20	<20	<20	<20	<20
Rb	39	17	17	11	10	14	<10	<10
Sr	160	185	200	155	96	185	140	410
Y	41	47	29	41	33	34	38	30
Zr	180	190	125	160	125	135	145	105
Nb	14	18	14	13	10	10	12	7
Mo	<5	<5	<5	<5	<5	<5	<5	<5
Sn	<9	<9	<9	<9	<9	<9	<9	<9
Ba	240	135	68	27	23	38	9	53
La	<20	<20	<20	<20	<20	<20	<20	<20
Ce	40	48	<28	38	<28	<28	28	37
Nd	20	27	<20	<20	<20	21	26	<20
W	<10	<10	<10	<10	<10	<10	<10	<10
Pb	22	91	22	21	21	24	28	89
Bi	7	7	<5	6	<5	7	<5	<5
Th	17	20	19	17	18	22	<10	<10
U	<10	<10	<10	<10	<10	<10	<10	<10
FeOt	14.83	16.62	14.32	15.09	12.91	13.76	14.00	21.31
Mg#(0.20)	43.20	38.66	48.10	47.42	48.58	49.05	46.13	27.49

* mineralised sample
FeOt is total iron expressed as FeO
Mg# (0.20) is molar 100*Mg/(Mg+FeII) calculated at Fe_2O_3/FeO (wt%) = 0.20
All analyses at MRT laboratories, Hobart. Analysts L. M. Hay, J. Taheri, W. Leong

Table 3 *(continued)*

Field No.	KJ355	KJ658	KJ668	KJ753	KJ802	KJ886	AR471	KJ674
Reg. No.	R005415	R005416	R005417	R005418	R005498	R005420	R004992	R005460
Anal. No.	930654	930660	930661	930663	930664	930668	941160	930662
AMG (mE)	365640	365950	366370	364640	368620	365260	368320	366170
AMG (mN)	5437560	5439180	5439620	5436860	5442130	5437400	5441110	5439840
Locality	Lyons R	Lyons R	Lyons R	Pinner Creek north branch	Relapse Creek bridge	Pinner Creek north branch	Arthur R	Lyons R
Rock type	amphibolite	amphibolite	amphibolite	amphibolite	amphibolite	amphibolite	mafic schist	mafic schist
SiO_2 (wt%)	50.51	48.44	48.18	47.00	49.58	48.50	51.44	45.64
TiO_2	2.02	2.56	2.51	1.77	2.15	2.07	1.28	2.14
Al_2O_3	12.74	12.33	13.27	12.52	12.94	13.46	14.32	11.28
Fe_2O_3	4.59	5.01	4.22	5.03	4.12	4.04	3.22	2.80
FeO	10.17	11.56	10.44	10.70	10.83	10.31	7.47	9.18
MnO	0.23	0.26	0.23	0.26	0.24	0.24	0.18	0.18
MgO	5.63	5.01	5.98	7.84	4.85	5.67	7.04	11.75
CaO	7.68	8.19	7.34	7.55	9.08	8.42	9.04	8.42
Na_2O	2.74	4.19	4.30	3.42	3.19	3.43	2.19	3.29
K_2O	0.71	0.29	0.29	0.30	0.22	0.21	1.68	1.51
P_2O_5	0.22	0.26	0.30	0.20	0.27	0.24	0.15	1.10
SO_3	0.07	0.06	0.08	0.07	0.13	0.11	0.07	0.08
CO_2	0.10	0.07	0.05	0.09	0.04	0.05	0.08	0.63
H_2O^+	3.11	2.32	2.84	3.39	2.52	3.22	2.79	1.59
Total	100.52	100.55	100.03	100.14	100.15	99.97	100.95	99.59
Sc (ppm)	44	52	47	46	49	50	37	15
V	445	482	415	379	434	439	270	117
Cr	60	18	81	70	29	37	240	504
Co	43	44	37	48	45	41	40	50
Ni	46	35	57	100	41	45	115	409
Cu	266	108	163	106	196	128	92	34
Zn	168	133	120	168	71	136	85	132
Ga	16	20	20	17	19	20	16	20
As	<20	<20	<20	<20	<20	<20	<20	<20
Rb	27	<10	<10	13	<10	<10	61	39
Sr	170	140	140	120	275	145	130	1050
Y	36	43	41	36	39	39	26	37
Zr	140	170	190	125	145	155	120	415
Nb	10	15	16	11	11	11	9	89
Mo	<5	<5	<5	<5	<5	<5	<5	7
Sn	<9	<9	<9	<9	<9	<9	<9	<9
Ba	221	51	28	58	14	28	230	494
La	<20	<20	<20	<20	<20	<20	<20	67
Ce	27	58	54	28	36	37	<28	158
Nd	21	26	25	30	<20	30	<20	80
W	<10	<10	<10	<10	<10	<10	<10	<10
Pb	14	<10	<10	<10	<10	10	12	<10
Bi	<5	<5	<5	<5	<5	<5	<5	<5
Th	12	14	10	<10	<10	11	<10	10
U	<10	<10	<10	<10	<10	<10	<10	<10
FeOt	14.30	16.07	14.24	15.23	14.54	13.95	10.37	11.70
Mg#(0.20)	45.30	39.61	46.91	51.99	41.24	46.10	58.82	67.87