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Garnet-bearing and other spotted porphyroblastic metasedimentary rocks from the Balfour area

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Abstract

Spotted rocks occurring around Balfour, in northwest Tasmania, have been considered in the past to contain cordierite and/or andalusite, indicating thermal metamorphism by postulated underlying granite. The spots are commonly totally altered to muscovite and quartz, but most are euhedral pseudomorphs which contain remnants of spessartine-grossular garnet. There are also prismatic/rhombic pseudomorphs containing muscovite and chlorite which morphologically resemble an altered chloritoid group mineral (e.g. ottrelite, a manganese silicate), and both this mineral and the garnet overprint minor metasomatic tourmaline, suggesting a syn-Devonian or post-Devonian granite age. Other rocks contain pseudomorphs after other minerals, possibly andalusite or staurolite, or possibly anhydrite or other evaporite mineral. Some rutile-rich clots represent altered ilmenite or sphene porphyroblasts. The garnet and associated minerals provide some constraints on the metamorphic history of the rocks, which probably formed at about 320–360°C and about 4.9–6.9 kbar, with no definite link to granites or other intrusive rocks. The Ca-Mn garnet, forming in the Balfour copper belt, may also indicate a tentative link to Mn-Ca rich mineralisation in the Temma district, and suggests potential for Broken Hill-style mineralisation.

Introduction

Spotted rocks occur in a few parts of the low-grade metamorphic Precambrian sequences around Balfour, in northwestern Tasmania, and have been considered to represent cordierite (Everard *et al*., 2001). This study shows that several different minerals are or were present, at least one representing an unusual, altered Mn-Ca rich garnet. The metamorphic grade of these rocks was poorly understood, but is interpreted from the present mineral assemblage.

Sample locations, descriptions

Samples with spotting studied include:

Sample No.	*Location*	*Rock type*
C108429	Sumac Road	Shale/siltstone
C108431	Temma Road	Shale/siltstone
C108437	The Clump	Shale/siltstone
C108440	North of The Clump	Shale/siltstone
C108444	Temma Road	Shale/siltstone
C108445	Temma Road	Shale/siltstone
C108455	North Mt Balfour	Shale/siltstone

The main site examined, and the only confirmed site for garnet in the area, is near the Heemskirk Road/Temma Road junction (at 320 760 mE; 5 437 640 mN).

Petrography

C108429

This is a siliceous siltstone with small equant spots (<~1%, <0.2 mm) of fine-grained quartz and mica, possibly representing altered garnet or an evaporite mineral? There is no obvious foliation. There are also relatively large porphyroblasts of leucoxene (~1%, <0.5 mm) as prisms or rhombs (pseudomorphing ilmenite or sphene?).

C108431, C108445 and C108444

The rocks in hand specimen are black shale or siltstone with fine white spots (<3 mm). There is some local minor quartz and clay (after carbonate?) veining.

Microscopic examination indicates that the rocks consists mostly of silt-sized quartz and sericite with minor chlorite, trace tourmaline and leucoxene, with up to 10% of spotting in parts. There is only a very weak foliation. Dark patches appear to represent irregular carbonaceous clots and shale clasts (<3 mm across). Tourmaline inclusions occur in the porphyroblasts and these commonly exhibit a blue detrital core with brown overgrowths, suggesting growth by boron redistribution during late-stage metamorphism or weak boron metasomatism (this can

happen independent of granitic influence, due to remobilisation of boron in micas and other minerals). There is no definitive evidence for any granitic influence in these rocks.

There are two distinct types of spots:

- abundant rhombic blades(?), mostly in aggregates of several individuals, possibly twinned (~5%, <2.5 mm long) (fig. 1). Some have an irregular to rounded or rhombic core of chlorite. Excepting the cores, these are totally altered to quartz and sericite, and probably pseudomorph a metamorphic mineral, possibly chloritoid or ottrelite (a manganese silicate of the chloritoid group). Some porphyroblasts overprint shale clasts and intersect garnet (although relationships are unclear). Alternatively they may have been an evaporite mineral like ikaite, anhydrite or gypsum, but the zoning and relationships with garnet, tourmaline and clasts make this doubtful.
- some equant (probably modified cubes, dodecahedral and trapezohedral?) pseudomorphs, commonly with a strong radial structure (fig. 2, 3). The equant mineral is largely altered to quartz and sericite, but some pseudomorphs contain remnant colourless garnet. This was analysed by electron microprobe in several grains and the results (Table 1) indicate mostly a calcian spessartine, grading into a manganoan grossular garnet.

Some microprobe analyses of coexisting chlorite and muscovite were also conducted in an attempt to constrain the metamorphic grade (discussed below).

C108437

The rock in hand specimen is a black shale or siltstone with fine white spots (<3 mm). Some quartz veining and limonitic weathering are present.

Microscopic examination indicates that the rock consists mostly of silt-sized quartz and sericite with minor chlorite and up to 10% of spotting in parts. There is no foliation. There is abundant limonite in parts, especially in quartz veins; this appears to replace both pyrite and carbonates (relics of both are present; <2 mm). There are also poikiloblastic, lozenge-shaped limonitic patches in siltstone suggesting oxidised ferroan carbonate porphyroblasts. Dark patches appear to represent irregular carbonaceous clots and shale clasts (<3 mm).

There are two distinct types of spots:

- abundant rectangular or flattened hexagonal prisms(?), some possibly with pyramidal(?) terminations (~5%, <0.2 mm long) (fig. 4). These are totally altered to quartz and sericite, but may have been an evaporite mineral like anhydrite (probably not gypsum as no twinning is evident), or a metamorphic mineral like staurolite or andalusite. By analogy with the above samples, a metamorphic origin is preferred; the morphology suggests ottrelite or chloritoid.
- some rarer equant (dodecahedral or trapezohedral?) shapes (trace, <2 mm long), largely altered to fine quartz and sericite (similar to that in C108431). This was probably originally a garnet, as in the above samples, but no relict material was observed.

C108440

The rock in hand specimen is a black shale or siltstone with fine white spots (<2 mm).

Microscopic examination indicates that the rock consists mostly of silt to clay-sized quartz and sericite with much fine carbonaceous material and up to 5% of spotting in parts. There is no distinct foliation.

There are two distinct types of spots:

- irregular aggregates of quartz and leucoxene (rutile?; ~2%, <0.5 mm) possibly representing altered ilmenite or sphene porphyroblasts?
- equant (dodecahedral or trapezohedral?) shapes (~2%, <1.5 mm long), largely altered to fine quartz and sericite (similar to that in C108431). This was probably originally a garnet, as above.

C108455

This is a siliceous siltstone with rhombohedral cavities, resembling those left by the dissolution of carbonate minerals. There is no foliation. No section was cut.

X-Ray diffraction

XRD of C108440 indicated the presence of quartz, gibbsite, chlorite, mica and rutile with a garnet (cell dimension a_o = 11.70 ± 0.02, indicating an unusual composition midway between the pyralspite and grandite garnets, closest to calcic spessartine).

Mineral compositions

Analytical procedures and formulae calculation

The minerals were analysed (Tables 1–3) with a Cameca SX-50 electron microprobe, using WDS spectrometers at 15 kV, at the University of Tasmania.

The garnet formulae and calculated Fe^{3+} were determined from the analysed weight percent oxides using the method of Schumacher (1997).

Results and interpretation

Chlorites

Chlorite compositions, especially Al contents, are known to be largely temperature dependant in metamorphic rocks (Laird, 1988). A chlorite geothermometer has been devised empirically from low pressure hydrothermal systems on this basis (Cathelineau and Nieva, 1985; Cathelineau, 1988). Despite being based on shallow hydrothermal systems, this gives sensible results where tested in both pelites and hydrothermal veins formed in regionally metamorphosed rocks (Cathelineau, 1988;

Table 1

Microprobe analyses and structural formulae of micas associated with garnet, C108431b.

Phase	108431b-alt1 (wt. %)	108431-mica1 (wt. %)	108431b-mica2 (wt. %)	108431b-mica3 (wt. %)
SiO_2	47.49	50.25	49.42	49.92
TiO_2	0.35	0.33	0.42	0.38
Al_2O_3	29.13	29.54	30.36	31.22
Cr_2O_3	0.05	0.00	0.04	0.01
V_2O_3	0.00	0.04	0.00	0.03
FeO(t)	3.98	1.96	1.99	1.70
ZnO	0.05	0.00	0.00	0.10
NiO	<0.01	0.05	0.00	0.05
MnO	0.02	0.07	0.06	0.01
MgO	2.32	2.64	2.44	2.31
CaO	0.04	0.02	0.00	0.02
Na_2O	0.22	0.09	0.14	0.11
K_2O	9.77	10.25	10.80	10.21
BaO	0.01	0.11	0.00	0.08
F	0.38	0.34	0.34	0.31
Cl	0.03	0.00	0.00	0.01
H_2O(c)	4.19	4.35	4.35	4.41
O = F	0.16	0.14	0.14	0.13
O = Cl	0.01	0.00	0.00	0.00
Structural formulae, for 11 oxygens				
Si	3.258	3.338	3.284	3.282
$Al^{(iv)}$	0.742	0.663	0.717	0.719
sum T	*4.000*	*4.000*	*4.000*	*4.000*
$Al^{(vi)}$	1.613	1.650	1.661	1.701
Ti	0.018	0.017	0.021	0.019
Cr	0.003	0.000	0.003	0.001
V	<0.01	0.003	0.000	0.002
Fe	0.228	0.109	0.111	0.094
Zn	0.005	0.000	0.000	0.005
Mg	0.237	0.262	0.242	0.227
Ni	<0.01	0.003	0.000	0.003
Mn	0.001	0.004	0.004	0.001
sum b	*2.100*	*2.045*	*2.040*	*2.050*
Ca	0.003	0.001	0.000	0.002
Na	0.029	0.012	0.018	0.015
K	0.855	0.868	0.915	0.857
Ba	<0.01	0.003	0.000	0.002
sum a	*0.887*	*0.884*	*0.933*	*0.875*
Total	6.987	6.929	6.973	6.925
F	0.164	0.071	0.071	0.065
Cl	0.007	0.000	0.000	0.001
Est. P (MPa)*	486	695	553	548

* Massone and Schreyer method, 1987.

Table 2

Microprobe analyses (wt. %) and structural formulae of the garnet, C108431b.

Point	#15	#16	#17	#18	#21	#22	#23	#24	#25	#26	#27	#28	ave
SiO_2	37.92	37.51	37.40	34.53	37.77	37.23	37.61	37.44	37.34	37.40	37.49	37.94	37.30
TiO_2	0.26	0.25	0.21	0.29	0.26	0.25	0.34	0.31	0.34	0.21	0.26	0.21	0.27
Al_2O_3	21.68	21.60	21.56	20.17	21.52	21.61	21.32	21.15	21.36	21.42	21.33	21.81	21.38
Cr_2O_3	0.00	0.00	0.04	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.00	0.00	0.01
Fe_2O_3(c)	0.00	0.91	0.76	1.40	0.21	1.60	0.52	1.54	1.26	1.29	0.69	0.11	0.86
FeO	9.40	8.28	8.80	6.71	8.15	7.87	7.76	8.24	7.36	7.92	8.31	9.13	8.16
MnO	17.67	18.71	18.81	17.20	19.00	17.25	20.06	17.54	20.14	17.73	17.67	17.03	18.23
MgO	0.22	0.23	0.23	0.22	0.18	0.25	0.12	0.16	0.13	0.24	0.22	0.22	0.20
CaO	13.89	13.61	13.02	13.31	13.81	14.81	13.27	14.67	13.25	14.53	14.41	14.66	13.94
ZrO_2	0.10	0.02	0.05	0.06	0.04	0.04	0.02	0.06	0.02	0.01	0.02	0.00	0.04
V_2O_3	0.00	0.03	0.00	0.00	0.03	0.03	0.00	0.02	0.00	0.01	0.00	0.00	0.01
Sum Ox%	**101.14**	**101.16**	**100.88**	**93.90**	**100.96**	**100.94**	**101.04**	**101.16**	**101.24**	**100.80**	**100.41**	**101.12**	**100.40**
Formulae, for 12 oxygens													
Si	2.980	2.954	2.957	2.927	2.977	2.932	2.971	2.950	2.947	2.951	2.968	2.976	2.958
Al/Al^{IV}	0.020	0.046	0.043	0.073	0.023	0.068	0.029	0.050	0.053	0.049	0.032	0.024	0.043
Sum T	**3.000**	**3.000**	**3.000**	**3.000**	**3.000**	**3.000**	**3.000**	**3.000**	**3.000**	**3.000**			**3.000**
Ti	0.016	0.015	0.012	0.019	0.015	0.015	0.020	0.019	0.020	0.013	0.016	0.012	0.016
Al^{VI}	1.988	1.959	1.967	1.942	1.976	1.938	1.955	1.914	1.934	1.943	1.958	1.993	1.956
Cr	0.000	0.000	0.002	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.000	0.000	0.001
Fe^{3+}	0.000	0.054	0.045	0.089	0.012	0.095	0.031	0.091	0.075	0.077	0.041	0.006	0.051
Sum B	**2.004**	**2.028**	**2.026**	**2.050**	**2.003**	**2.048**	**2.007**	**2.025**	**2.031**	**2.035**			**2.026**
Fe^{2+}	0.618	0.546	0.582	0.476	0.537	0.518	0.513	0.543	0.486	0.523	0.551	0.599	0.541
Mn^{2+}	1.176	1.248	1.260	1.235	1.268	1.151	1.342	1.171	1.346	1.185	1.185	1.132	1.225
Mg	0.026	0.027	0.027	0.028	0.021	0.030	0.014	0.019	0.016	0.028	0.026	0.026	0.024
Ca	1.169	1.149	1.103	1.209	1.167	1.250	1.123	1.238	1.121	1.228	1.223	1.232	1.184
Zr	0.004	0.001	0.002	0.002	0.002	0.002	0.001	0.002	0.001	0.001	0.001	0.000	0.002
V	0.000	0.002	0.000	0.000	0.002	0.002	0.000	0.001	0.000	0.001	0.000	0.000	0.001
Sum A	**2.993**	**2.973**	**2.974**	**2.950**	**2.997**	**2.953**	**2.993**	**2.974**	**2.970**	**2.966**			**2.974**
Sum Cations	**7.996**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**
Pyrope	0.9	0.9	0.9	1.0	0.7	1.0	0.5	0.6	0.5	1.0	0.9	0.9	0.8
Almandine	20.7	18.4	19.6	16.1	18.0	17.6	17.1	18.3	16.4	17.6	18.4	20.0	18.2
Spessartine	39.3	42.0	42.4	41.9	42.4	39.0	44.9	39.4	45.3	40.0	39.7	37.9	41.2
Andradite	0.0	2.7	2.2	4.4	0.6	4.6	1.5	4.5	3.7	3.8	2.1	0.3	2.5
Uvarovite	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0
Grossular	39.1	36.0	34.8	36.7	38.4	37.8	36.0	37.1	34.0	37.6	38.9	40.9	37.3

Table 3

Microprobe analyses and structural formulae of the chlorites.

Point	*108431b-alt2*
Label	*wt.%*
SiO_2	26.42
TiO_2	0.03
Al_2O_3	22.66
Cr_2O_3	0.02
FeO	23
MnO	1.21
MgO	11.7
CaO	0.07
Na_2O	0.05
K_2O	0.17
ZnO	0.08
NiO	0.01
H_2O(c)	11.22
Sum Ox%	**96.62**
Structural formulae, for 12 oxygens	
Si	5.649
Ti	0.005
Al/Al^{IV}	2.351
Sum tetrahedral	**8.005**
Al^{VI}	3.359
Cr	0.003
Fe^{2+}	4.113
Mn^{2+}	0.218
Mg	3.728
Ca	0.016
Na	0.021
K	0.045
Zn	0.013
Ni	0.001
Sum octahedral	**11.517**
Sum cations	35.523
XMg	0.475

Bevins *et al*., 1991; Taheri and Bottrill, 1994). It does, however, assume an open chemical system (Cathelineau, 1988).

Applying the chlorite geothermometer to the metasedimentary rocks in this study gives a temperature of about 320°C for chlorite in association with the garnet, although this may be a somewhat retrograde temperature. Analyses of other chlorites associated with the Balfour copper deposits indicate a range of temperatures from about 180 to 400°C (probably representing temperatures of hydrothermal alteration more than metamorphic grade).

Muscovite

The relationship between T (°C), P (MPa) and phengite composition (Si: number of Si per 4 tetrahedral sites), using the empirical data of Massone and Schreyer (1987), can be simplified to a formula:

$$P = 2682.Si + 1.2\ T - 8630.$$

Assuming T ~ 320°C from the chlorite geothermometer and Si = 3.25 in the phengite, P can be estimated at about 490–690 MPa (4.7 kbar). This is tentative, based on very limited analytical data and a non-equilibrium assemblage (lacking K-feldspar and chlorite), but it can still be taken as a minimum pressure for mica formation (Massone and Schreyer, 1987).

Garnet

The garnet is of a rather unusual composition, approximately midway between spessartine and grossular. This fits well with the X-ray pattern (calculated a_0 11.72 Å; measured 11.70 ± 0.02 Å).

Grossular (and most other Ca silicates) in metasedimentary rocks are usually considered to form largely by the metamorphism of clays with Ca carbonate minerals (calcite and dolomite; Winkler, 1976). Similarly, spessartine (and most Mn silicates) in metasedimentary rocks are usually considered to form largely by the metamorphism of aluminous clays mixed with Mn carbonate minerals (Peters *et al*., 1980; Bennett, 1989; Schreyer *et al*., 1992; Nyame, 2001) especially if Mn-oxides are absent. The precursor to this garnet may thus be a 1:1 mixture of calcite and rhodochrosite, or more likely kutnohorite ($CaMn(CO_3)_2$), recorded in metasedimentary rocks by Nyame (2001). No other Ca or Mn minerals were identified in the rocks, suggesting no other carbonates were present.

The low temperature stability limit of such garnets at low pressure is poorly known; Hsu (1980) considered the Ca-Mn intermediate to form below 420°C at 2 kbar, but this was poorly constrained. The low-T limit for pure spessartine is considered to be about 300°C (Theye *et al*., 1996; Nyame, 2001), for grossular about 375°C (Winkler, 1976) and for grossular-andradite intermediates ~300–400°C (Coombs *et al*., 1977). A temperature of about 320–360°C is thus estimated for the Ca-Mn intermediate garnet, in good agreement with the chlorite thermometer.

The garnet-chlorite thermometer of Grambling (1990) [T(°K) = (0.05.P + 4607.lnKd + 24156)/19.02, where Kd = (Mg/Fe)grt/(Mg/Fe)chl] gives a T of 266°C for 4.9–6.9 kbar, in poor agreement with the above figures. This thermometer is probably unreliable in these rocks because of the high Ca and Mn contents of the garnet. The high P/T gradient of the reaction makes it unsuitable for measuring the pressure from the temperature.

The unusual form of alteration may reflect the composition, with leaching of Ca and Mn from the system by fluids related to the quartz veining, accompanying quartz-sericite alteration and mineralisation.

The unusual composition of this garnet is typical of that in alteration zones about Broken Hill–style deposits (Walters, 2004).

Conclusions

The spots in this rock represented various minerals, now mostly entirely altered, including a garnet and

several unidentified minerals (possibly including anhydrite or another evaporite, or a metamorphic mineral like chloritoid or ottrelite). The textural relationships and association with garnet suggests the latter. The precursor to the garnet (and possibly some of the other porphyroblasts) probably included a Ca-Mn carbonate (kutnohorite) and aluminous clays. The silicification and sericitisation of the spots, and association with minor quartz veining, suggests the spotting pre-dates the mineralisation and associated alteration. Slight wrapping of foliation in micas about garnet indicates that garnet also formed pre-main deformation.

The garnet, and associated chlorite and muscovite can be interpreted to give a temperature of 320–360°C and a pressure of about 4.9–6.9 kbar. Turner (1994) took the presence of these spotted rocks to indicate local thermal metamorphism, but the relatively low temperature and scarcity of tourmaline and other metasomatic, granite-related minerals suggests no relation with granites or other intrusive rocks.

The Ca-Mn composition of the garnet is unusual but typical of that in alteration zones about Broken Hill–style stratabound Pb-Zn deposits (Walters, 2004). This may give an indication of the potential for such mineralisation in the area. This style of mineralisation is characterised by alteration haloes including tourmaline-rich rocks, quartz-gahnite rocks and banded iron formations, as well as manganese, lead and zinc haloes, and it is recommended that these indicators be explored for. On the negative side, these deposit types are usually in rocks of high metamorphic grade.

A garnet of unknown nature was reported at the Rebecca prospect, Temma, and Mn-rich rocks occur at Possum Creek, Temma, suggesting a possible link between the Balfour and Temma mineralisation. The Temma district thus may also have potential for Broken Hill–style stratabound Pb-Zn deposits.

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[17 June 2004]

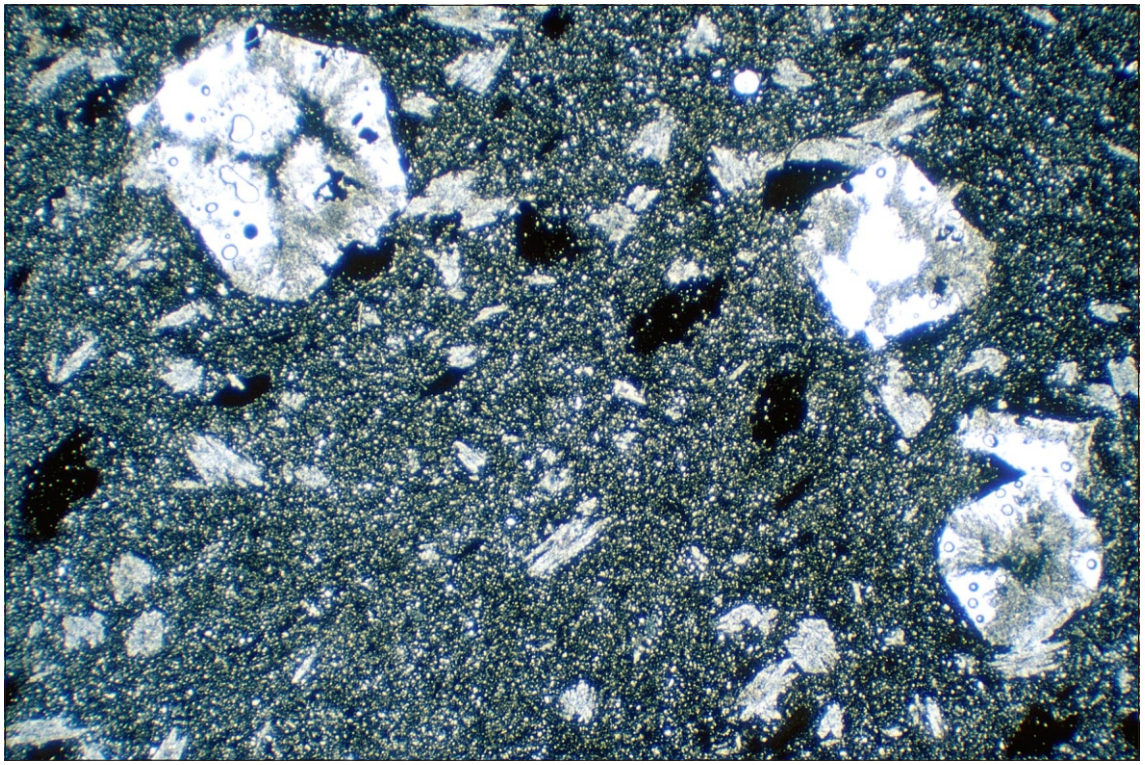

Figure 1

Photomicrograph of garnet pseudomorphs in siltstone, replaced by quartz and muscovite in sample C108431. Plain polarised light. Field of view: 4.3 2.8 mm.

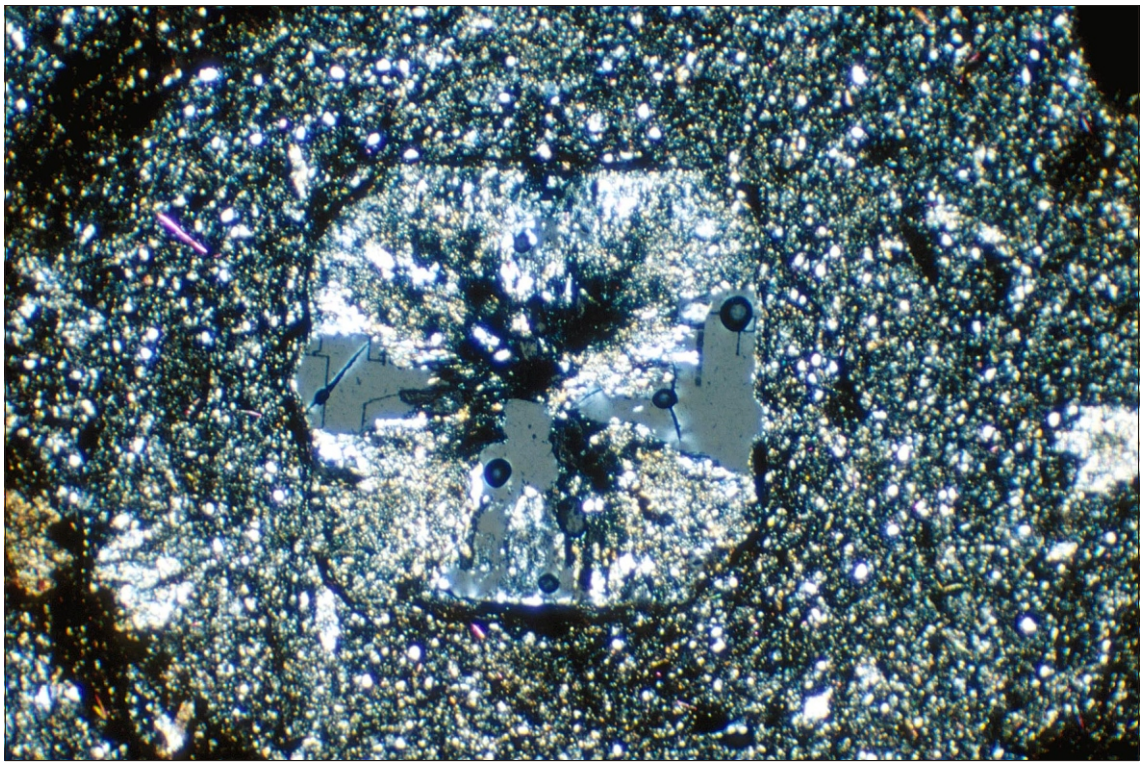

Figure 2

Photomicrograph of garnet pseudomorphs in siltstone, replaced by quartz (white) and muscovite (high birefringence) in sample C108431. Cross polarised light. Field of view: 1.2 1.8 mm.

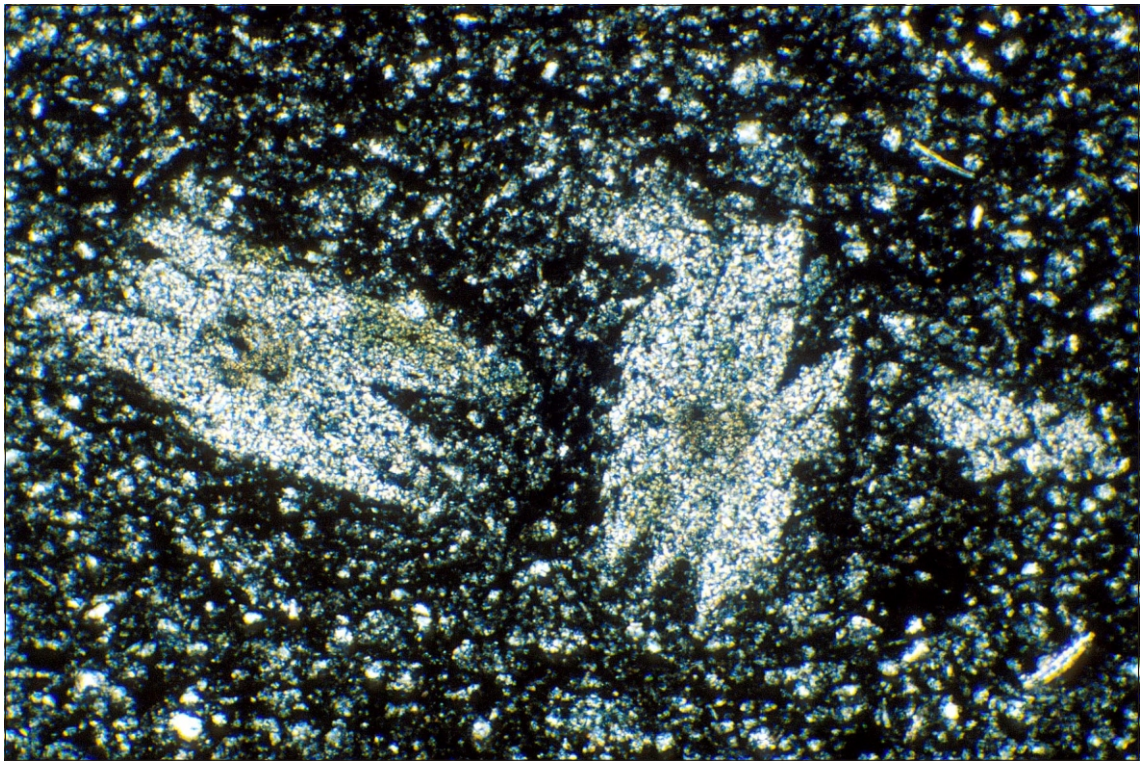

Figure 3
Photomicrograph of bladed pseudomorphs in siltstone, replaced by chlorite (green) and muscovite (high birefringence) in sample C108431. Cross polarised light. Field of view: 1.2 1.8 mm.

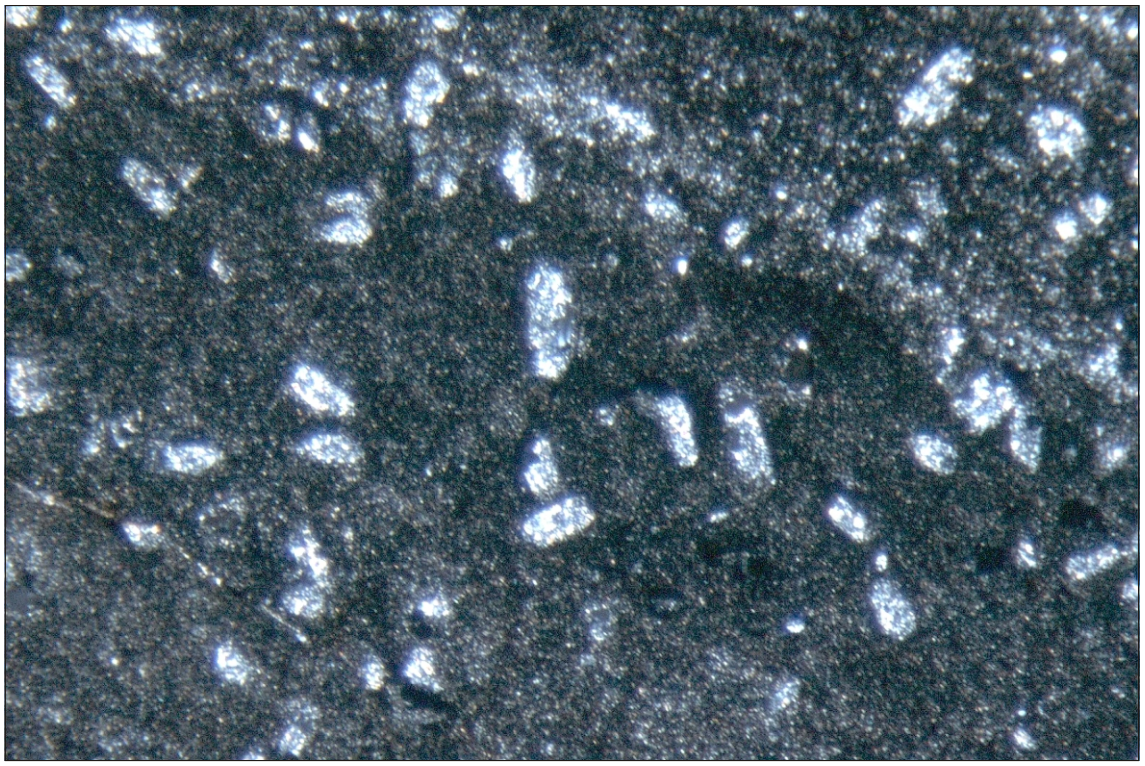

Figure 4
Photomicrograph of prismatic pseudomorphs in cherty siltstone, replaced by quartz (colourless) in sample C108437. Cross polarised light. Field of view: 4.3 2.8 mm.