Bustamite, rhodonite, spessartine, and tephroite from Meldon, Okehampton, Devonshire

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Summary. Chemical analyses together with optical and physical properties are given for ferroan bustamite, rhodonite, spessartine, spessartine-grossular, and tephroite from contact metamorphosed calc-silicate rocks of the Meldon Railway Quarry, Okehampton. The compositions of these minerals are compared to those from the Treburland manganese mine, Cornwall. An analysis is also given of a spessartine from a pyrrhotite–spessartine skarn rock from the nearby Meldon aplite quarry.

CONTACT metamorphism and metasomatism by the Dartmoor granite on the Calcareous Group of the Lower Culm (Lower Carboniferous) sediments of the Meldon district, south-west of Okehampton, Devonshire, has given rise to banded calc-flintas which locally have been converted to coarse calc-silicate hornfelses with the introduction of sulphur, fluorine, boron, iron, and manganese. In the basal bed of the Calcareous Group, in the core of an anticline exposed in one of the high-level quarries at the southernmost end of the British Railways Quarry complex, there is a small occurrence of manganiferous silicates, described briefly by Dearman and Butcher (1959) and by Dearman (1962). This assemblage has now been examined in more detail and is seen to include coarse radiating crystals of brown bustamite (fig. 1) often closely associated with pyrrhotite, together with relatively more massive pink rhodonite, with local development of tephroite and small (2–3 mm) golden yellow spessartine garnets. Quartz occurs patchily, and the black secondary oxidation products typically found with most manganese-rich assemblages are also present on joints and cracks: although rhodochrosite has been recorded it is not very abundant. In mineralogy and paragenesis the Meldon Railway Quarry assemblage is reminiscent of that of the old Treburland manganese mine in slate or phyllite a few hundred yards from the Bodmin Moor granite south of Altarnun, Cornwall: rhodonite and tephroite from this latter locality have been described by Russell (1946) and the bustamite from Treburland has been described by Tilley (1946).

Mineralogy

Bustamite. Some of the coarsely radiating bustamite (fig. 1) has been separated free from pyrrhotite and chemically analysed. Its analysis (table I) shows it to be a ferroan variety with an Fe:Mn ratio of approximately 1:4 and a Ca:Mn ratio of slightly greater than 1:2.

TABLE I. Bustamite analyses

	1	A	Anal. 1 recalculated on the basis of 18(O)		
SiO_2	47·24	46·32			
TiO_2	0·00	0·03	Si	5·881	6·00
Al_2O_3	1·91	1·02	Al	0·119	
Fe_2O_3	1·24	0·00	Al	0·161	5·93
FeO	6·89	8·63	Fe^{3+}	0·116	
MnO	30·37	26·50	Mg	0·019	
MgO	0·10	0·88	Fe^{2+}	0·718	
CaO	12·75	14·98	Mn	3·204	
Na_2O	0·02	—	Na	0·004	
K_2O	0·01	—	Ca	1·701	
H_2O^+	—	1·05	K	0·002	
H_2O^-	0·08	0·24			
Total	100·61	99·65			
α	1·695	1·692			
β	1·708	1·705			
γ	1·710	1·707			
$2V_\alpha$	34°	35°			
D	3·46	3·425			

1. Coarse radiating bustamite, B.R. Quarry, Meldon, Okehampton. Anal. R. A. Howie.

A. Pale flesh-pink bustamite, Treburland manganese mine, Altarnun, Cornwall (Tilley, 1946). Anal. Geochemical Laboratories.

A survey of bustamite analyses shows that the most comparable analysis is that of the bustamite from Treburland (Tilley, 1946) which has only a slightly greater total iron content (table I, anal. A). The Treburland mineral, however, has a higher amount of CaO, and the Meldon bustamite has in fact one of the highest (Fe+Mn) contents recorded: this is reflected in its relatively high refractive indices and specific gravity. Several bustamites studied in detail have come from Pb–Zn localities such as Långban and Franklin and contain appreciable amounts of zinc: a semi-quantitative X-ray fluorescence determination of zinc in the Meldon bustamite, however, showed only around 200–400 ppm.

Rhodonite. The chemical analysis of the pink massive rhodonite from Meldon Quarry is given in table II (anal. 2). The Treburland rhodonite

(anal. B) is seen to be rather similar, though the Meldon specimen is richer in manganese and poorer in iron: the calcium contents are similar but the Meldon rhodonite has negligible magnesium after it had been corrected for co-precipitated manganese. Zn was again found to be low, at less than 400 ppm. In thin section the rhodonite is colourless with well-developed cleavages and second-order polarization colours.

TABLE II. Rhodonite analyses

	2	B	Anal. 2 recalculated on the basis of 18(O)		
SiO_2	46·41	46·65			
TiO_2	0·00	—	Si	5·942	5·98
Al_2O_3	0·24	—	Al	0·037	
Fe_2O_3	0·66	—	Fe^{3+}	0·063	
FeO	3·03	7·65	Mg	0·015	
MnO	42·66	37·00	Fe^{2+}	0·325	
MgO	0·08	1·67	Mn	4·627	6·03
CaO	7·25	7·00	Na	0·002	
Na_2O	0·01	—	Ca	0·994	
K_2O	0·01	—	K	0·001	
H_2O^+	—	0·52			
H_2O^-	0·02	0·05			
Total	100·37	100·63			
β	1·734	—			
γ	1·742	—			
$2V_\gamma$	72°	—			
D	3·62	3·57			

2. Pink massive rhodonite, B.R. Quarry, Meldon, Okehampton. Anal. R. A. Howie.
B. Pale pink coarsely crystalline rhodonite, Treburland manganese mine, Altarnun, Cornwall (Russell, 1946). Anal. J. A. Smythe (includes CO_2 0·09).

Spessartine. An analysis of the golden yellow garnet from a rhodonite–garnet–pyrrhotite rock shows it to be a spessartine (table III, anal. 4) with a composition $Spess_{74·7}Gro_{11·2}Pyr_{7·9}Alm_{4·0}And_{2·2}$. A spessartine–garnet–pyrrhotite assemblage also occurs in a skarn-like assemblage in association with the Meldon aplite about 700 yards south-west of the B.R. Quarry manganiferous locality. The mineralogy of this aplite and its associated metasomatized country rocks is at present being studied (for a previous account see Worth, 1920), but the garnet analysis is given here (table III, anal. 6) and is that of a spessartine with a rather similar composition: $Spess_{68·1}Pyr_{12·9}Alm_{6·4}Gro_{6·3}And_{6·3}$. These appear to be the first recorded analyses of spessartines from England.

In the Meldon B.R. Quarry manganiferous locality there are occasional quartz-garnet veins in which the garnet is more reddish in colour and up

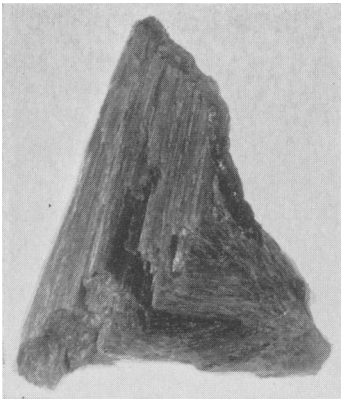

FIG. 1. Coarse bustamite, Meldon Railway Quarry ($\times \frac{1}{2}$).

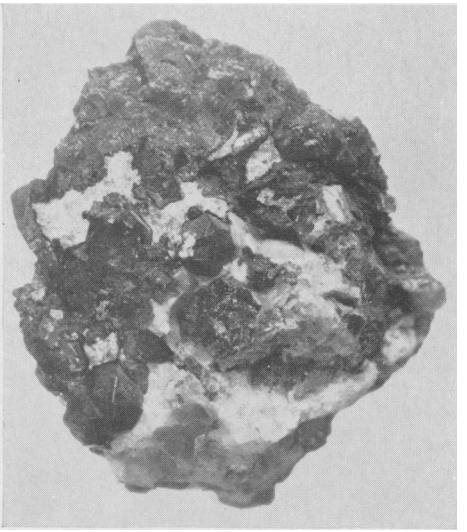

FIG. 2. Icositetrahedra of brownish red spessartine-grossular garnet, with quartz, Meldon Railway Quarry ($\times 1$).

to 5–6 mm in size (fig. 2). Because of the slightly different colour and paragenesis of this garnet from that found in the massive rhodonite assemblage its cell size was determined, and as it is appreciably larger than that of the other spessartine a sample was purified and analysed (table III, anal. 5). This garnet is thus seen to be a spessartine-grossular

TABLE III. Spessartine analyses

	4	5	6	C
SiO_2	35·84	36·24	36·24	36·52
TiO_2	0·03	0·02	0·28	0·18
Al_2O_3	20·83	21·28	20·36	20·74
Fe_2O_3	0·65	2·73	1·80	1·07
FeO	1·78	3·58	2·90	5·72
MnO	33·37	17·52	30·45	19·66
MgO	2·48	2·67	3·29	tr.
CaO	5·00	16·02	4·45	16·25
Na_2O	tr.	0·01	0·03	—
K_2O	tr.	tr.	tr.	—
P_2O_5	0·00	0·00	—	—
H_2O^+	—	—	0·02	—
H_2O^-	—	—	0·02	—
Total	99·98	100·07	99·84	100·14
n	1·787	1·778	1·79	1·780
D	4·12	3·90	4·07	3·92
a (Å)	11·653	11·730	11·637	11·725*

Numbers of ions on the basis of 24(O)

	4		5		6	
Si	5·808	6·00	5·714	6·00	5·842	6·00
Al	0·192		0·286		0·158	
Al	3·786	3·87	3·670	4·00	3·712	3·97
Fe^{3+}	0·080		0·324		0·219	
Ti	0·004		0·002		0·034	
Mg	0·598	6·29	0·627	6·15	0·790	6·11
Fe^{2+}	0·241		0·472		0·391	
Mn	4·581		2·341		4·159	
Na	—		0·003		0 005	
Ca	0·868		2·707		0·768	

Molecular composition (%)

	4	5	6
Alm	4·0	8·2	6·4
And	2·2	8·6	6·3
Gro	11·2	34·5	6·3
Spess	74·7	40·0	68·1
Pyr	7·9	8·7	12·9

4. Golden yellow spessartine, rhodonite–spessartine–pyrrhotite rock, B.R. Quarry, Meldon, Okehampton. Anal. R. C. Tyler.
5. Brownish red spessartine-grossular, B.R. Quarry, Meldon, Okehampton. Anal. R. C. Tyler.
6. Yellow-brown spessartine, pyrrhotite–spessartine skarn rock, Meldon aplite quarry, Okehampton. Anal. R. A. Howie.

C. Peach-tan spessartine-grossular, Victory mine, Gabbs, Nevada (Lee, 1962). Anal. W. H. Herdsman.

* This garnet contains two phases, the other phase having a 11·756 Å.

TABLE IV. Tephroite analyses

	7	D	Anal. 7 recalculated on the basis of 4(O)		
SiO_2	29·50	29·90			
TiO_2	tr.	—			
Al_2O_3	0·51	—	Si	0·973	0·99
Fe_2O_3	1·26	—	Al	0·020	
FeO	10·09	13·01	Fe^{3+}	0·031	2·01
MnO	53·25	53·26	Mg	0·146	
MgO	2·98	1·77	Fe^{2+}	0·278	
CaO	1·86	1·57	Mn	1·487	
H_2O^+	—	0·65	Ca	0·066	
H_2O^-	—	0·07			
Total	99·45	100·43			
β	$\simeq$1·80	$\simeq$1·74			
$2V_\alpha$	—	$\simeq$60°			
D	4·06	4·07			
d_{130} (Å)	2·863	—			

7. Tephroite, rhodonite–tephroite–pyrrhotite rock, B.R. Quarry, Meldon, Okehampton. Anal. R. C. Tyler.

D. Brown tephroite, Treburland manganese mine, Altarnun, Cornwall (Russell, 1946). Anal. J. A. Smythe (includes CO_2 0·20).

variety with molecular composition $Spess_{40\cdot0}Gro_{34\cdot5}Pyr_{8\cdot7}And_{8\cdot6}Alm_{8\cdot2}$. Garnets of this composition are rare, falling as they do midway between the two dominant garnet series pyralspite and ugrandite. Almost the only analysed garnet of comparable composition is one of the three garnet samples studied by Lee (1962) from a sheared and mineralized

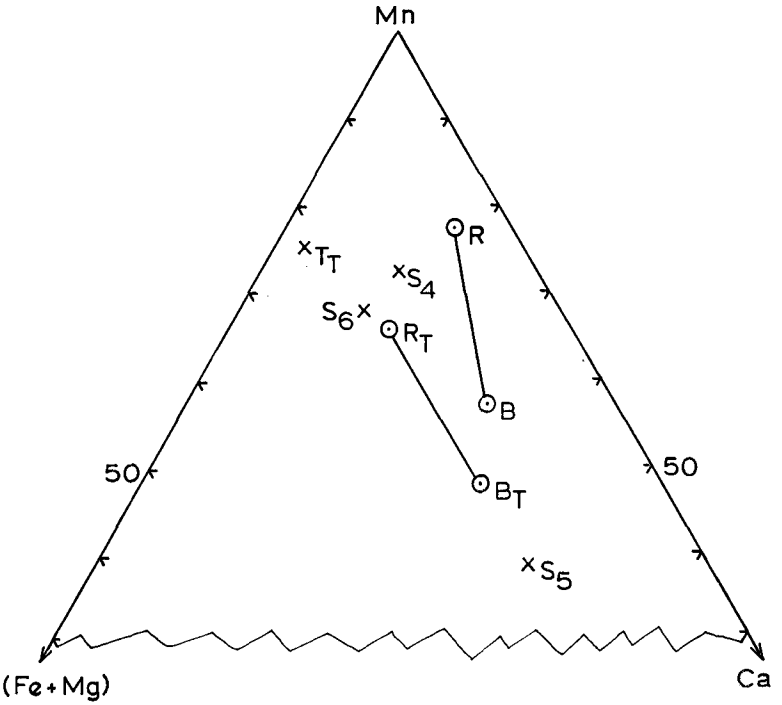

FIG. 3. Atomic % composition of the analysed manganese silicates from Meldon and from Treburland mine, Cornwall (subscript T). Bustamite, B; rhodonite, R; spessartine, S (numbered as in table III); and tephroite, T.

granodiorite at the Victory mine, Gabbs, Nevada, which is reproduced here as anal. C: composition $Spess_{42\cdot8}Gro_{41\cdot4}Alm_{12\cdot4}And_{3\cdot4}$. Although the Victory mine garnet was reported to give X-ray powder photographs showing the presence of two phases of different cell size only one of which was at all comparable with the calculated value, the Meldon spessartine-grossular gave a sharp X-ray powder pattern with no doubling of the reflections and its cell edge of 11·730 Å compares reasonably with the calculated value (11·720 Å). Garnets of this unusual spessartine-grossular

composition would seem to be typical of metasomatic calc-silicate assemblages and garnet-quartz rocks.

Tephroite. The light brownish tephroite from the rhodonite–tephroite–pyrrhotite rock has been analysed and the result is given in table IV, where it is also compared with the Treburland tephroite (anal. D). The Meldon tephroite is slightly poorer in iron than that from Treburland, showing in this respect the same relationship as do the bustamites and rhodonites from these two occurrences. It has been shown that the position of the X-ray powder reflection 130 varies with the Mn/Mg ratio in the tephroite series (Hurlbut, 1961); pure tephroite has d_{130} 2·867 Å, decreasing to 2·766 Å for forsterite, and to 2·833 Å for fayalite. For the analysed Meldon tephroite d_{130} = 2·863 Å.

The atomic percentage composition of the analysed minerals is plotted in fig. 3, in terms of the Mn, (Fe^{2+}+Mg), and Ca components. The tie-line relationship between the Meldon bustamite and rhodonite is seen to be similar to that for the Treburland minerals except that the latter are rather more iron-rich. Although, being orthosilicates, they plot on a different plane, the compositions of the analysed tephroites and spessartines are also shown.

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