oxidation and reaction with Ca and Cl (Rubin and Grossman, 1985). Thus, most ordinary chondrites may be viewed as having undergone a form of chlorine metasomatism.

If, on accretion, the clast contained crystalline plagioclase of the composition typical of the ordinary chondrites ($Ab_{82}An_{12}Or_6$; Van Schmus and Ribbe, 1968), but no P, scapolite locally could have formed in preference to chlorapatite as the product of post-accretion chlorine metasomatism. Certainly one small area of the clast appears to comprise intergrown diopside and plagioclase, $Ab_{85}An_{15}$, with no detectable P.

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KEYWORDS: scapolite, meteorite, chondrite, Bishunpur.

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Physics Dept., University of Essex, Colchester CO4 3SQ — C. M. O. ALEXANDER*

Mineralogy Dept., British Museum (Natural History), Cromwell Rd., London SW7 5BD — R. HUTCHISON†, A. L. GRAHAM

The Institute of Physical and Chemical Research, Wako, Saitama 351, Japan — H. YABUKI

* Present address: Dept. of Earth Sciences, The Open University, Milton Keynes MK7 6AA.
† Author for correspondence.

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Metasomatic phenomena adjacent to a granite pegmatite, Garry-a-siar, Benbecula, Outer Hebrides

REGIONAL metasomatism associated with Proterozoic deformation and amphibolite facies retrogression is a major feature of the Lewisian gneiss complex in northwest Britain (Drury, 1974; Beach and Tarney, 1978). The Garry-a-siar headland on the western coast of Benbecula provides some of the best exposures of Lewisian rocks in the southern Outer Hebrides (Dearnley and Dunning, 1968; Coward, 1973). It is an area of relatively low Early-Proterozoic Laxfordian deformation where discordant relationships are preserved between pre-Laxfordian basic dykes (Scourie dykes) and older 'Scourian' grey gneisses. Late Laxfordian granite pegmatites which are probably equivalent to post-tectonic intrusions elsewhere cut both dykes and gneisses. The purpose of this contribution is to describe some remarkable metasomatic phenomena which are intimately associated with one of these pegmatites.

The pegmatites at Garry-a-siar consist of megagraphic intergrowths of quartz and potassium feldspar with biotite and several accessory minerals including magnetite and columbite (Coward, 1973). A complex irregular pegmatite near grid reference NF756533 contains concentrations of magnetite crystals up to 2 cm in diameter near its margins. Similar magnetite crystals with distinctive quartz–plagioclase coronae locally occur *outside* the pegmatite, near its contact with an amphibolite dyke (Fig. 1a, b). The external magnetite crystals have

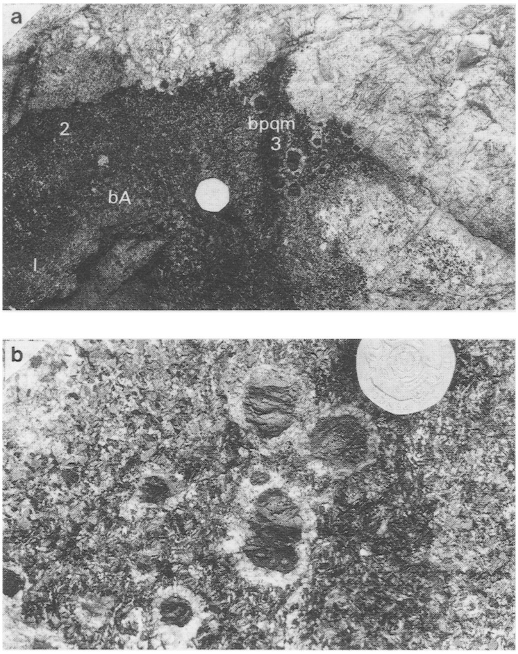

FIG. 1. (*a*) Contact of pegmatite (top and right) with basic dyke showing irregular development of biotite–plagioclase–quartz–magnetite rock (bpqm) in a contact embayment and grading into biotite–amphibolite (bA). The numbers correspond to areas roughly equivalent to the samples analysed in this study (Tables 1 and 2) though these samples did not come from the site shown in the photograph. (*b*) Detail of metasomatic biotite–plagioclase–quartz–magnetite rock showing a cluster of magnetite porphyroblasts with quartz–plagioclase coronae. Note how some of the coronae are shared between different magnetite grains and how the rock has a pseudo-igneous texture resulting from near random orientation of biotite grains.

distinctive rims of plagioclase feldspar and quartz, and occur in a coarse-grained biotite–plagioclase–quartz contact rock. Although this material is clearly part of the basic dyke (Fig. 1*a*) it has a much weaker foliation than is seen in the amphibolite and a coarse, almost igneous texture (Fig. 1*b*). Some of the magnetite crystals contain small (1 mm) discrete inclusions of ilmenite. The distinctive contact rock has a quite sharp but highly irregular contact with the pegmatite (Fig. 1). It passes outwards into foliated amphibolite consisting of hornblende and plagioclase with accessory quartz, sphene and apatite. These minerals are locally enclosed within large (up to 1 cm) poikiloblastic biotite crystals which decrease in abundance away from the pegmatite. The biotite–plagioclase–quartz–magnetite rock does not occur everywhere the basic dyke and pegmatite are in contact and its place is commonly taken by biotite-rich amphibolite. The latter material generally has a sharper and more regular contact with the pegmatite (Fig. 1).

Relatively unaffected amphibolite from the basic dyke (analysis 1, Table 1) is iron-rich and similar to some of the most evolved Scourie dyke dolerite compositions reported by Weaver and Tarney (1981). The compositions of a biotite-rich amphibolite (analysis 2) and biotite–plagioclase–quartz–magnetite rock (analysis 3) show the effects of progressive metasomatism. These effects cannot be quantified from the limited data as it would be

Table 1. Compositional variation in the altered basic dyke (cf. Fig. 1)

1. Amphibolite with rare biotite porphyroblasts
2. Biotite-rich amphibolite adjacent to granite pegmatite
3. Biotite-plagioclase-quartz-magnetite rock adjacent to granite pegmatite

SiO_2, Al_2O_3, Rb and Cs were determined by AAS; H_2O and CO_2 by Perkin Elmer Elemental Analyser and ferrous iron by the spectrophotometric method of Bower (1984). All other components were determined by ICP.

	1	2	3
wt %			
SiO_2	48.34	48.02	50.11
TiO_2	2.28	2.41	2.51
Al_2O_3	13.17	12.79	14.22
FeO	10.55	10.65	11.55
Fe_2O_3	5.82	6.34	6.61
MnO	0.27	0.38	0.40
CaO	10.14	9.49	1.99
Na_2O	2.64	2.31	2.64
K_2O	1.01	1.72	5.41
P_2O_5	0.32	0.28	0.26
H_2O	1.31	1.39	1.79
CO_2	0.03	0.00	0.03
TOT	100.75	100.60	100.99
$\frac{Fe_2O_3}{(Fe_2O_3 + FeO)}$	0.33	0.35	0.34
ppm			
Ba	261	175	146
Co	52	53	29
Cr	40	28	34
Cs	2	6	23
Cu	218	56	25
La	20	25	29
Li	31	57	207
Ni	85	85	69
Rb	22	122	690
Sc	36	37	18
Sr	241	108	74
V	290	303	169
Y	42	46	12
Zn	124	213	355

unreasonable to assume that any component was immobile during the alteration process or that the samples analysed are completely representative. However, the alteration must have included: (*a*) hydration/hydrolysis; (*b*) massive enrichment of the alkali metals excepting Na which is probably depleted; (*c*) enrichment of Mn, Zn and possibly Ti, all of which may be concentrated in the metasomatic oxides; and (*d*) depletion of the alkaline earths with the possible exception of Mg. Total iron contents are only slightly higher in the metasomatic rocks and it is quite possible that no significant amounts of this element were added to the basic dyke material. Oxidation ratios exhibit little variation despite the abundance of magnetite in the metasomatic material and the biotite must therefore be somewhat more reduced than the hornblende in the amphibolite. The development of the distinctive magnetite porphyroblasts does not appear to reflect any major chemical modification and may be related to the high primary iron content of the basic dyke. The limited data suggest that several elements such as Ti, Y and Sc which are commonly thought of as immobile, may have been redistributed during metasomatism.

The amphibolite contains an iron-rich hornblende associated with plagioclase varying in composition from An_{30} to An_{35}. Poikiloblastic biotite grains give slightly lower analytical totals and K-contents than might normally be expected which is probably due to incipient (submicroscopic) chloritization. However comparison with analysed retrograde chlorites suggests that Fe–Mg–Al interrelationships will not have been much affected. Poikiloblastic biotite has a slightly lower Fe:Mg ratio and Al-content than that in the biotite–plagioclase–quartz–magnetite rock. Plagioclase in this most altered material is considerably less calcic (An_{19-21}) than that in the amphibolite and exhibits no discernible variation between magnetite coronae and the groundmass. The large magnetite grains contain no elements other than Fe in proportions large enough to be detected by an energy-dispersive microprobe. Ilmenite inclusions are highly manganoan (Table 2) and contain small amounts of exsolved hematite.

Consideration of the field relationships, rock chemistry and mineral compositions suggests that metasomatic modification of the basic dyke occurred as a result of interaction with a fluid phase associated with the intrusion of the pegmatite. The major characteristics of this interaction might be expressed schematically in the form:

$$\text{Hornblende} + \text{plagioclase}(An_{30-35}) + \text{sphene} + K^+_{(aq)} + H^+_{(aq)} \rightarrow \text{biotite} + \text{plagioclase}(An_{19-21}) + \text{magnetite} + \text{ilmenite} + \text{quartz} + Ca^{2+}_{(aq)} + Na^+_{(aq)}$$

Table 2. Representative energy dispersive microprobe analyses of minerals from the altered basic dyke.

H1 - Hornblende (rock 1, Table 1)
B1 - Biotite (rock 1, Table 1)
B2 - Biotite (rock 3, Table 1)
C1 - Chlorite (retrograde product of biotite, rock 1, Table 1)
P1 - Plagioclase (rock 1, Table 1)
P2 - Plagioclase (rock 3, Table 1)
I1 - Ilmenite (inclusion in magnetite, rock 3, Table 1)

	H1	B1	B2	C1	P1	P2	I1
wt %							
SiO_2	41.38	33.52	34.92	27.82	58.89	62.59	0.30
TiO_2	1.05	3.28	3.21	0.40	nd	nd	51.95
Al_2O_3	12.11	15.25	15.61	16.17	25.54	23.37	nd
FeO	21.37	23.61	22.71	29.48	nd	nd	33.53
MnO	0.33	nd	0.48	0.32	nd	nd	13.66
MgO	8.20	10.25	8.91	13.58	nd	nd	nd
CaO	11.47	0.21	nd	0.24	7.15	4.28	nd
Na_2O	2.12	0.85	0.99	0.69	7.86	9.38	nd
K_2O	0.89	7.26	9.10	0.21	0.16	nd	nd
TOT	98.92	94.23	95.93	88.91	99.60	99.62	99.44
number of atoms							
Si	6.30	5.27	5.42	5.94	2.64	2.78	0.01
Ti	0.12	0.39	0.37	0.06	0.00	0.00	0.99
Al(IV)	1.70	2.73	2.58	2.06	1.35	1.22	0.00
Al(VI)	0.47	0.10	0.28	2.01	0.00	0.00	0.00
Fe	2.72	3.11	2.95	5.27	0.00	0.00	0.71
Mn	0.04	0.00	0.06	0.05	0.00	0.00	0.29
Mg	1.86	2.40	2.06	4.33	0.00	0.00	0.00
Ca	1.87	0.35	0.00	0.05	0.34	0.20	0.00
Na	0.63	0.26	0.30	0.28	0.68	0.81	0.00
K	0.17	1.46	1.80	0.05	0.01	0.00	0.00
(O)	23	22	22	28	8	8	3
$\frac{Fe}{(Fe+Mg)}$	0.59	0.56	0.59	0.55			

The textures of the magnetite grains and their coronae show that in addition to exchange of the mobile components (K^+, H^+, Ca^{2+}, Na^+) the metamorphic process must have involved centimetre-scale redistribution of relatively immobile components such as Al. Clustering of magnetite crystals (Fig. 1) indicates that Fe has been specifically concentrated in certain volumes of the altered material. This degree of mass transfer is quite large compared to that exhibited in most metamorphosed silicate rocks. It seems likely that the main mechanism of mass transfer was of the infiltration type involving exchange of components between minerals and a hydrous pore fluid. Small scale relationships demonstrate a clear association with the *emplacement* of a granite pegmatite but this does not imply an essentially magmatic fluid source. Metamorphic fluids from deeper levels or deeply convecting surface waters might have contributed to the metasomatism by being channelled through the structure into which the pegmatite was intruded.

Similar compositional changes involving K and Rb-enrichment and Ca, Sr and Ba-depletion have been reported to occur locally within major Laxfordian shear zones (Beach, 1976) and to characterise some areas of near pervasive amphibolitization of Scourian gneisses (Drury, 1974). It has been suggested that the major phase of fluid introduction

was associated with Scourie dyke magmatism and the earliest phases of Laxfordian deformation (Beach and Tarney, 1978). The metasomatic phenomena at Gary-a-siar overprint a Laxfordian deformation fabric and indicate that some of these distinctive chemical changes may have occurred during later stages of the Laxfordian cycle.

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Dept. of Earth Sciences, University of London, Goldsmiths' College, Rachel MacMillan Building, Creek Road, London SE8 3BU

PATRICK J. WILLIAMS

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Ceruleite: infrared spectroscopy and a new locality in Cornwall

CERULEITE, $Cu_2Al_7(AsO_4)_4(OH)_{13}\cdot 12H_2O$, is a rare supergene mineral, discovered by Dufet (1900) on material from the Emma Luisa gold mine near Huanaco, Taltal province, Chile, the only locality known until reported from Wheal Gorland, Gwennap, Cornwall, by Russell and Claringbull (1955), and from an unknown locality in southern Bolivia (Schmetzer *et al.*, 1976*a*, *b*, 1978).

In October, 1984, Mr V. T. Rae of Thornbury, Bristol, sent the author a specimen of suspected ceruleite he had collected, for confirmation or identification. This specimen was found in the material being excavated from 'the new shaft into Wheal Jane at St Day United'. Shortly afterwards Mr 'Sam' Weller notified the author of similar material sent to him and said to have been collected in 'Wheal Maid incline, part of Whiteworks mine', and accompanied by scorodite. Bryan V. Cooper, of Torquay Natural History Museum, carefully investigated the occurrence, and found the material only on a temporary dump at SW 745418 (since removed) derived from Western Decline, at SW 745421, a new incline shaft to Whiteworks lode in the Wheal Maid section of United Downs mine, a western extension of Wheal Jane. This shaft, in Gwennap parish, is 1.25 km SE of Wheal Gorland, the previous locality, and is about 0.6 km N of the site of Whiteworks shaft given in Dines (1956).

The ceruleite forms sky-blue radiating spherules of fine needles, mostly about 0.5 mm in diameter, closely invested or scattered on joint planes in grey tourmalinised killas, on sugary quartz or on felted crusts of sub-parallel aggregates of brown needles of tourmaline on killas. This tourmaline gives an infrared spectrum corresponding to that of the high-Al schorlite of Plyusnina *et al.* (1969). Other associated minerals include well-crystallised posnjakite in rippled crusts, thin crusts of pale greenish microcrystalline scorodite, cassiterite, very sparse tiny green square plates probably of zeunerite or metazeunerite, and small amounts of green to brown microcrystalline coatings giving ill-defined infrared spectra suggesting hydrated and probably basic sulphates and sulphate-arsenates. Native