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Metasomatic reaction between acid pegmatite and orthopyroxenite at Currywongaun, Connemara, Ireland

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SUMMARY. Late-stage acid pegmatites veining the predominantly ultrabasic Currywongaun-Doughruagh intrusion are frequently associated with amphibole-rich reaction borders in the adjacent wall-rocks. The chemical and mineralogical changes resulting from reaction between an acid pegmatite vein and the orthopyroxenite wall-rock are assessed from chemical analyses of rocks and microprobe analyses of the amphiboles forming the zoned reaction border. The main chemical change was the addition of H_2O to the wall-rock; otherwise the formation of the anthophyllite and hornblende of the reaction border from pyroxene was virtually isochemical. Enrichment in other chemical species, notably Ca and Al, was restricted to the region close to the interface between the reactants. This inhibited style of reaction is attributed to the initial marginal crystallization of the acid pegmatite melt acting as a barrier to subsequent metasomatic interchange.

THE Currywongaun-Doughruagh intrusion of northern Connemara is a folded sequence of ultrabasic cumulates with subordinate acid gneisses. Late stage granitic dykes and acid pegmatites transgress the earlier formed parts of the intrusion which was syntectonically emplaced into Connemara Schists of Dalradian age. The petrogenesis and structural development of this intrusion have been described in some detail by Kanaris-Sotiriou and Angus (1976).

The acid pegmatites are not found outside the contact of the intrusion and were concluded to have developed by crystallization from an acid differentiate of the same magma that had earlier produced the ultrabasic rocks (anorthosite-norites-pyroxenites all having plagioclase of around An_{90}) which form the bulk of the intrusion. Crystals, up to 10 cm in length, of sodic plagioclase (around An_{25}) and quartz with minor muscovite characterize the acid pegmatite, in which central tourmaline-quartz zones are sometimes evident.

The acid pegmatites occur as simple veins up to about 1 m thick, or as net-veining of ultrabasic rock which has locally been mechanically disrupted and rotated to form separate blocks surrounded by acid pegmatite. In both cases there is usually a marked reaction border to the ultrabasic rock at its contact with the acid pegmatite. The reaction borders appear as greenish margins to the ultrabasic rock, up to 10 cm thick, in which the fibrous minerals developed as a result of the reaction are aligned roughly perpendicular to the contact with the acid pegmatite vein. In the case of the simple veins, the reaction borders usually occur symmetrically to either side of the acid pegmatite (fig. 1).

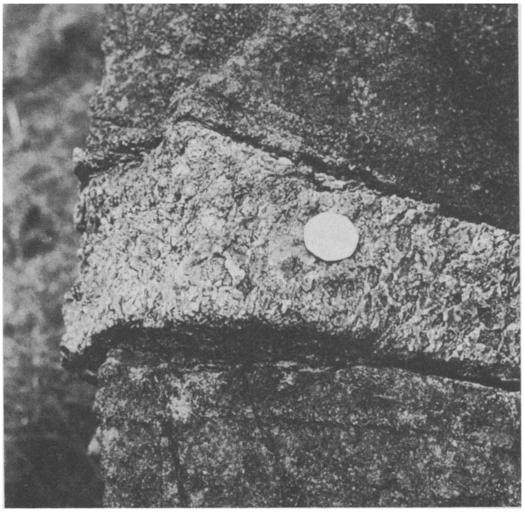

FIG. 1. Acid pegmatite vein intruding ultrabasic rock at Currywongaun, showing symmetrical reaction borders above and below the vein (the diameter of the coin is 2.86 cm).

Other examples of this type of reaction have been recorded. Carswell *et al.* (1974) and Kanaris-Sotiriou *et al.* (1978) described in detail the major and trace element chemistry respectively of a complex metasomatic reaction vein in peridotite at Kalskaret, Norway, where reaction had taken place along a fracture in the peridotite via hydrous fluids emanating from the acid gneiss country rocks, i.e. there was no direct contact between the acid and basic reactants. Curtis and Brown (1969 and 1971) described the metasomatic chemistry of the multiply-zoned ultrabasic bodies in Unst, Shetland, where direct reaction between peridotite and acid gneiss has taken place. There, however, the original peridotite is not now seen, and the reaction zones are not complete in any one instance. Reaction borders found in the Currywongaun-Doughruagh intrusion between acid pegmatite and ultrabasic rock might provide an example of metasomatic reaction where both original reactants and the products may be examined.

The samples selected for detailed study (samples C008 and C213A) show the reaction between acid pegmatite and orthopyroxenite. Sample C008 was halved and C008A was subsampled by cutting six slabs parallel to the contact as shown in fig. 2.

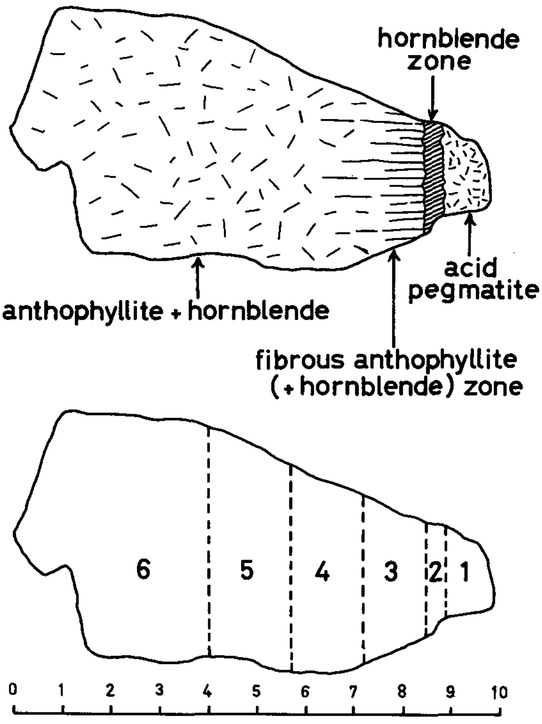

FIG. 2. Schematic mineralogical variations across the reaction border specimen C008A (top) with sub-sampling scheme shown below.

Each subsample and sample C213A were then analysed for major and trace elements by XRF with the exception of Na_2O and FeO, and were examined by XRD. Specimen C008B was used to prepare polished thin sections for electron microprobe analyses.

Mineralogy. The specimen of pyroxenite (sample C213A) not affected by reaction with the acid pegmatite vein is composed of hypersthene (70%), hornblende (15%), augite (12%) and magnetite (3%), with trace amounts of plagioclase and green spinel. The hornblende in this specimen has clearly formed after augite, presumably as a result of the pervasive amphibolization of the ultrabasic rocks which occurred in association with the metasomatic formation of the acid gneiss that preceded the injection of the acid pegmatites.

In the hand specimen (sample C008) the reaction border appears as a 10 cm wide, green selvedge to the pyroxenite, in which a fibrous structure is evident near to the acid pegmatite-pyroxenite contact.

Petrographic examination, confirmed by X-ray diffraction, showed that the bulk of the reaction border has been altered to amphibole, and that near to the contact, several zones may be identified that are characterized by different mineral assemblages or textures (figs. 2 and 3). Within the reaction border and immediately adjacent to the acid pegmatite is a dark-green zone, about 0.4 cm in thickness, composed almost entirely of hornblende. There is some optical evidence that, even across the small thickness of this hornblende zone, the composition of the mineral may not be constant, since the hornblende closest to the contact is darker in colour than that further away (fig. 3). Adjacent to

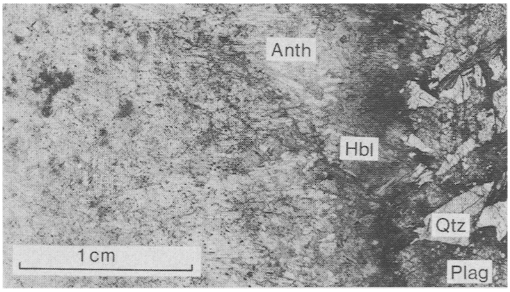

FIG. 3. Thin section (ordinary light) across part of the reaction border near to the contact with acid pegmatite. The contact is at the junction between the acid pegmatite (quartz (Qtz) with An_{65} plagioclase (Plag)) and the hornblende (Hbl) zone. Adjacent to the latter is the zone (Anth) in which fibrous anthophyllite grains are orientated roughly perpendicular to the contact. Magnetite (opaque) becomes coarser towards the contact before virtually disappearing at an irregular 'front'.

the hornblende zone is a zone of anthophyllite and hornblende (roughly 60% and 40% respectively), about 0.8 cm in thickness, in which the anthophyllite is strongly fibrous and shows a preferred orientation perpendicular to the acid pegmatite-pyroxenite contact. Some of the anthophyllite fibres penetrate into the adjacent region of the main bulk (about 9 cm thick) of the reaction border which is composed of slightly greater amounts of anthophyllite than hornblende, both of which are of equidimensional habit.

Although there is about 3% of magnetite in the unaltered pyroxenite, the mineral tends to occur in a few, quite large grains. In the reaction border, however, magnetite occurs in a finely disseminated form (fig. 3) which varies in grain size according to position, becoming gradually coarser towards the contact. Within about 0.6 cm of the contact little or no magnetite occurs. This abrupt disappearance of magnetite where the size of the grains is at a maximum seems to point towards the existence of some kind of 'front' controlling the formation of magnetite.

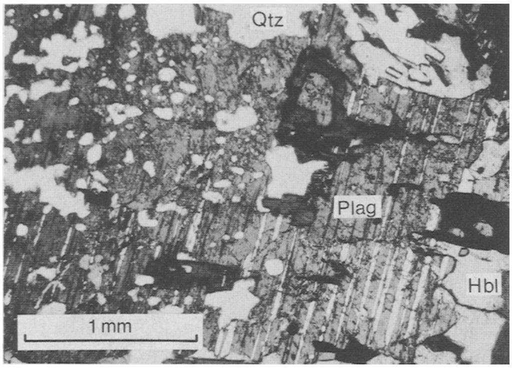

FIG. 4. Photomicrograph (crossed polars) showing exsolved quartz within plagioclase (An_{65}) immediately adjacent to the contact with the reaction border.

The acid pegmatite close to the contact is composed almost entirely of plagioclase and quartz (figs. 3 and 4). The plagioclase grains (*c.*An_{65} optically) immediately adjacent to the contact commonly show numerous irregularly shaped inclusions of quartz that seem to be alteration products. The inclusions do not occur within the more sodic plagioclase (*c.*An_{25}) of the bulk of the acid pegmatite and could be attributed to reactions taking place as a result of chemical interchange with the ultrabasic wall-rock.

In order to confirm the identity of the amphiboles and to investigate the possibility of chemical variations in the amphiboles across the reaction border, partial analyses were made by electron microprobe at appropriate positions across specimen C008B, the results of which are given in Table I.

The analyses average $Ca_{0.09}(Mg_{5.59}Fe_{1.36})Al_{0.06}(Si_{7.75}Al_{0.25})O_{22}(OH)_2$ for the anthophyllite and $Ca_{1.77}(Mg_{4.14}Fe_{0.94})Al_{0.39}(Si_{7.10}Al_{0.90})O_{22}(OH)_2$ for the hornblende. The anthophyllite shows little variation in composition across the reaction border, with the exception of the FeO content, which shows a decrease away from the contact. The hornblendes are more variable and show certain systematic variations that are undoubtedly reflected in the changes in optical properties noted earlier. The compositions change sharply across the hornblende zone itself where the most important variations are a decrease in the Fe/Mg ratio (from 0.30 to 0.20) away from the contact, coupled with a corresponding increase in the Si/Al ratio in the same direction (Table I). This has important implications as far as the mechanism by which the hornblendes grew is concerned, since it implies the growth of this mineral in activity gradients of the components concerned.

Chemistry. It can be confidently assumed that, prior to alteration, the material now represented by the reaction border (sample C008) was of virtually uniform composition. Certainly, any significant chemical movement between the orthopyroxenite and the acid pegmatite should be obvious from the chemical profiles across the reaction zones. Chemical analyses of the rocks (Table II) show, rather surprisingly, that the compositions across the region of the pyroxenite that has undergone reaction are somewhat uniform except for the first 1-2 cm adjacent to the acid pegmatite where irregularities in elemental distributions occur.

With the exception of water, the compositions representing the uniform part of the profiles (subsamples 3, 4, 5, and 6) are remarkably similar to that of the unaltered pyroxenite C213A. It can clearly be concluded from this that the main effect in the bulk of the reaction border was the introduction, from the acid pegmatite melt, of the water involved in the formation of amphiboles (anthophyllite and hornblende) from the pyroxene and that this reaction was essentially isochemical on a bulk rock scale, e.g.:

$$\underset{\text{hypersthene}}{8(Mg,Fe^{2+})SiO_3} + H_2O \rightarrow \underset{\text{anthophyllite}}{(Mg,Fe^{2+})_7Si_8O_{22}(OH)_2} + \text{'}(Mg,Fe)O\text{'}$$

This reaction implies the release of excess MgO and FeO. Whilst the former may be incorporated in further amphibole, there is evidence that the reaction is accompanied by oxidation (see FeO and

TABLE I. *Chemical analyses of minerals*

	Anthophyllite				
Analysis number	1/7A	1/2A	1/8A	2/3A	Average
Distance from contact (mm)	4	5	22	56	—
SiO_2	55.28	54.57	56.50	55.43	55.45
TiO_2	0.00	0.01	0.02	0.00	0.01
Al_2O_3	1.32	2.00	1.66	2.51	1.87
FeO	12.55	11.87	11.41	10.76	11.65
MgO	25.97	27.89	26.05	27.37	26.82
CaO	0.49	0.63	0.49	0.67	0.57
Total*	95.62	96.98	96.14	96.74	96.37
Fe/Mg (atomic)	0.27	0.24	0.25	0.22	0.25

	Hornblende						
Analysis number	1/1A	1/6A	1/7B	1/2B	1/8B	2/3B	Average
Distance from contact (mm)	1	1	4	5	22	56	—
SiO_2	46.57	49.18	49.26	50.27	52.13	51.05	49.74
TiO_2	0.58	0.03	0.23	0.14	0.11	0.06	0.19
Al_2O_3	9.23	9.04	7.56	6.81	6.19	7.33	7.69
FeO	9.65	8.92	7.61	7.59	7.25	6.19	7.87
MgO	18.35	18.33	18.93	21.35	20.17	19.61	19.46
CaO	11.48	11.48	11.63	11.59	11.38	11.95	11.59
Total*	95.86	96.97	95.23	97.76	97.23	96.19	96.54
Fe/Mg (atomic)	0.30	0.27	0.23	0.20	0.20	0.18	0.23

* It is estimated from the rock analyses (see Table II) that components not analysed for (which include H_2O, Na_2O, K_2O, MnO) would contribute around 3.5 wt.% to the total.

Fe_2O_3 figures in Table II) and that the released iron is incorporated in the magnetite that occurs in a disseminated form (fig. 3) throughout the reaction border but is absent in this form from the unaltered pyroxenite.

The hornblende zone (subsample 2) shows significant enrichment in Al_2O_3 and CaO (and to a lesser extent in K_2O and Na_2O) by comparison with the rest of the reaction sequence. The same sample also shows a corresponding depletion in all other major components. It seems clear from this that there has been movement of Ca, Al, K, and Na into the hornblende zone, either from the other parts of the reaction sequence or from the acid pegmatite. For Ca and Al it seems that the former may be true for the CaO profile shows a decrease towards the hornblende zone, suggesting that Ca may have been drawn towards the acid pegmatite vein but preferentially fixed in the hornblende. The CaO content (5.70%) of the marginal acid pegmatite (subsample 1) is higher than that of the typical acid pegmatite (2.67% CaO) and this would seem to support the release of Ca into the acid pegmatite rather than the reverse. Petrographic evidence of exsolution of quartz (fig. 4) within the plagioclase of the marginal acid pegmatite also supports the release of Ca into the acid pegmatite, in which the extra Ca has been incorporated into a more calcic plagioclase thus releasing SiO_2 and Na. This would also require the release of Al into the acid pegmatite and there is evidence that Al enrichment in the hornblende zone (7.62% Al_2O_3) may have arisen in a similar way to that of Ca: a decrease in the Al_2O_3 profile across the reaction sequence is detectable with 4.92% Al_2O_3 in the unaltered pyroxenite, varying through 4.51% Al_2O_3 in subsample 6 to 3.82% Al_2O_3 in subsample 3. Redistribution of Al derived from the original pyroxenite appears to have resulted in a preferential enrichment of this element in the hornblende, with the liberation of some Al into the marginal acid pegmatite where it is incorporated into plagioclase.

TABLE II. *Rock analyses*

	AVP	C213A	C008A						AVAP
			6	5	4	3	2	1	
SiO_2	50.78	50.81	50.61	50.98	51.26	52.16	50.42	77.09	75.93
Al_2O_3	5.36	4.92	4.51	4.18	4.04	3.82	7.62	12.98	13.42
TiO_2	0.29	0.21	0.20	0.21	0.20	0.19	0.17	0.05	0.12
Fe_2O_3	2.34	3.62	4.65	4.46	4.40	3.88	2.96	0.22	0.26
FeO	11.25	9.93	8.73	9.01	9.08	9.33	6.63	0.28	1.04
MgO	20.31	22.99	23.06	23.58	23.39	23.34	18.25	0.89	0.83
CaO	8.10	5.67	4.38	4.14	3.89	4.01	10.44	5.70	2.67
Na_2O	0.12	0.11	0.23	0.23	0.22	0.23	0.64	1.43	4.73
K_2O	0.07	0.05	0.04	0.05	0.05	0.05	0.15	0.32	0.47
MnO	0.17	0.19	0.21	0.22	0.12	0.15	0.10	0.06	0.00
P_2O_5	0.01	0.01	0.00	0.01	0.00	0.00	0.05	0.04	0.05
S	0.20	0.13	0.02	0.03	0.01	0.01	0.02	0.00	0.00
H_2O^+	1.10	0.92	3.10	3.13	3.09	3.00	2.63	0.87	1.04
Total	100.00	99.56	99.74	100.23	99.75	100.17	100.05	99.93	100.56
Ni	242	201	217	218	201	207	118	3	1
Co	114	102	104	106	107	111	98	67	40
Mn	1712	ND	1944	1958	1974	2042	1482	127	220
V	276	ND	217	224	216	198	181	4	23
Cr	1187	712	980	991	947	1028	488	9	17
Zn	79	76	78	82	81	85	61	12	15
Cu	100	58	11	9	7	14	6	12	4
Pb	3	—	1	—	4	6	8	21	21
Ba	26	15	18	12	19	16	29	84	91

AVP—average of twelve pyroxenites; AVAP—typical acid pegmatite; C213A—unaltered orthopyroxenite immediately adjacent to reaction zone samples C008A; ND—not determined.

The same mechanism cannot be applicable to the enrichment of K_2O and Na_2O in the hornblende and influx of these elements from the acid pegmatite into the reaction sequence must be proposed.

The trace elements, like the major elements, show little variation across the reaction border, with the exception of the hornblende zone. Here, Ba shows a predictable enrichment, but all other determined trace elements are diminished by comparison with the rest of the reaction sequence. Except for Cu, which appears to have been removed from the reaction sequence (presumably into the acid pegmatite vein), the trace element amounts in the bulk of the reaction sequence are very similar to those of the unaltered pyroxenite, paralleling similar observations for the major components.

Discussion. In this example of the reaction of a pyroxenite with an acid pegmatite, the main effect has been a virtually isochemical conversion of pyroxene to amphibole (anthophyllite + hornblende); a reaction that only requires the addition of water. Preferential enrichment of Al and Ca is limited to the interface between the two reactants although these elements seem to have been transferred from other regions of the altered pyroxenite rather than introduced via the acid pegmatite.

This behaviour clearly contrasts with that observed for the Kalskaret and Unst examples (op. cit.), where multiple monominerallic zones were developed in response to the extensive introduction of various zone-determining chemical species from hydrous metasomatizing fluids. The conclusion that the limited style of metasomatic reaction in the present example is due to the magmatic nature of the metasomatizing medium seems inescapable, although it may be the attendant physical conditions (P and T) that are the crucial factors.

The following mechanism is suggested for the origin of the Currywongaun reaction sequences. Injection of the acid pegmatite along a fracture in the ultrabasic rock was probably followed by marginal crystallization of the melt against the wall-rock. This seems to have occurred before any metasomatic exchange had taken place because the mineralogical evidence of quartz exsolution suggests *solid-state* alteration of the plagioclase. The fact that the acid pegmatite appears to have had a marginal, solid portion before any significant metasomatic reaction occurred, seems to us a possible reason why such reaction was inhibited, the solid marginal acid pegmatite acting as some sort of barrier to metasomatic interchange of components other than water.

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