

Origin of appinitic pockets in the diorites of Jersey, Channel Islands

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SUMMARY. Isolated pockets of pegmatitic appinite characterized by hollow-shell, prismatic amphiboles are common in the Pre-Cambrian metagabbros and metasomatic diorites of Jersey. Field relationships and petrography indicate a liquid phase in the formation of these appinitic pockets, which are chemically distinct from the associated gabbros and diorites. Close chemical ties between appinites and host rocks, however, prove a replacive, metasomatic, rather than intrusive origin for the pockets. Significant enrichment in SiO₂, K₂O, and Na₂O suggest that surrounding granite provided the metasomatic agents. The localized changes in composition of the basic rocks resulted in the formation of partially molten pockets from which the appinites crystallized. This mechanism probably necessitates a temperature in the region of 900 °C at 2-5 Kb P_{H_2O} : Fractured, hollow-shell, prismatic amphiboles of the pockets are consistent with quench crystallization, possibly due to the sudden loss of volatiles. An increase in the oxygen fugacity may have played a major role in inducing the rapid crystallization of kaersutitic amphibole. The envisaged conditions under which these changes took place are those of a high-level, sub-volcanic environment.

APPINITIC diorites occur within the basic plutonic complex of Jersey as discrete pockets or, occasionally, more extensive layers. They form a conspicuous facies of the dioritic rocks because of their coarse, often pegmatitic grain size and their distinctive texture dominated by euhedral, prismatic amphiboles. The term 'appinite' was originally applied to these rocks by Wells and Bishop (1955) to describe diorites characterized by prismatic amphiboles, and it is this feature alone that is in keeping with the original definition of the term proposed by Bailey (1916). In terms of bulk chemistry and mineralogy the Jersey appinites are closer to quartz-diorites or tonalities and bear little resemblance to the basic and ultra-basic rocks of the Caledonian appinitic suite.

The origin of small pegmatitic pockets of appinitic diorite presents problems of interpretation. Identical appinites at Bon Repos, Guernsey, have been ascribed by Roach (1964) to pegmatitic crystallization from residual fluids in magmatic diorite. The Jersey diorites, however, have been shown to be the result of the action of granitic metasomatism on an earlier gabbroic mass (Wells and Bishop, 1955; Bishop, 1963), and Wells and Bishop (1955) have suggested, from field and petrographic evidence, that the appinites represent localized areas of partial melting due to the concentration of volatile fluxes emanating from the granites that now completely surround the basic masses. The present work provides geochemical support for the previous interpretation of appinites and associated diorites and discusses the mechanism by which giant hollow-shell amphiboles were produced.

Field relationships of appinites

Throughout the dioritic complex, both in the south-east at Le Nez Point and in the north-west at Ronez and Sorel Point there occur numerous small pockets and irregular patches of

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pegmatitic appinite. Such bodies, which vary in diameter between a few cm and 2 m, always occur within the basic rocks but show no systematic distribution, and are as common in little altered gabbros as in completely recrystallized diorites. Where the dioritic or gabbroic country rocks contain a layered structure the appinites frequently show a cross-cutting relationship and are clearly later in age. There is, however, no evidence of an intrusive origin except where rheomorphism has produced very localized mobilization of appinitic material (Key, 1974). The contacts are frequently gradational and those that appear sharp are seen on close examination to be gradational over a short distance. Furthermore, although several appinitic pockets may be interconnected by a system of diffuse net veins, from the examination of split loose blocks some of the smaller bodies can be proved to be ductless. The fluidity of the appinites is demonstrated by turbulent-flow structure defined by prismatic amphiboles, and by occasional crystal settling, always in the same direction, of more equant amphiboles. In one case contemporaneous fracturing of the country rock has drained a pocket of some of its feldspathic melt. Liquid entered the narrow fissure and prismatic amphiboles were drawn towards the vein mouth but were too large to enter and now form a dense accumulation (fig. 1a).

Two structural types of appinitic body can be defined on the distribution of amphibole within the pockets:

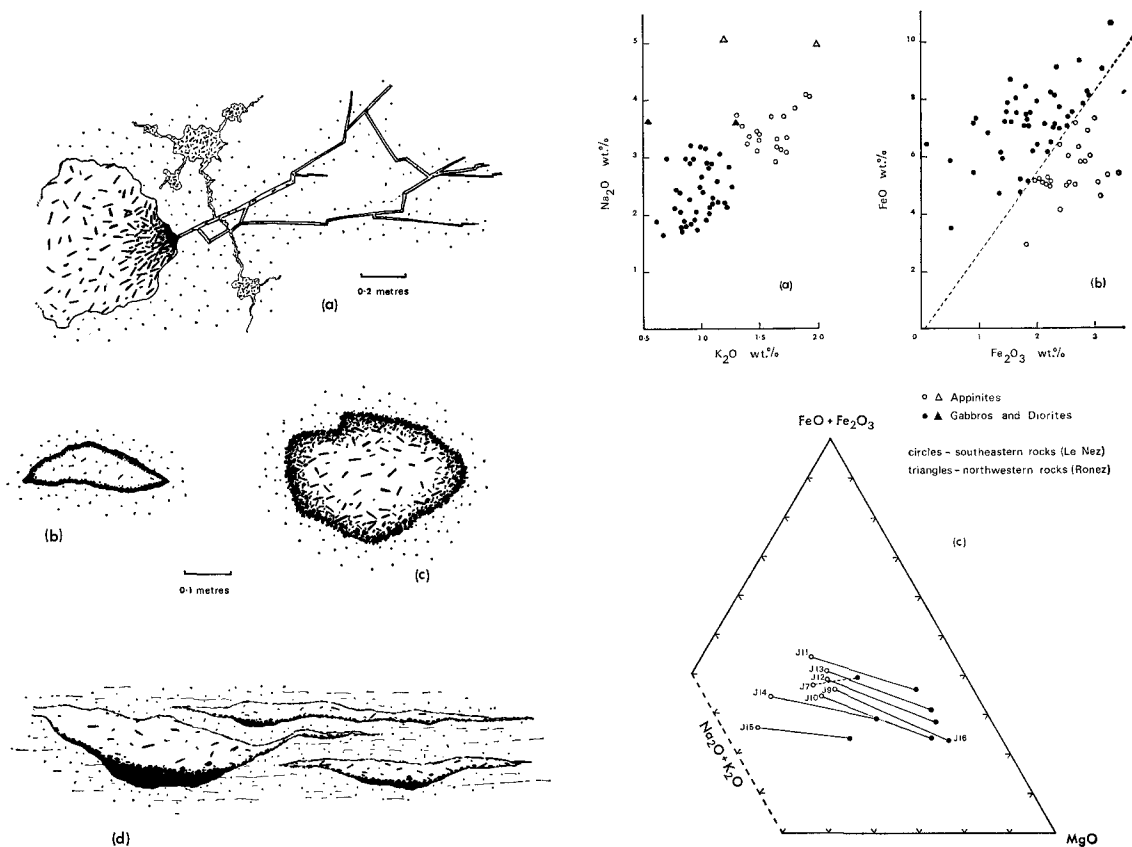
Differentiated pockets occur as elliptical pods or more extensive layers, which are parallel to the layered structure in the country rocks (fig. 1d). Differentiation has caused a basal accumulation of amphibole, which is always a stumpy, equant form. Any amphiboles in suspension in the upper feldspathic part are the prismatic type. There is an antipathetic distribution of the two forms of amphibole with the bulk amphibole content of all pockets remaining approximately the same. Pockets with the thickest basal accumulation contain no prismatic crystals and those with a high proportion of prismatic crystals have a thin basal accumulation.

Zoned pockets tend to be the larger and more numerous type and generally have a rounded or somewhat amoeboid shape (figs. 1b and 1c). Again both prismatic and equant amphiboles are present, the zonation being due to the occurrence of the latter as a marginal 'amphibolite' shell between the pod and the country rock. As with the differentiated pockets there is an antipathetic relationship in the amphibole distribution and the best developed amphibolite shells occur in pods with very few prismatic crystals. Many pods possess no such marginal shell and these are homogeneous with an even distribution of prismatic amphiboles.

Petrography

The country rocks. These are extremely variable and all gradations between little-altered gabbros and completely recrystallized gabbros and metasomatic diorites are present. The gabbros are typically coarse, ophitic rocks with large plates of diopsidic augite enclosing euhedral laths of labradorite. Some of the gabbros of the northern complex at Sorel Point also contain small amounts of olivine. Textural evidence (Key, 1974, figs. 2.21 and 2.22) suggests that the conversion to a dioritic mineralogy was initially by subsolidus recrystallization with brown and green amphibole replacing pyroxene, and andesine marginally replacing labradorite. Secondary amphibole initially preserves the relict ophitic texture virtually intact but more extensive recrystallization results in the growth of large, anhedral amphibole porphyroblasts poikilolitically enclosing the saussuritized cores of the original plagioclase.

The appinites. A detailed petrographic account of these rocks has already been given by Wells and Bishop (1955) and only the salient features need be repeated here. All the appinites are coarse grained and many are pegmatitic with amphiboles up to 10 cm in length. The amphibole is kaersutite, deep reddish-brown in colour, and strongly pleochroic. All crystals have margins of green amphibole, the junction between the two being irregular and slightly



FIGS. 1 and 2: FIG. 1 (left). a: Fluidity within an appinitic pocket demonstrated by the flow of prismatic amphiboles towards a draining vein. b: Lenticular, zoned pocket with a well-defined marginal 'amphibolite' shell. c: Zoned pocket with a diffuse marginal zone of equant amphiboles, and an internal feldspathic core with prismatic amphiboles. d: Lenticular, pegmatitic appinitic pockets showing extreme gravity differentiation producing a basal accumulation of equant amphiboles. Pockets parallel the relict layering in dioritic country rocks. FIG. 2 (right). a: Plot of Na₂O against K₂O for Jersey gabbros, diorites, and appinites. b: Plot of FeO against Fe₂O₃ for Jersey gabbros, diorites, and appinites showing an almost linear separation of the appinitic and gabbro-diorite groups at an FeO/Fe₂O₃ ratio of 2.7–2.8/1. c: AFM plot of associated appinitic–country rock (gabbro-diorite) pairs (see text for explanation).

TABLE I. Modal analyses of appinites

	J1	J2	J3	J7	J8	J9	J12	J13	J14	
Plagioclase	44.8	46.6	47.0	47.7	45.9	40.5	50.9	52.2	57.7	* Accessories include: chlorite, apatite, sphene, calcite, epidote, prehnite and pennine. Modes were made on three sides of a polished block using graph paper.
Orthoclase	2.0	0.4	1.7	0.9	5.2	6.3	1.2	1.4	2.9	
Quartz	14.8	11.4	14.0	12.9	7.4	11.1	8.7	8.0	9.3	
Amphibole	29.6	30.5	28.2	26.4	37.9	35.2	34.0	34.1	24.2	
Biotite	4.7	7.8	6.5	8.9	1.7	4.9	3.1	2.4	3.5	
Opacues	2.7	1.3	1.9	2.0	1.1	0.7	0.9	1.1	1.1	
*Accessories	1.4	2.0	0.3	1.0	0.8	1.3	1.2	0.8	1.3	

diffuse. The brown amphibole is strongly schillerized with irregular dark bars of minute, opaque magnetite rods in parallel orientation. The green rims truncate the schiller structure and contain magnetite as small, irregular granules in addition to thin lamellae of sphene along the cleavage. The relationship suggests that green amphibole is a replacement rather than an overgrowth and that the conversion of brown to green amphibole was accompanied by accretion of the schiller rods to form magnetite granules and exsolution of titanium to form sphene. The prismatic amphiboles are seldom perfectly euhedral and all larger crystals have a hollow-shell structure. That this is not the result of resorption is shown by the fact that the cores are bounded by negative crystal faces parallel to the prism faces of the amphibole. The majority of the prismatic amphiboles, especially the larger crystals, are broken in one or more places along their length. These breaks may be transverse hairline fractures or larger cracks, the unusual feature being that the resulting fragments are never dispersed over more than a few mm. Any of the felsic components can be found infilling the cracks and cores and these infills are invariably in structural and optical continuity with the external groundmass, showing that the crystal breakage was not due to post-solidification movement. Furthermore, the narrowest of fractures in the amphibole are rimmed by green amphibole suggesting that the conversion was effected by the late-stage fluid (cf. French, 1966).

The equant amphiboles are of the same composition as the prismatic type and are similarly brown in colour and rimmed by green amphibole. They are, however, invariably perfectly euhedral and are never cracked or possess felsic cores.

The felsic groundmass consists predominantly of clear oligoclase or andesine (An_{25-37}), often strongly zoned, especially at the margins. Angular interstices are occupied by quartz and orthoclase, both of which also form larger poikilitic plates enclosing euhedral plagioclase and amphibole and large numbers of hollow needles of apatite. The appinitic amphiboles are clearly of early formation, the whole assemblage showing a clear-cut sequence of crystallization, with quartz and K-feldspar representing a late-stage, interstitial liquid.

Accessory components include biotite, sphene, magnetite, and rare calcite and prehnite. Magnetite is noticeably more abundant than in the gabbroic and dioritic country rocks and frequently shows a marginal alteration to hematite.

Petrochemistry

Variation within the diorite-appinite complex. As a group the appinites show relatively little variation in either modal or chemical composition (Tables I and II). The chemistry is more tonalitic than truly dioritic. Their most distinctive mass characteristics are high alumina (16.08–19.73% Al_2O_3) and moderate to high silica content (55.42–58.50% SiO_2) together with high alkalis and an Na_2O/K_2O ratio of approximately 2/1. A plot of Na_2O against K_2O (fig. 2a) provides an effective separation of the appinites from the diorites and gabbros and also reveals differences between the south-eastern and north-western masses, the latter having higher total alkalis and a slightly higher Na_2O/K_2O ratio.

The FeO/Fe_2O_3 ratios of the Jersey diorites vary with the degree of recrystallization, the unaltered gabbros being least oxidized and the appinites the most, with the dioritic rocks falling between. A plot of FeO against Fe_2O_3 (fig. 2b) for all the analysed Jersey dioritic rocks shows a linear separation of appinites from diorites at an FeO/Fe_2O_3 ratio of 2.7–2.8. A significant feature of this is that rocks plotting very close to this line are those that show an abrupt change from a dioritic to an appinitic texture.

A feature of the appinite chemistry is high TiO_2 and P_2O_5 relative to the associated gabbros and diorites (Table II). There is no evidence of an extraneous source for these components since neither the granites nor the acid pegmatites contain more than trace amounts of TiO_2

TABLE II. *Chemical analyses and norms of appinites and associated rocks*

	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	J20
SiO ₂	58.50	56.96	58.10	56.78	56.46	56.74	58.04	58.40	57.10	55.53	57.02	56.93	55.97	55.42	58.20	47.58	66.90
Al ₂ O ₃	16.59	17.48	19.25	16.58	17.00	18.92	19.10	16.78	17.16	17.94	16.08	16.94	17.45	19.73	18.81	17.16	18.57
Fe ₂ O ₃	2.54	2.77	2.07	2.75	2.40	3.44	2.10	2.18	2.68	2.56	2.92	3.07	3.22	2.41	1.84	0.51	0.46
FeO	5.02	5.77	5.17	6.28	6.40	5.35	5.09	4.98	4.97	5.09	6.02	5.08	5.34	4.12	2.93	5.80	0.97
MgO	2.52	3.13	2.41	3.01	3.30	2.16	2.47	3.10	3.07	3.11	2.13	2.76	2.68	1.68	1.57	9.12	2.52
CaO	4.74	5.15	4.10	5.74	5.41	5.42	4.24	7.13	6.64	5.23	5.74	6.73	7.40	6.01	4.74	13.36	4.34
Na ₂ O	4.02	3.40	3.82	3.71	3.13	3.55	3.70	3.89	3.31	4.07	3.42	3.32	3.16	5.07	4.98	1.99	5.64
K ₂ O	1.94	1.50	1.81	1.31	1.68	1.30	1.71	1.23	1.65	1.91	1.48	1.74	1.66	1.16	2.00	0.90	0.37
H ₂ O ⁺	2.17	2.16	1.74	2.44	2.67	1.61	1.73	2.21	1.70	2.47	2.63	1.72	1.51	2.17	3.03	2.13	0.61
H ₂ O ⁻	0.17	0.22	0.23	0.16	0.17	0.18	0.24	0.14	0.11	0.46	0.48	0.17	0.15	0.52	0.42	0.42	0.19
TiO ₂	1.32	1.19	1.11	1.14	1.08	1.24	1.13	1.47	1.15	1.04	1.47	1.26	1.38	1.63	0.98	0.70	0.10
P ₂ O ₅	0.18	0.12	0.19	0.07	0.10	0.16	0.18	tr.	0.18	0.16	0.14	0.13	0.09	0.10	0.11	tr.	n.f.
MnO	0.13	0.13	0.11	0.15	0.13	0.10	0.11	0.14	0.11	0.14	0.11	0.11	0.12	0.10	0.07	0.11	0.04
Total	99.84	99.98	100.11	100.12	99.93	100.17	99.84	100.65	99.83	99.72	99.64	99.96	100.13	100.12	99.68	99.78	100.71

C.I.P.W. Norm

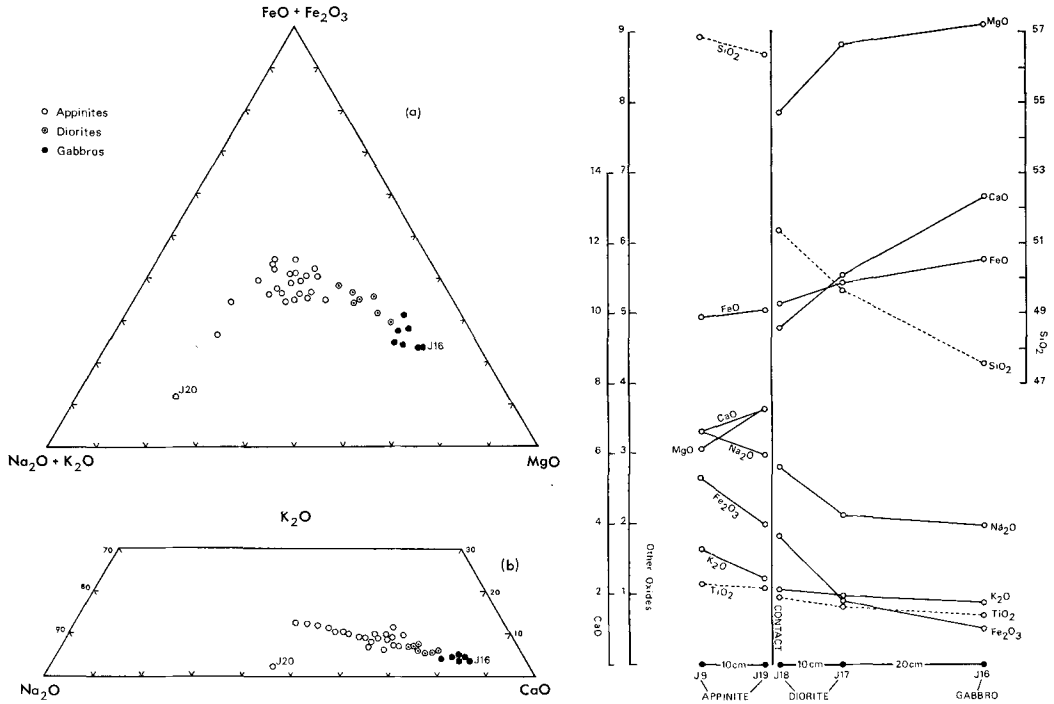
Q	12.0	12.7	14.2	9.8	11.5	14.1	14.5	11.1	11.7	6.2	14.0	12.2	10.9	5.1	7.6	—	21.0
C	—	0.9	3.6	—	0.2	1.8	3.4	—	—	—	—	—	—	—	—	—	1.7
or	11.1	8.9	10.6	7.8	10.0	7.8	10.0	7.2	10.0	11.1	8.9	10.0	10.0	7.2	12.8	5.6	2.2
ab	34.1	28.8	32.0	31.4	26.7	29.9	31.4	33.0	27.8	34.6	28.8	27.8	26.7	43.0	42.4	12.6	47.7
ne	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.3	—
an	21.7	25.6	20.3	24.7	26.7	26.7	21.1	24.7	27.2	24.7	24.2	26.4	28.4	27.2	21.7	35.3	21.7
di	1.6	—	—	3.3	—	—	—	8.8	4.8	1.1	3.7	5.7	6.8	2.0	1.6	25.1	—
hy	10.7	14.3	12.1	15.4	16.4	10.4	12.1	8.4	10.3	13.0	9.7	8.9	8.2	6.1	5.4	—	4.2
ol	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14.6	—
mt	3.7	4.2	3.0	4.2	3.5	4.9	3.0	3.3	3.9	3.7	4.2	4.4	4.6	3.5	2.6	0.7	0.7
il	2.4	2.3	2.1	2.1	2.1	2.3	2.1	2.9	2.3	2.0	2.9	2.4	2.7	3.0	2.0	1.4	0.2

J1–J15: Relatively homogeneous, coarse-grained to pegmatitic appinitic pockets (representative modal analyses given in Table I); J16: Coarse-grained ophiitic gabbro country rock showing minimal replacement of clinopyroxene by green and pale-brown amphibole. Strongly saussuritized labradorite shows incipient, marginal re-crystallization to oligoclase; J20: Upper part of a differentiated appinitic pocket representing an extreme felsic 'differentiate'.

* Chemical analyses used in plotting figures 2 and 3 but not presented in Table II are given in Key (1974) or are available from the author on request.

and P_2O_5 . It seems more likely that some form of segregation from the basic country rocks has produced the small but significant enrichment of these oxides in the appinitic pockets.

The AFM (fig. 3a) and K_2O - CaO - Na_2O (fig. 3b) diagrams are given to show the broader relationships between appinite, diorite, and gabbro. These diagrams include one composition (J20) representing the most leucocratic appinitic 'differentiate' formed by gravity separation



FIGS. 3 and 4: FIG. 3 (left). a: AFM diagram showing the calc-alkaline type variation trend in the gabbro-diorite-appinite 'series'. Compositions J16 and J20 represent the least altered gabbro and the most extreme felsic 'differentiate' respectively. b: K_2O - CaO - Na_2O plot of Jersey gabbros, diorites, and appinites showing a near linear trend at constant K_2O/Na_2O ratio and extreme relative soda enrichment in the most felsic 'differentiate' (composition J20). FIG. 4 (right). Graphical representation of chemical changes during progressive 'appinitization'. Specimens J17, J18, and J19 represent intermediate compositions across a sharply gradational contact between gabbroic country rock (J16) and a homogeneous appinitic pocket (J9).

of the amphiboles. Both diagrams show a relatively smooth, continuous variation from the most basic gabbros to the appinites. The trend appears to be the result of a progressive silica and alkali metasomatism of more basic rocks rather than liquid fractionation. The extreme relative enrichment of Na_2O in specimen J20 is not characteristic of fractional crystallization of the calc-alkaline series, which invariably produces a higher K_2O/Na_2O ratio in residual liquids (Nockolds and Allen, 1953).

Relationship between appinite and country rock. For eight of the smaller appinitic pockets a representative sample of country rock has also been analysed in an attempt to correlate the appinite chemistry with that of the host rock with a view to assessing whether a metasomatic, replacive origin is feasible for the pockets. An AFM diagram is used to represent the eight pairs since these parameters best illustrate the effect of introduced alkalis on originally more basic rocks (fig. 2c).

For seven of the pairs there is a remarkably close correlation in chemistry. All seven show similar increases in alkalis and an appreciable relative increase in iron due to displacement of MgO. The tie lines between these pairs are all of a similar length and nearly parallel, the slight deviation shown by the Ronez rocks (J14 and J15) probably being due to their geographical separation from the south-eastern mass and a possible difference in the composition of the metasomatic agents as well as of the original rocks.

This close correlation between the chemistry of the appinitic pockets and the surrounding country rocks is strong evidence of a metasomatic, replacive origin for the appinites. Appinite J7 does not conform with the other examples, suggesting a different relationship with its associated country rock. In this case the field relationships show that this appinite is an apophysis of a larger body, which, by rheomorphism, was capable of intruding the surrounding diorite, itself in a mobile but highly viscous state (Bishop, 1963; Key, 1974, pp. 134-40). This appinitic pocket is therefore regarded as being intrusive and not replacive towards the host rock.

Appinite J9 occurs as a small (0.27 m diameter) rounded pod within a gabbroic rock (J16) showing only incipient recrystallization. Intermediate compositions across the contact between the two end-members illustrate progressive changes leading to 'appinitization' (fig. 4). FeO, Fe₂O₃, TiO₂, Na₂O, and K₂O all show nearly perfect gradational variations across the contact, a fact that further supports a replacive origin for the appinites since it is unlikely that such a small body of 'magma' could produce such pronounced chemical changes in the country rock. The major bulk changes in chemistry are an increase in SiO₂ and corresponding decreases in MgO and CaO in passing from gabbro, through diorite to appinite.

Petrogenesis of Jersey appinites

Flow structures, crystal settling, and typically 'igneous looking' mineral assemblages and textures have established the presence of a liquid phase in the formation of the Jersey appinites. Close chemical ties between appinitic pockets and surrounding country rocks strongly suggest that the gabbros and their recrystallized dioritic equivalents were the starting material from which these appinites were formed. The transformation was one of metasomatic replacement with the introduction of SiO₂, Na₂O, and K₂O and resultant partial fusion of localized patches of rock. The basic rocks have been subjected to polyphase granite intrusion and both the north-western and south-eastern gabbro-diorite masses are now completely surrounded by acid rocks. Hydrous volatile emanations carrying silica and alkalis from the granites are therefore invoked as the agents affecting this transformation. The mechanism by which the volatiles entered the basic rocks is envisaged as one of intercrystalline diffusion, although some of the more extensive appinitic bodies may represent better defined channels, perhaps along structural defects in the original gabbro. The parallelism of certain appinitic layers with the original gabbroic layering suggests that variations in composition and texture of the gabbro, particularly its grain size, to some extent controlled the diffusion of volatiles and therefore the formation of appinites. This diffusion may also account for leaching of TiO₂ and P₂O₅ from the basic rocks and their concentration in the appinites.

The exact nature of the prevailing physical conditions are more difficult to establish. The north-western and south-eastern gabbros and metasomatic diorites are completely surrounded by granite and frequently contain a complex network of sheets, veins, and irregular apophyses of acid rock. From their close proximity to the granite it may be assumed that the basic rocks attained the temperature of the granitic magma at the time of intrusion. In order to initiate melting in gabbroic or dioritic rocks temperatures in excess of the ternary granite minimum are required, possibly of the order of 900 °C or more. Such temperatures may not be unreasonable in the envisaged high-level sub-volcanic environment since Fyfe (1970) points out several

lines of evidence suggesting that granitic magma temperatures can exceed 800 °C. The presence of poorly perthitic orthoclase rather than microcline in both granites and appinites supports a high temperature of formation.

Since the basic rocks would have been initially dry prior to the granite intrusion they would be below their solidus temperature under the envisaged conditions. If, however, their initial temperature was above the solidus temperature for conditions of $P_{\text{H}_2\text{O}} = P_{\text{Total}}$ then the introduction of water into the system would cause partial melting. Tuttle and Bowen (1958) describe the adiabatic crystallization of granite due to the removal of water, and Bailey (1970) points out that the reverse process, melting by addition of water, must be a possibility given the appropriate conditions. These conditions are that the rock must be within its 'wet-dry' melting range defined by the solidus curve at $P_{\text{H}_2\text{O}} = P_{\text{Total}}$ and the anhydrous liquidus curve. At any temperature and pressure within this field a dry rock will begin to melt or increase its volume of melt on addition of water to the system.

The original gabbroic composition (e.g. J16) is very similar to the high-alumina basalt of Yoder and Tilley (1962) and from their data on the hydrous solidus curve of this rock it seems unlikely that granitic magma could bring a rock of this composition to within its 'wet-dry' melting range. However, when the change in composition due to the metasomatic introduction of silica and alkalis is taken into consideration it becomes possible to produce a relatively high proportion of melting. In a tonalite of similar composition to the Jersey appinites Piwinskii (1968) was able to produce 30% melting at 800 °C and 2 Kb $P_{\text{H}_2\text{O}}$, and 45% melting at 900 °C and 2 Kb $P_{\text{H}_2\text{O}}$. More extensive melting is reported by Büsch (1970) who produced a 70% 'mobilizate' in a quartz-diorite at 790 °C and 2 Kb $P_{\text{H}_2\text{O}}$. In Piwinskii's experiments the proportion of melt increased considerably with relatively small increases in pressure above 2 Kb $P_{\text{H}_2\text{O}}$.

The production of large crystals and pegmatitic textures is normally interpreted as being due to very slow rates of cooling under tranquil conditions. Certain features of the Jersey appinites suggest that a much more rapid rate of crystallization was necessary to produce the observed textural features. The amphiboles are always of early formation and it is difficult to envisage a mechanism that would keep large prismatic crystals of high density suspended for any great length of time in a volatile-rich melt of low viscosity. A rapid crystallization of both amphibole and felsic minerals seems more feasible since this 'freezing in' process would also account for the breakage of the crystals, due to crystallization stresses in the surrounding medium. Rapid solidification of the felsic components is also necessary to prevent dispersion of the resulting amphibole crystal fragments. These skeletal, prismatic amphiboles, which invariably have a hollow-shell structure and many growth imperfections, are obviously more consistent with rapid crystallization than slow growth under equilibrium conditions, when more perfect crystals would be expected to form.

Cessation of the volatile influx and possible reduction in heat flow along volatile channels may have reduced the temperature to some extent but it is doubtful whether this process could have been rapid enough to cause quench crystallization. The outward diffusion of volatiles, including alkalis, from the melt is more likely to cause rapid crystallization by changing both the composition of the melt and the composition and partial pressures of the volatile phase. A significant point in this connection is that Piwinskii (1967; 1968) accidentally produced acicular quench amphiboles in experimental melting of tonalites by loss of water and dissolved alkalis and silica from the capsule. Further experimental work bearing on this problem is found in the investigations of Hamilton *et al.* (1964) on the effects of varying oxygen partial pressures in iron-bearing systems. They showed that low oxygen fugacities produced marked reductions in the melting temperatures of mafic rocks. In a system such as that envisaged for the Jersey

appinites where water is being added to the melt it is possible that increased oxygen fugacity may reverse the process so as to increase the liquidus temperature of the iron-bearing phases above a critical level and produce rapid crystallization of kaersutitic amphibole. The late-stage exsolution of magnetite, its marginal alteration to hematite, and the conversion of brown to green amphibole support the possibility of an increase in the oxygen partial pressure.

In contrast, the equant idiomorphic amphiboles, which lack felsic cores, are interpreted as early formed amphiboles crystallizing in equilibrium with the melt and settling under gravity to form a cumulus phase in the differentiated pods and layers. Their occurrence as a marginal amphibolite shell in the zoned pockets is probably due to the outward diffusion of Fe, Mg, and Ca inducing nucleation of amphibole at the pod margins. In this respect it is significant that the amphiboles produced in Yoder and Tilley's (1962) and Piwinski's (1967; 1968) experiments were always well-formed, stubby crystals under equilibrium conditions, whereas the quench amphiboles had a marked acicular form and were of relatively large size. The analogy is even closer in melting experiments on the Jersey dioritic rocks where quench amphiboles, as well as being acicular, have hollow, glass-filled cores (Condliffe, 1973).

The bulk chemistry of the appinites is quartz-dioritic or tonalitic rather than truly dioritic. Although they have a very narrow range of composition, the appinitic pockets have been shown to have retained some of the chemical characteristics of the host rocks, which show considerable variation. This is especially seen in the differences between the south-eastern (Le Nez) and the north-western (Ronez and Sorel Point) rocks. Gradational changes in chemistry between appinite and host rock suggest that at a certain compositional threshold, attained by progressive metasomatism, a considerable degree of partial melting occurred from which appinitic diorite pegmatite later crystallized. This threshold coincides with a specific FeO/Fe₂O₃ ratio of 2.7–2.8, suggesting that the oxygen fugacity played a significant role in producing the appinitic texture. The increase in oxygen partial pressure as indicated by chemistry and mineralogy is attributed to the dissociation of water and preferential loss of hydrogen from the system.

The gabbro–diorite–appinite series show smooth chemical variation curves but these cannot be directly attributed to a liquid line of descent. Progressive silica–alkali metasomatism has superimposed a typically calc-alkaline trend on gabbroic rocks of possibly tholeiitic affinities. This differs from similar trends assumed to be due to liquid fractionation in that late 'differentiates' show an unusual enrichment in TiO₂ and P₂O₅, and a marked increase in the Na₂O/K₂O ratio. These features are irreconcilable with crystal–liquid fractionation and may prove useful in distinguishing between calc-alkaline series produced by liquid fractionation and those produced by contamination or hybridization.

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