The Iglesia Irca intrusion and the role of gas brecciation in the emplacement of the Coastal Batholith of Peru

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Summary. In the Iglesia Irca intrusion early undifferentiated pulses of granitic magma were emplaced at pressures of approximately 1 kb as narrow dykes of vesicular felsite. These dykes are associated with penecontemporaneous burst breccias and gas breccias and are themselves sometimes brecciated. Subsequently a large dyke of granophyre, representing a more fractionated composition, was emplaced by subsidence and stoping along the line of earlier microbreccias, explosion breccias and felsites. The dyke cooled relatively slowly at low structural levels and retained its volatiles while at higher levels more rapid cooling accompanied the greater escape of volatiles. This resulted in marked potassium enrichment of the upper levels of the dyke and the country rocks of the hanging wall. It is argued that the Iglesia Irca intrusion provides an example of the association of gas brecciation with vesiculating and volatile-rich magma which is atypical of the Coastal Batholith as a whole.

1. Introduction

The Mesozoic–Cenozoic Coastal Batholith of Peru is one of the most pronounced linear zones of repeated intrusion in the world (inset, Fig. 1). The belt is everywhere straight, orientated parallel to the offshore trench and flagrantly cross-cuts the surface geology (Cobbing & Pitcher, 1972 *b*). In Central Peru it has been established by Cobbing & Pitcher (1972 *a*) that the batholith is intruded into eugeosynclinal strata of Cretaceous age. The composite batholith was emplaced over a time span of 100–10 Ma (Stewart, Evernden & Snelling, 1974) at a high crustal level (at pressures of 1–2 kb according to Atherton & Brenchley, 1972) and there is probably a close genetic connection between the Tertiary volcanic strata which unconformably overlie the Cretaceous rocks and the later phases of plutonism related to the well-defined ring complexes (Knox, 1974). Indeed there is evidence of contemporaneity of batholithic intrusion and vulcanicity over most of the time span of batholith emplacement (Bussell, Pitcher & Wilson, 1976).

In the type region of the Rio Huaura, Cobbing & Pitcher (1972 *a*) recognized a sequence of intrusions from early batholith gabbros, through large dioritic and tonalitic plutons of the Santa Rosa and Paccho suites, to a series of later stocks and cauldrons of the centred complexes with numerous high-level subvolcanic characteristics. A similar broad sequence of intrusions is present in the Moro region (Bussell, 1975, unpubl. thesis, Liverpool Univ.), where the Iglesia Irca porphyritic granophyre intrusion, the subject of this paper, is emplaced into Santa Rosa tonalite and is part of the relatively late evolution of the batholith. The intrusion possesses several interesting features which indicate the significance of brittle fracture, tectonic and gas brecciation and de-gassing of magma, to the intrusion process in this high-level structural environment.

2. Field relations

The Iglesia Irca intrusion has the form of a large N–S trending dyke emplaced close to the eastern margin of the batholith (Fig. 1) where the strong relief of the area makes possible the examination of the intrusion over a vertical range of 750 m. The dyke has steep, sharp contacts which generally dip to the E and the intrusion is emplaced along the line of a composite screen of gabbro and volcanics enclosed entirely by tonalite. Away from the outcrop of the Iglesia Irca dyke, the gabbro is undisturbed and itself forms a dyke in the volcanic and sedimentary envelope rocks (Fig. 1). Thus it seems that a marked N–S linearity existed along this eastern margin of the

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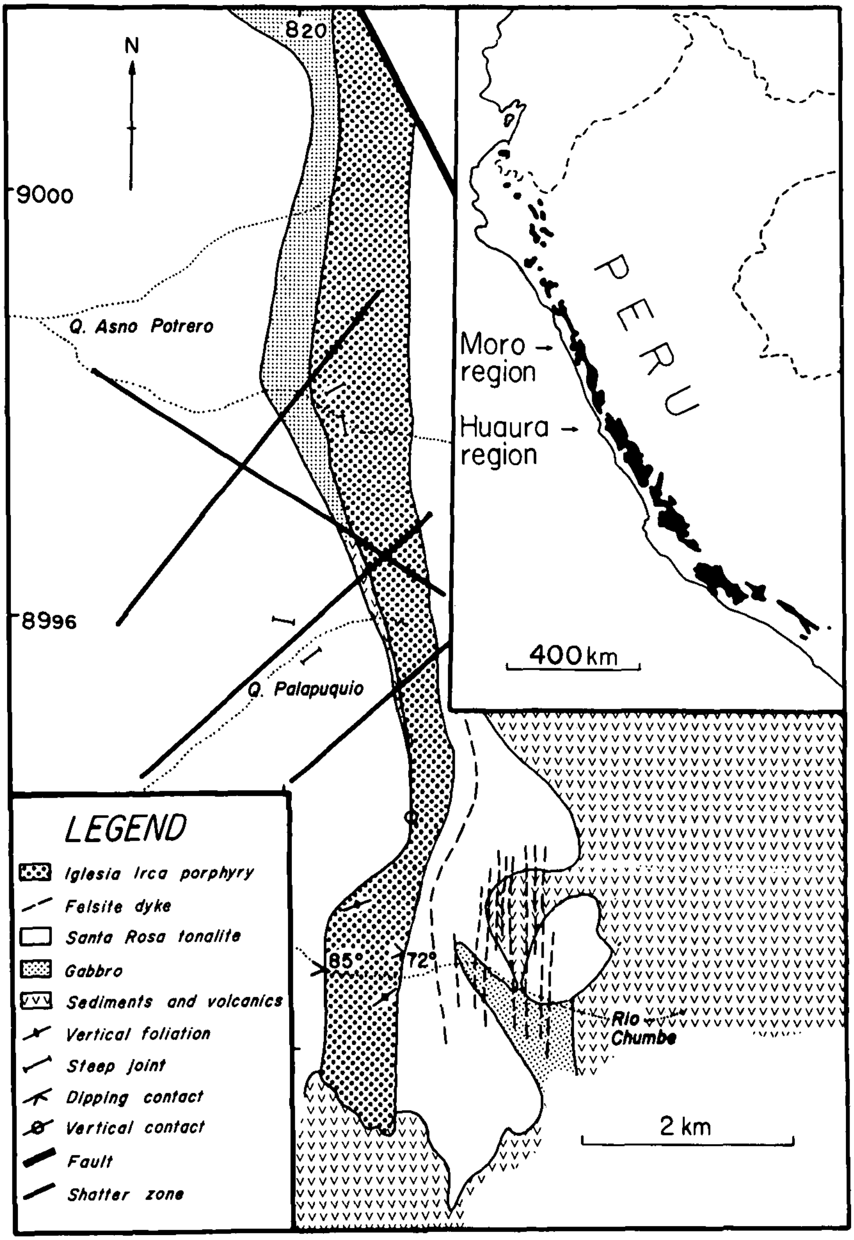

Figure 1. Geological map of the Iglesia Irca intrusion in the Moro region of Peru located in the inset.

batholith during the early episode of gabbro emplacement and that this structural line of weakness influenced the subsequent stoping of screen rocks into the Santa Rosa tonalite and the still later intrusion of the Iglesia Irca dyke.

Field observations indicate that a distinct sequence of events led up to the emplacement of the granophyre, the first of which was the formation of a series of breccias in the country rocks which now lie to the E of the main dyke. Breccia dykes within the siltstones of the envelope have irregular margins and clasts consist entirely of sub-angular to sub-rounded fragments of siltstone, ranging in size from microscopic to over 1 m in length. The matrix material consists of pulverized siltstone which contains euhedral and fragmented plagioclase phenocrysts. Breccias in the Santa Rosa tonalite are associated with irregular shear zones which develop into anastomosing networks of microbreccia and isolate blocks of relatively underformed tonalite. Such zones of breccia may have planar margins or, by contrast, pass outwardly into ramifying irregular shear zones and finally into undeformed tonalite (Fig. 2).

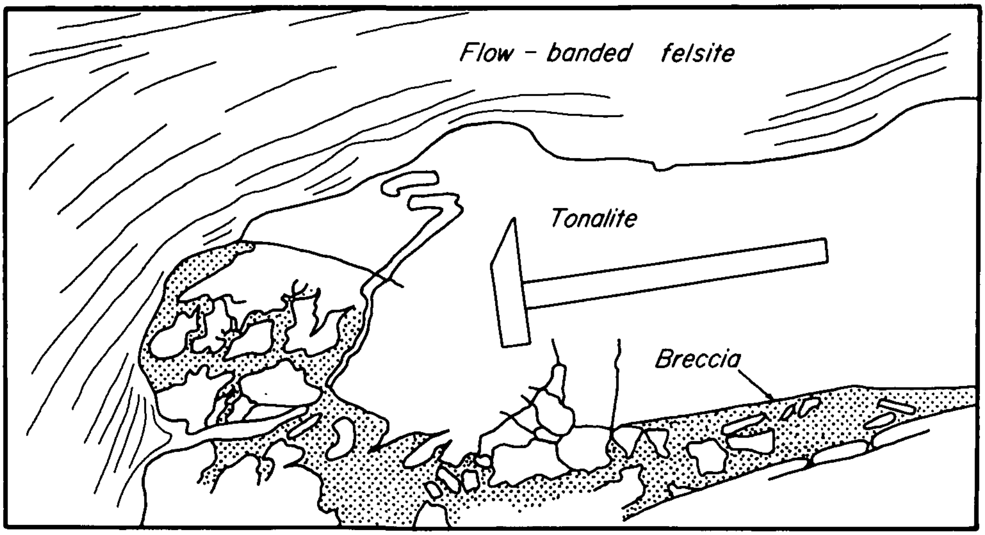

Figure 2. Early burst breccia in Santa Rosa tonalite showing the *in situ* nature of the fragments and the spalling effects along the margin of the breccia. Both tonalite (blank) and breccia (stippled) are cut by a flow-banded felsite dyke of the Iglesia irca suite.

The breccias are cut by a series of steep, flow-banded, amygdaloidal dykes of porphyritic felsite (Fig. 2) which strike parallel to the main dyke but, like the breccias, are restricted entirely to the E of the Iglesia Irca intrusion (Fig. 1). Faulting subsequently occurred along the potential contacts of the main granophyre intrusion and this was accompanied by the development of mylonitic rocks against which the fault-guided granophyre may now be found in contact. Deformation evidently occurred before granophyre intrusion since mylonitized felsite, gabbro and tonalite are all veined and stoped by the granophyre along steep contacts. Asymmetric microfolds which are developed in some contact mylonites suggest that subsidence of the country rocks which lie to the W of the intrusion took place either before or during the process of final intrusion.

The principal feature within the granophyre at low structural levels (at an altitude of 1050 m in the Rio Chumbe) is the development of vugs and cavities containing reniform hematite, epidote, pyrites and coarse granular quartz. These vugs are restricted to the eastern margin of the intrusion and are associated with NE–SW trending zones of mylonitic, possibly protoclastic, foliation in the granophyre. At intermediate structural levels (at an altitude of 1400 m in the southern branch of Q. Asno Potrero, Fig. 1) a steep NE–SW trending joint direction is very strongly developed and immediately adjacent to these joints the grey porphyry is converted to a coarser-grained pink rock with a granular texture, rich in orthoclase and quartz. Small vugs contain minute amounts of epidote and hematite. At the highest structural levels (at an altitude of 1800 m in the northern branch of Q. Asno Potrero) the whole dyke has undergone this alteration while a further significant feature is the development of patchy growths of pink orthoclase feldspar at all structural levels in the Santa Rosa tonalite which lies to the E of the Iglesia Irca intrusion. These field relations are summarized diagrammatically in Figure 3.

3. Petrography

3.a. The felsites

Few of these rocks are entirely glassy, some have a felsitic to spherulitic groundmass while others have recrystallized to a greater degree with the formation of large plates of feldspar. These overgrow earlier phenocrysts and smaller euhedral laths of oligoclase giving the rock distinctive porphyritic and poikilitic textures. Some felsites contain round and stretched elliptical amygdales containing epidote and radiating clusters of quartz. Phenocrysts are dominantly andesine (An_{32}) which in some cases have broad normally zoned rims down to An_{20}. Some of these phenocrysts have armoured rims of unusually coarse groundmass material while fine oscillatory zoning is not uncommon. Plagioclase alters readily to epidote while biotite and chlorite pseudomorph hornblende phenocrysts.

Vitrophyric felsites develop excellent banding along which phenocrysts, trails of ore and rock fragments are distributed; autobrecciation and incorporation of vesiculated shardic material occurs locally. Thus, it seems that the banding represents the flow of liquid past more viscous material. Elsewhere no sharp discontinuity across the banding can be seen but matrix foliation with pseudo-snowball structures around inclusions indicates differential flow of liquids either side of the banding, probably as a result of viscosity contrast.

3.b. The breccias

The matrix of a breccia developed in the siltstone consists of grains of unstrained clastic quartz with fine-grained muscovite and chlorite distributed interstitially and along intergrain boundaries. Large euhedral oligoclase phenocrysts are very similar to those of the felsites but have suffered a much higher degree of sericitization; some are fractured and broken.

3.c. The altered Santa Rosa tonalite of the eastern contact

In thin section the tonalite to the E of the main dyke is similar to the tonalite W of the dyke except for the evolution of very large patches of coarse orthoclase perthite, some of which develops Carlsbad twinning. This feldspar has a clearly corrosive relationship to the tonalite texture and it is especially important that it corrodes, isolates and includes earlier, much smaller interstitial patches of orthoclase perthite which are primary constituents of the normal tonalite texture (Bussell, 1975, unpubl. thesis, Liverpool Univ.). Within some of the orthoclase, excellent examples of graphic intergrowth are found and these are also foreign to the normal tonalite texture. Where the intergrowth is best developed there is a regular geometrical relationship between the orthoclase and the earlier quartz of the tonalite whereas elsewhere irregular corrosion and inclusion of earlier quartz is the norm.

3.d. The porphyry of the main dyke

Vertical petrographic variation in the dyke is particular significant and is illustrated by thin sections from the Rio Chumbe (1050 m altitude), Q. Palapuquio (1300 m) and Q. Asno Potrero (1400 m). In Q. Asno Potrero, plagioclase phenocrysts are euhedral and normally zoned with cores of An_{25-35} and rims of An_{16} while biotite, epidote, ilmenite, magnetite and sphene form pseudomorphs of earlier hornblende phenocrysts. The matrix material is dominantly a granophyric intergrowth of quartz and microperthite in a ratio of 36:64 and this forms radial

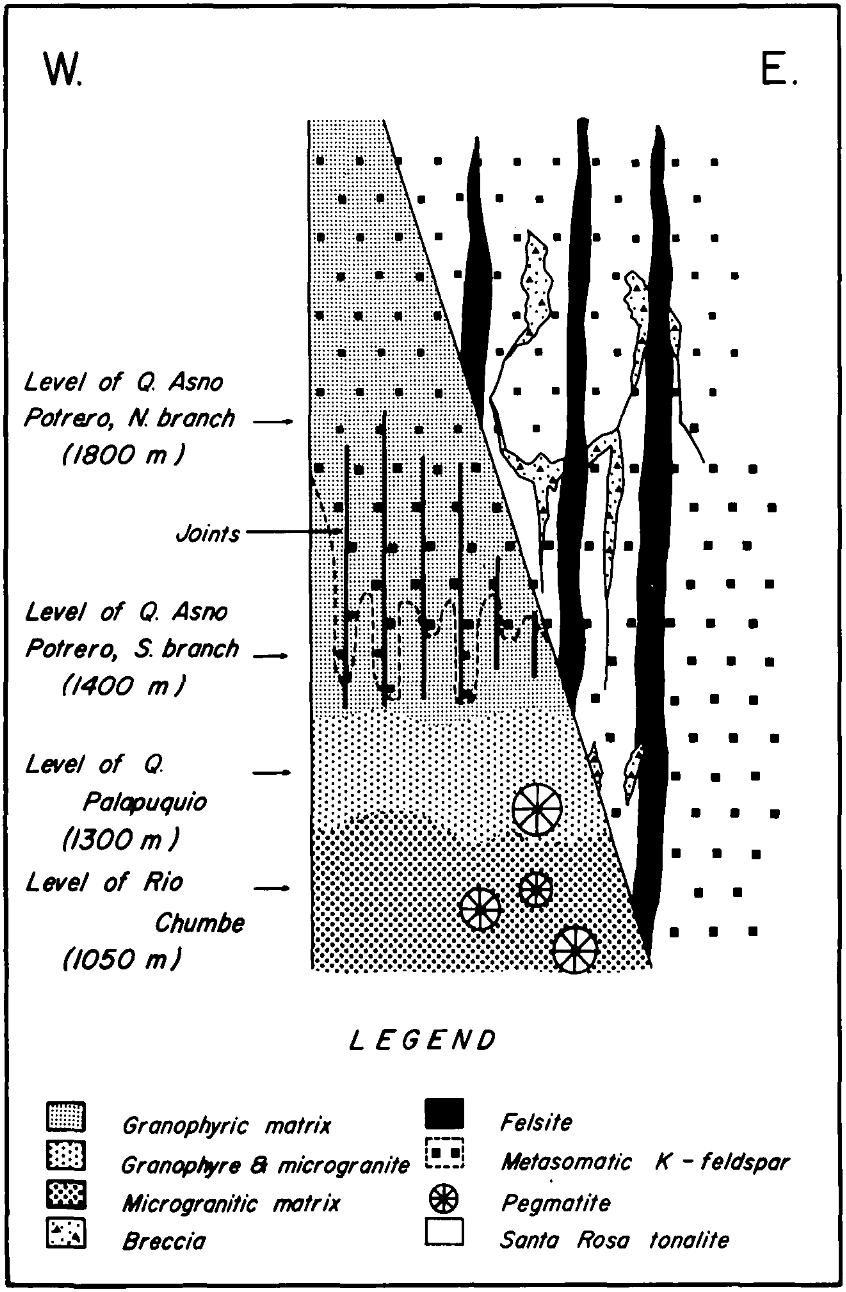

Figure 3. Diagrammatic synthesis of significant petrographic features and field relations of the Iglesia Irca intrusion.

patterns around the plagioclase phenocrysts. Less common are intergrowths of quartz with perthite; these intergrowths are much coarser than those involving microperthite and this coarse orthoclase perthite is also the dominant feldspar in those portions of the groundmass where granophyric intergrowths are subordinate and larger anhedral grains of quartz and feldspar are most common. A thin section of the altered rock adjacent to a joint at the same locality (section 2, above) discloses a modification of texture in which the granophyric matrix is entirely recrystallized to a coarser granitic aggregate which has also replaced earlier plagioclase phenocrysts to a large extent.

In the thin section from Q. Palapuquio a greater variety of phenocrysts is present with euhedral primary brown hornblende, biotite and zoned oligoclase. The hornblende is rimmed by granules of ilmenite or totally replaced by chlorite, biotite, ilmenite and sphene. Some plagioclase phenocrysts have several narrow discordant rims of more albitic feldspar and these are fringed by lobes of myrmekitic intergrowth which extend into adjacent orthoclase. Some plagioclase phenocrysts are shattered and fragmented with hollow cores which are filled and veined by more albitic rim plagioclase. The matrix consists of small euhedral crystals of oligoclase-albite composition, fragments of earlier phenocrysts, interstitial microgranitic material and a small amount of granophyre.

Finally, in the thin section from the lowest exposed levels of the dyke in the Rio Chumbe, phenocrysts of euhedral zoned plagioclase again dominate the texture with cores of An_{33-28} and rims of An_{25}. Aggregates of ilmenite, epidote, biotite and sphene probably represent degraded relics of ferromagnesian minerals. By contrast with the granophyres of higher structural levels, the matrix is a regular microgranitic network of slender laths of euhedral plagioclase with interstitial, anhedral quartz and orthoclase perthite. A notable feature is that circular patches of optically continuous quartz enclose smaller minerals and within these patches occasional very coarse relics of a granophyric texture can be found. These petrographic variations within the dyke, together with significant field relations, are summarized in Figure 3.

4. Discussion

The subvolcanic association of explosion breccias, felsite and granophyre is a phenomenon that has long been recognized in the Tertiary volcanic province of Great Britain and elsewhere (Dunham, 1965, 1967; Hughes, 1960, 1971). The writers have little hesitation in comparing the Cerro Iglesia Irca granophyre and associated minor intrusions directly with these other occurrences.

4.a. Breccias and felsites

An origin by explosive comminution for the breccias formed in the siltstones is undoubted from the field and microscopic observations (sections 2 and 3.b. above). The reconstituted siltstone matrix of the breccia clearly suggests pulverisation of the sediment and bears comparison with the breccia in a sandstone described by Barrington & Kerr (1961). The presence of the sometimes fragmented plagioclase phenocrysts links this to an explosively degassing phenocryst-containing magma at greater depth and the close association of the breccias with amygdaloidal felsites has been noted. The lack of any strong fabric orientations, and the local origin of the fragments, further argues for origin by explosive brecciation with little transport involved at the present level (Bowes & Wright, 1960); the lack of well-developed platey fabrics and penetrative mylonitic fabrics demonstrates that these rocks are explosion breccias with none of the characteristics of mylonites (Higgins, 1971).

The early microbreccia dykes which formed in the tonalite ahead of the advancing felsites (Fig. 2) probably formed the conduits along which emplacement and explosive de-gassing of the magma took place, thus fulfilling a similar function to the microbreccias of Gates (1959). These microbreccia dykes when most fully developed are remarkable for their lack of planar fabric and the disoriented nature of the fragments within them, some consist simply of irregularly developed networks of sheared rock and microbreccia enclosing *in situ* blocks and they lack even the sharp margins of the dykes. These breccias are evidently tectonically generated and are interpreted after Gates (1959) as burst breccias; the result of rapid dilation of a fracture which results in the fragmentation, collapse and comminution of the walls of the fracture. Such tensile fractures and tensile shear fractures were probably generated above the rising magma and followed the line of earlier ductile shear zones as described by Myers (1975) for similar structures.

The breccias are spatially associated with the felsites and are generally earlier; however, one of the breccias definitely formed after the emplacement of felsite but before faulting associated with porphyry emplacement. Hence a degree of overlap of explosive brecciation and felsite intrusion is indicated. The absence of explosive phenomena from the porphyry margins and the close association of breccias with felsites leads to the conclusion that the explosion breccias are closely related to the felsites. These show plenty of evidence, in their amygdales, of an exsolving gas phase and the volatiles probably reduced the viscosity of the magma permitting very rapid emplacement (Lacey, 1960) and equally rapid (probably explosive) de-gassing. The same relationship between felsites and explosive brecciation has previously been proposed by Dunham (1965) and Hughes (1960).

4.b. The crystallization of the Iglesia Irca porphyry

Before discussing the salient features of the Iglesia Irca dyke, a brief review of plutonic granophyres is necessary.

The work of Brown (1963) on the Skye granophyres demonstrated the possibility of producing granophyre by the high-level crystallization of a liquid. Interstitial granophyre in more basic intrusions has often been referred to crystallization of a granitic liquid at a eutectic and as early as 1921 such an explanation of granophyric texture had been proposed by Vogt. However, Jahns, Martin & Tuttle (1969) suggested that such mesostasis might equally well be the result of late metasomatic alteration and have provided experimental evidence in support of this. Field evidence of the *in situ* origin of granophyre through metamorphic and metasomatic alteration of solid rock is not lacking. Experimental work (Schloemer, 1964) demonstrated the possible polygenetic origin of granophyre as a product of:

(1) Simultaneous crystallization of quartz and orthoclase-feldspar from a liquid.

(2) Simultaneous crystallization of quartz and orthoclase-feldspar from a glass.

(3) Metasomatic alteration of a pre-existing quartzofeldspathic aggregate. Hence the most balanced view would be to concur with Barker (1970) that each occurrence of granophyre must be treated on its merits.

In the case under consideration the Iglesia Irca intrusion occupies a steep discordant conduit with the form of a dyke and is associated with earlier felsites, which were almost certainly emplaced as liquids. The crystallization sequences of the felsite and the granophyre are very similar with plagioclase always early, while veining and stoping by the granophyre are further suggestive of emplacement as a liquid. In thin section too, the evidence of resorbtion, corrosion, fragmentation and incorporation of the phenocrysts in the granophyric matrix suggests the suspension of the crystals in a fluid while no evidence of glass or its former presence was observed.

A consideration of the chemistry of the felsite and the granophyre shows them to be systematically related in composition (Table 1). The felsite composition (A) is more 'primitive' than that of the unaltered granophyre (B and C) and equilibrium plagioclase compositions are more anorthitic in the felsite than in the granophyre (Table 1), both features in keeping with the earlier injection of the felsite. The data indicates a steady trend of potassium and silica enrichment with calcium and sodium depletion (A–D in Fig. 4A), a trend to be expected from the fractionation of an acid liquid with one feldspar (Carmichael, Turner & Verhoogen, 1974, p. 232). This trend is consistent with the earlier emplacement of the felsites, the later emplacement of the

Table 1. Analyses, norms and selected modes of the Iglesia Irca suite and country rocks A: Sp99, felsite from 0821689939; B: Sp93a, porphyritic microgranite from 0820589927; C: Sp133, porphyritic granophyre from 0820389981; D: Sp133A, altered granophyre adjacent to a joint at 0820389981; E: Sp96, Santa Rosa tonalite W of the Iglesia Irca dyke at 0820489927; F: Sp117, Santa Rosa tonalite from the E of the Iglesia Irca dyke at 0821989925. Analyses and norms in wt. %, modes in vol. %.

	A	B	C	D	E	F
SiO_2	71.91	71.58	70.73	76.55	66.58	65.84
TiO_2	0.25	0.31	0.28	0.12	0.48	0.51
Al_2O_3	14.15	14.38	14.17	12.50	15.73	14.87
Fe_2O_3	0.55	—	0.36	1.21	1.56	1.81
FeO	1.05	1.13	1.32	—	2.33	2.50
MnO	0.08	0.08	0.10	0.06	0.14	0.14
MgO	1.00	0.76	0.94	0.52	1.73	1.80
CaO	2.39	1.83	1.37	0.64	4.21	3.32
Na_2O	4.80	4.27	4.31	3.61	4.76	3.86
K_2O	2.24	3.70	3.64	5.01	2.20	3.91
P_2O_5	0.06	0.08	0.05	0.02	0.14	0.13
Total	98.48	98.12	97.27	100.24	99.86	98.69
Quartz	28.0	27.0	26.3	33.4	17.4	16.6
Corundum	0.0	0.2	0.8	0.0	0.0	0.0
Orthoclase	13.2	21.9	21.5	29.6	13.0	23.1
Albite	40.6	36.1	36.5	30.5	40.3	32.7
Anorthite	10.5	8.6	6.5	3.0	15.1	11.7
Diopside	0.8	0.0	0.0	0.0	4.1	3.3
Hypersthene	4.7	3.6	5.1	3.2	8.6	9.8
Ilmenite	0.5	0.6	0.5	0.2	0.9	1.0
Apatite	0.1	0.2	0.1	0.0	0.3	0.3
Total	98.4	98.2	97.3	99.9	99.7	98.5

	A	B	C
Modal % plagioclase phenocrysts (vol. %)	12.82	23.00	20.47
An. content of phenocryst core	32	28–33	25–35
An. content of phenocryst margin	32	25	16

more differentiated granophyre and the large-scale potassic alteration associated with the late stages of consolidation of the main intrusion. Estimations of the percentage of plagioclase phenocrysts in three of the analysed rocks and optical determination of their anorthite contents have been made (Table 1), thus permitting the quenched liquid compositions represented by the matrices of these rocks to be calculated and these have been plotted on Figure 4A (G–I). Despite the error inherent in the assumption that all the alkali feldspar in the plagioclase is albite and the fact that amygdale quartz is present in the felsite, the trend of fractionation suggested by the four analyses is confirmed and it seems that the fractionation trend evolved dominantly by the early separation of plagioclase.

The Iglesia Irca data have also been plotted on the $An_{3.2}$ plane of the granodiorite tetrahedron in Figure 4B together with phase boundaries for $P_{H_2O} = 1$ kb and $P_{H_2O} = 3$ kb extrapolated from the data of James & Hamilton (1969). Considering the field evidence that the magmas were near saturation point at the present level, that they were strongly chilled and that plagioclase consistently crystallized first throughout the fractionation trend, it seems likely that the trend could not have been completed at water vapour pressures very much in excess of 1 kb (Fig. 4B). From Figure 4A it can be seen that, as a result of plagioclase separation, matrix compositions of the main granophyre (H and I) approached the whole rock chemical composition of the altered granophyre adjacent to the joints (D). It seems that adjacent to joints at these intermediate levels the rock was consistently more exposed to reaction with the residual magma and equilibrated with it to a greater degree than the bulk of the granophyre porphyry further from the joint

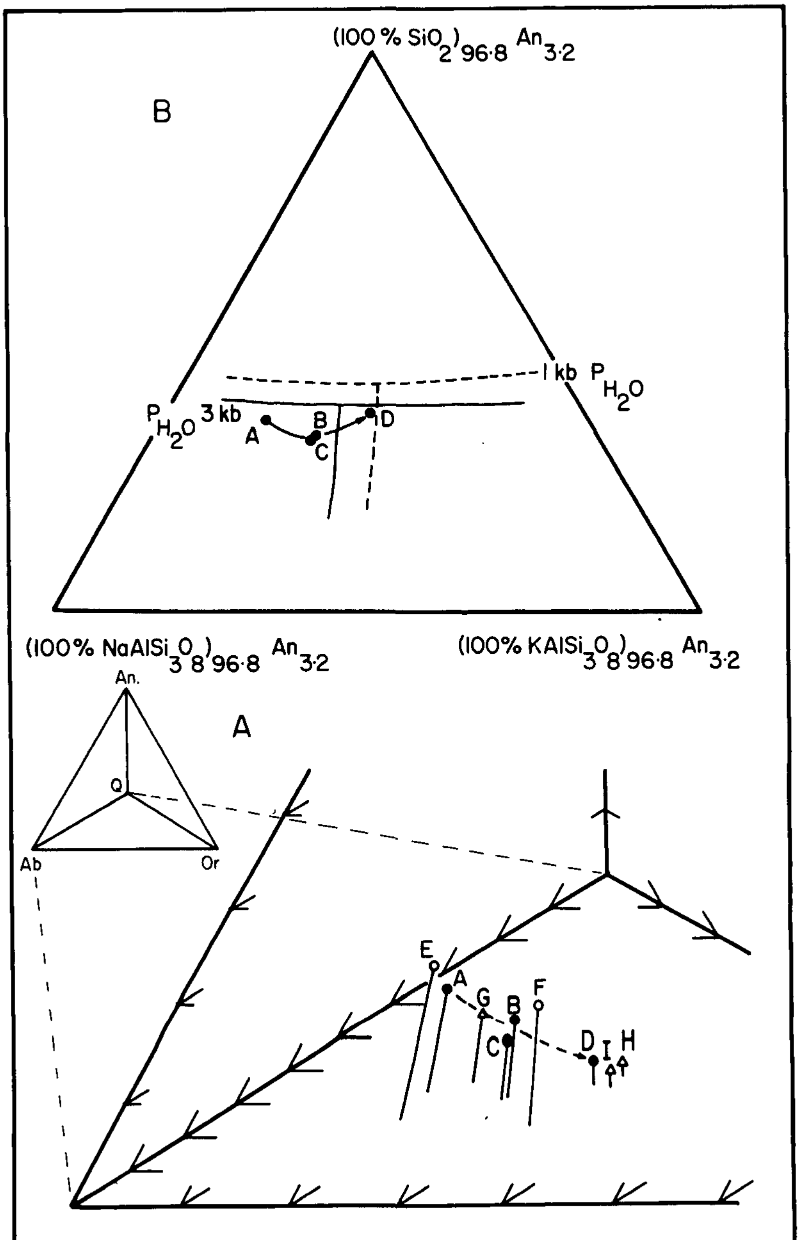

Figure 4(A). Diagram of the granodiorite system showing a plot of normative compositions calculated from Table 1 together with the estimated matrix compositions of specimens A, B and C. (B) Diagram of the $An_{3.2}$ plane of the granodiorite system with phase boundaries for $P_{H_2O} = 1$ kb and 3 kb (extrapolated from the data of James & Hamilton, 1969) with the normative compositions of the rocks of the Iglesia Irca suite from Table 1 plotted. Projection lines onto the base of the figure are from the anorthite apex.

surfaces. The matrix was recrystallized to a coarser microgranite at the same time (3.d, above) and at higher levels the whole dyke was similarly affected.

In thin section all gradations from a porphyritic texture dominated by a granophyric matrix at high levels to a porphyritic microgranite with rare relict patches of granophyre at lower levels were observed (see 3.d). Such a range of textures was interpreted by Hughes (1971) as being the result of successively slower cooling rates; the result of differential retention of a volatile phase, thus rapid volatile loss and rapid chilling results in granophyric textures while slower cooling produces a microgranite. These different facies of the Iglesia Irca porphyry display an interesting vertical distribution in the dyke (Fig. 3). The microgranite is found to be be dominant at the lower (1050 m) levels while the amount of matrix granophyre increases with altitude until, at the 1400 m level, granophyre is dominant with only small amounts of matrix microgranite. At the lower levels of the dyke, pegmatites are fairly common. At higher levels these are not found on the same scale but the granophyre along the joints is altered to give a similar assemblage to the pegmatites with the addition of orthoclase (Fig. 3). Thus it appears that slow rates of crystallization with greater retention of volatiles and *in situ* crystallization of the late magmatic liquids took place at low levels in the dyke giving a microgranite with pegmatitic cavities. At successively higher levels more rapid crystallization accompanied an increasingly greater loss of volatile-rich residual liquids which penetrated along joint conduits producing alteration effects; the de-gassing froze in a dominantly granophyric texture before crystallization of a large amount of coarser micrograniticmatrix could occur. The data demonstrates a fractionation trend of potassium enrichment and the highest level of the dyke was most affected by reaction with the potassium-rich residual magma which streamed off from the consolidating intrusion, thus the highest level of the dyke was entirely altered in the solid to an aggregate of coarse orthoclase perthite and quartz with vugs.

An interesting feature of the late magmatic–metasomatic alteration is that it is concentrated in the upper parts of the dyke itself and in the country rocks of the easterly dipping eastern margin, and this is emphasized by a comparison of the K_2O contents and normative compositions of Santa Rosa tonalite from the unaltered western and the metasomatized eastern margin of the dyke (see E and F of Table 1 and Fig. 4A). The possibility must be mentioned that the two Santa Rosa tonalite analyses represent unaltered members of an independent fractionation trend which evolved before the emplacement of the Iglesia Irca intrusion. However, it is thought more likely that the contrasting K_2O contents resulted from the vertical rise of volatile rich residual liquids within the dyke and their channelling along the hanging wall with subsequent permeation of the overlying Santa Rosa tonalite wall rocks. Similar kinds of effects have been noted elsewhere by Orville (1960) and Jahns & Tuttle (1963). Thus the absence of significant potassic alteration along the vertical western contact of the dyke is to be expected. Thin section observations support a metasomatic origin for the orthoclase and the intergrowths in the tonalite. The large K-feldspar plates are obviously much later than the rest of the tonalite fabric which they replace and enclose. The angular, sharp intergrain boundaries between replacive orthoclase and recrystallized quartz and the textural evidence of discordant graphic intergrowths are all indicative of metasomatic recrystallization in the solid. All field and textural observations combine to place the balance of the evidence strongly in favour of a metasomatic origin for the potassium in the tonalite.

A final point concerns the relationship of envelope and pluton joints. It has been shown that conjugate joints similar to envelope joints developed at an early stage in the consolidation of the host Santa Rosa tonalite (Bussell, 1975, unpubl. thesis, Liverpool Univ.). Lineaments trending approximately NE–SW are present on air photographs and in Q. Palapuquio, to the W of the dyke, NE–SW trending mylonites are found in the tonalite (Fig. 1). The strong development of similarly oriented joints in the dyke (and their early nature) is demonstrated by co-linear zones of protoclasis with horizontal lineations and by joint control of late alteration (see section 2.a, above). A strong case for the early deformation of the dyke, together with its structurally inhomogenous envelope can be made and the NE–SW trending joint direction was probably imposed on the porphyry dyke before its final consolidation. Further S in the Huaura region it can also be demonstrated that plutons of a variety of ages inherited a common fracture pattern during their consolidation (Bussell, 1976).

4.c. Gas brecciation in the Coastal Batholith

The emplacement of the Iglesia Irca dyke bears comparison with the Puscao plutons and their associated 'Baranda sheets' described by Myers (1975). According to Myers, the emplacement of these plutons was preceded by the active tectonic generation of microbreccias which were entrained by gasses emitted from the upper, volatile-rich portion of the rising magma. A progressive sequence from shear zones, microbreccia, entrained microbreccia, magma-breccia mixtures through turbid porphyritic Baranda granodiorite sheets to clean uncontaminated Puscao monzogranite emplaced by cauldron subsidence processes is traced by Myers and is thought to reflect the stages of pluton emplacement at this high crustal level.

In the case of the Iglesia Irca intrusion a similar evolutionary sequence can be traced out with additional highly significant evidence of the volatile-rich nature of the magma emplaced by this process. The amygdaloidal textures clearly indicate an intrusive magma in the process of de-gassing and these early minor felsite intrusions are associated with explosion breccias while the large scale metasomatic and autometasomatic effects are closely related to the late cooling stages of the volatile-rich granophyre magma. Such features are lacking both from the Puscao association described by Myers (1975) and a similar association described from the Huaura ring complex by Bussell (1975, unpubl. thesis, Liverpool Univ.). Here in the Huaura, as in the example of Myers, there is abundant textural and field evidence for tectonic brecciation, attrition and fluidization effects during the emplacement of the Puscao intrusions but the key evidence of vesiculation in the associated intrusive rocks, the proposed source of the fluidizing gas, is entirely lacking. Neither is there evidence of large-scale metasomatic effects, hydrothermal effects or significant mineralization. In view of these observations the writers feel that insufficient evidence for gas-driven fluidization effects exists in the case of the Puscao intrusions and that the variety of intrusive fragmental rocks involved may be principally tectonic in origin; possibly related to protoclastic deformation of magma and to the kinds of shock wave vaporization (Bennet, 1974) and fragmentation effects likely to effect both magma and wall rocks adjacent to active ring fractures in a caldera situation. By contrast, the present work strongly suggests an important role for gas-driven as well as tectonic brecciation effects in the emplacement of the Iglesia Irca suite which may prove to be an exception to the case in the batholith as a whole.

5. Summary of the emplacement of the dyke suite

It has been proposed that relatively undifferentiated granitic magma rose along N-trending fractures on the eastern margin of the batholith. Ahead of the magma, first ductile shear zones, then 'burst breccias' and fracture zones formed in the envelope rocks. Periodic pressure release caused vesiculation of the magma and the explosive disruption of the envelope rocks. Chilling of the magma resulted in the formation of the porphyritic amygdaloidal felsites, later emplacement of more fractionated magma along the same belt was accompanied by mylonitization along the lines of weakness picked out by earlier brecciation and felsite intrusion. Subsidence of country rock to the W of the fault zone provided some of the space for intrusion but marginal xenolithic zones show that stoping also contributed to emplacement.

Hughes (1960) and Dunham (1965) both suggested that the different characteristics of their felsites and granophyres (which were of the same composition) were the result of different environments of emplacement. This is probably so in the present case since the felsites and granophyres are closely associated in space and time and the earlier felsites represent less fractionated magma than does the granophyre. The felsites represent volatile-rich tongues of the main magma body at that time rising through lower levels. Thus the granophyre magma could de-gas to equilibrium (at lower levels) by way of the rapidly emplaced vesiculating felsite dykes. Later slower, more passive emplacement of more fractionated granophyre could permit greater volatile retention. This effect was strongest at lower levels in the dyke and resulted in the crystallization of a microgranitic texture with *in situ* pods and veins of pegmatite; at higher levels more rapid loss of volatiles chilled the magma to give a granophyric texture. A potassium-rich residual magma evolved and rose through the intrusion giving rise to potassic alteration adjacent to early formed joints at intermediate levels and the complete reconstitution of the granophyre at the highest levels. A similar alteration also affected the country rock above the hanging wall.

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