PETROGENESIS OF THE LAND'S END GRANITES

by

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Summary

Land's End granite is a serokinematic-post-kinematic, magmatic pluton which discordantly cuts the Mylor Series and associated basic intrusives, the shallow slope of the granite is reflected in the narrow thermal metamorphic-metasomatic aureole which does not exceed the grade of the amphibolite facies.

The granitic magma originated by differential anatexis of a deep-seated granite, granodiorite or granite-gneisse to produce a milieu mobilise corresponding in composition to the natural ternary field. This essentially quartzo-feldspathic liquid ascended in the crust by density difference, overhead stoping and assimilation. Towards the end of its emplacement history the magma consisted of a crystalline mash of both feldspars, micas and quartz, all lubricated by an interstitial fluid phase. Cooling was accompanied by autometasomatism.

Variations in the granite are due to contamination, while differentiation and filter pressing produced leucogranites and aplites which ascended through fractures in the essentially solid crust. This period was postdated by extensive potassium metasomatism along a thermo-chemical gradient with the production of the coarse porphyritic envelope surrounding the finer grained non-porphyritic core, the feldspar megacrysts arose by metasomatic, endoblastic growth upon nuclei (seed crystals) orientated by a regional stress gradient field.

Contents

Chapter 1

Introduction

Introduction.

Since the turn of the century there has been no detailed work on the granites of Land's End. In 1907 the Geological Survey published their Memoir dealing with this area and mapped the granite boundaries as accurately as is possible, but they laid practically no emphasis on the petrology of these rocks.

It therefore seemed appropriate to make a careful study of the granite, employing the latest statistical techniques which would make it possible to deal with large volumes of modal data, and so construct three dimensional modals, similar to those used by Whitten (in Shaw, 1963), of the various mineralogical contents of the granite.

A preliminary investigation of the area was made to decide on the best method of sampling the granite but the irregularity of granite outcrops precluded the possibility of sampling from regularly spaced sites based on a grid pattern. Material was therefore collected as objectively as possible from sites spaced as regularly as exposure would permit, mineralised granites being rejected when possible as late stage solutions had induced mineralogical changes which rendered them atypical for the purposes of this investigation.

(a) <u>Aims and scope of the research.</u>

The main objects of the research were :-

(i) The re-evaluation of field evidence to see if the granite boundaries between the coarse and later fine grained granites as mapped by the Geological Survey could be fixed more accurately and to see if an exposure showing the contact between these granite types could be located. In addition it was decided to investigate the fine grained granite which Carne(1828) noted as appearing near the summits of hills, with a view to mapping this variety.

(ii) To examine modal and chemical data to ascertain the degree of variation within the granites and to investigate if, as Brammall and Harwood (1932) suggest for the Dartmoor granite using Harker type variation diagrams, the variation is due to differentiation aided by syntexis.

(iii) To apply statistical mapping techniques to a granite body, to see if any trends produced by computing mathematical three dimensional surfaces from data from objectively collected material, could be verified in the field and used as an aid to mapping.

(iv) To examine the orientation of the large feldspar crystals and to investigate their relationship to south western tectonics, and to see if they are indicative of magmatic flow (Austin, 1960, believes this orientation is not necessarily indicative of magmatic flow in the

Carmenellis granite).

During preliminary field investigations the nature of the contacts examined suggested a magmatic origin for the granite. This had also been suggested by various other workers in the south western area (Exley, 1961, Stone, 1961), and it is considered pertinent to pose the following questions :-

(a) What was the initial composition and source of the magma?

(b) Was the magma emplaced as a single intrusion or a series of intrusions?

(c) To what degree has differentiation, assimilation and recrystallisation modified the original magma?

(d) What is the space form of the pluton?

(e) What were the physical conditions prevailing at the time of emplacement?

At granite-hornfels contacts the granite was mapped in detail at a scale of 25 inches to the mile; otherwise a scale of 6 inches to the mile was used. Sample sites for modal analysis were plotted on a scale of 2½ inches to the mile and later reduced to 1 inch to the mile for trend surface contouring.

The Land's End granite is unique in that it is the only granite in south west England to offer such a variety of exposure; although there are large areas inland where head, growan and valley gravel obscure the bedrock, this disadvantage is offset by the vertical exposure from which samples may be taken, (i.e. from 812 ft. O.D. on Trendrine Hill to -1100 ft. O.D. in Geevor Mine), and approximately 21 miles of excellent cliff exposures.

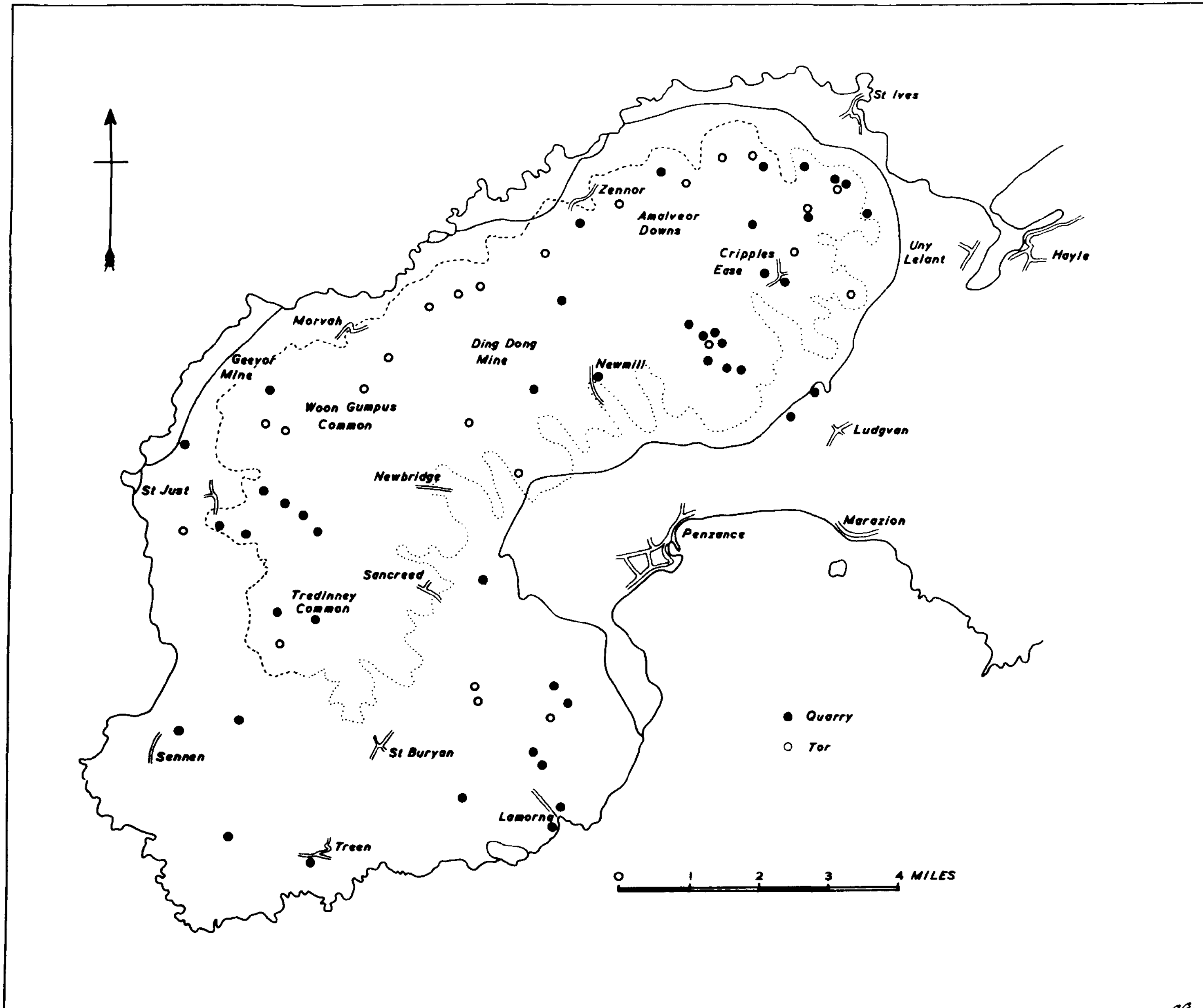
(b) Geographical setting and Physiography

The Land's End granite is situated at the westermost point of the Cornubian peninsula (Map. 3, Granites of Devon and Cornwall), and occupies approximately seventy-five square miles. (i.e. most of the country to the west of the A 30 road between Hayle and Penzance).

Topography is determined largely by the jointing and associated kaolinised-fracture zones, the drainage being along valleys running NNW-SSE and parallel to a major joint direction. (Map. 6, Land's End Granites). Gullick (1929) and Pounds (1945) suggested that the trends of the major water-courses in the S.W. granites are controlled by jointing; this is particularly evident in the Land's End district.

The granite forms a bold coastline in the north with cliffs of up to nearly 300 ft. in height falling vertically or near vertically into the sea. (Fig. 1). Along the north coast from St. Ives through Zennor to St. Just stretches a line of Tor-surmounted hills, (Figs. 5 and 6), ranging in height from 583 ft. to 827 ft. and with a mean height of

Locality Maps. Illustrating the distribution of quarry and tor exposures. The dotted line indicates the position of the 400 ft. contour and marine platform.


St Ives
Zennor
Amalveor Downs
Cripples Ease
Uny Lelant
Hayle
Morvah
Ding Dong Mine
Newmill
Geevor Mine
Woon Gumpus Common
Ludgvan
Newbridge
St Just
Penzance
Marazion
Sancreed
Tredinney Common
Quarry
Tor
Sennen
St Buryan
Lamorna
Treen
0 1 2 3 4 MILES

700 ft. To the north the hills end in a bluff sloping rapidly to the 420 ft. massive platform (Fig. 6 and P.6 Locality Map); this bluff is very prominent when viewed from a few miles out at sea. From 420 ft. to the coast, a distance of about half a mile, the plateau gently falls until terminated by the precipitous cliffs mentioned earlier. To the south the countryside is undulating and gently slopes to the coast ending in cliffs of up to 100 ft. in height in the south east, (Fig. 2), and up to 200 ft. in height in the south west.

Good exposures occur in the many disused quarries, on Tors and along the extensive coastal cliffs, (Figs. 4,5 and 6). Areas around Newbridge, St. Buryan and Amalveor have not yielded good specimens as the land in the first two areas is extensively cultivated and the Amalveor region is weathered and grassed over, (Fig.3).

Decomposed granite forms a thin covering on the higher ground and in the valleys rotten granite (growan) and head may reach 20 to 40 ft. in depth, (Figs. 82 and 83). This governs the number of exposures from which fresh material may be obtained although the limited number of monumental quarries still working have furnished extremely good specimens.

The region is a thinly populated one, except in the tourist season, and industries are chiefly confined to the area between Penzance - Marazion and Hayle. Market gardening is extensive on the rich soil resulting from decomposed aureole rocks, while sheltered cliff-slope enclosures on the granite near Lamorna are much in use for early spring flowers.

Tin mining, once an extensive industry in the region, has now declined with Geevor Mine on the north coast near St. Just being the only working tin mine west of Camborne-Redruth. China clay was once quarried at Georgia, Penderleath, Tredinney Common, Leswidden and Tregeseal, but today only the clay pit at Tregeseal is working, the others having closed down earlier in the century. In the past, granite was in great demand as a building stone and for monumental work, the now abandoned quarries at Lamorna, Mayon Green, Carn Crean, Castallack, Sheffield, Kerris, Newmill, Cripple's Ease and Crean being ample evidence of this. During 1963-1965 only the quarries at Kerris and Cripple's Ease were being worked for monumental stone. Granite for use as road aggregate is quarried in the fine grained inner mass at Castle-an-Dinas, the stone being transported by road to the main quarry and plant at Newlyn for crushing.

(c) <u>Regional Setting</u>

Land's End is one of six granite "cusps" which belong to an elongate, composite, serokinematic-postkinematic pluton (Eskola, 1960) stretching from Dartmoor in the east, to the Scilly Isles in the west. The shape of each "cusp" in plan is either circular or ellipsoidal and is occasionally constricted in the central region. The position of each "cusp" was believed by Robson (1945) to be due to intersecting anticlines of Caledonian, Malvernian (Osman, 1928), and Amorican trend. Large masses such as Dartmoor and Bodmin Moor have irregular boundaries, and the marginal country rocks into which the granites are emplaced are tilted and pushed aside (Dearman and Butcher, 1959). The contacts are usually sharp and chilled margins are known to occur; when these chilled selvedges are absent the coarse porphyritic granite abuts directly against the hornfels, the metamorphic grade of which ranges up to that of the hornblende hornfels-facies. The elongate shape of the pluton was postulated by De la Beche (1839). Worth (1930) proposed the west of England granites represented protrusions from a granite wedge forming the axis of the peninsula. The granites were described as cupolas on a batholith with underground connections at small depth by Rastall (1931), and geophysical data presented by Bott, Day and Masson-Smith (1958), and mineralisation data presented by Hosking (1962) lend good evidence to show that the granite outcrops are indeed connected at depth and lie on a continuous ridge of granite.

The Palaeozoic eugeosynclinal sediments of the Variscan foldbelt in the south-western peninsula are composed of rocks of pre-Devonian (?), Lower, Middle and Upper Devonian, and Middle Carboniferous age. The Culm Measures occupy the centre of a large trough with an east-west strike to the north of Launceston and Dartmoor. (Maps. Granites of Devon and Cornwall. Regional Structure.). The Devonian rocks are situated on the southerly limb of this synclinorium and occupy most of the country to the south and south-west of Dartmoor. The minor folds which are developed on the south-western limb of this trough are sub-parallel to its east-west strike, and some are truncated at their southerly ends by the Lizard-Bolt Head dislocation, which Dearman (1962) believed to be a discontinous thrust line.

The pre-existing and underlying Caledonian structure determined the Upper Palaeozoic geography, the sedimentary history, and the form of the Hercynian compression of the region (George, in Coe, 1962). Armorica and Cornubia strongly reflect this structure (Chauvis and Guigues, 1962), and constituted part of the Variscan geosyncline which extended from possibly Georgia and Carolina in the west, prior to continental drift (Miller and Mohr, 1964), through Eire to southwest Poland in the east. During the

Devonian the southern deep-water facies and associated minor geanticlinal facies sediments together with spilitic extrusions and minor igneous rocks, migrated slowly northwards to accompany the development of the arcuate trough of eugeosynclinal sedimentation.

The Bretonic orogenic phase did not affect south-western England, and sedimentation was able to continue undisturbed from the Devonian into the Lower Carboniferous. The deep water facies was sharply terminated during P_1-P_2 times (Prentice, in Coe, 1962) by the north and eastwards spread of turbidite sedimentation. This was probably related to the elevation of Armorica which lay to the south, and to early Sudetic folding, if the turbidites are interpreted as synorogenic. A suite of volcanic rocks was produced in Devon during Lower Carboniferous times, while greywacke continued to be deposited into the Upper Carboniferous, apart from north Devon and Somerset where it was replaced by Coal Measures facies. In Somerset the coalfield was affected by uplift and gentle folding movements during Muscovian times, the Prolifera zone of the Stephanian being the highest measures and therefore indicating that the tectonic climax is associated with Asturic movements and possibly Saalic movements. The intense overfolding and faulting of the sediments in Devon and Cornwall are also probably related to the Asturic orogeny.

The Lizard-Start Point dislocation referred to earlier bordered a frontal zone of orogenic crustal instability marked by a thick bed of flysch (Gramscatho-Mylor beds, Hendriks, 1959), and was thought to be a thrust plane running through Start Point, Dodman Point, and the "Meneage Crush Zone" (Hendriks, 1937, 1959), though Lambert (1962, 1965) disputes such an origin for the "Meneage" and suggests the Meneage breccias are in fact subaqueously slumped sediments. Hendriks gave a Fammennian-Tournaisian age for the thrusting and thought it was probably developing throughout the Carboniferous with a culmination during the late Variscan orogenic phase. She visualised this "Crush Zone" as the sheared middle limb of a great nappe, which was overthrust towards the north to north-west by a south-easterly pressure resulting from "Alpine type" tectonics. She believed this to account, not only for the northerly dipping thrust planes in the Tintagel region, but also for the metamorphic rocks of the Start Point-Bolt Head, Dodman Point and Lizard promontories; the metamorphism being due to the physical conditions generated by this overiding nappe into whose core the serpentine was emplaced. Miller and Green (1961), and Dodson (1961), believe this nappe to be composed of a metamorphosed and serpentinised Caledonian suite with Caledonian silicic intrusives.

Prior to the emplacement of the granite the uplifted and folded Culm of Devon was intruded by post-orogenic basic dykes (Dearman and Butcher, 1959).

This phase was followed by the intrusion of the granites which probably arose steeply in the south and then flowed more or less horizontally northwards achieving their present position by overhead piecemeal stoping and assimilation (Bott et al, 1958). Evidence for the northwards flow was presented by Dearman (1959) who found that at Meldon, Devon, the southern limit of the asymmetric anticline of Devonian and Carboniferous rocks with their zig-zag folds (due to intensive Armorican earth movements) was lifted up by the intruding granite and these recumbent folds were tilted to the north.

The Exeter region vulcanicity phase and the commencement of New Red Sandstone deposition are roughly coeval; this post-Hercynian sedimentation (Permo-Triassic) laid down a series of unfossiliferous continental deposits. Post-granitic sedimentation could be confirmed by proving the unmetamorphosed shales of the unfossiliferous Ugbrooke Group (Pre-New Red Sandstone) are not affected by wrench faults (Dearman, 1962 and Simpson, 1959).

Although the age of the east-west folding has generally been ascribed to the late Hercynian orogenic phase, Prentice (1958) believes the Devonian rocks to the south of the Culm Measures were deformed during Muscovian or Gzelian times and that the Culm was deposited in a trough thus created.

The region is cut by a system of numerous north-north-westerly dextral wrench-faults believed to be of Hercynian age which were probably rejuvenated in Tertiary times, (Dearman, 1963). In this paper (1963) Dearman removes the fault shifts and redraws south-west England. He postulates a cumulative dextral displacement of twenty one miles due to the wrench-faulting, and demonstrates a uniformity in the trend of the granite ridges of Hosking and Trounson (1959) and in the lode and dyke patterns of the region. The effect of these faults on the Bouguer anomaly map of Bott et al (1958, Fig.2) is interesting in that the ridge of low anomalies is now straightened and Dartmoor, Bodmin Moor, and St. Austell granites lie on a more or less straight line. Exceptions are the granites of St. Agnes Head, Cligga Head, Carmenellis and Land's End, all of which lie across the straightened anomaly line but not along it. When correlated with mining evidence from this area, which shows granite to lie at no great depth in the Camborn-Redruth area (approx. 900 ft.), and between the Land's End and the Carmenellis granites, it is concluded that these granites (i.e.: Land's End, Tregonning-Godolphin, Carmenellis, and St. Agnes-Cligga Head granites) are part of one large partially exposed cupola or "cusp".

(d) Historical Review of Previous Work

The earliest publications on this region (e.g. Carew, 1602) are of historical interest only and very little was written about the granite. Forbes (1822) noted that the granite gravel and head (he refers to these as alluvium) were scanty on higher ground, and in the valleys reached 20 or 30 ft. in depth, but it was not until a few years later that the main granite varieties were recognised by Carne (1828) who distinguished four main types :-
(i) Porphyritic granite, (ii) Fine grained granite (which he noted as appearing near the summits of hills),
(iii) Pegmatite, and (iv) Schorlaceous granite. In 1839 De la Beche in his classic report on the geology of Cornwall, Devon and Somerset thought the form of the granites of south west England agreed with the modern conception of a batholith, and Collins (1873) asserted that the granites throughout the peninsula were fundamentally the same and intrusive. Sorby (1858) investigated the temperatures of formation for minerals and rocks of the Carmenellis Granite and suggested that quartz inclusions in certain lodes formed at the same temperature as the surrounding granite, his temperature estimates range from 200^{o}C for a lode in the vicinity of Camborne, and 200 - 320^{o}C at a pressure equivalent to a 50-18,000 ft. column of granite for the

Gwennap Elvan, and approximately 200°C at a pressure equivalent to a 54,000 ft. column of granite for the Swanpool Elvan near Falmouth. Perhaps the first indication that these granites were thought to be composite intrusions is the statement by Miss Carne (1875) who believed that the granite at Land's End, west of Whitesand Bay-Logan Rock, was a separate mass which arose from under the south-eastern part after this had hardened. In 1888 Ussher suggested a laccolithic mode of emplacement for the Dartmoor granite, but this idea was not well received and was withdrawn in 1892. Worth (1888, 1889a) put forward the alternative suggestion that the exposed granite of Dartmoor was the lower portion of a volcanic focus denuded of its superstructure, and in 1892 described the main varieties of granites. Ussher (1892) then suggested a metamorphic origin for the granite of northern Dartmoor, this work was vigorously attacked by McMahon (1893) and was therefore dismissed; but in Part II of "The British Culm Measures" Ussher (1892) modified his thesis and entertained a palingenetic origin for the west of England granites, which he states - "seem to have resulted from metamorphism in situ, of pre-existing rocks". Hunt (1894) summarised the three main theories for the emplacement of the Cornubian granites, namely the plutonic theory of De la Beche, the Laccolitic-Plutonic theory of Ussher, and the Volcanic theory of North; and at the same time promulgated his own theory that the Dartmoor granites were pre-Devonian non-intrusives and post-Carboniferous intrusives. Holmes (1916) visualised the Dartmoor mass as an upper, lateral offshoot from an elongated diapir emplaced by a mechanism analogous to that presumed for the intrusion of salt domes.

The first major petrographic work on the granites of western Cornwall was by Flett (1904) who recognised them to be of a uniformly coarse character with finer-grained margins exhibiting a parallel structure (flow-foliation) and to be intruded by a fine grained later granite. Flett describes the occurrence of minerals in the granites and notes that the true pegmatites frequently occur in peripheral zones and contain orthoclase perthite, quartz, muscovite with occasional topaz, gilbertite, fluorspar and threads of tourmaline. Aplites are noted as rare and only occasionally cut the granite. Evidence of magmatic differentiation is almost absent as Flett finds none of the marginal diorites, pyroxenites etc. such as accompany Scottish granites. Pleochroic andalusite occurs peripherally and Flett correctly takes this as indicative of assimilation of alumina from the shales. Pinitic pseudomorphs after cordierite are also noted as occurring where "Killas" is being resorbed.

The new series Geological Survey sheet 351, 358 (Land's End) was published in 1907 together with the Geological Survey Memoir by Reid and Flett. The major part of the granite was mapped as a porphyritic biotite granite intruded by a later fine grained granite and cut by fine granite veins. Davison published many papers between 1925 and 1949 which illustrated the similarity in the Cornubian granites and suggested the emplacement of the two granite types of Carmenellis as mapped by the Survey were coeval as they were mutually crosscutting.

Between 1923 and 1933 Dr. Brammall, often with A. F. Harwood as co-author, published several papers dealing with the Dartmoor granite, and in 1932 attributed the variation in the Dartmoor granite to the bi-generic effect of the "basification of an initially acid magma while emplacement and differentiation were proceeding", and suggested that the initial magma was dominantly sodic and that the potassium rich phases could be differentiates from a magma contaminated by assimilated pelitic material. Reynolds (1946) demonstrated the desilication of shales in contact with granite and subsequent basification of the granite on completion of syntexis. She established a granitisation series on von Wolff diagrams with complete gradation from granite to aureole shales.

Hosking (1950) discussed the emplacement theories of Hulin and Emmons in his paper on fissure systems in Cornwall, and he related these to his own theory in which he suggested the granites to be emplaced in areas of weakness created by intersecting Armorican and ~~Variscan~~ Caledonian structures, this agrees essentially with Robson's (1945) thesis for conditions governing the position of each granite cusp.

Exley (1959, 1961) suggested the distribution of minerals in the St. Austell granite was due to magmatic differentiation and that the susceptibility of these granites to localised kaolinisation was a function of their original composition, and he correlated low ground with low orthoclase/plagioclase values. Exley suggested that potassium or sodium rich solutions capable of metasomatising earlier granitic fractions may have been produced, while Stone and Austin (1961) demonstrate the metasomatic origin of the potassium feldspar megacrysts in the south western granites on the basis of crystals growing across aplite-granite junctions.

Stone (1961) suggested a magmatic origin for the granites of Cornubia and accounted for the trend in sodium enrichment in time as being the trend of decreasing contamination and potash metasomatism, believing that rocks which most clearly represented the composition of the initial magma (less volatiles) lay to the sodium side of the 1000 bar water pressure ternary minimum of the experimental system of Tuttle and Bowen (1958).

In a recent gravity survey Scott (1962) found a strong correlation between the observed Bouguer Anomaly minimum over Land's End granite, and the outcrop of the less dense grained inner granite (see P. 241).

Recently, in a paper by Exley and Stone (1965 in press), the granitic rocks of south west England were described; in this paper the development of the texture was attributed to extensive metasomatism and recrystallisation within the granite. The authors derive granite variants, as did Brammall and Harwood (1932), by assimilation and magmatic differentiation by a palingenetic magma which had its original composition near the ternary minimum in the "experimental granite system". This lends support to the suggestion put forward by Booth (1965 in press) that Land's End granites were originally leucocratic in aspect and probably soda-rich in composition, and that the extensive contamination from which they have suffered is in part responsible for much of the biotite, alumina, and potash to be found in these granites.

(e) The "Aureole Rocks"

The rocks of the metamorphic aureole bordering the Land's End Granite occupy approximately 14 square miles (Map. Land's End Granites), and are divided into the sedimentary Mylor Series and a basic igneous series consisting of Pillow Lavas and massive dolerites.

In this research project the aureole rocks have only been examined where they were thought to bear an interesting relationship to the granite, and where their examination, mineralogically and chemically, would throw light on some of the events in the history of this pluton; the results of these investigations are classified under Granite/ Hornfels contacts.

(i) Mylor Sediments.

In the Falmouth region, and at the village of Mylor one and a half miles north of Falmouth, these sediments (locally known as "killas") are bluish coloured clay-slates with occasional arenaceous partings, although in some areas the blue colour gives way to a pale-yellow colour reflecting the degree of oxidation. Hendriks (1959) classified the Mylor Series as lower to middle Devonian, while Green (1904) considered that they represent passage beds between the Silurian and the Devonian.

In the Land's End region contact metamorphism by the earlier basic and later acidic igneous rocks has raised these sediments to the metamorphic grade of hornblende-hornfels facies with the development of quartz-biotite-muscovite-cordierite hornfels and biotite-amphibolite hornfels (Fig.9) in the granite contact zones; retrogression to chlorite and sericite is common and was probably brought about by a fall in temperature while in the continued presence of a hydrous phase. Hawkes (1961), who mapped the aureole between St. Ives and Porthmeor Cove, noted a secondary metamorphic phase which constituted a return to the earlier mineralogy; and Barclay (1959) who mapped the aureole from Portheras Cove to Cape Cornwall classified seven different types of pelitic hornfels differing on minor points only, such as degree of retrogression and mineralisation.

(ii) Spilites and Dolerites.

Locally known as "Blue Elvan", these basic igneous rocks occur as sills up to 100 ft. thick (Barclay, 1959) emplaced into the Mylor Series (Map.3, Granites of Devon and Cornwall and Figs. 7 and 8); the presence of an adinole at their upper and lower contacts (Fig.7) demonstrates their intrusive nature. Pillow structures are common (Fig.10) and their downward sag is regarded as a "way-up" criterion; they are conformable with the Killas banding (Barclay, 1959) and a green ferromagnesium mineral (probably hornblende) has frequently been noted filling shear cracks. Occasionally albitised rafts of Killas occur in the pillow lavas (e.g. Porthmeor Cove,); these adinoles are very conspicuous in the field and weather to a whitish colour.

The sediments intruded by the massive dolerite frequently show a pimply or knotty appearance due to the development of the mineral cordierite; these "pimple hornfels" have served as excellent indicators of the proximity of dolerite when mapping this rock at granite/hornfels contacts (e.g. Porthmeor and Wicca Pool).

The dolerites were amphibolised by thermal metamorphism to hornblende hornfelses and uralitised to actinolite hornfelses by the influx of hydroxyl and boron ions released from the granite, and Floyd (1962) demonstrated the production of anthophyllite-cummingtonite-cordierite hornfelses by the expulsion of calcium ions, and the formation of hornblende-diopside and grossularite rich hornfelses by the addition of these expelled calcium ions. Progressive desilication accompanied the calcium metasomatism with the production of diaspore and spinel, while the hornblende hornfels were biotitized by potassium ions expelled from the granite (Fig.9). Kaolinization occurred by the influx of water coupled with the loss of mafics and soda plus silica; these latter elements were responsible for felspathizing nearby hornfels (Floyd, 1962); the kaolinized hornfels were enriched in alumina by virtue of the bulk compositional change.

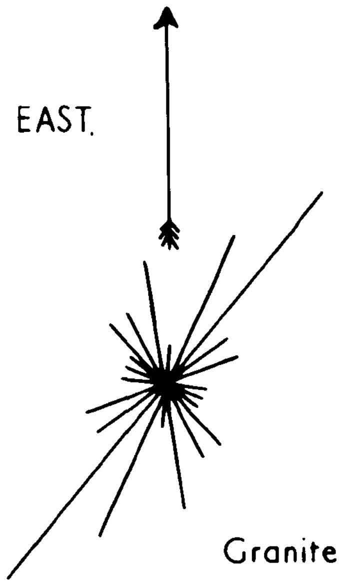
(iii) Structure.

The structures in the aureole rocks can be related to the granite emplacement, with the exception of the faint lineations and quartz augen in the "Killas" which probably originated during the tectonic movements that were associated with the Variscan Orogeny.

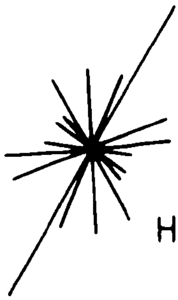
The "Killas" (which strikes NE-SW) dips off the granite at an average angle of 20° (Map. Land's End Granites), and two fold trends have been deduced by Barclay (1959); - one fold gently plunging to the NNE and one gently plunging to the NW; the former he attributes to Caledonian movements and the latter to Armorican disturbances. Minor folding can be seen in most "Killas" laminae which Hawkes (1961) interprets as drag folds resulting from behaviour of incompetent rocks between harder igneous bands during the formation of an anticlinal structure over the Land's End granite. The shear forces which produced the minor drag folds in the sediments were probably also responsible for the development of small tension fractures and pronounced axial plane cleavage. Hawkes (1961) noted that small dolerite bodies yielded to stress forces and as a result possess linear fabrics. Complementary sets of fractures are frequently to be seen in these small dolerite

PORTHMEOR COVE EAST. JOINTING.

MAGNETIC NORTH 1963.



Granite (28 Joints)



Hornfels (20 Joints)

A.B.

sheets, especially near the rounded nose of such bodies (Fig.7).

At many granite/"Killas" junctions the joints are observed to pass straight into the "Killas" from the granite (Text figure. P25.), Hawkes (1961) related this phenomenon to the forces set up in the magma during cooling.

Chapter II

The Granites (Structure)

(a) Flow structures

Brammall (1926A) stated that flow structures are rarely so good or so concordant over a large exposure as they are near the margins of a granite. He also noted eddying and convection phenomena in the Dartmoor granite. Osman (1928), Ghosh (1934), and Exley (1959) referred to the orientation of the long axes of the feldspar megacrysts and used these orientations to deduce the direction of "magmatic flow". All these workers came to the conclusion that the flow was from the south to south-east and was related to regional tectonics. Austin (1960) thought the large feldspars in the Carnmenellis granite to be wholly of metasomatic origin and pronounced the theories of magmatic orientation as untenable. Additional evidence for the metasomatic origin of these feldspars was presented in 1961 by Stone and Austin who gave examples of feldspathisation of the margins of aplite dykes, and examples of the occurrence of potassium feldspar megacrysts growing across xenolith/granite contacts and aplite/granite contacts.

If the potash feldspar megacrysts in these granites have resulted entirely from metasomatism by a liquid or vapour phase bearing potassium ions, then a tenable reason must be presented to account for the regional north west-south east alignment of the long axes of these crystals.

They probably grew under directed regional stress as suggested by previous workers, but while this is believed to be the case at Land's End it does not explain the "swirls" in the megacrysts at Wicca Pool and Trencrom Hill, nor how the "waves" in the feldspars at Lower Bussow Quarry have originated, nor why the long axes of the megacrysts are parallel to the xenoliths which they have also been observed to envelop in a manner suggestive of magmatic flow. Illustrated in Figures 15, and 16, are some of the flow structures to be seen in the Land's End granite; these structures are not consistent with the thesis of a post consolidation metasomatic origin for all the big feldspar, although this process is almost certainly responsible for the greater proportion of the megacrysts.

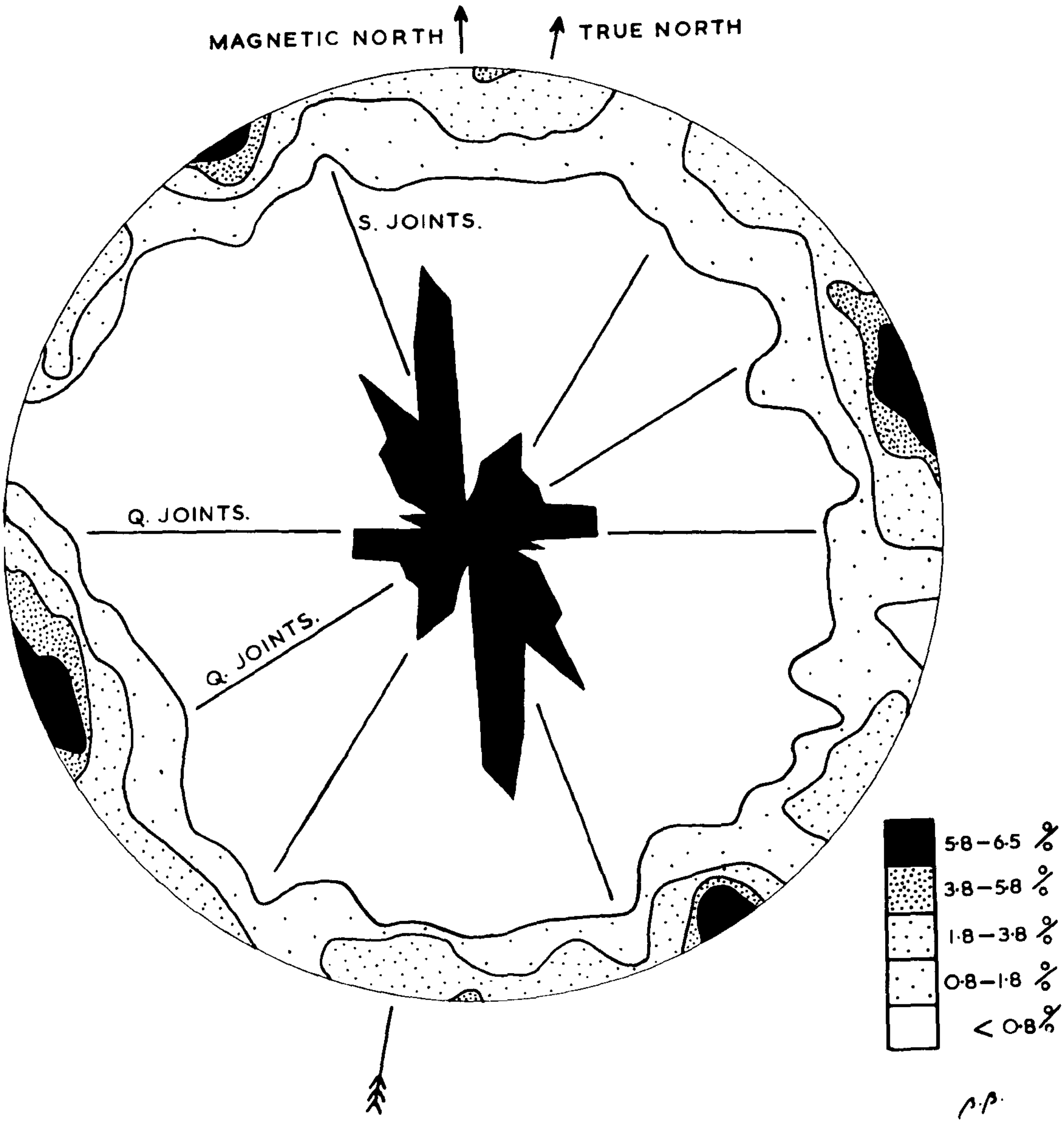
To account for the metasomatic growth of those megacrysts following "convection type" swirls it is necessary to postulate the existence of nuclei on which the potassium/sodium aluminium silicate material could grow; in other words the existence of "seed crystals" of alkali feldspar which were previously orientated by magmatic flow. To establish the north west-south east alignment of seed crystals a continued regional stress would be necessary while emplacement was proceeding, or at least prior to consolidation of the magma. The origin of these megacrysts is discussed on p. 143 .

In using the term "magma" a highly mobile silicate melt with partly formed crystals floating in it is not envisaged, but rather a partly crystalline silicate "mush" or "mash" which would not necessarily develop a chilled margin adjacent to the aureole hornfelses. There is very little evidence to suggest permeation of the aureole rocks by highly mobile silicate fractions (Figure 33 illustrates localised mixing of hornfels with the granite). For example the silica repository at the Avarak (on the coast near Pendeen) is not thought to have originated in this way, and Floyd (1964) believes it to represent the fixation of migrating silicon cations derived from progressive desilication of the basic hornfelses during the period of extensive calcium metasomatism of these rocks.

Because evidence of flow largely depends on feldspar orientation this phenomenon has been examined in some detail and it has been found that the potash microperthite megacrysts of the granite are tabular in habit with the (010) face constituting the planar side. The maximum elongation is along the line bisecting the acute angle between the "a" and "c" axis and the crystals are regionally orientated with the "b" axis roughly north east-south west. This means that the (010) planes are often steeply dipping and that in the field the feldspars appear to be elongated in a north west-south east direction over the major part of the granite. It is because of this fairly uniform planar orientation that the term foliation is used. (Figures 11 and 16).

On approaching the granite/hornfels margin the feldspars become inclined nearly parallel to the contact and within a few yards of the contact they lie with their clinopinacoids roughly parallel to the junction. (Figures 43 and 48). They follow the contact and have not been observed to pass into the hornfels except in those cases where late pegmatite fractions have become trapped beneath arched hornfels roofs as at Porth Ledden. (Figure 45).

Well-developed bands of tabular megacrysts occur parallel to the margin of the granite in several areas (e.g. Porth Ledden, Sennen Cove, Wicca Pool and Tater du). On the granite hills along the north coast (these hills are elongated NW-SE) the feldspars which are horizontal on the tops of the hills are observed to plunge off the north westerly spurs at 20°-30° towards the coast (i.e. north west) or the contact, while on the flanks of these ridges the feldspar clinapinacoids have a tendency to dip into the valleys at angles approximating to those of the hill slope. This phenomenon is common throughout the area and is always evident in coastal regions; in only a few inland exposures do the feldspars appear to lie at random.


MAGNETIC NORTH
TRUE NORTH
S. JOINTS.
Q. JOINTS.
Q. JOINTS.
5·8 – 6·5 %
3·8 – 5·8 %
1·8 – 3·8 %
0·8 – 1·8 %
< 0·8 %
P.P.

In the field it was found very difficult to measure accurately the plunge of the tabular feldspar crystals on exposed joint faces as they probably display an apparent orientation rather than the true one. Measurement of the azimuthal orientation of the megacrysts was somewhat easier and text-figure. P31 illustrates a cyclographic histogram (Rose diagram) of feldspar long axis orientations from the Land's End area. The collection of such data unfortunately tends to become subjective when the average azimuthal orientation and plunge of these feldspars is being determined at any one point. However, many of the measurements were taken from "floor joint" exposures which gave a fairly reliable estimate of the orientation of these crystals; other readings were taken on joint faces in quarries where the foliation was particularly good.

The cyclographic histogram shows a dominant generally north west-south east trend in the orientation of the long axes with a subordinate north east-south west trend; these directions conform to the directions of the major joints in the granite. The possibility of these orientations being affected by "die Schnitteffekt" has not been ignored. Voll (1960) and Kaemmel (1955) dealt with this problem, and Voll noted that if the elements being measured are "shape-anisotropic" then one section does not necessarily reveal the true density distribution of these elements in space. If plates and needles of minerals are orientated at angles to a section through the medium containing them, then they are more likely to be intersected by the section than if they are arranged parallel to it. Depending on its angle of intersection this "cut-effect" can produce pseudo-preferred orientations and distortion of real preferred orientations.

During detailed examination of feldspar orientations on quarry faces within the coarse highly porphyritic granite the distortion of the true orientation by "die Schnitteffekt" became obvious. Several measurements from joint or quarry faces with as high an angular discordance between them as possible were plotted on an equal area Schmidt net as apparent plunges of feldspar long axes on inclined joint faces. This enabled the mean plunge of the feldspars to be ascertained, but it was found on plotting many data in this way that the variability of the dip of the (010) faces about the vertical and the slight deviations in the azimuthal direction of elongation of the megacrysts gave poor results upon which no value could be placed. There is a slight indication of a regional easterly dip of (010) planes at 55° to 70° but this is thought to be statistically untenable as it is based on only 21 cumulative readings. An extended statistically-based sampling programme may yield more acceptable results.

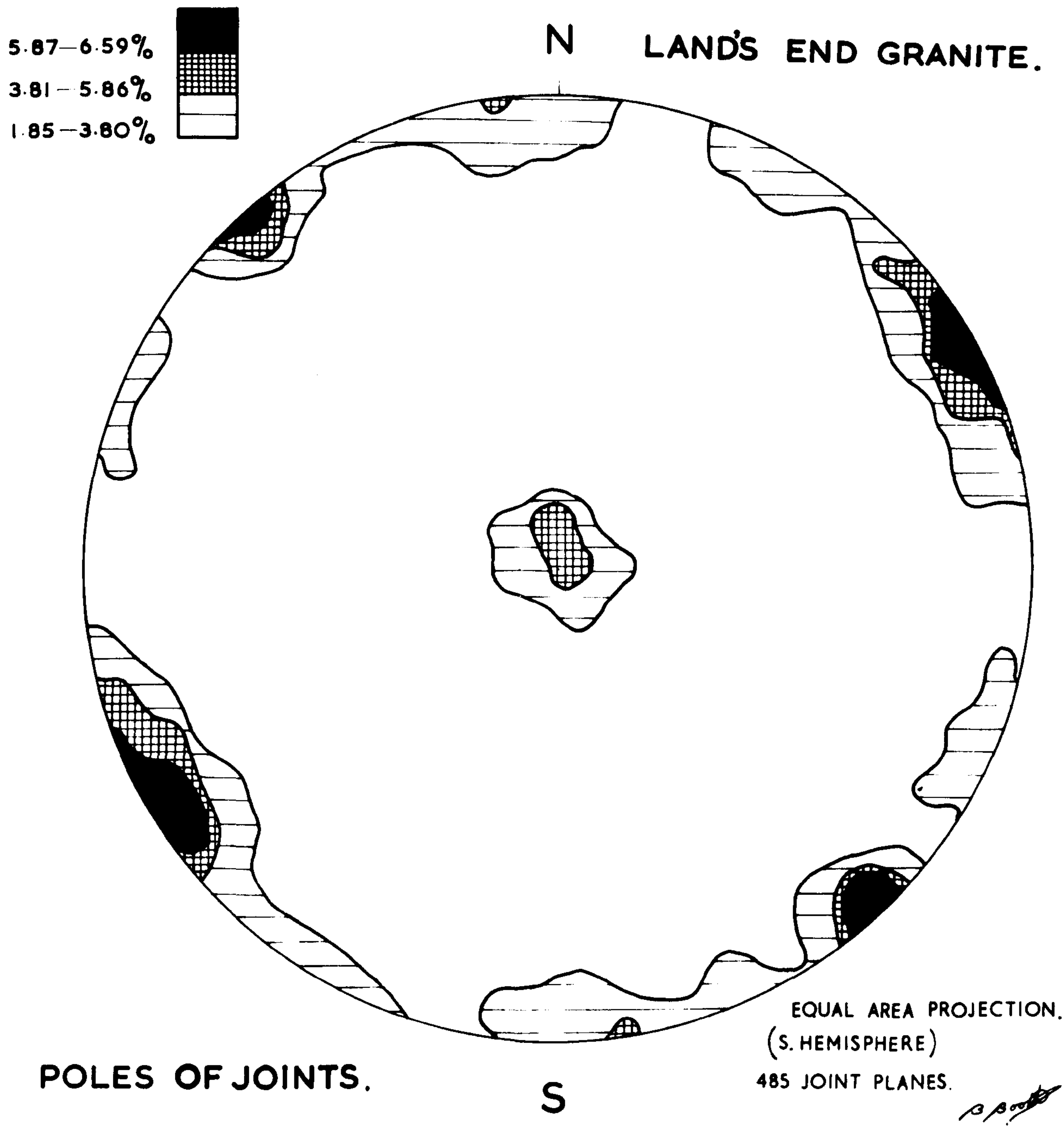
(b) Jointing

Martin (1953) used techniques initiated by Hans Cloos to investigate the structure and mode of emplacement of the Flamanville granite. In 1959 when Exley summarised the structure of the St. Austell granite with a view to obtaining more information on the zones of alteration, he distinguished four principal joint directions and used Cloos's terminology. They were:-

a) Closed S joints with a mean strike of north by west.

b) Open Q joints striking north-north-east, and east-south-east with a mean strike of east by north.

Exley suggested (in contradiction to Brammall, 1926A, p.261) that the L joints (pseudobedding or floor joints) were not related to topography, but were developed along established planes of weakness in response to unloading during denudation. These exfoliation planes are similar to those developed in the north Arran granite (Tyrrell, 1927) and in the Blue Ridge granite of North Carolina (Lobeck 1939). Austin (1960) described the jointing in the Carmenellis granite and decided that the joints were due to tectonic forces rather than a response to cooling of a magma chamber, and suggested that Cloos's nomenclature should be used with caution.


5.87—6.59%
3.81 — 5.86%
1.85—3.80%
N
LAND'S END GRANITE.
S
POLES OF JOINTS.
EQUAL AREA PROJECTION.
(S. HEMISPHERE)
485 JOINT PLANES.

The regional joint pattern in the south western granites is remarkably uniform (Exley 1959, p.208, Fig.3) and it suggests that they are tectonically related.

In the Land's End granite the following principal types of joints can be recognised:-

(i) Sub-horizontal floor joints (L joints). These give rise to the pseudobedding seen in many of the tors on the coarse porphyritic granite. (Figure 17).

(ii) Vertical joints, of which three sets can be distinguished. (Figure 18a). (Sub-varieties exist which are classified according to the mineral assemblage infilling the joint).

(iii) Striated joints, or "Slides" which dip at high angles and are frequently slickensided and coated with tourmaline (Figure 19).

(i) Floor joints (P35)

These joints are to be seen in every tor exposure at Land's End where they give the rock a pseudo-bedded appearance. They vary considerably in their distance from one another but generally they are found to be closer together at the tops of quarries, (Figure 20) and become more widely spaced with increasing depth as at Cripple's Ease quarry where they are separated by over twelve feet. At Down's Barn quarry in the Parish of St. Buryan a partly kaolinised, medium grained granite splits into two to three inch thick "flags" at the top of the quarry. In

Geevor Mine these joints are not immediately obvious, and on close examination this is found to be due to their wide spacing. These data suggest that the floor joints are developing in response to release of load pressure during denudation.

Other factors which would influence the development of floor joints are crystal orientation, cooling surfaces and tectonics. It has been suggested (Hill, 1924; Davison, 1926) that the floor joints in the south western granites are parallel to the feldspar orientation and to the basal planes of micas, and although there is some evidence to suggest that close correlation exists between these joints and the direction of long axis orientation of feldspars a detailed statistical investigation would be necessary to prove this point.

If the floor joints have developed as cooling surfaces then they must reflect the shape of the granite roof against which they are cooled, and on this assumption the roof of the granite is thrown into a series of folds striking north-north-west with a wavelength of one to two miles. They plunge to the north-north-west and flatten to the south-south-east, while they are conformable with both the southern and northern contacts.

The relationship of the floor joints to tectonics is difficult to prove, but if we accept Cloos terminology

(L joints) then we assume they are primary structures contemporaneous with Q and S joints, and that they are produced in response to tensions set up during the cooling and consolidation of the granite.

The attitude of these floor joints is variable, and while inland they tend to be sub-horizontal or dip at low angles to the south east, near the coast their dip steepens (Figures 1 and 2) and they plunge presumably towards the granite/hornfels contact. From Mousehole to Tater-du the floor joints dip to the south east at low angles (Figure 21). The eastern contact at Tater-du is strongly sheared (Figure 22) and that at Priests Cove faulted and mineralised, and the relationships are therefore not clear.

At the western contact at Tater-du however the floor joints which dip south east at 20° to 30° are conformable with the granite/hornfels junction (Figure 23). Other granite/hornfels junctions show a similar relationship to the floor joints (e.g. Mousehole, Sennen Cove, Porth Ledden, Porthmeor, and Tregerthen Cliff).

From Tater-du towards Gwennap Head the south easterly dip is variable ranging from 24°SE at Boscawen Cliff to 18°-22°SE at Cribba Head and 35°-45°ESE at Treryn Dinas.

From Gwennap Head to Dr. Syntax's Head the floor joints are nearly horizontal, which in conjunction with the nearly vertical north west-south east, and north east-south west joints is probably responsible for the steepness of the cliffs, which are frequently 200 ft. and vertical along this coastal section. (Figure 24 illustrates similar steep cliffs on St. Michael's Mount).

From Dr. Syntax's Head to Pedn-men-du the floor joints are subhorizontal but on the headland opposite Bo Cowloe and Cowloe the joints dip seawards at low angles towards the granite/hornfels contact which lies somewhere in the Tribbens.

If this seaward dip of the floor joints is taken as an indication of the proximity of the contact then it is concluded that the granite/hornfels junction is at no great distance from the westward facing coast between Sennen Cove and Cape Cornwall, for there is a uniformity in the westward dip along this three-and a-half mile cliff section (Figure 27).

In a similar manner the floor joints along the coastal section between Portheras Cove and Carn Veslan Cliff are observed to dip towards the north west, especially at Rosemergy Cliff and Halldrine Cliff.

The tendency for the floor joints to dip off the sides of the northern range of hills was quickly recognised during early field visits, and it was decided that an examination in detail of one of these hills might yield some information about the relationships of floor joints, hill slope and the planar orientation of feldspars.

(A) The Structure of Rosewall Hill.

Rosewall Hill is situated two miles south west of St. Ives and overlooks the B3306 road from St. Ives to St. Just. It forms a compact unit in which the relationships of the structural features mentioned above can be studied.

The hill is elongated north east-south west (the south-easterly elongation is not nearly so pronounced here as in other hills along this coast). The Tors of the eastern end are separated from those of the western end by a slight saddle where sporadic exposures of fine grained granite occur; elsewhere the granite is the coarse highly porphyritic variety.

The eastern and western hill slopes are found to be more steeply dipping than the northern hill slope, while the southern slope is of a very shallow angle indeed. (These hill slope dips were computed in degrees from $2\frac{1}{2}$ inch Ordnance Survey maps and plotted as poles to slopes on an equal area Schmidt Net using the southern hemisphere- Figure. P51).

(1) Hill Slope. The stereogram shows 16 hill slope angles plotted as poles to slopes. It can be seen that there is a southerly dip of roughly 5^{o} and a northerly dip

of approximately 10°; the dips on the flanks of the hill to the east and west are about 14°. This steeper slope on the flanks of hills is a common feature along the northern range of hills, while the northerly or north-north-westerly dips closely approximate to those observed in this case.

(2) Floor Joints. 37 floor joints are plotted on the stereogram as poles to joints, each point representing the mean of at least 6 separate readings taken at random at the sampling site. There is a cluster of poles at "A" which lies on a great circle and represents joints on the west flank dipping into the valley at approximately 25° (see also Figure 6). Other plots show a northerly to north-westerly dip of 14° to 20°. On the Rosewall Hill map the north western tor on the 600 ft. contour displays floor joints whose dips gradually steepen as they swing round into the valley on the western side, the values change from 20°NNW, to 23°NW, to 25°WNW, to 28°S of W.

(3) Feldspar Orientation. (Map. 1.). The map shows the azimuthal orientation of the potash feldspar megacrysts measured parallel to their long axis. Plunge was measured along the "c" axis, but for reasons given elsewhere this was approximate in many cases. There is a general direction of elongation of the crystals from north to south,

and from north-north west to south-south east while on the northern hill slope the feldspars plunge north at approximately 20^{o} and on the southern slope they plunge south at about 3^{o}; on the top of the hill the "c" axes are more or less horizontal.

The dip of the (010) faces at the northerly end of Rosewall Hill (though it was not possible to measure this accurately) probably varies about the vertical, and is seen as a prominent foliation at the southern end dipping 65^{o}E.

At the summit of the hill is exposed a fine grained granite which displays quartz and biotite banding parallel to the feldspar plunge in the coarse granite (Figure 31), and to the contact at 25M which dips 20^{o}NE. At 25L the fine granite has developed roof pegmatite and dips at 3^{o} SSE beneath the coarse porphyritic granite parallel to the feldspar plunge (Figure 32a).

A biotite schliere which outcrops on the west side of the hill near the 600 ft. contour is orientated NNW-SSE which is subparallel to the feldspar long axes and the granite and tourmaline veins, and the regional NNW-SSE vertical joints.

Carn Galver is similar in structure to Rosewall Hill. Here the easterly dip of the floor joints is 30^{o} which corresponds very closely to hill slope, the hill slope on the western side is determined by the NNW-SSE longitudinal joints which dip 80° to 50° W. The saddle between the northern and southern tors is occupied by medium grained non-porphyritic granite which underlies the coarse porphyritic variety.

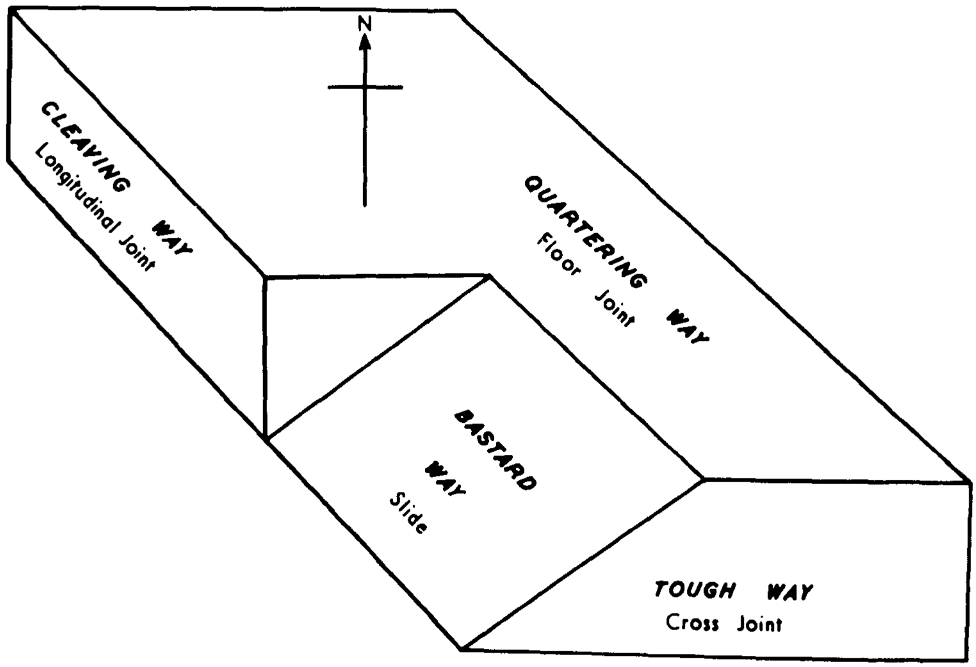
Field evidence suggests that there is a close correlation between floor joints and hill slope in the northern hills at Land's End. Rosewall Hill is typical of these and it is concluded that the hills have developed in response to granite structure in which the development of floor joints has played a considerable part. They are regarded as having formed along weakness planes which developed in response to cooling surfaces in the granite, and therefore mirror the shape of the hornfels cover subsequently removed by erosion.

(ii) Vertical joints

The joint planes in the Land's End granite are very undulatory along their strike and dip, so that when measuring these planes it was necessary to be very careful to select an average face or to take several measurements and compute the mean value. The availability of good joint planes for measurement is governed in quarries to a large degree by the quarrying techniques of the district.

In quarrying terms, the "Cleaving way" corresponds to the NNW-SSE longitudinal joints and is parallel to the

Quarrying Terms


N
CLEAVING WAY
Longitudinal Joint
QUARTERING WAY
Floor Joint
BASTARD WAY
Slide
TOUGH WAY
Cross Joint

azimuthal orientation of the feldspars, while the "Tough way" cuts across the feldspar elongation and is parallel to the ESE-WSW cross joints. The "Quartering way" is parallel to the floor joints discussed earlier and the "Bastard way" is parallel to the slides or diagonal joints. (See P. 45).

The spacing of the vertical joints varies considerably and there is no evidence at Land's End to suggest they are always more widely spaced than the beds as in the Carnmenellis granite.

(1) Longitudinal joints. The NW-SE longitudinal joints have smooth surfaces (Figure 25) and vary in dip 10^{o} either side of the vertical; they are responsible for most of the bold coastline (Figure 1) and govern the major directions of quarrying. Closely spaced longitudinal joints have probably developed as a result of movement and are thought to represent fracture zones (Figure 30, 80, 81, 82.); the granite is mylonised in many cases and nearly always kaolinised (Figure 29); the china clay pits in this area are elongated NW-SE (Map. Land's End Granites), and are situated on these fracture zones where many of the NW-SE river valleys have developed. It is highly probable that the other rivers drain along similarly argillised tracts of country.

These joints are followed by many lodes bearing such minerals as cassiterite, chalcopyrite, pyrite, wolfram, molybdenite together with tourmaline (Figures 63, 67), quartz (Figures 64, 65), and chlorite (Figure 28) which are locally known as "Peach"; fluorspar has been found only as blue-green cubic crystals on a NNW-SSE joint face in Castle-an-dinas quarry.

(2) Cross joints. The two main sets of cross joints strike E by N and NE respectively (Text figure P35) and may have developed as a result of stretching due to relief of stress, this joint direction is followed by the anomalous "elvan" or quartz porphyry dyke which was mapped by the Survey. However, other quartz porphyry dykes which strike along this direction are numerous to the east of Land's End granite.

(iii) Striated joints.

These joints commonly strike NE-SW, are slickensided and coated with a veneer of either tourmaline, chlorite or mylonised granite. They dip roughly to the SE and NW in the Castle-an-dinas quarry and form aretes on the quarry walls (Figure 19). Austin (1960) deduced from these slides a general downthrusting to the north in the Carnmenellis granite while Ghosh (1934) noticed that the acute angle between them sometimes accommodated the longitudinal or the cross-joints and argued that the regional pressure must have varied its direction.

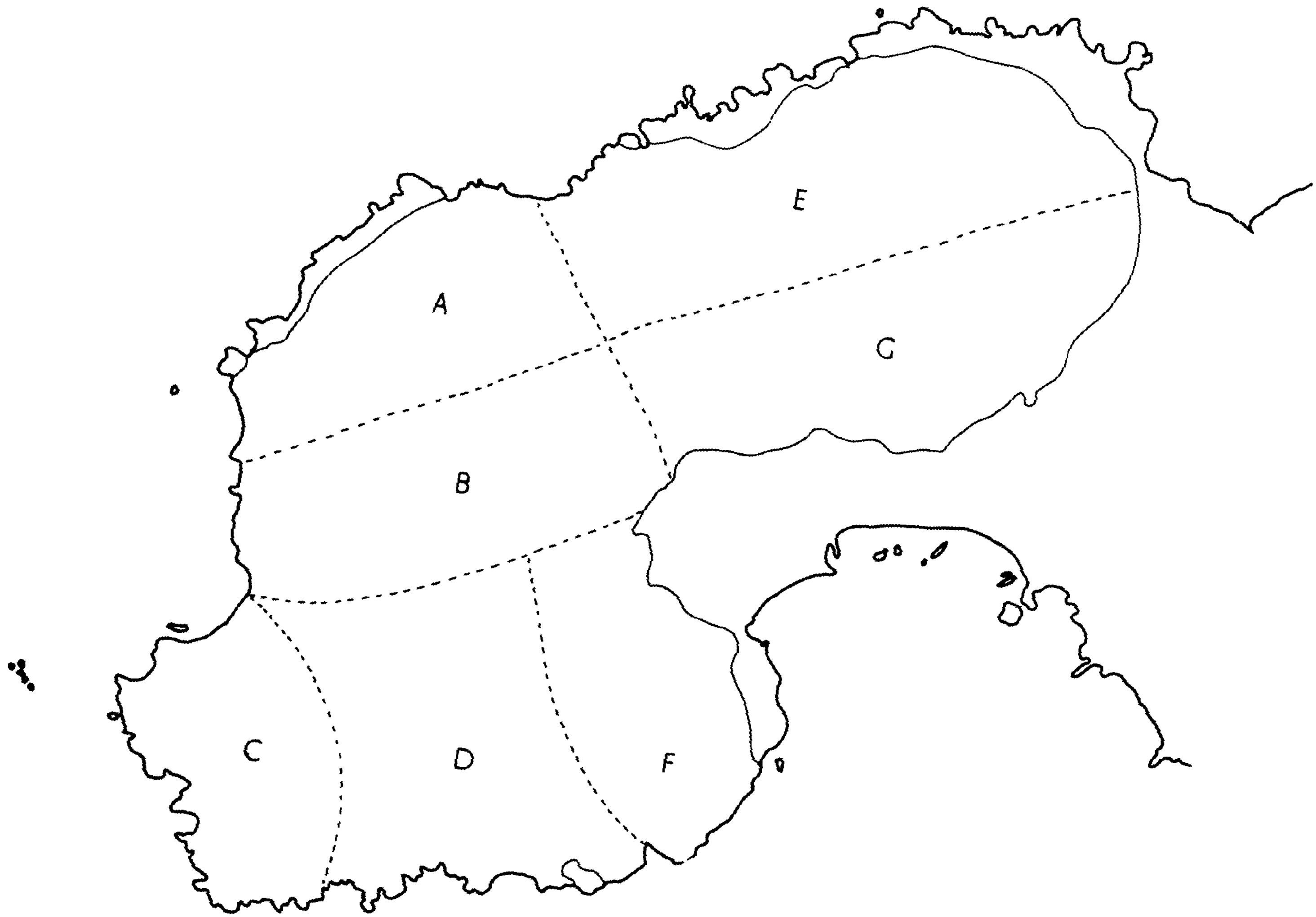
The slides examined in the Land's End granite are found to be variable in their direction of slip which generally downthrows between west and southeast; the striations indicate both vertical movement and oblique shear.

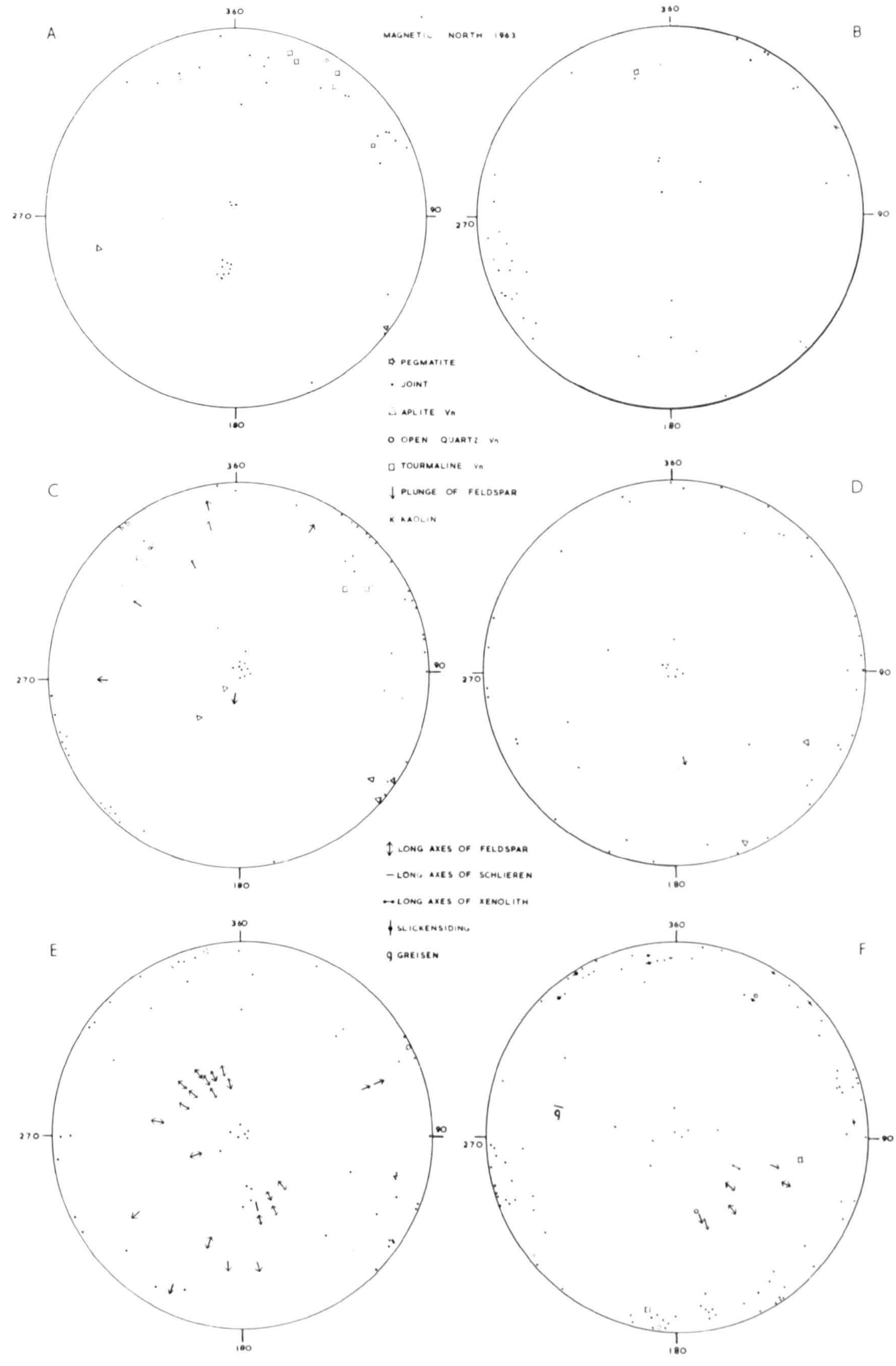
(iv) Distribution of joint trends. (P. 49, 50 & 51).

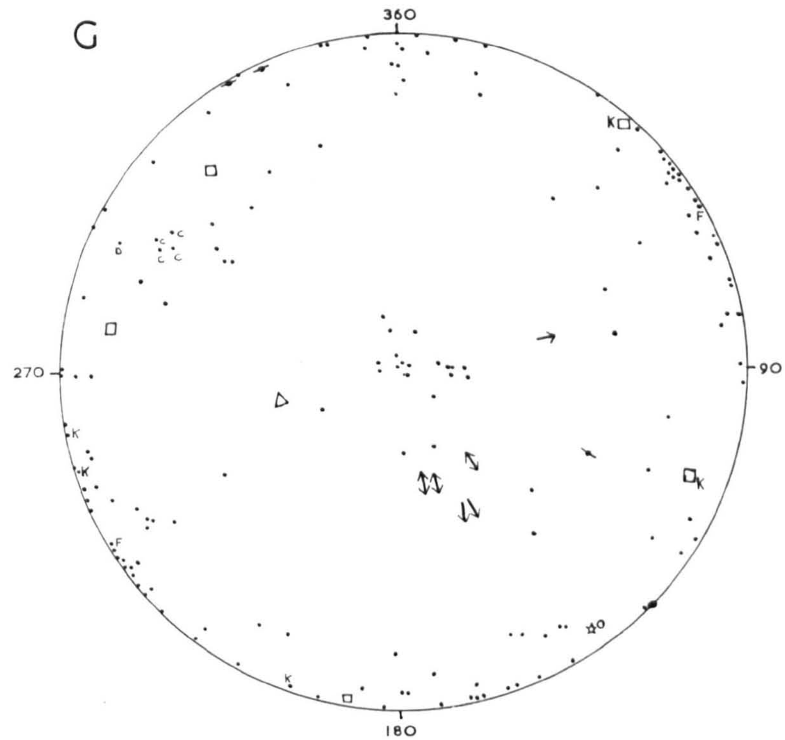
In order to investigate any variation in the joint pattern throughout the Land's End granite it was necessary for joint measurements to be broken down into selected areas (Text figure. P49).

Whilst it is realised that the low number of joint readings for areas A,B,C,E and C is statistically bad and may not give a wholly true quantitative picture of the joint pattern, it must be pointed out that definite maxima occur in all these cases, and it is therefore considered that these stereograms are qualitatively, if not completely quantitatively, correct.

Slight variations occur in areas F,G and B and while these are probably due to areal dominance of a particular joint pattern there is a general uniformity in the distribution of the maxima. The differentiated joints and vein directions are shown in text figures. P50 & 51.


E
A
G
B
C
D
F


A
B
C
D
E
F
360
270
90
180
MAGNETIC NORTH 1963
PEGMATITE
JOINT
APLITE Vn
OPEN QUARTZ Vn
TOURMALINE Vn
PLUNGE OF FELDSPAR
K KAOLIN
LONG AXES OF FELDSPAR
LONG AXES OF SCHLIEREN
LONG AXES OF XENOLITH
SLICKENSIDING
g GREISEN


G
360
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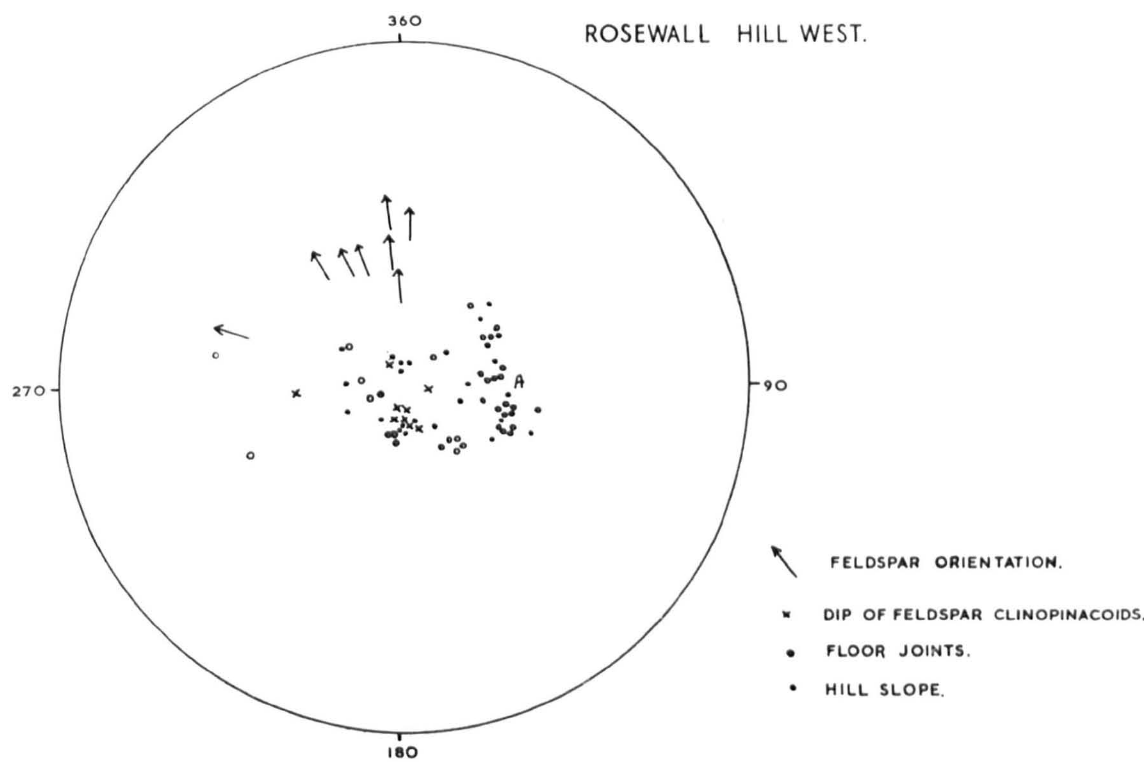

360
ROSEWALL HILL WEST.
270
90
180
A
FELDSPAR ORIENTATION.
DIP OF FELDSPAR CLINOPINACOIDS.
FLOOR JOINTS.
HILL SLOPE.

(v) Distribution of Joints in the other Cornish Granites.

(1) Dartmoor. There is very little information on jointing in this granite apart from a detailed study of the north eastern tract by Blyth (1962) who deduced four sets of joints :-

(a)	150°	bearing,	Vertical	NNW-SSE
(b)	164°	"	"	
(c)	77°	"	"	ENE-WSW
(d)	49°	"	"	NE-SW

Brammall (1926a) noted the following joints as being of regional importance.

(a)	N 32° W	NW by N-SE by S
(b)	N 55° W	NW by W-SE by E
(c)	E - W	
(d)	N - S	

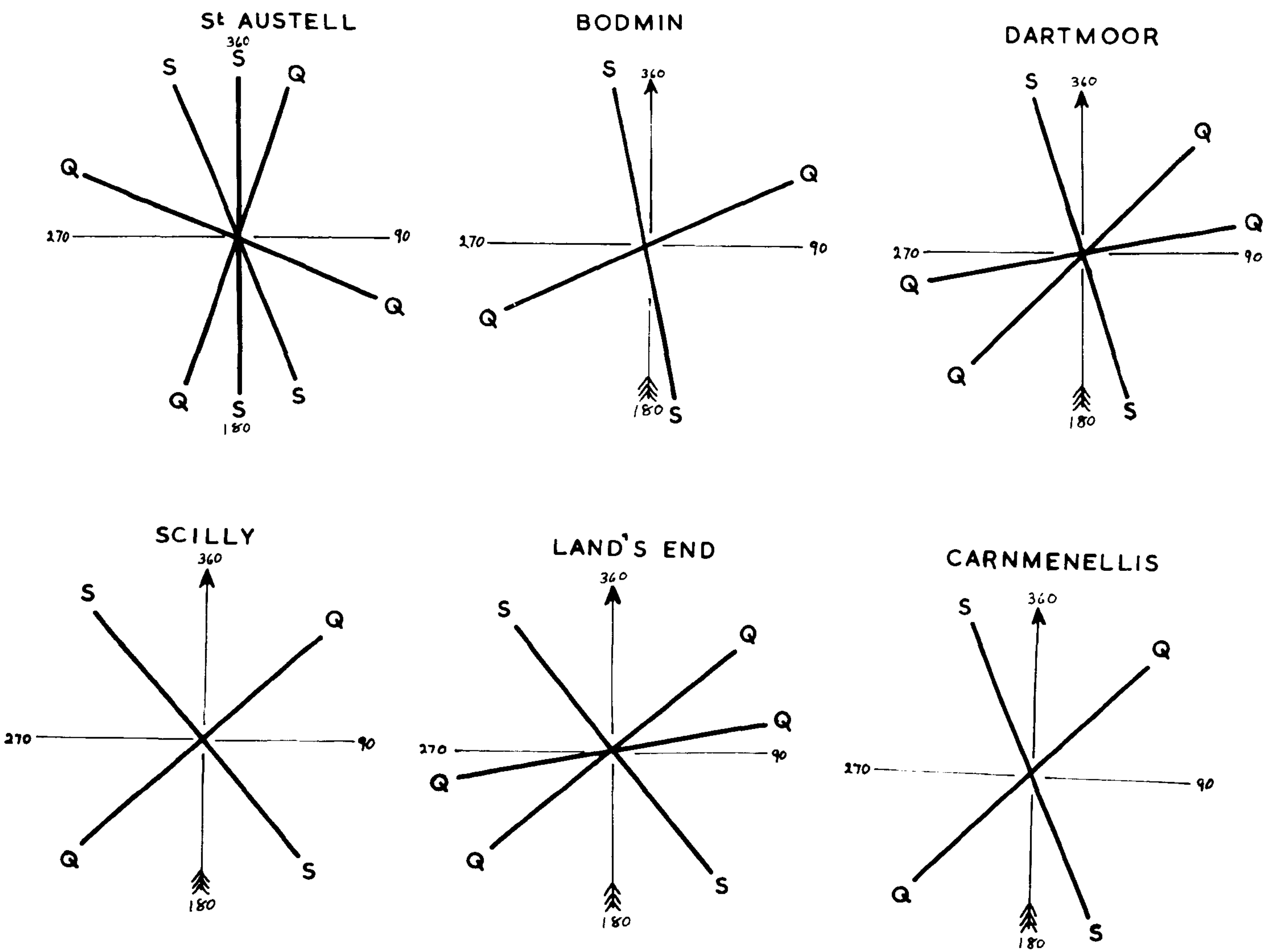
(2) Bodmin. Reid, Barrow and Dewey (1910) recorded two main joint directions.

(a) E - W
(b) N - S

Exley (1965) noted a difference in the structure of (i) the central zone and (ii) the northern and southern zones and suggested that "the general pattern of the South-West is a response to stresses of 'Armorican'-orientation".

(a) N by W - S by E
(b) ENE - WSW

(3) St. Austell. Exley (1959 p.206-207) recorded four principal joint directions and related them to regional


St AUSTELL
BODMIN
DARTMOOR
SCILLY
LAND'S END
CARNMENELLIS
360
270
90
180
S
Q

B B.

tectonics.

(a) N - S) closed S joints
(b) NNW - SSE)

(c) NNE - SSW) open Q joints
(d) ESE - WNW

(4) Carnmenellis. Austin (1960) described the jointing in this granite and recorded two main sets of high angle joints.

(a) NNW - SSE, vertical
(b) NE - SW, 70° NW

Ghosh (1934) recorded an ENE - WSW set which probably corresponds to (b) above.

(5) Scilly Isles. Osman (1928) noted the mean strike of two principal joints.

(a) NW - SE, (S joints)
(b) NE - SW, (Q joints)

(6) Land's End. Osman (1928) described the jointing and established the following distinct trends.

(a) NNW - SSE, (S joints)
(b) NE - SW, (Q joints)

In this Thesis two principal joint directions are deduced, plus a third which accounts for 3.81 to 5.86 per cent of the total number of measurements.

(a) NW - SE, (smooth S joints)
(b) NE - SW, (Q joints)
(c) N of E - S of W, (Q joints)

The regional distribution of joints is summarised in text figure. P53 using the most recent results.

(vi) Discussion and Conclusions.

There appears to be a dextral shift in the strike of the longitudinal (S-) joints from west to east although Bodmin is slightly anomalous in this series. The number of cross (Q-) joints varies and may be due to the sampling methods used being statistically unsound; nevertheless it is notable that the Q joint pattern for Land's End agrees with the pattern arrived at by Blyth for the Dartmoor granite, and stands in fairly close agreement with the patterns for Scilly, Carnmenellis and Bodmin. Unless mean values are taken there is little agreement between Land's End and St. Austell. The Q- joints, like the S- joints, show a dextral shift from west to east. This is in agreement with a regional tectonic control which is ascribed to internal stress fields set up in response to Hercynian movements.

The longitudinal or S- joints of Land's End could correspond closely to Riedel shears which Blyth (1962) noted as being associated with the main shearing at 150° on Dartmoor. Much movement has taken place along this direction, though whether any movement may be ascribed to Tertiary stresses is a matter for speculation; and if Dearman's (1963) argument for Tertiary dextral wrench faulting is applicable over the entire south-west then the possibility of the kaolinised fracture zones being partly due to this effect cannot be entirely dismissed. Unfortunately fracture zones cannot be traced into the adjoining hornfels; these zones are thought to correspond to the "belts" described by Exley (1965) who postulates a small vertical movement of Armorican origin.

The floor joints or subhorizontal joints are believed to be due to exfoliation in response to relief of load pressure as a result of weathering. Tyrell (1927), Barton (1938), and Harland (1957) demonstrated that exfoliation is the major factor in the development of these joints; and Jahns (1943), Ruxton (1958), and Chapman (1958) believed that weathering could reduce load pressure and hence lead to the development of joints which were essentially subhorizontal. The exfoliation appears to follow well defined planes of established weakness which is probably due to textural orientation and the development of cooling surfaces parallel to the granite roof. On this assumption it is concluded that the roof zone of the Land's End granite is thrown into a series of antiforms and synforms along the northern coast with their fold axes running parallel to the S joints. Similar antiforms occur in the feldspar foliation in Geevor Mine (R. Cox, personal communication).

Structures have been observed in the orientation of the alkali feldspar megacrysts which are ascribed to viscous flow. Wholly post-magmatic metasomatic perthite megacrysts would not be able to develop the contortions and swirls seen in this granite were it not for the existence of seed crystals pre-orientated by magmatic flow. The regional orientation of the long axes is believed due to a continuing regional stress field being in operation while emplacement was proceeding. The north eastern margin of Land's End still displays the predominant NNW-SSE orientation and the dip of the (010) clinapinacoid planes sub-parallel to the contact is presumably due to a drag effect in a viscous medium. This orientation of the clinapinacoids subparallel to contacts is a common feature throughout the granite and it is concluded that for such border phenomena to develop, the granite must have been a viscous "mash" of partly crystalline material lubricated by deuteric fluids at the time of emplacement. Evidence has been presented for other granites (Exley and Stone 1965), which suggests that a mainly solid flow component is involved, lubricated by "mineralising" fluids.

Chapter III

The Granites (Petrography)

A. Introduction

The authors of the Geological Survey Memoir (1907) distinguished two main types of granite at Land's End, firstly a coarse porphyritic muscovite-biotite granite forming the greater part of the area, and secondly a smaller mass at Castle-an-Dinas occupying about seven square miles which they described as a fine-grained granite. With this variety they also classified the Knill's Steeple granite which forms the NW-SE ridge overlooking Carbis Bay (Map.5, Land's End Granites. N.E. area). Robson (1948) summarised the geology of the area, briefly described the granites and distinguished the following varieties :-

(i) Marginal type - a coarse uniformly-grained granite.

(ii) Main porphyritic types - with large potash feldspar crystals of up to 12.5 cms. in length and occasional 'Maltese Cross' double twins. Occurring in this variety :-

(1) 'Basic patches' - rounded femic-rich xenoliths.

(2) Cognate xenoliths - mica balls of early unmixed formation.

(3) Accidental xenoliths of slate hornfels.

(iii) Fine Grained type - (Freestone) under which he classified both the Castle-an-Dinas and Knill's Steeple varieties.

B. Main Coarse Granite types.

In the field three main types of coarse granite can be distinguished and are classified as follows :-

(i) Coarse Grained Porphyritic Biotite Granites (Type (i)).

(1) Highly Porphyritic Biotite Granite. The length of the potassium feldspar megacrysts, as in all these granites, is variable to some extent but 6 cms. is an average length for this type. The average number of megacrysts per square metre is 400 (Fig.11).

(2) Moderately Porphyritic Biotite Granite. The length of the potassium feldspar megacrysts is commonly 4 cms. and the average number of megacrysts per square metre is 100 (Fig.12). As in i.1 the length of the megacrysts is variable to some extent.

(ii) Medium to Coarse Grained Non-Porphyritic Granite. (Type (ii)). This type is characterised by an almost complete absence of large feldspar megacrysts

(Fig.13). The rock is often rich in groundmass tourmaline and pegmatites of this mineral frequently occur (Fig.14).

(iii) Coarse Grained Non-Porphyritic Basic Granite. Although this rock has the composition of a melagranodiorite, evidence is presented (P.190) to show that it represents a granite which has become highly contaminated by assimilated aureole rock. It is recognisable in the field as a melanic, coarse grained, foliated rock containing abundant tourmaline nodules (Fig.77), and biotite crystals which are approximately 2-4 mm. across the basal plane (001). (Figs. 55 and 79).

(a) <u>Field Relations and Distribution</u>

The greater part (68 square miles) of the Land's End peninsular is occupied by the coarse porphyritic biotite granites. The average grain size is approximately 1 mm. which corresponds to a C.I. number (Coarseness Index - See Technical Procedures P.164) of 40; the very coarse varieties have C.I. numbers as low as 20 which corresponds to a grain size of 2 mm. This low value is very characteristic of the highly porphyritic granites such as occur at Cribba Head (Treen), Rosewall Hill (St. Ives), and from Maen Dower to Sennen, where the potassium feldspar megacrysts are frequently 6 cms. in length (Fig.16). The granites vary from highly porphyritic to moderately porphyritic, and although the number of potassium feldspar megacrysts within the rock varies as much as their length it is still possible to recognise these two varieties in the field.

The distribution of the coarse moderately porphyritic biotite granite is fairly regular with the greater proportion being located in the southern area around Polgigga, St. Buryan, Sancreed, and Sheffield. Age relationships between this variety and the highly porphyritic granite have not been established as they have never been found in sharp contact, one imperceptably merging into the other. It is therefore highly probable that they are slight variants of the same phase produced by an unequal distribution of potassium ions during metasomatic activity.

The moderately porphyritic variety occurs in parts of the cliff section between Mousehole and Tater-du, and occasionally between Merthen Point and Tree Cliff, while inland exposures occur at Redhouse, Castallack, Treen and near Boscawen-noon and Goldherring though the granite at these last two localities is contaminated with assimilated material. Land's End Granites map illustrates the distribution of these two varieties, and it can be seen that the boundaries, as interpreted from differences between sample points, are concave towards the moderately porphyritic type.

In several localities :- Maen Dower, Mayon Cliff, Treen Cliff, Carn Bargess and Land's End the porphyritic granite contains abundant cordierite crystals; although cordierite can be located in such areas as Mousehole to Rosemodress Cliff and from Boscawen Cliff to Cribba Point without much difficulty it is not so abundant as at the former localities. The cordierite crystals which are nearly always pseudomorphed by pinite (Sericite, chlorite and indefinite silicates), are of the characteristic pseudohexagonal form and measure up to 2 cms. in length along the 'c' axis and 1 cm. across the compound basal pinacoid.

Another common feature of the coarse porphyritic granites is the widespread occurrence of xenoliths of pelitic or basic material in all stages of assimilation (metamorphic convergence having destroyed traces of their original parentage). The development of andalusite-muscovite-biotite assemblages represents the penultimate stage in the digestion of the enclaves, the final stage being reached where the granite is so contaminated by dispersed xenolithic material that its composition corresponds to that of a melagranodiorite (Fig.55). This rock contains up to 28 per cent modal biotite in contrast to the usual 3-8 per cent, and plagioclase (An 17-21) is dominant with respect to alkali feldspar (Table SC1, SC2). (P 349)

From the Whirlpool and Morvah to Portheras Cove, (with the exception of the one quarter-mile wide coastal section between these localities which is composed of coarse porphyritic biotite granite), and thence down through St. Just to Porth Nanven a medium grained granite is exposed with C.I. numbers ranging from 40 to 70 giving an average grain size of from 1mm. to approximately 0.6 mm. This granite which is poorly porphyritic to non-porphyritic often contains abundant tourmaline prisms, while drusy pegmatites of this mineral are a common feature along the Priests Cove - Porth Nanven coastal section (Fig.14). Isolated exposures of this medium grained granite also occur at Nanquidno Downs, Carn Grean, Truthwall Common SE, Chun Downs, south of St. Buryan and near Drift Reservoir (Map.6, Land's End Granites).

The medium grained granite occurs beneath the porphyritic biotite granite and is probably intrusive into it. Contact relationships can be observed at the Whirlpool near Morvah (Fig.32), and 300 m. south of Porth Nanven. At the Whirlpool cliff exposure, the medium grained granite dips north beneath the coarse porphyritic granite; its contact with the latter is conformable with the foliation in the porphyritic type, and 'gneissose' streaks of biotite occur parallel and within a few feet of the contact (c.f. Rosewall Hill West p. 40 and Fig.31). Pods of tourmaline pegmatite are common (Fig.33) but the granite appears to have its highest concentration of groundmass tourmaline at the Priests Cove-Porth Nanven exposures.

Special techniques were found necessary to assist in mapping these granites. Inland, poor and sporadic exposures made comparison of rock types difficult, especially when the comparison was based on delicate gradations in texture and grain size. To combat this difficulty a technique which has been used by geophysicists for many years was employed. (See Griswald and Munn (1907), Corbeth (1919), Levorsen (1927) and Rich (1935a, 1935b)). Recently Allen and Krumbein (1962), and Whitten (in Shaw 1963) have demonstrated its usefulness in mapping areally distributed data in which one would find the greatest difficulty in perceiving a pattern. Trend Surface Analysis, which is fully described in a later section of this thesis, is a statistical method for fitting data from a number of sample sites to a surface by means of a mathematical equation based on the method of least squares. It is found that such a surface has a unique shape and position because no other configuration will satisfy the least squares criterion. Computation of mineral data shows that there is a low negative correlation between :-

Coarseness index and Colour index

" " " Clay minerals

" " " Biotite

These low correlation values (never exceeding - .155) can be regarded for the purpose of this exercise as only of slight significance. Further steps in the computation indicate that either :-

(a) Differences among the data are so evenly distributed as to be insignificant.

or (b) The areal pattern is very complicated and the present programming techniques are inadequate to deal with them.

These results were thought to be unsatisfactory and an isopleth map depicting deviations from the arithmetic mean of C.I. in positive and negative values was used. (Conclusions drawn from this exercise are plotted on Land's End Granites map). In other words the regional pattern was taken as a plane surface, equivalent to the arithmetic mean at any point and the residual pattern plotted as deviations from this plane at each sample site. This pattern, which is in agreement with residual isopleth maps for other variables, delineates the areas of coarse to medium grained non-porphyritic biotite granite and indicates where the contacts between this variety and the coarse porphyritic biotite granite might be located.

Subsequent detailed mapping has proved the predictions to be true in the majority of cases.

(b) Megascopic Characters (Type (i))

The coarse porphyritic biotite granites are recognisable in the field as light grey to buff-coloured rocks containing megacrysts of perthitic alkali feldspar set in a coarsely granular groundmass of quartz, perthite, plagioclase, biotite, subsidiary muscovite and frequently tourmaline. In areas where the granite has been highly contaminated with assimilated pelitic material pseudo-hexagonal crystals of cordierite occur which are nearly always pseudomorphed by secondary pinite; many biotite-rich accidental xenoliths also occur in these areas together with occasional schlieren, basic microgranite and basic granite.

(i) Quartz. Rather variable in its distribution and occurs as rounded "glassy" patches of greasy, smoky coloured, sometimes turbid crystals (displaying microconchoidal fractures) from 1 to 2 cms. across. These "pools" are composed of interlocking grains varying in size up to 4 mm, but more commonly 1-2 mm. across. Quartz tends to be interstitial and included, it constitutes on the average 35% of the rock, and weathers out as rounded grains 1 mm. in diameter. Replacement textures are common between feldspars and quartz, the quartz forming lobate protruberences into the feldspar. Inclusions are rare, although biotite and feldspar which are commonly sandwiched between quartz grains forming pools might be mistaken for inclusions.

(ii) Perthite. (1) Megacrysts. Conspicuous by their large size, the average length is 6 cms. and in the coarse grained porphyritic biotite granite constitute 24% of the total rock volume. In the moderately porphyritic biotite granite they account for 6% of the total rock volume. This is not to say that this figure represents an estimate of the percentage of potash feldspar in the granite; it does not, as much of the coarsely granular groundmass in which these megacrysts are set contains a high proportion of this mineral. In fresh specimens the megacrysts occur as euhedral white crystals with a pearly-lustrous appearance which is partly due to the excellent cleavage on the 001 face; they are tabular in habit parallel to the 010 (clinapinacoid) face and generally elongated about a line bisecting the acute angle between the a and c axes. The dimensions of a typical specimen are:- length 6 cms., width 4 cms., breadth 1 cm.; the ratio of crystallographic axes lengths is usually c > a > b.

The crystals are frequently twinned on the Carlsbad Law, and the composition plane is 010 and may be stepped (Austin, 1960 notes curved composition planes in the Carnmenellis granite). Interpenetrant twins are very common, and the rare Maltese Cross compound interpenetrant twins occur at Pedn-men-du, Carn-a-langa quarry, and Carn Barges; though Maltese Cross twins have been reported from Sheffield and Lamorna quarries they have not been found at either of these localities. Figure ~~10+~~ 16c illustrates a Maltese Cross double twin from Carn-a-langa quarry.

The margins of the megacrysts often show serrations and embayments. Where in contact with quartz, lobate protruberences form and sometimes serrations occur, though straight contacts are not unusual. Plagioclase contacts are serrate or lobate, while mica/perthite contacts are straight or "zig-zag" depending on the orientation of the mica basal pinacoid with respect to the feldspar crystal. Muscovite frequently penetrates the megacryst along cleavage cracks or follows perthite strings, but these are extremely difficult to see in hand specimens.

Inclusions in the feldspar megacrysts are both numerous and varied, and close examination reveals clear streaky patterns in the crystal which are due to strings and films of albite. The perthite strings cross twin planes and show variable directions, generally forming an acute angle with the c-axis direction, but it has been noted that on the clinopinacoid face where it intersects the basal pinacoid and hemiorthodome, the perthite strings sometimes curve to lie subparallel to the margin. In hand specimens both biotite and quartz are immediately obvious inclusions, the biotite sometimes forming well defined zones within the megacryst often parallel to the crystal faces. The number of zones occurring is variable, being generally one main inner zone which is perfectly formed and occurring half way between the crystal margin and the centre, and occasionally a peripheral zone 1 to 2 mm. from the margin. Sometimes the biotite inner zone is oval in shape and in no way reflects the crystal faces.

Quartz inclusions are, like biotite, sometimes arranged in peripheral zones as discrete, elongated, water-clear blebs.

Plagioclase occurs as subhedral to euhedral tabular crystals which vary considerably in shape and size. Rims of albite envelop these crystals which are often preferentially altered into clay minerals ("honey speck").

Muscovite is included in some megacrysts.

Tourmaline is occasionally seen as inclusions, but generally shows a replacement texture.

All chadocrysts may occur scattered throughout the oikocryst and are not always obvious in hand specimens.

(2) Interstitial. This type of perthite has a milky lustre and may contain both quartz and biotite "inclusions", though it is not always possible to ascertain whether these crystals have become trapped between feldspars growing in close proximity.

(iii) Plagioclase. This mineral is rather difficult to recognise in the hand specimen on account of the fact that it is frequently replaced by potash feldspar. It may, however, be recognised by the albite rim which frequently envelops the crystal or by staining for potassium feldspar and identifying the unstained crystals. The size varies up to approximately 8 mm. by 6 mm.

Both perthite and plagioclase are liable to undergo kaolinisation, the plagioclase tending to decompose first. The areas around Cold Harbour, Tregeseal and

Tredinney are extensively kaolinised and may reflect an initially high plagioclase content in this part of the granite, thus demonstrating it heterogeneity (see P 158).

(iv) Biotite. Variable in amount and distribution, but occurs as 2-3 mm. opaque, black-bronze flakes with a pearly to splendant lustre. The bronze colour component varies and is probably a reflection of the composition. Exley (1955) noted that lithium bearing micas in the St. Austell granite are frequently bronze in colour.

The biotite commonly occurs in clumps up to several mm. across, though in heavily contaminated areas (e.g. - Sennen Cove) this mineral may account for as much as 28% of the rock volume, and clumps may tend to be continuous where a strong foliation has developed. It normally accounts for 3% to 8% of the rock.

Inclusions are microscopic but sometimes biotite-muscovite intergrowths can be seen in hand specimens.

Biotite frequently alters to chlorite in some degree and at Knill's Steeple a granite is altered to chlorite-quartz-feldspar-tourmaline rock adjacent to a mineral vein.

(v) Lithionite. Occasionally bronze coloured flakes of mica occur which are very similar to those described by Exley (1955) as approximating to zinnwaldite in composition.

(vi) Muscovite. Flakes of silvery white mica approximately 1-2 mm. across are especially abundant in mineralised and greisenised areas. Muscovite seems to form at the expense of biotite, which in mineralised areas decreases in volume.

(vii) Tourmaline. Occurs as black, striated, prismatic crystals. It is variable in distribution, accounts for 0.5% to 1.0% of the rock and commonly replaces feldspar (fig. 14 illustrates typical tourmaline concentration in granite).

(viii) Cordierite. Grey-black barrel-shaped crystals with a subvitreous to dull lustre measuring up to 2 cms. in length by 1 cm. across occur in areas heavily contaminated by assimilated pelitic material. They are usually pseudomorphed by pinite.

(C) Megascopic Characters (Type (ii))

The medium to coarse grained non-porphyritic granite underlies the porphyritic variety along the north-west coast and is probably intrusive into it. This granite is distinguished from the porphyritic variety in hand specimens by the lack of feldspar megacrysts and the abundance of tourmaline; otherwise the minerals are megascopically similar. Slight differences are noted below :-

(i) Quartz. Evenly distributed and occurs as rounded, "glassy" patches of greasy, clear-turbid crystals 2 mm. to 4 mm. across. Replacement textures are common between feldspars and quartz, lobate margins frequently occurring. Inclusions are rarely seen in hand specimens.

(ii) Perthite. Fresh, creamy white amoeboid patches 10 mm. to 15 mm. across and lacking elongation. It is frequently replaced by tourmaline and contains biotite and quartz as irregular inclusions.

(iii) Plagioclase. Unless selectively altered to clay minerals there is very little to distinguish it from perthite in hand specimens.

(iv) Biotite. Occurs at 2 mm. to 3 mm. bronze-black flakes with a splendant lustre, the flakes occur singly unless associated with pegmatites which are common in this granite.

(v) Lithionite. Much of the bronze mica is probably lithionite. A pegmatite at Bosarren Carn contains "books" of lithionite 10 mm. to 15 mm. across and 5 mm. thick.

(vi) Muscovite. Occurs mainly in mineralised and greisenised zones.

(vii) Tourmaline. Very common as an interstitial mineral, the black variety "schorl" is predominant and fills most of the pegmatite druses occurring in this variety of granite along the Priests Cove - Porth Nanven exposure.

(viii) Cordierite. Rare.

C. Fine Granite Types.

Three varieties of fine granite occur and are confined to the northern and north-eastern are of Land's End. They are subdivided as below.

(i) Central Fine Granite (Castle-an-dinas granite). (Type (i)).

Grey rock which weathers extensively to a buff colour. The grain size is less than 0.3 mm. and occasionally small perthite megacrysts up to 2 cms. in length occur. The rock is contaminated by assimilated pelitic material and contains both accidental xenoliths and cordierite crystals. Pegmatites are rare.

(ii) Knill's Steeple Granite (Type (ii))

Creamy-white highly feldspathic rock with a grain size of approximately 0.6 mm., weathering is confined to 30 cms. to 50 cms. from the rock surface. It is non-porphyritic and contains conspicuous bronze-black flakes of biotite 2 mm. across together with crystals of "shorl" up to 5 mm. long. Pegmatites are both large and common in this variety while accidental xenoliths and cordierite crystals are rare.

(iii) Other Fine Granites (Morvah and Rosewall Hill types) (Type (iii)).

The distribution of both these types is

somewhat limited; that occurring on Rosewall Hill forms two isolated exposures a few hundred feet apart, and that at the Whirlpool, Morvah, occurs beneath the coarse porphyritic granite. Both contain small roof pegmatites of feldspar and tourmaline and both are rich in biotite; at Rosewall Hill the biotite occurs in bands ("Flow-lines") parallel to the roof contact.

Staining hand specimens of these fine granites shows them all to be rich in potash feldspar, soda feldspar probably accounting for less than 20% of the total volume.

(a) Field Relations and Distribution

(i) Castle-an-dinas granite. This forms the larger mass of fine granite lying between Trendrine Hill (NE corner), Trewey Hill (NW corner), Trezelah (SW corner), and Cucurrian (SE corner). The field relations with the coarse porphyritic granite are unknown as contacts are nowhere exposed; a few boulders on Beagletodn Downs show contacts between a fine granite and the porphyritic variety. However as these lie outside the postulated main area of fine granite, and as (a few hundred feet further north) a tor west of Trendrine Hill contains a vertical dyke of this fine granite it is presumed that these loose blocks consist of fine dyke material.

The mapped periphery of this fine granite, which is based on loose boulders, agrees with that of the Geological Survey, with the exception of the junction near Sperris Croft. Detailed mapping suggests the junction to lie 1,300 ft. south of that postulated by the Survey. The fine granite boulders at Sperris Croft then probably represent a large offshoot of the main fine granite mass as they lie amidst coarse porphyritic bedrock.

The relief over this fine granite area is gentler than that over the porphyritic variety. Tors are absent and most of the area constitutes rough pasture slopes covered with heather. However around Tredorwin and Little Amalebrea the granite is extensively kaolinised and readily weathers to yield a "fertile" podsol at least 18 inches in depth. The main kaolinised zone is shown on the map of Land's End Granite's NE area, the clay pit in the western corner representing the now disused Georgia Works situated due south of Woon Smith. Here a specimen of kaolinised granite was found which shows a sharp contact between fine and coarse varieties; the Geological Survey Memoir (1907, p.106) notes that "the newer granite was passed through at a depth of 60 fathoms (360 ft.) from the surface at Flat Rod shaft" in Wheal Georgia. Data from old workings in this area are scanty but the existence of a coarse granite roof pendant might be postulated. The extent of the kaolinised granite is shown by the fertile soils which overlie it an the many small clay pits scattered over Trenowin Downs.

Several quarries are situated in the centre of the southern zone of this fine granite immediately south of Castle-an-dinas. The largest quarry (S4) is approximately 1,000 ft. long by 600 ft. wide and contains fresh grey granite in the lower levels (100 ft. below surface), while the granite in the upper level (30 ft. below surface) has a buff colour attributable to deep surface weathering which is especially noticeable along joints.

The granite is cut by a "dyke" of reddened, tourmalinised fine grained granite with kaolinised margins. NNW-SSE zones of kaolinised granite also occur and are criss-crossed by tourmaline veins

(Fig.29), which show "sag effects" probably due to faulting. The granite at the eastern end of the quarry is very fractured and joint faces are often coated with chlorite (Fig.28); this may represent part of a fracture zone running through S24 and S11 (see Map. Land's End Granite. NE area). The eastern face of the abandoned quarry at S12 is slightly fractured and may lie on the border of this zone.

Located in S12 quarry are potash-rich areas which might be termed "pegmatoid". The rock in these areas is composed of a groundmass equivalent in grain size to the normal fine granite in which are set euhedral-subhedral megacrysts of perthite measuring approximately 7 x 3 x 1.5 cms.; they are so closely packed as to be touching in many cases.

As mentioned earlier (p.76) small megacrysts of perthite occur in the granite and the map of Land's End Granite. NE area, shows their distribution to be more or less central; this illustrates the heterogeneity of the granite and the existence of potash-rich centres which may represent the fixation of potassium ions displaced from soda-rich zones, or vice versa. Exley (1955) has shown the correlation of kaolinised areas with low ground which may represent the remnant of such a soda-rich zone.

(ii) Knill's Steeple Granite.

This occurs as a NW-SE elongated ridge of highly feldspathic granite overlooking Carbis Bay. Detailed mapping has shown this granite to occupy at least twice the area illustrated on the Geological Survey one-inch map and the eastern end is found to be extensively chloritised and haematised adjacent to a mineral vein. The tourmaline aplite which was noted in Little Wheal Speed probably represents an underground extension of this granite, and the miarolitic fine granite which occurs in Higg's Shaft near Carbis Water probably represents this granite in close proximity to the junction with the coarse porphyritic granite.

In addition to the exposure of this granite at the base of Knill's Steeple it is exposed in the surrounding woods and in two disused quarries which lie NNW of the Steeple; here the granite is riddled with very coarse tourmaline pegmatite composed of interlocking crystals of tourmaline, quartz and oligoclase, and was probably the reason for the quarries' abandonment.

(iii) Morvah and Rosewall Hill Granites

(1) Rosewall Hill Granite. Rosewall Hill is situated approximately 2 miles south west of St. Ives, and is composed of an eastern and a western tor separated by an area of low ground where fine grained non-porphyritic granite is exposed. Contacts with the coarse porphyritic granite can be seen only at the western tor (Fig.31) where the fine granite underlies the porphyritic variety. The domed conformable junction between the granites dips NNE at 20° and due S at 3°; fan-shaped pegmatites composed of tourmaline and feldspar occur within a few inches of the roof at the southwards-dipping contact, and at the northwards-dipping contact the rock is banded. These bands, which are composed of alternating quartz-biotite and quartz-feldspar rich zones, lie parallel to the contact.

(2) Morvah Granite. The Whirlpool, where this granite is well exposed on the northwards-facing cliffs, lies almost centrally between the granite/hornfels contacts at

Portheras Cove and Porthmeor Cove. Sporadic exposures also occur on the hill slope above Trevean Cliff and in the saddle between the NW and SE tors at Carn Galver. It always underlies the coarse porphyritic granite and at the Whirlpool it is observed to dip northwards beneath the coarse porphyritic granite at approximately 30°. The area of ground to the north of the road is covered with gorse shrub and scattered boulders of coarse porphyritic and fine granite, some with much schorl and occasionally boulders of schorl and quartz schorl appear on the surface. Patches of fine grained granite occur on the coarse porphyritic granite headland which is also cut by a NNW-SSE vein of fine grained leucogranite.

The NW-SE longitudinal joints are very prominent here and are often coated with tourmaline crystals which are occasionally deposited on a quartz lining. Several drusy quartz-tourmaline pegmatites occur (Fig.33) containing large radiating nests of tourmaline on massive white, and often well crystallised quartz; occasionally quartz is of the variety "rock crystal". Pinitic pseudomorphs of cordierite are common in the adjacent coarse porphyritic granite, but accidental xenoliths are rare.

The floor joints which dip at a shallow angle to the NNW (Fig.1) probably indicate that the granite/hornfels contact is not very far offshore.

(b) Megascopic Characters (Types (i) and (iii))

With the exception of the Knill's Steeple granite, the fine grained granites are recognisable as hypidiomorphic non-porphyritic or poorly porphyritic grey-coloured (buff when weathered) rocks containing quartz, perthite, plagioclase, biotite and tourmaline.

The Castle-an-Dinas and Morvah granites are contaminated, and pinitic pseudomorphs of cordierite are extensively developed; biotite-rich accidental xenoliths also occur but these are small in size when compared with those found in the coarse porphyritic granites and are rarely larger than 3 cms.

(i) Quartz. Evenly distributed and occurring as rounded, "glassy" patches of greasy water-clear crystals. Phenocrysts are common and form patches 7 mm. across, while the groundmass quartz is composed of anhedral grains. Inclusions are difficult to identify on account of their small size and only felspar can be made out with any degree of certainty.

(ii) Perthite. (1) Megacrysts. These occur as subhedral crystals approximately 2 cms. in length with a milky white lustre. They are frequently twinned on the Carlsbad law, and the Maltese Cross twins which occur in the coarse porphyritic granite have never been observed in this variety.

The margins of the megacrysts are finely serrate and the only inclusions observed are tourmaline threads which are probably replacing the feldspar.

(2) Interstitial. Amoeboid, milky-white crystals with included tourmaline.

Perthite accounts for 30% of the rock.

(iii) Plagioclase. Occurs as interstitial amoeboid patches which are replaced in varying degrees by perthite. Accounts for 22% of the rock.

(iv) Biotite. Evenly distributed as bronze-black flakes 2 mm. to 5 mm. across.

(v) Lithionite. Occasional bronze flakes 1 mm.

across occur which may be the lithium-bearing mica, but on the other hand thin plates of biotite are sometimes found to give this appearance.

(vi) Muscovite. This mineral was not observed in the groundmass of hand specimens, but plates 2 mm. to 3 mm. across occur on some joint faces.

(vii) Tourmaline. Mainly interstitial and occurring as brown-black amoeboid patches of "schorl"; occasionally minute transparent pale pink striated prisms of "rubellite" occur.

(viii) Cordierite. Grey-black barrel-shaped crystals with a sub-vitreous to dull lustre and measuring up to 1 cm. in length by 4 mm. across. Pseudomorphed by pinite.

(c) Megascopic Characters. (Type (ii)).

Knill's Steeple granite is a fresh, cream-coloured, fine grained, non-porphyritic, highly felspathic rock. The appearance of the minerals in hand specimens resemble those in the fine grained granites, apart from the following differences.

(i) Quartz. Occurs as rounded, water clear, anhedral patches 2 mm. across, some patches appear to be composed of aggregates of smaller crystals.

(ii) Perthite. Cream-coloured anastomosing amoeboid patches making up 39% of the rock, small quartz and biotite crystals appear as inclusions.

(iii) Plagioclase. This mineral accounts for 29% of the rock and occurs as creamy-white coloured anhedral to subhedral patches which have a tendency to be amoeboid, like perthite, although this texture may be due to replacement of the plagioclase by perthite. Inclusions consist of both perthite and quartz.

(iv) Biotite. Occurs as small bronze-black books.

It was not possible to determine lithionite, muscovite, or tourmaline in hand specimens, and cordierite is absent.

D. Microscopic Characters of the Granites

The component minerals of the different granite types are very similar and are described together; where differences referable to particular granite types occur a special note is made.

(i) QUARTZ

Four varieties of quartz occur which may be classified according to their textural relationships in the granites :-

(1) Quartz included in perthite.

(2) Quartz "Pools"

(3) Unstrained interstitial quartz

(4) Strained interstitial quartz

(1) Quartz included in perthite. This variety of quartz occurs as 0.8 mm. elongated, water-clear blebs in peripheral zones, or 0.3 mm. rounded water-clear crystals. It is usually unstrained although a few of the larger inclusions show undulose extinction. Irregular liquid inclusions are scattered throughout the smaller unstrained quartz crystals, while regular trains of undefinable inclusions occur in the generally larger quartz crystals. (Fig.89).

Quartz inclusions in perthites, though common in the coarse porphyritic granite, are rare in the coarse non-porphyritic variety.

(2) Quartz "Pools" This variety, which was described for the Carnmenellis granite by Austin (1960), is very common in the coarse porphyritic type where it occurs as large rounded pools approximately 1 cm. to 2 cms. across set in the groundmass of the granite. The "pools" are made up of interlocking grains of quartz 1 mm. to 2 mm. in size; these are strained and frequently give biaxial interference figures. (Fig.98).

The quartz shows a replacement texture towards both perthite and plagioclase, small islands of perthite sometimes occurring in the quartz "pools", and lobate quartz embayments against perthite and plagioclase are common. (Fig.98).

(3) Unstrained interstitial quartz. This is very similar to the included quartz. It rarely shows undulose extinction and deformation of the quartz is only slight when strain shadows do occur. The grains vary in size up to 1 mm. to 2 mm. and contain internal fractures which give rise to a jig-saw patterning within the crystal, the individual pieces measuring approximately 0.15 mm.

across. (Fig.104).

Clouds of inclusions occur in trains which may represent healed fractures.

Margins do not show replacement textures.

(4) <u>Strained interstitial quartz.</u> Strained quartz crystals occur with strong deformation lamellae. These crystals which are approximately 0.6 mm. to 1.5 mm. in size frequently occur between and adjacent to perthite megacrysts and accidental xenoliths. They do not show internal jig-saw patterning although their margins are frequently jig-saw. Trains of inclusions are numerous and many coincide with the strain lamellae. (Fig.103).

Margins do not show replacement textures.

(ii) <u>ALKALI FELDSPAR</u>

This is a common component of the granites and is particularly obvious in the porphyritic varieties. Although it accounts for 0.2% to 46% of the rock it occurs more frequently in the range 35% to 40% and is hence a major constituent.

If total orthoclase is calculated by adding to modal orthoclase the percentage of secondary mica within orthoclase then frequency diagrams show high values to occur within the range 30%

to 35% and 40% to 45%.

As pointed out by Austin (1960) it is very variable in amount at the microscopic scale and in estimating modal proportions it was found necessary to calculate a minimum area of thin section to point count; this parameter was based on (a) the coarseness of the rock, and (b) the number of points required to be counted, from which estimates for reproducibility errors and cumulative errors could be calculated.

The crystal form is variable in hand specimens where it may frequently appear to be euhedral in the case of the megacrysts and subhedral in the case of the smaller groundmass crystals. In thin sections however the crystals which are megascopically euhedral are subhedral and much of the groundmass material is anhedral. The size and number of alkali feldspar megacrysts is variable; they are generally tabular in habit being flattened parallel to the (010) clinapinacoid face; the basal pinacoid (001), the hemiorthodome $(10\bar{1})$ and the prism (110) faces are always represented in well developed crystals which are almost exclusively twinned on the Carlsbad law. The composition planes are normally straight, but curved and stepped composition planes are known to occur. Interpenetrant twinning is common but the rare compound interpenetrant Maltese Cross twins have only been observed in hand specimens.

The crystals are colourless in thin section when not altered, although such feldspars are rare, most having been partially decomposed to clay minerals and secondary mica which gives a turbid brown colour in thin section. (Fig.97).

Extinction angles were determined on "c" (001) and "b" (010) using the perfect and less perfect parallel cleavages; angles ranged as high as 14° and 8° respectively, indicating some degree of obliquity and high sodium content.

(1) Inclusions

Inclusions in the alkali feldspar are present mainly in the megacrysts, where they are numerous and include all the common minerals which occur in the granite.

(a) Quartz. This is frequently arranged in concentric peripheral zones where it appears as rounded water clear blebs or streaks, which vary considerably in dimensions but rarely exceed 2 mm. in length and are commonly 0.3 mm. to 1 mm. in length. Inclusions in this type of quartz are not abundant and strain shadows have only been observed where the quartz has developed astride or adjacent to twin planes, and adjacent to other inclusions.

(b) <u>Biotite.</u> Occurs either scattered randomly throughout the crystal or in well defined concentric zones which often coincide with the quartz zones; one prominent zone may be present which occurs just less than half way between the crystal margin and the crystal centre. The size of the biotite flakes varies up to 2mm. in length and the maximum absorption gives a reddish brown colour which varies slightly through X and Y. Intense pleochroic haloes around zircons and monazites are common and the biotite is occasionally chloritised and mantled with granular muscovite. Where it crosses twin planes neither the biotite nor the twin plane is affected, and when biotite has developed where the twin plane becomes stepped there is no bending of the cleavage. Inter-feldspathic biotites are not, as a rule, so large or so jagged in appearance as the intrafeldspathic varieties. Biotite included within alkali feldspar is sometimes also replaced by it along cleavages, the replacing feldspar being in optical continuity with the host feldspar but containing no perthite films. In cases where this phenomenon prevails the biotite is chloritised parallel to cleavages, the 'chlorite' showing anomalous gray blue birefringence (Penninite).

(c) Muscovite. Large flakes of muscovite 1 mm. across sometimes occur scattered haphazardly throughout the oikocryst without any replacement textures and are regarded as probably being of primary origin. They are transparent in normal light and show the typical bright blues of the upper second order under crossed polars. Occasionally these "primary" chadocrysts form the nuclei for secondary mica which replaces the host alkali feldspar along cleavages and adjacent to perthite strings. Secondary mica associated with perthite strings may have sodium instead of potassium in its composition and although detailed work on this problem yet remains to be done, it is probable that some such mica may be paragonite. Secondary mica is colourless in normal light, while under crossed polars it shows first order yellows and when well developed may show colours of the second order. Secondary muscovite also appears in ramifying networks which are quite unrelated to primary muscovite flakes and these give the illusion that they have not grown on primary nuclei; however it must be remembered that since in thin sections we are examining a three dimensional body in two dimensions the network of secondary may, outside the plane of the mineral section being examined, have a primary muscovite nucleus.

Highly altered alkali feldspars contain scattered grains of clear muscovite 0.12 mm. across which show excellent cleavages and under crossed polars give the typical second order polarisation colours.

(d) Tourmaline. Pale yellow-brown to moderate brown-yellow tourmaline commonly replaces feldspar, although blue-green tourmaline showing zonal structures occurs as radiating columnar crystals replacing feldspar in highly pneumatolysed granites.

The yellow-brown tourmaline occurs as subhedral to anhedral grains 0.6 mm. to 1.0 mm. across and showing colour banding. This is probably a compositional effect which reflects the iron content of the mineral. Usually, however, tourmaline is seen to replace feldspar as a series of pale brown ramifying, anastomosing veinlets of schorlite. Unlike the secondary mica the tourmaline veinlets are not related to cleavage or perthite string directions.

(e) Andalusite. Very rare in alkali feldspar and has only been observed in one isolated case where a digested xenolith lies adjacent to a feldspar crystal (S39b. Castallack granite). Here the andalusite, which is only centrally pleochroic, can be described as in "sub-ophitic" relationship to the feldspar; it has a discontinuous pellicle of granular sericite which in the stained specimen shows up a pale blue colour, and the andalusite itself is composite 1.0 mm. across, with the individual grains, which are not optically continuous, each surrounded by a similar discontinuous film of granular sericite.

(f) Plagioclase. Occurs in alkali feldspar in two major forms:-

(i) Discrete subhedral-euhedral crystals.

(ii) Perthite strings (described under 2).

(i) These individual crystals commonly measure up to 0.6 mm. in length and although much larger ones are known to occur they tend to be rare.

The crystals are scattered haphazardly

throughout the host feldspar except in those cases where they are associated with inclusion zones (e.g. - biotite zones), but in all cases their orientation appears to be quite random. They cross the host twin planes and perthite strings without being affected, although it is noticeable that the perthite strings tend to die out in their vicinity.

When twinning occurs it is on the albite law, and the crystals are zoned with cores corresponding in composition to An_{14} and margins to An_5; sometimes oscillatory zoning occurs. The soda-rich margins are usually clear, but rarely mirror the shape of the core and give an asymmetric shape to the crystal which suggests that they may be of secondary origin. Radiating vermicules of myrmekite often occur in this border zone while the cores are clouded with secondary mica.

(2) Perthite

Using Alling's (1938) classification, the perthite can be described as mainly rod and bead perthite in which the plagioclase lamellae vary in size from 0.01 mm. to 0.03 mm. across and 0.6 mm. in length. (Fig. 92). The shape of the perthite lamellae seen in thin section depends to a large extent upon the orientation within the alkali feldspar and is hence governed by the direction of sectioning. The perthite is water-clear in normal light, though near kaolinised zones slight clouding may occur due to incipient development of clay minerals; it is optically continuous over the whole of the feldspar crystal except where the lamellae undulate. They cut across twin planes without any visable displacement and are continuous up to the crystal margin where they infrequently dilate and form small albite mantles 0.01 mm. thick. Apart from this they do not extend outside the crystal boundary and in most cases become very thin and may die out. Where plagioclase has developed between adjacent alkali feldspar crystals and shows replacement textures towards one of them it is found that the plagioclase preferentially replaces the alkali feldspar and not the perthite lamellae. The lamellae are continuous up to their contact with included quartz, biotite, muscovite, tourmaline, and albite; but in the vicinity of these inclusions they may become thinner and in some cases die out. (Fig. 97).

Perthite strings in orientated specimens cut the (010) twin plane normally and lie parallel or subparallel to the b axis direction. The (001) cleavage makes a small angle (up to 15^{o}) with the perthite films which may extend stepwise diagonally to form angles as high as 40^{o} with the (001) cleavage, a phenomenon which gives an impression that perthite lamellae cross one another. The refractive index of the perthite is higher than that of the host and extinction angles against the composition planes lie in the region of 10^{o} to 16^{o} which corresponds to albite (i.e. An_4 to An_{12}).

(3) Alteration.

The alkali feldspar breaks down to form secondary alteration products which are chiefly due to two causes, (a) weathering, and (b) hydrothermal action.

The effects of both are very similar with the exception that weathered feldspar is usually stained brown by iron leached out of ferromagnesian minerals. Weathering effects are always superimposed upon hydrothermal effects and it is frequently impossible to attribute alteration products to one cause alone in the zone of atmospheric weathering.

The first sign of alteration is the slight cluding of the feldspars by sericite, the flakes of which increase in size and become accompanied by clay minerals developing along cleavages and margins as alteration progresses. Flakes of muscovite appear and the plagioclase in the perthite lamellae becomes replaced by paragonite or sericite (Fig.91) together with some clay mineral. In the final stages the feldspar is represented by granular aggregates of muscovite, quartz and sericite which in extensively argillised areas break down to form kaolinite and quartz. In some cases the alkali feldspar megacrysts are preserved as "Pigs-Eggs".

(4) Replacements.

Alkali feldspar is replaced by tourmaline, muscovite and quartz (Fig.90). These minerals form embayments into the feldspar and include rounded islands of the feldspar in optical continuity with the parent mass. Tourmaline generally replaces the feldspar by veining while muscovite replaces almost exclusively by lobate protruberances. The quartz replacements are chiefly confined to the margins of large "pools" where many rounded islands of feldspar and lobate quartz embayments occur. Plagioclase replaces alkali feldspar when rapakivi textures are developed in highly contaminated rocks such as the "basic granite" raft at Sennen Cove. Here staining hand specimens with sodium cobalt-initrite shows the centre of the megacrysts to be potash rich, while the margin is corroded and occupied by plagioclase feldspar crystals which are extensively altered to secondary mica (paragonite ?) and kaolinite.

(iii) PLAGIOCLASE

Occurs as euhedral to subhedral grains varying in size up to 8 mm. by 6 mm. for the very coarse granites and 0.6 mm. by 0.2 mm. for the fine grained granites. This description excludes those plagioclase crystals which occur within the alkali feldspar as inclusions and which have been described elsewhere. (P96).

Plagioclase is very common in the granites of Land's End and varies in amount between 3% and 28%, although the frequency diagram indicates high values between 10% and 15%. These values are in reality low because of kaolinisation; they are for pure plagioclase exclusive of secondary alteration products. If secondary mica and kaolinite are added then we arrive at high frequency values in the 20% to 30% range, and like alkali feldspar plagioclase is considered a major component of the granite. In some cases (e.g. S6, S28, S30, S36, S59, S66, S69, S70, S72, S76, S78, S79, S87, SC1, SC2), the plagioclase content is high enough to enable the rock to be classified as a granodiorite, or in the case of SC1 a melagranodiorite.

The composition varies considerably being as calcic as An39 in schlieren and melagranodiorite while the normal range is An_6 to An_{13}.

Twinning is common on the albite, (polysynthetically) pericline and Carlsbad laws. Pericline twinning rarely occurs on its own but is usually combined with albite and Carlsbad twinning, while albite twinning is often combined with Carlsbad twinning with or without pericline twinning and is universal; untwinned crystals are rare except where included in alkali feldspar in which case they are conspicuous by their altered cores and clear sodic rims. Some crystals show identical and complex twin patterns either side of a resealed fracture while others exhibit bent twin lamallae; neither of these phenomena has been observed to effect albite rims.

Zoning is common in plagioclase included in alkali feldspar, it is usually quite sharp upon the core and is normally asymmetric in its development. Normal zoning is widespread in the larger groundmass crystals whose cores correspond to An13 and rims to An3; this zoning is gradational and in highly contaminated granites the composition has been observed to change from An33 at the core through an intermediate composition of An21 to a thin selvidge of An1. Oscillatory zoning is not common but has been observed in several specimens where the rim is normally zoned, and the core is occupied by regular but complex oscillatory zoning in which over 50 zones may be present; these are crossed and unaffected by twin planes. As in the case of plagioclase inclusions the albite rim does not always conform to zones in morphology and is often asymmetric.

Replacement textures are very common, crystal margins being frequently embayed by lobate protruberances of the replacing mineral and also corroded. Islands of marginally corroded plagioclase often occur in optical continuity within alkali feldspar and grain boundaries are always irregular. The amount of plagioclase included in alkali feldspar is variable and ranges from small marginal quantities characteristic of preliminary replacement, to about 50% of corroded plagioclase representing replacement on an extensive scale; small corroded plagioclase fragments, still in optical continuity, scattered throughout the metasome probably represent penultimate stages in replacement. Pseudomorphs of plagioclase occur in extensively metasomatised granite.

Myrmekite develops on albite rims adjacent to potash feldspar in the groundmass. It is not usually extensively developed but most microsections will reveal this phenomenon on careful examination. The rims of plagioclase inclusions in alkali feldspar frequently exhibit radiating vermicules of quartz. (Myrmekite).

Alteration of plagioclase to minute scales of secondary mica of low birefringence is common, the calcic core being affected more than the sodic rim; highly birefringent mica forms in extensively altered feldspars. In crystals showing oscillatory zoning it is found that alteration products are chiefly confined to one or more definite zones which accentuates the zoning effect. Alteration products also form parallel to major cleavages (e.g. (010) and (001)) and around the crystal margin.

Clay minerals develop in later alteration stages as amorphous aggregates, which X-ray powder photographs have shown to be mainly well-ordered kaolinite and probably sericite together with quartz. Quartz-clay pseudomorphs of plagioclase, which in unstained specimens are nearly isotropic, are common in kaolinised granites; when stained with methylene blue these pseudomorphs show an anomalous red birefringence (Figs. 111 - 118).

Inclusions in plagioclase, apart from alteration products, are rare with the possible exception of tourmaline (which is ubiquitous), muscovite and biotite.

(iv) <u>BIOTITE.</u>

Occurs as well developed brown to reddish brown subhedral-anhedral crystals accounting normally for 2% to 10% of the rock and showing one excellent cleavage when cut normal to (001); it is partly because of this that they are jagged on the prism and pinacoid (not (001)) faces.

The pleochroic scheme is normally pale yellow-brown to orange-brown, but varieties which give pale brown to red-brown and deep red-brown colours occur in contaminated granites.

Pleochroic Schemes :-

	1.	2.	3.
X =	Very pale yellow.	Pale Brown.	Pale yellow-brown
Z =	Orange-brown.	Orange-brown.	Deep red-brown.
Y =	Pale brown.	Pale brown.	Orange-brown.

Extinction is usually parallel to the (001) cleavage traces, but in some crystals which have bent cleavage traces the extinction is wavy and may be up to 3^{o} oblique.

The composition of the biotite has been worked out from chemical analysis but the colour may give an indication of the ratio of $Fe_2O_3/(Fe_2O_3 + FeO)$ and the amount of TiO_2. The deep red-brown varieties indicate a high TiO_2 content while the paler colours are probably due to low TiO_2 and low Fe_2O_3, high Fe_2O_3 and low TiO_2 gives the rarer greenish biotites (Hayama, 1959).

Biotite is frequently intergrown with muscovite (in which cases cleavages frequently pass from one mineral to the next without any break), and occasionally orthoclase develops along cleavages, pushing the biotite plates aside, together with muscovite which sometimes mantles the biotite to form aggregates of granular crystals. (Fig. 106).

Inclusions include plagioclase, apatite, tourmaline (Fig. 108) and length slow euhedral crystals with pleochroic haloes which are of prismatic habit with parallel to slightly oblique extinction. These are probably zircon and monazite; the zircon usually shows a stronger relief. Ilmenite or rutile are frequent inclusions in the form of prismatic crystals up to 0.2 mm. in length which are very common in chloritised biotite.

Alteration proceeds along zones parallel to the cleavage and around the margin of the crystal with the formation of chlorite, penninite and magnetite; acicular rutile (in titanium rich varieties) and muscovite also occurs. Granites in which the groundmass biotite is completely chloritised frequently contain perfectly fresh biotite included in the alkali feldspar. Margins of biotites are embayed by quartz in contaminated granites and islands of ragged biotite occur in optical continuity with their host muscovite. Frequently the biotite is bleached and although it shows the bright upper second order polarisation colours of muscovite the zircons and monazites still retain their pleochroic haloes. (Fig. 107).

When biotite is replaced by tourmaline it often forms within the tourmaline dark brown ghost crystals in which the cleavage and sometimes the pleochroic haloes can be recognised.

Biotite is commonly associated with muscovite and andalusite; its association with tourmaline appears to be limited to those cases in which it is being replaced by this mineral.

Biotite selvedges on aplite veins are rare, the only localities where this phenomenon has been observed being Gwavas Quarry and near the western contact at Tater-du. The "c" axis is usually sub-parallel to the wall of the aplite vein and the crystals are corroded on the aplite side where they are in contact with the fine grained groundmass of quartz, plagioclase and orthoclase.

(v) MUSCOVITE

Normally accounts for 2% to 4% of the rock's composition and although plates several mm. across have been recorded it usually occurs as transparent flakes up to 1 mm. in length.

Several varieties occur which have been classified into :-

(1) Secondary muscovite released from feldspar. Colourless in normal light and showing first order

yellows under crossed polars, it occurs as a ramifying network and has been described in detail under alkali feldspar inclusions. (p. 94).

(2) Muscovite formed as a breakdown product of pelitic xenoliths. This variety occurs as large well formed flakes frequently associated with andalusite and biotite. The crystal boundaries mutually interfere and are therefore contemporaneous. (Fig.105).

(3) Secondary muscovite after biotite. (Fig.93).

In addition to the varieties listed above, muscovite also occurs as well-formed interstitial flakes which are not associated with any particular mineral. They show replacement textures towards feldspar and tourmaline.

Extinction is usually parallel to the cleavages which may be slightly bent; undulose extinction has been noted in several cases.

Muscovite intergrowths with biotite have been adequately described under biotite, but in addition biotite islands with diffuse boundaries have been observed in some muscovite flakes and these are regarded as penultimate stages in replacement. (Fig.107).

Inclusions in muscovite are rare with the exceptions of andalusite, zircon and monazite which give pleochroic haloes, and remnant biotite.

(vi) TOURMALINE

Except where it occurs in tourmaline granite it is a minor constituent accounting for only 2% of the rock. It occurs as prismatic crystals up to 4 mm. in length by 1 mm. wide; larger varieties occur but are uncommon. It is also interstitial and replaces alkali feldspar, plagioclase, quartz, and biotite. It is strongly dichroic, the pleochroic scheme varying slightly from pale orange-yellow to deep orange-brown and from neutral grey to pale slate-blue.

Zoning is common with yellow, yellow-brown and blue varieties alternating (Fig. 110). Oscillatory zoning is well displayed in sections of small crystals cut normal to the "c" axis, although larger crystals may exhibit patchy zoning. The zoning is asymmetric with the form of the inner zones rarely corresponding to the form of the outer zones. Colour zones are associated with replacement phenomena where the tourmaline is replacing biotite (Fig. 109). Here the dark brown zones show ghost images of the biotite being replaced and are continuous with the cleavage and shape of the biotite (Figs. 94, 109).

Tourmaline also occurs as blue radiating acicular crystals approximately 0.3 mm. in diameter and as granular aggregates in microveins 0.5 mm. wide. These veins dilate to form tourmaline nodes 12 mm. across which extensively replace feldspars and mica. Where tourmaline occurs in kaolinised granite it is often corroded and fractures parallel to basal plane (0001) are accentuated; crystals are commonly broken and pushed apart.

Inclusions are rare unless they are relicts of the mineral being replaced by tourmaline.

Tourmaline is associated with zones of chloritised and mineralised granite, it is frequently found in proximity to xenoliths and is common in some marginal granites; segregation of tourmaline under pegmatitic conditions is discussed in a later section.

(vii) <u>ANDALUSITE, SILLIMANITE, AND CORDIERITE</u>

(1) <u>Andalusite</u> occurs as "lozenge" shaped grains up to 0.5 mm. in length and as coarse columnar irregular aggregates in contaminated granites and at granite/hornfels contacts. It is conspicuous by its high relief ($n > 1.54$) and rose coloured pleochroic centres. Crystals are frequently rimmed by a thin selvedge (0.01 mm.) of secondary muscovite

or sericite and contain scattered opaque inclusions which are probably carbonaceous matter.

(2) Sillimanite is rare but has been observed in association with andalusite as interlacing acicular crystals.

(3) Cordierite is common in most of the Land's End granite as pseudohexagonal crystals up to 2 cms. in length along the "c" axis and 1 cm. across the compound basal pinacoid. They are invariably pseudomorphed by pinite, which is an aggregate of sericite, chlorite and indefinite silicates. Unlike andalusite the cordierite is not intimately associated with biotite and muscovite but is always present in contaminated granites, with the exception of SC1 and SC2.

(viii) ACCESSORY MINERALS

(1) Apatite has only been found in megascopic amounts at North Nanven. Otherwise it is a rare accessory mineral which occurs as prismatic crystals up to 0.01 mm. in length.

(2) Magnetite and "Chlorite". Formed as alteration products of biotite, pale green pleochroic "chlorite" shows either weak birefringence and straight extinction (Prochlorite), or anomalous "Berlin blue"

interference colours with straight extinction (Penninite). The "chlorite" often contains grains of secondary magnetite, the larger grains however may be primary.

(3) Rutile. Formed as an alteration product of titaniferous biotite, it occurs as felted masses of accicular crystals around the edges of chloritised biotite.

E. Modal Variation

Granite bodies are rarely homogeneous in composition and although it is possible to erect a series of "granite types" on the basis of textures, it does not follow that a single analysis from each "type" is representative of the area from which the specimen was derived. Unfortunately it has been hitherto customary to select samples of granite from various localities and to describe these samples in detail together with modal analyses. All too often such modes are statistically unsound and error estimates for mineral percentages may be so large as to create an overlap between different analyses. Thus the modes neither illustrate fully the granite they are supposed to illustrate nor do they give a true indication of the mineralogical variation within the granite. One simple fact remains, and this is that any mode is representative not just of one locality, nor even of that particular hand specimen collected, but only of the actual thin section point counted. For this reason a statistical treatment is to be preferred which will permit adequate sampling of the exposed granite (i.e. parent population) and give a reliable estimate of the mineralogical variation and how this is spatially arranged.

Two terms which will be used in this discussion of sampling problems are "orthogonal" and "non-orthogonal" sampling. The first is simply the objective collection of material from regularly spaced sampling sites which are based on a grid system, the specimens being collected from grid intersections. This method is obviously the one to be preferred if exposures outcrop regularly all over the granite being investigated. Non-orthogonal sampling involves the collection of specimens from irregularly scattered sites and is the method resorted to should the pluton prove to be poorly exposed.

During early sampling work on the Land's End granite an orthogonal system was tried which was based on a common origin for the V and U coordinates (geographic coordinates in which V represents eastings and U represents northings) sited a few miles SW of Land's End.

The granite, however, does not lend itself to easy sampling and many of the UV intersections were found to lie on ground from which no reasonable specimens could be obtained. An area contained by a circle 500 yds. in radius was therefore allowed in which a specimen could be collected; this left a distance of 500 yds. before the next sampling area was reached, thereby placing the sampling points (grid intersections) 1,500 yds. apart and lying parallel to the National Grid system.

The data collected from within a circle (sampling area) could be referred to the intersection of the V and U values at its centre, or taken at its true position in terms of fractions of V and U. Referring the value to the centre of the circle would be convenient from a statistical point of view but would give a false picture of the area. The results were therefore taken at their true position and a non-orthogonal system adopted.

Biased sampling of the population is difficult to eliminate, for while a quarry will supply fresh specimens of granite suitable for analysis it must be realised that this quarry is sited on atypical rock, in other words a rock which is suitable for monumental work or roadstone is usually free from alteration products and fractures. Again the ease with which a specimen may be removed from a quarry will allow a considerable amount of unconscious subjectivity to creep into the sampling technique, and the initially objective sampling method may become influenced by this to an extent which will lay the method open to criticism.

Site sampling may also be affected by small-scale within-site variation and in order to eliminate this variation it was considered necessary to collect three or four large hand specimens from each exposure.

Large microsections were cut at random from all specimens for quantitative mineralogical analysis (Modal

Analysis) by point counting, and to facilitate rapid identification of the minerals the sections were stained as described in the section on "research techniques" (p. 274). This eliminated some of the errors due to eye strain and fatigue.

The modal variation of the Land's End granite is illustrated in tables P339-49 and frequency diagrams.

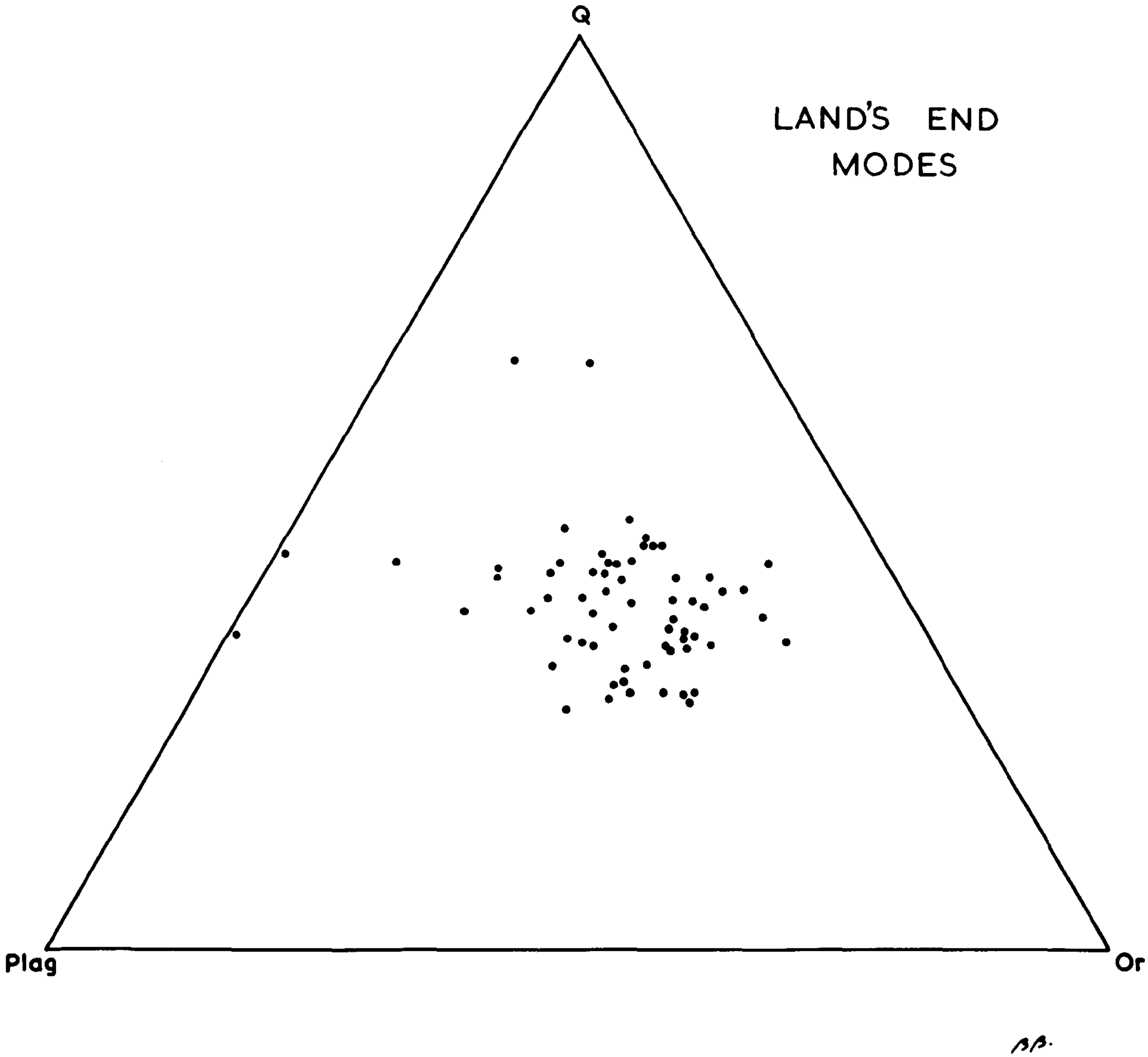
(i) MAJOR MINERALS

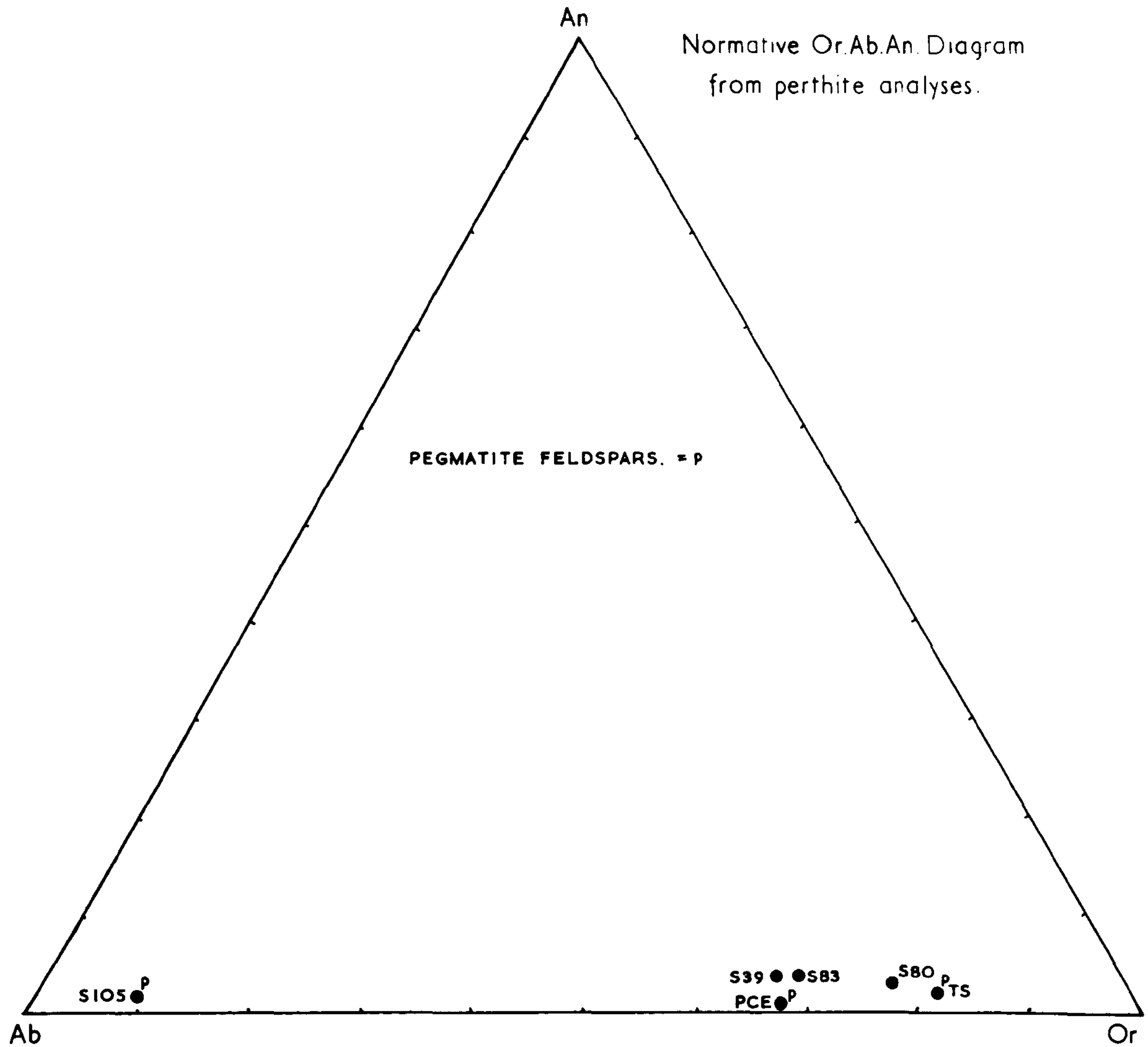
(1) QUARTZ. Of the 64 specimens examined none contained less than 24% quartz which is 4% above the lower limit suggested for granites using Chayes (1951) classification. Although his upper limit of 40% for quartz is exceeded by 15% this is not regarded as important in the classification of these rocks for no other igneous rocks are more siliceous than granites and the firm establishment of an upper limit is regarded as unnecessary. The mean value for quartz is 33.4% which is slightly above the 30% quoted by Chayes and 4.7% above the mean quartz content of the 260 thin sections of granite from eastern United States. Tuttle and Bowen (1958) suggest that a spread in quartz values may be due either to inaccurate analysis or to location of the specimens, as in the case of the Skye granites

where samples were selected from near contacts, but they conclude by regarding these granites as "normal" insofar as the quartz content is concerned. The quartz content of the Land's End granite is illustrated in text figure P137 . In the frequency diagram there is a normal distribution with a peak between 30% and 35% and in the triangular variation diagram the values lie scattered between 20% and 50%. This scatter is not regarded as being due to analytical error, for errors calculated for modes using Barringer's tables (1953) are less than 1.6% for 50% modal proportion and less than 0.9% for 10% modal proportion. The scatter is therefore considered the result of normal variation resulting from uneven distribution of quartz rich fluids during recrystallisation.

(2) <u>FELDSPARS</u>

(a) <u>ALKALI FELDSPAR</u>. The perthite of the Land's End granite accounts for between 0.2% and 46% of the rock's total volume and is only slightly dominant over plagioclase which it frequently replaces. Much of the perthite is present as megacrysts in the coarse porphyritic granite; these probably arose by endoblastic


Q
LAND'S END
MODES
Plag
Or
B.B.


An
Normative Or.Ab.An. Diagram
from perthite analyses.
PEGMATITE FELDSPARS. = P
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S39
S83
PCE P
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B.B.

growth under late magmatic-metasomatic conditions.

In the triangular variation diagram the scatter from the quartz-orthoclase sideline towards the quartz-plagioclase sideline reflects the varying degrees of replacement of the plagioclase by the potassium felsdpar, and the varying amount of plagioclase held in solid solution in the alkali feldspar (Text figP120). The orthoclase frequency diagram (Text figP137) shows a skew distribution of orthoclase building up to a maximum around 35% to 40%.

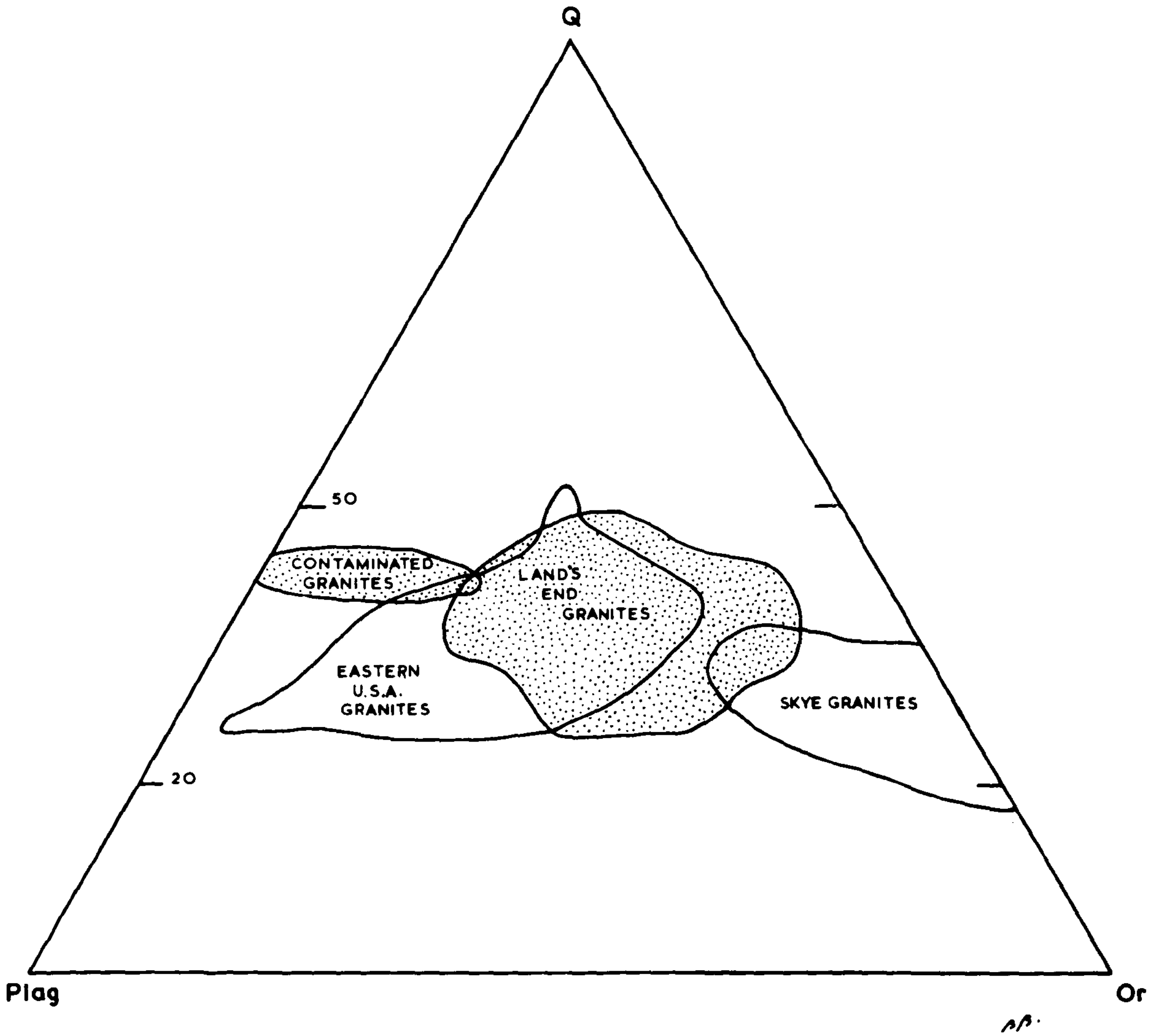
(b) PLAGIOCLASE FELDSPAR. The percentage of modal plagioclase in the granite varies from 3% to 28% and as it is replaced in varying degrees by the alkali feldspar, it varies inversely with respect to this mineral (Text fig. P121). Tuttle and Bowen (1958) suggest that the modal variation in Chayes' triangular diagrams can only be attributed to the different amounts of plagioclase held in solid solution in the alkali feldspar. In the present study it was not possible to count separately plagioclase lamellae in alkali feldspar (this is all counted as alkali feldspar); normative values for feldspars which were extracted from the granite and analysed chemically show that the amount of albite held in solid solution (or exsolved) does vary considerably, and this factor must not be disregarded when explaining the spread of points between the quartz-orthoclase sideline and the quartz-plagioclase sideline in the ternary diagram (Text fig. P119).

The frequency diagram shows a skew distribution with high values between 10% and 15% and is attributed to kaolinisation.

(ii) Quartz-Alkali feldspar - Plagioclase Diagram. (Text fig. P124).

The first diagram shows the scatter of 64 modes from the Land's End granites to fall in the adamellite-granite field, while the contaminated varieties SC1 and SC2 fall in the tonalite and granodiorite fields of Johannson (1917).

In text fig. P124 the field of 260 modal analyses by Chayes (1951) of granites from the eastern United States is shown together with the field of 42 modal analyses, also by Chayes (1949, 1951), of Skye granites. According to Tuttle and Bowen (1958) this forms a continuous band from the quartz-orthoclase sideline to just past the centre of the diagram. The superposition of the Land's End granite field upon the diagram completes and reinforces the continuity, completely bridging


Q
50
20
CONTAMINATED GRANITES
LANDS END GRANITES
EASTERN U.S.A. GRANITES
SKYE GRANITES
Plag
Or

the gap between the eastern United States granite field and the Skye granite field. There is now an established variation from the quartz-orthoclase sideline to the quartz-plagioclase sideline where granites, whose quartz content rarely varies outside the range 20% to 50%, pass from potassium-rich Skye varieties through the normal granite field, as typified by the Land's End granites, and then to the adamellite-granodiorite-tonalite fields as illustrated by the overlapping fields of the Land's End, eastern United States and Land's End contaminated granites.

The Skye granites may be atypical as they carry a relatively large amount of plagioclase in solid solution and are regarded as high temperature granites by Tuttle and Bowen (1958), who also suggest that the trend from the Skye granite field towards the adamellite field represents falling temperature of the final crystallization of granites. This means that the Land's End granites can be regarded as low-temperature granites which, like the late-Hercynian post-tectonic granites of northern Portugal, were probably not wholly magmatic. Soen (1960), who discusses these granites, suggests that rapid crystallisation immediately followed emplacement with the production of a more or less solid framework of crystals, the interstices of which were filled by potash-rich liquids forced in by magmatic pressures.

If two-feldspar granites initially completed crystallisation from liquid with a modal composition near the quartz-orthoclase sideline, as suggested by Tuttle and Bowen (1958), then the question arises as to how the Land's End granites (and the eastern United States granites) come to have compositions ranging over the granodiorite-alkali granite fields.

It is thought that some degree of differentiation could effect this variation, but as shown later (P.140-68) evidence is presented which suggests that a considerable amount of recrystallisation has taken place and this, aided by metasomatism and mineralisation would mask the original composition in varying degrees depending on the extent of the deuteric effects. This takes no account of the contaminated granite series (discussed later) which extends to the quartz-plagioclase sideline, and it is impossible to estimate the volume of potassium, iron and aluminium which became incorporated in the granite which was digesting pelitic xenoliths during its progressive emplacement by piecemeal overhead stoping.

The migration of sodium ions from areas where plagioclase was undergoing metasomatic replacement by potassium-rich residual fluids would provide an adequate variation in the modal composition of alkali and soda feldspar, and these sodium ions would either re-establish themselves under more favourable conditions or remain in the residual fluids to contribute to the juvenile high temperature mineralising springs which are common in many of the tin mines in the Land's End area. Analyses of waters from two of these springs are shown in tables P281-2, and it is doubtful if the high sodium content of these springs could be ascribed to sea water seepages to so great a depth, even in Tertiary times when the sea level was considerably higher with respect to the land surface.

(iii) MINOR MINERALS

(3) BIOTITE. Accounts for 2% to 28% of the granite but the more usual range lies between 2% and 10%. The exceptionally high values are only found in granite which has become highly contaminated by assimilated xenolithic material, while exceptionally low values - 0.3% - occur in aplites. Where chilling

has taken place at the margin of the granite the biotite content tends to be lower than average which suggests that the initial granite was poor in this mineral. The frequency diagram shows that the wide variation in biotite content has a normal distribution with high values occurring between 5% and 7%; a xenolithic origin for the greater part of this mineral is envisaged.

(4) MUSCOVITE. In the frequency diagram there is a skew distribution with values ranging between 0.1% and 7.0% with 2% to 4% representing the range of high values.

Muscovite occurs in a variety of forms, as demonstrated earlier, but in estimating modes all varieties were classified together. The small flakes of secondary mica included in orthoclase and plagioclase are alteration products of these minerals and are described separately, but the large flakes of mica which may or may not be associated with andalusite and/or biotite, and the interstial granular muscovite, and the vein muscovite have been counted as one variety.

The variation in the modes is attributed to:-

(a) muscovite released from feldspars during their breakdown under mineralising condition. (b) muscovite

formed from the breakdown products of pelitic xenoliths, the muscovite-biotite-andalusite clots being regarded as relicts of digested xenoliths.
(c) muscovite formed as a replacement of biotite.
It is not clear how complete these replacements are but the rutile produced when TiO_2 is eliminated and the remaining zircons may be taken as an indication of the former extent of the biotite.
It has been found (Schwartz, 1958) that mineralizing solutions commonly leach iron and magnesium out of biotite and substitute potassium, yielding secondary muscovite and sericite pseudomorphs after biotite.

(5) SECONDARY MICA IN PLAGIOCLASE. The secondary alteration products in plagioclase consist of both mica and clay minerals. Exley (1959) noted that "kaolinization is a process affecting chiefly plagioclase" and has shown that alteration may proceed to completion with the production of kaolinite/mica pseudomorphs. The alteration in the Land's End granite is identical with that of the St. Austell granite and the frequency diagram illustrates the distribution of the secondary mica, where it will be observed that high values occur between 2% and 4%.

It is not proposed to discuss the composition of this mica here, the point is adequately covered elsewhere (P.104,157), but bearing in mind the high sodium content of the feldspar it is believed probable that some of this mica may be paragonite. Morey and Chen (1955) found that at 350°C and 5000 lb/in² hot water would produce muscovite and paragonite as alteration products, the muscovite being derived from the potassium within the albite; and at over 400°C and 15,000 lb/in² albite alters to paragonite plus quartz. At lower temperatures montmorillonite and kaolinite are produced together with some illite.

(6) SECONDARY MICA IN ORTHOCLASE. Occurs mainly as small flakes of sericite and its distribution is shown in text fig. P138 where it can be seen that the most frequent occurrence is between 0.2% and 1.0%.

Kaolin forms where alteration of the alkali feldspars is intense and Folk (1947) has shown that a high Al/K ratio accompanied by a temperature of 350°C in acid solution promotes kaolin formation; below this temperature muscovite forms. The sericite is attributed to the alkaline metalliferous solutions (Folk, 1947) while the kaolin may form by replacement of sericite under the leaching action of carbonate

and sulphate rich solutions. (See table P281-2).
Some of the secondary mica produced from the alkali feldspar may have the composition of paragonite which is derived from the exsolved albite and sodium still held in solid solution in the orthoclase.

(7) TOURMALINE. Varies in amount between 0.2% and 10.9% although the frequency diagram (text fig. P138) shows it to occur most commonly between 0% and 2%. The high values are due to the occurrence of fine veinlets of tourmaline which occasionally dilate replacing alkali feldspar. Brammall and Harwood (1927) suggest three modes of origin for tourmaline :-

(a) Primary pre-solidification
(b) Secondary pre-solidification
(c) Secondary post-solidification.

and conclude by attributing a secondary mode of origin for the greater part of the tourmaline.

This classification also applies in the Land's End granite but the primary pre-solidification tourmaline is not regarded as contributing towards the variation encountered in modal analysis as it is only a minor constituent. On the other hand both types of secondary tourmaline occur and the areal variance of this mineral is considered as a function of :-

(a) The uneven distribution of post-solidification tourmalinisation which is frequently associated with mineralisation and deposits of cassiterite.

(b) The localised accumulation of volatiles in marginal areas beneath hornfels roofs.

(c) The higher volatile (and hence tourmaline) content of granites which occur beneath the coarse porphyritic variety and which are probably intrusive into it.

(8) <u>TOPAZ</u>. Has been recorded from only two localities at Land's End. Knill's Steeple granite is recorded by the Survey as containing this mineral but during modal analysis of this rock no topaz was seen. Topaz is, however, recorded in specimen S41 at the extremely low value of 0.02%. The analytical error for this percentage calculated from Barringer's (1953) tables for the 4902 points counted is 0.02%, and the modal topaz content can therefore be dismissed as insignificant.

(9) <u>ANDALUSITE</u>. Varies in amount up to 2%, but most frequently occurs in the 0% to 0.5% range. It is not always present in the granites, but when it does occur it is commonly associated with

muscovite flakes and occasionally with muscovite and biotite clots. These associations occur in granites which are contaminated by xenoliths of pelitic material and the mineral is frequently found around the margins of these xenoliths. The andalusite associations with biotite and muscovite is regarded as the remains of digested pelitic xenoliths.

(10) ZIRCON. The percentage of zircon in the mode is directly related to the amount and type of biotite present; it varies between 0.01% and 0.40%, and occurs most frequently in the range 0.10% to 0.15%.

(11) ORE. Mainly magnetite which is associated with biotite undergoing alteration to chlorite. The modal values of this mineral which vary between 0.04% and 0.61% are a direct function of the degree of choritization.

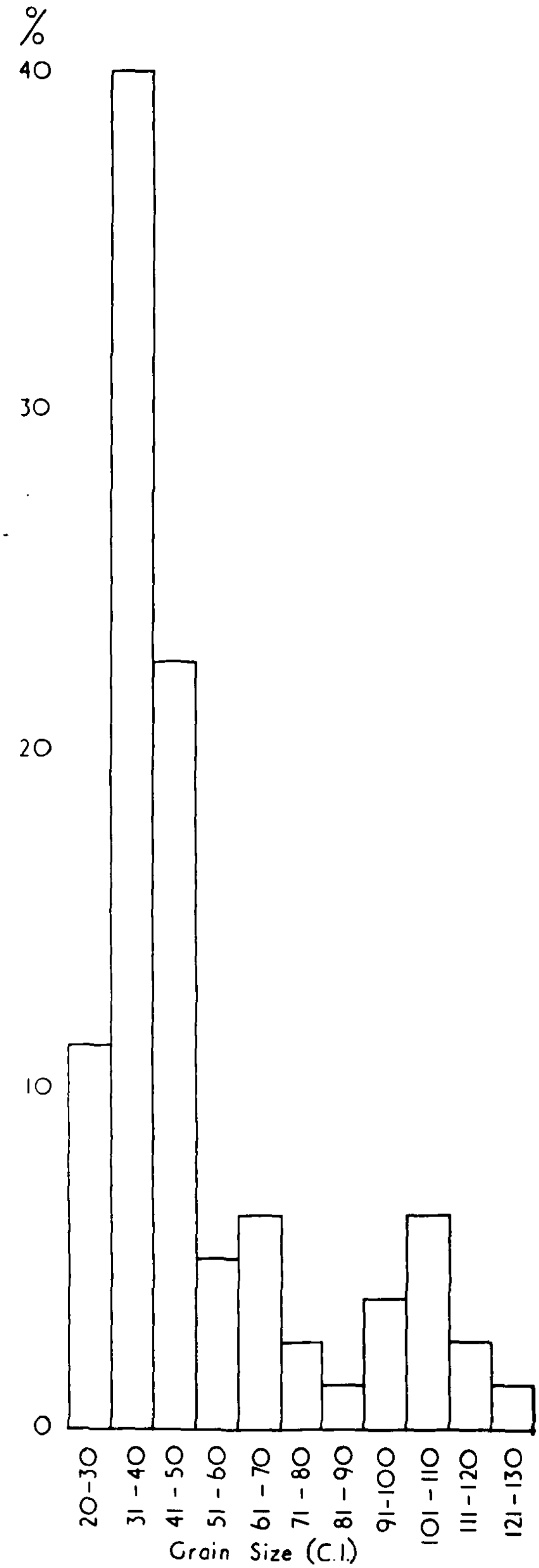
(12) CLAY MINERALS. In the mode the percentage varies between 0.2% and 60%, the latter figure representing complete kaolinisation of the rock. The presence of kaolinite is confirmed by X-ray powder photographs and chemical analysis of the rock which is being quarried or has been quarried for kaolin.

During analysis, the kaolin is selectively stained with an aqueous solution of methylene blue which aids identification of small flakes of this mineral. Under crossed nicols stained kaolinite commonly shows a reddish anomalous birefringence (Fig.118).

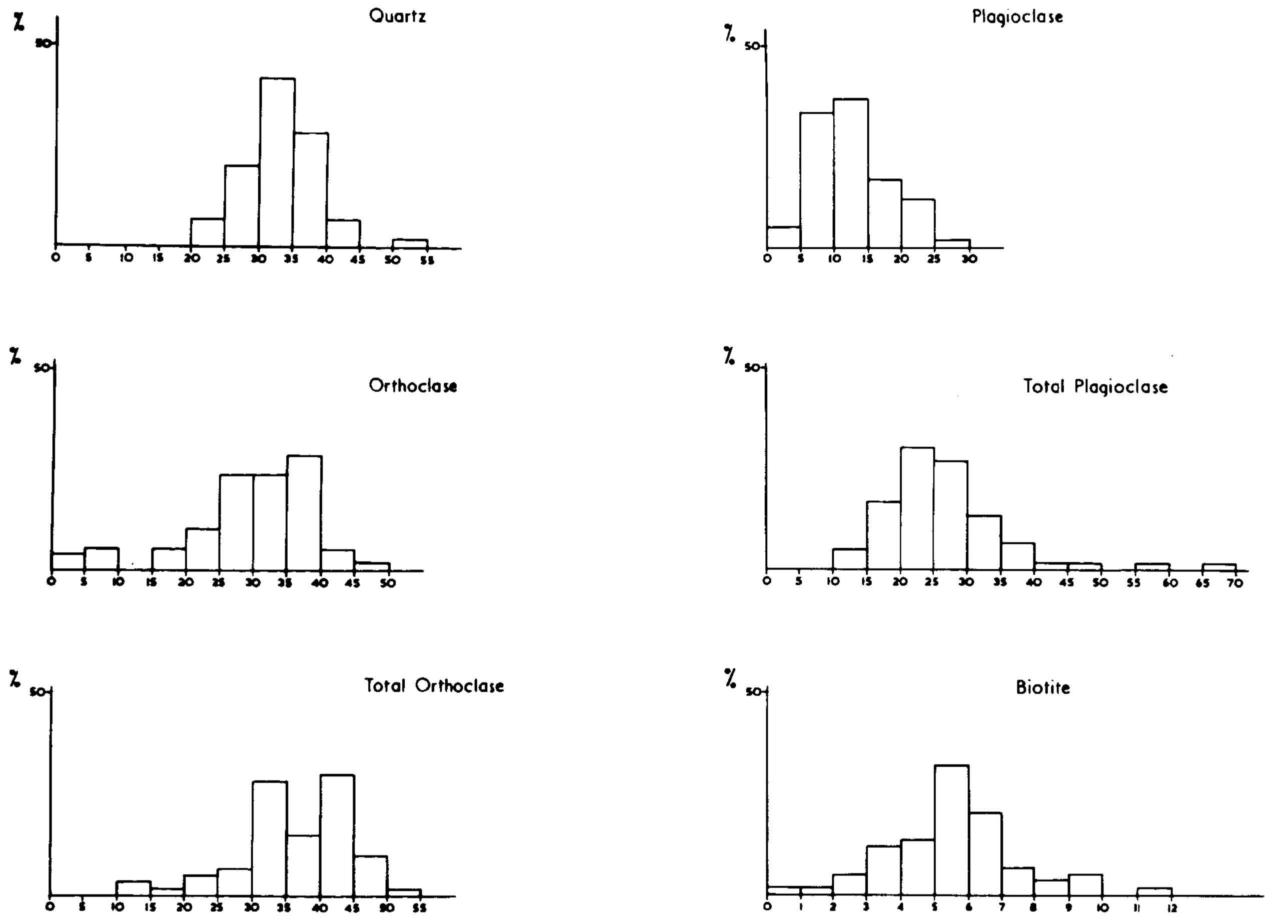
Kaolinisation is common at the 0% to 4% level, and higher values are always associated with kaolinised fracture zones and kaolinised joints. Therefore a block of granite bounded by toughway and cleavingway joints along which kaolinisation has acted is often quite fresh in the centre (assuming the granite is fine grained or close textured), and argillised in varying degrees adjacent to the joints. The distribution of clay minerals at Land's End is governed by the occurrence of the NNW-SSE fracture zones, which in all the cases examined are kaolinised, and it will be seen from map (Land's End Granites) that the more important clay pits are situated on these zones where kaolinisation is usually complete.

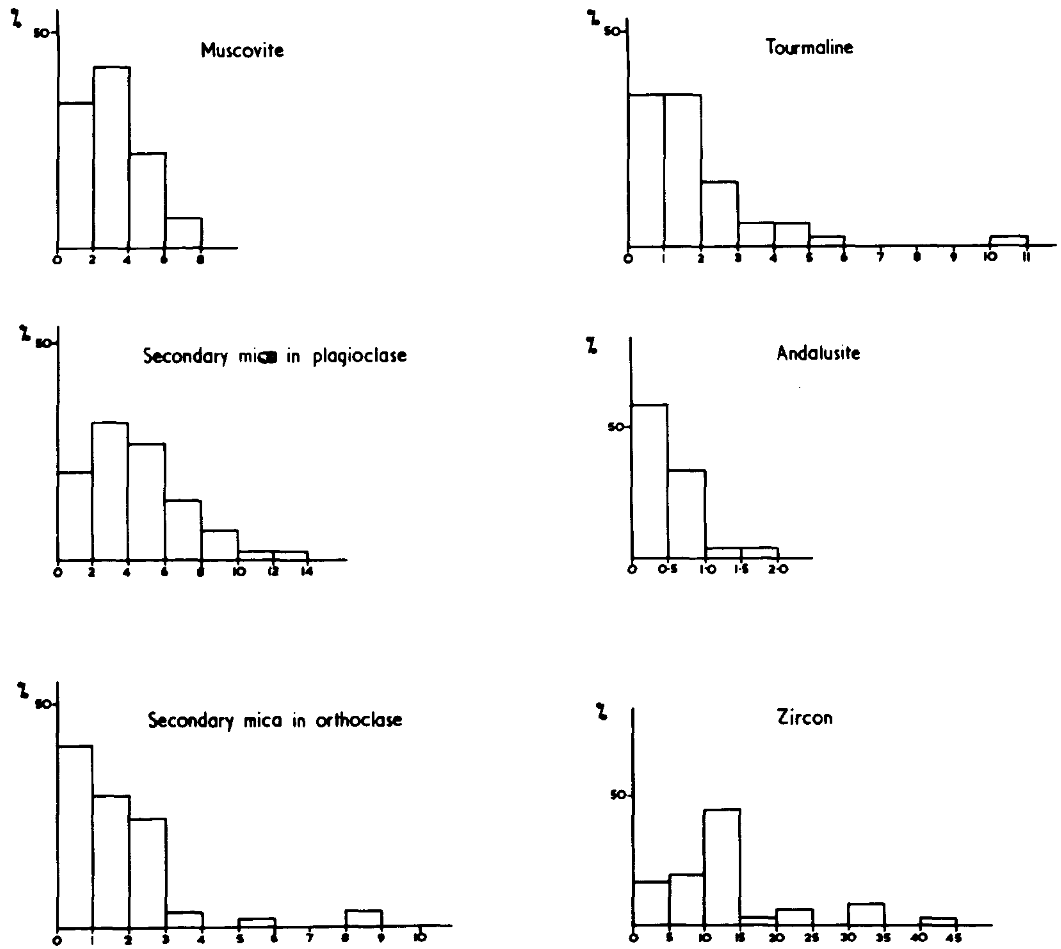
The coarseness frequency diagram opposite is compounded on 120 grain size measurements. It illustrates a large field of coarse porphyritic granites (C.I. 20 - C.I. 50), merging into a medium grained field (C.I. 51 - C.I. 80). The field of fine grained granite is quite distinct (C.I. 81 - C.I. 130).

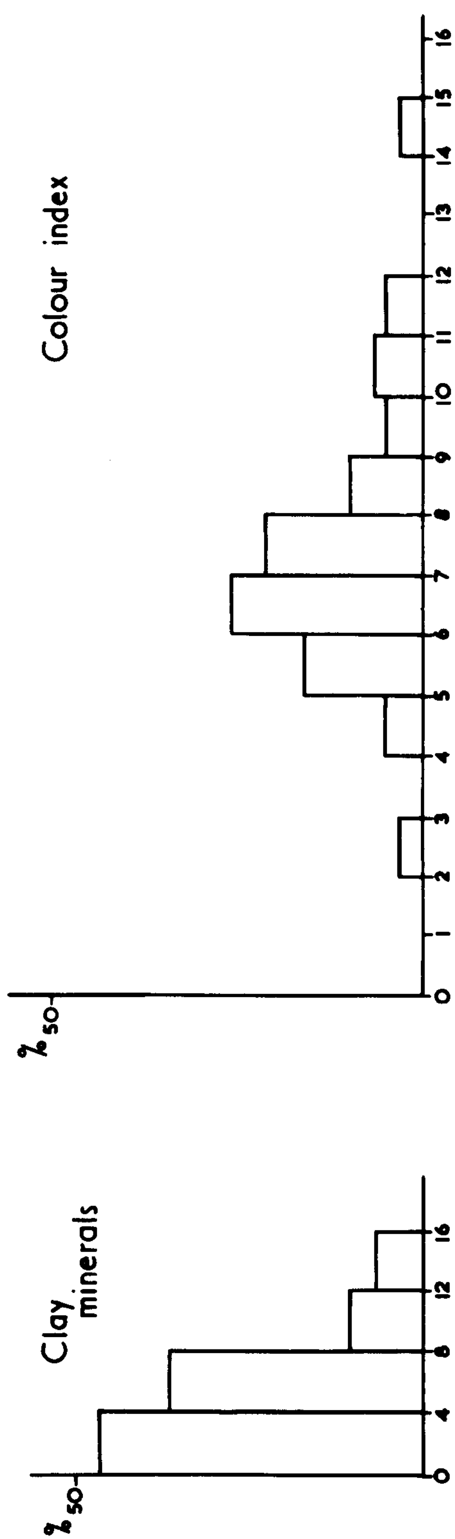
Note that the actual mean grain size is equal to $40 \times C.I.^{-1}$ mm.



COARSENESS FREQUENCY DIAGRAM.


Quartz
Plagioclase
Orthoclase
Total Plagioclase
Total Orthoclase
Biotite
%
50


Muscovite
Tourmaline
Secondary mica in plagioclase
Andalusite
Secondary mica in orthoclase
Zircon
%
50


Colour index
% 50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Clay minerals
% 50
0
4
8
12
16

F. DISCUSSION.

(i) Quartz. It is thought that type (i) quartz which occurs as inclusions in perthite may be primary and represents the remains of a postulated aplitic texture which developed in a more or less stress free environment. Austin (1960) thought that the small rounded quartz grains in the groundmass of the Carnmenellis granite represented an earlier aplitic rock, while the "pools" were regarded as representative of a silicification "front". Exley (1959) regarded much of the quartz in the St. Austell granite as being of secondary origin and recognised recrystallisation in this mineral. The quartz "pools" in the Land's End granite show replacement textures towards the feldspars at their margins and are also regarded as of secondary origin.

The interstitial type (iii) quartz may have a similar origin to type (i) quartz, the internal fracturing probably representing the absorbed strain which gave rise to type (iv) quartz in which marked undulose extinction always occurs. While Chayes (1952) suggests the strain may have been derived by the squeezing effect of two or more alkali feldspar crystals growing metasomatically in a solid medium, Whitten (1951) believes that parallel strain spindles in country rock, like those encountered in type (iv) quartz, are produced by intrusion and Austin (1960) suggests that this quartz may have been derived from inclusions of quartzose Gramscatho rocks in the Carnmenellis granite. Strained quartz crystals of this type have not been observed in the metamorphosed Mylor Slates surrounding the Land's End granite and it is therefore concluded that the development of this type of quartz is dependant on internal stresses set up during late stage metasomatic activity.

In fine grained granites the larger "pools" in the groundmass which replace feldspars at their margins show strain spindles in optical continuity throughout. In this case either the period of replacement was succeeded by a deformation phase, or the replacement took place during the continuance of an earlier imposed regional stress field. While protoclasis is common in the Land's End granite it appears only to affect quartz and seems to be a deformation contemporaneous with the consolidation and post-consolidation periods of the rock.

Inclusions in quartz which have been noted as occurring in regular trains and scattered uniformly in the crystal were thought by Sorby (1858) to be formed during crystal growth and were hence primary in origin. He suggested that if the temperature of the quartz was raised until the two phases in the gas/liquid inclusions became one phase then the temperature at which this phenomenon occurred would indicate, after suitable pressure and temperature corrections, the temperature of formation of the quartz. Ingerson (1947) on this basis calculated a temperature of formation of 250°C for pegmatitic quartz, while Bailey (1949) found a variation of 163°C for adjacent inclusions and concluded that none of the liquid inclusions that he observed were primary. Cameron et al (1953) and Peach (1951) also showed that considerable variation could be expected in experimentally calculated temperatures of formation for quartz. Deicha (1955) came to the conclusion that the inclusions were isolated crystals, aqueous solutions of alkali chlorides or compressed carbon dioxide, and that the gas might be carbon dioxide; he suggested that these substances occurred free in the mobilised milieu at the moment of crystallisation of quartz, which in itself would suggest a primary origin for some of the inclusions.

Vogelsang (1867) suggested that inclusions trains formed in fracture planes that were later resealed, while Tuttle (1949) and Cameron (1945) have shown that planes of secondary liquid inclusions are related to regional structure and are continuous through adjacent quartz grains. Austin (1960) agrees with the above workers on the formation of secondary liquid inclusions in resealed fracture planes and suggests that the scattered inclusions may be primary.

In the Land's End quartz it is found that irregular liquid inclusions are scattered throughout the type (i) unstrained quartz, especially if these crystals are small. Only in the larger grains, which may be composite, do inclusion trains occur; and it is found in type (iv) quartz that the inclusion trains which coincide with strain lamallae in severely strained crystals may be resealed fractures.

(ii) Alkali Feldspar.

Raguin (1965) states that potash feldspar in granites is either orthoclase or microcline or both. While the typical cross-hatched twinning of microcline has not been observed in the Land's End granite, Mackenzie and Smith (1962) found in the Dartmoor granite that the perthites had a triclinic potassium phase although the monoclinic potassium phase was dominant, and that the sodium phase was close to low albite. Single crystal X-ray studies on the perthites at Land's End yet remains to be done, but it is probable, due to other similarities between Dartmoor and Land's End, that similar structural states in these feldspars exist. Austin (1960) found that the alkali feldspars of the Carnmenellis granite corresponded closely to microcline in optical characters as defined by Dana (1958), and extinction angles, though not regarded in themselves as conclusive, suggest this is also the case in the Land's End perthites.

All the minerals commonly occurring in the granite occur as inclusions in the alkali feldspar. Thus while Ghosh (1934) recognised plagioclase inclusions in the perthites of the Carnmenellis granite but did not pursue the point any further, Stone and Austin (1961) described aplite matrix included in a perthite megacryst and used this to support their argument in favour of an original aplitic rock which was subsequently recrystallised and metasomatised.

The porphyroblastic alkali feldspar crystals in the Kloof granite at Cape Town were examined by Shand (1949), who suggested that the potassium rich core which contained few idiomorphic crystals of plagioclase and the sodium-rich margin which contained quartz and biotite grains were magmatic in origin, but during crystallisation the magmas composition was modified by assimilation.

It is particularly noticeable in many of the perthite megacrysts in the Land's End granite that the inner biotite zone is also the quartz and plagioclase zone, and that outside this zone inclusions are more numerous than inside it. The alkali feldspars of the Castle-an-dinas central microgranite, which is not normally porphyritic, rarely contain inclusions except where replacement textures occur. It is therefore suggested that this inner core in the alkali megacrysts of the porphyritic granite was probably magmatic in origin, and that on commencement of metasomatic growth the groundmass minerals immediately adjacent to the feldspar became enveloped during the preliminary burst of growth which later probably slowed down due to lack of adjacent material; additional zones may be due to repetition of this same phenomenon which may represent advancing waves of potash metasomatism, or advancing waves of physico-chemical conditions which made potash metasomatism possible.

Soen (1960) suggested for the late-Hercynian, post-tectonic granites of Portugal that the foliation could be explained by rapidly crystallising a liquid magma to form a solid framework of crystals, and metasomatising orientated seed crystals within this framework by potash-rich liquids; in such a manner he derives "real megacrysts" by magmatic and endoblastic growth in situ under an earlier-imposed orientation. This theory agrees essentially with that suggested for the Land's End granite.

Discrete subhedral-euhedral crystals of plagioclase included in alkali feldspar are thought to be primary although isolated crystals with diffuse margins which are in optical continuity may indicate replacement by the alkali feldspar. Robertson (1959) describes late deuteric potassium metasomatism of plagioclase to give relict plagioclase and secondary (reorganised) plagioclase as discrete blebs and stringers.

Fine regular perthitic intergrowths are usually accepted as being of exsolutional origin (Deer, Howie and Zussman, 1963) and have been morphologically classified by Alling (1932), although it is not clear how his types are crystallographically orientated. Goldich and Kinser (1939) showed that the albite is braid-like parallel to (100) with discontinuous blebs parallel to (110) and ($1\bar{1}0$) faces.

Although it has been suggested that the perthite is an exsolutional feature it is pertinent to review other modes of origin. There are three possibilities:-

(1) Unmixing of an originally homogeneous alkali feldspar.

(2) Simultaneous crystallisation of potassium-rich and sodium-rich feldspar.

(3) Replacement of potassium by sodium feldspar.

Experimental evidence favours unmixing as homogenised feldspars develop their perthitic texture on cooling; this was demonstrated by Chao, Smare and Taylor (1939) and Bowen and Tuttle (1950) who observed the perthite structure to disappear on heating to 850°C and to reappear on slow cooling. They also found that structurally the crystallographic axes were parallel in both the albite strings and the alkali feldspar with the exception of the "b" axis, where an angular discordance of 3° was measured. This was interpreted as being due to the degree of obliquity within the potassium phase compared with the monoclinic low albite.

Anderson (1928), and later Wallace (1956), considered that simultaneous crystallisation would account for the high sodium content in some perthites in alkali granites, and Spencer (1938) suggested that Vogt's analyses on Dartmoor perthites indicated eutectic proportions (Or_{71}, Ab_{27}, An_2). He decided on the grounds of parallelism of (010) composition planes in the two feldspar crystals that simultaneous crystallisation must have occurred.

While the replacement theory for the origin of perthites was based on investigations of pegmatite perthites (Higazy, 1949), Barth (1956) considered the uniform composition of Pre-Cambrian perthites of Norway to be governed by temperature control, in contrast to Anderson (1928) who supported the replacement theory on this issue.

Lehmann (1895) found that heated microclines developed fractures parallel to (100), (110) and ($1\bar{1}0$) when water cooled, and Dittler and Kohler (1925) related unmixed perthite films to contraction planes in the alkali feldspar. Gates (1953) supported this theory and found that there was an increase in the development of perthite in fracture zones while Emmons (1953) described perthite unmixing during shear action to give concentrations of sodium feldspar which later replaced potassium feldspar.

Orville (1963) demonstrated that alkali ion exchange would take place in a temperature gradient of 30°C at 2000 bars at 600°C, and thought that alkali metasomatism would naturally occur under the physico-chemical conditions within the earth's crust. Daly (1917) suggested a temperature of less than 100°C for the crystallisation of alkali feldspars in the Paris Basin, while Spencer (1937) essentially agreed. Barth (1951) considered that perthites were formed by exsolution of a phase containing both triclinic and monoclinic feldspars, homogenisation occurred at 700°C and exsolution occurred on cooling below this temperature; he advocated a crystallisation temperature of 500°C for pegmatitic feldspar.

Exley (1959) suggested that alteration of the alkali feldspars in the St. Austell granite occurred subsequent to tourmalinisation and in an acid environment. Folk (1947) suggested kaolin formed at up to 350°C in acid solutions, providing the K/Al ratio was low; if the pH of the solution lay in the region of 7.0 and the K/Al ratio was nearly unity, both components having a high concentration then muscovite would form at 200°C, whereas at 300°C to 550°C pyrophyllite, commonly described as "sericite", would form if K and Al were both low. As most metalliferous solutions tend to be alkaline sericite generally forms, though Folk (1947) suggested this might be replaced by kaolin near the surface due to the leaching action by sulphate and carbonate rich waters (see table p281-2).

Alkali feldspars in the Land's End granite appear to be primarily affected by alkaline solutions as sericite (or perhaps pyrophyllite) is invariably the first alteration product to form. Later acid solutions migrating along channels in the rock from concentrate zones where kaolinisation was intense would favour the development of clay minerals. Within concentrate zones only kaolinite and quartz represent the former feldspar, but intermediate stages in which secondary muscovite develops after "sericite" flakes followed by increasing kaolinite content may represent the transition from relatively fresh alkali feldspar to clay-quartz aggregate.

Rapakivi texture is developed only in contaminated granites which suggests it is probably a reaction phenomenon. Sylvester (1964) describes mantled potassium feldspars from the Vradal granite in Norway and found that they exhibited an orthoclase distribution gradient, suggesting that the plagioclase mantle is a reaction phenomenon which was derived by exsolution of albite towards the mantle, which thus left the core rich in orthoclase.

(iii) Plagioclase Feldspar.

The composition of the plagioclase lies in the normal range for alkali granites of albite-oligoclase, and while contaminated rocks may contain zoned plagioclase as basic as andesine this is relatively uncommon. Vance (1962) believed oscillatory zoning to be due to recurrent supersaturation of the melt in anorthite adjacent to individual crystals and suggested that abrupt changes in normal zonation was due to late-stage saturation of the residual melt in volatiles; he interprets the zoning sequence as being directly related to the water content of the magma. Bowen (1956) suggested that zoning was due to magmatic circulation of crystals to zones of varying composition and Emmons et al (1953) considered a magmatic origin for oscillatory zoning in plagioclase. While Carr (1954) agreed with Emmons, suggesting cyclic pressure changes to accompany convection circulation, it is difficult to visualise Bowen's (1956) thesis for movement in a heterogenous magma as this is not considered a satisfactory explanation for rhythmic zoning. Vance (1962) goes on to suggest that rhythmic discharges of volatiles in a magma are unlikely as there is no built-in mechanism that would achieve this end. However, on consideration of the rhythmic zoning of pegmatite and aplite in structural traps, as at Porthmeor and Porth Ledden (Figs. 41,45,46 and 48), it is concluded that in the absence of evidence for multiple injection a postulated series of negative pressure pulses would enable volatiles to be replaced in sufficient quantity to enable these pegmatite complexes to form within a texturally aplitic crystal 'mush'. In a similar manner, therefore, it is postulated that this kind of mechanism could be responsible for oscillatory zoning. Karl (1959), and Boone (1959) agree with the theory for volatile release and pressure fluctuation and attribute oscillatory zoning to this cause, while Vance (1962) still spurns this evidence, arguing that oscillations in his zonal sequence could not be thus explained. Fuster and Ibarrola (1956) attribute oscillatory zoning to diffusion in the solid state (this could also account for banded aplite-pegmatite complexes), while Turner and Verhoogen (1960) suggest that it may be due to unmixing. Harloff (1927) and Hills (1936) account for the zoning, supporting Bowen's (1913) scheme, by suggesting diffusion followed by supersaturation during progressive crystallisation :-

(a) Supersaturation of the melt adjacent to the crystal occurs due to diffusion of anorthitc material.

(b) Crystallisation occurs in a small normal zone when an optimum degree of supersaturation is reached. The adjacent melt is thus impoverished in its anorthite content.

(c) Diffusion of new anorthitic material fails to keep pace with crystal growth which slows down and stops.

(d) The sequence is then repeated.

As long ago as 1927 Harloff experimentally produced oscillatory zoning in salt by a diffusion-supersaturation mechanism.

While there are thus two main theories to explain oscillatory zoning it is felt that the layered pegmatite complexes may have some bearing on this problem. To account for the regular aplite-pegmatite layerimg the negative pressure pulses referred to earlier would probably bring about such an end, and if such a mechanism is in operation for one phenomenon then it is considered that it could also produce the necessary conditions for the other. Whether this process could operate in conjunction with the diffusion-supersaturation mechanism is not known, but it forms an interesting possibility.

Zoned plagioclase inclusions in alkali feldspar are interpreted as magmatic when oscillatory zoning is present. However, as many crystals show water clear asymmetric albite rims this has been attributed either to diffusion of albitic material from the perthites to the plagioclase crystal, because the perthite films die out in the vicinity of plagioclase inclusions; or to normal zoning prior to metasomatism. Hills (1936) suggests normal zoning in the sodic rims reflects boiling-off of the volatile phase after saturation, migration of newly formed volatiles having agitated the melt and kept it homogeneous. The twinning of the feldspars which is unaffected by the zoning probably developed contemporaneously with it, the composition planes being controlled by those occurring in the earlier cores.

Myrmekite is common on albite rims adjacent to potash feldspar. It is described by Sederholm (1916) as an intergrowth of plagioclase and vermicular quartz, and accepted by most workers to be of replacement origin according to the following reactions :-

$$2\ KAl\ Si_3O_8 + Na_2O \rightarrow 2Na\ Al\ Si_3O_8 + K_2O$$

$$2\ KAl\ Si_3O_8 + CaO \rightarrow Ca\ Al_2\ Si_2O_8 + K_2O + 4SiO_2$$

Deer, Howie and Zussman (1963) describe the vermicules as commonly projecting from the plagioclase into the orthoclase. Myrmekite resulting from replacement of albite by potassium feldspar was described by Osterwald (1955), and Drescher-Kaden (1939) discussed the occurrence of myrmekite which predated the crystallisation of potassium feldspar. Spencer (1945) did not accept the replacement theory and suggested that the vermicules were the result of "the segregation of microperthitic albite present in solid solution in the potassium feldspar". Sarma and Raja (1959) argued that unstable portions of plagioclase would break down under stress to give myrmekite, and Drescher-Kaden (1948) concluded that solutions capable of metasomatism would corrode plagioclase along "Smekal defects" and deposit silica; he attributed the habit of the quartz to cations filling empty spaces in the plagioclase lattice. Shelley (1964) discussed the origin of myremekite and attributed it to recrystallising quartz being incorporated in growing, exsolved albite, while

Phillips (1964) follows Schwanlke's (1909), Spencer's (1945) and Tuttle's (1952) views which suggests a hypothetical silicate $Ca(Al\ Si_3O_8)2$, which held in solid solution within the feldspars, would release quartz on reverting to anorthite. Phillips (1964) therefore proposes that the presence or absence of myrmekite is dependent on the original calcium content of the alkali feldspar.

Myrmekite in the Land's End granite is confined to albite rims adjacent to alkali feldspar and the vermicules have never been observed to pass into the potassium feldspar. The vermicules are regarded as being due to unmixing, and while they could be explained by either Phillips' or Spencer's theory it is necessary to point out that the albitic rims are regarded as a probable exsolutional phenomenon, and that the percentage of anorthite in the analysed perthites (Table P335) varies between 0.3% and 3.7%.

Kaolinisation of the plagioclase feldspars in the granites of south-west England has been discussed by Exley (1959 and 1963b), who suggests that acid hydrothermal "solutions" which were injected through fissure systems were responsible. While the possible alteration series Albite/Oligoclase-Montmorillonite-Kaolinite is recognised, this would require an initial alkaline environment followed by a fall in pH to provide suitable conditions for kaolinisation; this is also dependent upon a low K/Al ratio according to Folk (1947). Schwarz and Trageser (1933) found that anorthite treated with hydrochloric acid at a temperature of 320°C to 330°C gave kaolinite. Hemley et al (1961) found that at over 400°C and at 15000 lbs/in^2 an aqueous chloride environment altered albite to paragonite and quartz; using hot water only at a lower temperature and pressure Morey and Chen (1955) obtained muscovite together with paragonite and attribute the muscovite to the small amount of K_2O in the albite. Hemley et al (op.cit.) also found that by repeating their experiment at lower temperatures the following reaction occurred:-

Albite → Montmorillonite → Kaolinite.

Umegaki (1938) reported a pH of 8.46 for albite which is alkaline and would probably favour the formation of montmorillonite under the influence of water vapour at low temperatures, but as mineralising solutions are generally alkaline this would overide the pH factor. While fluorine would perhaps provide the necessary pH change to allow kaolinite to form from montmorillonite, it has been shown by Exley (1963) that it is not an important constituent of the kaolinising fluid, while the role of boron is uncertain. $HSiO_3^-$ may also provide the necessary pH change, as described by Hawkins and Roy (1962), and Kennedy (1950), but would require higher temperatures for its formation in an appreciable amount.

Chemical analysis shows kaolinised granite to be high in silica and alumina while X-ray powder photographs show this granite to contain quartz, mica (sericite probably) and well ordered kaolinite. X-ray powder patterns for alkali feldspar extracted from kaolinised granite shows that no kaolinite is present, nor is their SiO_2 and Al_2O_3 content (Table P333) slanted towards argillisation. It is therefore concluded, in agreement with Exley (1963b), that it is the albite/oligoclase feldspar that primarily decomposes to give kaolinite and that the alkali feldspar also breaks down in the final stages (Modal analysis S30), (Figs. 111-118).

(iv) Biotite.

Several varieties of biotite are recognised on the basis of their colour, which is attributed to varying amounts of TiO_2 and $Fe_2O_3/(Fe_2O_3 + FeO)$. Austin (1960) referred to one pleochroic scheme for

Carnmenellis biotites and indicated a variation in 2V from 2° -ve to 16° -ve which is well within the range quoted by Dana (1958), and attributed by Deer et al (1962) to weathering.

Brammall and Harwood (1932) analysed five biotites from the Dartmoor granite and concluded that:-

(1) They occupied a transitional position between true biotite and lepidomelane.

(2) They became iron and lithium rich progressing from older to newer granites.

(3) The most acid mica was not found in the most acid granites as would be expected if phase equilibrium were assumed. They suggested that these relationships were due to contamination, or "removal of the micas from the liquids which precipitated them".

Black-bronze biotite extracted from contaminated granite (SC1) at Sennen Cove is found to be very similar in chemical composition (Table P332) to those analysed by Brammall and Harwood (1932). The lithium content in SC1 is higher (1.60 per cent compared with 0.37 per cent) and the titanium content compares favourably with that in their specimen 66. The $Fe_2O_3/(Fe_2O_3 + FeO)$ ratios for the Dartmoor granites are generally lower in value than for SC1 which reflects a higher Fe_2O_3 value. These facts indicate that the biotites of SC1 type are relatively late and that they are probably due to contamination. Cundy et al (1960) found a strong resemblance between lithium-bearing Cornish mica and zinnwaldite from Zinnwald, but suggested the Trelavour mica should be grouped with lithium-containing biotites rather than with zinnwaldite. Table P331 shows the composition of zinnwaldite and Trelavour biotite which should be compared with SC1 biotite from Land's End. It will be shown later that biotite alters to muscovite and during potash metasomatism of meta-igneous hornfels lithium is introduced into the rock. It is therefore suggested that lithium, along with potassium, may be substituted in biotite to yield a lithium-rich "muscovite".

X-ray diffraction powder photographs of biotites extracted from feldspar megacrysts are, apart from slight variations, identical with SC1 biotite. Variations are due to contamination and are identified as follows :-

SC1 Bi (L1020) Pure biotite. Contains suspected traces of well-ordered kaolinite.

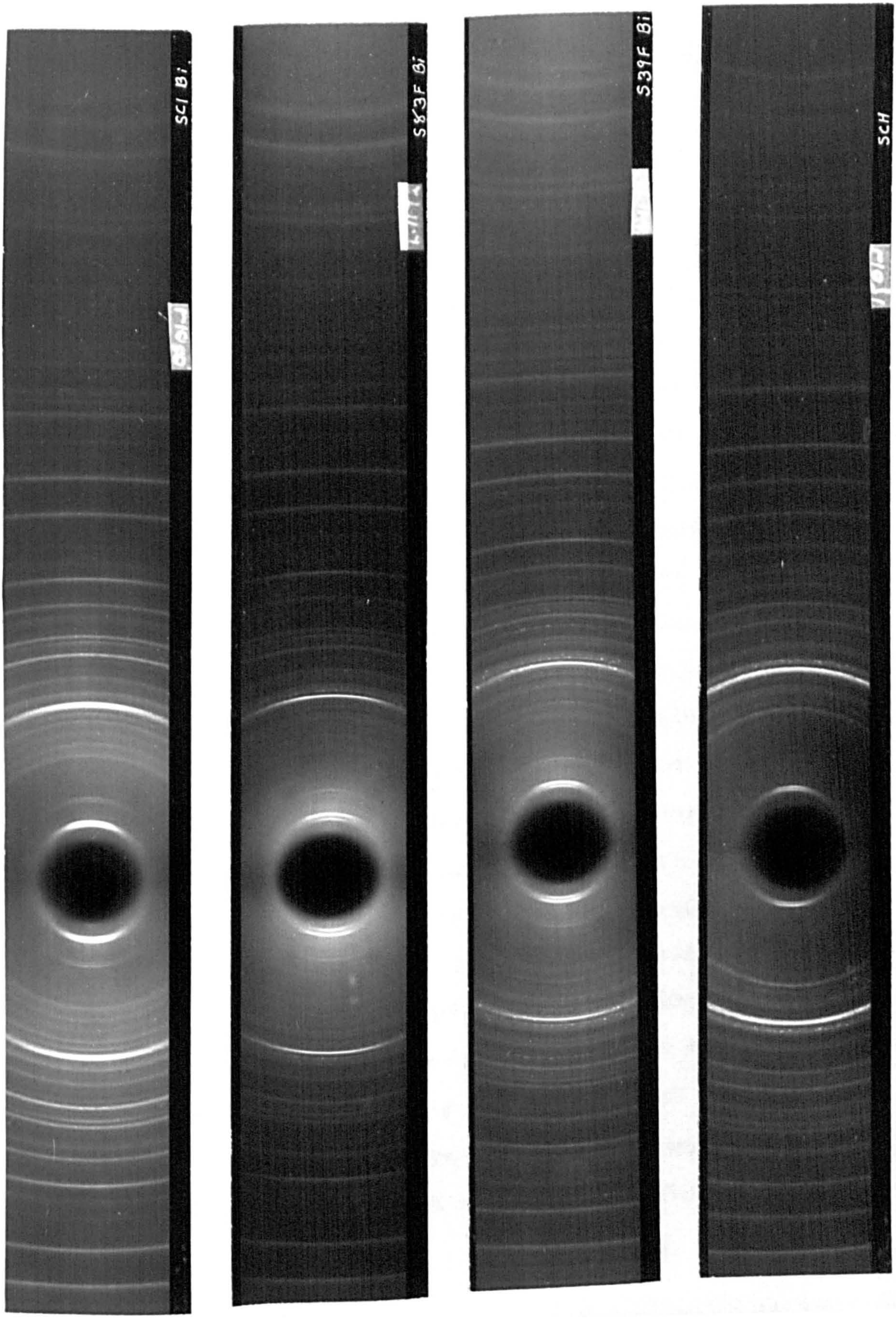
The X-ray powder pattern photographs opposite illustrate the structural similarity in some of the biotites of Land's End.

SC1/Bi Biotite extracted from a highly contaminated granite (melagranodiorite) at Sennen Cove. Its chemical analysis is given in table p.332. In addition to biotite, traces of well ordered kaolinite occur.

S83F/Bi Biotite extracted from feldspar megacryst (S83F) see analyses tables). It contains some well ordered kaolinite together with traces of quartz and feldspar.

S39F/Bi Biotite extracted from feldspar megacryst (S39F. see analyses tables). Containing traces of feldspar and well ordered kaolinite.

SCH Schlieren (type 5 xenolith). Contains much biotite together with quartz and feldspar.


SC1 Bi
S83F Bi
S39F Bi
SCH

S39F Bi (L1171) Mainly biotite. Contains some feldspar and traces of kaolinite.

S83F Bi (L1172) Mainly biotite. Contains in addition small amounts of quartz.

This suggests that the biotite inclusions in the feldspars and SC1 biotite are structurally and compositionally identical (Text fig. P162). Potassium metasomatism, which is responsible for a large proportion of the megacryst volume, post-dates much of the contamination effects as shown by megacrysts growing across zenoliths and hornfels/granite contacts; it is therefore suggested that the included biotites may be due to assimilation of adjacent pelitic hornfels and metadolerites prior to potash metasomatism. The associations of muscovite and andalusite with biotite lend additional evidence in support of its xenolithic origin. The textural relationships between orthoclase and biotite suggest that potash metasomatism is responsible for the development of the feldspar. In the presence of later mineralising solutions the biotite would become decolourised by leaching of iron and magnesium and substitution of potassium to give secondary muscovite after biotite. This process did not always attain equilibrium for many biotites show partial alteration internally, while externally they are encrusted with sericite and granular muscovite; some muscovites show patchy islands of remnant biotite. This alteration is believed to post-date potash metasomatism, for inter-feldspathic biotites are frequently unaltered while intrafeldspathic varieties are chloritised. The fact that the deuteric solutions were capable of diffusion is shown by the occasional interfeldspathic biotites which are partly chloritised along cleavage planes.

Feldspathisation of aplite veins is a common feature around the margin of the Land's End granite. Potassium rich metasomatising fluids in the veins have migrated along chemical and thermal gradients towards the margins where they have formed coarse alkali feldspar selvedges. Adjacent to pelitic hornfels these margins are common, but where the aplites cut basic meta-igneous rocks the amphibole has been biotised up to several cms. from the contact. Frequently biotite selvedges from 2mm. to 5 mm. across develop. Analysis of hand specimens using sodium cobaltinitrite shows the centre of the aplite vein to contain potassium feldspar while the marginal areas are potassium deficient. Chemical analysis of specimens from Gwavas quarry, Newlyn, show that the marginal meta-igneous hornfels are desilicated and enriched in potassium and lithium. It is believed that potassium metasomatism has occurred along a thermo-chemical gradient from the hotter centre of the aplite vein towards the cooler margins, and that potassium was introduced into the marginal metadolerites to bring about biotization. The development of biotite at the junction is regarded as evidence of a build-up of migrating potassium ions.

(v) Muscovite.

It has been suggested (Deer et al, 1962) that muscovite in the Dartmoor granite may have been derived in whole or part from the alteration of cordierite xenocrysts. Cordierite crystals in the granites of south-west England, particularly Land's End, are usually altered to "pinitic mica" and cases of partial absorption and remnant cordierite crystals have not been observed. Type (2) muscovite (P.109) is very common and is always associated with the final stages in the breakdown of pelitic xenoliths. The following reaction may approximate to the mechanism involved :-

$$3Al_2SiO_5 + K_2O + 3SiO_2 + 2H_2O \longrightarrow 2KAl_3Si_3O_{10}(OH)_2$$

The aluminium silicate being derived from xenoliths bathed in the silicon-potassium-rich granitic mass, water would be available during late magmatic stages to complete the transformation.

Andalusite which has been observed to be slightly marginally altered to sericite could have entered into a more extensive replacement reaction and the granular muscovite-sericite aggregates may represent relict andalusite-cordierite patches.

Late muscovite which replaces feldspar and tourmaline is ascribed to the break-down of feldspar under the action of greisening fluids which post-date tourmalinisation.

(vi) Tourmaline.

On textural evidence tourmalinisation pre-dates kaolinisation. It is extensively developed in some areas of Land's End granite where it is attributed to :-

(1) Concentrations of boron building up in structural traps to give roof zones of tourmaline pegmatite (Fig.51).

(2) Boron "fronts" (Fig.66) where advancing waves of tourmaline have been preserved in a marginal aplite at the eastern Tater-du contact.

(3) Enrichment in volatiles to give pod shaped masses rich in boron during the plastic phase prior

to consolidation. This is evidenced by the sigmoid form of many of these pegmatites in granite apophyses. e.g. :- Tregerthen Cliff.

(4) As referred to earlier the layered pegmatite sequences which contain well defined zones of tourmaline are attributed to negative pressure pulses, which would repeatedly release volatiles from the late granitic fractions until all the volatile material was used up. Field evidence correlates with the fact that the pegmatite bands would be expected to decrease in thickness from the roof zone downwards, due to the diminishing supply.

(5) Late stage mineralising fluids rich in boron were injected along fissures. These veins are often rich in cassiterite and occasionally they produce a deep reddening of the adjacent feldspar in zones a few feet across. Trevalganite, a pneumatolysed granite, consists of deep red-yellow feldspars and tourmaline. The type area is no longer exposed but identical material has been found as loose boulders over 8 miles away. Trevalganite is attributed to the same mechanism described by Wells (1946) for the formation of luxullianite; that is the pneumatolytic modification of granite in an isolated plug by boron emanations which became

trapped as in roof pegmatites. A similar metasomatic mechanism would account for Roche Rock north of the St. Austell granite, and the marginal schorl rock at Porth Ledden.

(G) SUMMARY

Petrography reveals a complex crystallisation and replacement history. The zoned plagioclase which occur poikilitically in the potassium feldspars are regarded as relicts of the original microleucogranite, in which assimilation, recrystallisation, metasomatism, mineralisation and other deuteric replacement phenomena have almost completely obscured the original "aplitic" texture. Quartz shows evidence for recrystallisation, and quartz/feldspar granophyric intergrowths of the type described by Augustithis (1964) are attributed to metasomatism. The biotite content is attributed mainly to assimilation effects which also enriched the magma in alumina to give cordierite and andalusite xenocrysts, and enriched the deuteric fluids in potassium. These were responsible for the wholesale internal metasomatism of a partly solidified crystal network orientated by contemporaneous or earlier imposed stress. Towards the termination of the development of the alkali feldspar megacrysts they were growing in a solid environment, and field evidence demonstrates post-solidification alkali feldspars growing across aplite/

granite (Fig.72) and hornfels/granite (Fig.75) junctions. Perthitic intergrowths are attributed to exsolution and perhaps replacement, while Rapakivi texture is due to reaction with a basified xenolithic granite.

Chapter IV

The Granites (Chemistry)

CHEMISTRY OF THE GRANITES

A. Introduction

This section presents the results of chemical analyses of a selection of granites from Land's End, illustrates the chemical variation and seeks to review the changes that have brought about this variation. Stated briefly the main aims are :-

(i) To ascertain the composition of the original magma that was emplaced into the aureole rocks and review its possible mode of origin.

(ii) To study the effect of differentiation within the granite and to investigate how this is modified by assimilation.

(iii) To review the effects of metasomatism in the granite and adjacent aureole rocks.

B. Precision of Analysis

Precision is dependant upon several factors which, if unchecked, would give a cumulative high degree of inaccuracy.

(i) Operative errors. These are mainly due to inexperience in analytical technique or fatigue when excessively long analysis runs are attempted. Poor sampling techniques, both in the field and more especially in quartering the crushed sample to obtain a weighing sample are also important. Loss of lighter constituents in the powder during crushing and sieving could be serious, and it was found that great care had to be taken to ensure that there was not an excessive loss of powder when dismantling sieves, as upward air currents produced when the top component was removed caused a fine cloud of material to escape. Some errors might be due to contamination by foreign matter, steel from the crushing rollers (although case-hardened) and quartz from the automatic agate mortar and pestle; the inclusion of such foreign matter will affect weighings, and failure to ensure the balance pans are repeatedly brushed will also introduce inaccuracies. Great care had to be taken when fuming off perchloric acid as spitting was experienced during early analyses, but this was practically eliminated by more careful control of the distance of the Vitreosil heater from the sample. With practise most of these personal errors are eliminated.

(ii) Procedural errors. Are those inherent in the method employed although they can be controlled to some extent by ensuring that correct chemical conditions are present, e.g. pH in R_2O_3 precipitation to ensure all the interfering elements are removed.

Low totals in analysis may be due to the non-determination of various elements such as Li, Sn, Cr, Ba, Cu, B and F etc.

Accuracy and precision in chemical analysis has been reviewed by Fairbairn et al (1951), and more recently by Stevens et al (1960) who finds for G-1 and W-1 that low SiO_2 results are obtained by most analysts, there is a lack of precision in results for Al_2O_3 and Fe_2O_3, and results for K_2O tend to be low. Groves (1951) who also summarised poor analyses found that SiO_2 was low, Al_2O_3 was high by the amount of SiO_2, CaO and MgO contained. CaO was high by the amount of SiO_2 and MgO contained and offset by coprecipitation with Al_2O_3 removed earlier. MgO was low by the amount of MgO, Al_2O_3 and CaO coprecipitated. Coprecipitation would offset inherent high values and accentuate low values.

Adopted limits of acceptability are given for G-1 (Granite) by Stevens et al (1960) and are reproduced in Table p173 together with the author's results. At least one sample of G-1 was included in each analysis batch as a standard check. Where basic rocks were analysed W-1 (Diabase) was used as a standard.

	G - 1 (Author)	Adopted limits of acceptability. $\bar{x} - s$ to $\bar{x} + s$. (Stevens, 1960)
SiO_2	71.81 - 72.45	71.87 - 72.83
Al_2O_3	14.01 - 14.81	13.95 - 14.69
Na_2O	3.50 - 3.60	3.08 - 3.54
K_2O	5.35 - 5.90	5.03 - 5.81
MgO	0.41 - 0.60	0.27 - 0.53
CaO	1.36 - 1.52	1.28 - 1.52
FeO	0.89 - 0.98	0.89 - 1.10
MnO	0.023 - 0.025	0.02 - 0.04
P_2O_5	0.06 - 0.07	0.04 - 0.16
TiO_2	0.22 - 0.25	0.22 - 0.30

Analyses were not duplicated at the same time. Groves (1951) quotes Larson (1938) and points out that duplicate analyses do not necessarily offer any guarantee of accuracy when carried out by the same analyst at the same time, as similar errors are repeated. Inclusion of G-1 and W-1 standards give good indications of any major errors, but it must be pointed out that if one element for either of these standards is in error then it does not follow that the rest are also incorrect, nor does it follow that unknowns are incorrect as the error may have been introduced individually. Conversely this means that because G-1 and W-1 are correct it does not follow that the unknowns are correct. Analyses totals give some indication of accuracy, but again failure to analyse for certain minor elements may give low results; high values are usually attributed to cumulative errors: e.g. adsorption of moisture when weighing for water determination, faulty pipetting, subnormal low tension feed on the spectrophotometer leading to erratic behaviour of the galvanometer.

Analyses of G-1 and W-1 standards by the author show close agreement with the adopted limits of acceptability, N.B.S.99 was found to agree within the limits of experimental error and it is therefore submitted that the analyses presented are tolerably correct.

C. Presentation of Results.

The analyses tables are presented in six sections dealing in turn with :-

(i) Granites from Land's End mainly objectively selected, but illustrating the variation within normal and contaminated types.

(ii) Porthmeor granite and aplite veins which illustrate a clear-cut intrusion sequence.

(iii) Geevor Mine 6W3 crosscut granite/hornfels contact. This being the only contact at Land's End from which fresh material could be collected, it was considered advisable to take the opportunity to study this junction as the passages leading to it are falling into disrepair with several recent roof falls making the journey extremely hazardous.

(iv) Inclusions of aureole hornfelses in the granite. These are classified as xenoliths, schlieren, and high contaminated "hybrid" marginal granites. They illustrate the chemical changes undergone by the metamorphosed Mylor slates and intrusive dolerites on becoming incorporated in the granite.

(v) Gwavas Quarry dolerite and crosscutting aplite, where the dolerite has been marginally biotised and enriched in lithium at the expense of the aplite.

(vi) Mineral analyses. The chemical analysis of biotite has already been discussed elsewhere (P.158), and is presented together with analyses of 3 alkali feldspar megacrysts and 3 pegmatite alkali feldspars.

D. Presentation of Data

(i) Variation

Chemical analyses establish the following variation within the granites of Land's End.

SiO_2	59.97	-	75.77%	SC1	-	PCES
Al_2O_3	13.75	-	19.39%	PCES	-	S47/K
Na_2O	0.30	-	7.00%	S47/K	-	PCEA
K_2O	1.80	-	6.77%	S47/K	-	G24
Li_2O	0.00	-	0.20%	S47/K	-	AV(1)
MgO	0.20	-	2.73%	PCEA	-	P3
CaO	0.42	-	2.38%	PCES	-	S47/K
Fe_2O_3	0.09	-	3.34%	PCEA	-	SC1
FeO	0.24	-	6.66%	PCEA	-	SC1
MnO	0.00	-	0.11%	2C	-	SC1
P_2O_5	0.03	-	0.58%	S47/K	-	SC1
TiO_2	0.01	-	1.39%	2C	-	SC1

where SC1 = Group 6 xenolith (marginal highly contaminated granite).

PCES = Fine grained tourmaline aplite vein.

S47/K = Kaolinised granite.

PCEA = Fine grained aplite vein.

G24 = Coarse grained biotite granite.

AV(1) = Aplite vein.

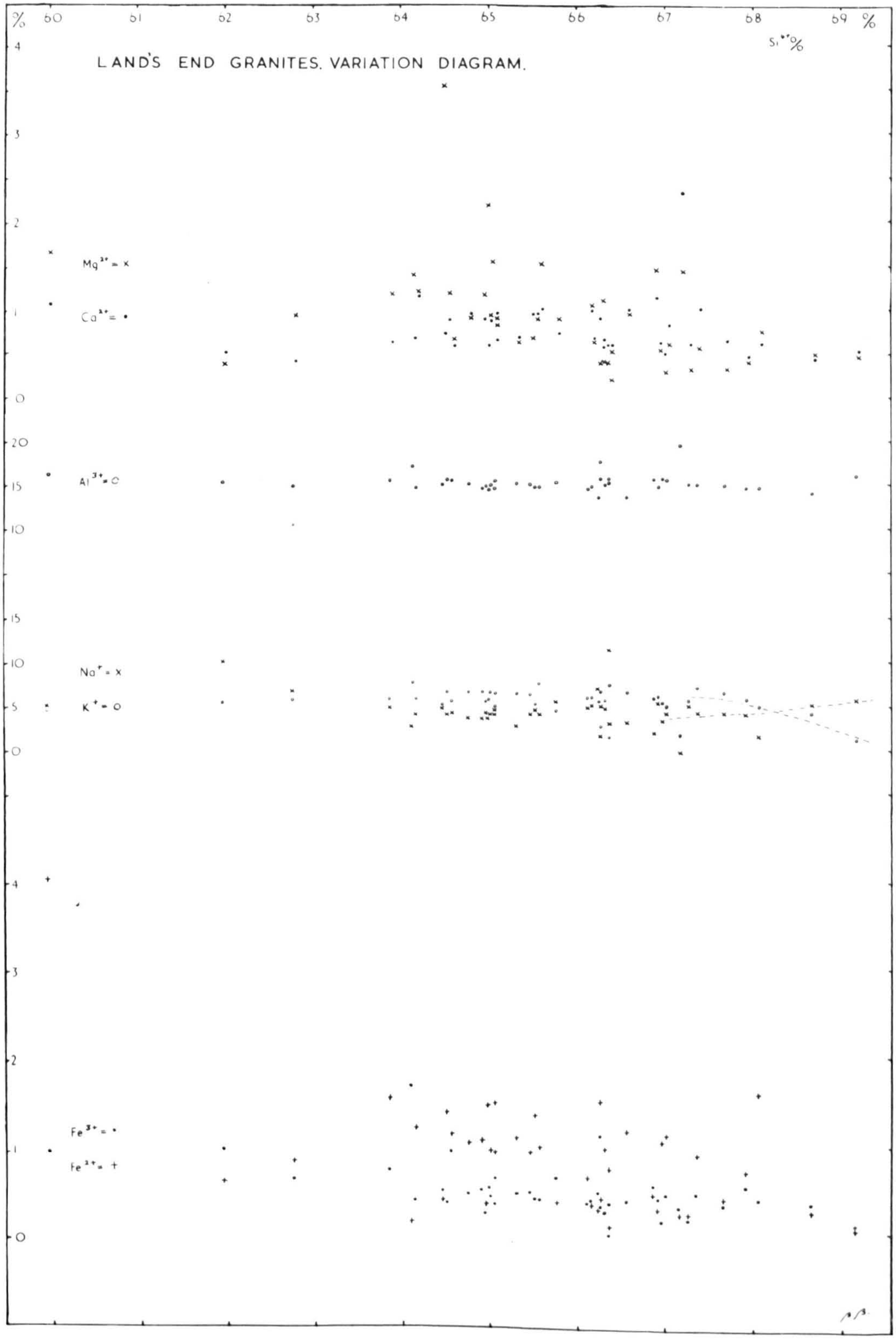
2C = Medium grained biotite granite lying beneath coarse porphyritic granite. (Rosewall Hill).

P3 = " (Morvah).

Within this range lie the compositions of representative main granites and their varieties. It is found that the fine grained later granites cannot be separated from the coarse on the basis of chemical composition, as the wide variation in the main granites completely overlaps the compositions of the finer varieties.

(ii) Harker-type Variation Diagram.

Brammall and Harwood (1932) noted a wide variation in the Dartmoor granite between such end members as aplites and "biotite-rich veins", and concluded that the variation features presented were consistent with differentation as the sole factor. Ghosh (1934) found similar results for the Carnmenellis granite but attributed the variation only partly to differentiation. He says that the Dartmoor and Carnmenellis granites, which were possibly initially sodic could have been modified by selective assimilation of potassium rich sediments; he concludes that basic segregations


LAND'S END GRANITES. VARIATION DIAGRAM.
Si^{4+}%
Mg^{2+} = x
Ca^{2+} = •
Al^{3+} = o
Na^{+} = x
K^{+} = o
Fe^{3+} = •
Fe^{2+} = +

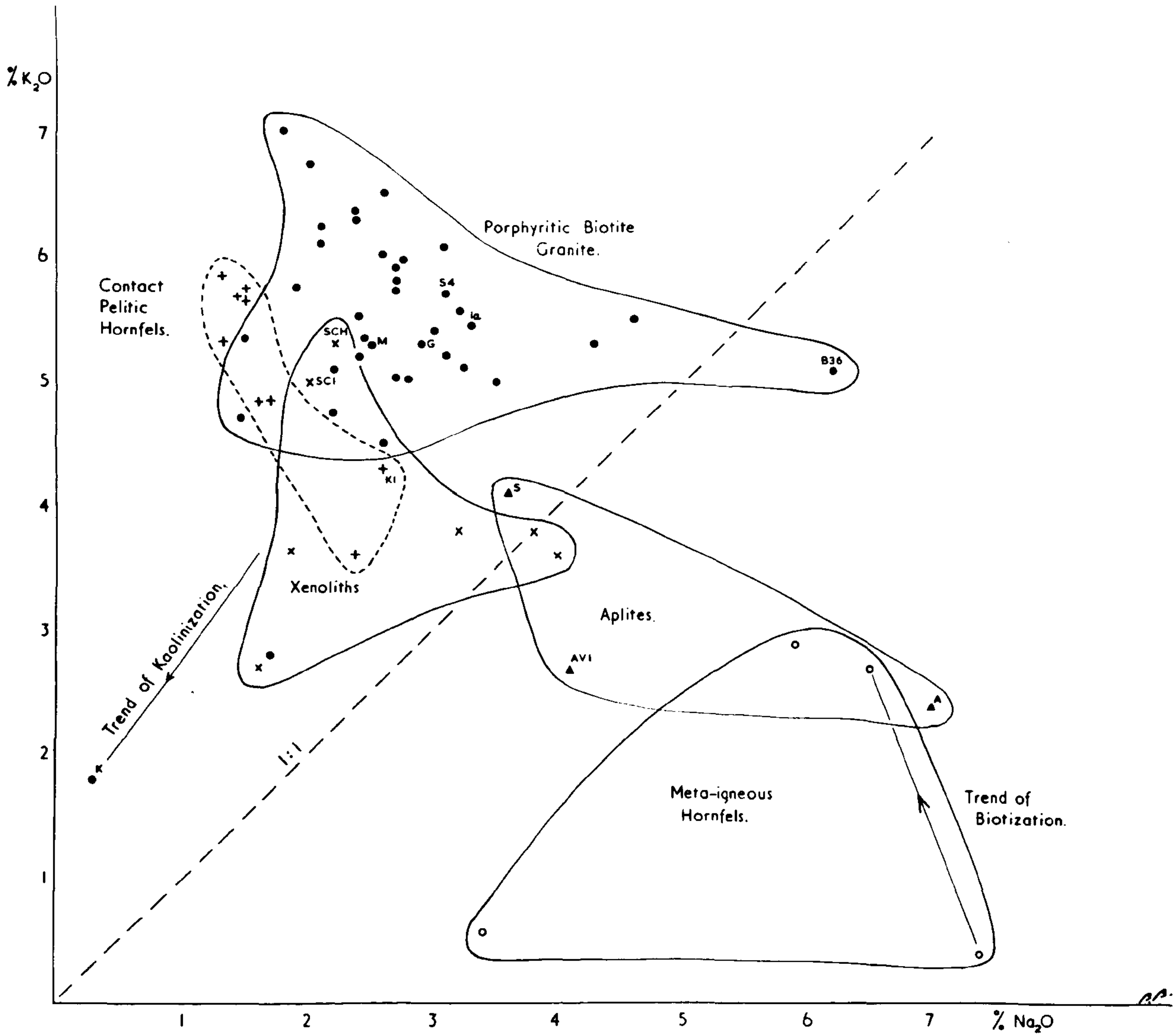
(accidental xenoliths) and leucocratic varieties are the result of magmatic differentiation in complementary directions.

The variation diagram (Text fig. P178) for Land's End granites, in which various cations are plotted against Si^{4+} per cent, shows the relationship between Al^{3+}, Na^{+}, K^{+} and Si^{4+}. There is a slight terminal inverse relationship between Na^{+} and K^{+} in favour of Na^{+} in the aplites. Ca^{2+}, Mg^{2+}, Fe^{3+} and Fe^{2+} show a slight decrease in value with increasing Si^{4+} percentage, a trend which agrees with that found by Brammall and Harwood (1932), and which according to them would suggest that differentiation is the cause of the variation; but, as Chayes (1964) points out "....strong negative correlations of the typical Harker diagram could be generated by any process which would greatly enlarge the variance of silica relative to other oxides...", and concludes that this type of diagram is of little use for discriminating between the effects of any process important in the differentiation of volcanic suites. This argument suggests that correlation between major elements means little, for an increase in one major constituent would naturally lead to a decrease in the others, which together make up the total of 100 per cent. It is thought that minor elements would not be affected as they only contribute slightly towards the total, and that a terminal reciprocal variation in Na^+ and K^+ would be totally unaffected as their sum is more or less constant; thus the variation diagram illustrates a decrease in femics as silica increases, to give aplite end-members in which lithium (analysis AV(1)) and sodium enrichment occurs at the expense of potassium. Stone (1963) notes that an increase in sodium and fluorine in granite is accompanied by an increase in lithium in the time sequence, and that lithium exhibits a metasomatic trend.

As these effects are only seen in the silica-rich end members it is suggested that they are differentiates from the main contaminated granite; the lack of correlation of silica with other elements suggests a chemically homogeneous granite, in which isolated contamination patches occur.

(iii) K_2O-Na_2O Variation.

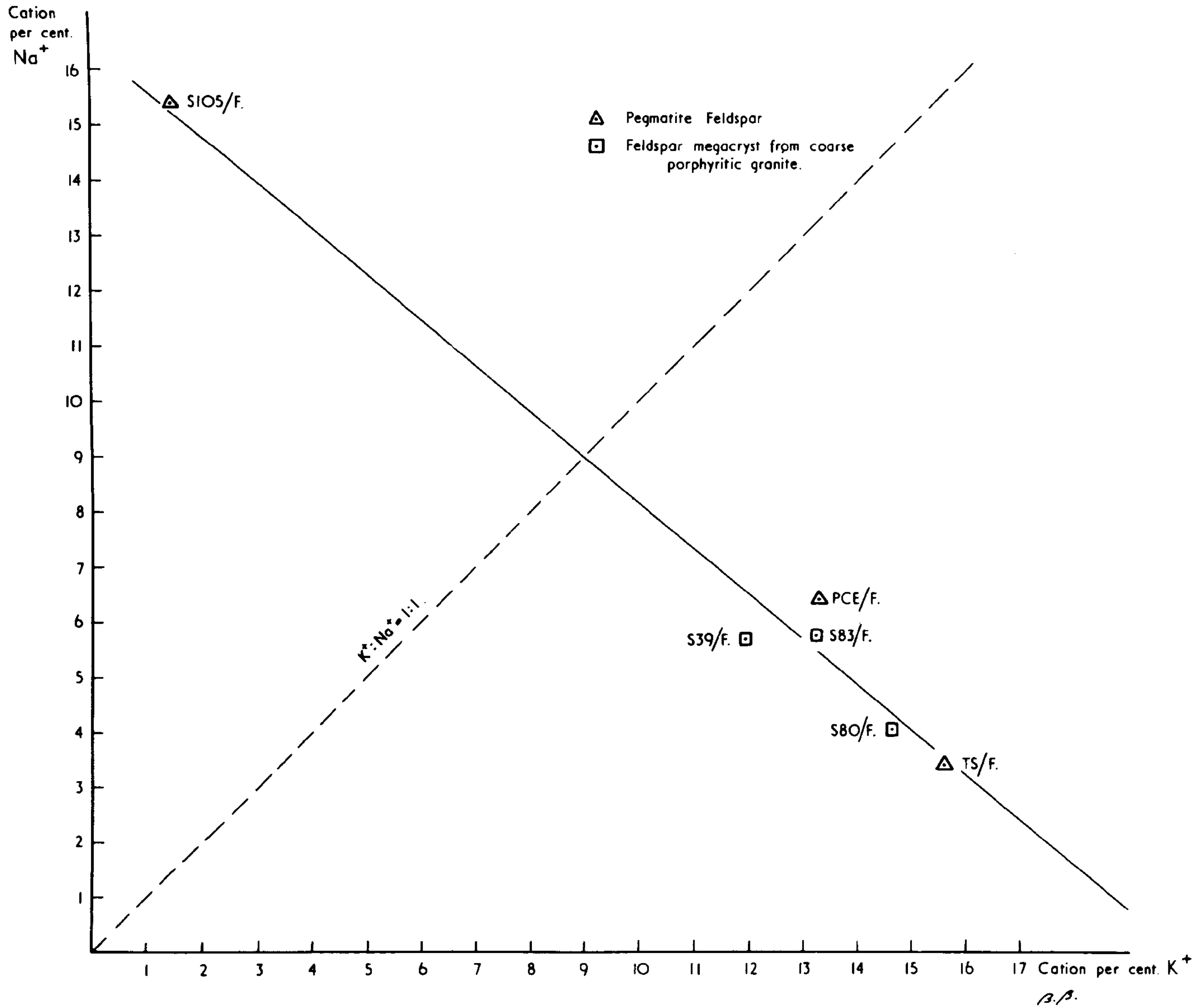
Brammall and Harwood (1932) and Ghosh (1934) plot K_2O against Na_2O and show the relation of the Dartmoor and Carnmenellis granites, aureole rocks and sediments to alkali variation. They conclude that the granites straddle the dividing line between the


% K2O
% Na2O
Porphyritic Biotite Granite.
Contact Pelitic Hornfels.
Xenoliths
Aplites.
Meta-igneous Hornfels.
Trend of Kaolinization.
Trend of Biotization.
1:1
SCH
SCI
M
G
S4
Ia
B36
KI
S
AVI
A
K

soda and potash fields, and because the aureole shales and aplites lie in the potash field they suggest that the sodipotassic main granites merge into potassic granites by virtue of assimilation of potassic shales. Stone (1961) concluded that the antipathetic relationship between plagioclase and alkali feldspar was evidence for metasomatism, but later argues that as modal quartz accounts for 30 per cent of the rock, the feldspar which accounts for the greater proportion of the remaining 70 per cent will always show an inverse relationship, for either one will increase at the expense of the other.

The diagram (Text fig. p181) shows the main bulk of the granites to lie well in the potash field and therefore have a K_2O/Na_2O ratio greater than unity; they are also more potassic than the Dartmoor granites (Brammall and Harwood, 1932, p.177, fig.2) and are comparable with the Dartmoor marginal facies and the rocks in Carnmenellis granite field (Ghosh, 1934, p.255, fig.4). These data suggest that the potash-rich granites of Land's End (and Carnmenellis) are associated with the highly metasomatised pluton envelope and that the sodic varieties (e.g. B36, and the late lithionite granites of the St. Austell granite - Exley, 1959) represent later differentiates from which the potassium has been lost.

The aplite field closely corresponds to that of Exley and Stone (1965), and to the sodic felsites of Brammall and Harwood (1932); it also indicates a progression from sodium rich aplite "A" to potassium rich aplite "S". However, as these are both postdated in intrusion sequence by "G" - which is a sodium rich term of "M" (see P. 248.); - it is suggested that they are the sodium differentiates of, perhaps, an earlier intrusion. Furthermore, it is thought that the medium grained non-porphyritic granite, of which B36 is a sample, which underlies the coarse porphyritic variety may represent the relatively potash-deficient pluton core referred to earlier (P.73), and is intrusive into the porphyritic granite. Generally, however, the compositions of these non-porphyritic granites are similar to those of the porphyritic varieties, and while this seems inconsistent with the argument that they are later, soda-rich derivatives of the former, it is possible to account for their present composition if the hypothesis is entertained that they attained their present position in a similar manner to the coarse porphyritic type, i.e. by overhead stoping and assimilation of the earlier granite. This would account for the relative absence of accidental xenoliths



Cation per cent. Na+
Cation per cent. K+
Pegmatite Feldspar
Feldspar megacryst from coarse porphyritic granite.
S105/F.
PCE/F.
S39/F.
S83/F.
S80/F.
TS/F.
K+:Na+=1:1
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

183a

in these varieties, yet explain the existence of xenocrystic cordierite pseudomorphs which represent the now assimilated xenoliths of the coarse porphyritic type. The megacrystic patches (pegmatoids) in the Castle-an-dinas granite may therefore represent reconstituted earlier pegmatitic material.

The contact hornfels and xenolith fields show a sodium enrichment trend, (K1) representing a specimen taken one inch from the granite margin. This trend supports the views of Brammall and Harwood (1932), Ghosh (1934), Exley and Stone (1965), and Booth (1965), who believe that the original granite magma was sodium rich and would have enriched the aureole rocks immediately bordering the granite in this element. Specimens (SCH) and SC1) represent hybrid marginal type rocks in which the pelitic hornfels are being granitised and assimilated.

The K_2O/Na_2O variation diagram for feldspars (Text fig. P183a) shows a similar relationship to that of the granites, illustrating the varying amounts of sodium the potassium feldspar is capable of holding, and may reflect the composition of the fluids affecting metasomatism (i.e. they may exhibit a sodium enrichment trend as the pegmatitic feldspar at Knill's Steeple consists of sodium-rich chessboard oligoclase (Fig.102).

The meta-igneous hornfels field shows a trend in potassium metasomatism with biotisation (desilication accompanies this trend) where adjacent to granites. The potassium may have been transported by fluorine which was being expelled from the granite.

To sum up: the variation diagram shows an inverse relationship in the granites which is mainly attributed to the replacement of sodium feldspar during internal potassium metasomatism; it shows progressive enrichment in sodium in the contact and assimilated hornfels which is attributed to metasomatism; it illustrates the existence of a sodium-rich aplite field which is regarded as a late differentiate, and the possibility of a sodium rich primary magma.

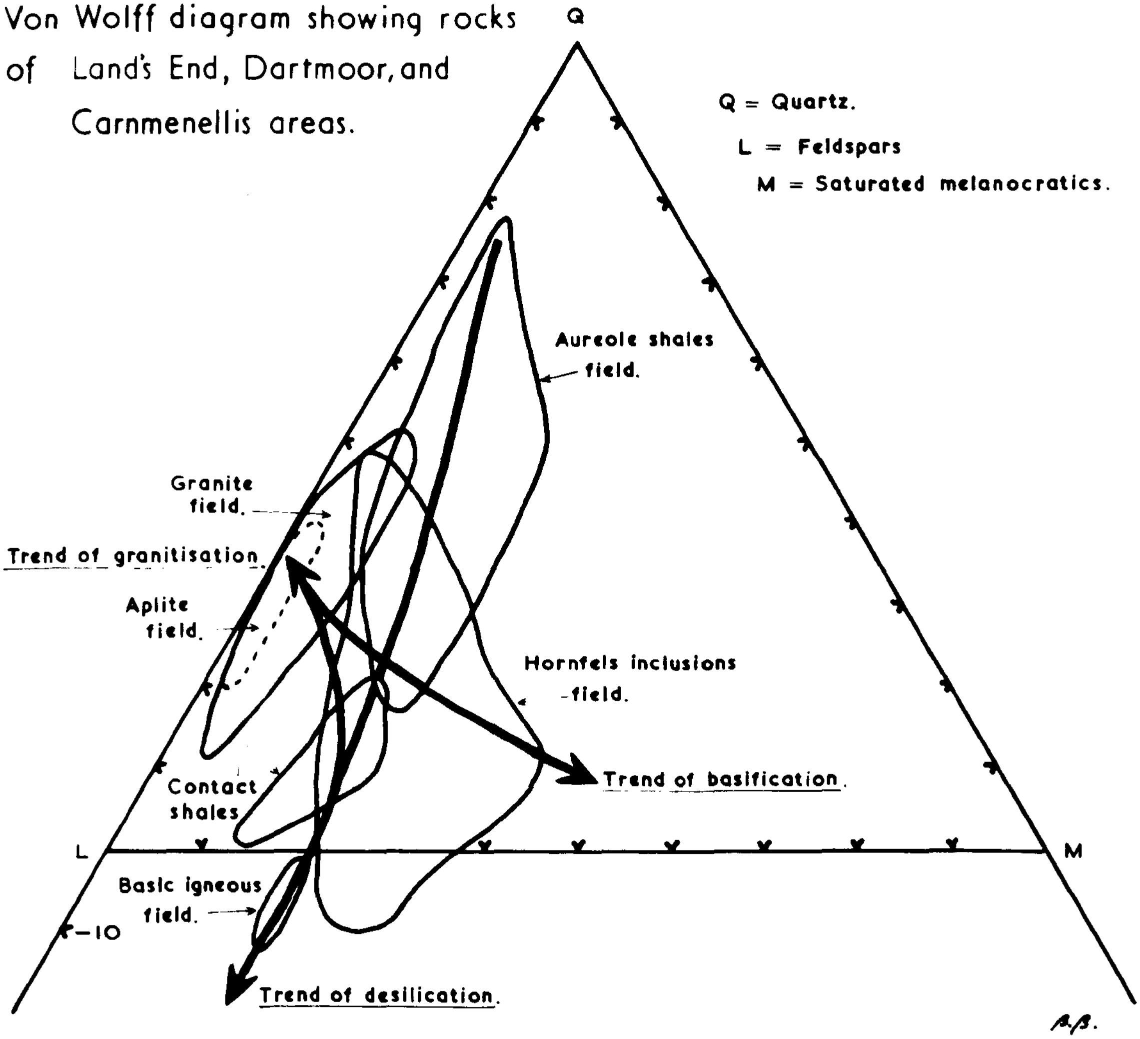
(iv) Von Wolff Variation Diagram.

In calculating the values of Q,L, and M for this diagram the normative constituents were summed as follows :-

$$Q = \text{Quartz } (+ \text{ or } -)$$
$$L = Or + Ab + An + C$$
$$M = En + Fs + Mt + Il + Ap$$

This is a slight modification which was introduced

Von Wolff diagram showing rocks of Land's End, Dartmoor, and Carnmenellis areas.



because it allowed Q, L, M values to be calculated more readily from normative values, the original calculation being :-

Q = Quartz (+ or -)

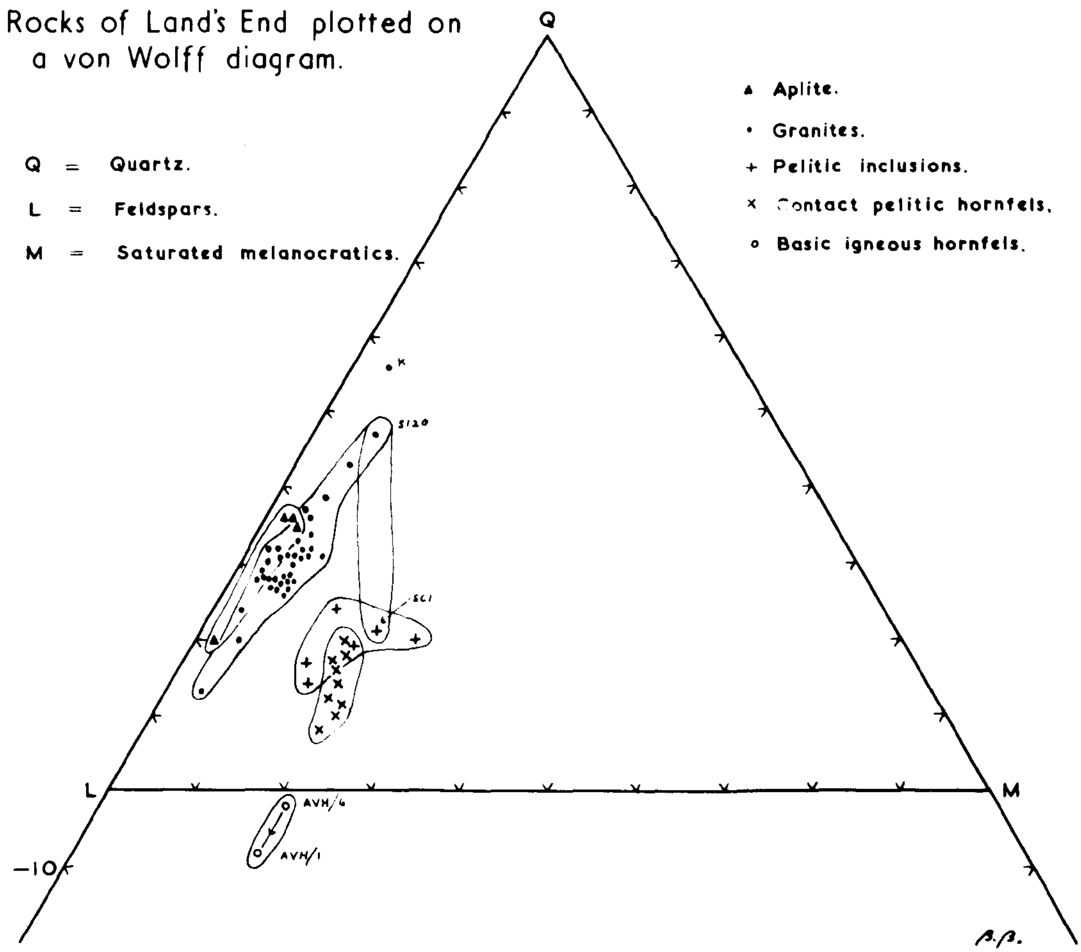
L = Or + Ab + An + C

M = Mt + Aug + Aegirine

Reynolds (1946) who discusses granitisation of marginal and xenolithic aureole rocks, suggests that -

(1) Pelitic and semipelitic rocks are metasomatically altered. They become desilicated and are "characterised by higher values of alkalies and/or cafemics". Basification, which leads to desilication, involves the introduction of Fe_2O_3 (total), MgO and CaO and Reynolds finds that TiO_2, P_2O_5 and MnO frequently attain a geochemical culmination. Feldspathisation may also effect desilication when TiO_2, P_2O_5 and MnO tend to decrease. During the final stage of granitisation SiO_2, Na_2O or K_2O are introduced while Al_2O_3, CaO, MgO, Fe_2O_3 (total), TiO_2, P_2O_5 and MnO decrease.

(2) Basic igneous rocks are also metasomatised in two similar stages - desilication and/or basification occurs by the introduction of CaO, MgO, Fe_2O_3 (total) and either one or more of the following - TiO_2, P_2O_5


Rocks of Land's End plotted on a von Wolff diagram.
Q = Quartz.
L = Feldspars.
M = Saturated melanocratics.
▲ Aplite.
• Granites.
+ Pelitic inclusions.
× Contact pelitic hornfels.
o Basic igneous hornfels.
Q
L
M
−10
K
S120
SC1
AVH/4
AVH/1
B.B.

and MnO. Granitisation occurs by the addition of SiO_2, K_2O and/or Na_2O, Al_2O_3 and loss of other constituents.

Text fig.P186 shows the various fields in the Dartmoor, Carnmenellis and Land's End granites and should be compared with text fig.P188 which illustrates similar fields in the Land's End granites only.

The most striking difference is the size of the granite fields, which in Reynolds diagram lies between Q27 and Q42; and in the Land's End diagram lies between Q13 and Q47. This difference is due to both the greater number of specimens analysed (41 as against 28) and the careful selection of end members in order to demonstrate the range of variation within the granites. The diagram also shows the existence of a large aplite field between Q20 and Q36 which also includes some of the more leucocratic main granites.

The field of contact hornfelses (9 analyses) shows a desilication trend away from the main aureole sediments of Reynolds (Q17 to Q78) and lies between Q8 and Q20. This field corresponds closely to that for the Dartmoor granite (Q3 to Q24).

The xenoliths field in the Land's End triangular diagram lies between Q14 and Q24; it shows a basification trend and in this respect corresponds to the "- igneous-looking-inclusions-" field (granitisation series) of Reynolds. It also overlaps both the contact hornfels field and the contaminated granite field, specimen SCH representing a biotite rich schlieren or streaked out xenolith, and specimen SC1 representing a coarse grained, recrystallised, marginal, highly contaminated granite - hybrid rock - adjacent to the hornfels/granite contact. In this case SC1 fits into the granitisation series of Reynolds, but specimen S120, which is from a contaminated granite raft, is relatively high in silica and may represent a huge digested xenolith of psammitic parentage.

The meta-igneous field shows a desilication trend from Q, - 2.4 to Q, - 7.8. M and C in Text fig. represents the margin and core of a pelitic xenolith in the granite which probably originated from stoped contact hornfels which in turn were derived from the aureole sediments/shales field of Reynolds.

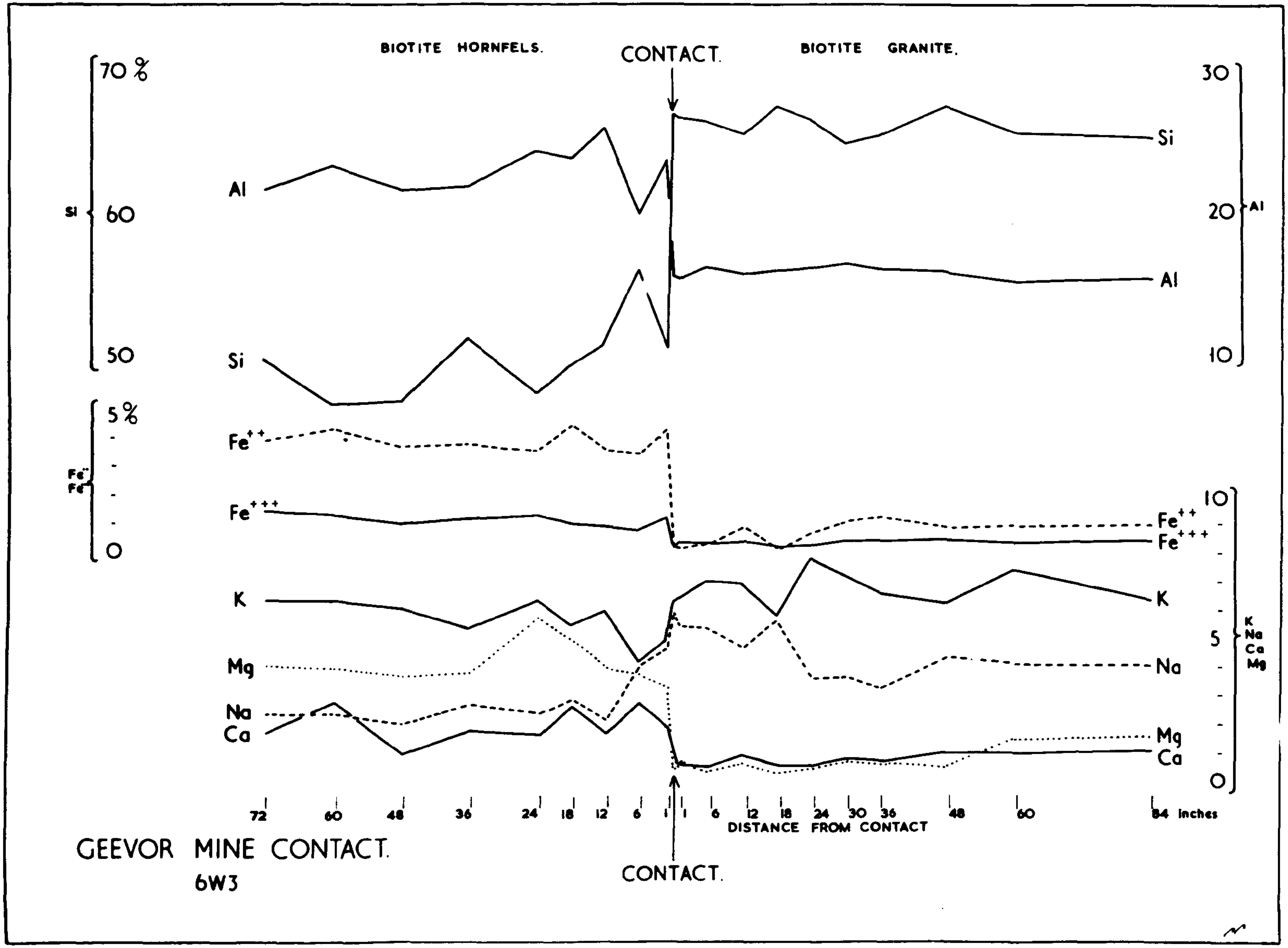
Text fig. P186 illustrates the superimposed fields of Land's End, Dartmoor and Falmouth (Carnmenellis) granites and the main desilication, basification and granitisation trends within these rocks. The desilication trend from the aureole shales of Dartmoor and Falmouth granites passes into the contact hornfelses, which on becoming included within the granite undergo granitisation through the xenolith field while the granites complementarily undergo basification.

Analyses of four xenoliths in the diagram are from types that would have been classified by Brammall and Harwood (1932) as basic segregations and by Ghosh (1934) as sub-melanocratic varieties. In fact there is evidence - high plagioclase content, andalusite-biotite-muscovite assemblages - that indicates these "basic segregations" are undigested reconstituted xenoliths.

The data expressed in the von Wolff diagrams agree closely with those of Reynolds (1946), and the suggestion by Brammall and Harwood (1932) and Ghosh (1934) that the granites are contaminated. The contamination was brought about by assimilation of stoped potassic shales which were desilicated, and later granitised by the metasomatic addition of alkalis and silica.

(v) Geevor Mine Contact Transect.

Land's End granite is unique amongst the south western granites in exhibiting such diverse marginal phenomena and so many granite/hornfels contacts. In all, sixteen contacts are exposed, but only thirteen are normally accessable and these are weathered,



GEEVOR MINE CONTACT.
6W3

kaolinised or exposed to daily immersions in the sea. The remaining three are in Geevor Tin Mine. Of these three only one is relatively free of mineralisation effects and is located in the 6W3 cross cut. Specimens were taken from the west wall of this cross cut (Fig. P192), in a line perpendicular to the contact. For this reason it was only possible to obtain specimens up to 84 inches perpendicularly below the contact (granite), and 72 inches perpendicularly above the contact (hornfels). Unfortunately the travelling ways to this locality are about 25 years old and are rapidly falling into disrepair with increasingly frequent roof falls, and it is probable that this excellent contact from which perfectly fresh specimens may be obtained will soon become unapproachable.

Bowler (1959) discusses chemical and spectrographic analyses from Tater-du western contact and Portheras Cove contact. He finds a tendency for K^+ to rise and Na^+ to fall at Portheras Cove, while at Tater-du the K^+ value shows a rise in two close contact rocks but falls further up the vein; as this contact (Tater-du, west) is complicated by the marginally emplaced differentiated granite vein (Figs. 47, 48 and 49) it is understandable why Bowler's K^+ values behave erratically.

Close chemical examination of 20 specimens (Text fig. p192 and Table p307-21) selected at distances of 1 inch, 6 inch, and 24 inch intervals from either side of the Geevor Mine contact shows that the 24 inch wide marginal chilled phase (R. Cox - personal communication - describes this chilled marginal facies as a homogeneous, leucocratic rock resembling an aplite) is relatively sodium rich and is found to grade rapidly into coarse porphyritic biotite granite. The diagram shows the hornfels adjacent to the granite to be enriched in Na^{+} and this can be interpreted as having been metasomatised by the earlier sodium rich "magma".

Silicon values are fairly constant in the granite at about 66 per cent Si^{4+} and fall to around 49.9 per cent in the hornfels, but in the hornfels contact zone the value lies above 50 per cent and as high as 56 per cent. Ferrous iron increases by 3 to 4 per cent in the hornfels and is accounted for by the sharp rise in the biotite content, while ferric iron shows only a slight increase. Magnesium and calcium values in the granite are constant around 1 per cent, but in the hornfels the value of magnesium suddenly increases by 3 per cent and like the ferrous iron, is probably accommodated in the biotite; the calcium increases by ~~only~~ 1 to 2 per cent and is accounted for by the more calcic plagioclase. Potassium is more irregular in distribution but in the hornfels there is a sharp drop in this element in the region of the contact and it may have migrated into the adjacent granite.

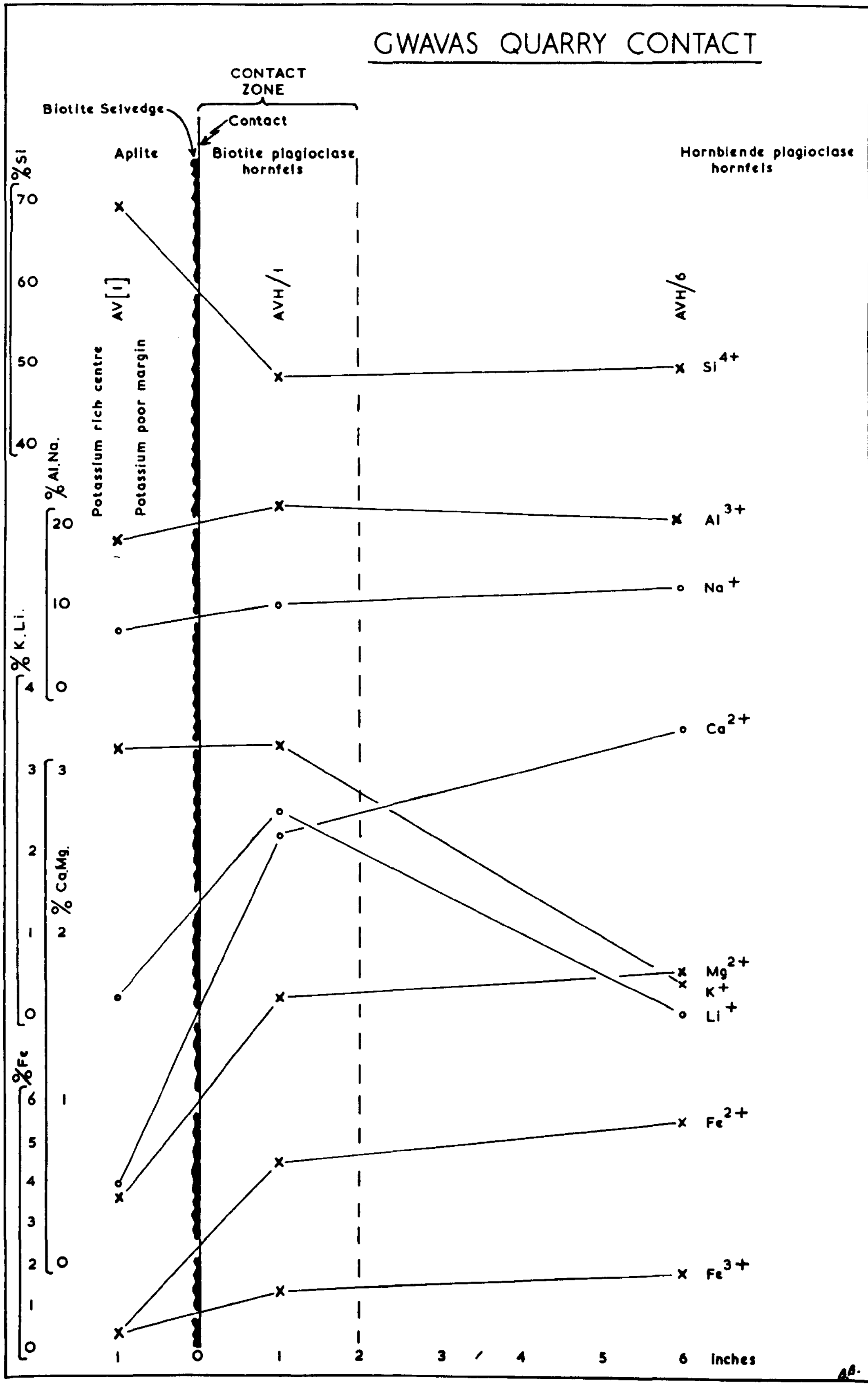
The main porphyritic biotite granites contain from 2.0 to 3.4 per cent (by weight) total iron, while the marginal phase in the Geevor contact contains only 1.0 per cent (by weight) total iron. This leads to the suggestion that if the marginal phase represents the original sodium-rich "magma", then it was leucocratic in aspect; but on the other hand some explanation must be sought to account for the higher iron values in the main granites. There is overwhelming evidence in favour of assimilation and contamination which could account for the higher iron, aluminium, and potassium values in the main granites. This process would necessitate assimilation on a grand scale, for it has been estimated by various workers that the inclusion of 20 to 30 per cent of pelitic aureole rocks would be necessary to satisfy these requirements.

Contact evidence therefore suggests the granites were originally leucocratic in aspect and probably sodium-rich in composition, they became modified by assimilation of the pelitic and meta-igneous hornfels stoped away during the emplacement period. Contamination is held largely responsible for the excess alumina, which is normatively expressed as corundum, the high potassium content, and much, if not all, of the modal biotite which accounts for a large proportion of the iron.

(vi) Gwavas Quarry Transect.

During quarrying activities in the early summer of 1964 an aplite vein cutting meta-igneous hornfels was exposed by blasting operations.

The aplite vein, which post-dates N-S tourmaline veins, varies in width up to 3 feet; it strikes at 150° and dips to the north at 40°. In hand specimens it is a light grey, compact, saccharoidal rock with a very fine matrix. It is demonstrably intrusive into the meta-igneous hornfels and contains many xenoliths of this rock. The xenoliths are brown in colour compared with the parent rock which is greenish black over 12 inches from the vein, though adjacent to the vein the parent "metadolerite" is also brown in colour; both are fine grained, close textured rocks which are extensively quarried for road stone. In thin section they are seen to be composed of interlocking plagioclase


GWAVAS QUARRY CONTACT
CONTACT ZONE
Biotite Selvedge
Contact
Aplite
Biotite plagioclase hornfels
Hornblende plagioclase hornfels
AV[1]
AVH/1
AVH/6
Potassium rich centre
Potassium poor margin
% Si
% Al.Na.
% K.Li.
% Ca.Mg.
% Fe
Si4+
Al3+
Na+
Ca2+
Mg2+
K+
Li+
Fe2+
Fe3+
1 0 1 2 3 4 5 6 inches

laths interspersed with hornblende plates (Figs. 99 and 100), the plagioclase varies in composition around andesine and the hornblende is sometimes chloritised to penninite or replaced by calcite and epidote; occasionally concentrations of small plates occur, which Floyd (1962) suggests may indicate amphibolisation of pyroxene. Adjacent to the contact the hornblende is replaced by biotite to form a plagioclase biotite hornfels. The actual contact is occupied by a 2-3 mm. wide zone of biotite crystals which on the hanging wall is sometimes partly replaced by tourmaline. Adjacent to the margin within the aplite the biotite selvedge is corroded where it projects into the fine grained quartz, orthoclase, plagioclase groundmass.

Text fig. P197 shows the cation percentage of various elements plotted against distance either side of the contact. Striking differences within the meta-igneous hornfels are :-

(1) The high value of K^+ and Li^+ in the contact zone.

(2) The decrease in Ca^{2+}, Mg^{2+} and Fe^{2+} on approaching the contact zone.

Stained specimens of the aplite show the centre to be potassium rich and the margin to be potassium poor. Orville (1963) experimentally produced alkali migration in a thermal gradient, (see P.148), and Green (1963) explains alkali metasomatism in Kragerö pegmatites in a similar manner, while Floyd (1962) showed that displaced calcium, magnesium and iron contributed towards the formation of amphibole veinlets in the Land's End aureole.

It is believed that alkali metasomatism is responsible for the biotisation of the hornblende plagioclase hornfels, and that both K^+ and Li^+ migrated along a thermo-chemical concentration gradient into the meta-igneous rocks and displaced both Ca^{2+}, Fe^{2+} and Mg^{2+}. The aplite vein has been shown to be deficient in potassium marginally. This may be due to the diffusion of K^+ to the cooler margin and potassium deficient meta-igneous hornfels, the low value of Na^+ in the hornfels contact zone is attributed to back-diffusion to replace the incoming K^+ which appears to have built up outside the hornfels to form the biotite selvedge; no doubt this was in part due to the relative impermeability of the hornfels. Many aplite veins in the Land's End aureole have lost potassium and are marginally feldspathised, as at Tregerthen Cliff and Priests Cove (Figs. 39, 59, 68 and 69), and it is suggested that the loss of Fe^{2+} in the meta-igneous rocks of the contact zone can be accounted for by this biotite selvedge. (e.g. Gwavas quarry: Tater-du western contact).

Evidence therefore indicates that late sodium-rich differentiates intruded the pelitic and meta-igneous hornfels in the Newlyn area as inclined dykes. These metasomatised and biotised the adjacent meta-dolerites thereby enriching them in potassium and lithium.

(vii) Variation Diagram of Inclusions.

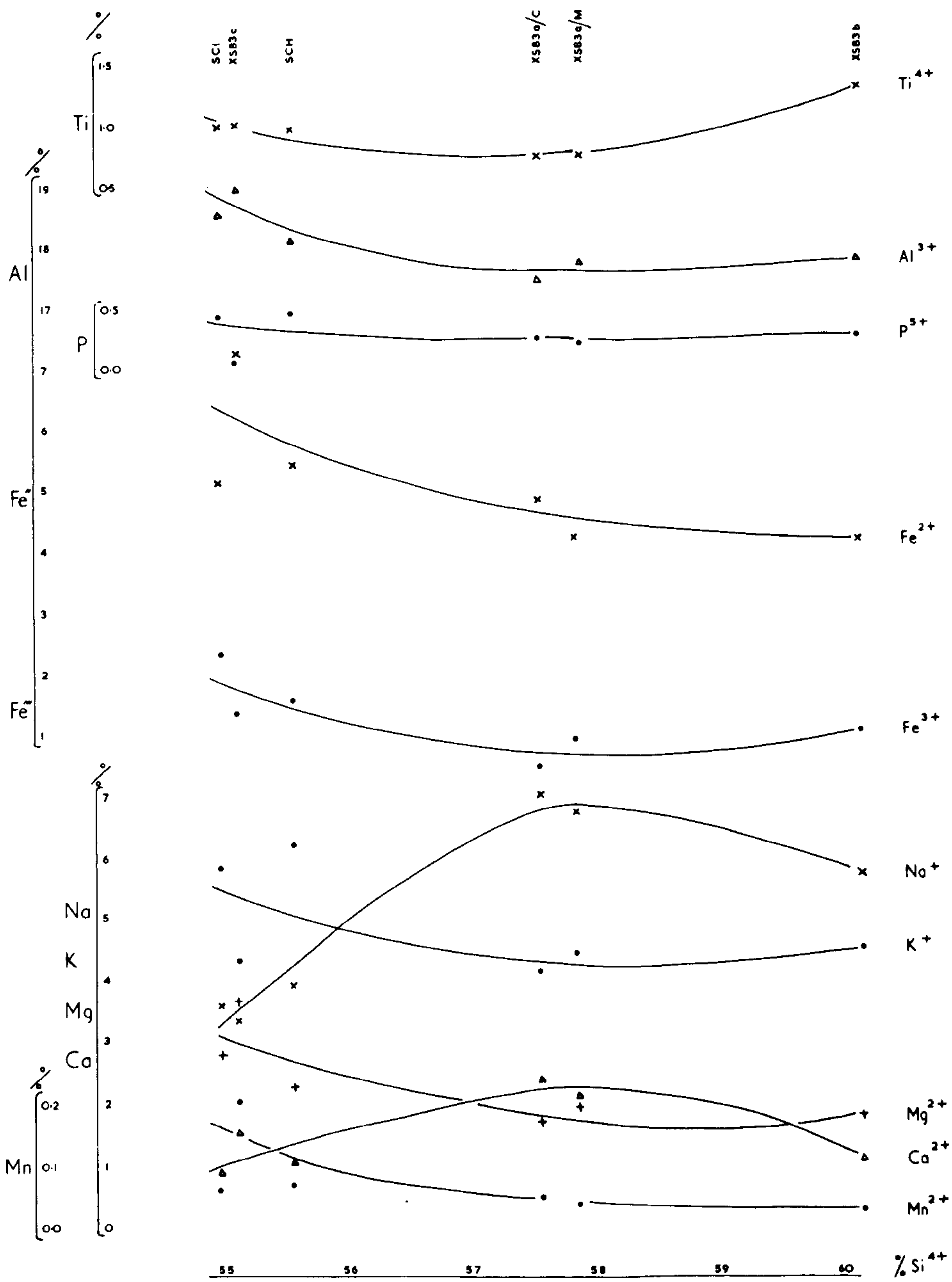
The variation of the cation percentages of analyses of 6 hornfels inclusions are shown in text figure P201 where they are plotted against cation percent silica. Notable points are :-

(i) As Si^{4+} increases Mn^{2+}, Mg^{2+}, Fe^{3+}, Fe^{2+}, P^{5+}, Al^{3+} and K^{+} decrease.

(ii) As Si^{4+} increases Ti^{4+}, Na^{+}, Ca^{2+} increase, but Na^{+} and Ca^{2+} decrease slightly towards maximum Si^{4+} content.

Brammell and Harwood (1932: p.181, fig.5) give a variation diagram for basic inclusions in the Dartmoor granite which is based on weight percentage; the results are similar to those for Land's End which show an enrichment in silica and alkali on granitisation, and a corresponding fall in cafemics. The aluminium

HORNFELS INCLUSIONS



content is low, especially when compared with the high values (e.g. 25.98 per cent) of the contact hornfelses (table P314); this is in accordance with metasomatism and granitisation.

On account of their mineralogical similarities inclusions have been grouped as follows :-

(1) Spotted cordierite hornfels xenoliths.
(2) Xenoliths with irregular margins, showing planar orientation of biotite giving a schistose appearance and rarely containing potash feldspar megacrysts (Fig.38).
(3) Homogeneous, rounded xenoliths containing potash feldspar megacrysts (double enclaves) (Figs. 57, 58, 73 and 76).
(4) As above but lacking potash feldspar megacrysts and occurring as coarse and fine varieties (Figs. 74 and 78).
(5) Schlieren, streaked out xenoliths (Figs.79, 95 and 96), or biotite veins of Brammall and Harwood (1932, p.224).
(6) Contamination patches - dispersed xenoliths now recognised only by andalusite - muscovite, - cordierite, - or biotite-rich areas. (Fig.105).

Transitions between many of these groups occur. Petrographically the inclusions resemble quartz-diorites, granodiorites and melagranodiorites (see Modal analyses tables, Nos. SC1, SC2 and S83X). The normative values for plagioclase range from An5 (SC1) to An33 (XS83c) - albite to andesine. The metasomatic addition of sodium effects albitisation which is reflected in the norm feldspar by the lower anorthite content.

Specimens XS83a/C and XS83a/M (Table P323) represent analyses of the core and margin of an inclusion. The core is rich in sodium while the margin is rich in potassium. This suggests that the initial phase of albitisation was followed by potassium metasomatism when the incoming potassium ions displaced the sodium ions from the margin and concentrated them in the core. There is a reciprocal exchange of calcium and magnesium between the core and margin. The ferrous iron in the margin increases its valency state, while that in the core remains constant, though lower in the inclusion series due to overall granitisation.

The variation agrees very closely with that found by Brammall and Harwood (1932) for the Dartmoor granite. It illustrates the granitisation of hornfels xenoliths and the complementary basification of the adjacent magma.

(viii) Fe.Mg. - K.Na.Ca. Variation Diagram. (Text fig. p.205).

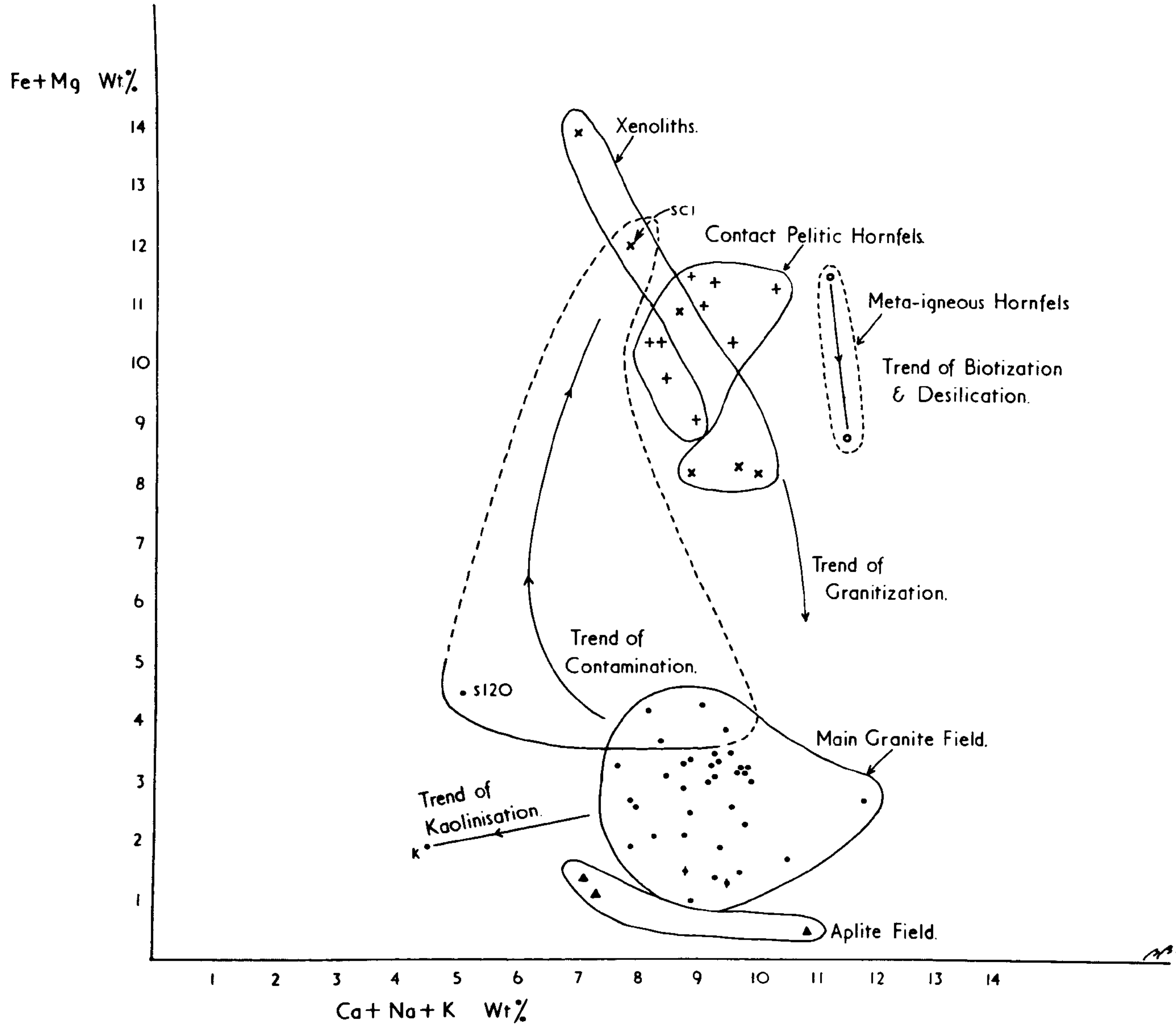
Analyses of various rocks from Land's End are plotted on this diagram and show several delineated fields.

(1) Meta-igneous Hornfels.

These are hornblende-plagioclase aureole hornfels which have been marginally desilicated and biotised by permeating potassium and lithium ions (Text fig.p205). The field shows a sharp fall in Fe+Mg while only a slight increase in Ca+Na+K is indicated. However, Table p327 shows the increase in potassium is partly compensated for by the decrease in calcium and sodium.

(2) Contact Pelitic Hornfels and Xenoliths.

The contact hornfels field is traversed by a linear xenolith field which shows both basification and granitisation trends away from the pelitic hornfels. While Hawkes (1961) describes metamorphic convergence in the aureole between Porthmeor Cove and St. Ives, reference to Tables p315 - 316 shows chemical differences between marginal hornfels - particularly noteworthy is the alkali content - which do not indicate convergence. Therefore if we accept the contact pelitic hornfels as being the representative parent material of the xenoliths then, as Reynolds points out, there is a



Fe+Mg Wt%
Ca+Na+K Wt%
Xenoliths.
SC1
Contact Pelitic Hornfels.
Meta-igneous Hornfels
Trend of Biotization
& Desilication.
Trend of
Granitization.
Trend of
Contamination.
S120
Main Granite Field.
Trend of
Kaolinisation.
K
Aplite Field.

trend towards basification followed by a trend towards granitisation, when the enclaves pass through the series "diorite" - "granodiorite" - "granite". Specimen SC1 represents a melanic granodioritic stage and specimen S120 represents a transition between this and the granitic stage.

On this evidence a tentative field of contamination is proposed in which the reciprocal processes of contamination and granitisation operate.

(3) Granites and Aplites.

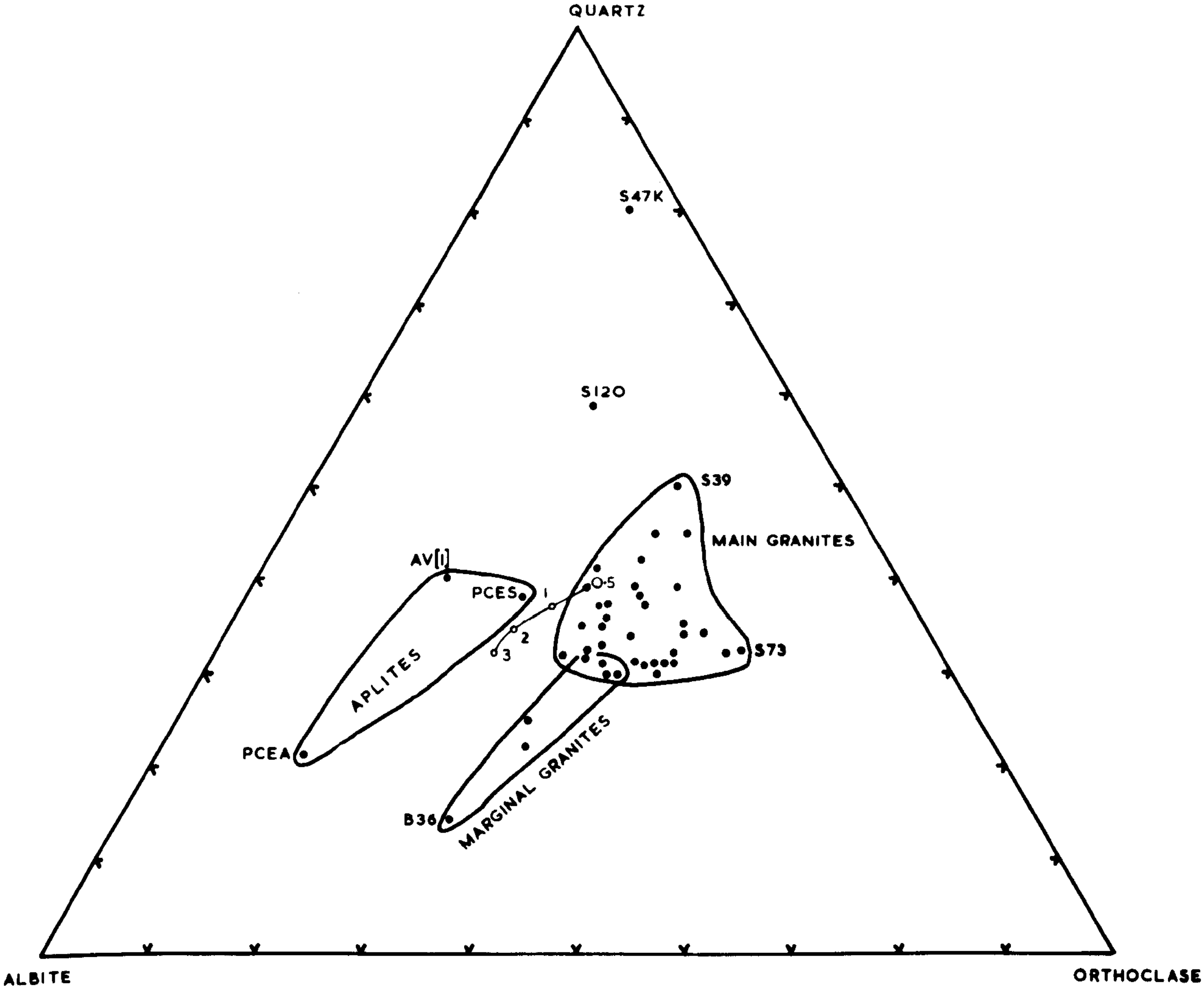
The linear aplite field encloses the end members of the contamination/granitisation trend and although it represents late stage differentiates of the main granite mass, it corresponds closely to the more leucocratic granites. These leucogranites lie at the base of the granite field, which shows progressive contamination towards the hornfels field.

This evidence, which is supplementary to that already presented, illustrates progressive contamination - basification of leucogranite accompanied by reciprocal granitisation of pelitic hornfels inclusions.

(ix) Quartz, Orthoclase, Albite, Normative Variation Diagram.

Normative data from Land's End granites are plotted on Text fig.p208 in relation to the experimental "granite system". Tuttle and Bowen (1958) found under experimental conditions, in the system $NaAlSi_3O_8$ - $KAlSi_3O_8$ - SiO_2 - H_2O, that the composition of the "granite" melt altered, with fall in temperature under given isobaric conditions, towards the boundary between the quartz and feldspar fields, and thence to the ternary minimum when crystallisation became complete. They summarise by stating that "... the compositional variations of the analysed rocks containing 80 per cent or more albite+ orthoclase+ quartz are so closely related to the thermal valley on the liquidus surface $NaAl_3O_8$ - $KAlSi_3O_8$ - SiO_2 that there is no doubt that liquid $\rightleftharpoons$ crystal equilibria are involved in the origin of the bulk of the granites...". Chayes (1952) studied the relationship of modal values to the thermal valley of Bowen (1937), and concluded that the observed distribution is compatible with a magmatic origin for the granites.

The diagram (p. 208) shows a sodium-rich aplite field together with a potassium-rich main granite field and a linear field of marginal granites. The marginal granite B36, and the marginal field, correspond very closely to the shallow trough (Tuttle and Bowen, 1958, p.p. 54-56, 65) extending from the albite-orthoclase sideline (at Or30. Ab70) to the centre of the diagram slightly to the orthoclase side of the experimental


QUARTZ
S47K
S120
S39
MAIN GRANITES
AV[1]
PCES
1
O·5
2
3
S73
APLITES
PCEA
MARGINAL GRANITES
B36
ALBITE
ORTHOCLASE

AP.

ternary points. The main granite field extends from the ternary minimum (500 Kg/cm^2) towards the quartz-orthoclase sideline, but mainly towards the orthoclase apex, thus demonstrating progressive enrichment in potassium away from the ternary minimum. The aplite field, which Exley and Stone (1965) suggest to correspond with a "ternary minimum" of the natural granite system lies to the albite side of the experimental ternary point, and is probably due to the many additional constituents in the natural system modifying, as it were, the less complex experimental system. As the natural ternary minimum will vary areally depending on the fluxes at any given point it is suggested that the term "natural ternary field" be used. Since the aplites represent the final stages in the crystallisation of a granite, and are later differentiates of the "magma", it is to be expected that the final composition of the crystallising magma would alter towards this natural ternary field. In a similar manner, therefore, differential anatexis (Eskola,1933) would produce a "milieu mobilise" corresponding in composition to a natural ternary field (i.e.-aplite).

The aplite field of Exley and Stone (1965) falls between the Land's End aplite and marginal granite fields and therefore corresponds to the "shallow trough" of

Tuttle and Bowen (1958), which is the area towards which feldspar rich liquids compositionally trend on crystallisation. Specimen B36 although a marginal granite, is the medium to coarse grained non-porphyritic granite which is probably intrusive into the main granites (p. 73). Its sodium-rich trend towards an aplitic composition and its high tourmaline content suggests it postdates the main porphyritic granites and represents an intermediate stage between the outer coarse porphyritic envelope and the later aplites and that it represents the potassium deficient core.

The ternary minimum (field) for the natural granite system lies somewhere to the albite side of the experimental ternary minimum, and is there by virtue of the many complex factors entering into a natural system. On differentiation, the composition of the "melt" moves in the direction of this natural ternary field to give, on final crystallisation, rocks of aplitic composition.

Differential anatexis of a postulated low-level parent granite or granodiorite or granite-gneiss would produce a "milieu mobilise" of aplitic composition. Internal potassium metasomatism would modify this aplitic composition towards the main granite field.

E. Discussion and Summary.

(i) Variation. A wide chemical variation exists in the granites of Land's End which cannot be directly attributed to differentiation. The composition of all the granites is very similar within the range of the variation and it is therefore not possible to identify granite types with any degree of certainty on the basis of chemical composition alone. However, the isolated case of B36 is an exception which represents a later, more sodic granite presumably arising by differentiation after the main period of internal potassium metasomatism. Considerable overlap also occurs in modal composition between the coarse and fine granites and similarly it has not been possible to identify one type or the other on the sole basis of its mineralogical composition. Text figure P124 shows Land's End modes plotted on a three point diagram, where they are observed to complete the postulated sequence of Chayes (1951). (See also P. 123).

(ii) Cause of Variation. The cause of variation has been attributed to either differentiation or contamination or both.

(1) Differentiation.

Evidence has been presented (p. 179 and Chayes (1964)) to show that Harker type variation diagrams are not altogether reliable, and although a reciprocal variation may occur in major elements, this is attributed to a decrease of one parameter being accompanied by an increase in another especially when they both contribute substantially towards the total. However, a reciprocal variation between two elements whose sum is nearly constant might be recognised as being important, as in the increase in sodium at the expense of potassium in the late stage silica rich fractions. Fluorine and lithium show an increase in late granite fractions (Exley, 1959, Stone, 1963) and this provides evidence for magmatic differentiation according to Goldschmidt (1954). There is additional evidence to show that the sequence -

Early sodium-rich granite
↓
Potassium-rich granite
↓
Late sodium-rich granite

- as indicated by Brammall and Harwood (1932), and Ghosh (1934) holds good.

(2) Contamination.

The effects of contamination are widespread and are seen in the modes (Tables P339-49) as andalusite and cordierite, and in the field as numerous pelitic xenoliths (Figs. 37, 38, 52, 58, 73, 74, 76, and 78 illustrate their diversity). The granites are classified on a normative basis as peraluminous by virtue of the excess aluminium (corundum). The variation diagrams presented illustrate the contamination-basification series in the granites accompanying the reciprocal granitisation series in the aureole inclusions.

There is thus ample evidence to illustrate the extensive contamination which the granites have undergone during their emplacement.

(3) <u>Starting Material.</u>

Evidence for a sodium-rich leucocratic origin (aplitic composition) is provided by relation to the experimental granite system and the erection of a hypothetical "natural ternary minimum" within the aplite field. Evidence from the margin favours an early relatively sodium-rich leucogranite, while arguing in favour of hypothetical decontamination of the existing granite would reverse the basification trend in the von Wolff diagram, and reverse the contamination trend in the Fe+Mg - Ca+Na+K diagram; de-metasomatising the granite would shift the main granite field on the "experimental granite system" towards the aplite field and natural ternary field.

(4) <u>Source of Starting Material.</u>

Field evidence and chemical evidence both point to a magmatic origin for the granite which is believed to have had its original composition within the natural ternary field. On this assumption it is necessary to postulate differentiation from a larger, more basic body at depth, or differential melting of such a body. Geophysical data set a limit on the depth of the pluton which makes it unlikely to be very basic in aspect; lack of dioritic satellites also lead to the conclusion that the Land's End granite, and the other granites of south-west England - if they are to be considered one whole - represent a contaminated (figs. 35 and 36) and differentiated "milieu mobilise". It is suggested that this mobilised environment was the result of differential anatexis of a low-level parent granite, granodiorite or granite-gneiss. The Haige-Fras granite recently discovered in the southern Irish sea may represent an extension of this parent mass (Smith, Stride and Whittard, 1965).

F. Conclusions.

It is concluded that the Land's End granite represents a remobilised parent rock of granitic, granodioritic or gneissic composition. It was mobilised by differential anatexis and contaminated by assimilation of aureole rocks which indirectly contributed to the extensive internal potassium metasomatism. Recrystallisation of quartz and diapthoresis was brought about by the heat of crystallisation released by the crystallising feldspars. As a result the granite mass is very inhomogeneous with many local concentrations of various elements, which may, as Hoskings suggests (personal communication), reflect the shape of the roof.

Chapter V

The Granites (Trend Surface Analysis)

A. Introduction

(i) The problem of sampling granites

Mapping variations in the south-western granites of Cornwall and Devon has always been a problem as the rock is often poorly exposed and contacts between the "types" described are difficult, if not impossible, to trace. In addition, chemical analysis of the "type" specimens does not necessarily serve to distinguish these from other variants. For these reasons the "type" granites as rigorously laid down by Brammall and Harwood (1932) and Ghosh (1934) are not regarded as entirely satisfactory, for in the past it has been customary to select granites from chosen localities as "types" representative of the rock in that particular area, and quite often the "type" specimen is only an approximation and does not even correlate with the mean value for the bulk composition. The "type" granite for a particular area, selected from a single locality as a single hand specimen is not representative of that area - unless the unlikely case of absolute homogeneity is attained, indeed it is not necessarily representative of that particular locality; it is only representative of that particular specimen. No matter how carefully the sample is prepared to avoid, say, contamination, or how accurately the analysis is carried out, the analyst's effort will have been wasted unless the same care is exercised in the method of sampling and collection of material in the field, as is shown in the laboratory.

For these reasons a statistical approach to the problem is to be preferred (see P. 44 & P. 114).

(ii) Selection of samples.

Rock samples are collected either objectively or subjectively. The normal procedure is to collect subjectively with a particular end in view, such as illustration of the mineralogy of a particular variety. Many factors enter into subjective choice, such as the access of an exposure, the height of the exposure, or the ease with which a particular sample can be removed.

Objective collection is based upon the selection of material at a particular position on the map prior to seeing the area; under ideal conditions this means that personal choice in the field is not very important, and material is collected irrespective of its quality. However, as it is only the granite that is being sampled only granite will be collected and should a sample point fall upon elvan or vein material, then this material is just ignored insofar as the sampling programme is concerned.

The prime object of the study is to make generalisations about the target population (granite), but exposure precludes the possibility of sampling this population, except in limited areas. The population actually sampled is referred to as the sampled population, and inferences are then made about this population which it may be applicable to extend to the target population. Krumbein (1960) discusses population sampling and describes the following scheme :-

Target Population

↓

(All individuals not directly available)

↓

Sampled Population

↓

(Choose sampling plan and select samples by an operation procedure)

↓

(Compute sample statistics)

↓

(Draw statistical inferences and make estimates about the sampled population)

↓

(Apply these to the - Target Population - on the basis of subject-matter reasoning).

In order to test the homogeneity of the Land's End granite at each sample site it was necessary to collect three or four large hand specimens for modal analysis.

Quartz, being a major component of the granite and affected by recrystallisation, was recognised as a suitable mineral on which to test the degree of within- and between-site variability.

Analysis of Variance is essentially a procedure for testing the differences between different groups of data for homogeneity, and for a single dependant variable an analysis may be carried out to show estimates of the variance between and within classes (sites) whether the class numbers are equal or not. Homogeneity is then tested by comparing the estimates.

During point counting the total number of points was often split into several sub-totals depending on the number of slides analysed. Samples of specimens (quartz) were chosen which contained two items, each of which had a total number of points in excess of 2000; it was argued that if the variance estimate for between samples was greater than the variance estimate for within samples, then a safety factor of (X2) (i.e. 4000 points) would provide suitable reliable results for areal sampling (i.e. between-site sampling) upon which statistically-drawn inferences could be based.

B. Analysis of Variance - Quartz

Source of Variation	Sum of Squares	Degrees of Freedom	Variance Estimate
Between samples	291.5	9	32.3
Within samples	16.0	10	1.6
Total	307.5	19	

$F = 20.1$

F is a ratio of the variance estimates and from statistical tables it is found that -

at the 5% level $(F_{.95}) = 3.02$

at the 1% level $(F_{.99}) = 4.94$

The analysis of variance shows an F value of 20.1 for quartz, which is greater than 4.94 and 3.02, the critical values of F for (9,10) degrees of freedom at the 1% and 5% confidence levels respectively. The data therefore support the fact that at the 1% and 5% confidence levels there is a 99% and 95% probability of a specific between site variability.

C. Systematic Sampling.

In the simplest case a grid of N equally spaced intersections is positioned over the area by a procedure, and specimens collected from grid intersections. This is known as orthogonal sampling and is considered the best method if rock exposure permits its use. Initially this method was chosen for sampling the Land's End granite with the grid intersections places 1500 yds. apart, the origin of the grid lying some three miles south-west of Land's End point. It soon became apparent during early field work that this method could not be used due to poor or total lack of exposure, and a non-orthogonal sampling method was finally employed. At this point subjectivity became a real problem for sites were now being selected where relatively fresh granite could be obtained, either from the numerous quarries which supplied many specimens or from evenly scattered exposures of tors, cliffs, wells, and pits excavated by the use of explosives. Large micro-sections were cut at random from all specimens and analysed quantitatively by point counting as outlined in Research Techniques (p.264). The mineralogical variation is discussed in Section III E of this thesis (p.p.114 - 139).

D. Mapping problems in granites.

Due to poor exposure and possible gradational contacts between texturally-differing granites within the same mass, it is not always possible to present a useful map of granite plutons which displays compositional variability and which illustrates whether this variability is a regional one or is due to local effects. For this reason a statistical approach is used in which large volumes of data are collected and processed on high speed electronic computers.

E. Review of Trend Surface literature.

During the past decade (1955-1965) the study of geographic variation of variables within geologic units has been gaining popularity. Miller (1956) discusses the application of trend surfaces to the analysis of sedimentary environments and points out "...that a continuous pattern which avoids "unrealistic definite" boundaries can be established for each measurable property of an environment of sedimentation...". In other words the application of "trend surfaces" makes it possible to represent areally delicate gradations in a parameter between geologic units with gradational or obscured contacts. There is thus continuity in the map to represent continuous merging. Moreover the method is objective in that the subjective technique of using discrete boundaries to represent continuous merging is dispensed with, it avoids direct contouring of the raw data and hence enables both the more widespread regional pattern to be produced, and the local deviations from this regional pattern which together make up the original data. These local deviations tend to obscure the regional distribution of a parameter, and to obtain a diagnostic pattern for the region these local irregularities must be removed. Miller used the method of Ezekial (1930) to arrive at his surface; this is based on partitioning the curves, which are calculated by graphic approximation, into sections requiring only second degree polynomials.

Krumbein (1959) processed non-orthogonal data on an I.B.M. 650 high speed computer, and recognised the value of deviations and components for examining special problems. He discussed the fitting of polynomials to successively higher degrees (linear, quadratic, cubic) in order to account for as much of the data as possible (i.e. - to minimise the sum of squares of the residuals). The trend surface is expressed as :-

$$t = f\ (U.V) = A_{00} + A_{10}U + A_{01}V + A_{20}U^2 + A_{11}UV + \text{----} + A_{pq}U^pV^q$$

where Apq = non-orthogonal polynomial coefficients.

U and V = geographic coordinates

and $t_{ij} = E_{ij} = X_{ij}$

Where t = computed value of chosen parameter.

E = residual value not accounted for by the polynomial.

X = observed data.

All measurements are taken at the $i.j^{-th}$ point

If the values of the dependant variable are selected from a grid then the value of (t) at (U.V) is Y and

$$Y = a_{00} + a_{10}\xi_{1u'} + a_{01}\xi_{1v'} + a_{20}\xi_{2u'} + a_{11}\xi_{1u'}\xi_{1v'} + \text{---}$$
$$\text{---} + a_{pq}\xi_{pu'}\xi_{qv'}$$

where a = orthogonal polynomial coefficients.

$\xi_{ru'}$ = " " of degree r in u direction.
$\xi_{sv'}$ = " " " " s " v "

a is derived as follows :-

$$a_{rs} = \left[\sum X_{i.j}\,\xi_{r.u'}\,\xi_{s.v'}\right].\left[\sum \xi_{r.u'}^{2} . \sum \xi_{s.v'}^{2}\right]^{-1}$$

The reduction in the total sum of squares accounted for by $a_{r.s}$ is given by Z_{rs}^{2} where :-

$$Z_{r.s}^{2} = g_{r.s}^{2}\left[\sum \xi_{r.u'}^{2} . \sum \xi_{s.v'}^{2}\right]^{-1}$$

and $g_{r.s} = \sum X_{i.j.}\,\xi_{r.u'}\,\xi_{s.v'}$.

The values of $\sum \xi'^{2}$ are given by De Lury (1950) who also discusses Z^2.

The Z^2 array, in which linear, cubic and higher degree terms are set out in U and V directions, enables computed coefficients to be chosen so as to arrive at the optimum trend. This trend may contain all of the first and second degree terms and only one of the third degree terms (terms can be accepted or rejected at will), but will be the best fit without including unnecessary higher degree terms.

The theory of non-orthogonal polynomial analysis in terms of linear coefficients is reviewed by Krumbein (1959, p.827) who refers to Anderson and Bancroft (1952) for the development of the matrix algebra.

Whitten has discussed composition trends and aerial variation in several granite masses in several succeeding papers. In 1959a he analysed the Donegal granite and obtained excellent trend surfaces for colour index, quartz, and total feldspar, but only when the latter two were derived from averaged data. He suggested that local deviations reflected ghost stratigraphy and concluded that deviation maps could illuminate the nature and petrogenesis of granite plutons. In 1961 (a) he discussed sample theory and indicated that the use of one specimen per square mile would give spurious results. Colour index again gave better results than total feldspar, and (1961b) he suggested that deviation studies would indicate such phenomena as assimilation of xenolithic material by magma. Also in 1961(c), Whitten computed trend surface maps for the Beinn an Dubhaich granite and confirmed King's (1960) hypothesis that the granite sheet is folded, by demonstrating a southwesterly grain and a more mafic and feldspathic base which varies inversely with quartz on ascending through the sheet. In 1962d he concluded that trend components suggested that the Lacorne granite is a composite body and he made a plea for the collection of areally distributed quantitative data of all types.

Allen and Krumbein (1962) presented a "case history" for secondary trend components, and suggested that it was possible to account for interlocking source areas feeding a sedimentary area of deposition. They pointed out that had these techniques been available earlier their work might have been advanced by ten or twenty years, at less cost and effort. The economic uses of trend surface analyses were recognised by Whitten (1961b), who calculated the average composition of a granite pluton by dividing the volume between the trend surface and the U.V plane by the area of the pluton's outcrop on the U.V plane. The volume was calculated by double integration when U and V coordinates were employed, and triple integration when topographic height (W) was added to the coordinates.

Wadsworth (1963) computed trend surfaces for coarseness index in the Twelvefoot Falls pluton and suggested, on the basis of a practically non-existent linear trend, that the earlier metasomatic theory for origin of this pluton should be abandoned.

Additional papers by Saha (1963), Duff and Walton

(1964), and Whitten, (1963 (in Shaw, 1963) were published illustrating both the method and the usefulness of the trend surface mapping technique. Koch et al (1964) employed this method to analyse assay data from ore deposits in Vida uranium mine. They found that statistical analysis of samples enabled predictions to be made about the direction of best mineralisation beyond the sample area, and the most favourable direction in which to extend the mine.

During 1963 trend surface analysis came under criticism (Chayes and Suzuki, 1963), who referred to Whitten's recent work (1962).

Many of their arguments and criticisms of Whitten's approach are valid, especially in connection with the percentage of the data accounted for by the regional trend, and they suggest that "...geologists will not take seriously a contour map which leaves more than a small fraction of the observed variation in the "unexplained" or "residual" category", and that "...variability of modal and chemical variates closely approximated by surfaces computed by mathematical analysis are wildly unrealistic".

Trend surface analysis or polynomial surface regression is not simply an end in itself, but rather a useful statistical method, which enables the research worker dealing with large volumes of data to illustrate the areal variability of his data. Firstly the data can be fitted to the mathematical surface which may or may not account for a large percentage of it. Secondly, to give a complete picture the "residual" pattern or "deviations" can also be presented (e.g.:- Allen and Krumbein, 1962), as these are capable of interpretation. It has been found during work at Land's End (Booth, 1964) that the residual patterns obtained correspond very closely to known areas of different granite types. Even so, the regional patterns obtained from this area account for over 90 per cent of the sum of squares using a modified equation in which topographic height is taken into consideration.

A severe criticism of Whitten's work is based on his statement that "It is appropriate to extend a surface across limited unexposed areas where the confidence level associated with the surface is high"; in this case he draws contours, as pointed out by Chayes and Suzuki (1963), not only across open sea and across younger granite complexes but through surrounding sediments. This is considered to be taking extrapolation too far, and while it is appropriate to extend the isopleths across poorly-exposed granite where computed values can be checked against diamond drill core samples, the extension of the surface haphazardly over everything which gets in the way is an abuse of a technique which deserves better and more thoughtful use.

Whitten has illustrated in his own way the usefulness of trend surface analysis, but his method of application has been justly criticised by Chayes and Suzuki. In using this technique the original objective must always be borne in mind. The problem must be approached realising what information is required, and as pointed out by Exley (1963), the data must be presented so as to emphasise whatever point the author is trying to make. Trend surface analysis is a technique to aid the geologist and not an end in itself. It should not be condemned out of hand because it has perhaps been misused, or because poor presentation has "sloughed aside" geological experience and commonsense.

F. Trend Surface Mapping.

As discussed above, modes can be conveniently represented on a map by a Trend Surface, which is a surface depicting the mineralogical values at sample sites (or other positions determined by the coordinates) from which local fluctuations or "noise" have been removed. It can therefore be considered as a smoothed "Response Surface", which before smoothing is governed by the composition and geometry of the rock body and may consist of both regional and local effects.

(i) Regional Effects.

These correspond to the trend map of Miller (1956), and refer to the underlying smoothed surface from which local fluctuations, perturbations or noise has been removed.

(ii) Local Effects.

These correspond to the "residuals" of Krumbein and the "error terms" of Miller, and in both cases are the difference between the original contoured surface and the fitted or computed surface at data points. These residual data can also be mapped (Allen and Krumbein, 1962) and may be open to interpretation as with regional trend maps.

Non-orthogonal geographic coordinates (independant variables) fix the sample site at which ordinates may be erected, their height represents the value of the dependant variable. The various equations used are Linear, Quadratic, and Cubic. (These are often referred to as first, second and third degree equations. The degree in this context refers to the power to which the independant variables are raised).

(iii) Linear Surface.

This will establish a gradient (inclined plane surface) in a particular direction indicating an increase, or decrease in a particular parameter. The linear equation is :-

$$X_n = a_o + a_1 U + a_2 V + R_a$$

where X_n = observed value of dependant variable at UV. (e.g. mineral constituent).

a_o = constant (height of surface at origin of U.V).

a_1 & a_2 = regression coefficients of U & V

R_a = residual or deviation from the linear surface,

and contains components higher than the first degree plus local fluctuations.

(Components higher than linear can only be accounted for by using higher degree polynomials).

(iv) Quadratic Surface.

This is a second degree surface tilted along the slope of the first degree (linear) surface. It contains first degree terms which are computed together with the second degree terms, but the low order regression coefficients change on introducing the higher degree terms. The quadratic equation is :-

$$X_n = b_o + b_1 U + b_2 V + b_3 U^2 + b_4 UV + b_5 V^2 + R_b$$

b_o = constant

b_1, b_2 etc. = regression coefficients

R_b = residual, and contains trend components higher than the quadratic plus local fluctuations.

(v) Cubic Surface.

This is a third degree surface and usually accounts for most of the trend components. i.e. it accounts for a large proportion of the total sum of squares. The cubic equation is :-

$$X_n = c_o + c_1 U + c_2 V + c_3 U^2 + c_4 UV + c_5 V^2 + c_6 U^3 + c_7 U^2V + c_8 UV^2 + c_9 V^3 + R_c.$$

c_o = constant

c_1, c_2 etc. = regression coefficients.

R_c = residual.

(vi) The Sum of Squares.

The sum of squares of deviations is a measure of the dispersion of the dependant variables about the mean ($\bar{X}$) of the (X) values for a given sample, and it can be used as a measure of goodness of fit for the trend surface.

Let $\bar{X}_{n_{obs.}}$ equal the mean value of the observed values $X_{n_{obs.}}$

The deviation from the mean at the ij-th point is

$$(X_{n_{ij_{obs.}}} - \bar{X}_{n_{obs.}}).$$

Total sum of squares = $SS_{x_t} = \sum_{1}^{N} (X_{n_{obs.}} - \bar{X}_{n_{obs.}})^2$

For N control points.

The sum of squares of the computed values $X_{n_{comp}}$ is obtained in a similar way.

$$\text{as } \bar{X}_{n_{obs}} = \bar{X}_{n_{comp}}$$

Sum of squares of computed values =

$$SS_{X_c} = \sum_{1}^{N} (X_{n_{comp.}} - \bar{X}_{n_{obs.}})^2$$

The sum of squares of the deviations is equal to :-

$$SS_{X_d} = \sum_{1}^{N} (X_{n_{obs.}} - X_{n_{comp}})^2 = \sum_{1}^{N} X^2{}_d$$

The amount of the total variance accounted for by the Trend Component is thus expressed as a percentage :-

$$\left[\sum_{1}^{N} (X_{n_{comp}} - \bar{X}_{n_{obs}})^2\right] . \left[\sum_{1}^{N} (X_{n_{obs}} - \bar{X}_{n_{obs.}})^2\right]^{-1} .100$$

$$= SS_{X_c} \;.\; SS_{X_t}^{-1} \;.\; 10^2\%$$

G. The P.N.S.R. Programme.

A stepwise polynomial surface regression programme (Burnaby,1963) has been written for the I.B.M. 1620, 20K store, solid-state digital computer. The programme is partly based on "Stepwise Multiple Linear Regression" - Tape (Bukaeck and Galle. I.B.M. File No.6.0.006). The programme is designed to run in five distinct phases, phases I, IV and V being written into a single programme and form alternative pathways.

Unlike preceeding trend surface programmes, this method includes the additional independant variable - height - which is represented by (W), and three dimensional mathematical surfaces can be erected upon a plane surface of any specified height.

The programme computes -

$X_j = (U - C_1)^m \; (V - C_2)^n \; (W - C_3)^r$ in phase I

Phase II accepts the output from phase I and computes the correlation matrix of (X_j), obtained in phase I, in i and j. Phase III inverts the matrix and computes multiple regression equations of the form -

$$Y = \sum (C_i X_j)$$

Regression coefficients (C_i) printed out by phase III are accepted by phase IV which computes "predicted" values of (Y) for each data point (U,V,W) and prints out these values together with the deviations between the observed and predicted values. Phase V accepts sets of (C_i) coefficients and computes predicted (Y) values corresponding to a fixed value for (W), on a 10 by 10 grid of (U) and (V), the origin and interpoint spacing of which is predetermined by the values of (CX1, CX2, and SCALX) chosen by the operator. There is no restriction on the number of grid points for it is possible to build up a grid of N.100 points by repeating the run (N) times with suitably chosen values of (CX1) and (CX2).

H Trend Surface Analysis of Land's End Granite.

Third degree component analysis of single granite plutons would be expected to show a sequence of concentric shells in their composition, and older masses cut by later intrusions would have this sequence broken. Whitten (1963) discusses the problem of multiple intrusions and notes a lack of concentricity in regional trends, then proves his case by partitioning the area and regressing each of these. He then finds concentricity which he argues indicates that more than one intrusion has occurred.

Mineralogical data (modes) for Land's End granite together with the topographic height and geographic coordinates have been processed on an I.B.M. high speed digital computer. Phase II output gave the correlation matrix of Xj in i and j (P. 235).

The more important correlations are between :-

Coarseness Index and Colour Index	- 0.1176
Coarseness Index and Clay	- 0.1548
Coarseness Index and Biotite	- 0.1295
Colour Index and 2ry Mica	+ 0.2199
Colour Index and Tourmaline	+ 0.3658
Colour Index and Biotite	+ 0.8394
Colour Index and Quartz	- 0.3799
Total Feldspar and 2ry Mica	- 0.1071

Total Feldspar and Clay	+ 0.2029
Total Feldspar and Muscovite	- 0.4998
Total Feldspar and Quartz	- 0.8713
2ry Mica and K/Na Feldspar	+ 0.1366
2ry Mica and Tourmaline	+ 0.1632
2ry Mica and Muscovite	+ 0.1313
2ry Mica and Biotite	+ 0.1355
2ry Mica and Clay	- 0.2578
K/Na Feldspar and Clay	- 0.4576
K/Na Feldspar and Quartz	- 0.2087
Clay and Tourmaline	- 0.1579
Clay and Muscovite	- 0.1570
Clay and Quartz	- 0.1435
Tourmaline and Muscovite	- 0.2779
Tourmaline and Biotite	- 0.1574
Tourmaline and Quartz	- 0.1096
Muscovite and Quartz	+ 0.2320
Biotite and Quartz	- 0.2885

(A plus sign indicates a positive relationship between two minerals, and a minus sign indicates an inverse relationship).

The correlation matrix confirms many petrographic observations on replacement phenomena, and indicates where other such relationships occur.

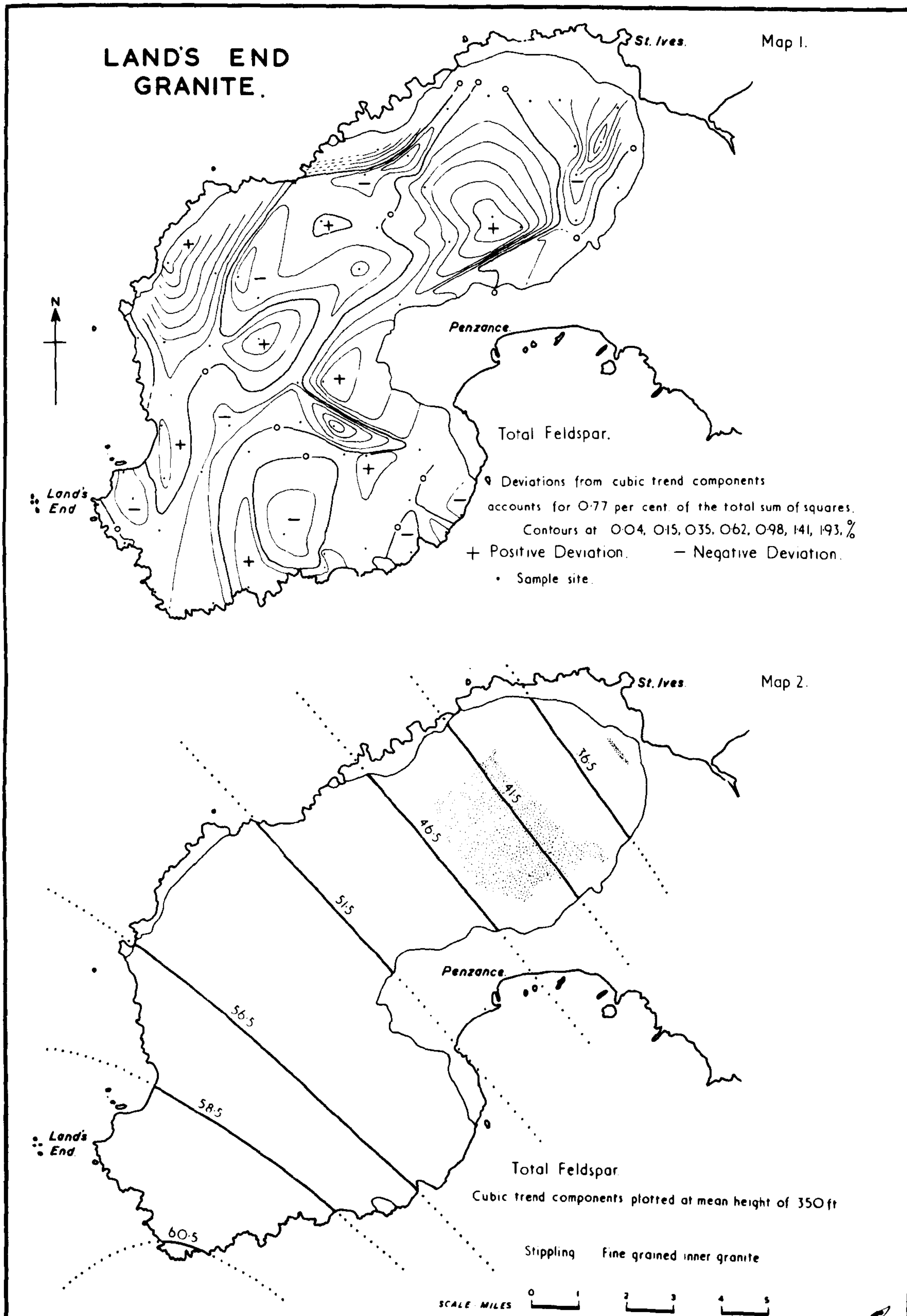
The regional trend surface for colour index at the mean height of 350 feet (Text figure P243) shows an increase in value from south-east to north-west, the isopleths in the north-west running parallel to the coastline. The regional pattern for colour index at zero feet (Text figure P243) is similar to that at 350 feet but towards the north the isopleths run from east to west and are of a lower value. Biotite contributes considerably towards the colour index and it is thought these high values along the north-west and south-west coast are a reflection on the degree of contamination the granite has suffered. If the granite arose in the south in a similar manner to the Dartmoor mass and flowed towards the north, then it might be expected that the upper part of this "cusp" would become more contaminated than the lower part, especially if it was stoping and assimilating as it was being emplaced. The southern part of the "cusp" would therefore be expected to be less contaminated, although lack of exposure in the south-eastern area would probably influence these results to some degree. It is tentatively suggested on this evidence that the granite was emplaced towards the north and that the advancing tongue of granite became more contaminated than the rest.

The regional trend surface for total feldspar at a mean height of 350 feet (Text figure P244) shows an increase in value from north-east to south-west. It bears no relationship to the granite margin but correlates quite well with the degree of porphyricity of the rock. This suggests that the south-western part of Land's End is more heavily metasomatised than the rest, and if the theory for an outer coarsely porphyritic envelope is entertained, then the inner part of this envelope is exposed to the north-east where the central, less metasomatised, granite occurs. If the mobility of this inner granite was increased by differentiation, rise in temperature and accumulations of fluxes beneath the outer coarse envelope, then conditions may have become favourable for this fine granite to stope away parts of the overlying coarse granite.

Text figure P244 illustrates the regional trend surface at 350 feet in colour index for the south-western area of Land's End. There is an increase from the centre towards the margins which is largely obscured in the trend surface for the whole area. This is thought to be due to the more extensive contamination effects along the north-west coast, and a possible domed roof in the southwest. As discussed earlier (P. 210), the inner granite would tend to be less contaminated than the outer envelope, and the low values in the south-western part of Land's End suggests that this has occurred.

Deviations from the arithmetic mean of the observed quartz values show patterns which correlate to some extent with those obtained by computation (Text figure P245).
Low values are associated with the area in which the fine grained Castle-an-dinas granite occurs and along the western and south-eastern coasts.

Text figure P245 illustrates negative bouger anomalies (Bott, Day and Masson-Smith, 1958) in the Land's End area. The low values in the north-east have been attributed to the presence of the fine grained Castle-an-dinas granite. It is also probable that the low values in the west may be due to a similar cause, namely a mass of rock physically like that at Castle-an-dinas but still covered by a veneer of coarse porphyritic granite.



LAND'S END GRANITE.
Map 1.
St. Ives.
Penzance.
Land's End
N
Total Feldspar.
Deviations from cubic trend components accounts for 0·77 per cent. of the total sum of squares.
Contours at 0·04, 0·15, 0·35, 0·62, 0·98, 1·41, 1·93, %
+ Positive Deviation.
− Negative Deviation.
• Sample site.
Map 2.
St. Ives.
Penzance.
Land's End
36·5
41·5
46·5
51·5
56·5
58·5
60·5
Total Feldspar
Cubic trend components plotted at mean height of 350 ft
Stippling Fine grained inner granite
SCALE MILES
0 1 2 3 4 5

243 a

Text Figures P243

P.N.S.R. Run Series 2 10164

Phase III. Land's End Modal Data Anal.

Dep. Variable 1. (Colour Index) Arc Sin $\sqrt{}$ Transformation

	Regr. Coeff.		Var
1	- 0.00043025	u	0.00002174
3	0.00000357	uv	0.00000073
4	0.00000421	u^2	0.00000027
6	- 0.00000005	u^2v	0.00000000
9	0.00000010	v^3	0.00000000
10	0.00004080	h	0.00000285

Regr. Const. 0.25489892

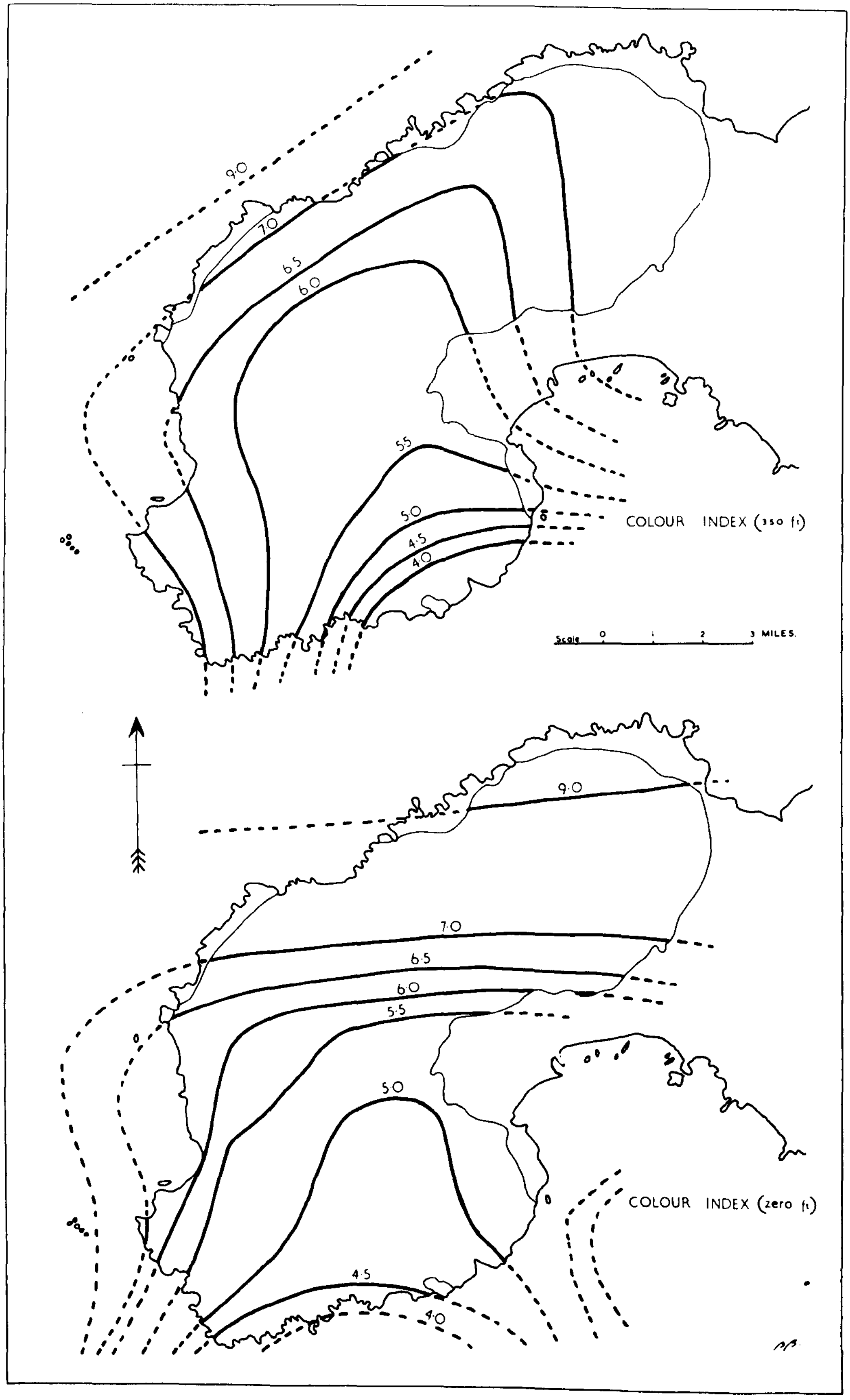
For the above regression coefficients and variances the square of the coefficient of multiple correlation R**2 = 0.054683

$\therefore$ R $\doteq$ 0.23

Increasing R to 0.284 decreases the number of terms to u and u^2 with 4 per cent variance estimates.

FIXH = 350.000 for upper map

FIXH = 000.000 for lower map


9·0
7·0
6·5
6·0
5·5
5·0
4·5
4·0
COLOUR INDEX (350 ft)
Scale 0 1 2 3 MILES.
9·0
7·0
6·5
6·0
5·5
5·0
4·5
4·0
COLOUR INDEX (zero ft)

Text Figure P244

P.N.S.R. Run Series 2. 10164

Phase III. Land's End Modal Data Anal.

Dep. Variable 2. (Total Feldspar) Arc Sin $\sqrt{}$ Transformation

	Regr. Coeff.		Var.
1	- 0.00047371	u	0.00002752
2	- 0.00025648	v	0.00001315
4	- 0.00000445	u^2	0.00000023
13	- 0.00000034	h^2	0.00000001
14	0.00000004	u^2h	0.00000000

Regr. Const. 0.8695835

For the above regression coefficients and variances the square of the coefficient of multiple correlation R**2 = 0.153244

$\therefore R \doteq 0.39$

FIXH = 000.000

244 b

Text Figure P244

P.N.S.R. Run Series 3. 3464

Phase III. Land's End S-W Part Only

Dep. Variable 2. (Colour Index) Arc Sin √ Transformation

	Regr. Coeff.	Var (St. Error)
1	- 0.194180 E - 02	0.184905 E - 01
2	- 0.287635 E - 03	0.162170 E - 01
3	0.300056 E - 04	0.261980 E - 02
4	- 0.119171 E - 04	0.190416 E - 02
5	- 0.298582 E - 04	0.227197 E - 02
6	0.406917 E - 06	0.561623 E - 03
7	0.826044 E - 07	0.706328 E - 03
8	0.108276 E - 05	0.939617 E - 03
9	0.330329 E - 06	0.533013 E - 03
10	- 0.101239 E - 07	0.711779 E - 04
11	- 0.128795 E - 07	0.786120 E - 04
12	0.165660 E - 09	0.780853 E - 04
13	- 0.758643 E - 08	0.796149 E - 04
14	0.952899 E - 08	0.331556 E - 04
15	0.590820 E - 04	0.329787 E - 02

Regr. Const. 0.297157 E - 00

For the above regression coefficients and variances the square of the coefficient of multiple correlation R**2 = 0.04015840

$\therefore R \simeq 0.20$

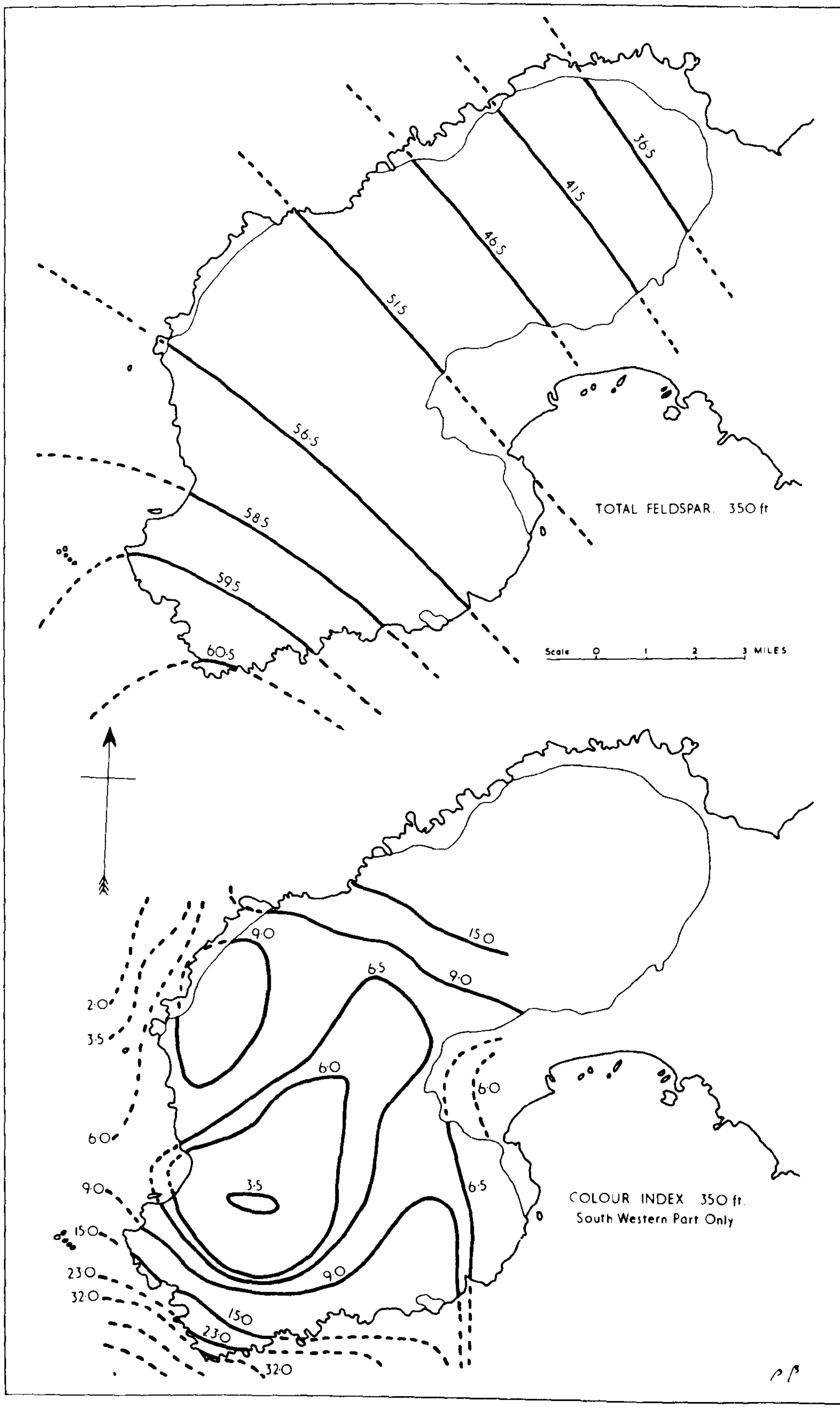
FIXH = 350.000

Note: In run series 3, Floating-Point arithmetic was used in order to retain as many significant digits as possible during calculations.

e.g. - 0.194180 E - 02

where - 0.194180 is the mantissa and E - 02 is the exponent.

- 0.194180 E - 02
= - 0.00194180



TOTAL FELDSPAR 350 ft
36·5
41·5
46·5
51·5
56·5
58·5
59·5
60·5
Scale 0 1 2 3 MILES
COLOUR INDEX 350 ft.
South Western Part Only
15·0
9·0
6·5
6·0
3·5
2·0
23·0
32·0

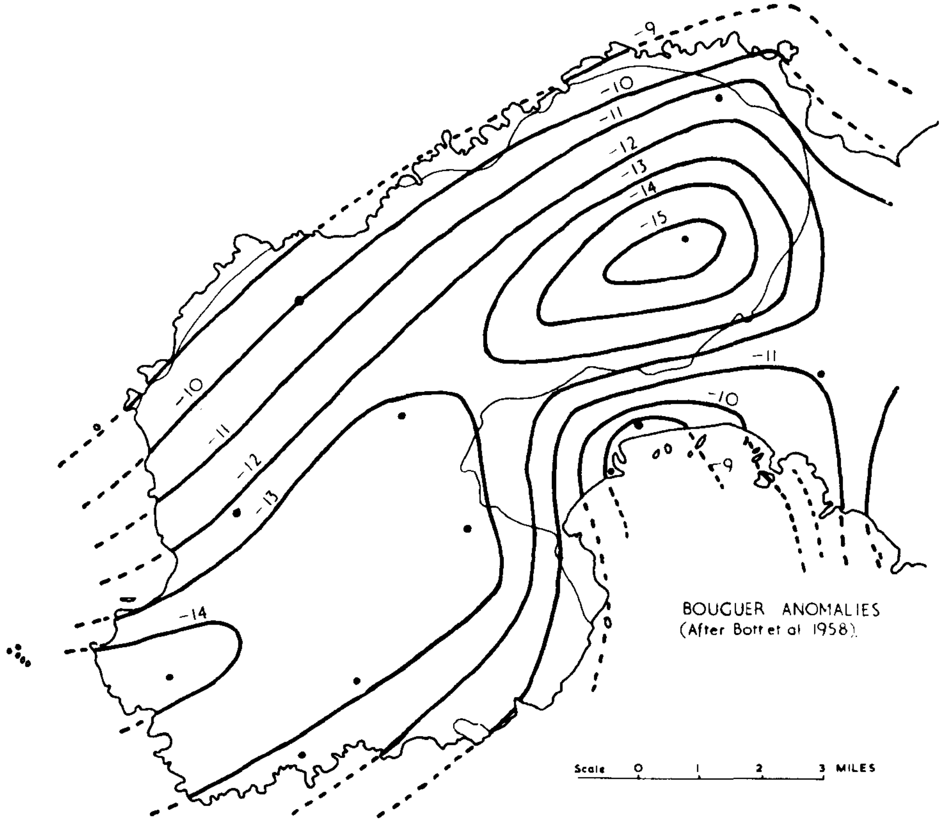
Text Figure P245 (upper)

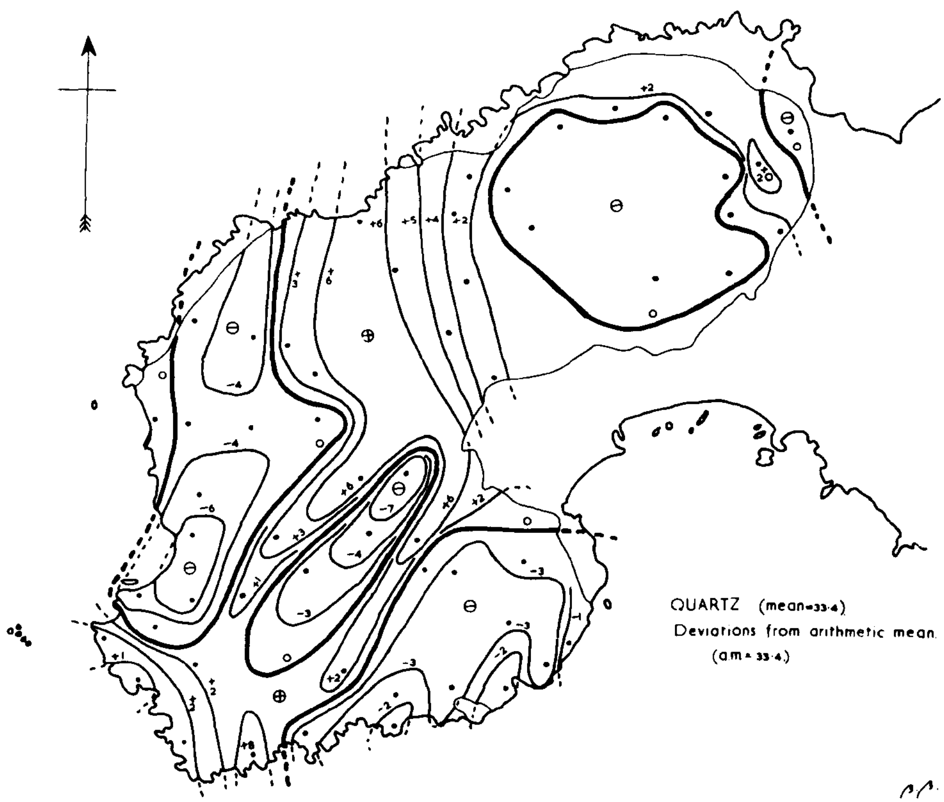
(After Bott, Day and Masson-Smith 1958)

Bouguer anomaly map of Land's End district illustrating the concentration of negative values (-15) over the fine grained Castle-an-dinas granite. Note also the negative value (-14) over the south-western part which correlates very well with text fig. P244b where a more leucocratic granite occurs. It is thought that both these high negative values may be due to the existence of a relatively leucocratic microgranite beneath the coarse porphyritic envelope. (see p. 241).

Text Figure P245 (lower)

Deviations from the arithmetic mean of modal quartz. Note how the negative values in the north-east correlate with the areal distribution of the Castle-an-dinas granite and how the south-western area is made up of alternating ridges and troughs of positive and negative values.


-9
-10
-11
-12
-13
-14
-15
BOUGUER ANOMALIES
(After Bott et al 1958)
Scale 0 1 2 3 MILES


QUARTZ (mean=33·4)
Deviations from arithmetic mean.
(am=33·4)

Chapter VI

Granite - Hornfels Contacts

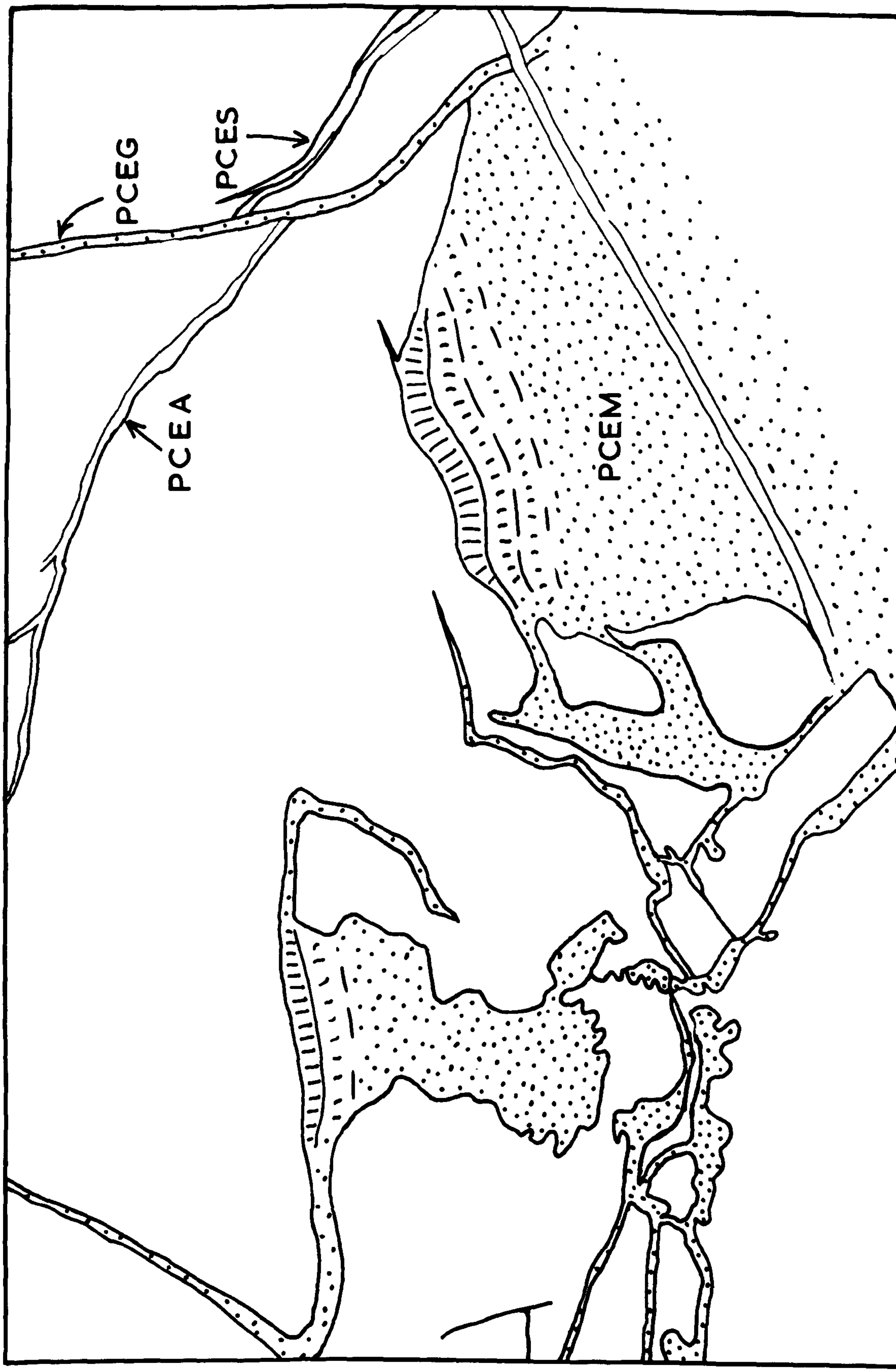
Granite/Hornfels Contacts.

The magmatic nature of the granite at the time of emplacement is clearly shown by the granite/hornfels contacts, where all stages of stoping and veining of the pelitic hornfels are exhibited. It is at these contacts that aplitic and pegmatitic differentiates occur.

A. Zennor Cliff-Wicca Pool contact. (Map.6,Land's End granites).

Granite first makes its appearance in adits leading into the hillside at Porthzennor Cove, where it underlies the interbedded dolerites and pelitic hornfels. Below Tremeader Cliff the coarse granite appears on the foreshore as two tongue-shaped apophyses; below the old pumping station a few yards to the east of the gully, huge xenoliths of pelitic hornfels are caught up in the granite which exhibits quartz segregation-banding rather like those of the "complex-zone" in South Crofty tin mine. The most northerly extension of Gala Rocks appears to be granite but is impossible to approach closely. Below Tregerthen Cliff the granite apophysis runs parallel to the shore for several hundred feet and gives off numerous quartz veins, some of those previously attributed to the granite being probably segregation bands from the hornfels. The apophysis is observed to become finer in grain towards its extremity and where it is overlain by a hornfels roof complexly banded aplite/pegmatites occur which are similar to those at Porthmeor; these are succeeded by distorted tourmaline-feldspar pegmatites set in the fine grained leucocratic groundmass. The aplogranite passes into aplite veins with feldspathised margins and is lost under the numerous huge granite boulders, although here and there isolated veins of aplite, tourmaline, and further eastwards quartz and tourmaline occur.

From the old pumping station the granite boundary curves southwards and swings round to run across the fields above Tregerthen Cliff, exposures are discontinuous but the massive boulders and occasional exposures give a fairly reliable indication of the position of the junction. At the western side of Wicca Pool the granite appears as a small apophysis branching into two aplogranite veins, while a few yards to the east the main boundary appears marked by excellent fluxion in the feldspars. The junction is nearly vertical and passes out into the cove to reappear in a zawn below Wicca Cliff (Deep Zawn). Here large veins of aplogranite arise from the roof of the apophysis and penetrate the hornfels towards the north. Numerous thin pegmatites interbanded with aplite occur in this roof zone and many are observed to pass


PCEG
PCES
PCEA
PCEM

into the aplogranite veins (Fig.60). A few aplogranite veins with quartz or tourmaline rich centres occur at Cornelias Zawn and Mussel Point, but the main granite contact is lost in vegetation below Wicca Cliff and swings inland to the east.

The main features of these apophyses is that they generally tongue to the north east; this is a common feature along the north coast at Land's End, as will be demonstrated.

B. Great Zawn-Porthmeor Cove Contact. (Map 4, Porthmeor Cove).

A small raft, or roof pendant, of metasediments containing numerous ptygmatically folded quartz veins occurs in the granite headland to the west of Carn Veslan Cliff while to the north of Carn Veslan Cliff an apophysis of coarse granite intrudes the pelitic hornfels and associated dolerites. Below the carn the contact is sharp without a fine grained marginal phase and is occupied by several massive quartz and quartz tourmaline veins. The granite is occasionally faulted which slightly offsets its contact with the hornfels. The contact swings round the upper part of Great Zawn and reappears on the rocky coast below Carn Moyle Cliff, where the granite is coarse in texture, contains abundant small quartz pegmatites usually 3 to 4 inches in length and occasionally 4 ft. in length. A shatter zone runs along, and is responsible for, West Zawn 3 where the granite sends off a tongue of aplogranite with a small roof pegmatite of feldspar. Aplogranite veins extend to the east across dolerite and pelitic hornfels and are rich in roof pegmatites; these pegmatites contain masses of tourmaline needles in clusters up to 2 feet across and several yards in length. Minor offshoots from the main aplogranite have feldspathised margins, while intersecting main veins develop tourmaline nodes at their point of contact and heavily biotise adjoining hornfels.

Two veins occur near Anthophyllite Zawn and pass towards the west, the tourmaline vein postdating the aplite vein. The main granite contact which runs south of Carn Moyle Cliff reappears at West Zawn 1 in Porthmeor Cove. Here the granite is coarsely porphyritic and contains many xenoliths of country rock in all stages of stoping and digestion, and there is a distinct chilled margin beneath the pelitic hornfels which roofs the granite at this locality.

On the west side of the cove the granite is well exposed and contains many tourmaline and quartz tourmaline veins, though towards the east exposures are generally poor beyond the aplogranite vein, and the old river valley is filled with head (growan, earth and granite boulders).

A small exposure in the north-east corner of the cove a few yards north of the stream marks the continuation of the main granite contact where two aplogranite veins pass into the hornfels. From Little Porth Carn to Porthmeor Point the granite appears in a series of small plugs with well developed roof pegmatites. These plugs send off numerous aplogranite and granite veins into the pelitic hornfels and occasionally complex interelations occur within the veins (text figure P248 and analyses P303). Below Long Carn the roof of a granite plug is perfectly exposed in a section which displays a sharp contact cut by a 20 inch schorl vein. To the south and below Little Porth Carn the complex pegmatite referred to earlier occurs (p.152 and text figure P248), where volatiles, released by negative pressure pulses or a diffusion-supersaturation mechanism, occur trapped beneath the hornfels roof. Nearly every aplite or aplogranite vein shows separation of a pegmatite (volatile) phase of one sort or another (Fig.59); these pegmatites vary considerably in size from wavy faint bands of tourmaline, to well crystallised tourmaline feldspar sigmoids and the major feldspathic pegmatites which usually occur immediately beneath hornfels roofs.

C. Portheras Cove Contact. (Map.6, Land's End granites).

The granite/hornfels contact at this locality is quite sharp although several stoped hornfels blocks are to be seen just within the granite. There is no chilling of the granite at the contact suggesting that some degree of thermal equilibrium had been attained, although the cliff face in Pendeen Cove is cut by several veins of fine granite which are accompanied by a small thermal aureole. In this cove the granite is slightly sheared and partly kaolinised. Further east, towards Chypraze Cliff, quartz veins cut the partly altered, medium grained granite. At Chypraze Cliff and Blinker's Bed the medium granite passes into a distinctly coarse porphyritic type; due to the inaccessibility of the cliffs, the junction between the two textures has not been located.

D. Priests Cove - Porth Ledden - Wheal Castle Contacts. (Map.6, Land's End granites).

Apart from Porthmeor Cove contact, this is one of the most interesting and easily accessible contact exposures in south-west England.

Tracing the main contact from the north where it occurs near a stream a few yards west of Carn Praunter, it follows the stream down to Wheal Castle where the junction is clearly seen in the stream bed. The contact is quite sharp with a chilled margin and tourmaline is developed beneath the hornfels cover.

The contact is again seen south of the pumping station in Porth Ledden although the adit supplying water to the pump passes through the junction only a few yards to the south-east. Broadly speaking the granite/hornfels contact at this locality is sharp and can be divided into two major units :-

(a) Banded marginal phase (Porphyritic)

(b) Quartz schorl rock (Non-porphyritic)

The banded marginal phase becomes less porphyritic and rapidly grades downwards into the quartz schorl rock. At the base this is seen to grade into coarse non-porphyritic tourmaline granite. Figures 42, 44, 45, 46 and 75 illustrate the aplite-pegmatite banding and the development of alkali feldspar megacrysts at the margin penetrating the hornfels for several millimeters. Granite veins and mineral lodes cut these phases and the hornfels to the south-west of the bay below the old Stamps.

The granite contact reappears in an old part-kaolinised adit in Priests Cove and runs straight out to sea. It is presumably vertical but due to kaolinisation and mining operations is largely obscured. To the north-west of the slipway, aplogranite with schorl outcrops, and north of this a large aplogranite vein penetrates the hornfels, bifurcates and passes westwards into large quartz veins. Small aplite offshoots of this apophysis in the hornfels are controlled by jointing which impart a distinct zig-zag course. Feldspathisation is common, both at the roof of the apophysis and at the margins of the small aplite veins where coarse feldspar occurs in which needles of tourmaline grow with their "c" axes at right angles to the contact.

A theory to explain the phenomena at Porth Ledden is that originally the area consisted of coarse to medium grained non-porphyritic granite. At a later pre-mineralisation, post-emplacement stage when the mass had come to rest, but was probably not in its final consolidation stages and was still like a mash carrying an interstitial hydrous phase, the area suffered an influx of boron and other volatiles from the inner, now rapidly differentiating, relatively potassium-deficient granite. This ~~succeeded in displacing~~ took the place of most of the elements in the sub-marginal granite, particularly potassium and aluminium. At this stage it may seem reasonable to ask if the potassium in the original medium grained granite could have migrated in a hydrous "vapour" phase along a thermo-chemical gradient away from one region towards the contact. Experimental evidence favours this hypothesis, and loss of heat to the surrounding aureole rocks would establish the thermal gradient; the abundance of potassium in the granite relative to the hornfels would provide a chemical gradient, especially if it were being ~~ousted~~ mobilised from a lower level by incoming ~~boron ions~~ volatiles.

E. <u>Sennen Cove Contact</u>. (Map. Land's End granites.)

Unfortunately the contact at Sennen Cove is not always exposed as it lies on the foreshore and is frequently covered by shifting sand. However, during numerous visits to this site sufficient exposures were located to map the contact with a fair degree of accuracy. It is not always sharp and localised mixing occurs between the hornfels and the granite.

The biotite-cordierite-hornfels which overlies the granite is stoped in many places and small granite veins show volatile-pegmatite segregations on the hanging walls. "Lambs Tails" are common and may represent pegmatisation by potassium-rich fluids associated with volatiles. The contacts are by no means uniformly gradational and chilled margins several inches across occur which grade into normal, coarse porphyritic biotite granite.

To the west the contact presumably passes through the Tribbens - a deep channel between the "bedded hornfels" of Cowloe and the granite foreshore. On the cliffs due north of the Signal Station small patches of biotite-cordierite-hornfels lie upon the granite. The hornfels is not seen again until it outcrops at Longships Rocks - a few hundred yards off Land's End point - and it may be assumed that the contact at Sennen Cove passes to the west and curves southwards to the Longships exposure.

Chapter VII

Conclusions

Conclusions

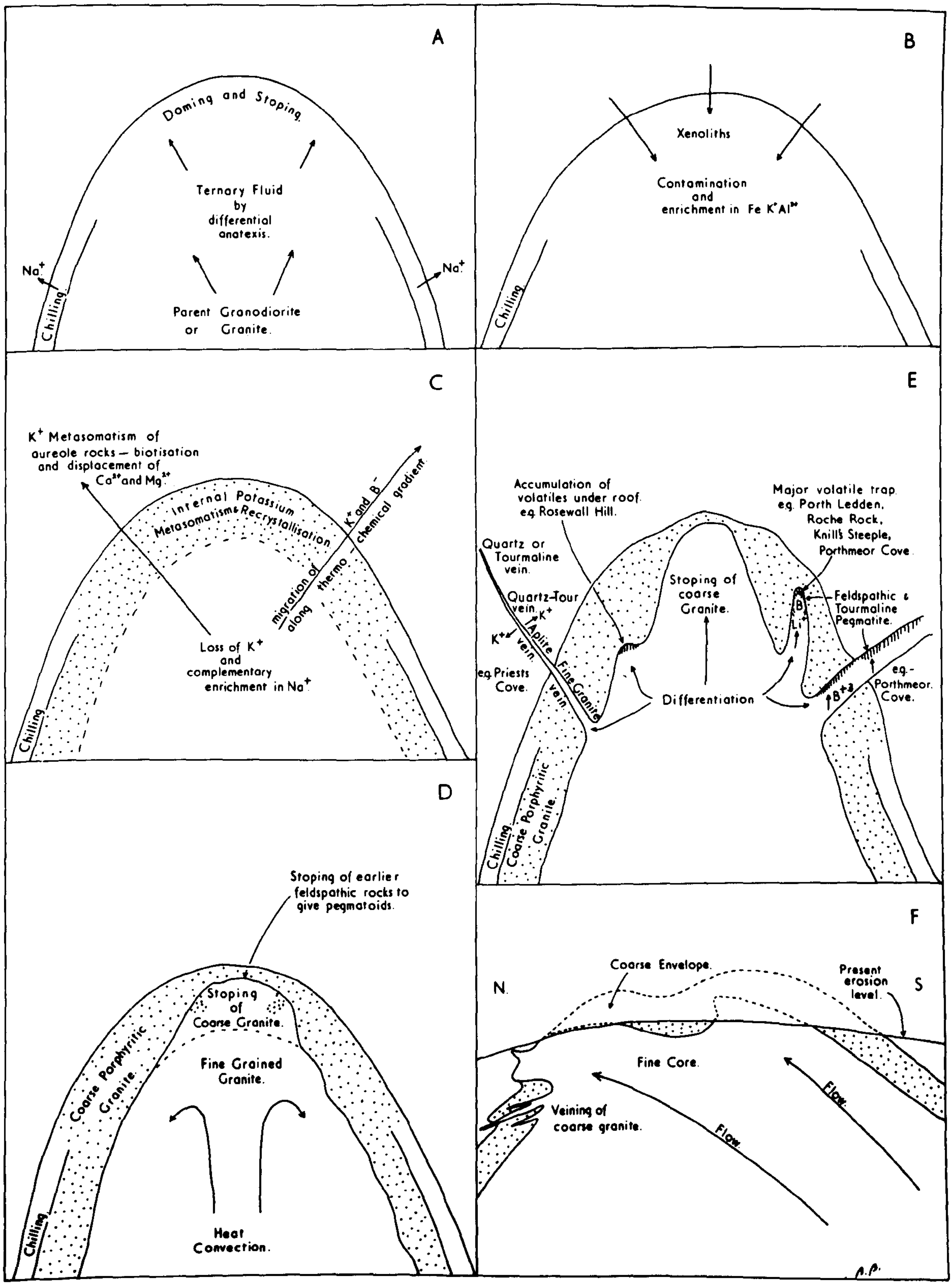
A study of the available data suggests that the granite at Land's End was magmatic (See P.246) in aspect at the time of emplacement, and was associated with tectonic forces which are regarded as being responsible for its forceful emplacement. Data from Levant Mine shows tongues of granite to penetrate the hornfels along the north-west coast; this phenomenon is by no means uncommon along the northern coast as is shown by the numerous apophyses which occur at Wicca Pool, Porthmeor Cove and other localities and if this is taken to be analogous to the Dartmoor granite then it reinforces the theory for a northerly movement of the magma during emplacement within a regional stress gradient.

Doming of the country rocks by the ascent of the granite magma from lower levels was probably associated with the tectonic forces accompanying the final stages of the Hercynian earth movements; in this sense therefore the granite can be termed serokinematic, whereas movement of the granite postdating the Hercynian movements would merit the term postkinematic. During progressive emplacement the doming of the crust probably exceeded the elastic limit of the rocks and gave rise to faulting on a regional scale.

Further movement by the uprising magma caused foundering of faulted roof blocks which either subsided directly into the magma, or slid down low angle dislocation planes; in this manner therefore large blocks of sedimentary rocks were engulfed in the granite magma, which then rapidly ascended to occupy the spaces vacated by these foundered blocks. This phenomenon led to a sub-concordant relationship between the granite boundaries and major dislocation trends.

The foundering of these large blocks of sedimentary rocks is believed to have taken place early in the granite's history and prior to the more extensive periods of potassium metasomatism; for many blocks that must have resulted from this period of major stoping were granitised, and reciprocal basification of the granite magma occurred. The variability in the composition of the granite indicates that extensive contamination on assimilation must have ensued, for areas of basified granite with abnormally high modal biotite occur (p.62).

Assimilation on such a grand scale presupposes a fairly acid magma and while this could arise by differentiation of a more basic body, the dioritic satellites that would be presumed to accompany such a phenomenon do not occur. Moreover, the dimensions of the Cornubian pluton as defined on the basis of geophysical evidence are not consistent with the existence


A
Doming and Stoping
Ternary Fluid by differential anatexis.
Na+
Na+
Chilling
Parent Granodiorite or Granite.
B
Xenoliths
Contamination and enrichment in Fe K+Al3+
Chilling
C
K+ Metasomatism of aureole rocks — biotisation and displacement of Ca2+ and Mg2+
Internal Potassium Metasomatism & Recrystallisation
migration of K+ and B− along thermo chemical gradient
Loss of K+ and complementary enrichment in Na+
Chilling
D
Stoping of earlier feldspathic rocks to give pegmatoids.
Stoping of Coarse Granite.
Fine Grained Granite.
Coarse Porphyritic Granite.
Heat Convection.
Chilling
E
Accumulation of volatiles under roof. eg. Rosewall Hill.
Major volatile trap. eg. Porth Ledden, Roche Rock, Knill's Steeple, Porthmeor Cove.
Quartz or Tourmaline vein.
Quartz-Tour vein.
K+
K+
Aplite vein
Fine Granite vein
eg. Priests Cove.
Stoping of coarse Granite.
Feldspathic & Tourmaline Pegmatite.
B
Li+
B+3
eg.- Porthmeor Cove.
Differentiation
Chilling
Coarse Porphyritic Granite.
F
N.
S
Coarse Envelope.
Present erosion level.
Fine Core.
Veining of coarse granite.
Flow
Flow

of a massive body of basic rock at depth. Differential anatexis of an existing granite, granodiorite or granite-greiss would result in a magma which was compositionally identical with the natural ternary field (i.e. soda rich) and such a magma would be capable of wholesale assimilation of sedimentary xenoliths.

Rapid ascent by the magma involved, by virtue of a steep thermal gradient, fairly rapid cooling with the production of an aplitic texture lubricated by residual fluids. This partly crystallised granite was capable of slow movement under tectonic influences and seed crystals of feldspar formed under this stress field in the interstices of the partly solidified rock. Wholesale movement of the crystal 'mush' or movement of the liquid residuum and seed crystals in the rock interstices within a regional stress gradient orientated the seed crystals of feldspar in a NNW-SSE direction with a vertical foliation, although near the walls and roof of the magma chamber the foliation is largely concordant.

By accretion of material from the metasomatising solutions the seed crystals increased in size by irregular endoblastic growth. In the final stages they were growing in a near solid environment, the double enclaves suggest growth in a solid environment though whether this occurred along sedimentary planes is not clear.

The heat of crystallisation produced by the metasomatic growth of the feldspars coupled with heat convection deeper in the pluton is thought to be largely responsible for the recrystallisation of the original aplitic matrix. Where the metasomatising fluids were unable to diffuse out into the surrounding sediments the foliation is concordant with the granite/hornfels contact; but that some such diffusion occurred is demonstrated by the alkali feldspars which have endoblastically grown across these contacts, and in such cases the foliation is discordant. The series of fairly symmetrical folds within the granite roof zone is thought to have governed the development of the northern hills although further evidence is needed to clarify this point.

Due to the establishment of a thermal gradient between the margin and the core of the pluton and a chemical gradient between the granite and the sediments, loss of alkali cations from the centre of the pluton resulted in a build-up of potassium ions in the marginal zone of the granite. This was accompanied by an increase in water content and the development of a phase rich in such elements as boron, fluorine and lithium. These metasomatising juices migrated into adjacent hornfels causing biotization of basic igneous rocks and displacement of calcium and magnesium ions which were released to effect calcium and magnesium metasomatism elsewhere in the aureole. Introduction of hydrogen ions was responsible for the hydration and argillisation of the feldspars. Tourmalinisation is in evidence in the coarse envelope, but field evidence demonstrates that much of this volatile rich material was in fact trapped beneath the coarse envelope and beneath arched hornfels roofs to develop as pegmatites.

Further subcrustal movement, possibly accompanied by magmatic convection currents, locally reheated the fine grained inner granite which succeeded in stoping and veining parts of the coarse envelope. Existing pelitic xenoliths were digested and only cordierite xenocrysts remains as an indication of their former extent, with perhaps the occasional freshly stoped xenolith. Feldspathic pegmatites in the coarse material were resorbed to give localised potassium-rich areas, which on cooling formed pegmatoids (alkali feldspar megacrysts up to 7 cms in length set in a fine grained aplogranitic matrix). This movement by the mobilised inner granite resulted in the development of numerous NNW-SSE granite veins along the northern margin accompanied by a total break through in marginally weak areas.

Further release of metasomatising fluids caused greisening and tourmalinisation along fractures which had by now developed in the consolidated envelope. Emanative centres which were rich in differentially concentrated elements such as tin, copper, iron, tungsten and molybdenum gave rise to NNW-SSE mineralising veins. These are largely postdated by the more aqueous deuteric effects. Kaolinisation which may be considered as hydrogen metasomatism of feldspars, acted along fracture zones in the granite, the argillisation being particularly intense where these zones intersect.

Chapter VIII

Technical Procedures

A Modal Analysis

The volume percentage of actual minerals present in each specimen was calculated after the method described by Chayes (1956). Large micro-sections ($1\frac{1}{2}$ in. x $\frac{7}{8}$ in.) were cut at random from each rock specimen in such a manner that no two sections were cut parallel to one another. Prior to covering the micro-sections they were double-stained in Methylene Blue and Sodium Cobaltinitrite; mica and clay minerals were stained varying intensities of blue, while potassium feldspar was stained bright yellow. This aided rapid identification and eliminated some of the errors due to eye strain and fatigue.

For each specimen a minimum number of 4,200 points was counted, this number being determined from graphs given by Barringer (1953) which relate the analytical error (twice the standard deviation) to the number of points counted. While reducing the number of points counted to 1,200 would involve increasing the analytical error by approximately 50%, to substantially reduce the error based on 4,200 points would involve counting no less than 9,600 points, and in view of the large number of specimens being analysed this was not found practicable. The area of rock section point counted was calculated from tables given by Chayes (1956) in such a manner as to keep the error of reproducibility below 1.41 per cent. A north-south spacing was determined which would give a total count of no less than 4,200 points using the following formula :-

$$\frac{9 \times \text{Total area}}{4{,}200}$$

(This formula is based on an EW movement of 0.3 mm. using a Swift Automatic point counter).

The I.C. number referred to by Chayes (1956) is taken as - "the number of major mineral identity changes" in a given traverse distance, which he gives as 40 mm. Wadsworth (1963) computes the textural variation in a quartz diorite pluton and refers to the variable as the Coarseness Index, which appears to be a modification of Chayes' I.C. number (1956), but Wadsworth records the number of major mineral identity changes along a "40 mm. traverse instead of a 25 mm. traverse".

In a personal communication to Dr. C.S. Exley, Chayes (1963) states that Wadsworth is correct about the 25 mm. traverse. If a traverse length of 25 mm. is used then this gives a grain size for the Carmenellis granite of just over 1 mm. and approximately 0.3 mm. for the Westerly granite (cf. Chayes 1956, p.75), which in both cases is much too fine. An I.C. number of 20.8 (Chayes 1956, p.75) for a 40 mm. traverse of the Carnmenellis granite correlates very well with field observations, however.

In view of this confusion on the measurement of grain size it was decided to use a traverse length of 40 mm. recording changes in major mineral boundaries and call this parameter Coarseness Index; this unit of measurement is very similar to a 40 mm. I,C. traverse and in practice was found to be quite suitable for the calculation of areas on which to base modes.

Total orthoclase (Perthite) was calculated by adding the percentages of orthoclase and secondary mica in orthoclase.

Total plagioclase was calculated by summing the percentages of plagioclase, secondary mica in plagioclase, and clay minerals.

Colour index is the sum of the percentages of biotite, tourmaline and ore.

In the tables, quartz, total orthoclase, and total plagioclase are recalculated to 100 per cent.

B Chemical Analysis of Rocks

(a) CRUSHING. The amount of rock crushed depended upon its coarseness and therefore varied between 500 gms. and 2,000 gms. of bulked samples (Wager and Brown, in Smales and Wager, 1960).

All rocks were crushed to pass through No.120 nylon mesh bolting cloth as follows :-

Primary crushing was by a Splitter mounted on a "Fly-Press" to provide two inch cubes followed by case-hardened steel mortar and pestle mounted on a "Fly-Press".

Secondary crushing was by case-hardened serrated and smooth steel rollers. After this stage all material passed through No.30 nylon mesh. The powder was mixed and quartered, 150 gms. was ground to pass No.120 nylon mesh bolting cloth using an automatic agate mortar and pestle.

Sieves were constructed of perspex with removable nylon mesh to reduce contamination. The nylon was used only once for each sample, then destroyed.

Prior to analysis all samples were dried at 110°C. for 24 hours to remove H_2O^- and thereafter kept in a dessicator.

(b) ANALYSIS. The following elements were determined spectrophotometrically using a Unicam SP.500 Spectrophotometer.

(i) Silicon as SiO_2 - The yellow silicomolybdate complex was reduced to molybdenum blue and the optical density measured at 812mμ (Riley,1958).

The following modification was used for the ammonium molybdate reagent :-

8 gms. of ammonium molybdate were dissolved in 300 ml. of distilled water (from polythene containers) and 20 ml. of concentrated hydrochloric acid plus 25 ml. of 0.5N sulphuric acid were added and the whole diluted to 1 litre.

Preparation of solution A for this determination was modified as follows :- The alkaline solution from the fusion was neutralised with 20 ml. of 1:1 hydrochloric acid in place of the recommended 25 ml. of 2.5N sulphuric acid.

(ii) Aluminium as Al_2O_3 - The optical density of the calcium aluminium alizarin red - S complex produced was measured at 475mμ using the method of Shapiro and Brannock (1962). Solution A was made up as above (Riley, 1958, Modified).

NBS feldspar No.99 was used as a standard for aluminium, the solution containing 0.0502 gms./litre. (19.06% Al_2O_3 for NBS Feldspar No.99).

According to the amount of Al_2O_3 expected within the sample the volume of Solution A taken was adjusted as follows :-

15 ml.soln.A $\quad Al_2O_3\% = 19.06 \times \frac{1}{2} \times \frac{\text{OD of Unknown}}{\text{OD of Standard}}$

(where OD = optical density)

10 ml.soln.A plus
5 ml.soln.A blank. $Al_2O_3\% = 19.06 \times \frac{3}{4} \times \frac{\text{OD of Unknown}}{\text{OD of Standard}}$

5 ml.soln.A plus
10 ml.soln.A blank. $Al_2O_3\% = 19.06 \times 3/2 \times \frac{\text{OD of Unknown}}{\text{OD of Standard}}$

Solution B was made up as described by Riley (1958) and used in the following determinations :-

(iii) Total Iron as Fe_2O_3 - The iron was reduced with hydroxylamine at pH 4.8-5.0, complexed as the red ferrous-dipyridyl complex, and the optical density measured at 522 $m\mu$ (Riley, 1958).

(iv) Manganese as MnO_2 - The manganese was oxidised to permanganate by means of ammonium persulphate in the presence of phosphoric acid and a catalytic amount of silver ion and the optical density measured at 525 $m\mu$ (Riley, 1958).

(v) Titanium as TiO_2 - The optical density of the yellow compound formed by the addition of hydrogen peroxide to the acid solution was measured at 400 $m\mu$.

Iron was suppressed with phosphoric acid (Riley, 1958).

(vi) Phosphorous as P_2O_5 - Determined by the single solution molybdenum blue method, using ascorbic acid as the reducing agent and the optical density measured at 827mμ (Riley, 1958).

(vii) Alkalis (K_2O, Na_2O). Iron, Aluminium and Titanium were removed in an ion exchange resin. The alkalis were then determined with an Eel flame photometer using ammonium sulphate as a spectroscopic buffer. (Riley, 1958).

Modifications :- $\frac{1}{4}$ dilutions were found necessary for rocks and minerals rich in alkalis - e.g. feldspar crystals.

Standard solutions of Na_2O up to 7μg Na_2O/ml. were found to give more reproducible readings for calibration purposes.

(viii) Calcium and Magnesium as CaO and MgO - Determined by titration with ethylenediaminetetraacetic acid after removal of interfering elements by precipitation of their oxides (R_2O_3) at pH 5 (Riley, 1958 Modified).

Modifications :- For procedure for removal of interfering elements the following was substituted :-

100 ml. of solution B was pipetted into a 250 ml. beaker and 50 ml. of distilled water added. 5% ammonia solution was added to bring the pH to 3-4 and dilute ammonia solution added until a pH value of 5 was obtained.

(Using a Pye Master pH Meter standardised with a buffer of pH4).

The contents of the beaker were diluted to exactly 250 ml. and filtered through Whatman grade 40 filter paper. This solution was used for the determination of both calcium and calcium + magnesium.

Determinations were carried out as in Riley (1958) but using the following standards:-

50 ml. of 100μg /ml. CaO
20 ml. of 250μg /ml. MgO

(ix) Ferrous iron as FeO - Determined on a separate sample by titration with a standard dichromate solution with diphenylamine sulphonic acid as the indicator. (Shapiro and Brannock, 1962).

Modifications :- Diphenylamine sulphonate indicator - 1 litre of 85 per cent H_3PO_4 was used instead of 5 litres. The stronger indicator gave a better end point.

50 per cent sulphuric acid was substituted for 1+3 sulphuric acid.

The crucibles were placed for 25 mins. on a hotplate kept at a temperature of 200°C.

The spike solution was omitted except for solutions known to be low in iron and where the end point was accidently passed.

(x) H_2O+ - By ignition, and absorption in magnesium perchlorate (Riley, 1958).

C Impregnation of Kaolinised granites

A technique for the impregnation of these friable rocks was given by Exley (1956) and Taylor (1960) using a Bakelite polyester resin.

During work on the Kaolinised rocks of Land's End both these methods were tried and found to be unsuitable for the material under investigation. In many cases penetration was very poor and during subsequent sectioning the central part of the specimen which the resin had not reached would crumble away. Accordingly the method given by Exley (1956) was modified and an account of this modified procedure, which gives satisfactory results, now follows :-

The basic resin mixture as described by Exley is made up from:-

Polyester Resin SR 17431	100 gms.
Styrene	10 gms.
* Catalyst Q 17447	1 gm.
Accelerator Q 17448	2 gms.

This basic mixture was diluted in the ratio of 1:1 with Styrene and poured into waxed paper moulds containing the specimen to be impregnated. The mould was filled not more than one third full with rock to allow for reduction in the volume of the resin with the evaporation of the Styrene. The resin gels in approximately 31 hours and sets hard in a further two days. This slow setting action facilitates thorough penetration of the rock, but as very friable rocks may crumble when the resin mixture is poured onto them it is recommended that any space in the mould should be packed with a crushed quantity of the same friable rock.

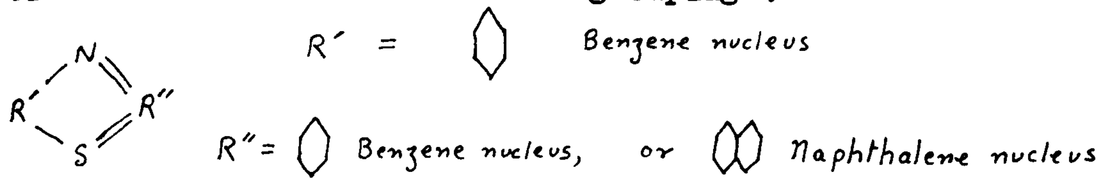
Sectioning is carried out in the usual way, no modifications were found necessary.

x Bakelite Catalysts are very powerful oxidising agents and great care must be exercised in their handling. They should never be directly mixed with the Accelerator as this may lead to an explosive reaction, and under no circumstances should they be allowed to come into contact with the skin or eyes.

D Procedure for staining thin sections of granite for Modal Analysis by point counting.

This method which is essentially a double staining technique for micas (including sericite and clay minerals), and potash feldspars, is based on an adsorption stain and a precipitation reaction.

Methylene blue, a basic dye-stuff of the Thiazine class with the characteristic grouping :-



is used to stain micas and clay minerals blue by adsorption onto the (OH^-) group.

The reaction of an aqueous solution of sodium cobaltinitrite with the potassium ion (K^+), to form the bright yellow complex of potassium cobaltinitrite is used to stain potash feldspars. The potassium is probably present as the fluoride (KF) after etching the rock section in fuming hydrofluoric acid vapour (HF), and possible reactions are as follows :-

$$Na_3\left[Co(NO_2)_6\right] + 3\,KF \text{ (in excess)} \longrightarrow K_3\left[Co(NO_2)_6\right] + 3\,NaF$$

or

$$Na_3\left[Co(NO_2)_6\right] + 2\,KF \longrightarrow K_2\,Na\left[Co(NO_2)_6\right] + 2\,NaF$$

(Note:- This technique, which is basically the same as that given by Chayes (1952b) and Keeling (1954) has slight modifications such as stain concentration and staining times which have been found to give more desirable results).

Staining Procedure

1. The microsection of rock was rinsed with a liquid detergent and then thoroughly washed in distilled water. (This procedure was to remove traces of grease which would otherwise interfere with the etching process).

2. The section was stained in 2 per cent aqueous Methylene blue for 10 minutes. (The maximum time is not critical and satisfactory results are obtained when stained for over 60 minutes).

3. The excess stain was rinsed off with tap water and the slide allowed to dry.

4. A 1 inch-wide strip of Sellotape was attached to the reverse side of the slide to protect the glass from the hydrofluoric acid vapour.

5. The section was etched for 1 minute in the vapour of hydrofluoric acid over a water bath held at 50°C.

6. The slide was removed from the etching chamber and placed in 50% aqueous Sodium Cobaltinitrite for 20 minutes to allow the insoluble colour complex to develop.

(At no time after etching should the rock section surface be touched as the thin gel may be damaged).

7. The slide was washed gently in tap water and the Sellotape backing removed, and the slide thoroughly dried.

8. The surface of the rock section was carefully coated with Pyroxylin and covered in the usual way.

E Use of Explosives

During this research it was found very difficult to obtain fresh samples of granite from cliff and tor exposures that were suitable for chemical analysis. Much time was spent in boulder splitting using a sledge-hammer and cold chisles to obtain very poor specimens. As the author had been using explosives for blasting in caves it was decided to employ this method for obtaining fresh rock samples on cliff and tor exposures.

The method used is classified as secondary blasting in quarrying, and as no shothole is needed plaster shooting was quick and economical. It provided a ready means of breaking large stones where other methods would have been difficult and expensive. A charge of one or more cartridges was threaded on to "Cordtex" detonating fuse and placed in position on the surface of the boulder which had been previously wetted. It was then covered with clay or turfs and earth. A high-velocity (6,500 ft. per sec.), high-strength gelatine-type explosive is suitable, and a special explosive with these characteristics, Plaster Gelatine and Submarine Blasting Gelatine has been developed for this kind of work.

"Cordtex" was used simply as a safety measure, for in the event of a misfire the piece of "Cordtex" with the detonator attached can be severed. The charge could then be safely pulled out on the "Cordtex", or refuzed as necessary.

Where it was possible to shelter behind boulders the charges were electrically detonated from a distance of not less than 50 feet. But on more open ground capped fuses were taped to the "Cordtex" at the detonator end and crimped onto Slow Plastic Igniter Cord at the beanhole connector. This allowed the shotfirer to retreat to a safe distance (400 yds. on open moorland).

Plaster shooting offers the following advantages :-

1. No drilling is required, thus saving labour and time.

2. A group of plaster shots, if necessary, can be prepared more quickly than the same number of pop shots. (Drillhole shots).

3. The stone is broken where it stands, and stones are not scattered over a wide area.

4. There is less likelihood of damage or injury through flying debris.

The main disadvantage of the method is the noise, as it creates more air disturbance than others. Care must therefore be taken to see that farm animals are not frightened, and explosives should never be used during the lambing season or when nearby animals are known to be in young. Prior to any blasting, the permission of the landowner (not tenant) should be obtained in writing (this does not apply in the case of intertidal zones), and the Chief Officer of Police for the district informed.

F Photographic Procedures

Field photographs were taken with a Periflex Gold Star 35 mm. camera using Ilford F.P.3 film. Light readings were taken with a Weston Master II light meter using both incident and reflected techniques. Films were developed in Promicrol and fixed in Kodafix, and enlargements made on Kodak bromide paper using an Envoy enlarger, developed in Kodak 0-163 and fixed as above.

Photomicrographs were taken on Ilford F.P.3 film with a Swift Reaearch microscope using a Carl Zeiss Basic Body II attachment and a Periflex Gold Star camera. Development and printing carried out as above.

Low power photomicrographs were taken by projecting the image from a thin section onto Kodak 0.250 plates using an Envoy enlarger, the plates developed in D-163 and fixed in Kodafix.

All prints were glazed and mounted using Ademco dry mounting tissue.

Data

(Chemical and Modal Analyses)

Analysis of water from Wheal Clifford Spring.

Dr. W.A. Miller 1864.

	grains per imperial gallon
Li Cl	26.05
K Cl (+ Cs)	14.84
Na Cl	363.61
Mg Cl_2	8.86
Ca Cl	216.17
Ca SO_4	12.27
SiO_2	3.65
Oxides of Fe, Al, Mn.	Traces
	645.45

Temperature 125°F.
150 gallons per minute.
230 fathoms.

Analysis of water from Wheal Seton

J.A. Phillips 1873.

	gms.per gallon
Ca CO_3	6.45
Fe CO_3	0.31
Mg CO_3	Trace
Ca SO_4	2.12
Cu Cl_2	Trace
Ca Cl	473.88
Mg Cl_2	11.98
Al_2Cl_6	63.02
K Cl	6.43
Co Cl	Trace
Na Cl	409.09
Li Cl	34.22
K Br	Trace
$K_4(SiO_4)$	4.85
NH_3	Trace
HNO_3	Trace
Total by adding	1012. 35
Total directly	1005. 61
Free Carbonic Acid	2. 61

Temperature 92°F
50 gallons per minute
160 fathoms

I Sheffield granite. Sheffield quarry.
Analyst C.M.L. Bowler (1959).

II Castle-an-dinas microgranite. Castle-an-dinas quarry.
Analyst C.M.L. Bowler (1959).

* Bowler notes on his analyses that the precision for Si and Al are moderate although no direct analyses were attempted. The Si/Al concentration ratio was determined using the following assumption.

$$100 - CaO, MgO, TiO_2, MnO, (\text{Total Fe as FeO}) \; Na_2O, K_2O$$

$$= SiO_2, Al_2O_3$$

Weight Percentages

	I	II
SiO_2	(70.5)*	(75.5)*
Al_2O_3	(14.5)*	(12.5)*
TiO_2	0.47	0.28
Fe_2O_3	ND	ND
FeO	ND	ND
Total Fe as FeO	2.96	1.70
MnO_2	0.053	0.04
MgO	0.79	0.37
CaO	2.13	1.21
Na_2O	2.73	2.79
K_2O	5.69	5.50
P_2O_5	ND	ND
H_2O (Total)	ND	ND
F	0.24	0.4

I Newlyn dolerite sill. Gwavas Quarry.
Analyst Dr. W.Pollard.

II Newlyn dolerite sill. Quarry in Newlyn Village.
Analyst J.A. Phillips (Q.J.G.S. Vol.xxxii 1876, p.167)

III Hornfels xenolith from granite in Lamorna Quarry.
Analyst Dr. W. Pollard.

Weight Percentages

	I	II	III
SiO_2	59.84	50.57	47.45
Al_2O_3	15.71	19.65	27.48
Na_2O	6.52	3.46	1.62
K_2O	2.76	1.08	2.75
Li_2O			0.09
MgO	1.37	7.93	4.14
CaO	3.71	7.47	2.23
Fe_2O_3	1.68	1.46	1.44
FeO	7.03	7.24	8.60
MnO	0.12	Tr.	0.15
P_2O_5	0.20	0.12	0.26
TiO_2	0.64		1.26
H_2O+	0.31	(0.74)	1.97
H_2O-	0.14		0.17
S	0.10		
Cl			0.04
F			0.37
B_2O_3			Tr.
(CoNi)O			0.02
Cr_3O_2			0.02
V_2O_3			0.03
Total	100.13	99.72	100.09
Less O for F Cl.			0.17
			99.92

I Lamorna granite. Lamorna quarry.
Analyst Dr. W. Pollard.

II Botallack granite.
Analyst J.A. Phillips (1875)

III Georgia kaolin. Georgia Works.
Analyst Dr. W. Pollard.

Weight Percentages

	I	II	III
SiO_2	70.17	74.54	71.15
TiO_2	0.41	-	0.16
Al_2O_3	15.07	14.86	19.41
Fe_2O_3	0.88	2.53	1.32
FeO	1.79	0.23	0.09
MnO	0.12	Tr.	0.09
CaO	1.13	0.29	0.21
MgO	1.11	Tr.	0.45
K_2O	5.73	3.73	1.44
Na_2O	2.69	3.49	0.05
Li_2O	0.11	Tr.	0.03
H_2O (105^o)	0.18)	0.87	0.16
H_2O ($+105^o$)	0.70)		5.09
P_2O_5	0.34	-	0.07
Cl	0.06	-	Tr.
F	0.15	-	0.11
S	0.04	-	-
B_2O_3	strong trace	-	0.33
Total	100.68	100.54	100.16
Less O for F and Cl	.01		.04
	100.67		100.12

Chemical Analyses Tables

(Granites)

	(V/U)
S120	50/54
S91	78/119
S17	140/29
114	188/157
S39	137/43
S33	121/53
S15	192/155
S44	83/36
S34	55/123
S28	187/180
95	11/138
S5	32/41
S73	99/70
S61	70/135 (-650.O.D.)
S83	140/62
S10	66/25
S47/K	85/77
S4	174/136
S48	76/79
S31	206/178
S58	74/129
B36	46/96
S52	42/106
2C	177/182
P3	100/151

Note:- The geographical location of the above specimens is given as coordinates V/U - see map. Land's End Granites.

The coarseness is indiated by the C.I. number.

Weight Percentages

	S120	S91	S17	114	S39	S33
SiO_2	72.00	71.88	69.99	71.64	72.98	71.45
Al_2O_3	16.92	15.58	15.68	14.57	13.98	14.58
Na_2O	1.60	2.70	3.00	2.85	1.45	3.50
K_2O	2.80	5.05	5.40	5.05	4.70	5.00
Li_2O	ND	ND	0.00	0.15	ND	0.00
MgO	0.82	0.53	0.92	0.64	0.55	0.67
CaO	0.72	0.62	0.69	0.93	1.57	0.79
Fe_2O_3	1.65	1.54	1.27	0.72	0.64	1.03
FeO	2.02	1.62	2.10	1.90	2.12	1.64
MnO	0.04	0.01	0.03	0.05	0.06	0.02
P_2O_5	0.27	0.22	0.28	0.25	0.23	0.46
TiO_2	0.43	0.29	0.33	0.36	0.34	0.61
H_2O	0.67	0.75	0.45	0.61	0.53	0.40
Total	99.94	100.79	100.14	99.72	99.15	100.15

Weight Percentages

	S15	S44	S34	S28	95	S5
SiO_2	71.72	71.37	71.02	72.90	71.50	71.12
Al_2O_3	15.56	14.48	14.36	14.97	14.54	14.64
Na_2O	3.10	2.65	2.74	2.60	4.60	2.38
K_2O	5.20	6.50	5.75	4.50	5.50	6.37
Li_2O	0.00	0.15	ND	0.15	0.15	ND
MgO	0.67	0.63	0.94	0.45	0.71	0.89
CaO	1.00	0.72	1.30	0.83	0.51	0.92
Fe_2O_3	0.61	1.03	0.65	0.76	1.07	0.86
FeO	2.06	1.34	1.64	1.52	1.24	1.54
MnO	0.04	0.03	0.03	0.03	0.02	0.03
P_2O_5	0.28	0.22	0.18	0.28	0.25	0.17
TiO_2	0.34	0.36	0.35	0.29	0.30	0.28
H_2O	0.41	0.59	0.72	0.53	0.81	0.57
Total	100.99	~~99.07~~ 100.07	99.68	99.81	101.20	99.73

Weight Percentages

	S73	S61	S83	S10	S47/K	S4
SiO_2	71.64	72.60	70.59	69.34	73.10	72.44
Al_2O_3	14.89	13.75	14.87	16.20	19.39	14.26
Na_2O	2.70	2.18	2.58	1.80	0.30	3.08
K_2O	5.80	6.11	6.05	7.00	1.80	5.73
Li_2O	0.15	ND	ND	0.00	0.00	ND
MgO	0.64	0.68	0.91	1.02	1.04	0.67
CaO	0.83	0.96	0.99	0.74	2.38	1.03
Fe_2O_3	0.86	0.74	0.66	2.53	0.53	0.68
FeO	2.04	1.66	1.92	0.32	0.36	0.97
MnO	0.05	0.05	0.04	0.02	0.01	0.03
P_2O_5	0.28	0.21	0.19	0.18	0.03	0.16
TiO_2	0.42	0.28	0.34	0.15	0.03	0.15
H_2O+	0.51	0.56	0.52	0.37	0.75	0.47
Total	100.81	99.76	99.66	99.67	99.72	99.67

Weight Percentages

	S48	S31	S58	B36	S52	2C	P3
SiO_2	72.77	73.47	73.26	69.60	72.84	73.80	72.40
Al_2O_3	13.90	15.32	14.14	15.05	14.98	14.72	15.00
Na_2O	4.27	2.25	2.70	6.20	1.47	2.90	2.70
K_2O	5.34	5.10	5.90	5.10	5.35	5.20	4.75
Li_2O	ND	0.00	0.00	0.15	0.00	ND	ND
MgO	0.29	0.20	0.24	0.32	1.07	1.74	2.73
CaO	0.85	0.51	0.69	0.55	1.18	0.70	0.79
Fe_2O_3	0.74	0.30	0.67	1.57	0.93	0.56	0.86
FeO	0.64	1.46	0.52	0.86	0.66	0.58	0.64
MnO	0.03	0.01	0.01	0.02	0.02	0.00	0.00
P_2O_5	0.21	0.23	0.25	0.27	0.30	0.16	0.19
TiO_2	0.08	0.12	0.13	0.14	0.19	0.01	0.02
H_2O+	0.39	0.71	0.47	0.36	0.50	0.85	0.68
Total	99.51	99.68	98.98	100.19	99.49	101.22	100.76

Cation Percentages

	S120	S91	S17	114	S39	S33
Si^{4+}	66.30	64.61	63.94	65.55	68.14	65.88
Al^{3+}	18.38	16.50	16.87	15.69	15.40	15.82
Na^{+}	2.87	4.75	5.32	5.06	2.61	6.25
K^{+}	3.32	5.78	6.30	5.88	5.61	5.87
Li^{+}	-	-	-	-	-	-
Mg^{2+}	1.13	0.69	1.23	0.87	0.76	0.90
Ca^{2+}	0.68	0.60	0.65	0.91	0.59	0.76
Fe^{3+}	1.16	1.01	0.86	0.46	0.47	0.73
Fe^{2+}	1.55	1.21	1.59	1.42	1.64	0.48
Mn^{2+}	0.02	-	0.01	0.03	0.03	0.01
P^{5+}	0.15	0.13	0.20	0.16	0.18	0.36
Ti^{4+}	0.29	0.21	0.23	0.25	0.25	0.44
H^{+}	4.11	4.48	2.74	3.69	3.31	2.43
Total	99.96	99.97	99.94	99.97	99.[illegible]	99.93

Cation Percentages

	S15	S44	S34	S28	95	S5
Si^{4+}	65.10	65.03	64.27	67.05	62.82	65.02
Al^{3+}	16.63	15.52	15.33	16.23	15.03	15.74
Na^{+}	5.45	4.71	4.79	4.64	7.81	4.19
K^{+}	5.99	7.55	6.63	5.30	6.12	7.43
Li^{+}	-	-	-	-	-	-
Mg^{2+}	0.89	0.85	1.26	0.61	0.91	1.19
Ca^{2+}	0.98	0.68	1.25	0.81	0.48	0.90
Fe^{3+}	0.44	0.69	0.46	0.51	0.71	0.58
Fe^{2+}	1.55	1.00	1.23	1.17	0.92	1.15
Mn^{2+}	0.02	0.01	0.01	0.02	0.01	0.01
P^{5+}	0.20	0.13	0.14	0.20	0.19	0.13
Ti^{4+}	0.23	0.25	0.24	0.21	0.21	0.20
H^{+}	2.46	3.55	4.34	3.26	4.77	3.40
Total	99.94	99.97	99.95	100.01	99.98	99.94

Cation Percentages

	S73	S61	S83	S10	S47/K	S4
Si^{4+}	65.07	66.61	64.59	64.18	67.21	66.25
Al^{3+}	15.92	14.87	16.02	17.67	20.98	15.39
Na^{+}	4.80	3.87	4.58	3.22	0.55	5.46
K^{+}	6.76	7.17	7.06	8.27	2.09	6.68
Li^{+}	-	-	-	-	-	-
Mg^{2+}	0.86	0.91	1.22	1.41	1.44	0.90
Ca^{2+}	0.79	0.94	0.97	0.71	2.35	1.02
Fe^{3+}	0.61	0.49	0.47	1.75	0.36	0.48
Fe^{2+}	1.55	1.27	1.45	0.23	0.28	0.75
Mn^{2+}	0.02	0.02	0.02	0.01	0.005	0.01
P^{5+}	0.19	0.17	0.15	0.14	0.13	0.12
Ti^{4+}	0.28	0.20	0.24	0.08	0.01	0.10
H^{+}	3.11	3.41	3.18	2.27	4.63	2.80
Total	99.96	99.93	99.95	99.94	100.03	99.96

Cation Percentages

	S48	S31	S58	B36	S52	2C	P3
Si^{4+}	66.39	67.02	67.74	62.03	67.43	65.07	64.56
Al^{3+}	14.96	16.47	15.37	15.78	16.32	15.26	15.75
Na^{+}	7.51	3.94	4.89	10.70	2.62	4.97	4.66
K^{+}	6.23	5.91	6.99	5.78	6.34	5.82	5.41
Li^{+}	-	-	-	0.53	-	-	-
Mg^{2+}	0.37	0.27	0.32	0.41	1.47	2.29	3.62
Ca^{2+}	0.93	0.50	0.66	0.53	1.16	0.63	0.74
Fe^{3+}	0.51	0.22	0.44	1.05	0.64	0.37	0.57
Fe^{2+}	0.48	1.11	0.40	0.65	0.51	0.41	0.47
Mn^{2+}	0.01	-	-	0.01	0.01	-	-
P^{5+}	0.17	0.14	0.17	0.20	0.22	0.16	0.15
Ti^{4+}	0.04	0.07	0.08	0.09	0.16	-	0.01
H^{+}	2.35	4.33	2.91	2.20	3.11	4.97	4.05
Total	99.95	99.98	99.97	99.96	99.99	99.95	99.99

Catanorm

	S120	S91	S17	114	S39	S33
Quartz	45.04	31.07	26.28	29.61	46.95	28.30
Orthoclase	16.60	28.90	31.50	29.40	28.05	29.35
Albite	14.35	23.75	26.60	25.30	13.05	31.25
Anorthite	2.15	1.90	1.60	3.20	1.45	0.80
Corundum	11.33	5.21	4.61	3.47	4.60	3.38
Enstatite	2.26	1.38	2.46	1.74	1.52	1.80
Ferrosilite	1.40	1.00	1.86	1.94	2.38	(0.63)*
Magnetite	1.74	1.51	1.29	0.69	0.70	0.05
Ilmenite	0.58	0.42	0.46	0.50	0.50	0.88
Apatite	0.40	0.35	0.53	0.43	0.48	0.96

* Heamatite.

Catanorm

	S15	S44	S34	S28	95	S5
Quartz	27.49	26.16	25.95	34.93	19.43	26.95
Orthoclase	29.95	37.75	33.15	26.50	30.60	37.15
Albite	27.25	23.55	23.95	23.20	39.05	20.95
Anorthite	3.25	2.05	5.10	2.40	0.80	3.40
Corundum	3.89	2.44	1.87	5.33	0.78	2.76
Enstatite	1.78	1.70	2.52	1.22	1.82	2.38
Ferrosilite	2.20	0.84	1.52	1.46	0.74	1.32
Magnetite	0.66	1.03	0.69	0.76	1.06	0.87
Ilmenite	0.46	0.50	0.48	0.42	0.42	0.40
Apatite	0.53	0.40	0.37	0.53	0.51	0.35

Catanorm

	S73	S61	S83	S10	S47/K	S4
Quartz	27.60	30.43	26.03	27.34	53.16	26.88
Orthoclase	33.80	35.85	35.30	41.35	10.45	33.40
Albite	24.00	19.35	22.90	16.10	2.75	27.30
Anorthite	2.35	3.30	3.60	2.40	11.50	4.10
Corundum	3.40	2.51	2.94	5.22	13.74	1.61
Enstatite	1.72	1.82	2.44	2.82	2.88	1.80
Ferrosilite	1.98	1.66	1.96	(0.45)*	0.18	0.82
Magnetite	0.91	0.73	0.70	0.45	0.54	0.72
Ilmenite	0.56	0.40	0.48	0.16	0.02	0.20
Apatite	0.51	0.45	0.40	0.37	0.08	0.32

* Heamatite.

Catanorm

	S48	S31	S58	B36	S52	2C	P3
Quartz	23.32	35.73	30.92	12.28	37.46	29.46	29.57
Orthoclase	31.15	29.55	34.95	28.90	31.70	29.10	27.05
Albite	37.55	19.70	24.45	50.00	13.10	24.85	23.30
Anorthite	3.25	1.35	1.90	(2.80)≁	3.95	1.80	2.45
Corundum	0.00	6.08	2.73	(0.40)*	5.78	3.75	4.70
Enstatite	0.74	0.54	0.64	0.82	2.94	4.58	7.24
Ferrosilite	0.36	1.86	0.20	0.80	0.08	0.46	0.36
Magnetite	0.77	0.33	0.66	0.52	0.96	0.55	0.85
Ilmenite	0.08	0.14	0.16	0.18	0.32	-	0.02
Apatite	0.45	0.37	0.45	0.53	0.59	0.43	0.40

≁ Acmite

* Wollastonite

Chemical Analyses Tables

(Porthmeor Cove Granites and Aplites)

Specimens PCEM, PCEG, PCEA and PCES were selected from a series of crosscutting granites and aplites at Porthmeor Cove a few yards south of the Pegmatite Complex.

Weight Percentages

	PCEM	PCEG	PCEA	PCES
SiO_2	73.92	72.47	73.92	75.77
Al_2O_3	14.08	14.54	15.24	13.74
Na_2O	2.50	2.90	7.00	3.60
K_2O	5.35	5.30	2.40	4.10
Li_2O	ND	ND	ND	ND
MgO	0.26	0.33	0.20	0.36
CaO	0.49	0.60	1.20	0.42
Fe_2O_3	0.88	0.45	0.09	0.71
FeO	1.00	1.38	0.24	0.38
MnO	0.01	0.03	0.02	0.00
P_2O_5	0.18	0.21	0.25	0.16
TiO_2	0.22	0.27	0.06	0.08
H_2O	0.57	0.63	0.09	0.61
Total	99.46	99.11	100.71	99.93

PCEM. Medium-fine grained alkali granite. Main granite cut by PCEG.

PCEG. Medium-fine grained biotite granite. Granite vein cutting PCEM and PCEA.

PCEA. Fine grained aplite vein cut by PCEG and PCES.

PCES. Fine grained tourmaline aplite vein cutting PCEA.

Cation Percentages

	PCEM	PCEG	PCEA	PCES
Si^{4+}	67.96	66.35	66.40	68.73
Al^{3+}	15.28	15.66	16.12	14.70
Na^{+}	4.47	5.17	12.19	6.32
K^{+}	6.29	6.21	2.75	4.74
Li^{+}	ND	ND	ND	ND
Mg^{2+}	0.37	0.43	0.27	0.48
Ca^{2+}	0.44	0.60	1.13	0.40
Fe^{3+}	0.59	0.30	0.09	0.49
Fe^{2+}	0.77	1.03	0.18	0.30
Mn^{2+}	-	0.02	0.01	-
P^{5+}	0.14	0.17	0.21	0.12
Ti^{4+}	0.17	0.20	0.03	0.04
H^{+}	3.47	3.83	0.58	3.66
Total	99.95	99.97	99.96	99.98

Catanorm

	PCEM	PCEG	PCEA	PCES
Quartz	34.58	30.46	19.83	34.65
Orthoclase	31.45	31.05	13.75	23.70
Albite	22.35	25.85	60.95	31.60
Anorthite	1.05	1.60	2.95	1.00
Corundum	4.10	3.64	(0.38)*	3.24
Enstatite	0.74	0.86	0.54	0.96
Ferrosilite	0.62	1.36	0.22	0.04
Magnetite	0.88	0.45	0.13	0.73
Ilmenite	0.34	0.40	0.06	0.08
Apatite	0.37	0.45	0.56	0.32

* Wollastonite

Chemical Analyses Tables

(Geevor Mine Section)

Granites

Specimens G1a to G84 were selected from sites perpendicularly below the granite/hornfels contact on the west wall of the GW3 cross cut in Geevor Tin Mine, Pendeen. Care was taken to ensure the specimens were free from mineralised joints.

Weight Percentages

	G1a	G1	G6	G12	G18	G24
SiO_2	73.57	73.90	72.79	71.87	73.94	72.90
Al_2O_3	14.41	14.34	14.98	14.71	14.87	14.98
Na_2O	3.38	3.18	3.08	2.76	3.24	2.08
K_2O	5.45	5.57	6.09	5.99	5.10	6.77
Li_2O	ND	ND	ND	ND	ND	ND
MgO	0.39	0.46	0.32	0.52	0.27	0.38
CaO	0.64	0.69	0.58	0.97	0.63	0.60
Fe_2O_3	0.53	0.68	0.56	0.80	0.41	0.54
FeO	0.39	0.40	0.58	1.34	0.34	1.06
MnO	0.02	0.02	0.02	0.04	0.02	0.03
P_2O_5	0.22	0.21	0.21	0.25	0.21	0.17
TiO_2	0.06	0.05	0.08	0.23	0.06	0.16
H_2O+	0.53	0.61	0.48	0.56	0.54	0.57
Total	99.59	100.11	99.77	100.04	99.63	100.24

G1a	Fine grained biotite granite in immediate contact with K1 of biotite-muscovite-quartz-plagioclase-tourmaline hornfels.					
G1	Fine grained biotite granite	1 inch from contact.				
G6	" " " "	6 inches	"	"		
G12	Medium grained biotite granite	12 inches from contact				
G18	" " " "	18	"	"	"	
G24	Coarse grained biotite granite	24	"	"	"	

Weight Percentages

	G30	G36	G48	G60	G84
SiO_2	70.98	71.90	72.86	71.64	71.85
Al_2O_3	15.28	14.96	14.54	14.11	14.50
Na_2O	2.12	1.90	2.46	2.38	2.38
K_2O	6.25	5.75	5.35	6.37	5.51
Li_2O	ND	ND	ND	ND	ND
MgO	0.62	0.58	0.48	1.15	1.21
CaO	0.89	0.84	1.08	1.06	1.09
Fe_2O_3	0.86	0.83	0.79	0.67	0.73
FeO	1.62	1.74	1.28	1.39	1.45
MnO	0.04	0.04	0.03	0.03	0.04
P_2O_5	0.28	0.25	0.26	0.28	0.25
TiO_2	0.25	0.26	0.25	0.24	0.24
H_2O+	0.62	0.79	0.38	0.42	0.68
Total	99.81	99.84	99.76	99.74	99.93

G30 Coarse grained biotite granite 30 inches from contact

G36 " " " " 36 " " "

G48 " " " " 48 " " "

G60 " " " " 60 " " "

G84 " " " " 84 " " "

Cation Percentages

	G1a	G1	G6	G12	G18	G24
Si^{4+}	66.94	66.77	66.38	65.52	67.39	66.42
Al^{3+}	15.47	15.29	16.08	15.78	15.95	16.06
Na^{+}	5.96	5.55	5.44	4.76	5.70	3.68
K^{+}	6.34	6.42	7.10	6.94	5.91	7.84
Li^{+}	ND	ND	ND	ND	ND	ND
Mg^{2+}	0.53	0.64	0.41	0.69	0.35	0.51
Ca^{2+}	0.62	0.64	0.58	0.95	0.63	0.60
Fe^{3+}	0.36	0.47	0.39	0.54	0.27	0.37
Fe^{2+}	0.31	0.32	0.42	1.00	0.26	0.79
Mn^{2+}	0.01	0.01	0.01	0.02	0.01	0.01
P^{5+}	0.17	0.16	0.16	0.19	0.16	0.13
Ti^{4+}	0.03	0.02	0.04	0.18	0.03	0.09
H^{+}	3.22	3.64	2.93	3.39	3.28	3.44
Total	99.96	99.93	99.94	99.96	99.94	99.94

Cation Percentages

	G30	G36	G48	G60	G84
Si^{4+}	64.81	65.35	67.41	65.60	65.14
Al^{3+}	16.43	16.00	15.82	15.24	15.46
Na^{+}	3.76	3.33	4.41	4.20	4.16
K^{+}	7.29	6.66	6.33	7.44	6.38
Li^{+}	ND	ND	ND	ND	ND
Mg^{2+}	0.84	0.78	0.64	1.56	1.65
Ca^{2+}	0.86	0.80	1.08	1.05	1.07
Fe^{3+}	0.58	0.56	0.55	0.47	0.50
Fe^{2+}	1.22	1.33	0.98	1.03	1.08
Mn^{2+}	0.02	0.02	0.01	0.01	0.02
P^{5+}	0.20	0.19	0.20	0.20	0.19
Ti^{4+}	0.19	0.19	0.19	0.18	0.18
H^{+}	3.75	4.74	2.33	2.94	4.11
Total	99.95	99.95	99.95	99.92	99.94

Catanorm

	G1a	G1	G6	G12	G18	G24
Quartz	28.73	29.41	27.53	26.94	31.38	30.06
Orthoclase	31.70	32.10	35.50	34.70	29.55	39.18
Albite	29.80	27.75	27.20	23.80	28.50	18.40
Anarthite	1.70	1.85	1.55	3.15	1.80	1.95
Corundum	2.49	2.58	2.92	2.82	3.62	3.76
Enstatite	1.06	1.28	0.82	1.38	0.70	1.01
Ferrosilite	0.20	0.14	0.40	1.26	0.22	1.06
Magnetite	0.54	0.70	0.58	0.81	0.40	0.55
Ilmenite	0.06	0.04	0.08	0.36	0.06	0.18
Apatite	0.45	0.43	0.43	0.51	0.43	0.34

Catanorm

	G30	G36	G48	G64	G84
Quartz	29.00	32.76	32.52	27.05	30.56
Orthoclase	36.45	33.30	31.65	37.20	31.90
Albite	18.80	16.65	22.05	21.00	20.80
Anerthite	2.65	2.40	3.25	3.60	1.60
Corundum	4.32	5.05	3.58	2.16	4.28
Enstatite	1.68	1.56	1.28	3.12	3.30
Ferrosilite	1.52	1.76	1.06	1.26	1.34
Magnetite	0.87	0.84	0.82	0.70	0.75
Ilmenite	0.38	0.38	0.38	0.36	0.36
Apatite	0.53	0.51	0.53	0.53	0.51

Chemical Analyses Tables

(Geevor Mine Section)

Pelitic Hornfels

Specimens K1 to K72 were selected from sites perpendicularly above the granite/hornfels contact on the west wall of the GW3 cross cut in Geevor Tin Mine, Pendeen. Care was taken to ensure the specimens were free from mineralised joints.

Weight Percentages

	K1	K6	K12	K18	K24	K36
SiO_2	56.04	61.63	57.55	54.91	53.74	57.95
Al_2O_3	22.23	18.63	22.36	22.47	23.43	21.09
Na_2O	2.66	2.38	1.28	1.68	1.44	1.60
K_2O	4.37	3.65	5.35	4.85	5.71	4.85
Li_2O	ND	ND	ND	ND	ND	ND
MgO	2.58	2.87	3.15	3.76	4.24	3.04
CaO	1.98	2.97	1.87	2.81	1.81	1.93
Fe_2O_3	1.98	1.39	1.61	1.61	2.21	2.00
FeO	5.88	4.82	5.08	6.02	5.06	5.36
MnO	0.11	0.07	0.08	0.11	0.06	0.05
P_2O_5	0.29	0.13	0.08	0.06	0.04	0.08
TiO_2	0.76	0.65	0.88	0.92	0.95	0.83
H_2O+	0.60	0.61	0.59	0.68	0.99	1.16
Total	99.~~54~~ 48	99.80	99.88	99.88	99.68	99.94

K1 Biotite-muscovite-quartz-plagioclase-andalusite-tourmaline hornfels 1 inch from contact with fine grained biotite granite.

K6 Sericite-quartz-tourmaline hornfels 6 inches from contact.

K12 Biotite-sericite-quartz hornfels 12 inches from contact.

K18 Muscovite-biotite-quartz-sericite-tourmaline hornfels 18 inches from contact.

K24 Muscovite-biotite-quartz-sericite hornfels 24 inches from contact.

K36 Biotite-sericite-muscovite-quartz hornfels 36 inches from contact.

Weight Percentages

	K48	K60	K72
SiO_2	56.51	53.40	56.89
Al_2O_3	22.12	22.62	21.04
Na_2O	1.28	1.46	1.46
K_2O	5.85	5.73	5.73
Li_2O	ND	ND	ND
MgO	3.02	3.07	3.12
CaO	1.10	3.10	1.91
Fe_2O_3	1.81	2.19	2.39
FeO	5.56	6.08	5.50
MnO	0.10	0.10	0.07
P_2O_5	0.06	0.07	0.08
TiO_2	0.78	0.89	0.81
H_2O+	2.32	1.33	1.26
Total	100.51	100.04	100.26

K48 Muscovite-sericite-quartz-biotite-tourmaline hornfels 48 inches from contact.
K60 Chlorite-muscovite-sericite-quartz-biotite hornfels 60 inches from contact.
K72 Biotite-quartz-muscovite-sericite-tourmaline hornfels 72 inches from contact.

Cation Percentages

	K1	K6	K12	K18	K24	K36
Si^{4+}	50.65	56.02	50.88	49.44	47.42	51.21
Al^{3+}	23.71	19.95	25.98	23.82	24.35	21.96
Na^{+}	4.65	4.13	2.19	2.94	2.44	2.75
K^{+}	5.01	4.23	6.02	5.54	6.43	5.43
Li^{+}	ND	ND	ND	ND	ND	ND
Mg^{2+}	3.45	3.88	4.14	5.05	5.80	3.99
Ca^{2+}	1.93	2.87	1.77	2.71	1.70	1.83
Fe^{3+}	1.34	0.97	1.06	1.08	1.48	1.32
Fe^{2+}	4.44	3.66	3.76	4.55	3.74	3.95
Mn^{2+}	0.06	0.03	0.04	0.06	0.03	0.02
P^{5+}	0.21	0.08	0.08	0.06	0.04	0.08
Ti^{4+}	0.52	0.46	0.57	0.61	0.63	0.54
H^{+}	3.97	3.65	3.45	4.08	5.87	6.85
Total	99.94	99.93	99.94	99.94	99.93	99.93

Cation Percentages

	K48	K60	K72
Si^{43}	46.90	46.66	49.86
Al^{3+}	21.65	23.27	21.73
Na^{+}	2.06	2.45	2.46
K^{+}	6.18	6.38	6.40
Li^{+}	ND	ND	ND
Mg^{2+}	3.71	4.02	4.07
Ca^{2+}	0.99	2.88	1.80
Fe^{3+}	1.15	1.41	1.57
Fe^{2+}	3.86	4.45	4.05
Mn^{2+}	0.04	0.05	0.03
P^{5+}	0.05	0.07	0.08
Ti^{4+}	0.48	0.57	0.53
H^{+}	12.86	7.74	7.37
Total	99.93	99.95	99.95

In order to compare the chemical data on modified Von Wolff diagrams it was considered necessary to calculate Catanorms for the pelitic hornfelses instead of Mesonorms.

Catanorm

	K1	K6	K12	K18	K24	K36
Quartz	11.81	19.01	16.13	10.27	9.33	16.51
Orthoclase	25.05	21.15	30.10	27.70	32.15	27.15
Albite	23.25	20.65	10.95	14.70	12.20	13.75
Anorthite	7.90	13.20	8.20	13.05	8.20	8.50
Corundum	9.89	6.31	14.49	10.22	12.20	10.38
Enstatite	6.90	7.76	8.28	10.10	11.60	7.98
Ferrosilite	6.50	5.50	5.40	6.92	4.80	5.54
Magnetite	2.01	1.45	1.59	1.62	2.22	1.98
Ilmenite	1.04	0.92	1.14	1.22	1.26	1.08
Apatite	0.56	0.21	0.21	0.16	0.10	0.21

Catanorm

	K48	K60	K72
Quartz	13.78	7.38	13.10
Orthoclase	30.90	31.90	32.00
Albite	10.30	12.25	12.30
Anorthite	4.55	13.85	8.35
Corundum	11.59	8.90	9.53
Enstatite	7.42	8.04	8.14
Ferrosilite	5.70	6.46	5.54
Magnetite	1.72	2.11	2.35
Ilmenite	0.96	1.14	1.06
Apatite	0.13	0.18	0.21

Chemical Analyses Tables

(Xenoliths and Schlieren)

Specimens series XS83 are xenoliths which were carefully hand picked from granite S83 in Carn-a-langa quarry.

Specimens SCH and SCI are schlieren and contaminated granite respectively which were collected at Sennen Cove.

Weight Percentages

	XS83 a/M	XS83 a/C	XS83 b	SX83 c	SCH	SCI
SiO_2	63.87	63.51	64.95	59.58	60.50	59.97
Al_2O_3	16.62	16.34	16.29	17.41	16.75	17.16
Na_2O	3.80	4.00	3.20	1.85	2.20	2.00
K_2O	3.80	3.60	3.80	3.65	5.30	5.00
Li_2O	ND	ND	ND	0.15	0.15	ND
MgO	1.47	1.27	1.36	2.66	1.64	2.03
CaO	2.14	2.43	1.91	1.53	1.20	0.91
Fe_2O_3	1.33	0.65	1.46	1.94	2.24	3.34
FeO	5.52	6.30	5.36	9.34	7.04	6.66
MnO	0.08	0.10	0.07	0.26	0.12	0.11
P_2O_5	0.34	0.35	0.39	0.11	0.58	0.58
TiO_2	1.15	1.11	1.16	1.41	1.38	1.39
H_2O+	0.51	0.57	0.40	0.53	0.70	0.74
Total	100.63	100.23	100.35	100.42	99.80	99.89

XS83a/M	Margin of fine grained Group 4 xenolith from coarse porphyritic biotite granite S83. Carn-a-langa quarry.
XS83a/C	Centre of fine grained Group 4 xenolith from coarse porphyritic biotite granite S83. Carn-a-langa quarry.
XS83b	Group 3 xenolith from coarse porphyritic biotite granite S83. Carn-a-langa quarry.
XS83c	Group 2 xenolith from coarse porphyritic biotite granite S83. Carn-a-langa quarry.
SCH	Group 5 xenolith from coarse porphyritic biotite granite at Pedn-men-du, Sennen Cove.
SCI	Group 6 xenolith from margin of coarse porphyritic biotite granite. Sennen Cove.

Cation Percentages

	XS83 a/M	XS83 a/C	XS83 B	XS83 C	SCH	SCI
Si^{4+}	57.84	57.54	60.15	55.11	55.55	54.99
Al^{3+}	17.75	17.46	17.78	18.96	18.15	18.51
Na^{+}	6.69	7.02	5.72	3.31	3.92	3.58
K^{+}	4.40	4.13	4.50	4.31	6.23	5.83
Li^{+}	ND	ND	ND	0.15	0.15	ND
Mg^{2+}	1.97	1.70	1.88	3.66	2.25	2.78
Ca^{2+}	2.05	2.37	1.16	1.53	1.16	0.89
Fe^{3+}	0.90	0.46	1.05	1.35	1.57	2.30
Fe^{2+}	4.19	4.79	4.15	7.21	5.39	5.10
Mn^{2+}	0.04	0.05	0.03	0.20	0.07	0.06
P^{5+}	0.23	0.24	0.27	0.06	0.43	0.42
Ti^{4+}	0.78	0.76	0.81	1.00	0.97	0.98
H^{+}	3.10	3.42	2.44	3.27	4.30	4.51
Total	99.94	99.94	99.94	100.~~97~~12	100.~~99~~14	99.95

Catanorm

	XS83 a/M	XS83 a/C	XS83 b	XS83 c	SCH	SCI
Quartz	16.30	14.60	23.34	19.99	18.26	20.63
Ortho-clase	22.00	20.65	22.50	21.55	31.15	29.15
Albite	33.45	35.10	28.60	16.55	19.60	17.90
Anorth-ite	8.35	9.85	3.55	7.15	2.20	0.95
Corun-dum	3.32	2.37	6.14	8.48	7.12	8.72
Enstat-ite	3.94	3.40	3.76	7.32	4.50	5.56
Ferros-ilite	5.92	7.70	5.70	11.48	7.42	5.94
Magnet-ite	1.35	0.69	1.57	2.02	2.35	3.45
Ilmenite	1.66	1.52	1.62	2.00	1.94	1.96
Apatite	0.61	0.64	0.72	0.16	1.15	1.12

Chemical Analyses Tables

(Gwavas Quarry)

These analyses are from a short transect across the junction between an aplite vein which cuts and biotises meta-igneous hornfels.

Weight Percentages

	AV(1)	AVH/1	AVH/6
SiO	74.14	54.51	55.84
Al_2O_3	16.33	21.19	20.23
Na_2O	4.13	5.90	7.40
K_2O	2.75	2.90	0.40
Li_2O	0.15	0.70	-
MgO	0.30	0.83	1.15
CaO	0.46	2.75	3.45
Fe_2O_3	0.47	1.93	2.85
FeO	0.36	6.02	7.48
MnO	0.03	0.19	0.23
P_2O_5	0.31	0.12	0.16
TiO_2	0.03	0.57	0.63
H_2O+	0.07	0.65	0.73
Total	99.53	98.26	100.55

AV(1) Aplite vein cutting hornblende plagioclase hornfels. Sample taken 1 inch from contact.

AVH/1 Biotised meta-igneous hornfels (originally hornblende plagioclase hornfels) 1 inch from contact.

AVH/6 Hornblende plagioclase hornfels 6 inches from contact.

Cation Percentages

	AV(1)	AVH/1	AVH/6
Si^{4+}	69.20	48.15	49.00
Al^{3+}	17.97	22.07	20.90
Na^{+}	7.45	10.08	12.59
K^{+}	3.25	3.29	0.42
Li^{+}	0.20	2.49	-
Mg^{2+}	0.39	1.09	1.50
Ca^{2+}	0.46	2.60	3.24
Fe^{3+}	0.32	1.31	1.87
Fe^{2+}	0.29	4.47	5.47
Mn^{2+}	0.02	0.15	0.17
P^{5+}	0.23	0.07	0.10
Ti^{4+}	0.02	0.39	0.43
H^{+}	0.39	3.82	4.26
Total	100.19	99.98	99.95

Catanorms

	AV(1)	AVH/1 *	AVH/6 *
Quartz	36.44	(-8.93)	(-2.47)
Orthoclase	16.25	28.90	2.10
Albite	37.25	50.40	62.95
Anorthite	0.40	12.45	15.40
Corundum	7.11	1.23	0.73
Enstatite	0.78	2.18	3.00
Ferrosilite	0.22	6.86	9.56
Magnetite	0.48	1.96	2.80
Ilmenite	0.04	0.78	0.86
Apatite	0.61	0.18	0.26

* Norms for AVH/1 and AVH/2 were calculated on the assumption that unlimited silica was present. This modification was introduced into the method for the construction of modified Von Wolff diagrams, the difference between available silica and that used in the calculation is shown above as minus values.

Chemical Analyses Tables

(Minerals)

Specimen SCI/Bi is black-bronze biotite extracted from contaminated granite (SCI) at Sennen Cove.

Specimens TS/F, S80/F, PCE/F, S83/F, S39/F, S105/F are all feldspar megacrysts extracted from fresh coarse porphyritic biotite granites and pegmatites.

Weight Percentages

	I	II
SiO_2	38.90	46.74
Al_2O_3	22.00	21.78
Na_2O	0.33	0.54
K_2O	9.32	10.37
Li_2O	1.49	3.72
MgO	0.50	-
CaO	1.30	-
Fe_2O_3	0.50	1.19
FeO	18.80	10.22
MnO	0.34	0.37
P_2O_5	ND	ND
TiO_2	0.36	-
H_2O+	4.58	0.89
F_2	4.00	6.75
Total	102.42	102.57
Less O for F	1.68	2.85
	100.74	99.72

I Trelavour Mica, Cornwall.

II Zinnwaldite, Zinnwald.

(After Cundy et al 1960)

Weight Percentages

	SCI/Bi
SiO_2	35.18
Al_2O_3	20.90
Na_2O	0.30
K_2O	8.60
Li_2O	1.60
MgO	3.43
CaO	0.05
Fe_2O_3	6.03
FeO	18.54
MnO	0.23
P_2O_5	0.13
TiO_2	3.20
H_2O+	1.80
Total	99.99

Black-bronze biotite from highly contaminated granite at Sennen Cove. (The mineral was extracted by crushing the rock, which contains 28% modal biotite and sifting off the feldspar and quartz fraction. This was followed by further crushing and fractionation of biotite on a Franz Isodynamic Magnetic Separator. Any impurities remaining were removed by hand picking.

Weight Percentages

	TS/F	PCE/F	S105/F	S80/F	S83/F	S39/F
SiO_2	62.04	64.59	65.90	62.01	63.78	63.58
Al_2O_3	19.01	19.19	20.26	19.83	19.15	20.41
Na_2O	2.00	3.70	9.20	2.40	3.28	3.28
K_2O	14.00	11.70	1.30	13.20	11.45	10.50
Li_2O	0.80	0.15	ND	0.80	ND	ND
MgO	0.68	0.14	0.65	0.53	0.93	0.46
CaO	0.71	0.37	0.86	0.79	0.81	0.81
Fe_2O_3	0.00	0.00	0.53	0.08	0.02	0.00
FeO	0.26	0.00	0.28	0.28	0.07	0.12
MnO	0.01	0.00	0.01	0.01	0.01	0.01
P_2O_5	0.47	0.20	0.48	0.15	0.13	0.14
TiO_2	0.02	0.02	0.01	0.17	0.26	0.45
H_2O+	0.36	0.31	0.58	0.36	0.05	0.42
Total	100.36	100.37	100.06	100.61	99.94	100.18

TS/F Perthite megacryst from roof zone of Tremearne pegmatite sheet.
PCE/F Perthite megacryst from roof zone of Porthmeor pegmatite.
S105/F Megacryst from pegmatite at Knill's Steeple.
S80/F Perthite megacryst from granite 700 yds S of Halse Town.
S83/F Perthite megacryst from granite at Carn-a-langa.
S39/F Perthite megacryst from granite at Castallack.

Cation Percentages

	TS/F	PCE/F	S105/F	S80/F	S83/F	S39/F
Si^{4+}	54.31	57.61	56.84	54.11	57.88	56.66
Al^{3+}	19.62	20.18	20.58	20.37	20.49	21.46
Na^{+}	3.41	6.37	15.39	4.03	5.74	5.67
K^{+}	15.62	13.28	1.45	14.67	13.25	11.96
Li^{+}	2.84	-	ND	2.83	ND	ND
Mg^{2+}	0.87	0.17	0.83	0.67	1.25	0.60
Ca^{2+}	0.64	0.34	0.79	0.72	0.77	0.76
Fe^{3+}	-	-	0.34	0.04	0.01	-
Fe^{2+}	0.18	-	0.19	0.19	0.03	0.06
Mn^{2+}	-	-	-	-	-	-
P^{5+}	0.35	0.16	0.35	0.10	0.08	0.05
Ti^{4+}	0.01	0.01	-	0.12	0.19	0.29
H^{+}	2.10	1.87	3.21	2.09	0.27	2.47
Total	99.95	99.99	99.97	99.94	99.96	~~100.07~~ 99.98

Normative Percentages

	TS/F	PCE/F	S105/F	S80/F	S83/F	S39/F
Ortho-clase	80.8	67.4	8.4	76.3	67.4	65.3
Albite	17.6	32.2	89.8	20.8	29.2	30.9
Anorth-ite	1.5	0.3	1.7	2.8	3.2	3.7

	Q	L	M	Alk	Fm
XS83a/M	16.8	69.3	13.7	9.7	8.3
XS83a/C	15.1	70.4	14.4	10.0	8.2
XS83b	23.9	62.4	13.7	8.9	8.2
XS83c	20.6	55.6	23.7	7.0	13.9
SCH	19.1	62.8	18.0	8.7	10.9
SC1	21.6	59.4	18.8	7.9	12.0
AV(1)	36.44	61.01	2.13	7.3	1.1
AVH(1)	-7.8	81.6	10.5	11.5	8.8
AVH(6)	-2.4	81.2	16.5	11.2	11.5
K1	12.4	69.6	17.9	9.6	10.4
K6	19.7	63.8	16.3	9.0	9.1
K12	16.7	66.0	17.2	8.5	9.8
K18	10.7	68.4	20.8	9.3	11.4
K24	9.8	68.8	21.2	8.9	11.5
K36	17.7	64.3	17.8	8.4	10.4
K48	15.8	65.8	18.2	8.2	10.4
K60	8.0	72.5	19.4	10.3	11.3
K72	14.1	67.1	18.6	9.1	11.0
PCEM	35.8	61.0	3.0	8.3	2.1
PCEG	31.6	64.6	3.6	8.8	2.1
PCEA	19.9	78.5	1.5	10.8	0.5
PCES	35.9	61.8	2.2	7.1	1.4
G1a	29.6	67.9	2.3	9.5	1.3
G1	30.5	66.7	2.7	8.8	1.5
G6	28.3	69.2	2.3	9.7	1.5
G12	28.1	67.2	4.5	9.6	2.6
G18	32.5	65.6	1.8	8.9	1.0
G24	31.1	65.5	3.2	9.4	1.9
G30	30.1	64.6	5.2	9.3	3.1
G36	34.3	60.2	5.3	8.5	3.1
G48	33.5	62.2	4.2	8.9	2.5
G60	27.8	66.0	6.1	9.8	3.2
G84	32.0	61.4	6.5	8.9	3.4

	Q	L	M	Alk	Fm
S120	47.0	46.2	6.6	5.1	4.5
S91	32.5	62.5	4.8	8.4	3.7
S17	27.0	66.0	6.8	9.1	4.3
114	30.7	63.8	5.4	8.8	3.3
S39	42.8	51.3	5.8	7.7	3.3
S33	28.9	66.2	4.8	9.3	3.0
S15	28.2	65.9	5.8	9.3	3.3
S44	27.2	68.1	4.5	9.9	3.0
S34	27.1	67.0	5.8	9.8	3.2
S28	36.1	59.3	4.5	7.9	2.7
95	20.3	74.8	4.7	9.7	3.2
S5	27.9	66.6	5.4	9.7	3.2
S73	28.5	65.5	5.8	9.3	3.5
S61	31.5	63.2	5.2	9.2	3.0
S83	26.1	66.9	6.2	9.6	3.5
S10	27.8	66.2	6.0	9.5	3.9
S47/K	55.8	40.2	3.8	4.5	1.9
S4	27.7	68.3	3.9	9.8	2.3
S48	23.8	73.6	2.4	10.5	1.7
S31	37.3	59.2	3.3	7.9	1.9
S58	31.8	65.9	2.1	9.3	1.4
B36	13.5	83.6	2.8	11.8	2.7
S52	38.7	56.2	5.0	8.0	2.6
2C	31.1	62.5	6.3	8.8	2.9
P3	30.9	59.9	9.1	8.2	4.2

Modal Analyses

(Granites).

	(V/U)		(V/U)
S1	119/122	S62	153/37
S2	108/138	S63	150/30
S3	97/150	S64	115/61
S4	174/136	S65	71/8
S5	32/41	S66	43/43
S6	41/28	S67	75/70
S7	40/53	S68	109/26
S8	53/51	S69	109/17
S9	67/53	S70	95/31
S14	192/164	S71	82/13
S15	192/155	S72	52/31
S16	139/26	S73	99/70
S18	51/13	S74	111/68
S19	149/132	S75	56/78
S20	141/150	S76	53/65
S22	149/177	S77	83/59
S23	163/180	S78	85/112
S25	177/179	S79	201/165
S28	187/180	S81	123/27
S29	164/141	S82	122/58
S30	136/160	S83	140/62
S31	206/178	S84	109/83
S32	126/162	S85	99/83
S33	121/53	S86	45/96
S34	55/123	S87	53/96
S36	86/97	S89	193/138
S38	69/95	S91	78/119
S39	137/43	S92	72/121
S59	206/150	S93	125/136
2S	177/182	S94	131/110
SC1	45/53	S83X	140/62
SC2	45/53		

Note:- The geographical location of the above specimens is given as coordinates V/U - see map. Land's End granites.

The coarseness is indicated by the C.I. Number.

Modal Analyses

	S1	S2	S3	S4	S5	S6
Quartz	38.28	39.26	41.06	36.79	34.48	34.27
Orthoclase	27.81	28.56	30.95	28.71	31.03	22.52
Plagioclase	18.07	13.01	12.15	16.38	9.25	10.53
Biotite	6.18	5.78	4.78	3.44	4.90	7.46
Muscovite	1.66	4.38	1.57	4.98	3.81	3.06
IIry Mica in Plagioclase	1.45	1.42	1.09	5.83	5.63	7.58
IIry Mica in Orthoclase	1.01	2.28	0.90	1.99	5.44	2.94
Tourmaline	2.59	0.31	0.98	0.87	0.56	0.12
Topaz	-	-	-	-	-	-
Andalusite	-	0.69	0.17	0.31	0.91	0.37
Zircon	0.08	-	0.02	0.09	-	-
Ore	0.04	-	0.35	0.04	-	0.61
Clay Minerals	2.85	4.26	5.95	0.50	3.99	10.53
Total	100.02	99.95	99.97	99.93	100.00	99.99
No. of points counted	4947	4149	5104	4558	4102	4634
CI	57	67	45	129	42	46
Colour Index	8.81	6.09	6.11	4.35	5.44	8.19
Or/Plag Ratio	1.28	1.65	1.65	1.35	1.93	0.88
Total feldspar	51.19	49.53	51.04	53.41	55.34	54.10
Quartz	42.7	44.2	44.58	40.6	38.38	38.78
Total Orthoclase	32.2	34.7	34.58	34.1	40.60	28.81
Total Plagioclase	25.0	21.0	20.83	25.3	21.01	32.41

Modal Analyses

	S7	S8	S9	S14	S15
Quartz	29.18	24.74	34.63	25.49	33.52
Orthoclase	30.07	39.20	42.27	31.73	32.31
Plagioclase	12.15	10.03	7.98	14.26	11.69
Biotite	9.13	9.82	4.41	11.76	6.93
Muscovite	1.49	1.43	2.55	1.96	3.99
IIry Mica in Plagioclase	7.68	3.39	2.37	3.21	6.08
IIry Mica in Orthoclase	0.63	1.88	0.34	1.60	0.51
Tourmaline	1.29	1.67	0.68	2.32	0.79
Topaz	-	-	-	-	0.02
Andalusite	0.14	-	1.02	-	0.16
Zircon	0.10	0.14	-	-	0.06
Ore	0.14	0.11	-	-	0.22
Clay Minerals	7.96	7.51	3.73	7.55	3.65
Total	99.96	~~100.03~~ 99.92	99.98	99.88	99.93
No.of points counted	4948	3862	4178	4683	4902
CI	38	48	41	40	41
Colour Index	10.56	11.60	5.09	14.08	7.94
Or/Plag Ratio	1.10	1.96	3.02	1.33	1.79
Total Feldspar	58.49	62.01	56.69	58.35	59.81
Quartz	33.28	28.52	37.92	30.39	35.91
Total Orthoclase	35.00	47.35	46.66	39.75	41.13
Total Plagioclase	31.69	24.12	15.42	29.84	22.95

Modal Analyses

	S16	S18	S19	S20	S22	S23
Quartz	32.84	34.48	33.41	30.26	24.74	33.25
Orthoclase	34.80	27.33	36.17	38.37	40.22	28.32
Plagioclase	5.76	11.14	10.84	5.93	12.22	9.38
Biotite	9.31	5.45	6.04	5.19	5.83	5.84
Muscovite	2.45	2.18	6.36	3.12	1.94	3.82
IIry Mica in Plagioclase	5.39	4.70	0.87	2.81	1.94	3.96
IIry Mica in Orthoclase	3.06	0.87	1.92	9.25	2.59	1.09
Tourmaline	1.22	1.95	0.63	1.60	0.86	1.09
Topaz	-	-	-	-	-	-
Andalusite	-	-	0.82	0.51	0.23	0.31
Zircon	-	0.30	0.04	0.06	0.35	0.07
Ore	-	0.12	0.04	-	0.07	0.10
Clay Minerals	5.15	11.26	2.80	2.81	9.00	12.71
Total	99.98	99.~~9~~78	99.94	99.91	99.99	99.94
No. of Points counted	4632	3996	4103	4808	4321	3824
CI	46	37	42	33	30	31
Colour Index	10.53	7.52	6.71	6.85	6.76	7.03
Or/Plag Ratio	2.32	1.03	2.62	3.56	1.85	1.12
Total feldspar	54.16	55.50	52.60	52.73	65.97	55.46
Quartz	37.75	38.32	38.84	36.45	27.27	37.48
Total Ortho-clase	43.52	31.34	44.28	49.62	47.19	33.15
Total Plagio-clase	18.73	30.34	16.87	13.91	25.53	29.36

Modal Analyses

	S25	S28	S29	S30	S31	S32
Quartz	32.19	41.73	33.42	24.07	26.46	36.36
Orthoclase	36.36	22.35	33.01	32.08	38.86	25.94
Plagioclase	7.56	17.00	15.09	7.74	22.52	20.39
Biotite	6.28	5.38	3.93	5.33	4.46	3.26
Muscovite	4.28	4.28	4.06	3.63	0.66	4.80
IIry Mica in Plagioclase	3.03	1.86	5.10	4.61	1.49	3.95
IIry Mica in Orthoclase	0.96	0.62	2.27	0.60	0.45	1.69
Tourmaline	1.57	1.62	1.31	0.35	-	3.26
Topaz	-	-	-	-	-	-
Andalusite	0.37	-	0.14	0.17	-	0.02
Zircon	0.14	0.27	0.07	0.12	0.09	-
Ore	0.18	-	0.14	-	-	0.13
Clay Minerals	7.01	4.88	1.45	21.26	5.02	0.15
Total	99.93	99.99	99.99	99.96	100.01	99.95
No. of points counted	4246	5164	4353	3992	4218	4476
CI	37	32	107	36	61	101
Colour Index	8.03	7.00	5.38	5.68	4.46	6.65
Or/Plag Ratio	2.12	0.97	1.61	0.97	1.35	1.12
Total Feldspar	54.92	46.71	56.92	66.29	68.34	52.12
Quartz	36.95	47.18	36.99	26.63	27.91	41.05
Total Orthoclase	42.84	25.97	39.05	36.16	41.46	31.24
Total Plagioclase	20.20	26.84	23.95	37.19	30.62	27.69

Modal Analyses

	S33	S34	S36	S38	S39	S59
Quartz	35.80	31.61	31.98	31.93	30.11	35.80
Orthoclase	22.21	30.34	0.39	37.47	36.68	22.70
Plagioclase	16.10	21.42	0.07	12.41	12.47	10.34
Biotite	4.00	6.58	4.53	6.26	6.20	5.10
Muscovite	6.12	1.77	0.07	0.84	4.09	4.31
IIry Mica in Plagioclase	4.71	2.16	0.28	1.68	1.36	3.72
IIry Mica in Orthoclase	2.10	2.10	0.07	0.60	1.38	1.10
Tourmaline	1.60	1.11	1.83	1.68	0.42	1.90
Topaz	-	0.24	-	-	-	-
Andalusite	0.21	0.10	-	-	0.77	0.51
Zircon	0.12	0.41	-	-	0.18	0.04
Ore	0.18	2.08	0.14	-	0.05	0.20
Clay Minerals	6.62	0.04	60.62	7.71	6.27	13.82
Total	99.~~69~~ 77	99.96	99.98	100.~~05~~ 58	99.98	99.~~90~~ 54
No. of points counted	4641	4571	4259	4503	4274	4318
CI	39	61	32	30	37	34
Colour Index	5.7	8.10	6.50	7.94	6.67	7.2
Or/Plag Ratio	1.97	1.26	0.01	1.79	1.89	0.85
Total Feldspar	51.7	58.10	61.36	59.27	58.16	51.60
Quartz	40.91	35.23	34.20	35.0	34.11	40.96
Total Orthoclase	39.20	36.15	0.50	41.7	43.12	27.23
Total Plagioclase	19.88	28.60	65.20	23.2	22.77	31.80

Modal Analyses

	S62	S63	S64	S65	S66	S67
Quartz	33.50	29.8	30.71	41.8	32.1	37.1
Orthoclase	33.13	36.7	39.52	27.2	17.6	18.3
Plagioclase	6.20	7.8	11.20	15.1	28.4	16.5
Biotite	7.41	5.2	5.41	4.1	6.5	3.7
Muscovite	6.42	3.2	3.12	4.5	1.9	3.2
IIry Mica in Plagioclase	7.31	8.4	3.53	3.0	1.6	9.6
IIry Mica in Orthoclase	2.70	1.5	1.10	1.1	0.6	1.6
Tourmaline	1.82	4.1	2.41	1.6	4.6	2.5
Topaz	-	-	-	-	-	-
Andalusite	-	0.5	-	-	-	-
Zircon	0.41	0.1	0.20	-	0.1	-
Ore	0.04	0.1	-	0.2	0.2	0.3
Clay Minerals	0.90	2.1	2.41	1.1	5.9	6.7
Total	99.84	99.5	99.61	99.7	99.5	99.5
No.of points counted	4392	3730	4406	3909	3735	3930
CI	40	47	34	33	34	34
Colour Index	9.2	9.40	7.80	5.9	11.3	6.5
Or/Plag Ratio	2.48	2.08	2.37	1.47	0.50	0.60
Total Feldspar	50.2	56.50	57.70	47.5	54.1	52.7
Quartz	40.02	34.53	31.19	46.80	37.23	41.31
Total Orthoclase	42.77	44.26	41.26	31.69	21.11	22.16
Total Plagioclase	17.20	21.20	27.54	21.50	41.64	36.52

Modal Analyses

	S68	S69	S70	S71	S72	S73
Quartz	30.8	32.8	36.0	28.6	35.6	28.6
Orthoclase	45.9	30.2	17.4	36.5	27.2	27.8
Plagioclase	8.9	9.7	5.6	12.4	11.9	9.8
Biotite	4.0	6.6	5.6	7.7	5.5	8.4
Muscovite	0.8	3.9	4.2	1.1	0.7	5.6
IIry Mica in Plagioclase	3.1	9.0	4.2	4.1	3.1	5.6
IIry Mica in Orthoclase	2.4	1.8	2.3	0.8	0.5	0.8
Tourmaline	3.3	0.9	0.5	2.3	1.3	0.3
Topaz	-	-	-	-	-	-
Andalusite	-	0.8	-	0.6	-	0.05
Zircon	-	-	0.1	0.1	0.5	0.1
Ore	0.1	0.1	0.4	-	0.1	0.2
Clay Minerals	0.1	3.8	23.2	5.1	12.9	13.0
Total	99.4	99.6	99.5	99.3	99.3	~~99.6~~ 100.2 (s)
No. of points counted	4145	3740	4292	4595	3762	3937
CI	44	33	41	45	40	41
Colour Index	7.4	7.6	6.5	10.0	6.9	8.9
Or/Plag Ratio	3.99	1.42	0.59	1.72	0.99	1.02
Total feldspar	60.4	54.5	52.7	58.9	55.6	56.4
Quartz	33.77	37.57	40.58	32.68	39.03	33.64
Total Orthoclase	52.96	36.65	22.20	42.62	33.22	33.64
Total Plagioclase	13.26	25.78	37.20	24.68	27.74	22.70

Modal Analyses

	S74	S75	S76	S77	S78	S79
Quartz	39.4	38.92	27.3	29.5	38.48	55.6
Orthoclase	29.1	29.29	25.1	37.1	24.38	8.7
Plagioclase	6.9	21.94	20.7	8.4	14.33	16.3
Biotite	5.9	1.86	7.3	6.5	2.6	7.0
Muscovite	5.8	3.20	1.2	2.1	2.8	4.9
IIry Mica in Plagioclase	2.6	1.72	7.9	5.7	7.2	3.5
IIry Mica in Orthoclase	1.1	0.97	3.3	2.3	0.9	2.3
Tourmaline	0.2	0.46	3.3	1.4	2.5	-
Topaz	-	-	-	-	-	-
Andalusite	0.4	-	-	0.1	0.1	0.5
Zircon	0.2	0.09	0.1	0.03	-	-
Ore	0.2	0.16	-	0.1	0.1	-
Clay Minerals	7.6	1.34	3.3	6.3	6.3	0.8
Total	99.4	99.95	99.5	99.5	99.~~5~~ 6(9)	99.6
No. of points counted	4201	4301	4544	3853	4113	4564
CI	34	86	21	39	42	27
Colour Index	6.3	2.48	10.6	8.0	5.2	7.0
Or/Plag Ratio	1.76	1.21	0.89	1.93	0.91	0.53
Total Feldspar	47.3	55.26	60.3	59.8	53.1	31.6
Quartz	45.44	41.32	31.16	33.03	42.01	63.76
Total Orthoclase	34.83	32.12	32.42	44.12	27.60	12.61
Total Plagioclase	19.72	26.54	36.41	22.84	30.38	23.62

Modal Analyses

	S81	S82	S83	S84	S85	S86
Quartz	29.7	30.3	30.5	26.0	41.2	39.3
Orthoclase	36.5	41.3	37.6	39.7	31.1	29.2
Plagioclase	10.8	9.5	7.3	10.0	6.5	16.9
Biotite	6.8	5.1	6.0	5.5	5.2	2.6
Muscovite	2.6	3.8	4.4	2.3	0.7	0.9
IIry Mica in Plagioclase	7.0	2.8	2.5	5.0	4.6	4.9
IIry Mica in Orthoclase	1.4	0.8	0.4	0.7	3.2	2.6
Tourmaline	1.0	0.2	0.4	1.1	-	2.5
Topaz	-	-	-	-	-	-
Andalusite	0.3	0.06	0.5	-	-	-
Zircon	-	0.06	0.04	-	-	-
Ore	0.1	0.1	0.2	0.1	-	-
Clay Minerals	3.1	5.9	9.6	8.9	7.2	0.7
Total	99.3	99.~~5~~9(2)	99.4	99.3	99.7	99.6
No.of points counted	4044	4597	4491	3685	3854	4486
CI	29	31	34	45	26	39
Colour Index	7.9	5.4	6.6	6.7	5.2	5.1
Or/Plag Ratio	1.81	2.35	1.95	1.69	1.87	1.41
Total Feldspar	58.8	60.0	57.4	64.3	52.6	54.3
Quartz	33.55	33.55	34.69	28.79	43.92	42.07
Total Orthoclase	42.82	46.62	43.23	44.73	36.56	34.04
Total Plagioclase	23.61	19.82	22.07	26.46	19.50	23.87

Modal Analyses

	S87	S89	S91	S92	S93	S94
Quartz	33.3	24.36	38.91	29.2	36.1	36.0
Orthoclase	30.9	23.43	24.48	39.8	39.2	38.7
Plagioclase	24.3	13.65	8.07	14.7	3.2	12.7
Biotite	0.3	3.58	6.86	2.2	4.8	4.3
Muscovite	0.4	4.06	3.89	3.5	1.8	0.2
IIry Mica in Plagioclase	3.1	10.84	3.94	4.5	6.8	4.0
IIry Mica in Orthoclase	0.5	8.32	2.87	0.7	2.5	1.0
Tourmaline	2.3	10.94	0.27	4.1	1.7	0.2
Topaz	-	-	-	-	-	-
Andalusite	-	0.09	-	-	0.2	0.6
Zircon	-	-	0.23	-	-	0.1
Ore	0.2	-	-	-	-	-
Clay Minerals	4.2	0.67	10.38	0.8	3.2	1.8
Total	99.5	99.94	99.90	99.5	99.5	99.6
No. of points counted	4545	4130	4312	3926	3991	3797
CI	38	106	70	48	40	32
Colour Index	2.8	14.52	7.13	6.3	6.5	4.5
Or/Plag Ratio	0.99	1.26	1.22	2.02	3.15	2.14
Total Feldspar	63.0	56.90	49.74	60.5	54.9	58.2
Quartz	34.57	29.97	43.89	29.2	39.67	38.21
Total Orthoclase	32.60	39.05	30.85	40.5	45.82	42.14
Total Plagioclase	32.81	30.96	25.25	29.9	14.50	18.57

Modal Analyses

	2S	SC1	SC2	S83X
Quartz	36.75	25.59	32.72	30.87
Orthoclase	26.62	6.55	0.21	8.13
Plagioclase	12.47	14.35	24.61	2.19
Biotite	8.63	28.23	5.13	43.66
Chlorite	-	1.85	4.96	0.38
Muscovite	3.48	2.23	7.03	6.07
IIry Mica in Plagioclase	8.62	13.83	18.48	5.94
IIry Mica in Orthoclase	0.93	0.90	0.47	1.29
Tourmaline	0.39	2.66	5.39	-
Cordierite	-	3.18	-	-
Topaz	-	-	-	-
Andalusite	1.63	-	-	-
Zircon	0.05	-	-	-
Ore	0.02	-	-	1.42
Rutile	-	0.61	0.94	-
Clay Minerals	0.38	-	-	-
Total	99.97	99.98	99.94	99.95
No. of points counted	3534	2104	2316	3774
CI	68	-	-	-
Colour Index	9.04	31.50	11.46	45.08
Or/Plag Ratio	1.28	0.26	0.01	1.15
Total Feldspar	49.02	35.63	43.77	17.55
Quartz	42.84	41.78	42.77	63.75
Total Orthoclase	32.12	12.17	0.91	19.45
Total Plagioclase	25.03	46.04	56.30	16.79

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Text figure 1. Trevean Cliffs situated on the north coast near Morvah. This photograph illustrates the ruggedness of the northern cliffs when compared with those of the south east coast (Text figure 2). Note also the floor joints which dip at a few degrees from the horizontal towards the north and the more or less vertical NNW-SSE (from left to right) and NE-SW (towards camera) joints.

Text figure 2. The Gazell, situated on the south east coast near Lamorna. This photograph illustrates the gentler nature of the coast in this area which slopes down to sea level. Note also the floor joints, which dip quite steeply to the south, and those at approximately 70° running NE-SW (towards camera).

Text figure 1

Text figure 2

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Text figure 3. View looking southwards across Amalveor Downs. The photograph illustrates the poor exposure on this downland which is very typical of the fine grained granite areas. The central region of this fine granite is kaolinised and weathers to give a very fertile soil.

Text figure 4. Photograph illustrating typical hillside clitter on the coarse porphyritic and medium grained granites at Morvah, looking south. Note the sporadic tor exposure of bedrock as opposed to the many loose boulders. Floor joints in the tors can be seen to dip very gently towards the left (north).

Text figure 3

Text figure 4

Text figure 5. Photograph illustrating coarse porphyritic granite country on the northern coast below Carn Galver. Note the two arrowed tors with a slight saddle between them, in many cases along the north coast this saddle is occupied by medium grained non-porphyritic granite.

Text figure 6. Photograph of Rosewall Hill west showing one of the many tor exposures such as occur along the north coast. The granite here is the coarse porphyritic variety and the floor joints can be seen to dip gently off the hill-side towards the coast in the distance (north).

Between the tor and the coast can be noted the extensively farmed 400 ft. marine platform through which the granite/hornfels contact runs.

Text figure 5

Text figure 6

Aureole Rocks

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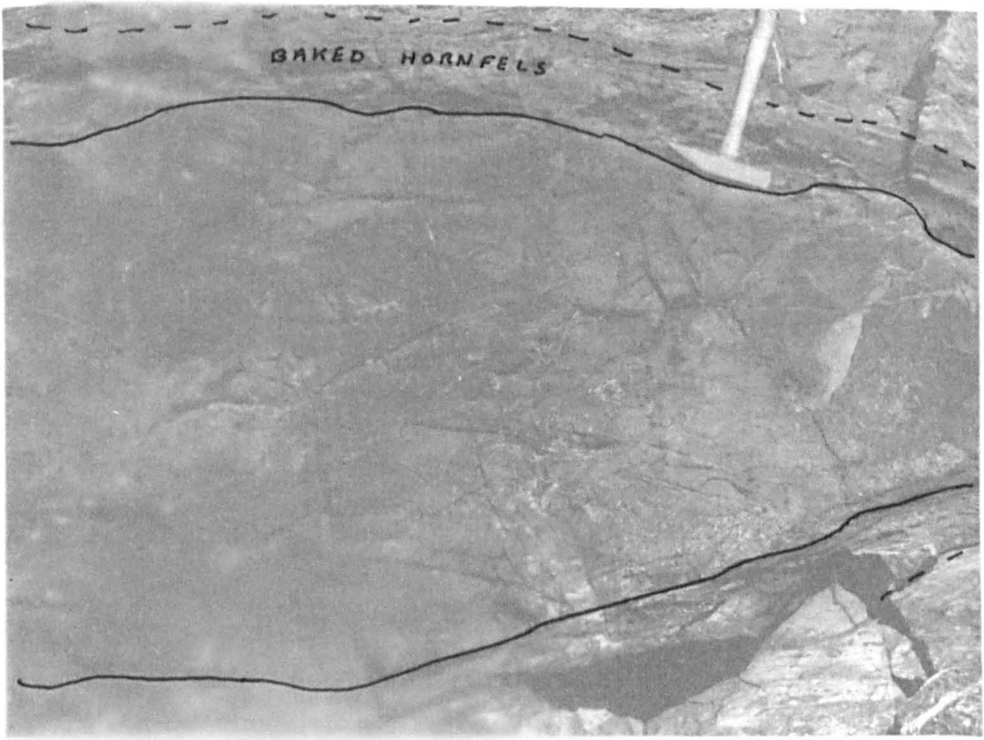
Text figure 7. Priests Cove. Sill of massive dolerite invading biotite-muscovite-cordierite hornfelses. Note the baking of the pelitic hornfels as indicated on the tracing overlay and the resolved stresses as now shown by amphibole filled cracks.

Text figure 8. Priests Cove. Photograph of the discordant junction between the massive dolerite and the adinolised pelitic hornfels.



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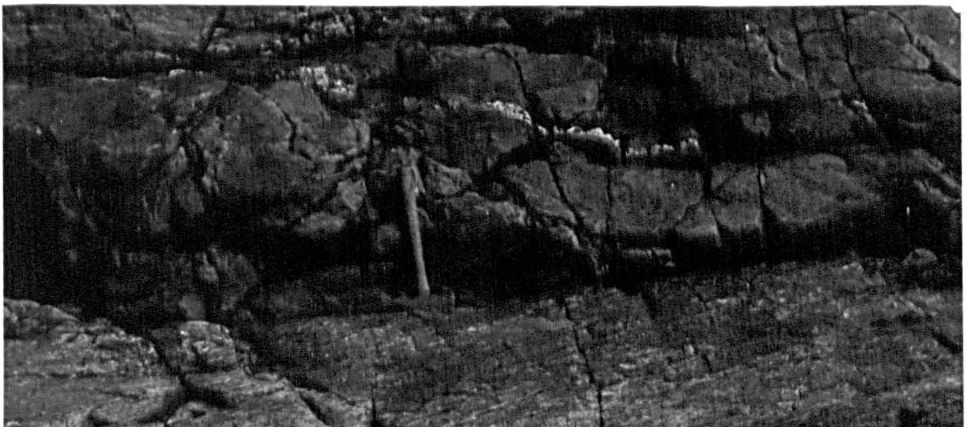

Text figure 8

Text figure 9

Text figure 10

Main Granite Types

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Text figure 11. Highly Porphyritic Biotite Granite, Land's End.

Text figure 12. Moderately Porphyritic Biotite Granite, Mousehole.

Text figure 11

Text figure 12

Text figure 13. Medium to Coarse Grained Non-Porphyritic Granite, Priest's Cove.

Text figure 14. Tourmaline Pegmatite in Medium to Coarse Grained Non-Porphyritic Granite, Priest's Cove.

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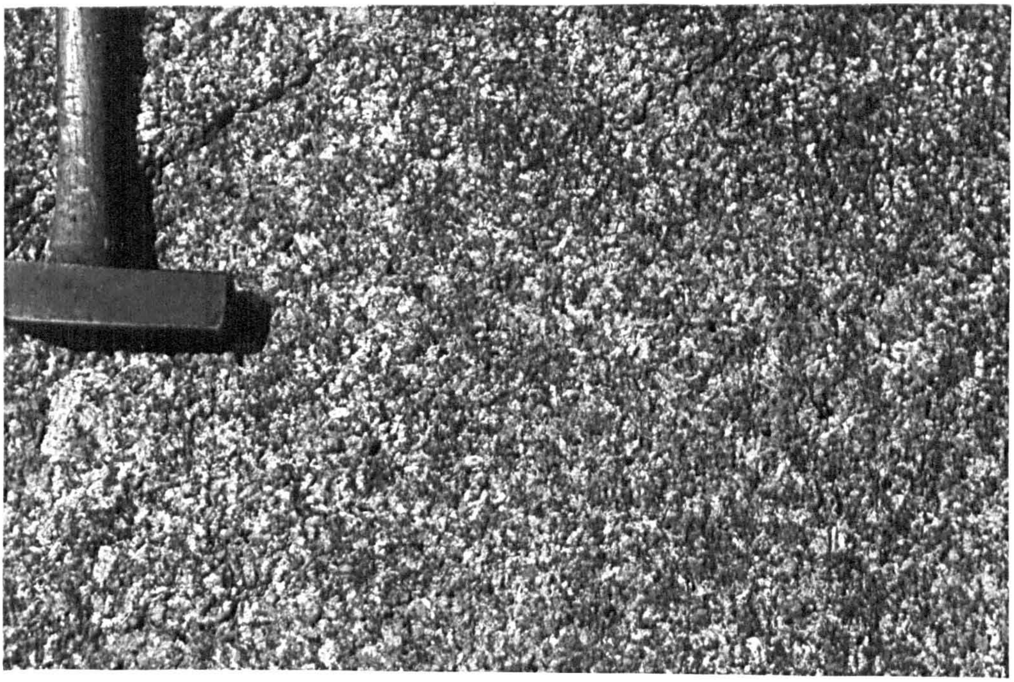
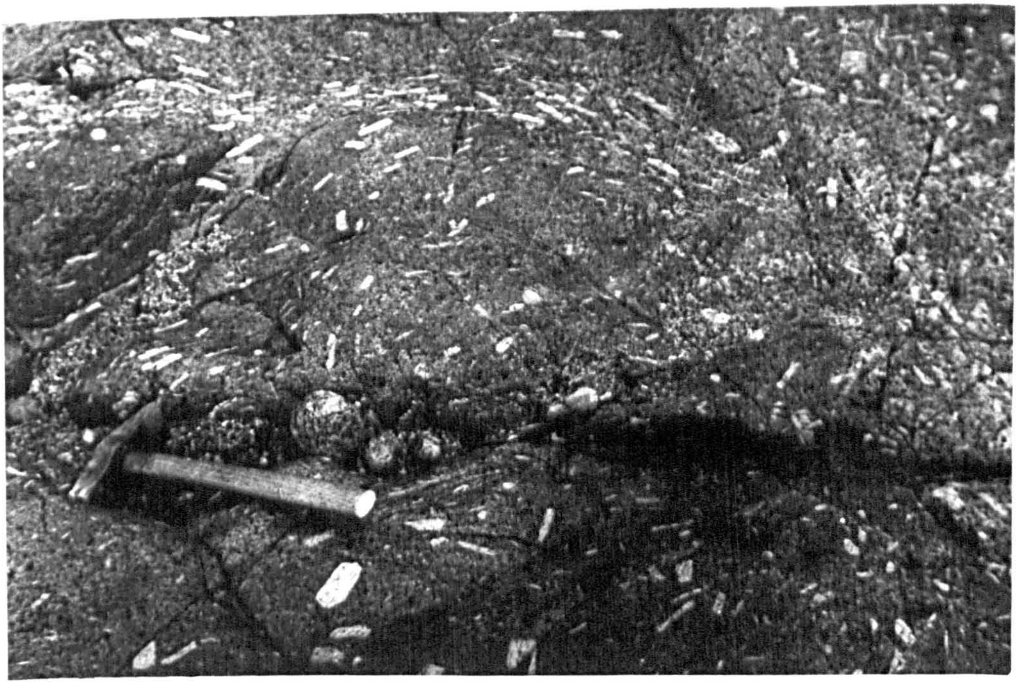


Text figure 13

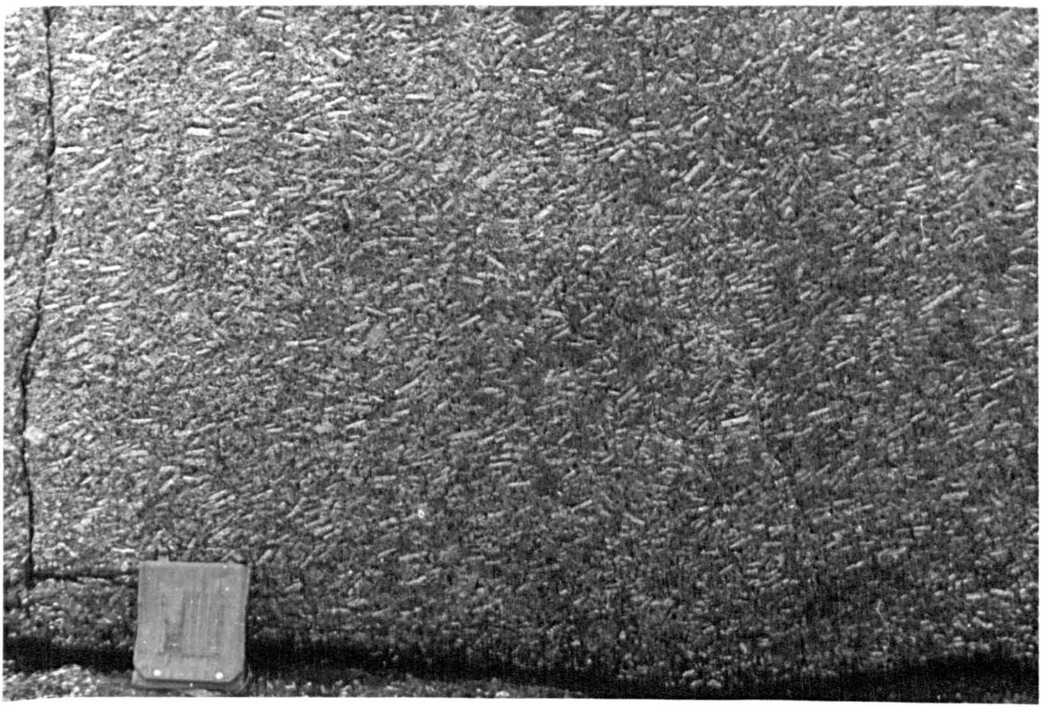
Text figure 14

Text figure 15. Flow foliation around contaminated granite, Sennen Cove.

Text figure 16. Highly porphyritic biotite granite, Pedn-men-du. Illustrating the uniform orientation of the feldspar megacrysts.



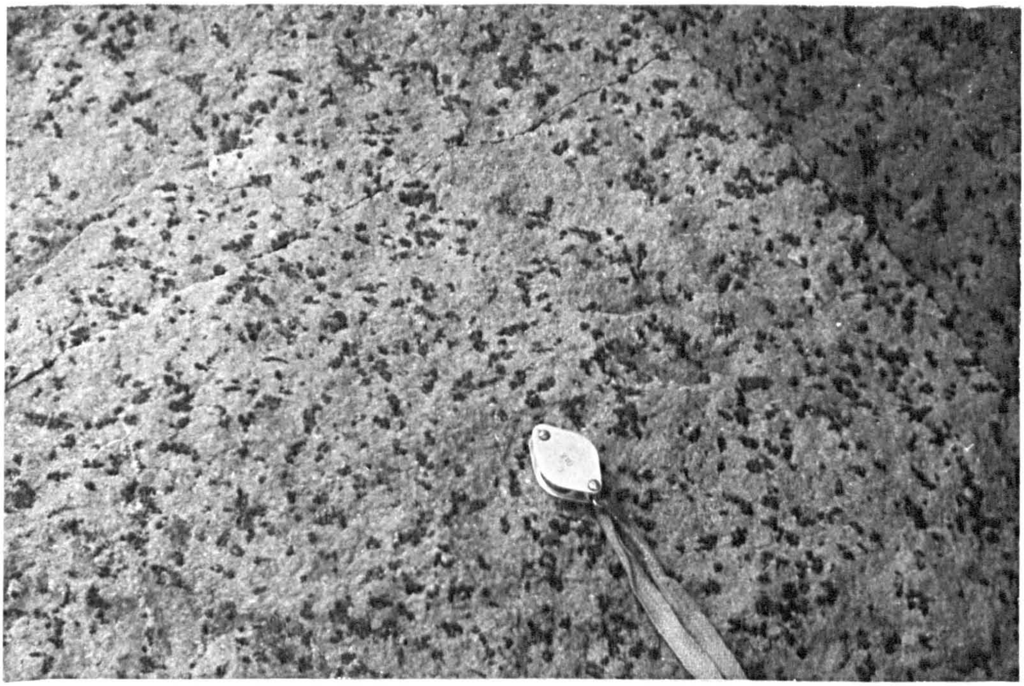
Text figure 15



Text figure 16

Text figure 16a. Spotted tourmaline aplite.
South of Lamorna Point.

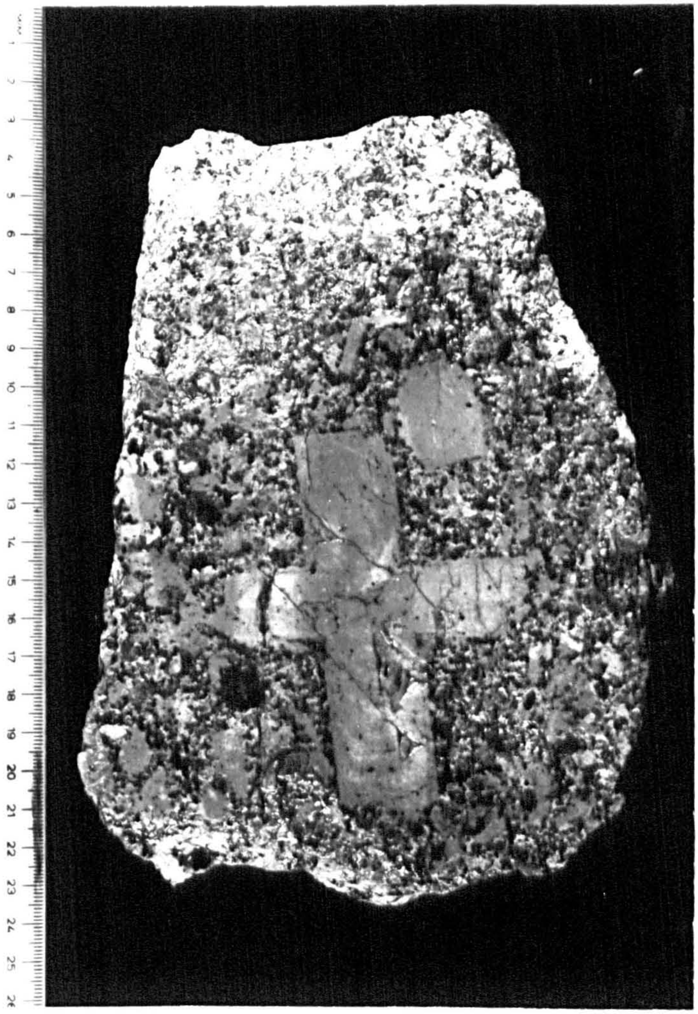
Text figure 16b. Quartz tourmaline in granite
near Lamorna.



Text figure 16a

Text figure 16b

Text figure 16c. Maltese Cross doubly twinned alkali feldspar megacryst. Carn-a-langa.

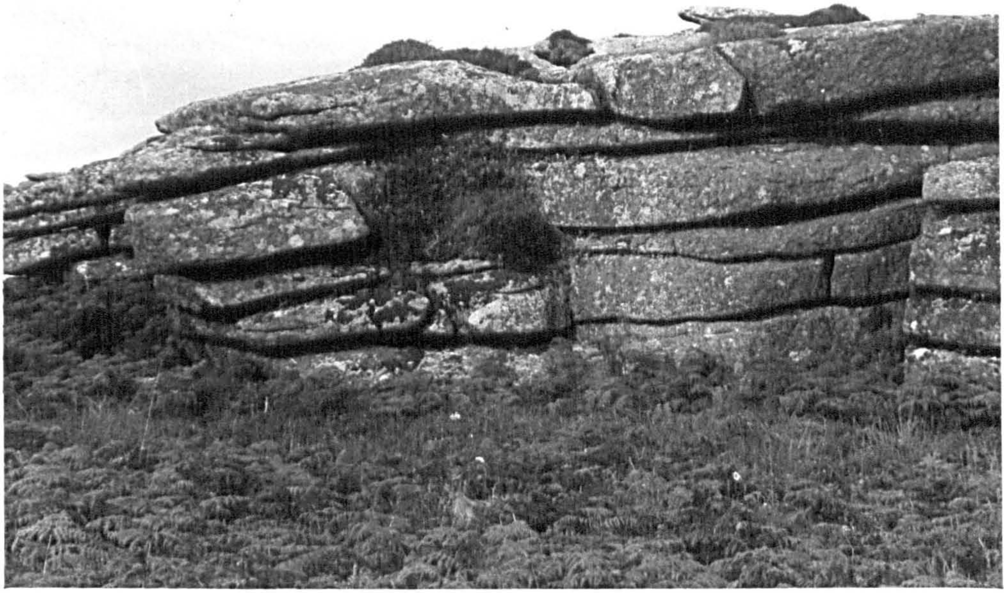


Text figure 16c

Structural Features

<u>Text figure 17</u>. Floor joints or "pseudo-bedding" in coarse porphyritic granite, Tremeader Common.

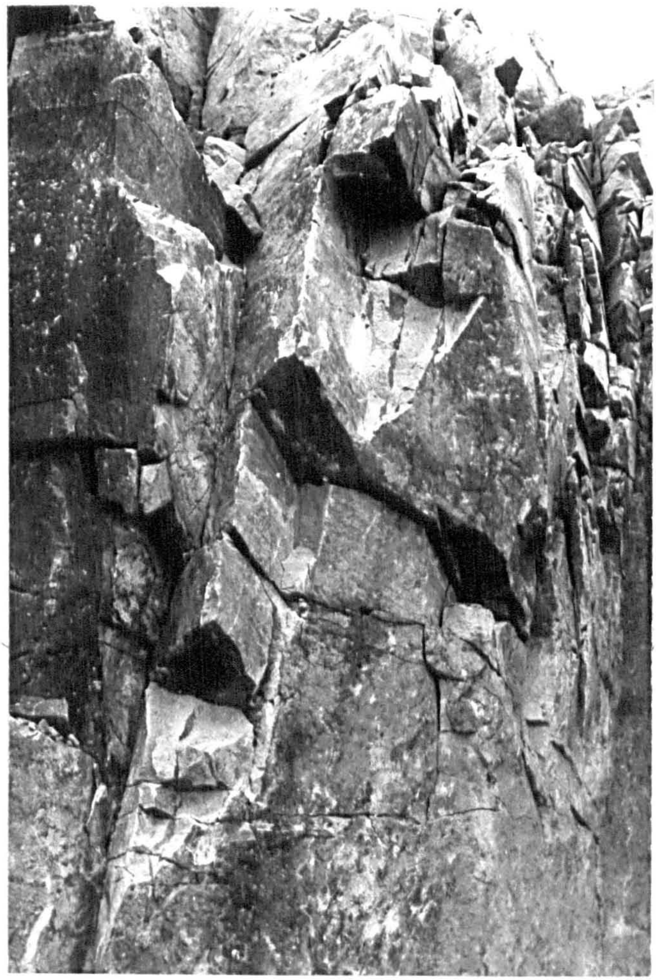
<u>Text figure 18</u>. Vertical joints (longitudinal and cross joints), and poorly developed floor joints in coarse porphyritic granite at Carn Burgess, Lamorna.



Text figure 17

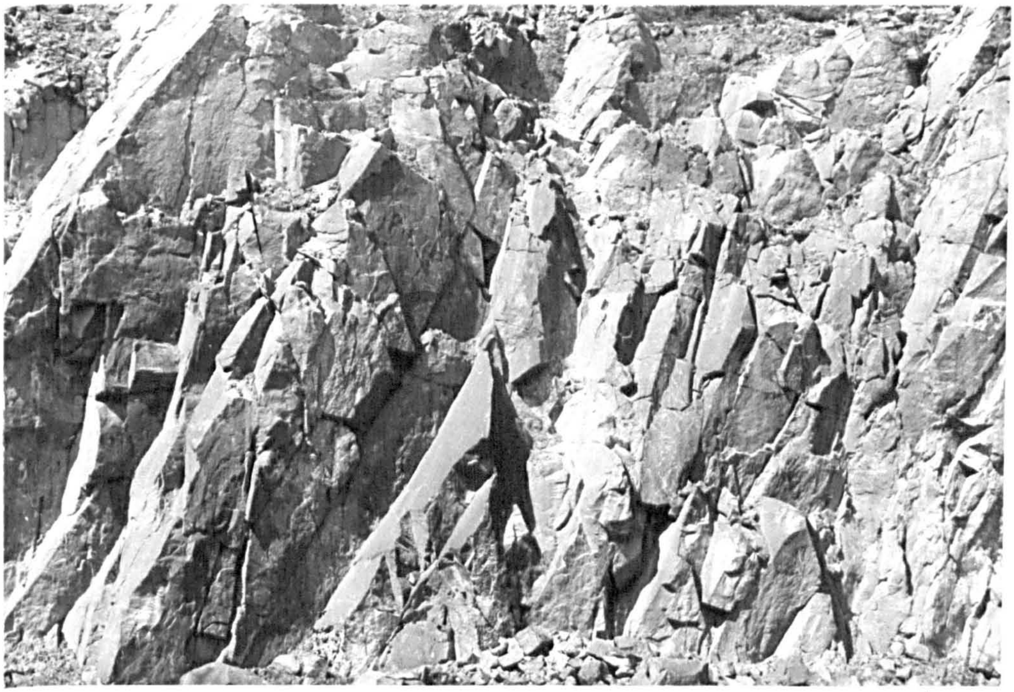
Text figure 18

Text figure 18a. Intersecting vertical joints in fine grained granite, Castle-an-dinas.



Text figure 19. "Slides" in fine grained Castle-an-dinas granite. These are often coated with a veneer of tourmaline, chlorite or mylonised granite.

Text figure 20. Floor joints in fine grained Castle-an-dinas granite. The photograph illustrates that these joints are closer together near the surface, and their distance apart increases with depth.



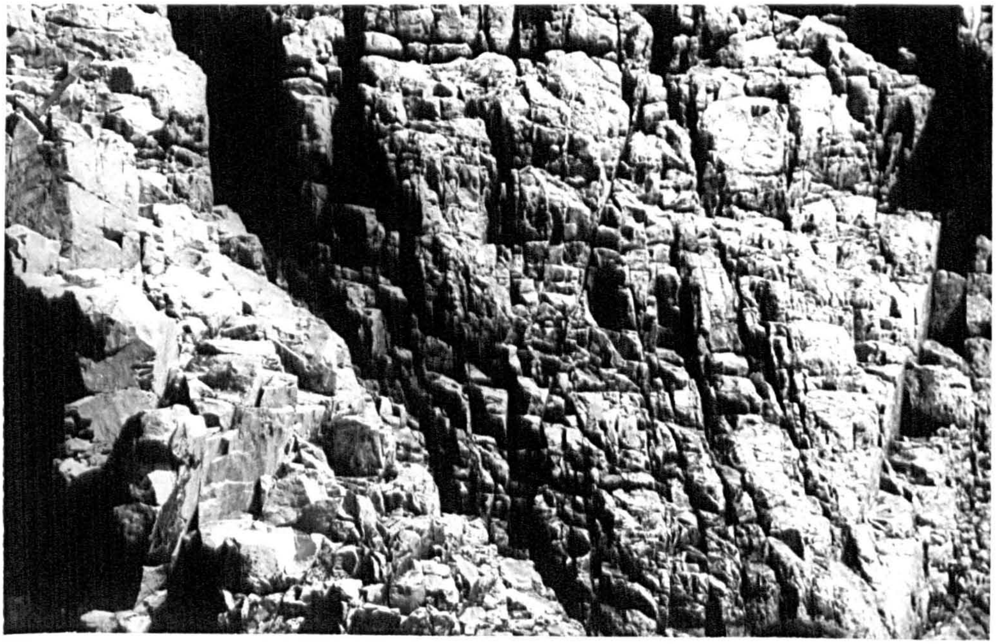
Text figure 19

Text figure 20

Text figure 21. Gently shelving floor joints near Mousehole. These joints control the gentler cliff profile on the south east coast.

Text figure 22. Strongly sheared marginal aplogranite contact phase. Tater-du eastern contact.

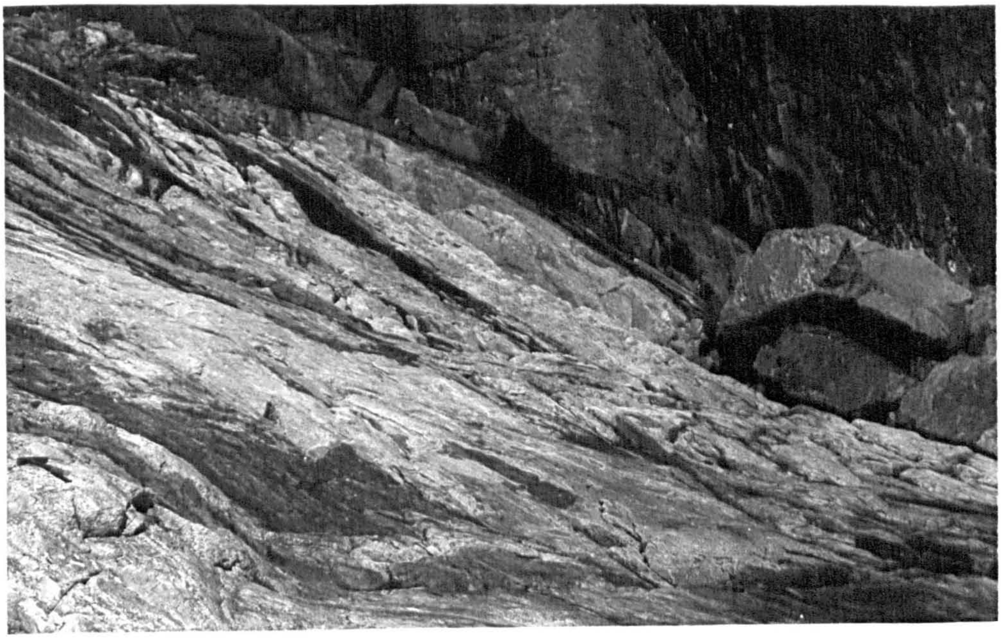
Text figure 21



Text figure 22

Text figure 23. Tater-du western contact. Note that the floor joints are conformable with the granite/hornfels contact.

Text figure 24. Weathering along vertical and floor joints to give castellated granite. St.Michael's Mount.



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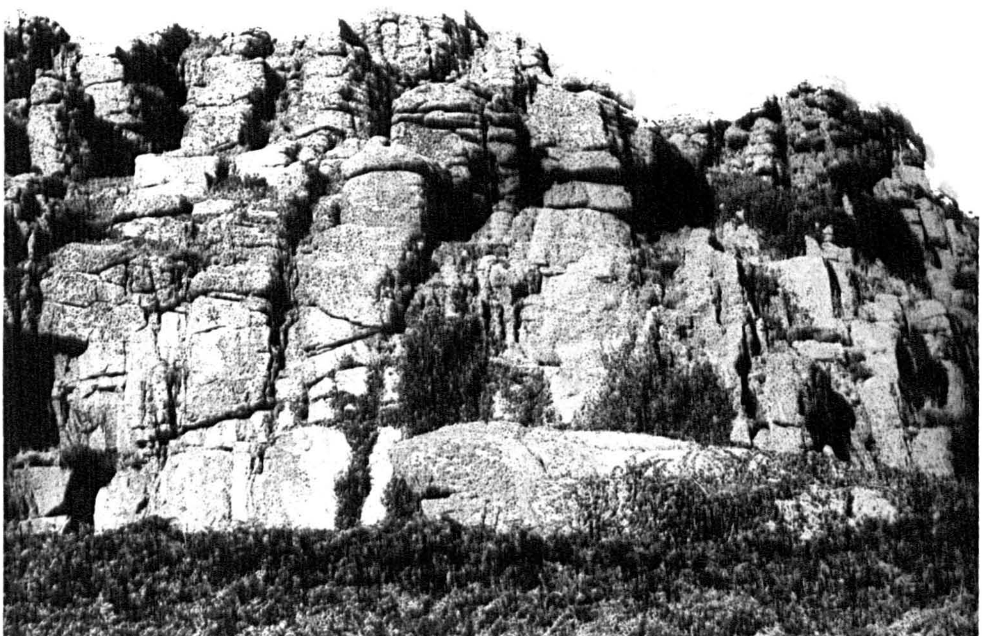
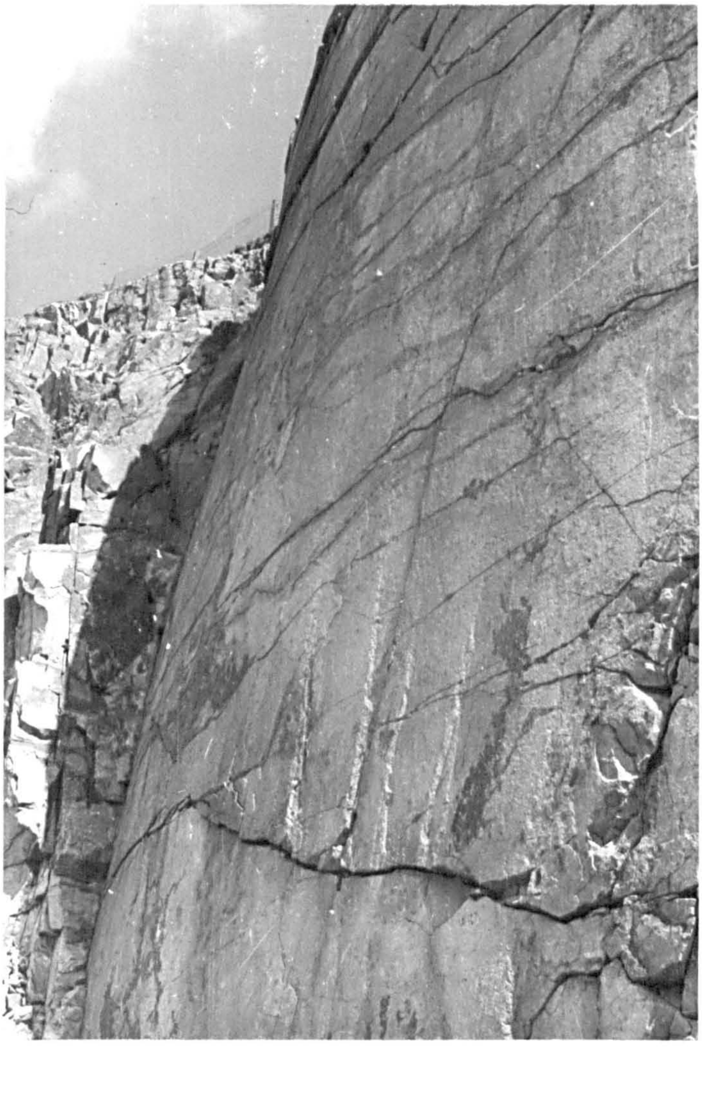


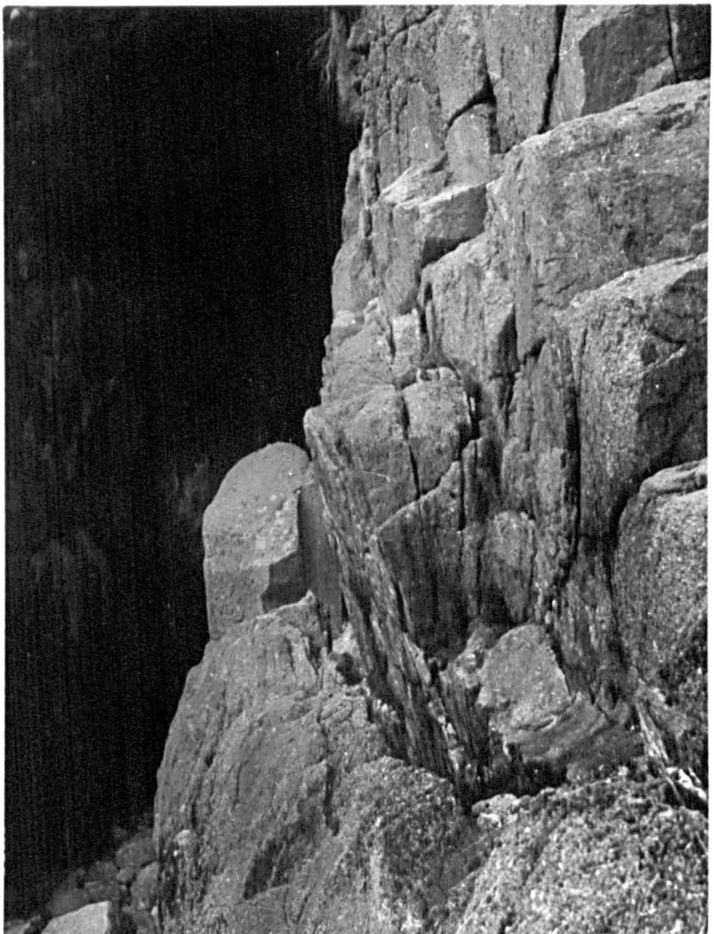
Text figure 24

Text figure 25. Curved, smooth joint face in fine granite, Castle-an-dinas.



Text figure 25

<u>Text figure 26</u>. The Mousehole. This sea cave is eroded along a fracture zone in the granite. Note the fractured granite (lower part of photograph) and slickensided fault plane.



Text figure 26

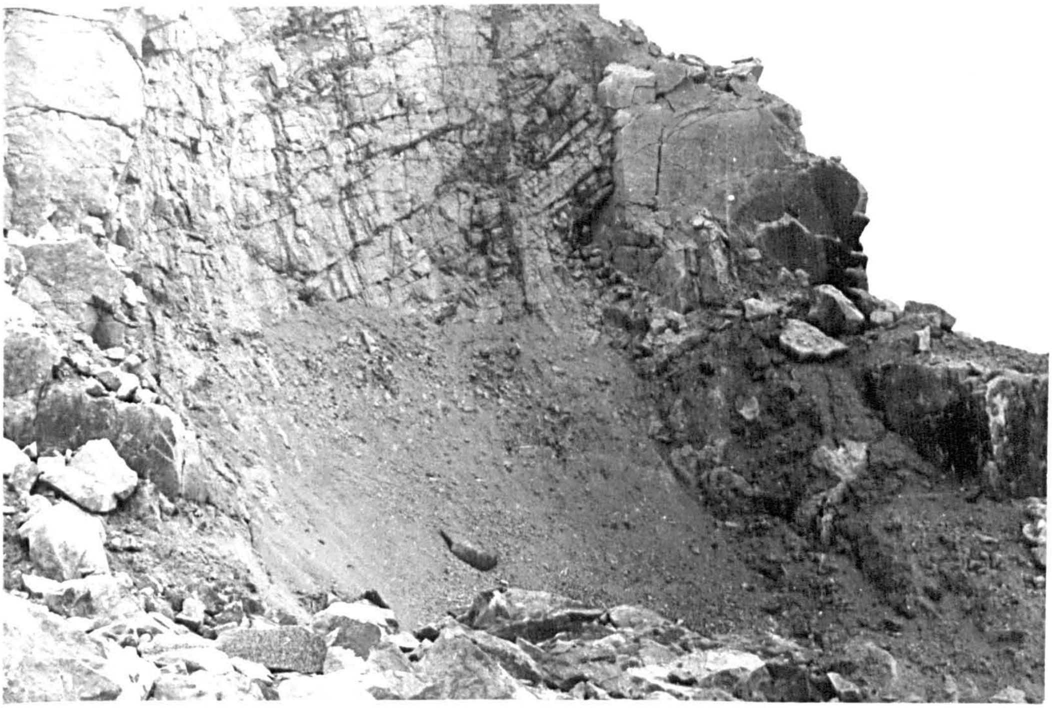
Text figure 27. Nanjulian Cliff showing the dip of the floor joints. Along this section of coast these joints uniformly dip towards the sea and indicate the proximity of the contact.

Text figure 28. Chloritised vertical joints in fine granite. Castle-an-dinas.

Text figure 28

Text figure 29. Kaolinised seam in fine grained granite. Castle-an-dinas quarry. Note the "sag" effects in the tourmaline veins in this seam.

Text figure 30. Fractured fine granite in Castle-an-dinas quarry. Many of these vertical joints are coated with chlorite. (See text figure 28).

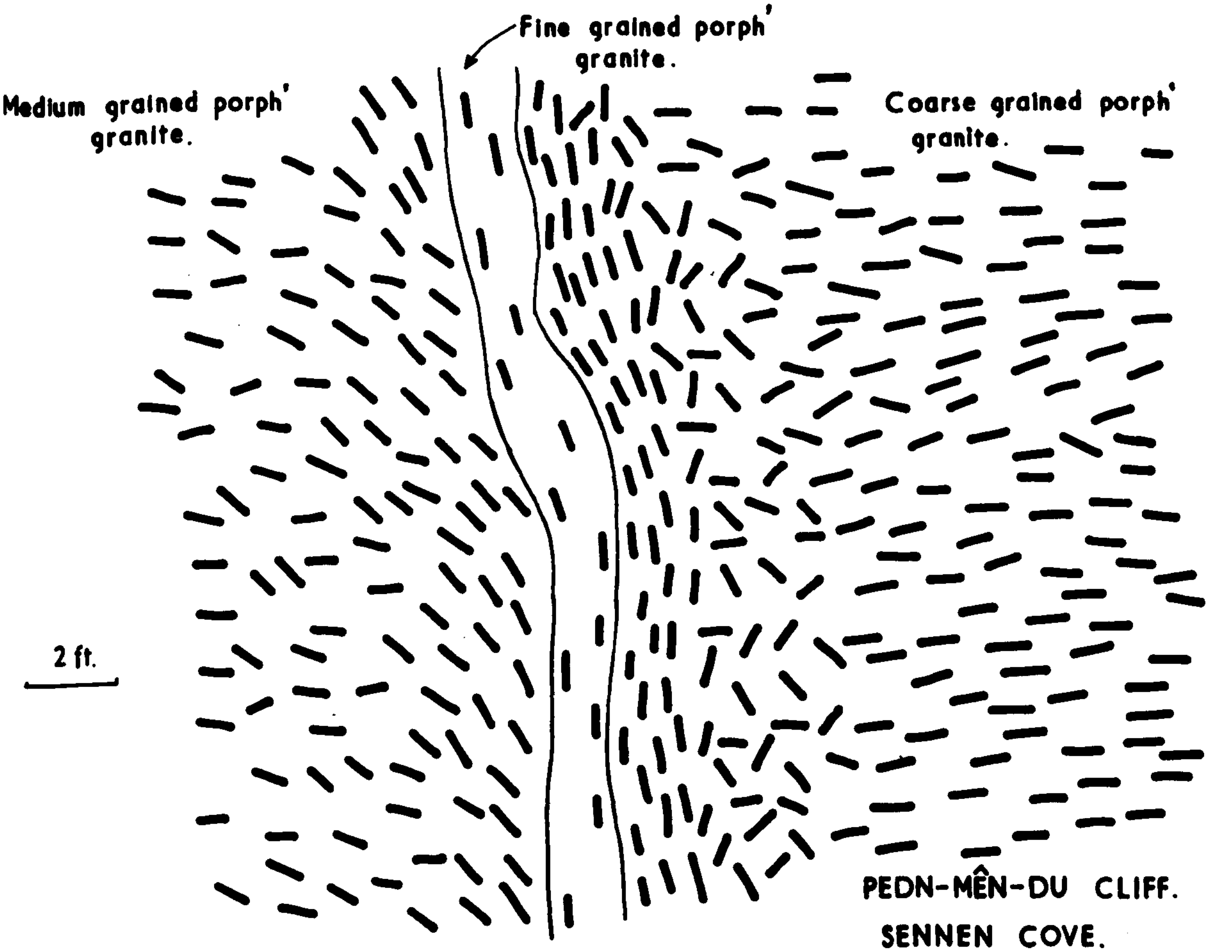


Text figure 29

Text figure 30

Contact Phenomena

Text figure 30a. Sketch of a contact between medium grained porphyritic granite and coarse grained porphyritic granite at Pedn-men-du cliff, Sennen Cove. Note the flow foliation relationships between the two varieties.

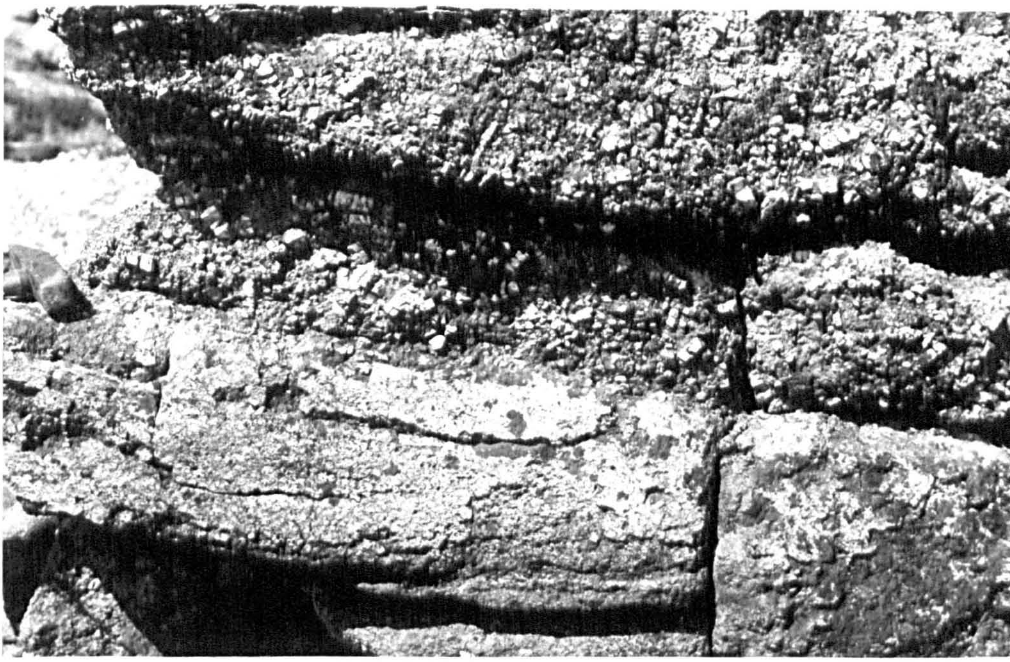

Fine grained porph' granite.
Medium grained porph' granite.
Coarse grained porph' granite.
2 ft.
PEDN-MÊN-DU CLIFF.
SENNEN COVE.

AB.

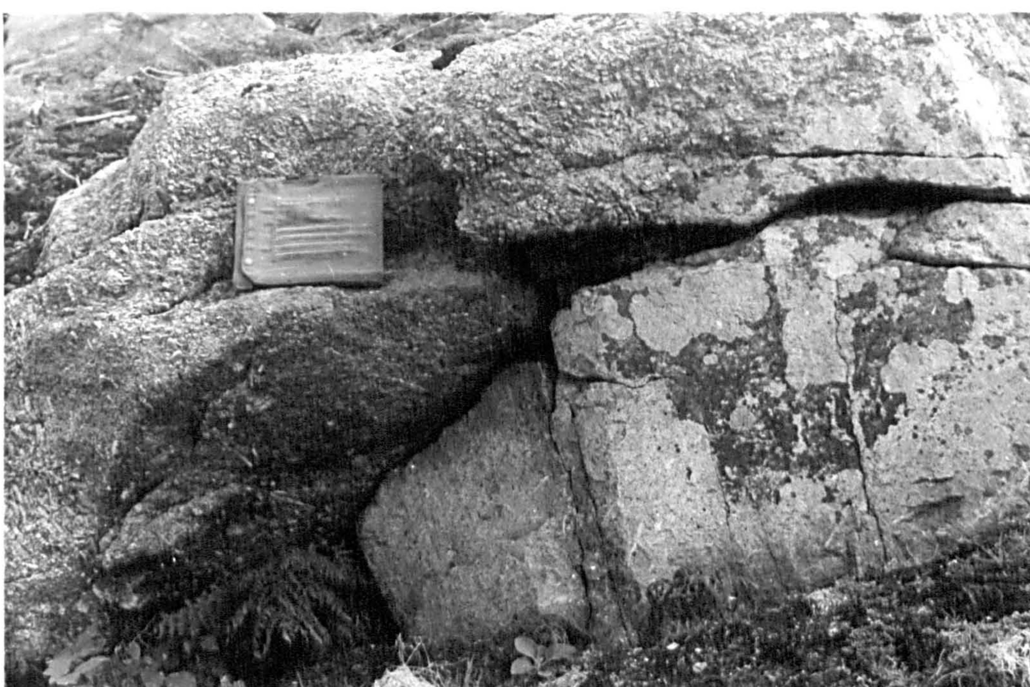
30a

Text figure 31. Junction of coarse highly porphyritic granite and fine grained granite at Rosewall Hill west.

Text figure 32. Junction of coarse highly porphyritic granite and fine grained granite at Trevean Hill.



Text figure 31



Text figure 32

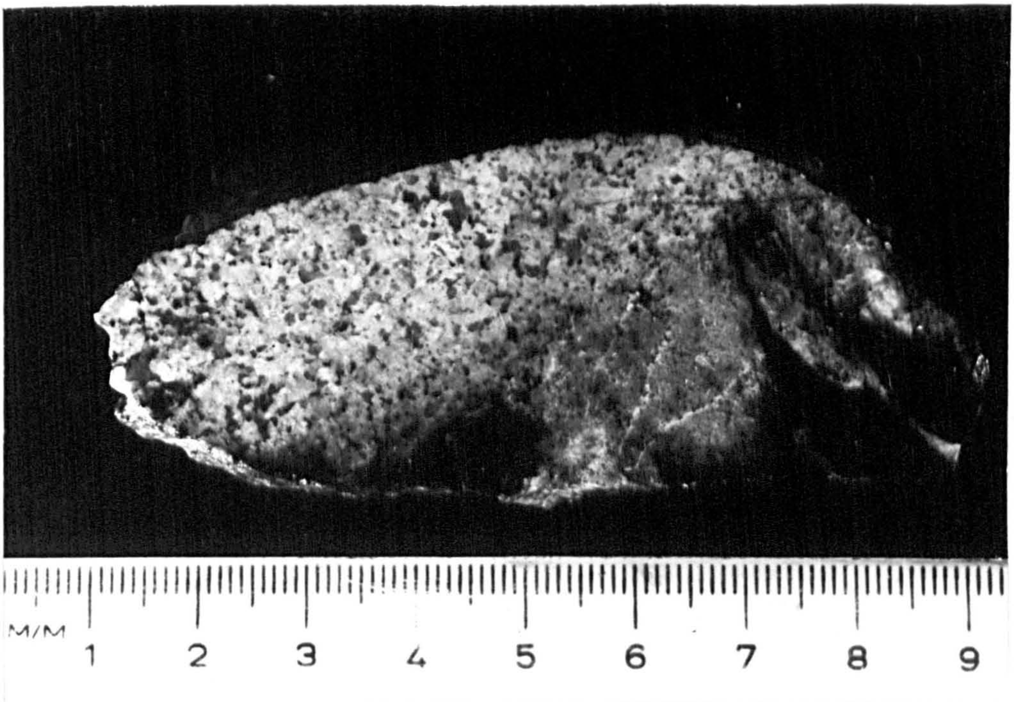
51

Text figure 32a. Small roof pegmatites of tourmaline in fine grained granite beneath coarse porphyritic granite at Rosewall Hill, west.

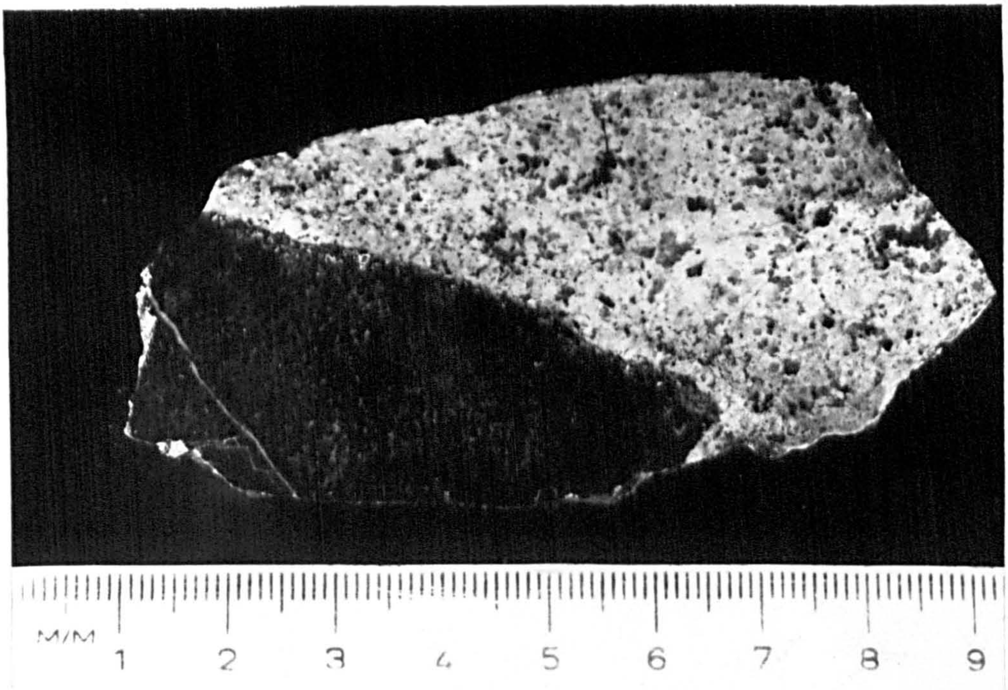
Text figure 32a

Text figure 33. Specimen from Porthmeor Cove, illustrating localised mixing at the contact. (Compare with Text figure 34)

Text figure 34. Specimen of marginal granite showing the sharp contact with the pelitic hornfels. This is the reverse side of the specimen in Text figure 33, thus illustrating the extreme variability of the granite/hornfels contact. Porthmeor Cove.



Text figure 33



Text figure 34

Text figure 35. Contamination streaks in coarse porphyritic biotite granite at Carn Bargess, Lamorna. Note the foliation in the finer contaminated material is parallel to its contact with the coarse porphyritic rock.

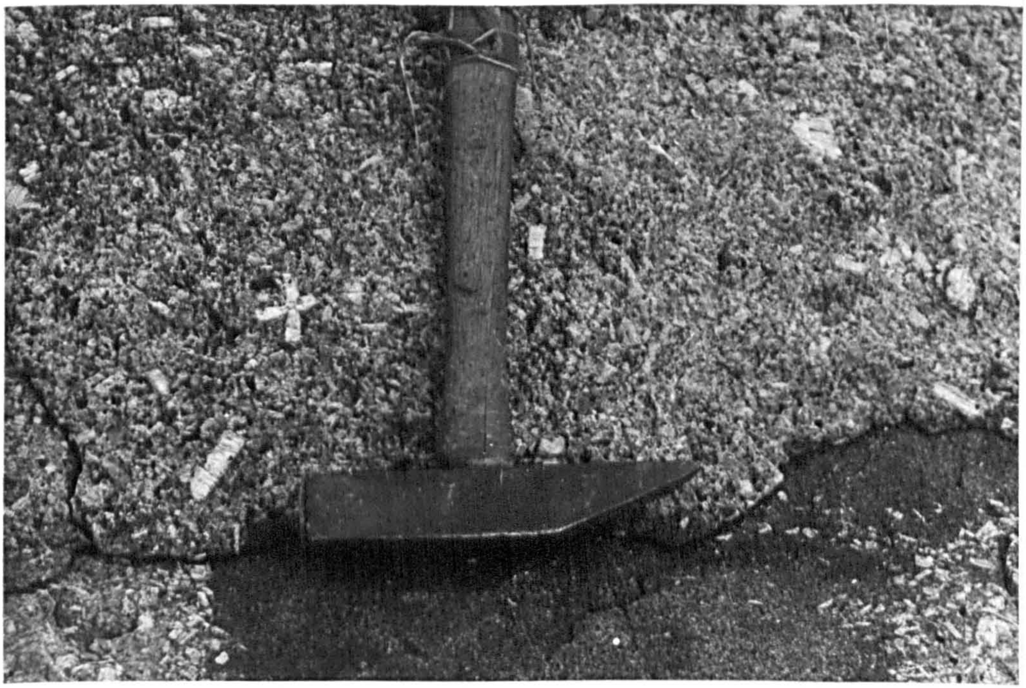
Text figure 36. Contamination bands in coarse porphyritic biotite granite. Carn Bargess, Lamorna.

Text figure 35

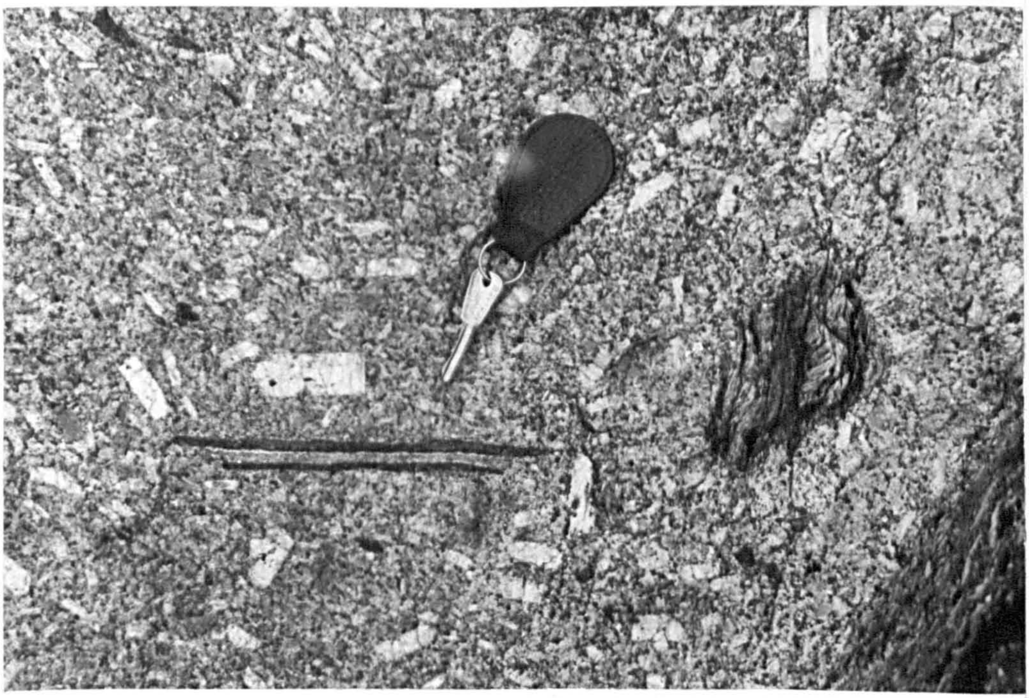
Text figure 36

Text figure 37. Coarse porphyritic granite, Carn Bargess, Lamorna. Note (i) the fine grained homogeneous xenolith below the hammer, and (ii) the rare Maltese Cross double interpenetrant feldspar twin.

Text figure 38. Coarse porphyritic granite at Carn Bargess, Lamorna, illustrating "schistose" pelitic xenoliths.



Text figure 37



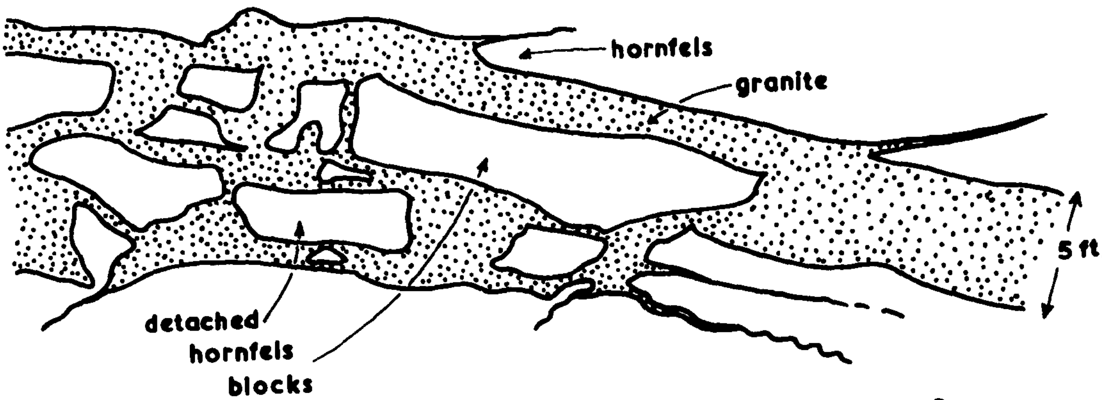
Text figure 38

Text figure 39. Part of the banded sequence at Porth Ledden beach. Note the alkali megacrysts in the patch of hornfels roof (upper left), the pegmatitic phase underlying this, succeeded by aplogranite and pegmatite.

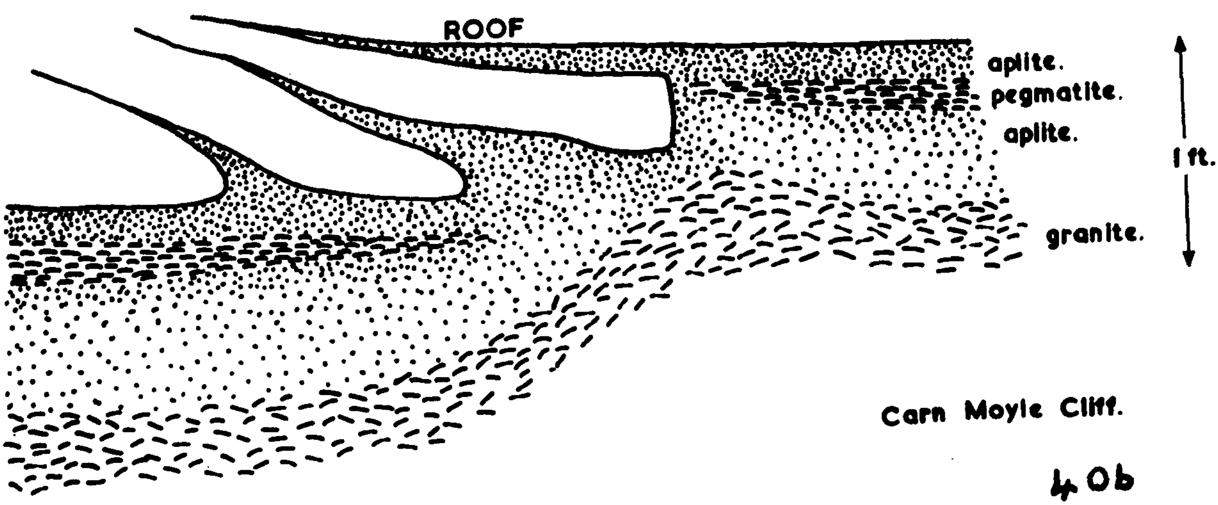
Text figure 39

Text figure 40a. Sketch of granite vein emplaced into pelitic hornfels at Carn Moyle Cliff. Note the detached hornfels blocks that have been stoped away.

Text figure 40b. Sketch of a granite/hornfels contact at Carn Moyle Cliff. Note the aplitic contact phase with discontinuous pegmatite bands. The contact aplite which veins the hornfels roof may represent the original chilled marginal aplogranite.


hornfels
granite
5 ft.
detached
hornfels
blocks

40 a

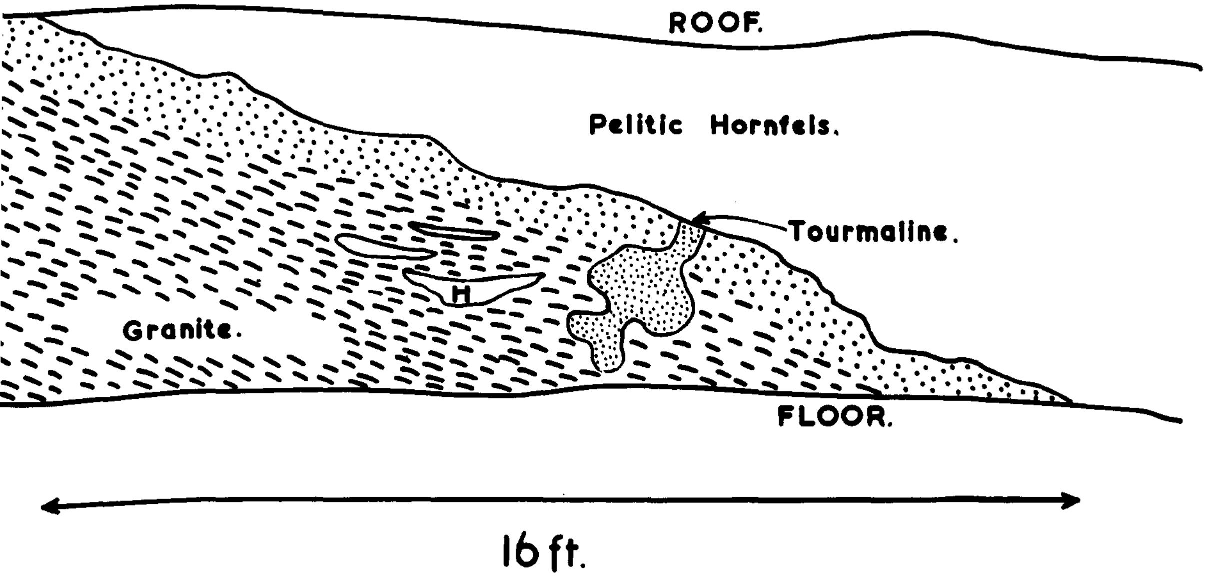

ROOF
aplite.
pegmatite.
aplite.
1 ft.
granite.
Carn Moyle Cliff.

40 b

Text figure 40c. Geevor Mine Contact (6W3)
H = detached hornfels block.

Text figure 40d. (6W3) Detailed sketch of the contact. Note that the fine tourmaline veins (see inset also) penetrate every phase with the exception of the chilled contact.

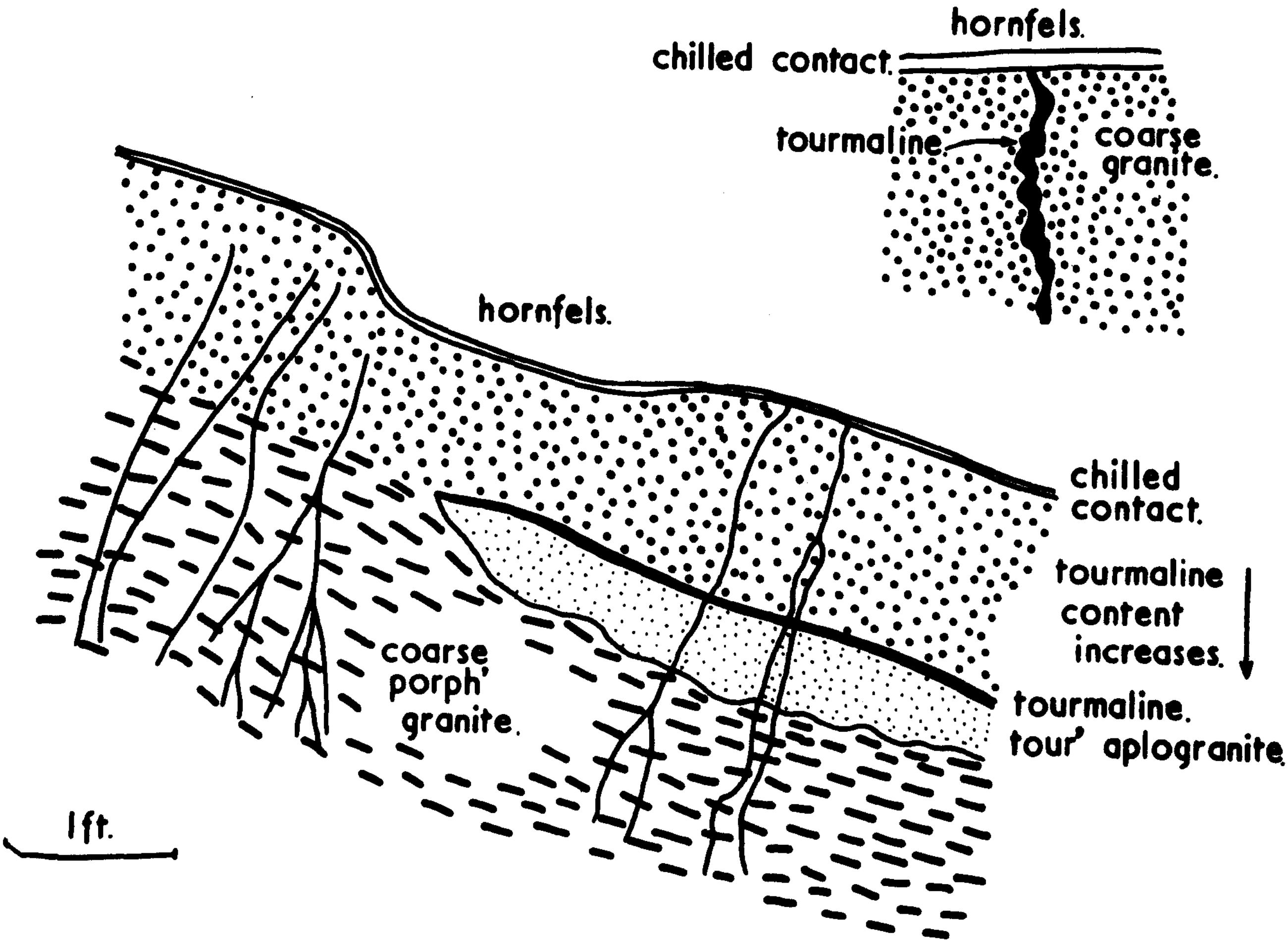
Text figure 40e. (6W3) Detailed sketch of the tourmaline aplogranite showing potash feldspar crystals that have developed beneath the tourmaline roof.



Geevor Mine Contact. (6W3)

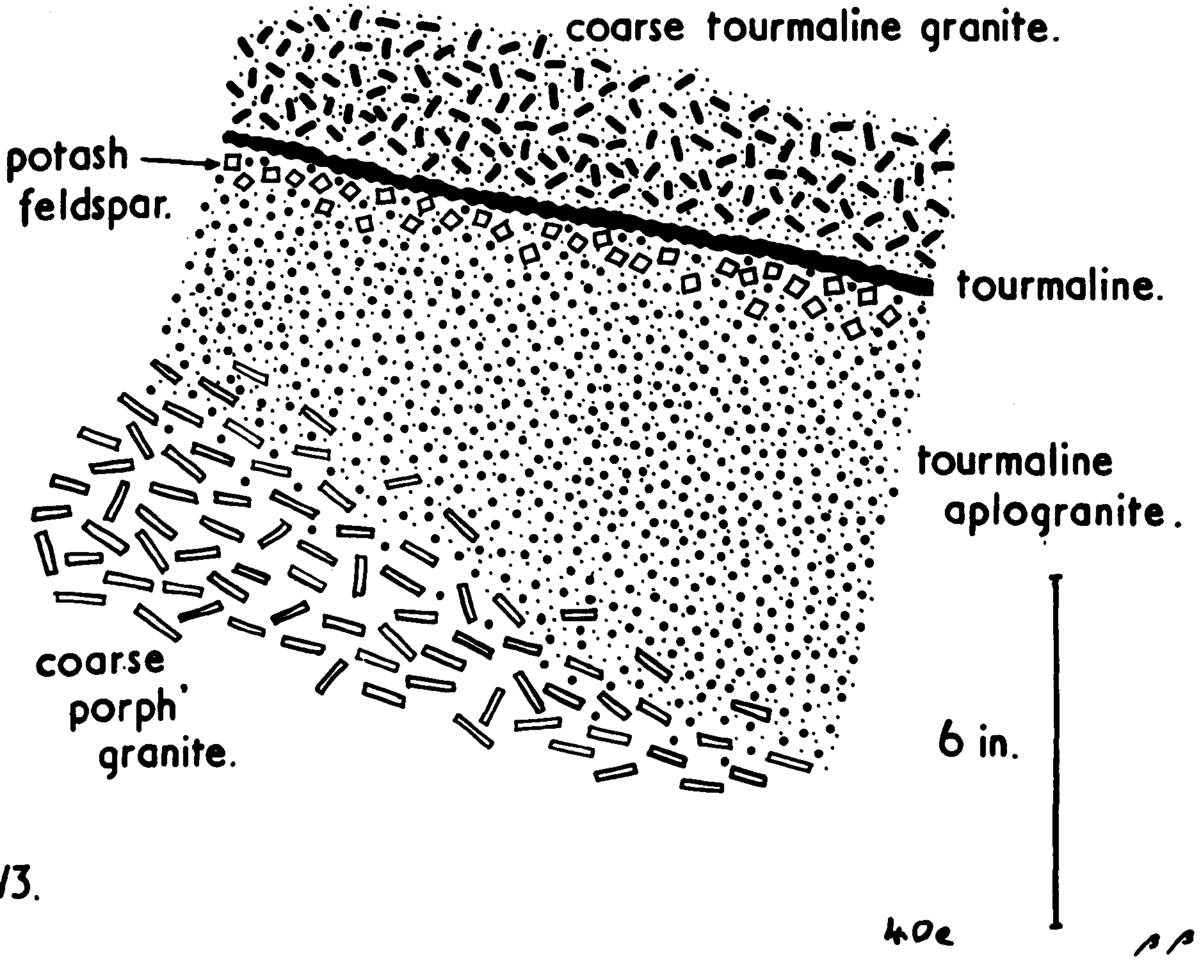
40c

PP.


hornfels.
chilled contact.
tourmaline.
coarse granite.
hornfels.
chilled contact.
tourmaline content increases.
tourmaline.
tour' aplogranite.
coarse porph' granite.
1ft.

6W3.

40d ff.


coarse tourmaline granite.
potash feldspar.
tourmaline.
tourmaline aplogranite.
coarse porph' granite.
6 in.
40e
pp.

6W3.

Text figure 41. Tater-du western contact, showing alternately banded coarse porphyritic granite and aplogranite.

Text figure 42. Porth Ledden beach. Illustrating the square shaped feldspar megacrysts in the contact hornfels. Note the chilled margin below the lens and the fine grained tourmaline interposed between this and the coarser granite.

Text figure 41

Text figure 42

Text figure 43. Porth Ledden beach. Illustrating the alkali feldspar megacrysts which are orientated with their clinopinacoid faces sub-parallel to the contact.

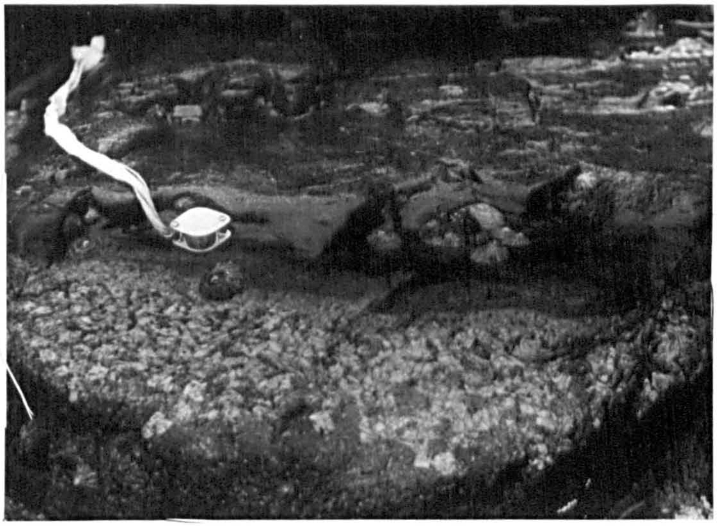
Text figure 44. Priest's Cove. Pegmatite under hornfels roof.

Text figure 43

Text figure 44

Text figure 45. Alkali feldspar (pegmatite) developed under hornfels cover.

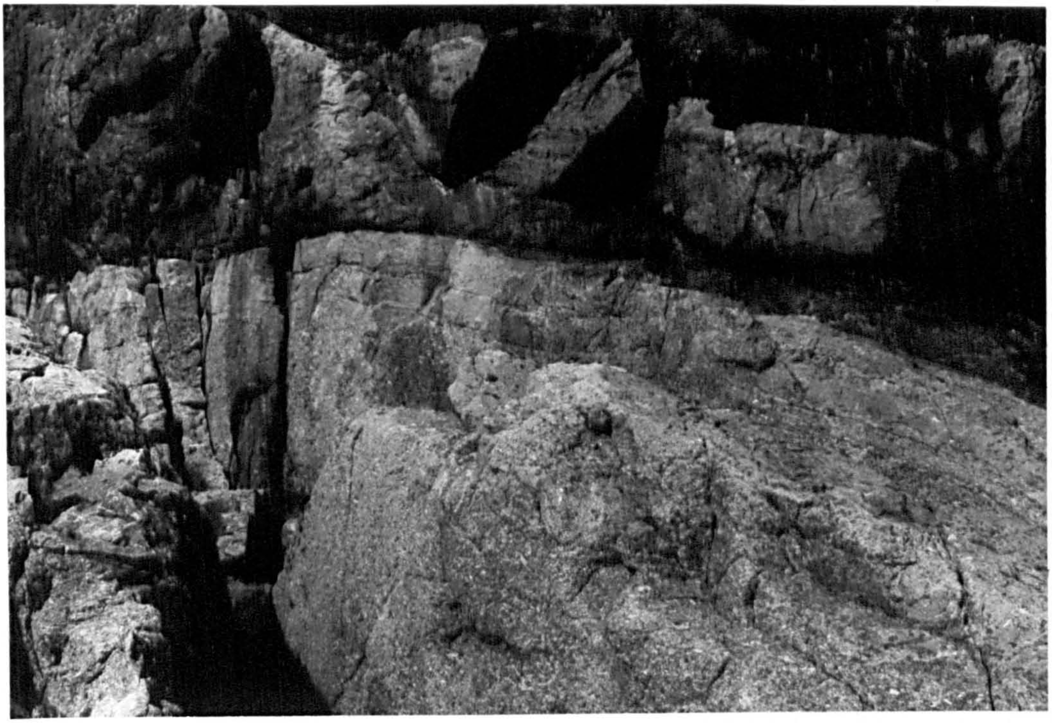
Text figure 46. Alkal feldspar megacrysts growing at right angles to the contact. (Upper part of photograph).



Text figure 45

Text figure 46

Text figure 47. Granite/hornfels contact. Tater-du, western contact. Note the aplogranite vein running parallel to the contact.



Text figure 47

Text figure 48. Tater-du, western contact. Note the foliation in the megacrysts is subparallel to the contact, and the aplo-granite vein 10 inches below the contact which shows evidence of potassium segregation.

Text figure 48

Text figure 49. Tater-du, western contact. Note the discordant junction with the hornfels, the chilled margin, and the aplogranite vein (centre of photograph) with small tourmaline pegmatites.

Text figure 50. Tater-du, western contact. The photograph illustrates roof remnants, beneath which the granite contact phase is chilled.

Text figure 49

Text figure 50

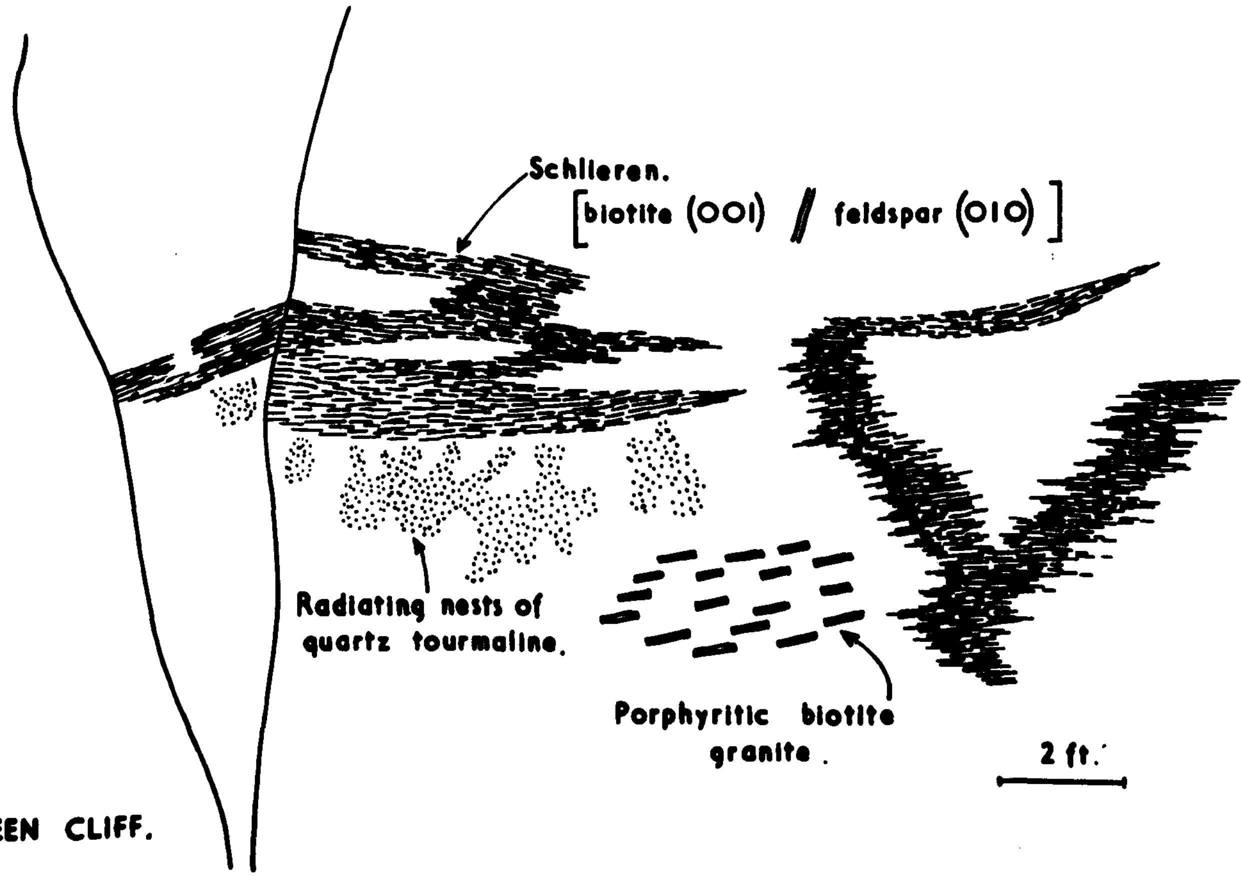
Text figure 51. Tater-du, western contact. The tourmaline (beneath hammer) is practically coincident with the hornfels roof (top right).

Text figure 52. Tater-du, western contact. Illustrating contamination bands in the granite parallel to the contact.

Text figure 51

Text figure 52

Text figure 53. Schlieren in coarse porphyritic biotite granite at Treen Cliff. Note the quartz tourmaline pegmatites that have developed beneath the schlieren cover.


Schlieren.
[biotite (001) // feldspar (010)]
Radiating nests of quartz tourmaline.
Porphyritic biotite granite.
2 ft.

TREEN CLIFF.

Contamination Phenomena

Text figure 54. Small tourmaline pegmatites in contaminated fine granite. Near Tater-du.

Text figure 54

Text figure 55. Sennen Cove. Highly contaminated granite (melagranodiorite) adjacent to the hornfels (top right).

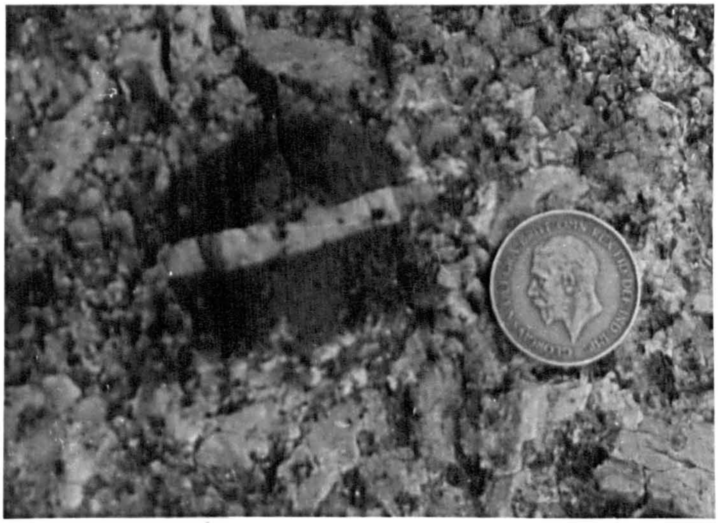
Text figure 56. Sennen Cove. Veining of hornfels by the chilled marginal phase.

Text figure 55

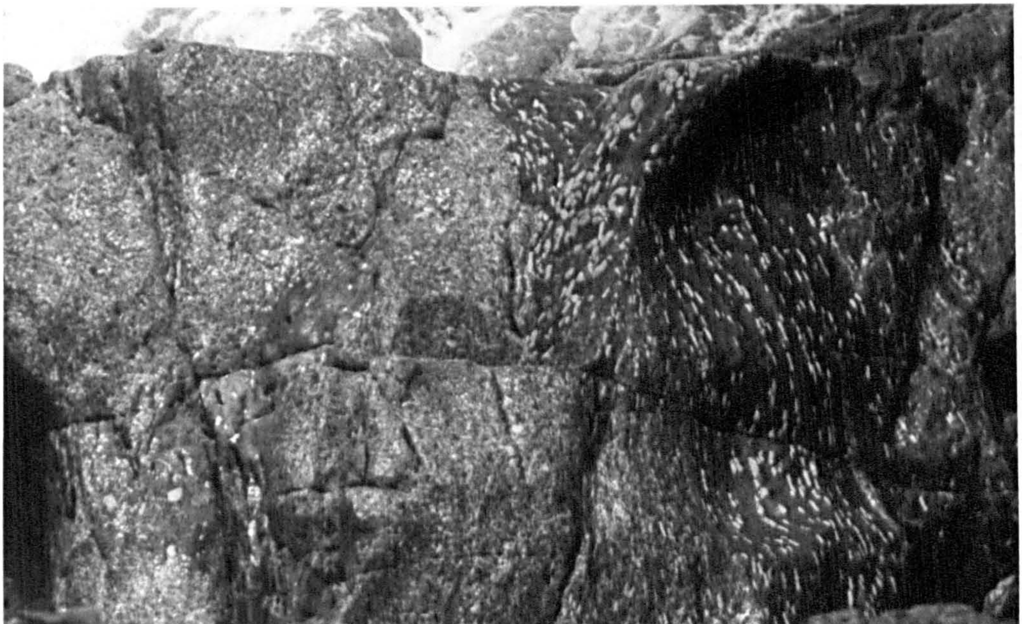
Text figure 56

Text figure 57. Pedn-men-du cliff. Rounded homogeneous pelitic xenolith with a metasomatic alkali feldspar megacryst grown across it.

Text figure 58. Wicca Pool. Large xenolith of pelitic hornfels in coarse grained marginal granite. Note the well orientated metasomatic alkali feldspars that have developed in this rock.

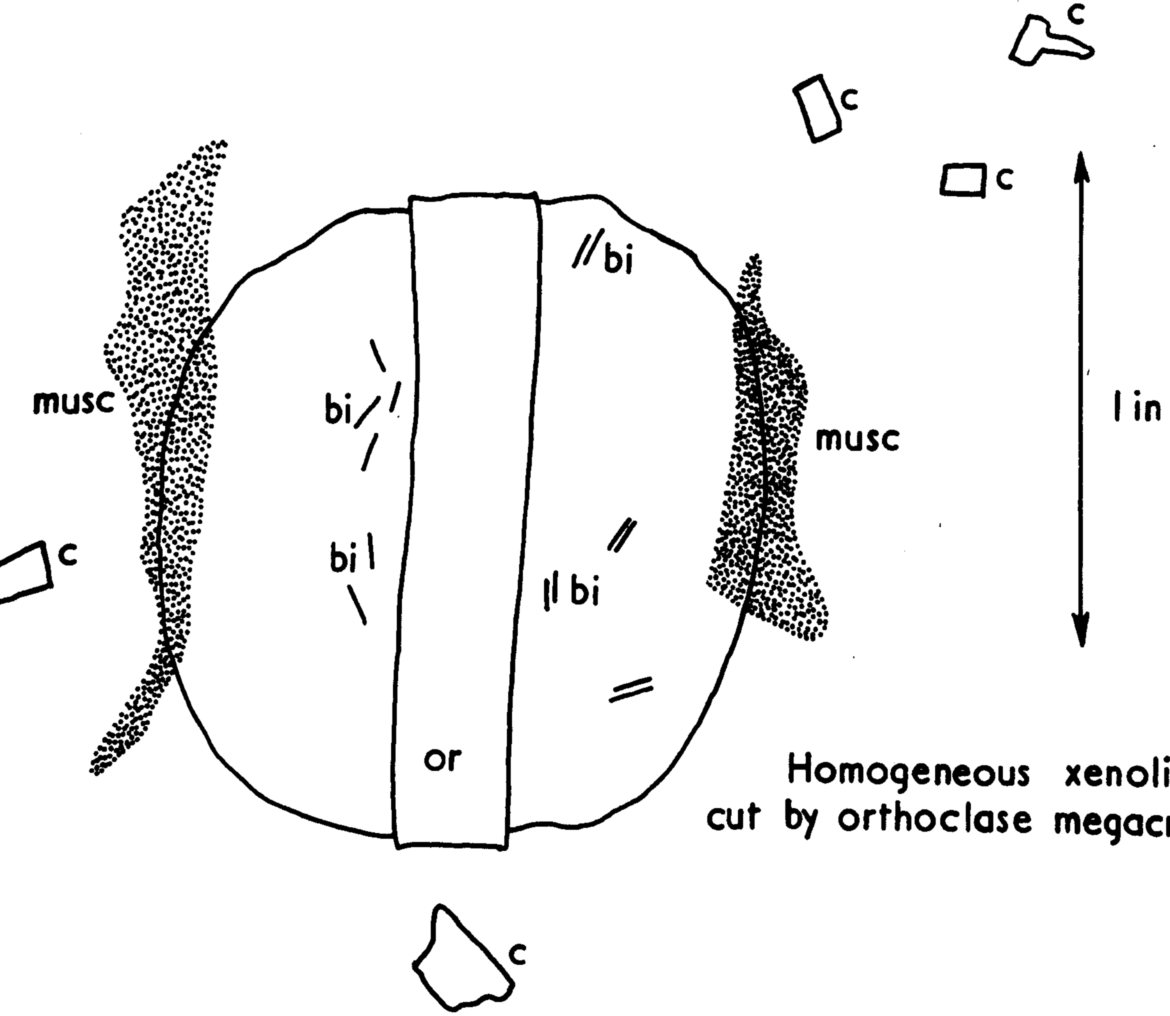


Text figure 57



Text figure 58

Text figure 57a. Homogeneous xenolith cut by orthoclase megacryst.



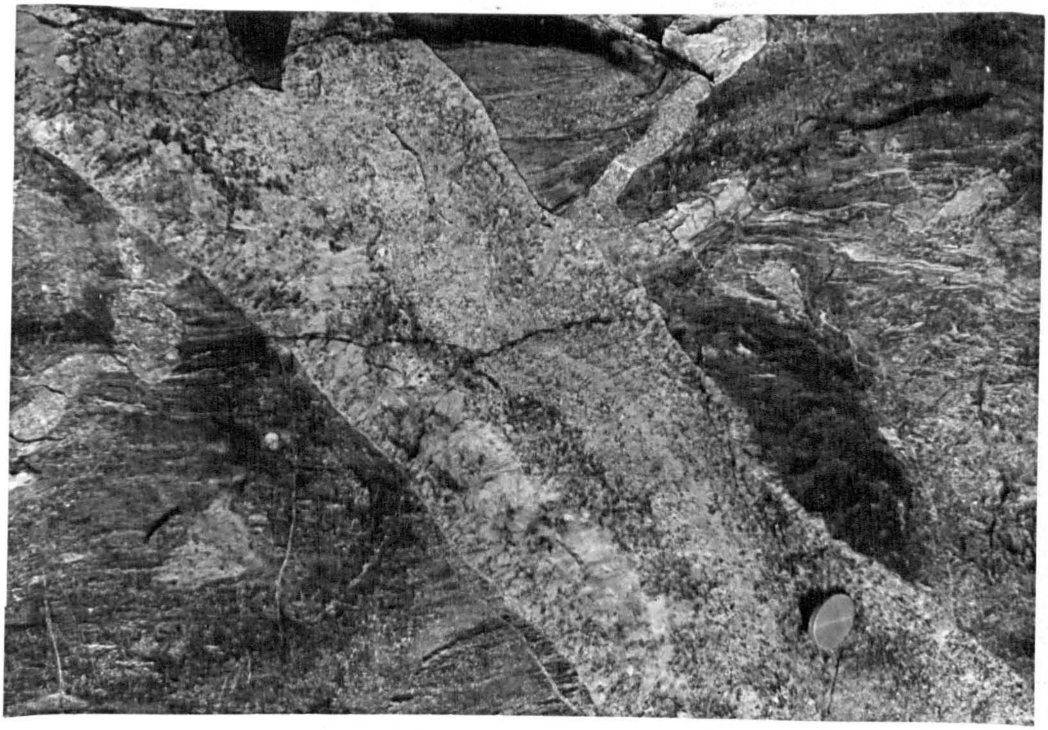
Homogeneous xenolith cut by orthoclase megacryst.

Sennen Cove.

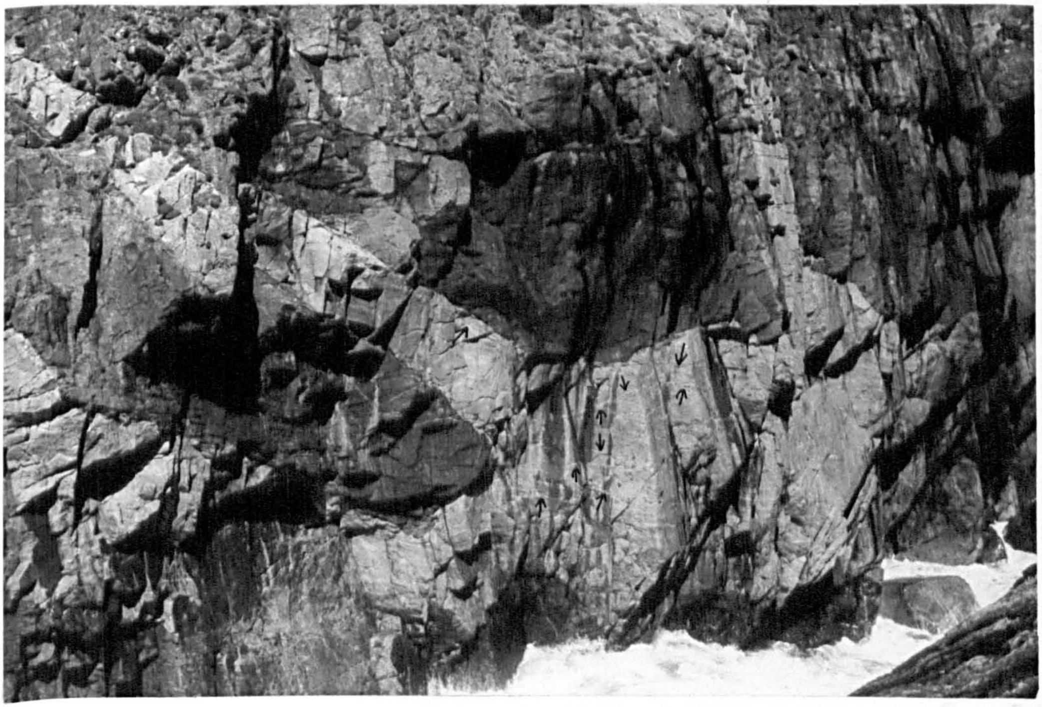
57a

Text figure 59. Priest's Cove. Aplogranite vein cutting pelitic hornfels and wavy segregation bands of volatiles. Note also the feldspathised margins with tourmaline needles growing with their "c" axes at right angles to the contact.

Text figure 60. Wicca Pool. Showing a granite roof zone sending off apophyses into the pelitic hornfels. Note also the numerous pegmatite bands (arrowed).



Text figure 59

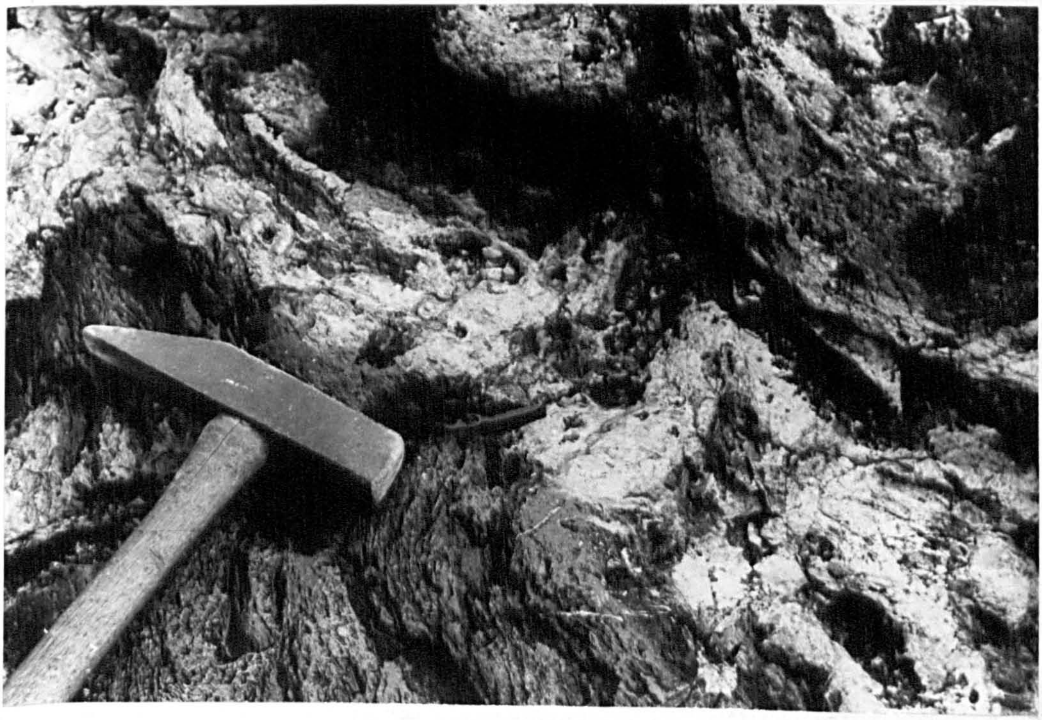


Text figure 60

Text figure 61. Quartz-tourmaline pegmatite in granite. Priest's Cove.

Text figure 62. Quartz rich vein emplaced into and stoping pelitic hornfels. Priest's Cove.

Text figure 61



Text figure 62

Text figure 62a. Feldspathic pegmatite node in coarse grained granite. Tater-du eastern contact.

Text figure 62b. Tourmaline pegmatite node in large open quartz vein. Trevean Cliff.

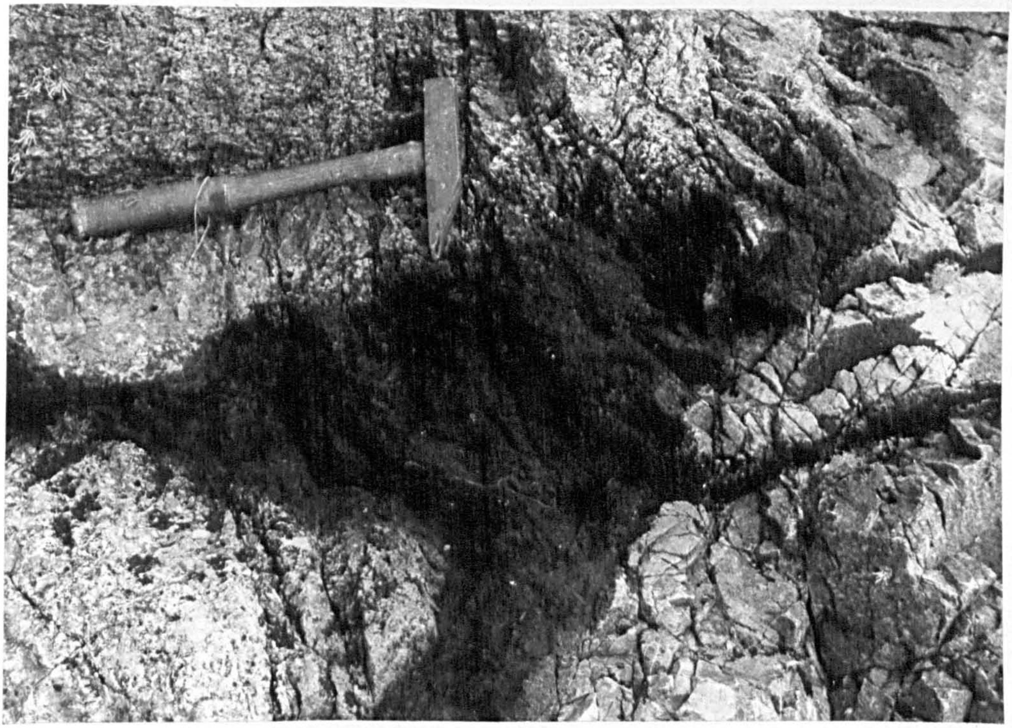
Text figure 62a

Text figure 62b

Veining

Text figure 63. Large tourmaline node developed at the intersection of two tourmaline veins. Porthmeor Cove.

Text figure 64. Fractured tourmaline vein which is postdated by a crosscutting quartz vein. Lamorna.



Text figure 63

Text figure 64

Text figure 65. Large open quartz vein. Mousehole.

Text figure 65

Text figure 66. Waves of tourmaline in marginal aplogranite. Tater-du, eastern contact.

Text figure 66

Text figure 67. Fractured granite cut by two quartz tourmaline veins, note the fracturing postdates the veining. Lamorna Point.

Text figure 68. Aplogranite vein cutting biotite plagioclase hornfels at Tater-du western contact. Note the well developed selvedge of biotite crystals at the margin of the vein.

Text figure 67

Text figure 68

Text figure 69. Aplogranite vein emplaced into pelitic hornfels. Priest's Cove. Note the marginal feldspathisation and the control of the vein's direction by jointing.

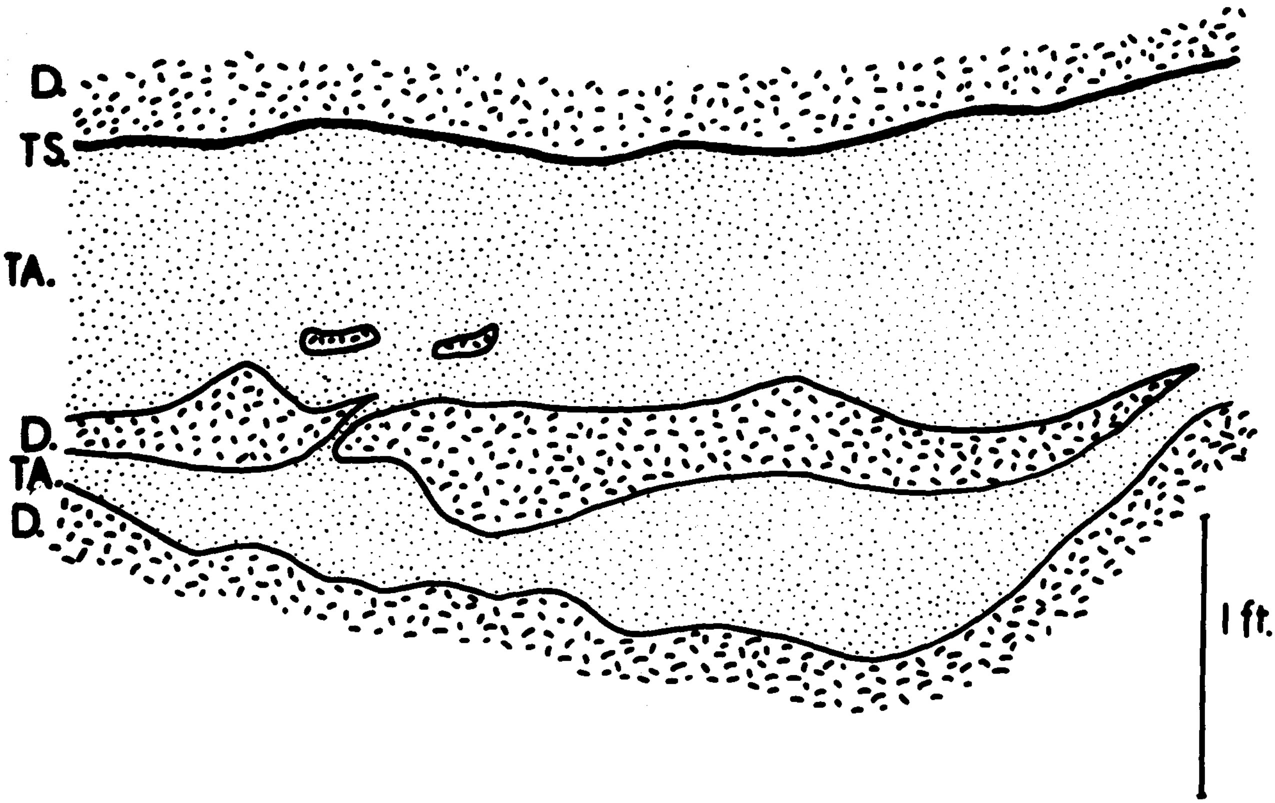
Text figure 70. Aplite vein at Sennen Cove showing alkali feldspar megacrysts growing across the aplite/granite contact and within the aplite.

Text figure 69

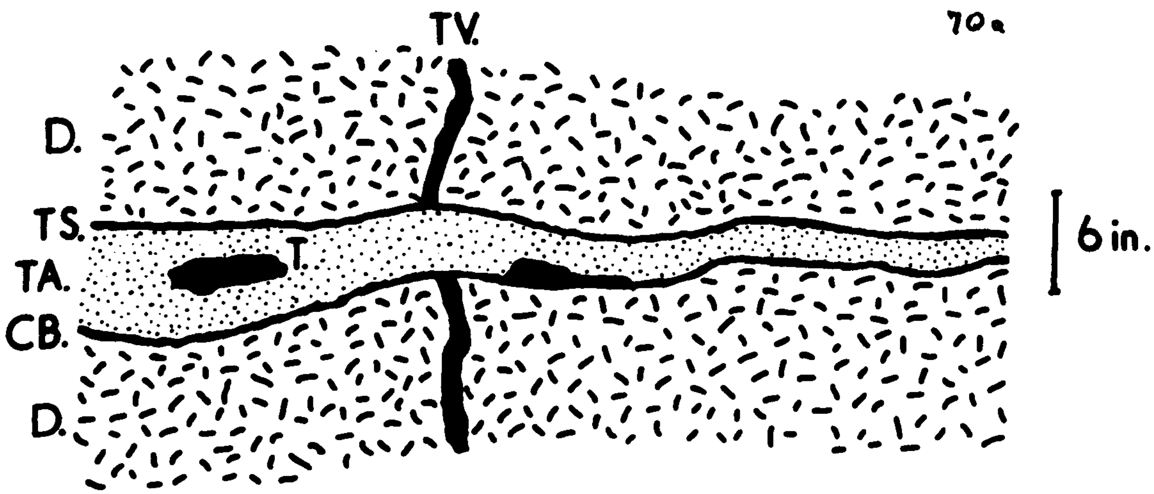
Text figure 70

Text figure 70a. Sketch of aplite sheet (TA) cutting meta-igneous hornfels (D) in Gwavas Quarry, Newlyn. (TS) is a marginal biotite selvedge frequently altered to tourmaline on hanging walls.

Text figure 70b. Detailed sketch of part of the above aplite sheet. (TV) is a tourmaline vein cut by the aplite (TA) which contains a tourmaline (T) nodule. (D) is the biotised meta-igneous hornfels and (CB) is a biotite selvedge on the hanging wall which is often partly replaced by tourmaline.



70a



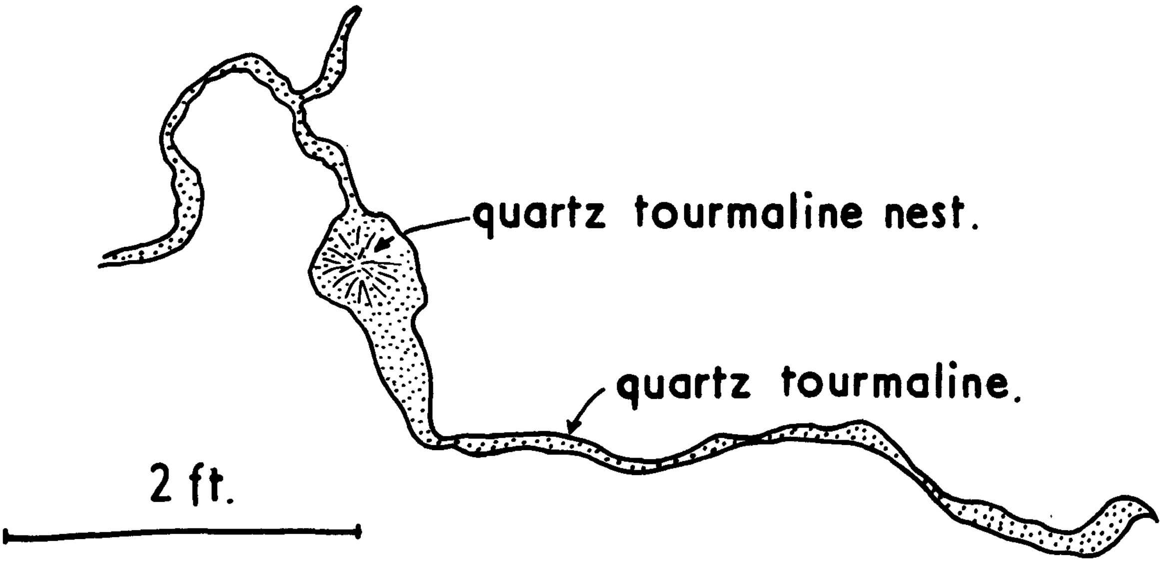
Aplite Sheet. Gwavas Quarry.

70b

A.B.

Text figure 70c. Sketch of quartz tourmaline vein in granite at Priest's Cove with pegmatitic dilation to form a quartz tourmaline nest.

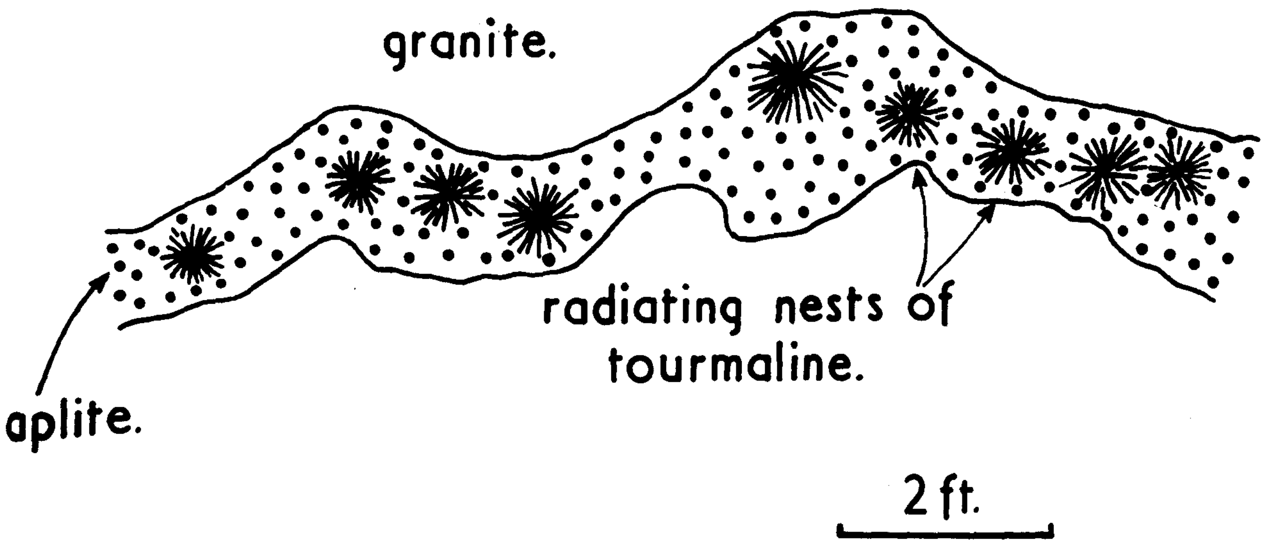
Priest's Cove.



A.B.

70c

Text figure 70d. Sketch of aplite vein in granite near Castle Zawn illustrating radiating nests of tourmaline pegmatite.



Castle Zawn.

B.B.

70d

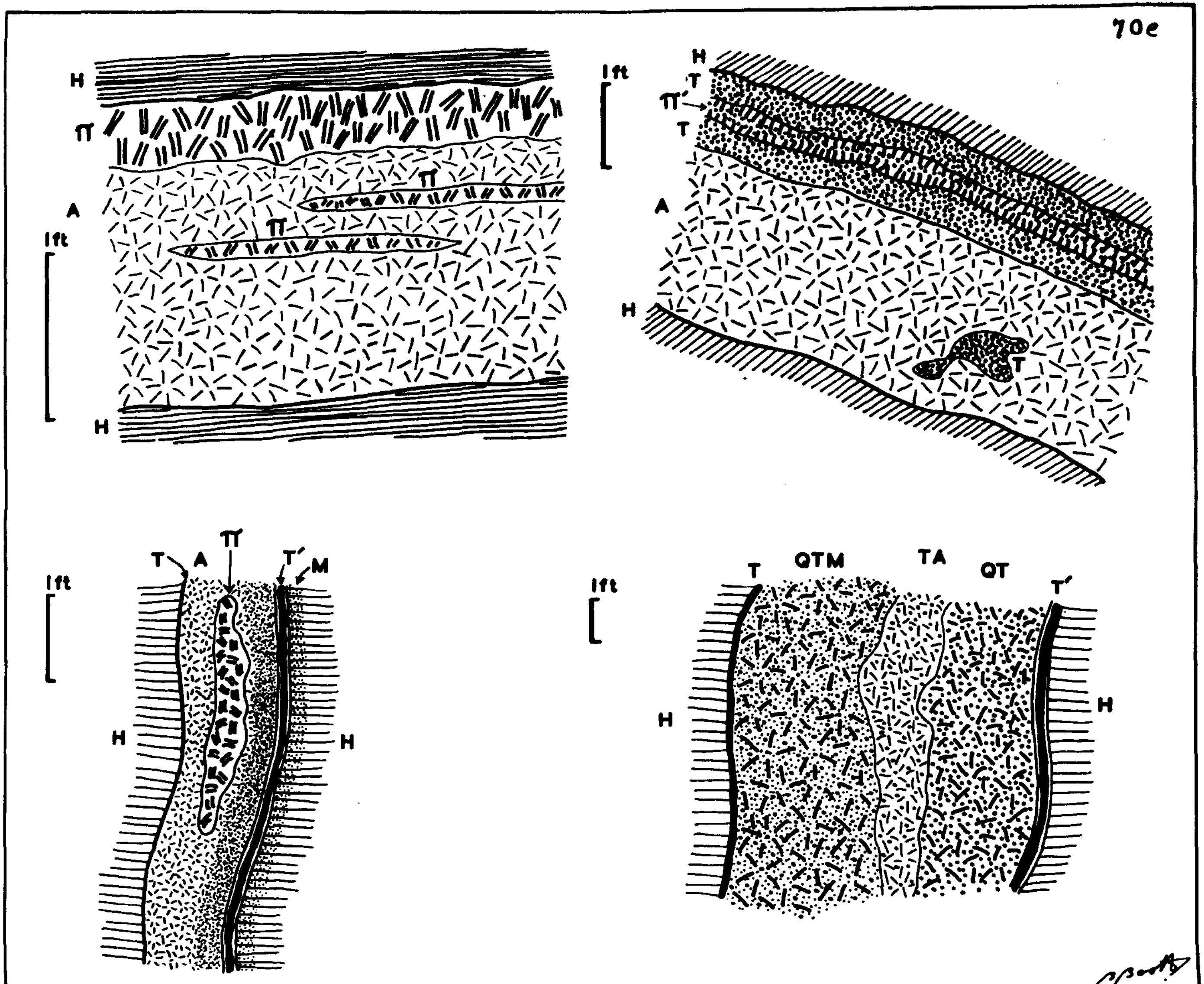
Text figure 70e.

A. Aplite vein (A) concordantly cutting pelitic hornfels (H) and showing feldspathic pegmatites (π) which have developed beneath the hornfels roof.

B. Aplite vein (A) discordantly cutting pelitic hornfels (H) and showing the tourmaline rich phase (T) which contains drusy pegmatite (π) beneath the hornfels roof.

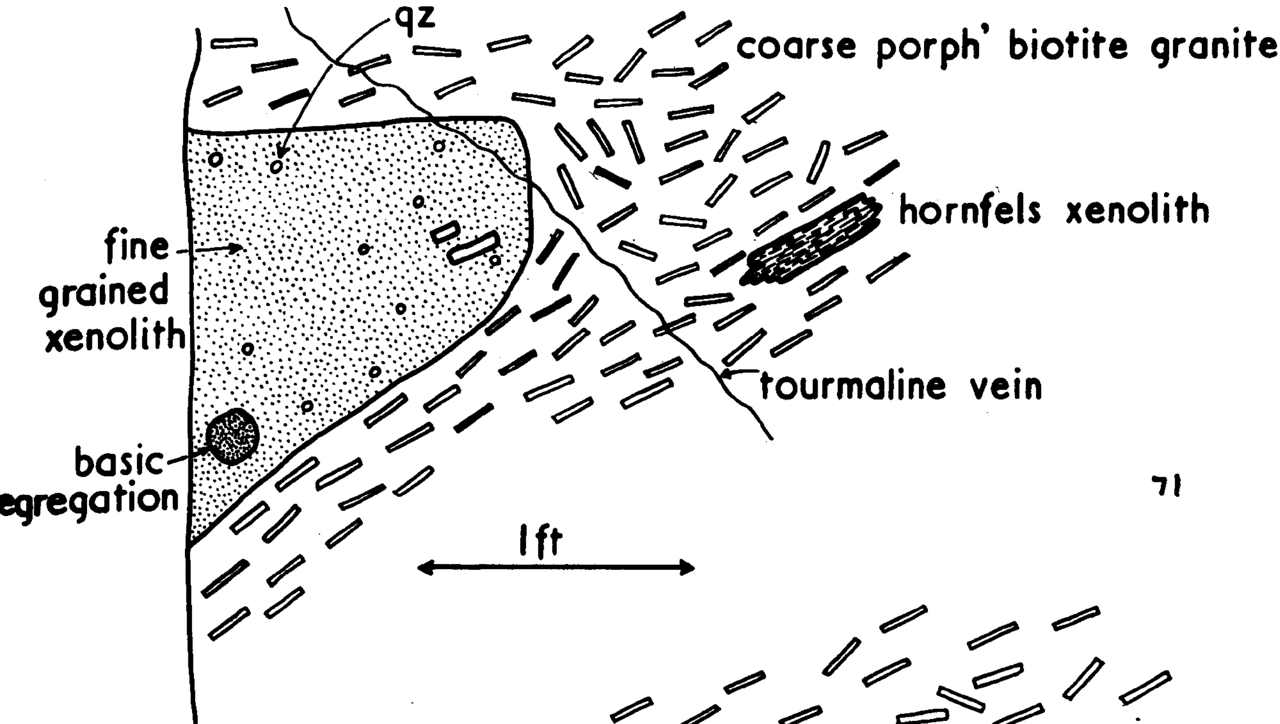
C. Aplite vein (A) discordantly cutting pelitic hornfels (H) and containing a central feldspathic pegmatite (π). Note the tourmaline margin (T) and the quartz tourmaline margin (T) which appears to be associated with greisening and the development of muscovite flakes (M).

D. Compound tourmaline aplite vein discordantly cutting pelitic hornfels (H). Note the tourmaline (T) and quartz tourmaline (T) margins, the greisenised tourmaline aplite (QTM) and the non-greisenised tourmaline aplite either side of a later tourmaline aplite infilling.

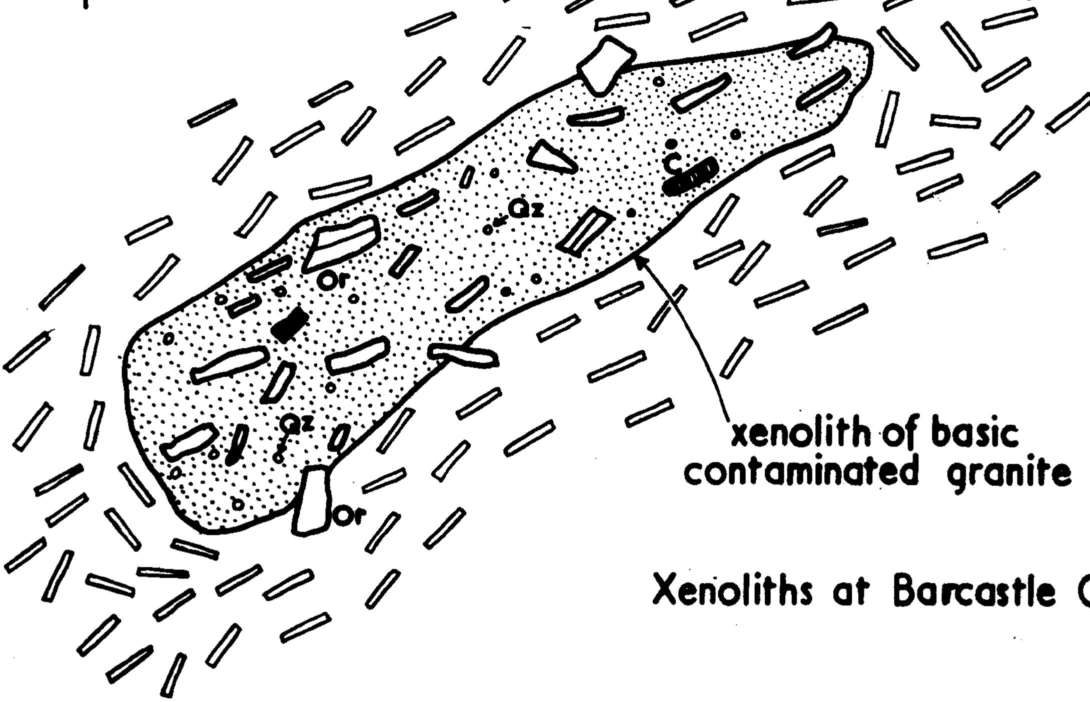

70e
H
Π
Π
Π
A
1ft
H
1ft
H
T
Π′
T
A
H
T
1ft
T
A
Π
T′
M
H
H
1ft
T
QTM
TA
QT
T′
H
H

Xenoliths

Text figures 71 and 72. Sketches illustrating two round xenoliths (Type 3) and one hornfels xenolith (Type 2). Qz = Quartz. C = cordierite. Or = Alkali feldspar.



71



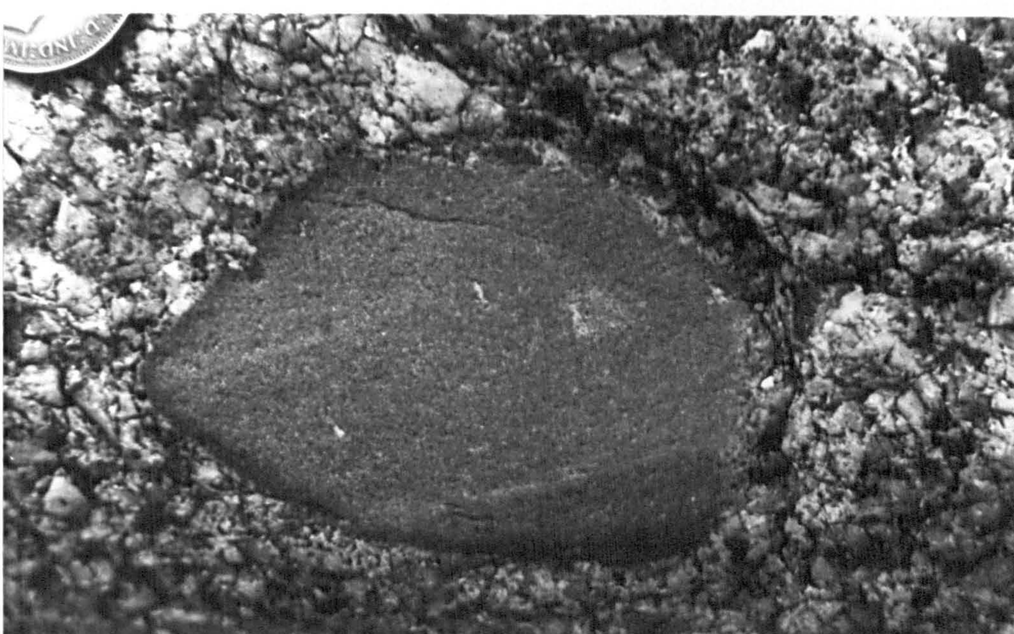
Xenoliths at Barcastle Cove.

72

Text figure 73. Rounded xenolith of hornfels in coarse, highly porphyritic granite at Sennen Cove. Note the flow foliation around the xenolith and the metasomatic alkali feldspars that have developed within it.

Text figure 74. Xenolith of hornfels in coarse, highly porphyritic granite at Sennen Cove. Note the absence of megacrysts, the slight banding in the xenolith and its rounded margin.

Text figure 73

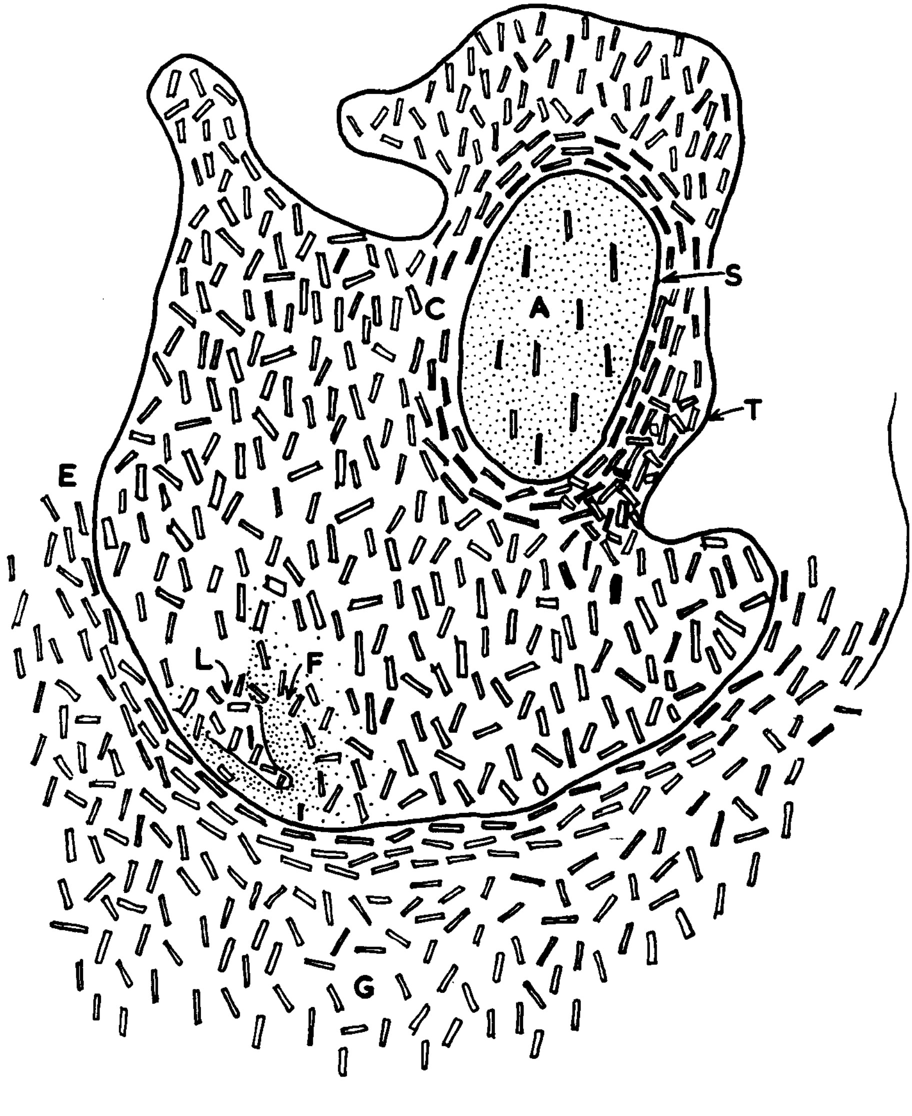


Text figure 74

Text figure 75. Contaminated granite raft (A) in sharp contact (S) with coarse foliated moderately contaminated granite (C). (T) is a highly porphyritic patch and (F) is fine grained material in sharp contact with the coarser rock (L).

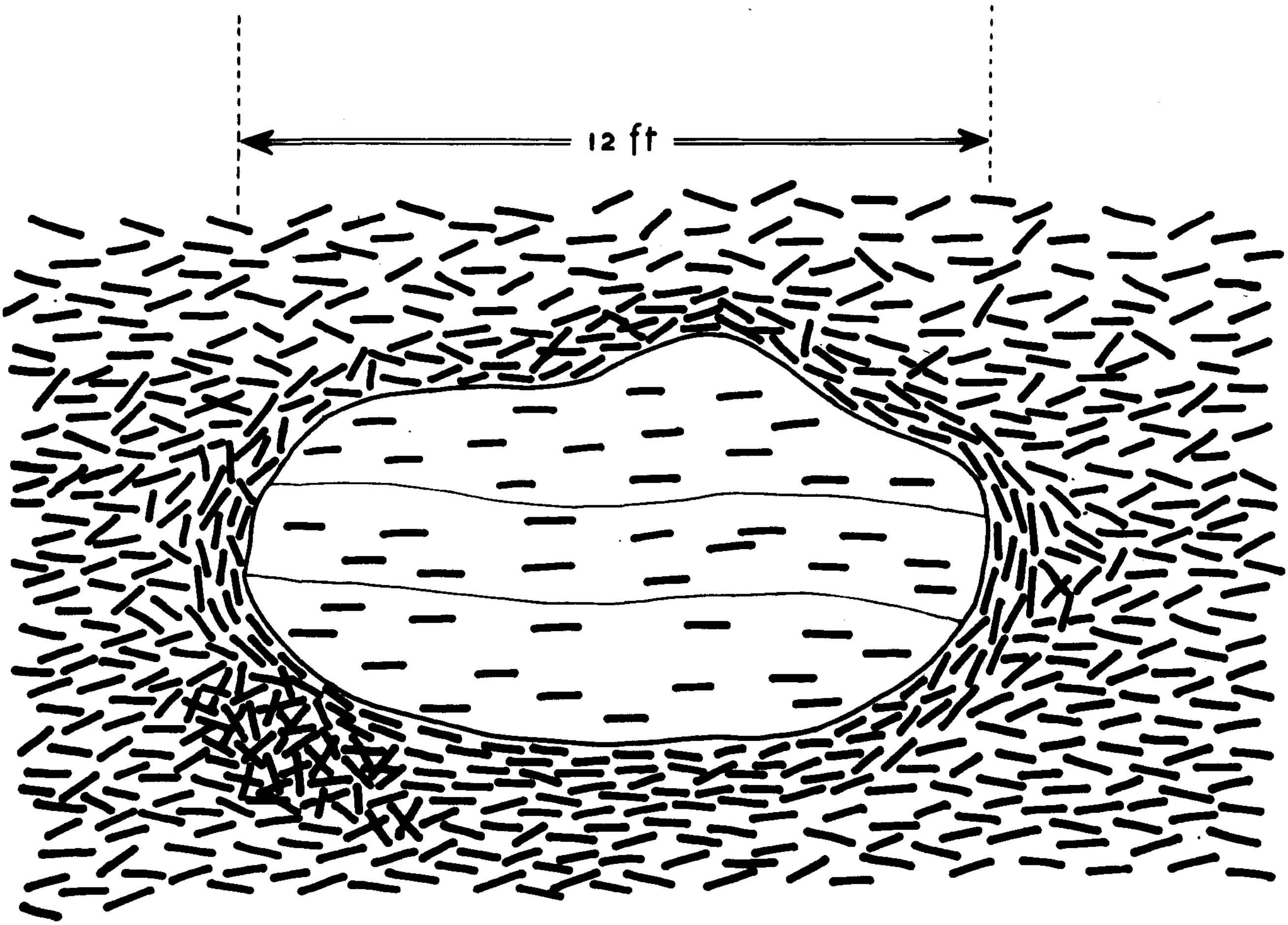
This moderately contaminated granite is in sharp contact with the normal coarse porphyritic biotite granite (G) which forms a distinct flow foliation (E) around it.

(The raft (A) is 12 feet long).



75

Text figure 75a. Sketch of the contaminated granite raft of figure 75 to illustrate the flow foliation.

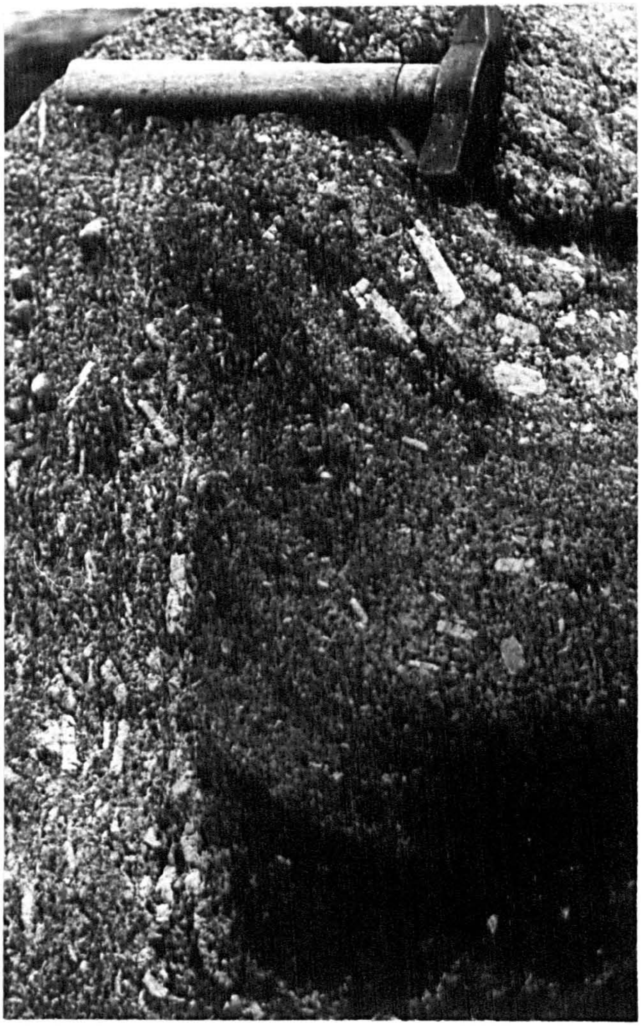


Raft of dark, more 'basic' granite. Sennen Cove.

B.B.

75a

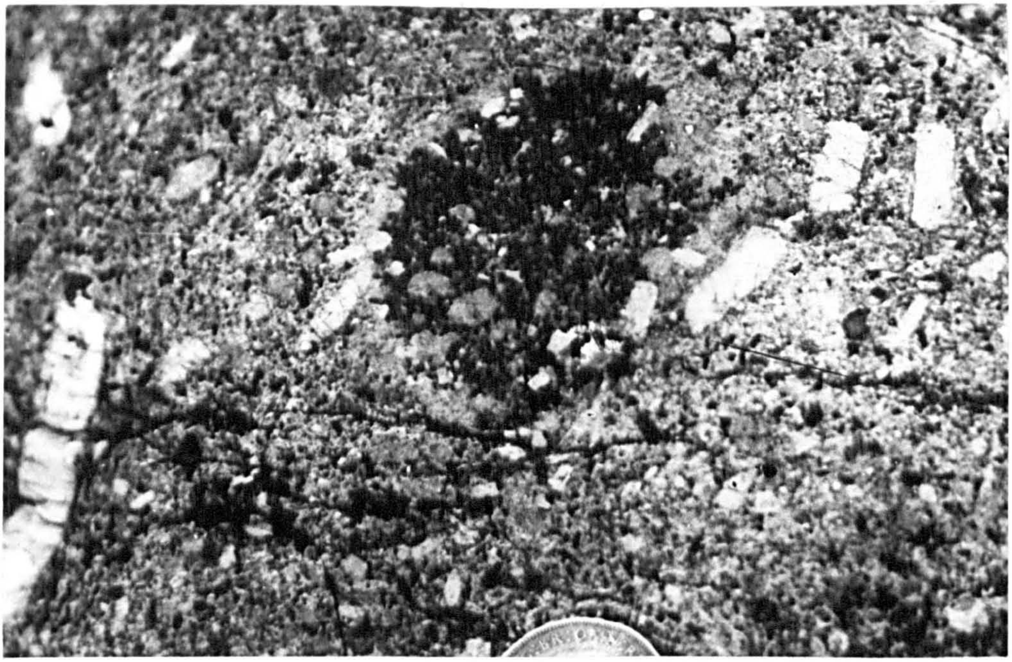
Text figure 76. Rounded xenolith of banded, highly contaminated granite. Note the flow foliation in the feldspars and the alkali feldspar megacrysts within the xenolith. Sennen Cove.



Text figure 76

Text figure 77. Tourmaline nodule in highly contaminated granite raft at Sennen Cove. Note the quartz blebs within the nodule and the rim of quartz across which alkali feldspar megacrysts have developed.

Text figure 78. Xenolith in coarse porphyritic granite at Sennen Cove. This photograph illustrates a stage in the granitisation of a pelitic anclave which is becoming granodioritic in aspect.

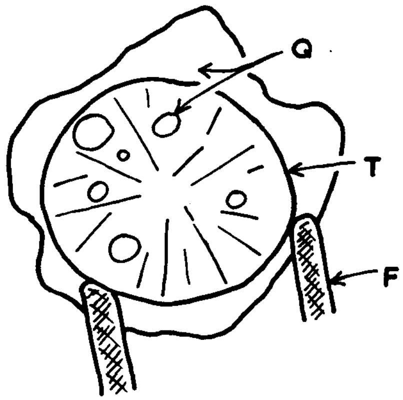


Text figure 77

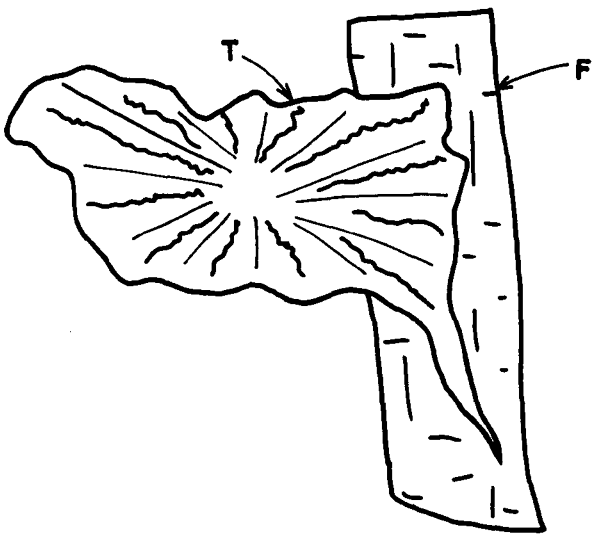
Text figure 78

Text figure 77a. Sketch of tourmaline (T) nodule in highly contaminated granite. Note the quartz (Q) margin and inclusions and the metasomatic alkali feldspar (F) which has grown across the quartz margin. X1.

Text figure 77b. Tourmaline nodule (T) replacing an alkali feldspar megacryst (F). X1.



77a

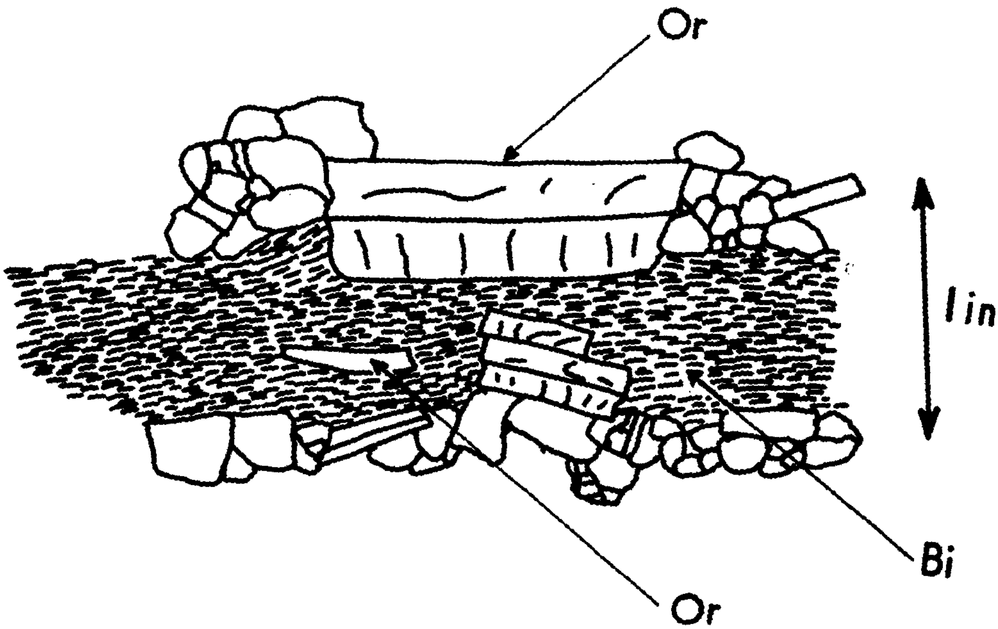


77b

Text figure 79. Contamination bands in coarse porphyritic granite. Sennen Cove.

Text figure 79

Text figure 79a. Sketch of schlieren near Bosigran Castle showing alkali feldspar megacrysts (Or) which have developed parallel and within the biotite rich (Bi) band.



Schlieren

Bosigran Castle.

Fracturing and Kaolinisation

Text figure 80. Fractured granite. Sennen Cove.

Text figure 80

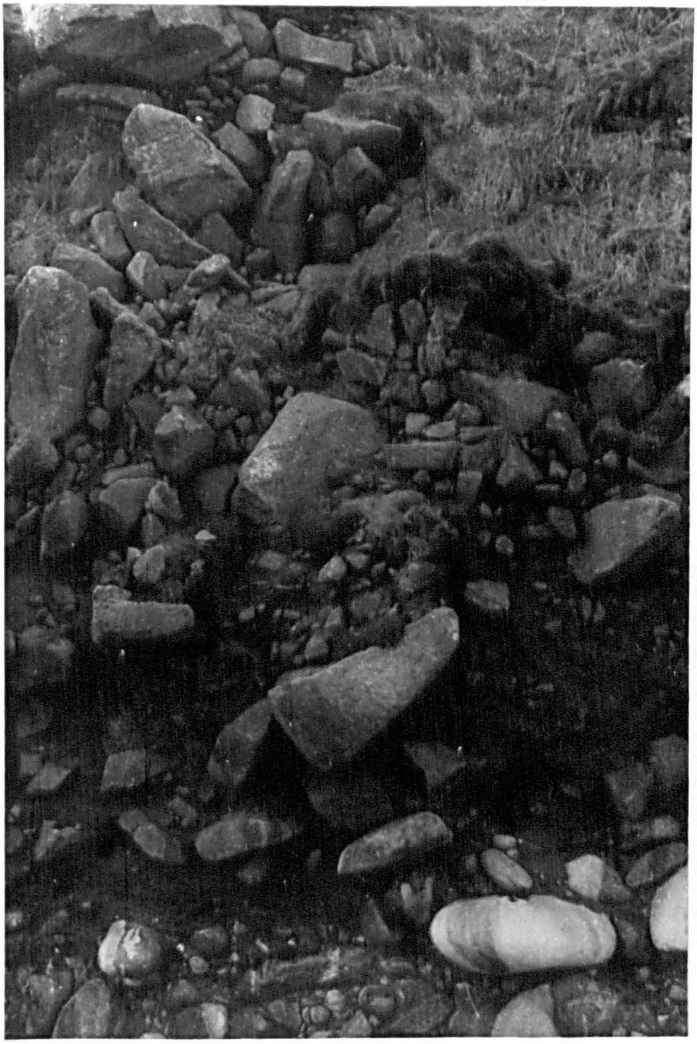
<u>Text figure 81</u>. Highly fractured, and part kaolinised granite. Mousehole.

<u>Text figure 82</u>. Highly fractured, part kaolinised and tourmalinised granite. This area (near The Mousehole) is partly mineralised - note adit on left. Note also the head overlying the granite, this is composed of rounded boulders, earth and growan. Raised beach deposits not obvious at this locality.

Text figure 81

Text figure 82

Text figure 83. Head overlying granite at the Mousehole, note the traces of raised beach deposits in the lower part of the photograph.



Text figure 83

Text figure 84. Rosemodress Cliff, Lamorna. Illustrating the heavily vegetated "growan" cover a few yards behind the coastal cliffs. This vegetation consists of gorse, brambles and bracken which often covers quite boggy ground making access to the cliffs difficult.

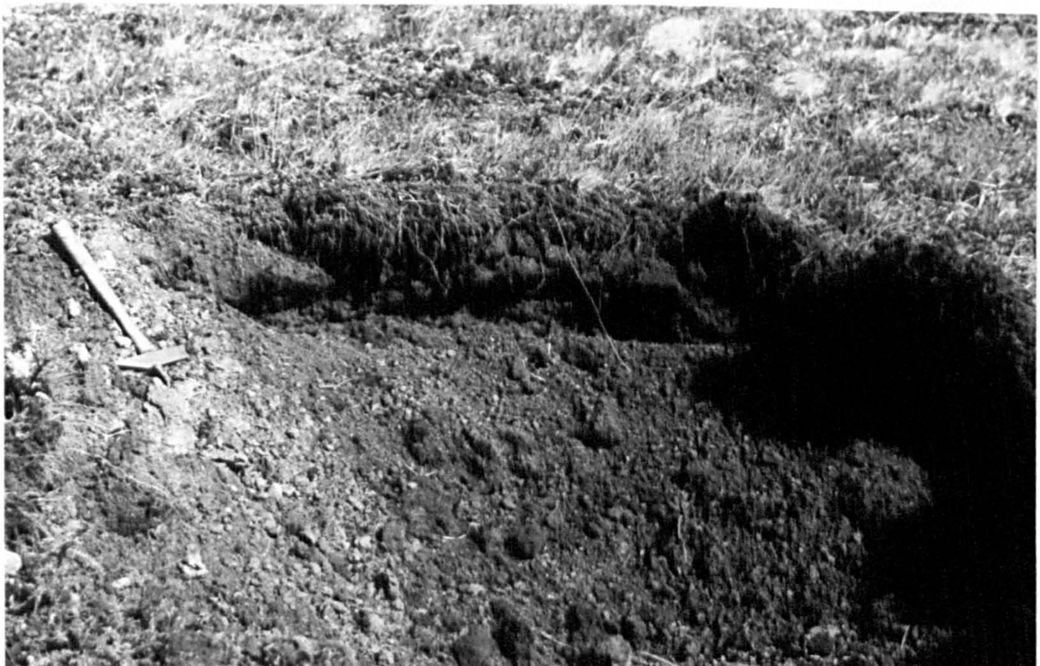
Text figure 84

Use of Explosives

14?

Text figures 85 and 86. Excavation by blasting, Castle-an-dinas. This time-saving technique was used in several instances to clean away topsoil and head and exposed granite bedrock. 6 lbs. of high explosive was used on this occasion.

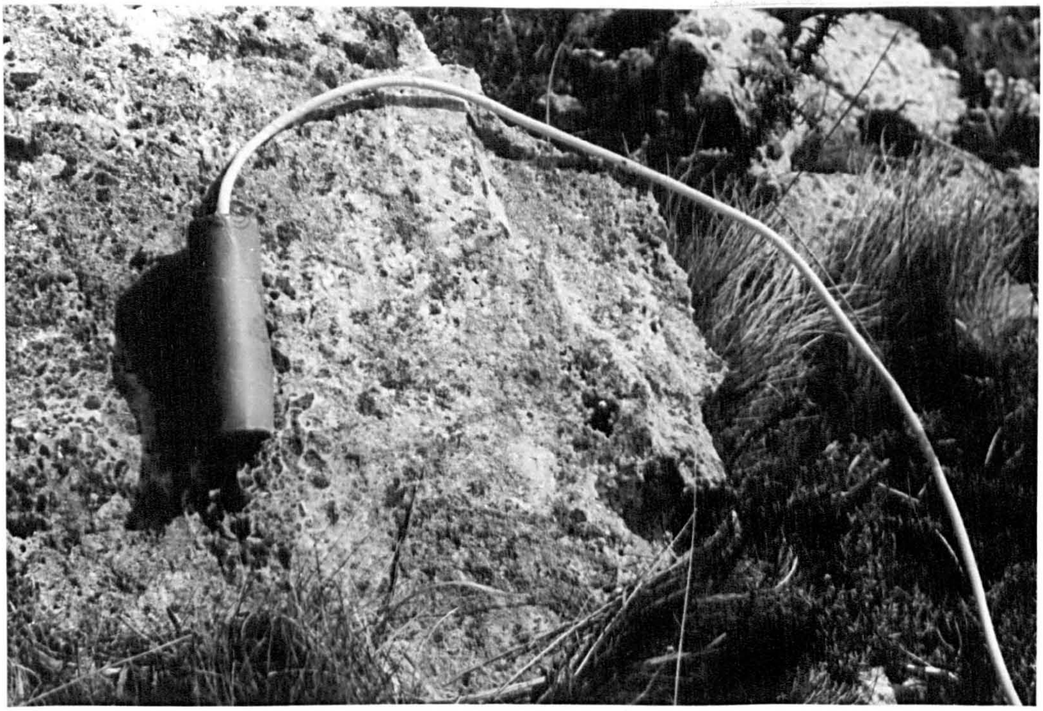
Text figure 85



Text figure 86

<u>Text figure 87</u>. 4 oz. cartridge of polar ammon gelignite suitably fused for plaster shooting the specimen shown.

<u>Text figure 88</u>. The tourmaline-quartz specimen after blasting. This technique was found invaluable for obtaining fresh samples of rock from deeply weathered exposures, or where considerable time and effort would have been expended obtaining specimens.



Text figure 87

Text figure 88

Photomicrographs

Text figure 88a.

Upper left. Alkali feldspar (OR) replacing biotite (Bi), which is intergrown with muscovite (MS). Quartz (QTZ) and plagioclase (PL) are also enclosed, note the formation of quartz vermicules within the plagioclase. X30.

Upper right. Quartz (QTZ) replacing biotite (Bi), which is partly mantled with muscovite (MS). X30.

Upper centre. Biotite (Bi) - muscovite (MS) intergrowth. X30.

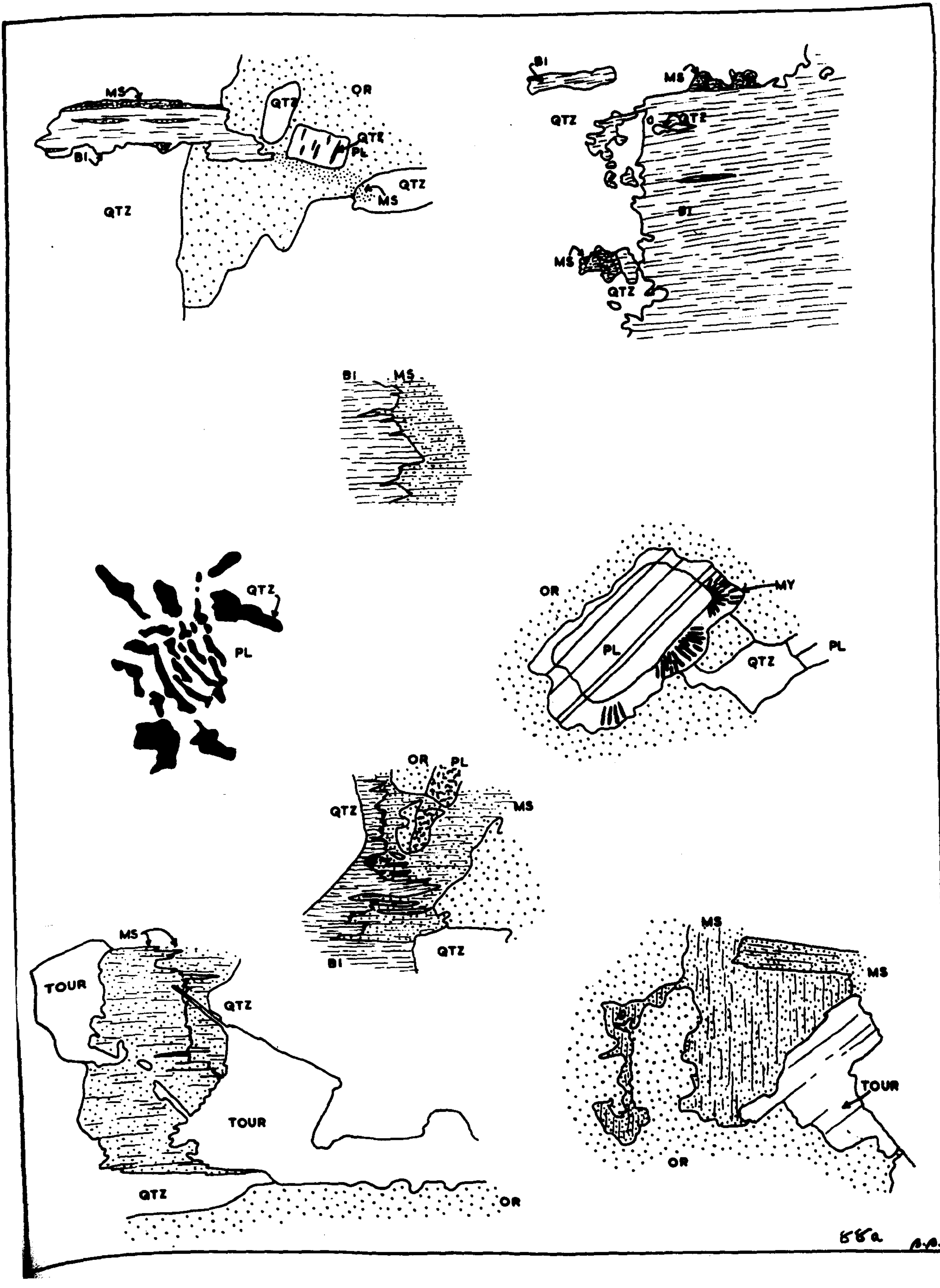
Centre left. Micrographic quartz (QTZ) in plagioclase. X30.

Centre right. Myrmekite (MY) developed in albite rim of plagioclase (PL) enclosed by alkali feldspar (OR). X80.

Lower centre. Muscovite (MS) replacing feldspar (PL & OR) and biotite (Bi). X30.

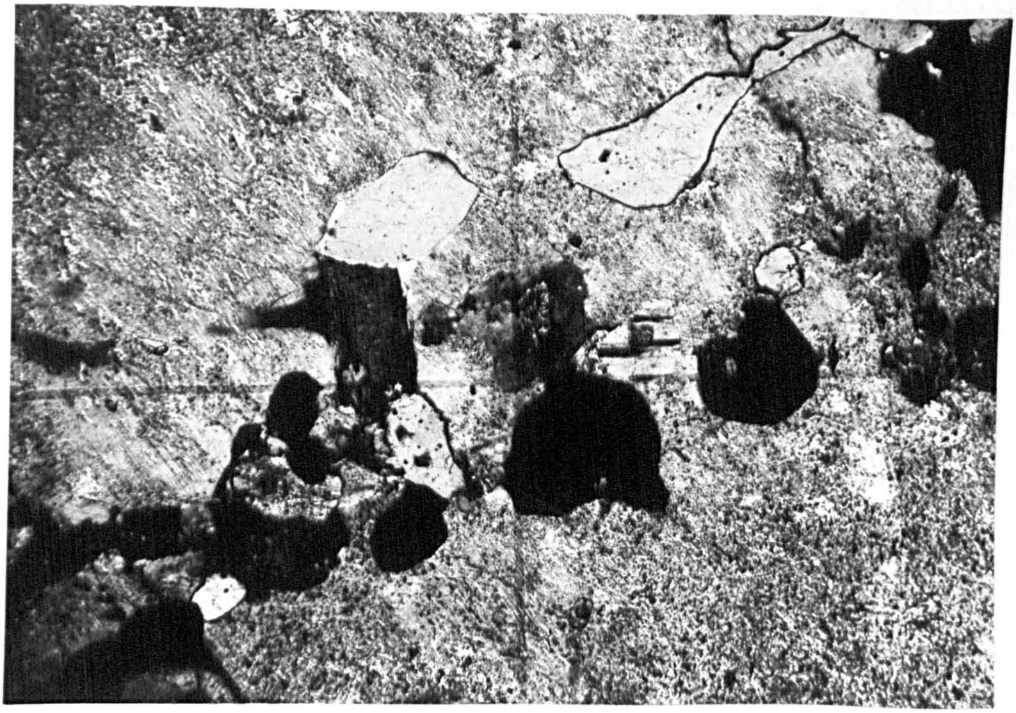
Lower left. Tourmaline (TOUR) replacing alkali feldspar (OR) and muscovite (MS). X30.

Lower right. Alkali feldspar (OR) replaced by muscovite (MS). X30.

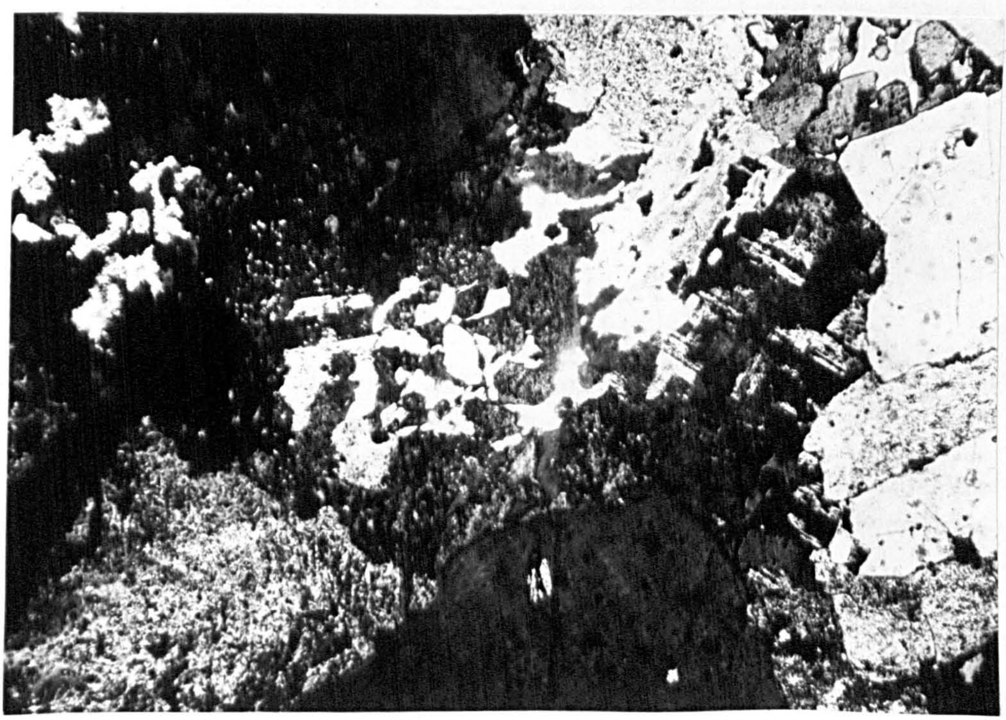

MS
QTZ
OR
QTZ
PL
BI
QTZ
MS
QTZ
BI
MS
QTZ
QTZ
BI
MS
QTZ
BI
MS
QTZ
PL
OR
MY
PL
QTZ
PL
OR
PL
QTZ
MS
BI
QTZ
MS
TOUR
QTZ
TOUR
QTZ
OR
MS
MS
TOUR
OR
58a

Text figure 89. Quartz inclusions in perthite. These inclusions occur in concentric zones and are often associated with biotite and plagioclase inclusions as in the photograph. Coarse porphyritic biotite granite. X30. Mousehole.

Text figure 90. Micrographic quartz in alkali feldspar. Note on the right of the photograph the alteration of plagioclase to secondary mica. Coarse porphyritic biotite granite. X30. Lamorna.



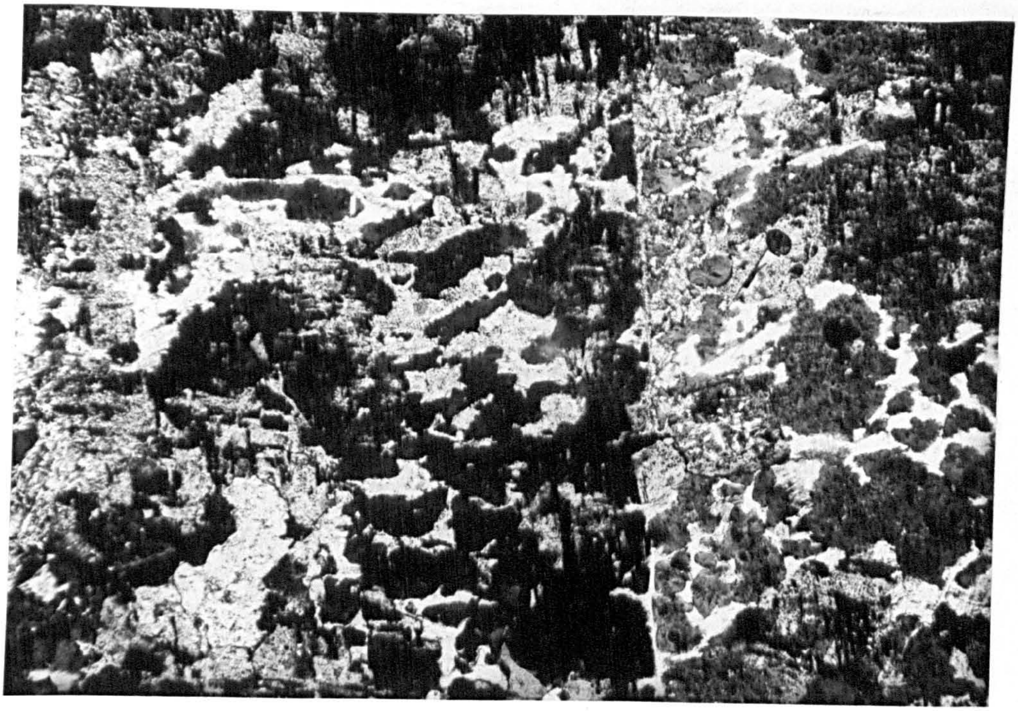
Text figure 89



Text figure 90

Text figure 91. Alkali feldspar (dark) replaced by secondary mica (white). Note the alteration proceeds along the twin plane and at right angles to it. Coarse porphyritic biotite granite. X40. Mousehole.

Text figure 92. Perthite. Coarse porphyritic biotite granite. X40. Mousehole.

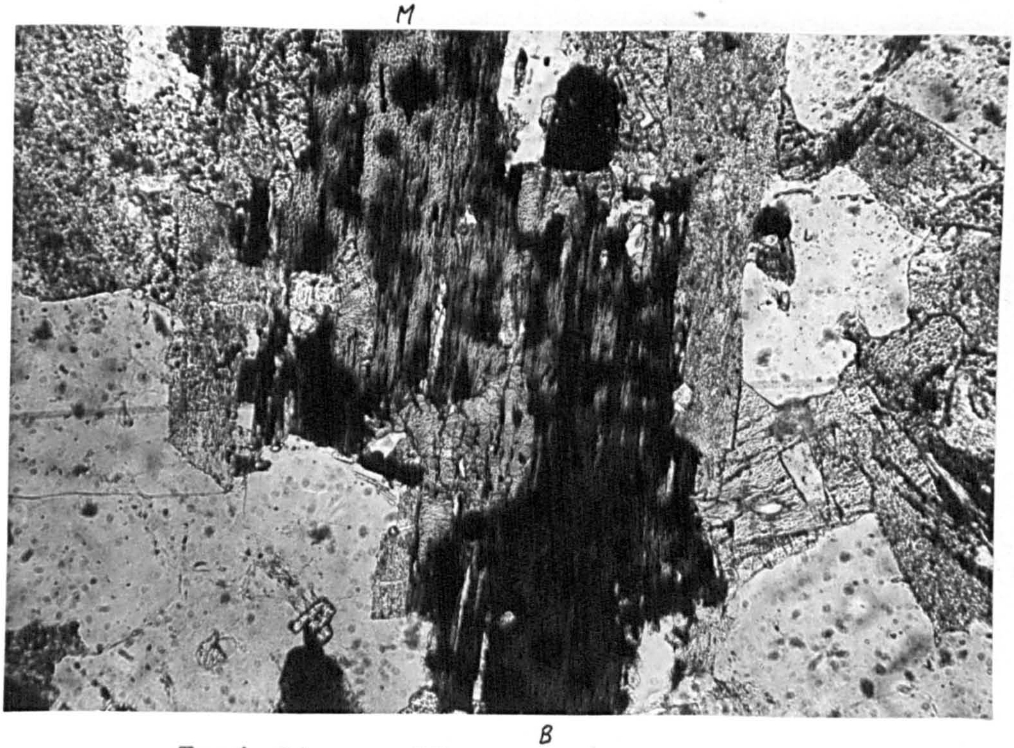


Text figure 91

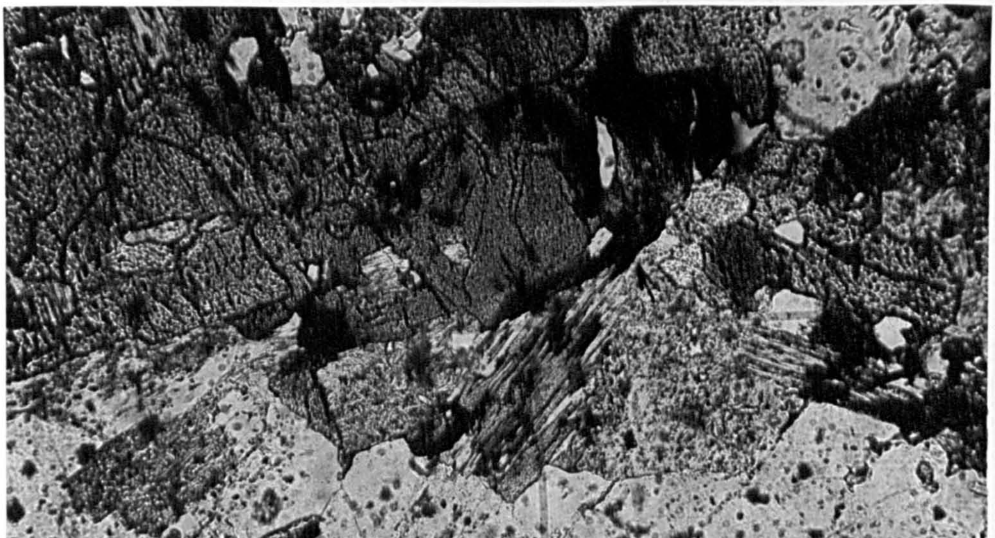
Text figure 92

Text figure 93. Biotite (B) altered to muscovite (M) which retains the pleochroic haloes. Coarse porphyritic biotite granite. X20. Mousehole.

Text figure 94. Tourmaline replacing biotite (arrowed). Note that the tourmaline is of a darker colour where it replaces the biotite. Coarse porphyritic biotite granite. X20. Mousehole.



Text figure 93

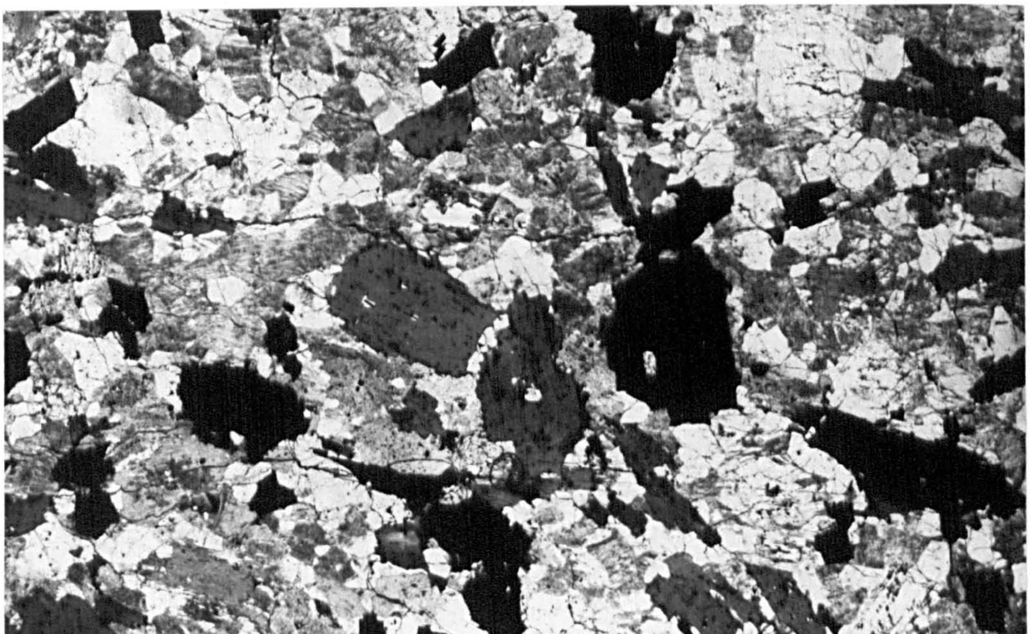


Text figure 94

Text figure 95. Fine grained contaminated granite. Note the contamination bands which are rich in biotite alternate with quartz-feldspar rich bands. X10. Pedn-men-du.

Text figure 96. Schlieren from Pedn-men-du. Note the relatively large flakes of fresh biotite and the numerous pleochroic haloes. X10.

Text figure 95



Text figure 96

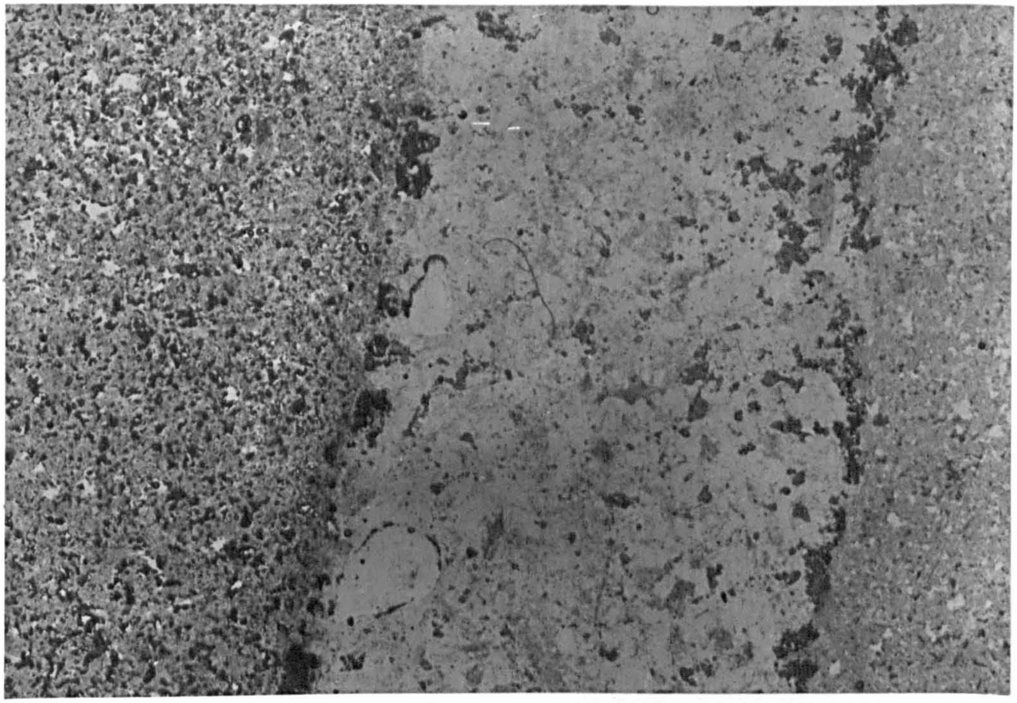
Text figure 97. Coarse porphyritic biotite granite. Note the twinned perthite and the plagioclase inclusions within the perthites have clear albite rims. X10. Newmill.

Text figure 98. Quartz "pools". Note the amoeboid margins of the pools and the numerous inclusions of feldspar around the periphery. Coarse porphyritic biotite granite. X5. Rosewall Hill west.

Text figure 97

Text figure 98

Text figures 99 and 100. Photographs in plane polarised light and crossed polarisers of an aplite vein cutting biotite plagioclase hornfels. Note the biotite selvedge which has developed at the junction of the aplite and the hornfels. X5. Gwavas Quarry, Newlyn.



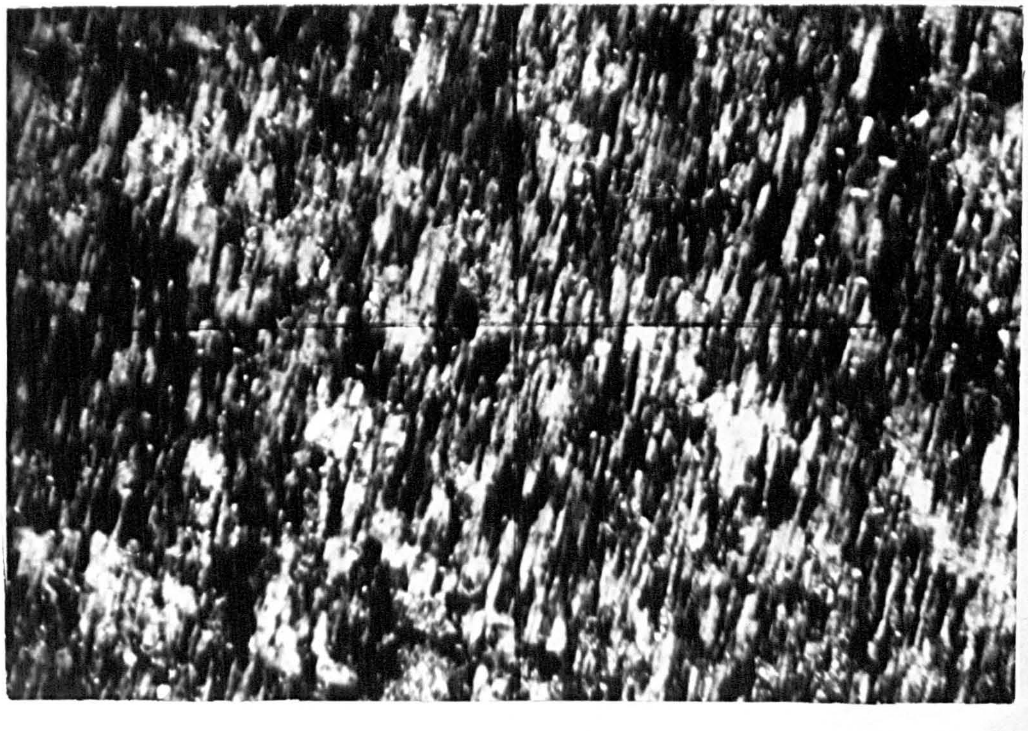
Text figure 99

Text figure 100

Text figure 101. Zoned plagioclase feldspars. Note the alteration products which follow the concentric zones, and the albite rim on the smaller crystal (arrowed). X80.

Text figure 102. Chessboard oligoclase. Knill's Steeple pegmatite. X160.

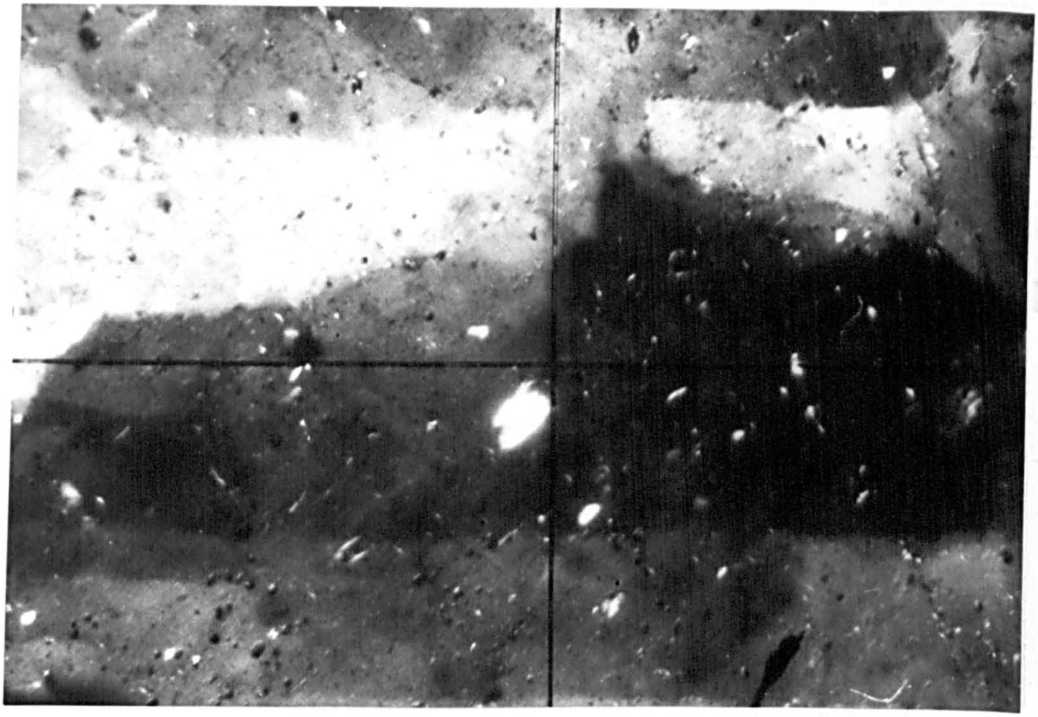
Text figure 101



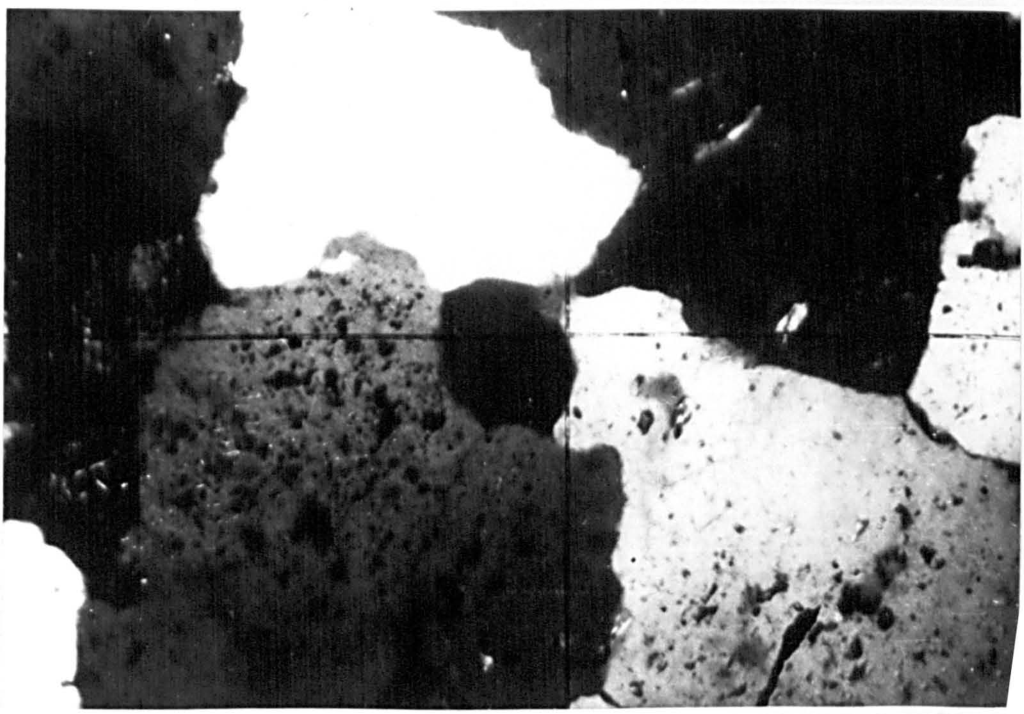
Text figure 102

<u>Text figure 103</u>. Parallel strain spindles in quartz. Medium grained non-porphyritic granite. X160. Porth Nanven.

<u>Text figure 104</u>. "Jig-saw" contacts between quartz grains. Coarse porphyritic biotite granite. X160. Lamorna.



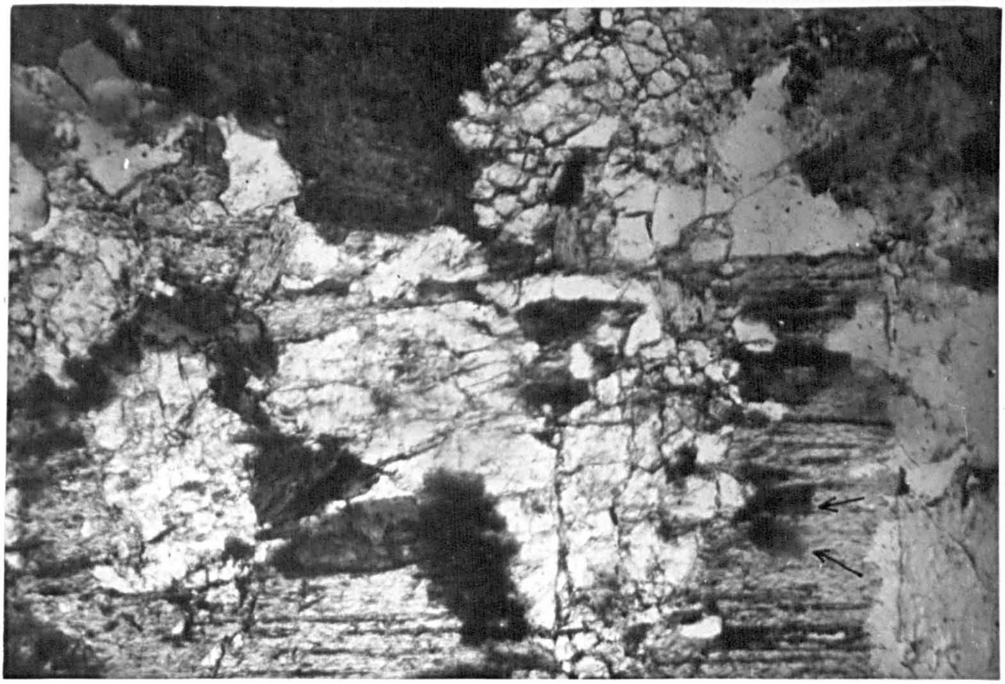
Text figure 103



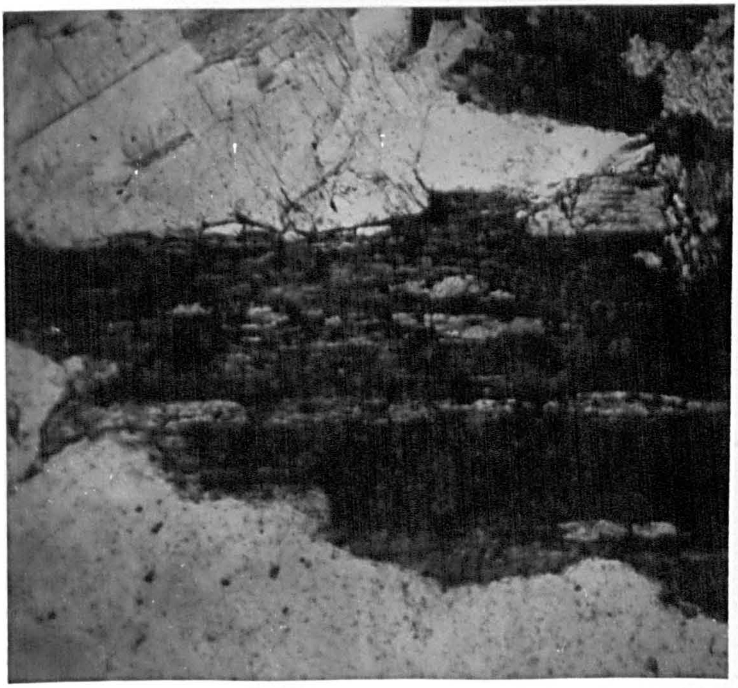
Text figure 104

Text figure 105. Andalusite-muscovite-biotite assemblage in relict xenolith. Note the biotite remnants within the muscovite (arrowed). Coarse porphyritic biotite granite. X80. Lamorna.

Text figure 106. Biotite flake illustrating alkali feldspar growing along the cleavage and pushing the cleavage plates apart. Coarse porphyritic biotite granite. X80. Mousehole.



Text figure 105

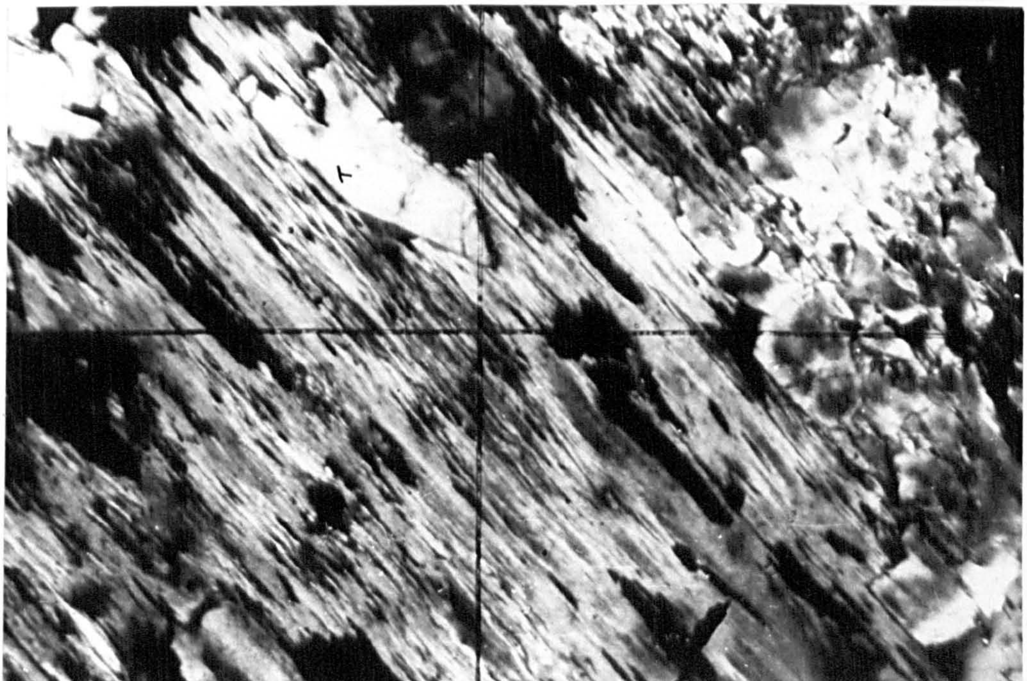


Text figure 106

Text figure 107. Biotite replaced by muscovite. Note the dark remnant patches of biotite. Medium grained granite. X80. Priest's Cove.

Text figure 108. Tourmaline inclusion in biotite. Note the many tabular crystals parallel to the biotite cleavage. Coarse porphyritic biotite granite. X160. Lamorna.

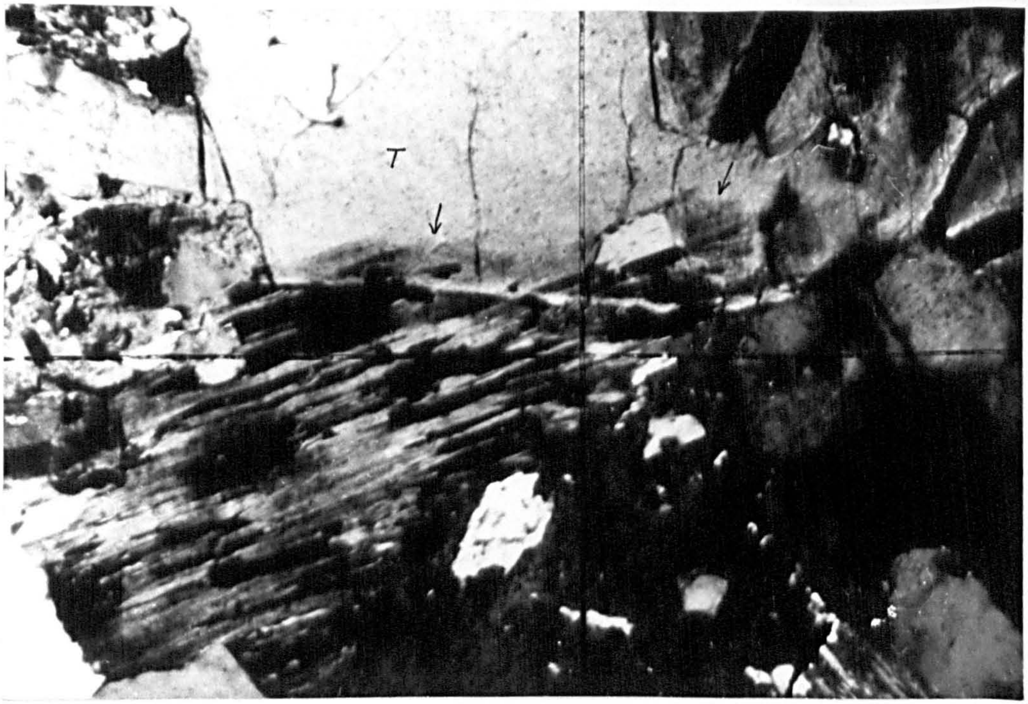
Text figure 107



Text figure 108

Text figure 109. Tourmaline (T) replacing biotite (arrowed). See page 110 in text. Coarse porphyritic biotite granite. X80. Mousehole.

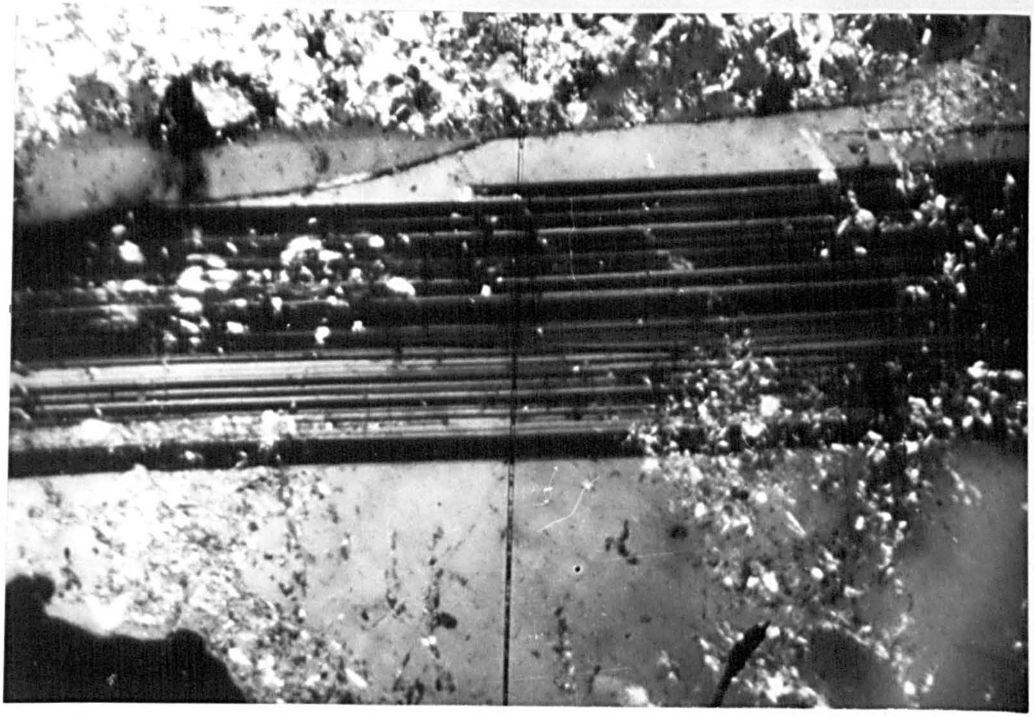
Text figure 110. Colour zoning in tourmaline. The darker bands are either dark yellow or deep blue, the lighter bands are pale yellow. Quartz schorl rock. X80. Porth Nanven.



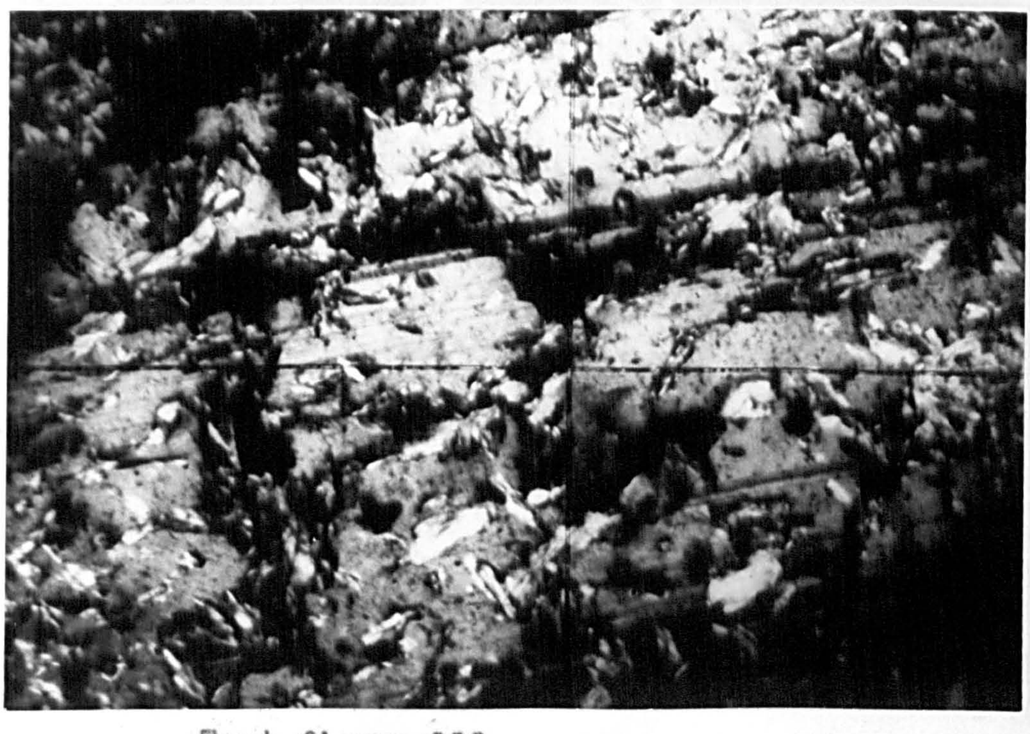
Text figure 109

Text figure 110

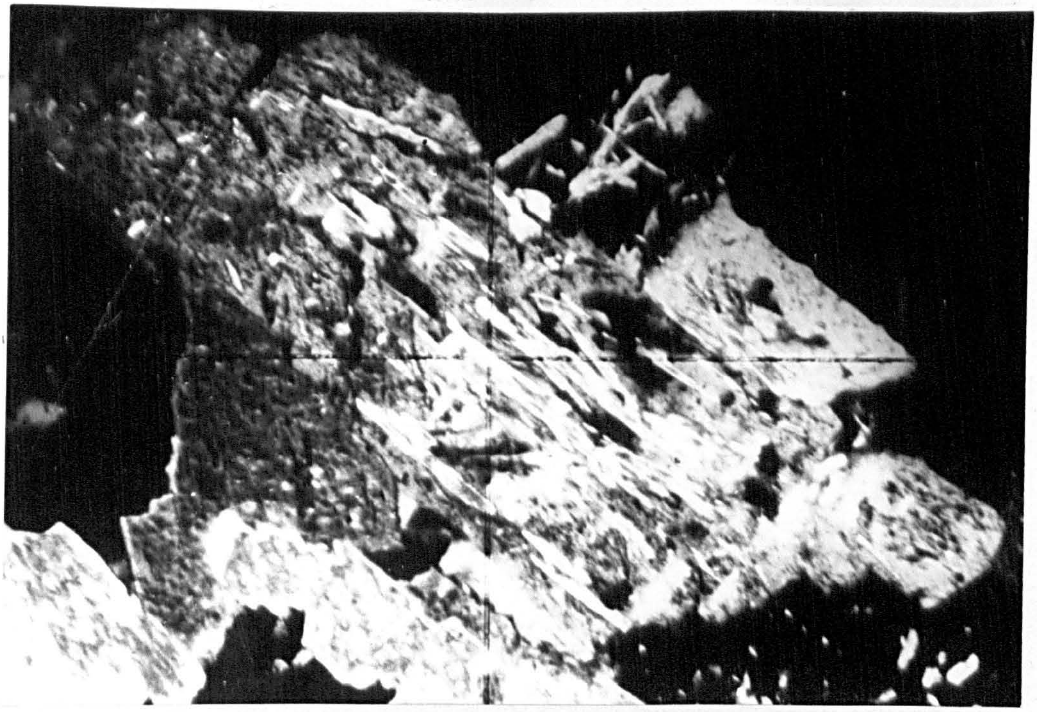
Text figures 111 to 118. Illustrate varying degrees of replacement of plagioclase feldspar by secondary mica and kaolinite. Note how the directions of secondary mica growth is governed by such factors as twin planes, and cleavage directions. 114 and 115 illustrate the secondary mica forming quite large patches of secondary muscovite. Note in 116 how the size of the mica flakes decreases towards the crystal margin reflecting changing composition, quite frequently only the more calcic centres are altered.
117 - high power photograph to show the mica flakes growing in two distinct directions.
118 illustrates a kaolinised granite in which the keolinite is isotropic (black), the rest is secondary mica.
Magnifications are X80 except for 117 which is X160.



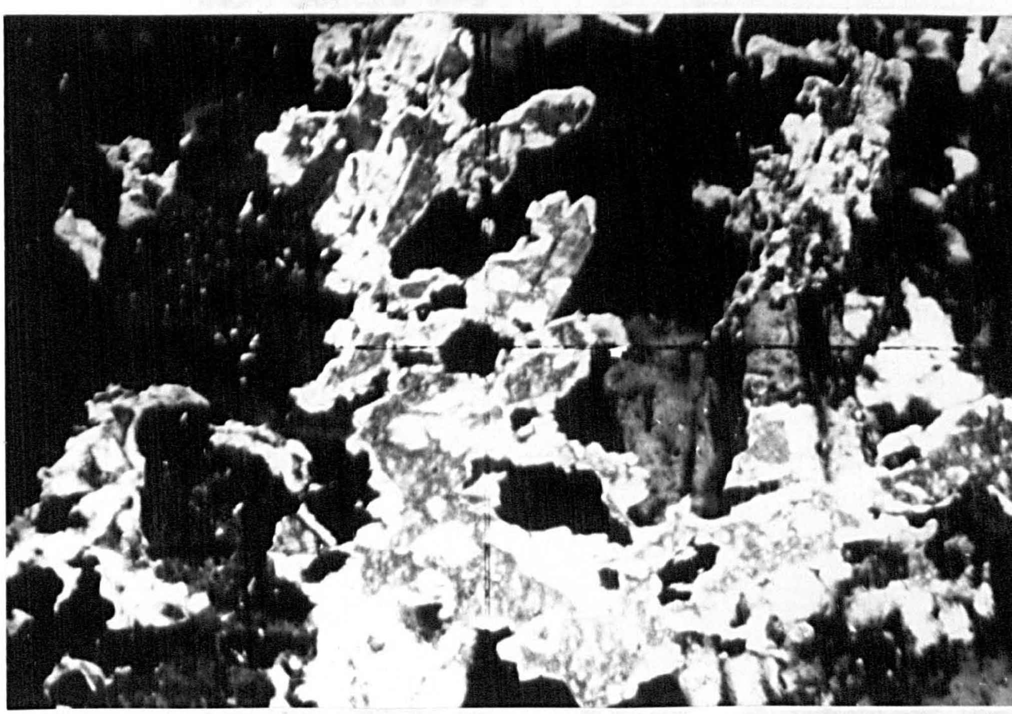
Text figure 111



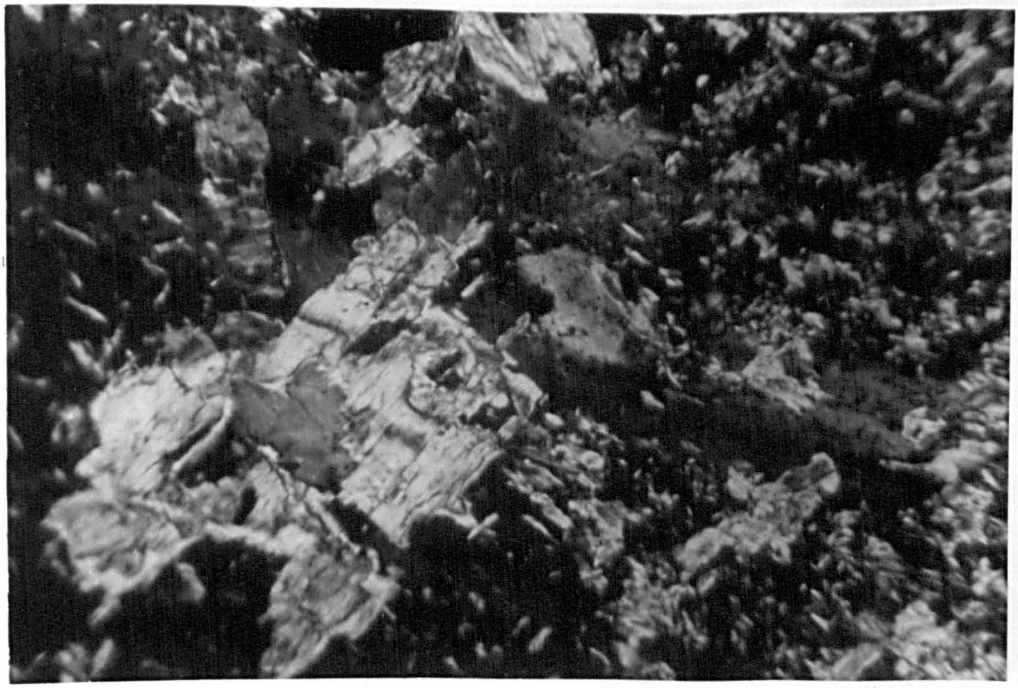
Text figure 112



Text figure 113

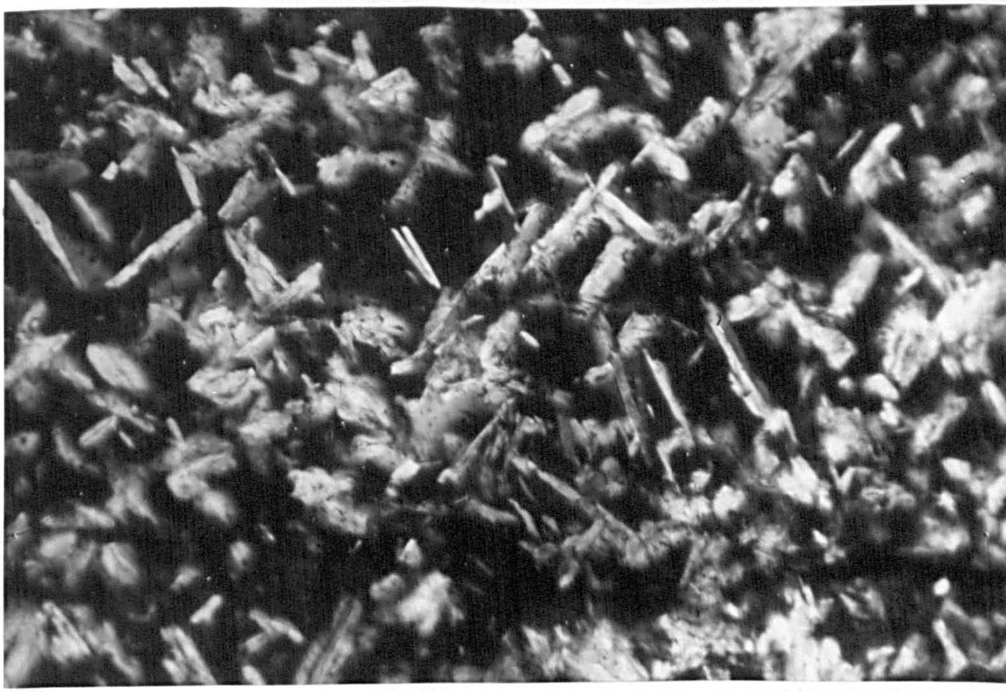


Text figure 114



Text figure 115

Text figure 116



Text figure 117

Text figure 118

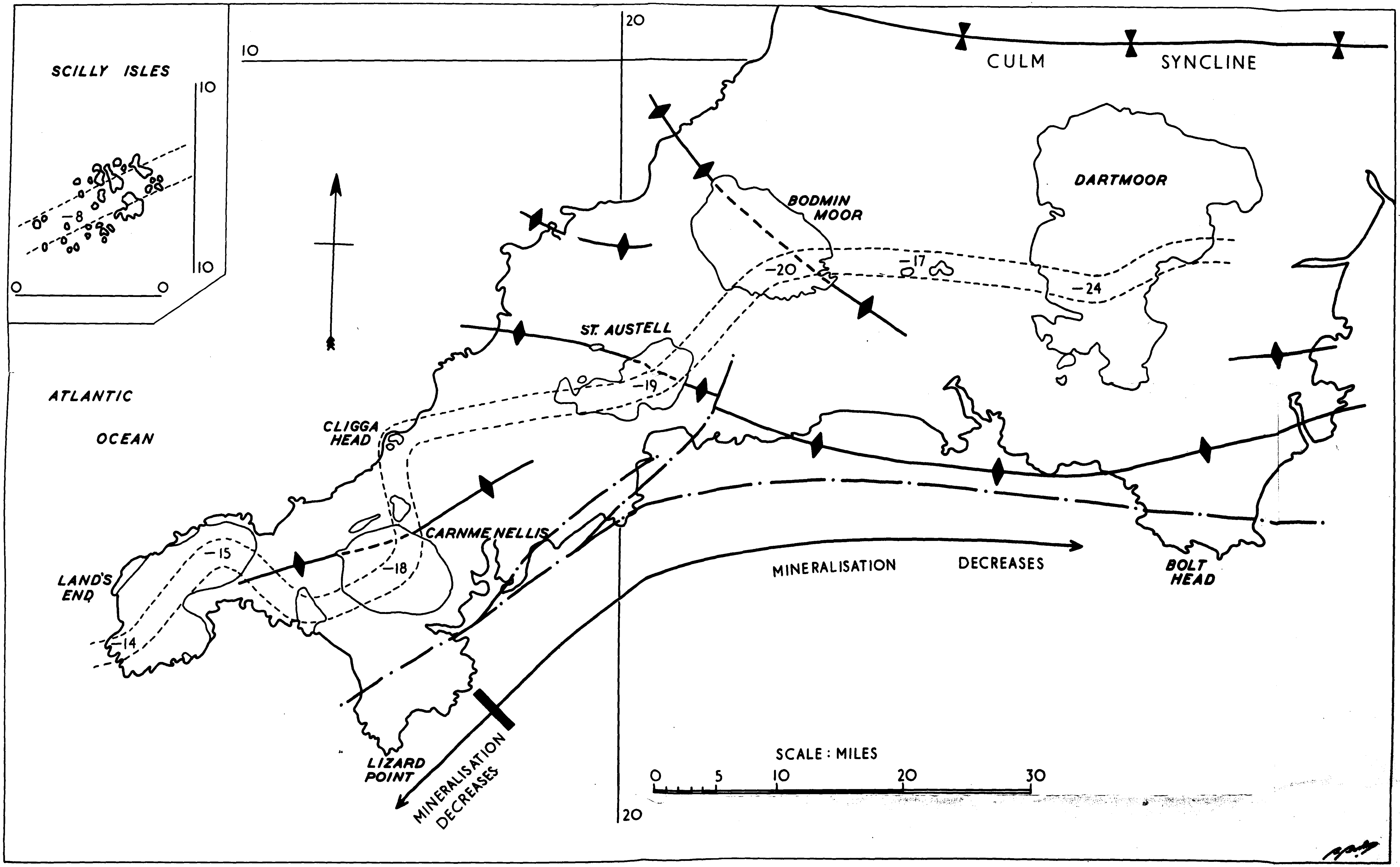
Regional Structure Map.

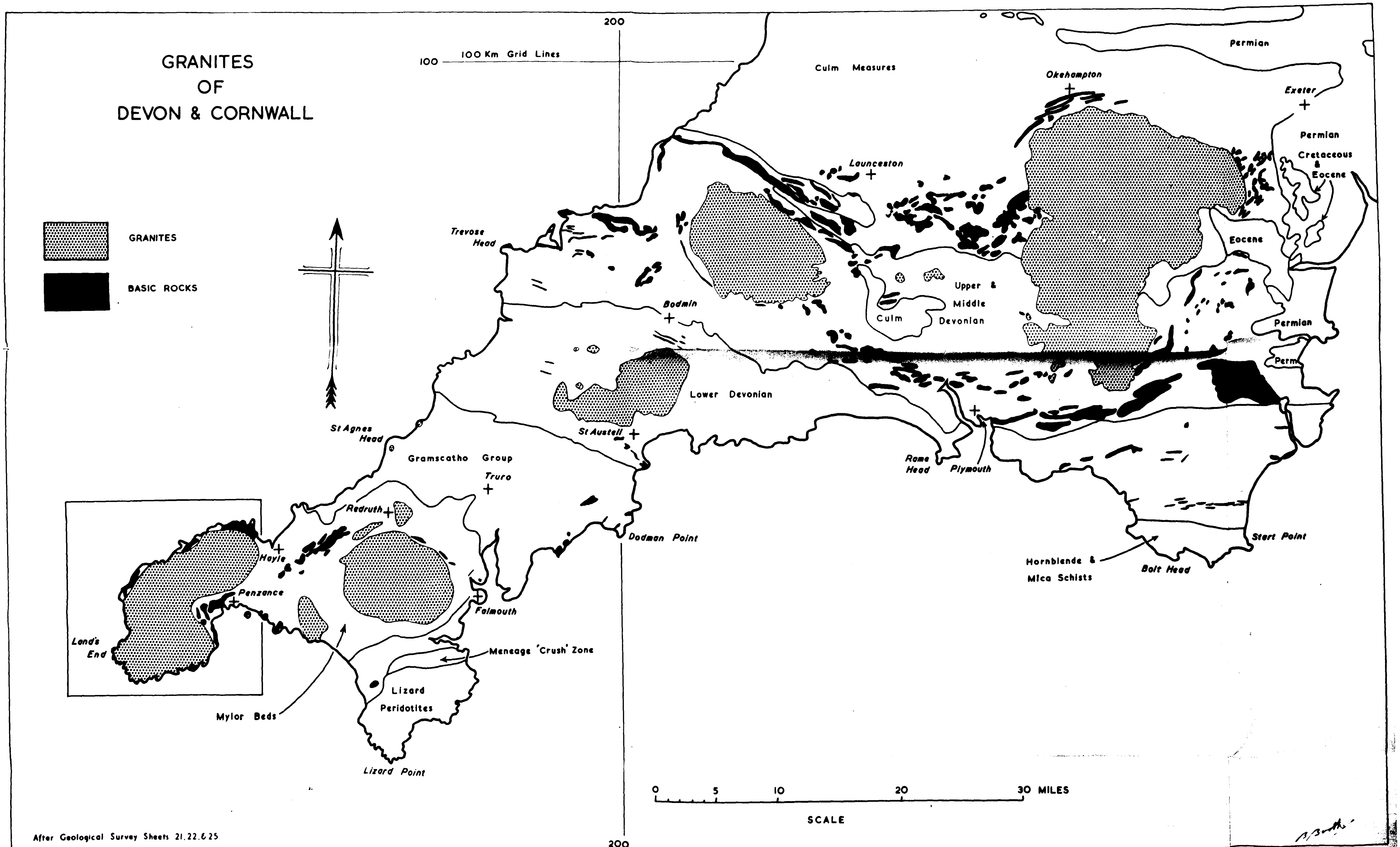
Illustrates:-

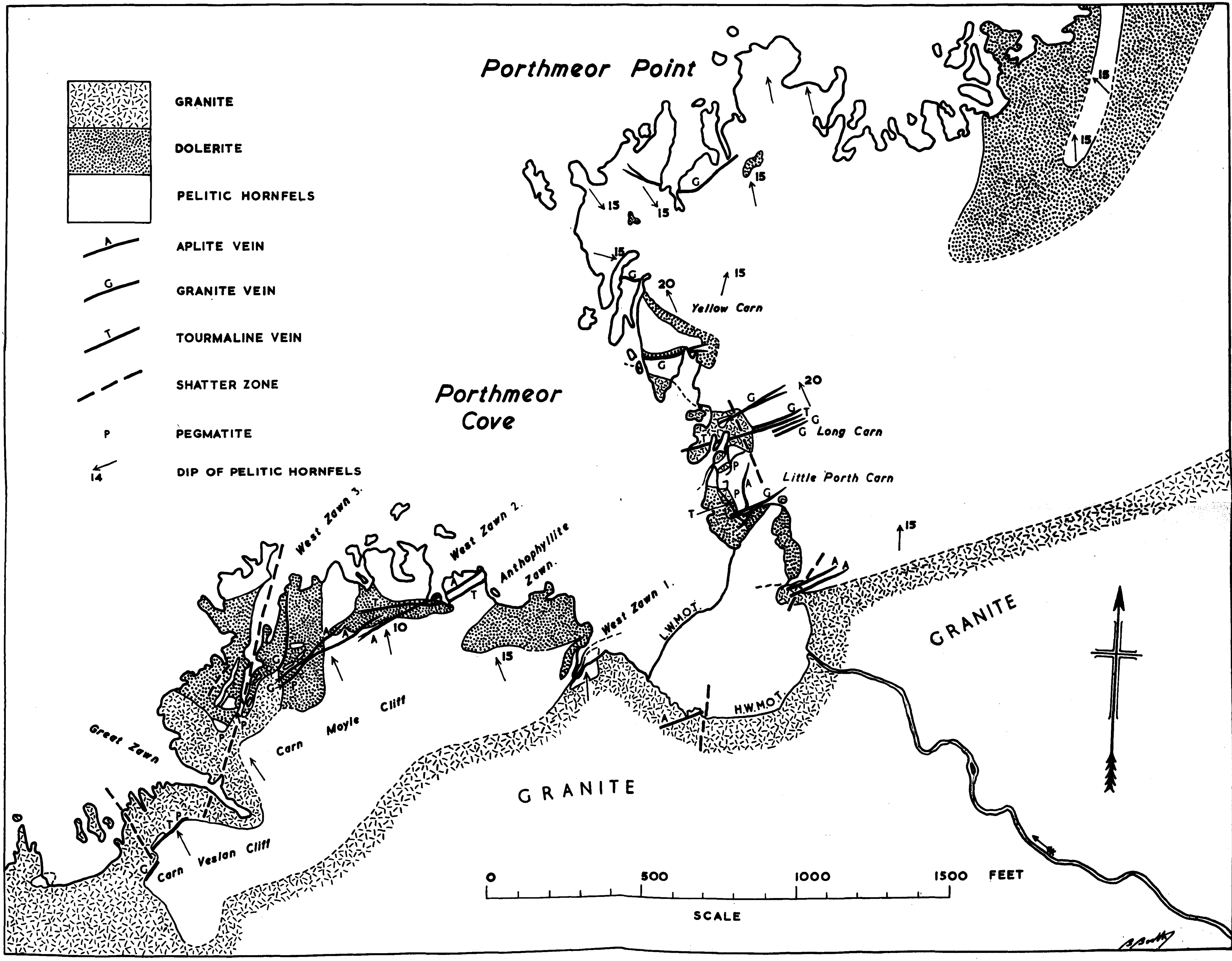
(a) the belt of negative Bouguer anomalies associated with the granites, the values decrease from east to west (-24 to -8) and reflect the thinning of the granite pluton in this direction.

(b) the major anticlinal and synclinal axes.

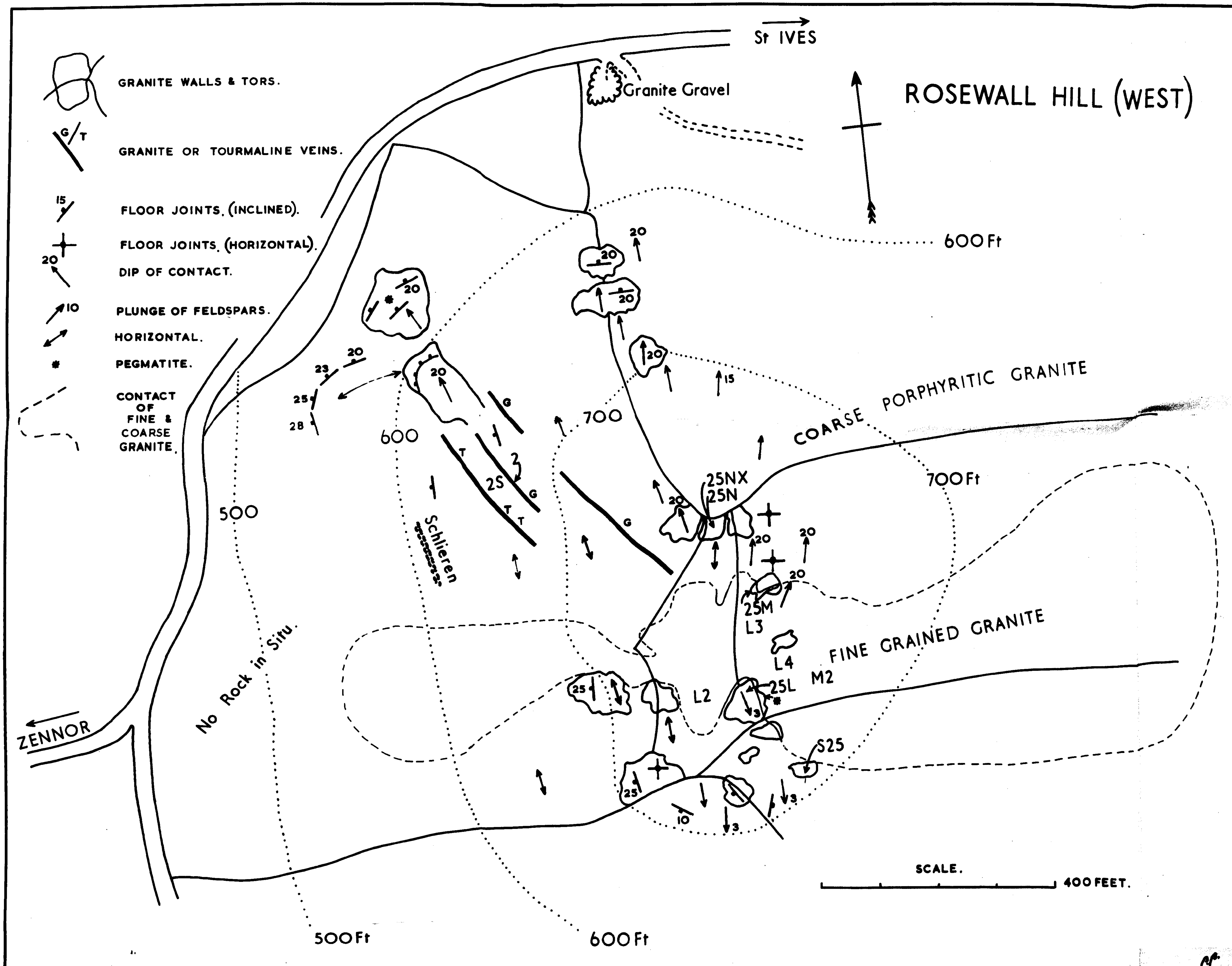
(c) regional degree of mineralisation.


SCILLY ISLES
10
8
10
CULM SYNCLINE
20
DARTMOOR
BODMIN
MOOR
20
17
24
ST. AUSTELL
19
ATLANTIC
OCEAN
CLIGGA
HEAD
CARNMENELLIS
15
18
LAND'S
END
14
MINERALISATION DECREASES
BOLT
HEAD
LIZARD
POINT
MINERALISATION
DECREASES
SCALE : MILES
0 5 10 20 30
20


GRANITES
OF
DEVON & CORNWALL
GRANITES
BASIC ROCKS
100 Km Grid Lines
100
200
200
Culm Measures
Permian
Okehampton
Exeter
Permian
Cretaceous & Eocene
Launceston
Trevose Head
Eocene
Upper & Middle Devonian
Culm
Bodmin
Permian
Perm
Lower Devonian
St Agnes Head
St Austell
Gramscatho Group
Truro
Rame Head
Plymouth
Redruth
Dodman Point
Start Point
Hayle
Hornblende & Mica Schists
Bolt Head
Penzance
Falmouth
Land's End
Meneage 'Crush' Zone
Lizard Peridotites
Mylor Beds
Lizard Point
0 5 10 20 30 MILES
SCALE
After Geological Survey Sheets 21, 22, & 25

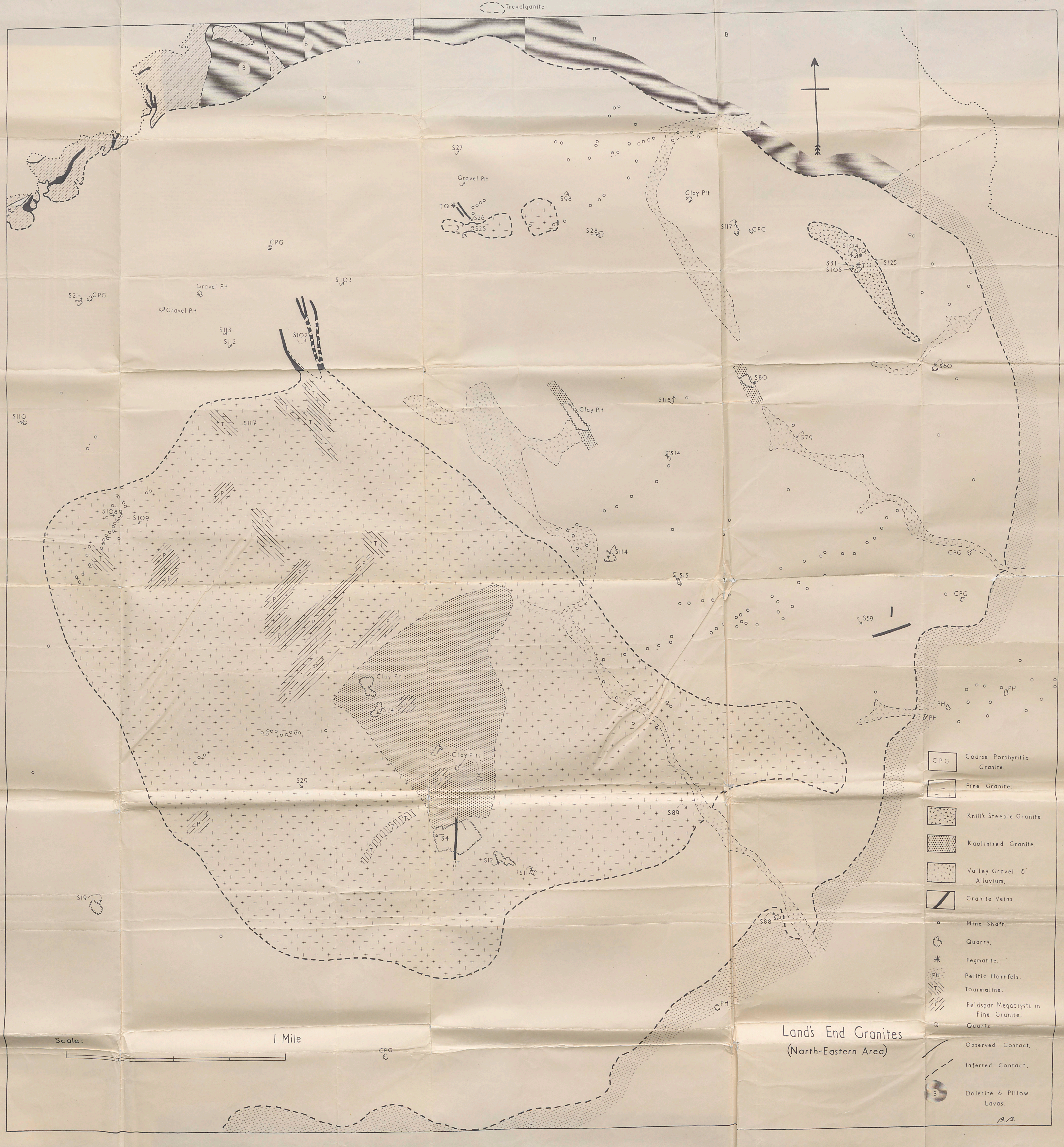


Porthmeor Point
Porthmeor Cove
GRANITE
DOLERITE
PELITIC HORNFELS
APLITE VEIN
GRANITE VEIN
TOURMALINE VEIN
SHATTER ZONE
PEGMATITE
DIP OF PELITIC HORNFELS
Yellow Carn
Long Carn
Little Porth Carn
West Zawn 3.
West Zawn 2.
West Zawn 1.
Anthophyllite Zawn.
Great Zawn
Carn Moyle Cliff
Carn Veslan Cliff
L.W.M.O.T.
H.W.M.O.T.
GRANITE
GRANITE
0
500
1000
1500
FEET
SCALE



ROSEWALL HILL (WEST)
St IVES
ZENNOR
GRANITE WALLS & TORS.
GRANITE OR TOURMALINE VEINS.
FLOOR JOINTS. (INCLINED).
FLOOR JOINTS. (HORIZONTAL).
DIP OF CONTACT.
PLUNGE OF FELDSPARS.
HORIZONTAL.
PEGMATITE.
CONTACT OF FINE & COARSE GRANITE.
Granite Gravel
600 Ft
700 Ft
500 Ft
600 Ft
500
600
700
COARSE PORPHYRITIC GRANITE
FINE GRAINED GRANITE
No Rock in Situ.
Schlieren
25NX
25N
25M
L3
L4
L2
25L
M2
S25
2S
SCALE.
400 FEET.


LAND'S END GRANITES.
U
V
St IVES BAY
WICCA POOL
GURNARD'S HEAD
ZENNOR
PORTHMEOR COVE
PORTHERAS COVE
WHIRLPOOL
MORVAH
THE AVARACK
BOTALLACK HEAD
WOON GUMPUS COMMON
BOSWARVA COMMON
NEWMILL
CROWLAS
CANON'S TOWN
PORTH LEDDEN
PRIEST'S COVE
St JUST
PORTH NANVEN
PENZANCE
MAEN DOWER
SANCREED
NEWLYN
AIRE POINT
BREA
SHEFFIELD
SENNEN
MOUSEHOLE
LONGSHIPS
LAND'S END
St BURYAN
POLGIGGA
MILL BAY
LAMORNA
TATER-DU
MERTHEN POINT
PORTH CURNO
GWENNAP HEAD
MYLOR SERIES (PELITIC HORNFELSES)
BASIC ROCKS (DOLERITES & SPILITES)
FINE GRANITE
COARSE GRANITE
PORPHYRITIC GRANITE
KAOLIN
QUARTZ VEIN
TOURMALINE VEIN
APLITE VEIN
GRANITE VEIN
QUARTZ PORPHYRY
XENOLITHS
CONTAMINATED GRANITE
PEGMATITE
TOURMALINE
AREA OF POOR EXPOSURE
PRESUMED CONTACT
PLUNGE OF FELDSPARS
FOLIATION 70°-90°
DIP OF FELDSPARS
FRACTURE ZONE
0 1 2 MILES.
B.B.


Trevalganite
B
Gravel Pit
TQ
S26
S25
S27
S98
S28
Clay Pit
S117
CPG
S104
S31
S105
S125
S103
S21
Gravel Pit
S113
S112
S107
S111
S110
S108
S109
S80
S115
S79
S14
S60
S114
S15
S59
S29
S89
S4
S12
S11
S19
S88
PH
Scale:
1 Mile
Land's End Granites
(North-Eastern Area)
CPG Coarse Porphyritic Granite.
Fine Granite.
Knill's Steeple Granite.
Kaolinised Granite.
Valley Gravel & Alluvium.
Granite Veins.
Mine Shaft.
Quarry.
Pegmatite.
PH Pelitic Hornfels.
Tourmaline.
Feldspar Megacrysts in Fine Granite.
Q Quartz.
Observed Contact.
Inferred Contact.
B Dolerite & Pillow Lavas.
B.B.