CORNISH PEGMATITES AND BODIES WITH PEGMATITE AFFINITIES

by K. F. G. Hosking, M.Sc., A.M.I.M.M.

Abstract

A large number of granite pegmatites and bodies with pegmatite affinities exist in Cornwall but they have received much less attention than they deserve, probably because the majority of them are small and of no economic importance.

The author describes the occurrence, structure and paragenesis of most of the known granite pegmatites and suggests a tentative classification of pegmatitic bodies.

In order to establish the degree of relationship existing between the pegmatites and the granites on the one hand, and between the pegmatites and normal lodes on the other, some discussion is included of miarolytic granite, together with those fissure veins and lodes which, from a mineralogical point of view, bear some resemblance to pegmatites. Their continued study is certain to shed new light, not only upon the mechanisms of pegmatite development, but also upon the origin and development of the normal lodes.

THE TIMES AND PLACES OF PEGMATITE FORMATION

Apart from the complex suite of igneous and metamorphic rocks of the Lizard Peninsula, Cornwall is composed of a series of Devonian and Carboniferous rocks which are essentially slates, grits and limestones, with which are associated numbers of small basic and ultra-basic intrusives together with some extrusives. In Permo-Carboniferous times these rocks were invaded by a succession of waves of granite magma which consolidated as a mass of granite with a markedly undulating surface, and which extended from the Scilly Islands to Dartmoor. Erosion has exposed the higher portions of this mass. The composite nature of some of the exposed granite masses has been demonstrated by Ghosh (1934) and others. Ghosh, for example, has shown that the Carn Menellis mass is composed of three major types of granite and associated with each of these is a series of minor intrusives, veins and pegmatites.

Generally, following the emplacement of the latest granite, and usually after the consolidation of the minor intrusives, a series of hypothermal and mesothermal lodes were formed. These were sometimes preceded by a phase when pegmatites containing such heavy minerals as cassiterite, wolfram and arsenopyrite were developed, but the normal lodes completely overshadow the heavy-mineral pegmatites. The Castle-an-Dinas wolfram deposit is one example of a lode which was formed before the whole of the granite had been emplaced, and examples of lodes displaced by porphyry dykes occur in the literature.

These facts make it clear that the once widely held conception that the order of formation was granite, porphyry dykes, pegmatites and aplites lacking heavy minerals, pegmatites with heavy minerals and normal lodes is erroneous.

Field evidence indicates that in Cornwall pegmatites certainly developed both during and after, and possibly before the emplacement of the granite.

At Priest's Cove (Cape Cornwall), a quartz-felspar vein is cut by a vein of fine-grained granite with a pegmatitic core.

At Porthmeor Cove (Zennor), a marginal pegmatite (described below) exists, which developed during the emplacement, but before the consolidation of the granite which it fringes. Similar, but much smaller examples, have been noted by the writer at St. Michael's Mount and St. Agnes.

Ghosh (1934) suggests that several comparatively large pegmatites are genetically related to the second of the three granite phases in the Carn Menellis mass.

In the cliff section at Tremearne (Porthleven), a porphyry dyke is clearly cut by granite veins which are partially fringed by pegmatite.

At Trolvis Quarry, Long Downs, pegmatites occur which were developed before the joints in the surrounding granite, whilst at De Lank Quarry (Bodmin Moor), small pegmatites occupy granite joints.

No example is known to the writer of a pegmatite displacing a normal lode, but at Tremearne, St. Michael's Mount and elsewhere, lodes intersect and sometimes displace pegmatites.

The larger, and mineralogically and structurally most interesting of the pegmatites lacking heavy minerals, almost invariably occur near the junction of the parent intrusive and the intruded rock and some are confined to the former. It is important to remember that the intruded rock may be an earlier phase of granite. Thus, although the Long Downs pegmatites are at a considerable distance from any past or present granite-killas junction, they are very near the junction between Ghosh's earlier and later granites. On the other hand, some of the most well-known pegmatites carrying heavy minerals occur at considerable distances from known junctions. Thus, a pegmatite consisting of felspar, quartz, muscovite, garnet and cassiterite was cut at Williams' Shaft, Dolcoath Mine, at a depth of nearly 4,000 feet from the surface of the granite, (Davison, 1927, p.327). At South Crofty Mine, a pegmatite containing wolfram and arsenopyrite, and termed the Complex Lode, is situated at about a thousand feet inside the granite-killas junction.

Although pegmatites are widely distributed in and around the granite outcrops of Cornwall, there are certain areas in which they are much more markedly developed than others. Thus the granite-killas coastal section between Tremearne and Prah Sands, and the Long Downs area (Penryn), are outstanding examples of areas where pegmatites lacking in heavy minerals are abundant. The north-eastern and eastern marginal zones of the Bodmin Moor granite contain more wolfram-bearing pegmatites than the whole of the rest of Cornwall. On the other hand, both the outcropping and known underground portions of the Carn Brea granite are practically devoid of "normal" pegmatites, although in depth several wolfram/arsenopyrite-bearing pegmatites exist. The significance of these distribution variations is discussed later.

THE CHARACTERISTICS OF THE PEGMATITES AND OF BODIES WITH PEGMATITE AFFINITIES

The Cornish pegmatites and bodies with pegmatite affinities may be classified according to the time of their formation with respect to that of the associated granite, and further sub-divisions may be made by taking into account their developmental and mineralogical characteristics. A broad classification, based on such considerations appears below (Table I), and in order to appreciate the characteristics of the bodies under review, dominant types of each group are considered in some detail.

TABLE 1.

CLASSIFICATION OF CORNISH PEGMATITES AND BODIES WITH PEGMATITE AFFINITIES

Time and order of formation	Type localities
I. PEGMATITES FORMED BEFORE GRANITE EMPLACEMENT :—	
Order 1. Pre-granite pegmatites ...	Priest's Cove ? (Land's End)
II. PEGMATITES FORMED DURING GRANITE EMPLACEMENT :—	
2. Before consolidation of granite crust	Porthmeor Cove, St. Michael's Mt., Cligga Hd.
3. During consolidation of granite crust :—	
a. Miarolytic granite ...	Polkanuggo (C. Menellis)
b. Schlieren and blebs ...	Scilly Is., Carbis Bay, Dolcoath Mine.
III. PEGMATITES FORMED AFTER CONSOLIDATION OF GRANITE CRUST :—	
4. Pegmatites devoid of heavy minerals :—	
(i) formed by replacement with relict felspar ...	S. Crofty Mine, Botallack, Cligga Hd.
(ii) derived from pegmatite "fluid": felspars formed by replacement of granite or in solution cavities	Priest's Cove, Knills steeple Qy., Trolvis Qy. (C. Menellis)
(iii) occupying mechanically formed spaces ...	Tremearne (Godolphin), Rinsey Cove, Trelavour.
5. Pegmatites with marked quantities of heavy minerals (cassiterite, wolfram, arsenopyrite)	S. Crofty, E. Pool, New Dolcoath (C. Brea), Hawkswood Mine (Bodmin Moor).
6. Hydrothermal (and/or pneumatolytic) veins reminiscent of pegmatites	St. Michael's Mt., Wheal Edward, Penberthy Croft, Cligga Hd.

Group I. Pre-granite pegmatites.

That the development of pegmatite veins may precede the emplacement of granite in a given area is not a new concept. Thus, Sederholm (1926, p.138) thinks that "the granitic masses, which have been mobilised already at a very great depth, and their emanations, invade the solid rock masses rising from below, when their vanguard of pegmatitic veins may advance even long before the great army . . ." To date, only a single example of a pegmatite which may be pre-granite has been observed in Cornwall and this occurs at Priest's Cove, Cape Cornwall, where a felspar-quartz vein is cut by a vein of fine-grained granite. Webb, who first described this example, remarks that "the granite vein is similar to many which are contemporaneous with the main mass of the granite, and it may be assumed therefore, that the quartz-felspar vein is pre-granite." (1947, p.47). On the other hand, whilst the quartz vein is undoubtedly earlier than the granite vein, the felspar in the former may not be. The shape of the felspar mass strongly suggests that it has been developed by replacement of the quartz as a result of the action of liquids and/or vapours which migrated along a steeply dipping fissure which transects the felspar and with which is associated another lenticular mass of felspar in the country rock below the "pegmatite" vein. In the writer's opinion, the time of formation of the felspar is definitely uncertain.

It is possible, that some of the numerous, small, quartz/felspar veins encountered in the country rock near the granite, may also be pegmatite vanguards of the granite. Typical examples may be found on the waste dumps of Wheal Edward (St. Just), Trenwith Mine (St. Ives), Wheal Alfred (Hayle) and Penberthy Croft (St. Hilary).

At Wheal Edward, Trenwith and Penberthy Croft, quartz-felspar veins carrying chalcopyrite, cassiterite, etc., also exist so it is possible that all the felspathic veins in these areas may be associated with the phase of normal lode development. The felspathic veins of Wheal Alfred are invariably barren, and as this mine is situated some miles from the nearest granite outcrop, but is intersected by a large porphyry dyke, it is possible that these veins may represent the vanguard of the dyke.

In the cliffs half-way between Gwithian and Hayle the chloritised slate is intersected by a network of small quartz/pink-felspar veins. In these veins the felspar occupy the marginal areas and are so orientated that their long axes are approximately at right-angles to the vein wall. This exposure is some miles from the nearest granite outcrop, but elsewhere the writer has brought forward evidence in support of the theory that there the granite is at no great distance below the present surface. (Hosking, 1949, p. 41). It is possible that these bodies may be pre-granite pegmatites.

Pre-granite quartz-veins were certainly formed. An example at Priest's Cove has already been noted, and in a granite apophysis on the western side of St. Michael's Mount there are xenoliths of hornfels containing portions of these early quartz veins.

One pictures a granite magna advancing from the south, preceded by a very mobile, silica-rich fraction and possibly also by a pegmatitic fraction. Whenever the magmatic pressure exceeded that of the overlying rock fracturing ensued. The earliest fractures thus formed were infilled with quartz and possibly with pegmatite, whilst later fractures were infilled with granite. That there is a tendency for advancing granitic magma to be preceded by a volatile-rich fraction capable of forming pegmatite and quartz veins is indicated at Tremearne. Here "veins" occur which change laterally from granite to pegmatite and aplite and thence to quartz.

PEGMATITE FORMED DURING THE EMPLACEMENT OF THE GRANITE

Group 2. Pegmatites formed before the consolidation of the associated granite crust.

There is considerable evidence to show that both during the formation of the larger granite masses and of the associated minor intrusives that volatiles tended to migrate into structural traps. Here they accumulated, unless the nature of the roof was such that they could react with and/or diffuse through it, or the magmatic pressure was sufficiently great to cause roof fracture. If the accumulated volatiles were unable to escape they acted as fluxes to the magma also in the trap and thus set up the conditions necessary for the development of a fringing pegmatite. Webb (1947, pp. 27-28) discussed the factors governing the development of fringing pegmatites and described the most outstanding Cornish example which occurs at Porthmeor Cove, near Zennor. Here the granite is intrusive into tourmalinised slate and "greenstone". The structural trap within which the pegmatites (which are pene-contemporaneous with the granite) occur, is made up of vertical walls of country rock upon which rests a nearly horizontal roof. The pegmatite bands consist of crystals of potash felspar, quartz and muscovite, and are separated by bands of aplogranite. The first pegmatite band that was formed is the largest and is attached to the roof. This resulted from the accumulation of volatiles just beneath the roof, and acted as fluxes to the magma in the immediate vicinity and caused the deposition of large crystals, of which the felspars were orientated at right-angles to the contact. This was quickly followed by the development of aplogranite from a magmatic fraction poor in fluxes. Somewhat later a further concentration of volatiles was built up beneath the aplogranite band and produced a second band of pegmatite, followed by a second band of aplogranite. This process was repeated several times, but in each succeeding case the quantity of volatiles which collected decreased, so that with time there was a progressive decline in the size of the pegmatite band formed.

A boulder found near St. Michael's Mount causeway, exhibited on a small-scale, features similar to those at Porthmeor. With a series of bands of comparatively large felspar crystals which alternate with bands of aplogranite. The felspars are orientated approximately at right-angles to the band junctions, and there is a progressive decrease in the size of these crystals from band to band. It is probable that this boulder is a detached portion of an intrusive which developed in the same manner as the Porthmeor pegmatites and aplogranites.

Two small specimens found recently in the detritus above the quarry on the northern side of St. Agnes Beacon, show that locally a rock which is texturally a granite-porphyry, but which is probably a peripheral portion of the granite mass, is separated from the metamorphosed slate country rock by a complex band about 3 cm. thick. This band is composed of numerous small bands, all parallel to the contact, of felspar and quartz crystals, and these bands are either separated by bluish-grey hair-like partings, or by grey-blue or buff bands of extremely fine-grained material. The coarse-grained bands, which are rarely more than 2 mm. thick, are composed of felspar crystals, so orientated that their long axes are approximately at right-angles to the contact, and the spaces between these crystals contain quartz. Traces of bluish hair-like partings also occur in the fine-grained groundmas of the porphyritic portion just below the complex band. The bluishness of some of the partings and bands may be due to tourmaline.

Whilst it is unwise to make a dogmatic statement concerning the genesis of the complex band before thin sections have been prepared and examined, the available evidence strongly suggests that here is an example of the development of pegmatites and possibly aplites by roof-replacement, rather than by deposition beneath the roof.

Doubtless many pegmatites of the Porthmeor and St. Agnes types were developed near the highest parts of the roofs of the granite cusps but have since been removed by erosion.

Group 3. Pegmatites and bodies with pegmatite affinities formed during the consolidation of the associated granite crust.

Miarolytic granite, pegmatite blebs and schlieren.

By far the best example of miarolytic granite known to the writer occurs at Polkannugo Quarry (Carn Menellis), where it constitutes a portion of Ghosh's Type III granite-dykes, which there penetrate TypeI granite. Exposures are generally overgrown and dirty now as the quarry is no longer in production. Specimens obtained from the waste-dumps consist of fine-grained muscovite in which irregular cavities occur. These cavities are lined with comparatively large crystals of white and buff orthoclase, quartz and muscovite, and all the species are locally coated with small orthoclase crystals, usually with an adularia habit. Robson (private communication) stated that he found one specimen which contained beryl.

Fine-grained granite occuring on the mine-dumps immediately above Carbis Bay sometimes contains numerous small cavities lined with felspar crystals and infilled with comparatively large quartz, muscovite and tourmaline crystals. Similar pegmatite blebs occur in the fine-grained granite on the dumps of Dolcoath Mine (Camborne).

Webb noted streaky lenticles (schlieren) of pegmatite aligned parallel with the flow orientation in fine-granite on the Scilly Islands, and suggested that they may represent local segregation rich in volatiles formed in the granite magma or migma. (1947, p. 32).

On the Botallack Mine dumps occasional small cavities are sometimes seen in the granite which are lined with felspar crystals, and which sometimes contain tourmaline, fluorite and cassiterite.

When considering the genesis of the above bodies, it is necessary to bear in mind the following facts :—

(i) The lined cavities and pegmatite blebs within a given rock do not appear to be interconnected.

(ii) The mineral assemblage may vary from cavity to cavity within a given rock.

(iii) Crystals of a given mineral species occurring within both the host-rock and the cavities, are usually larger in the latter.

(iv) A mineral such as cassiterite which is characteristic of certain heavy-mineral pegmatites and normal lodes may be present in the cavities.

(v) The miarolytic facies of the Type III granite at Polkannugo Quarry occurs just below the Type I granite roof.

It has been noted earlier, that during the emplacement of the granite, that volatiles tend to migrate towards the roof, and this may result in the accumulation of flux-rich magmatic fractions in structural traps. Under conditions of comparatively low pressure, resurgent boiling may occur in the flux-rich magma and result in the formation of globules of vapour. If then the magma consolidates comparatively rapidly, the globules become gas-filled cavities within hot rock. It is clear that miarolytic granite is most likely to be formed in deeply dipping granite apophyses in which volatiles would tend to collect, and which have a large surface area to volume ratio so that heat is lost rapidly, and which are covered by a comparatively shallow roof which will permit resurgent boiling to take place. As such cavities within a given rock may contain differing mineral assemblages, it is unlikely that the latter could be derived solely from the components of the original entrapped vapour. It is possible that the residual fluid within the groundmass migrated along crystal boundaries and entered the cavities, having first reacted with crystals of the host-rock, and by so doing, obtained the necessary components for the formation of the greater part of the cavity minerals. It is also probable that solutions migrating along micro-fissures and crystal boundaries from much later centres of pegmatite and normal lode development may have formed and/or filled some of the cavities. Probably the Botallack filled-cavities were so formed.

Mineral-lined cavities of the Botallack type may also occur in porphyry dykes. Thus, Sir A. Russell (1949, p.527) noted that some of the Wherry Mine porphyry contained innumerable small cavities which were approximately square in outline and lined with minute, pink, adularia-habit crystals of orthoclase, upon which were rosettes of dark-green chlorite, occasionally accompanied by tourmaline needles. The formation and filling of these cavities is doubtless related to the development of the net-work of cassiterite veins which also occur in the porphyry.

PEGMATITES FORMED AFTER THE CONSOLIDATION OF THE GRANITE CRUST

Group 4. Pegmatites essentially devoid of heavy minerals.

(i) Pegmatites formed by replacement, and in which the felspar is essentially relict.

In 1946 Webb described a quartz-felspar "pegmatite" vein which occurs at South Crofty Mine (Camborne), well within the granite, at about 600 feet from the granite-killas junction. The granite in which the vein occurs is grey and coarse-grained, and contains both muscovite and chloritised biotite, together with quartz and phenocrysts of pink felspar. The "pegmatite" vein is about three-quarters of an inch wide, has well-defined walls and a fairly uniform strike. Greisenisation of the granite alongside the vein has resulted in the development of greyish-brown mica and a slight silicification of the felspars. The vein consists essentially of quartz and felspar crystals, and some of the latter completely bridge the vein and protrude into the granite on either side. Some of the vein felspars are embayed and partially replaced by quartz. Webb considers that this vein was formed by silicification of the granite and that this alteration was localised by a narrow fissure zone consisting of numerous extremely narrow fissures, rather than by a limited diffusion from a central fissure. In view of the close nature of the channelways, the solution transporting the silica was probably under a high pressure and more or less tenuous.

Replacement pegmatites of the type described above are probably far from uncommon in Cornwall, and an excellent example was found by the writer on the Wheal Owles dumps. This inch-wide vein, which possesses a constant strike, consists of quartz and bridging felspars and occurs in coarse-grained granite. The granite, unlike that of the South Crofty example, has not been greisenised.

Another interesting example has been noted in the kaolinised granite about halfway down the path to Cligga beach. The vein, which can be traced for several yards, is approximately 0.4 cm. wide, has parallel and well-defined walls. It consists of quartz and numerous bridging felspars. Those portions of the felspar which are within the vein are orange, whilst those within the granite are white.

Another illuminating example occurs in a portion of porphyry built into a wall in the lane between Camborne School of Mines and the School Club. This vein is only a few millimetres wide and is composed of quartz and bridging felspars, together with discontinuous selvedges of white mica. These mica selvedges not only separate the quartz component of the vein from the porphyry, but are sometimes developed across portions of the bridging felspars. Locally the vein contains small druses. This example is of considerable interest in that it gives a clue as to the manner of development of some of the mica-fringed cassiterite-wolfram veins occurring at St. Michael's Mount. There is no reason why replacement pegmatites of the type described above should not have developed at any period between the time of consolidation of the earliest granite and the cessation of lode development.

(ii) Pegmatites in which the felspar have been derived from a pegmatite "fluid", and which have either been formed by replacement of the granite, or deposited within cavities formed by solution of the granite.

The shapes of some Cornish pegmatites are such that it is certain that these bodies must either be occupying spaces formed by solution of the granite, or they must have developed by direct replacement of the granite. It is, of course, possible that a pegmatite body of irregular shape may be formed by injection of a pegmatite fraction into a *plastic* granite. Under such circumstances it is possible that the crystal components of the granite would be re-orientated during the period of injection and so provide evidence of the mode of origin of the pegmatite body. Pegmatite bodies of irregular shape occur at Priest's Cove (Cape Cornwall) and in the quarries near Knill's Steeple (near St. Ives), but neither these, nor any other similar examples examined by the writer, show any evidence of having been formed by the injection of pegmatite "fluid" into a plastic granite.

TROLVIS QUARRY PEGMATITES

Certain small, lenticular pegmatites occurring in Ghosh's

Type I granite at Trolvis Quarry (Carn Menellis), are members of the group under discussion. These are considered in some detail as their study has revealed certain important facts underlying the mechanism of pegmatite development.

These pegmatites are essentially steeply dipping, vein-like bodies tend to develop at various horizons into comparatively small lenticular bodies. The dip varies from one pegmatite to another and not infrequently the slope of an individual pegmatite changes rapidly from one level to another, so that in a vertical distance of 4 to 5 feet, the body is sometimes marked curved.

Although the dimensions of the pegmatite lenses are subject to considerable variation, any given one seldom extends for more than two feet along the dip and strike, and rarely has maximum width in dip section greater than six inches. Occasionally, however, a lens maybe about a foot longer than this along the dip and strike, and attain a maximum width of eighteen inches. These wider lenses always contain central cavities, · lined frequently with an interesting mineral assemblage.

Usually, it is difficult to trace the pegmatite beyond the lens : its extensions may be indicated by nothing more than an occasional large felspar crystal, a book of pegmatite-type mica, or a large tourmaline crystal developed along the prolongation of the axis.

The junction between the granite and the pegmatite lenses is always undulatory, but it is reasonably well-defined because of the sudden diminution in dark-brown biotite when passing from granite to the felspar-quartz marginal zone of the pegmatite.

It is clear that the pegmatites were formed before the granite joints since they are intersected by the latter and differ from them both in dip and strike.

The mineralogically simple lenses consist of perthitic felspar, quartz, brown tourmaline and pale-brown to white muscovite mica, and were developed in the following manner :— A quartz-felspar border zone was initiated, some of the components being simply pegmatite-phase extensions of the felspar and quartz crystals of the granite. After the marginal portions of the border zone were formed, tourmaline crystals developed and these, in some cases, grew most profusely in the upper part of the lens. At the same time the earlier-initiated felspar and quartz crystals continued to grow and new quartz and felspar crystals formed. Both these minerals partially, or entirely, invested the tourmaline crystals. During the final stage of quartz-felspar development, and sometimes shortly afterwards, pale-brown or white mica was deposited.

The mineralogically complex lenses vary in numbers of mineral species present and one lens may contain a much greater quantity of a given mineral than another. The most spectacular example has a quartz-felspar border zone and inside this zone is a band composed of much larger crystals of felspar and quartz together with groups of randomly orientated brown tourmaline crystals. Continued deposition of quartz and felspar resulted in the development of large crystals which project beyond the border zone into the central cavity. During this phase books of pale-brown mica developed. There were two distinct periods during which tourmaline was deposited. The earlier tourmaline crystals noted above are deep-brown, often an inch long and a third of an inch wide, and are sometimes partially or entirely enveloped by large quartz or white felspar crystals. Their development commenced soon after the earliest quartz and felspar and they grew contemporaneously with the large felspar and quartz crystals. These latter crystals continued to grow after the large tourmaline crystals had ceased to do so.

The later tourmaline consists of myriads of needle-like crystals, often an inch long, but seldom more than a millimetre wide. They are most profuse in the upper parts of druses and some of them were partially entrapped by large felspar and quartz-crystals during the final stages of development of the latter. Some of these tourmaline crystals fringe bodies which were once felspar crystals but are now composed of a quartz-tourmaline border zone surrounding a pink felspar core. In the vicinity of later tourmalines the felspars are pink and the faces upon which the mineralising agents impinged are markedly corroded.

The early tourmaline crystals were deposited directly from a magmatic fraction carrying the complete components for their development. On the otherhand, the later tourmalines were developed from agents which obtained some of their ingredients from felspars, which were either replaced by tourmaline and quartz, or, as was more frequently the case, some of the felspar was dissolved and the material transported and utilised elsewhere for the formation of tourmaline.

Subsequently, further minerals were deposited in the order indicated in table 2.

TABLE 2.

THE MINERAL PARAGENESIS OF THE COMPLEX TROLVIS PEGMATITES

Mineral	Duration of Deposition
Felspar	
Quartz	
Tourmaline	
Pale-brown mica	
Topaz	
White mica	
Gilbertite	
Apatite	
Fluorite	
Bertrandite	
Chlorite	
Stilbite	
Chalcedony	

The later minerals were largely deposited directly on pre-existing crystals and only gilbertite and chlorite, apart from the second generation tourmaline already discussed, show any tendency to develop by replacement.

The disposition of the later minerals is such that there is no doubt that the large quartz and felspar crystals projecting into the central cavity acted as baffles to the mineralising solutions, which though changing in composition with time, continued to use the same paths throughout the whole period of lens development. Those faces of the baffles which faced the ascending solutions are heavily coated with later minerals, whilst the other faces are largely devoid of them. Furthermore, the size of the crystals of a given species of "later" mineral decreases as the lens is ascended, as also does the number of species. These facts are due to the mineral-depositing solutions being progressively depleted as they rose through the lens.

Observations on the mode of development of the Trolvis **pegmatites.**

Trolvis Quarry is situated on a comparatively narrow exposure of Ghosh's Type I granite which is bordered on the east by Type 2 granite and on the west by Type 3. As there is a tendency for pegmatites to develop near the junction of the parent intrusive with the overlying rock, and as it is likely that the upper portions of Type I granite have been eroded, it is probable that the pegmatites of Trolvis Quarry are genetically related to Type 2 or Type 3 granite. As the underground extensions of these later granites are not known with certainty, either could have supplied the pegmatite material.

As a result of magmatic pressure, the light pegmatite fraction invaded the granite roof along planes of maximum weakness, by a process of wedging. The extensions of any given fissure by this process could only continue as long as the magmatic pressure was greater than that exerted by the overlying rock. It is to be expected that fluctuations in magmatic pressure should be such that during comparatively short periods of geological time, it might be greater than, equal to, or less than the pressure of the overlying rock. Whenever the magmatic pressure equalled, or was only slightly in excess of the rock pressure, the fissure ceased to be extended, or was lengthened only very slowly. The magmatic wedge then exerted a solvent action upon its confining walls, especially at the apical region where the lightest fractions would tend to accumulate.

The field evidence suggests that these solvents preferred to attack the smaller crystal components of the granite, thereby producing irregular walls which, in the apical regions, are markedly curved. As a result of the further changes mentioned below, these curved portions became, in due course, the walls of the pegmatite lenses.

At Trolvis, the stage of chemical attack on the wall-rock was followed by a period when the magmatic pressure once again considerably exceeded the wall-rock pressure, so that the fissures were extended rapidly. How far the fissures extended beyond the quarry horizon can only be guessed at, but they probably reached the granite-slate contact at least, because the evidence is clear that mineralising agents moved along them in one direction for a considerable period of time. It is likely that those parts of the mineralising fluids which were not deposited within the lenses and fissures under discussion, induced pneumatolytic and/or hydrothermal changes in the overlying cooler granite and in the near-contact slate.

The marked change in dip encountered in some of the pegmatitic bodies may well have been due to large felspar crystals within the granite acting as deflecting wedges during the stages of fissure development.

Following the final phase of fissure formation and whilst the temperature was too high to permit mineral deposition within the fissures, it is suggested that the magmatic pressure decreased to such an extent that it was exceeded by the wall-rock pressure. This caused the walls of the fissure to approach each other, so that the only spaces available for appreciable deposition were within the areas, now lenticular in dip section, where wall-rock solution had been most effective. Complete closure of the fissures, both above and below the lenses, was not caused by the above mechanism, because the walls were, as a result of differential solution, uneven.

The field evidence suggests that the fissures connecting the lenses to the source of the material being precipitated within them, were extremely narrow. The fact that different lenses show varying mineral assemblages and that the relative proportions of minerals present in the lenses vary, suggests that the fissures were only open intermittently during the period of pegmatite development. Periodic fissure closure was probably due to crystal deposition, whilst intermittent re-opening was occasioned by the fracturing of crystals and by vibrational movements such as one would expect to occur in a comparatively thin granite crust overlying consolidating magma. That such movement did take place is indicated by the fact that within the lenses a certain amount of crystal fracture has taken place.

As a result of declining temperature, pegmatite development eventually took place within the available spaces and was naturally most marked in the lenses. Here it started with the renewed growth of some of the felspar (and probably quartz) crystals of the walls, and the establishment of new felspar and quartz centres of crystallisation. Slightly after the initial felspar-quartz stage, tourmaline and pale-brown mica were deposited.

Whether these early pegmatite minerals were deposited from more or less static material trapped within the lens during the stage of "wall closure," or whether they were deposited from pegmatite magma which was slowly moving along the fissures, cannot be ascertained.

It is suggested that the last of the large felspar and quartz crystals to be formed were developed from a *moving* magmatic fraction and it is certain that the still later minerals were so developed.

Replacement during the growth of the pegmatites was of a very subsidiary nature and only contributed towards the growth of some of the later tourmaline, gilbertite-mica and chlorite. The corroded nature and reddening of the felspars in areas where there is conspicuous development of second generation tourmaline or chlorite, suggests that the ascending solutions derived some of the ingredients necessary for the development of these later minerals by partial solution of the felspar crystals.

Decrease in both the size and number of later crystals per unit volume in passing from the lowest to the highest horizons of the druses, is clearly due to the earlier large felspar and quartz crystals acting as baffles, upon which the later minerals were deposited mainly on those portions which faced the ascending current of mineral-depositing agents. These agents, after impinging upon any given baffle would, if crystallisation took place there, ascend to higher levels in a depleted state. This inducement of deposition by crystal baffles must be one of the major factors controlling the late mineralogical variation so often encountered in pegmatites as they are traced away from their source.

That the development of the late minerals is most marked in the large druses is doubtless due to some extent to a decrease in velocity of the fluids as they entered the wider channel.

Finally, variation in the mode of development of the earlier and later tourmalines indicates that with passing time there was at least one major change in the nature of the agent from which the minerals were deposited. It is probable that whilst the earlier felspar and quartz, together with the pale-brown mica and large tourmalines were deposited from a flux-rich magma, the later minerals crystallised either from a vaporous phase followed by a liquid phase or entirely from a liquid phase.

COMPARISON OF THE TROLVIS PEGMATITES WITH OTHER CORNISH EXAMPLES

Several Cornish pegmatites, which have either been examined by the writer and/or are described in the literature, possess characteristics similar to those of the Trolvis pegmatites. This suggests that at least during some stages of their development, the controlling factors must have been much the same as those which operated at Trolvis. Thus, some of the Knill's Steeple Quarry pegmatites are lenticular bodies composed of felspar, quartz, tourmaline and a little muscovite mica, and in two of them there is a marked development of tourmaline near the apex. These are very similar, therefore, to the mineralogically simple pegmatites of Trolvis and were probably developed in essentially the same way. In the Knill's Steeple area the pegmatites tend to follow the major joint systems in the granite and in this respect they differ from their Trolvis counterparts. These spatial characteristics may either indicate that the joints were the passage-ways for the pegmatite fluids, or that the planes now indicated by joints were, during the phase of pegmatite development, the planes of maximum weakness.

At Priest's Cove (Cape Cornwall) a lenticular pegmatite composed essentially of felspar, quartz and tourmaline and with a marked concentration of the latter mineral near the apex, is also very similar to the simpler Trolvis pegmatites.

However, tourmaline is not always present and at Cligga a small, crudely lenticular pegmatite occurring in the granite and only a few inches below its junction with the killas, consists of a pink-felspar/quartz marginal zone which reaches its maximum development near the apex, and a core composed of quartz and large flakes of muscovite mica. Small, purple crystals of fluorite occur in tiny druses in the apical portion of the marginal zone.

No Cornish pegmatite is known to the author which is as mineralogically complex as the Trolvis type. However, a pegmatite occurring at Harvey's Quarry (Carn Marth) and described by Davison (1921) exhibits considerable mineralogical complexity and the deposition of the later minerals within its druses was clearly controlled by crystal baffles. This is indicated by a description of the disposition of the encrusting minerals on two felspar crystal twins of Baveno type and which were extracted from the druses. Concerning the first, Davison states that "two sides were coated with a layer about 1/16" thick, of small mica crystals on the surface of which are scattered irregularly :—Crystals of blue apatite ; cubes of purple fluor ; and needles of black tourmaline coated with a thin film of mica crystals." The second crystal "is partially coated with a layer of mica crystals on which lie crystals of blue apatite, purple fluor and tourmaline. The crystal faces free of mica show corrosion." (pp.334-5). The pegmatite itself is composed of quartz, pink orthoclase, reddish mica (lithium bearing) and tourmaline. The druses are lined with large felspar, quartz and mica, on which later minerals are encrusted.

TABLE 3. PARAGENESIS OF CARN MARTH PEGMATITE.
(from Davison's description)

STAGE	MINERALS DEPOSITED
I.	Quartz, Orthoclase, Biotite, and large prismatic crystals of Tourmaline.
II.	Sericite and Gilbertite micas.
III.	Fluorite, Apatite and fine Tourmaline needles.

The paragenesis differs from that of the Trolvis pegmatites in that the second generation tourmaline followed sericite, whilst at Trolvis it preceded both white micas.

The later minerals occurring in pegmatite druses in Cornwall invariably show indications of having been deposited from *moving* solutions (and/or vapours) which followed the same paths throughout the whole period of mineral development. On the other hand, there is little or no indication that the early felspar, mica, quartz and tourmaline crystals, that is the pegmatite proper, was deposited from a moving magmatic fraction. The asymmetrical development of the latest felspar and quartz crystals in the Trolvis druses, is however, the possible result of development in an open system.

A further point of interest is the fact that in the true Cornish pegmatites there is very little replacement. Replacement, however, is not completely absent in any of the more complex pegmatites, and quartz, tourmaline, sericite and gilbertite micas and chlorite may replace felspar, whilst chlorite and secondary micas may replace biotite mica. It is, on the other hand, not uncommon to find early felspar crystals in drusy pegmatites showing signs of corrosion and the material removed from such felspars may well have been utilised elsewhere during the development of other minerals such as tourmaline and mica.

PEGMATITE LENSES IN GRANITIC VEINS

Not infrequently granitic veins contain pegmatite lenses. A given granitic vein may show only one such lens, or it may contain several lenses which may be connected by thin pegmatite stringers. These lenses are all mineralogically simple and have probably been formed by replacement brought about by tenuous pegmatitic fluids migrating along microfracture zones, or by chemical solution of the granite followed by deposition. The fractures, necessary in either case, may have been caused by the contraction of the granite as it cooled.

Pegmatite lenses in granite veins are beautifully developed near the granite-killas junction at Rinsey Cove. Here the central portions of vertical granite veins are occupied by a series of elongated, crudely lenticular masses of pegmatite which are connected to each other by narrow pegmatite veins.

The fine-grained granite vein cutting the possibly pre-granite pegmatite at Priest's Cove discussed earlier contains an elongated lenticular core of felspar-quartz-tourmaline pegmatite.

Davison (1920, p.317) described an example occurring at St. Michael's Mount as follows :—"The margins were composed of fine-grained granite with a central zone of coarsely crystalline pegmatite, which, as the width of the vein decreased thinned out to a narrow band of coarsely crystallised mica." The tendency for peripheral mica to be developed during somewhat similar replacements is indicated by formation of a greisen band along the South Crofty replacement "pegmatite" and by the mica selvedges noted earlier as occurring in a replacement vein in porphyry.

Another interesting St. Michael's Mount example occurs in tourmaline aplogranite and is crudely circular, having a diameter of about five inches. The pegmatite body is composed of a strong peripheral zone of radially disposed felspar crystals and a core of quartz and randomly distributed books of pale-brown lithium-bearing mica. The pattern suggests that the pegmatite developed within a cavity formed by solution of the granite.

PEGMATITES IN ROCKS OTHER THAN GRANITE

The shapes of certain pegmatites occurring in killas leave no doubt that they must have been formed either by direct replacement or by solution of the rock followed by pegmatite deposition. Thus, associated with the small pegmatite, aplite, granite and greisen veins in the biotite-hornfels on the eastern side of St. Michael's Mount, are irregularly shaped pegmatites and aplites which could not possibly have resulted from deposition within mechanically formed spaces. This being so, one wonders whether the "vein" pegmatites and aplites with which the irregular bodies are associated, occupy mechanically formed fissures, as has generally been assumed.

Unsuccessful search has been made for completely isolated pegmatite pods surrounded by a basic front and completely isolated in hornfels near the granite. Such pods have been described by Reynolds (1949) who noted them in a quarry at Goraghwood, Co. Armagh, Northern Ireland. In order that these pods could develop, Ca, Na and Si must have migrated through the solid hornfels into the pod area and Al, Fe, Mg, K, Ti, P and Mn must have diffused out. These outward-diffusing constituents resulted in the development of a basal selvedge around each pod. If the constituents necessary for the development of a replacement pegmatite in hornfels moved to the site via a feeder-channel, then those constituents of the hornfels which were not required for the development of the pegmatite might well be removed by way of the feeder-channel. Thus a basal selvedge would not develop. This is probably why irregularly shaped pegmatite bodies in the Cornish hornfelses, such as those at St. Michael's Mount, lack basal selvedges.

(iii) Pegmatites and aplites occupying mechanically formed spaces.

It is certain that some, and perhaps many Cornish pegmatites, occupy certain mechanically formed spaces.

The writer believes that the majority of these bodies originated in the manner described below. The most notable possible exceptions are the texturally complex Tremearne types discussed later, which may owe their development partially to somewhat different processes.

The work of Morey (1922), Niggli (1929) and others indicates that as the silicates crystallise from a magma the vapour pressure of the residual fraction increases up to the time when pegmatites or lodes are developed. If the vapour pressure becomes greater than the pressure of the overlying rock, then fracturing of the latter will take place and some of the magmatic residual products will enter the fractures. If the roof pressure is exceeded at a comparatively early date, then a pegmatitic fraction will enter the fissures and if fracturing is comparatively late then a siliceous fraction will enter from which quartz may develop, possibly together with other minerals, which may or may not include notable amounts of cassiterite and other heavy minerals of economic importance. The amount of heavy minerals present in a pegmatite or vein is dependent, at least partially, on the concentration of heavy mineral components in the residuum, and this in turn depends on the initial quantity of magma from which the residuum was derived. The presence of numerous pegmatites in Cornwall which are devoid of, or which lack notable quantities of heavy minerals, is probably due to the fact that they developed from comparatively small pockets of residual fluid which collected in the cupolae during the crystallisation of the granite there. On the other hand, the heavy mineral pegmatites and lodes, were probably derived from large, deep-seated "pools" of residual fluid which accumulated later during the crystallisation of the main body of granite. These deep-seated pools, having been derived by differentiation from vast quantities of magma, are likely to contain appreciable amounts of such elements as tin and tungsten, which only occur in trace amounts in the pools which developed from the comparatively small masses of magma in the cupolae. Whilst there is good reason for believing that the vapour-pressure of the residual magmatic fractions would be sufficiently great to fracture the roofs of the cupolae, it is by no means certain that a pressure could ever develop sufficiently great to fracture the mass of rock overlying the deep-seated pools. This problem will be discussed below.

It is, however, a reasonable assumption that the pegmatites and aplites essentially lacking in heavy minerals and of the type under discussion, were derived from fractions which collected in the cupolae, and that as the pressure of the residual magma locally exceeded that of the overlying rock, fracturing took place along planes of maximum weakness into which magmatic wedges were driven. The fractures were often parallel to the present granite joint-planes. If and when the wedges penetrated completely through the granite they continued along planes of weakness. Thus, at Rinsey they follow the granite-hornfels junction and also the joint-planes in the hornfels, and locally at Tremearne they follow cleavage planes. Occasionally the advancing wedge moved from one plane of weakness to another, so that the body which resulted from its consolidation shows sudden changes in strike. This phenomenon is beautifully displayed at Rinsey where a pegmatite's strike is coincident, first with one set of joints in the hornfels and then with another. Sometimes a pegmatite mesh developed, as at St. Michael's Mount, and as a result of later wedges advancing along planes which differed considerably in strike from those along which the earlier wedges had moved. Depending on the degree of differentiation before injection a given wedge might consolidate as a pegmatite, aplite, pegmatite-aplite, or a granite-pegmatite-aplite body. When pegmatites and aplites are closely associated, in all cases pegmatite is found immediately below the hanging wall and the aplite occurs below it. Occasionally a comparatively thin pegmatite band separates the aplite from the foot-wall. The "pegmatite over aplite" structure is either due to the differentiation of the "magma" in situ into a light, volatile-rich fraction and a heavy, volatile-poor fraction, or to differentiation near the source into two such fractions, followed by the more rapid advance of the former and from which pegmatite crystallised from the roof, or from both walls. Later, the slower moving, volatile-poor fraction entered the zone of pegmatite development and crystallised in the available spaces as aplite.

THE TREMEARNE PEGMATITE-APLITE BODIES

Along the Tremearne coastal section, near Porthleven, are to be seen the results of an invasion of earlier granite and porphyry and the surrounding thermally metamorphosed slate by tongues of granitic magma, which, by differentiation, etc., resulted in the development of granite, pegmatite, aplite and possibly quartz veins. During the initial stages of this invasion, volatile-rich magmatic fractions formed the vanguard and subsequently pegmatites and aplites developed from these. This also resulted in the development of a certain amount of lateral zoning, and near the Godolphin granite/hornfels contact the later intrusives are composed essentially of tourmaline aplo-granite, whilst further away they are made up of aplites and pegmatites. Beyond the pegmatite/aplite zone, numerous quartz-veins are to be seen in the cliff, but it is uncertain whether these are genetically connected with the bodies under review. One small example of a vein which changes laterally from aplite to quartz has, however, been noted.

The paths followed by the invading fractions were few and these locally converged and then diverged once more. The initial invasion was followed by subsequent invasions of magmatic material capable of producing pegmatites and aplites which followed the earlier paths, but the time between two successive invasions was variable. In some instances an invasion took place whilst the products of some of those preceding it were in a plastic condition, whilst on other occasions the earlier products were already completely solidified, and therefore capable of being fractured, when the next invasion occurred. As might be expected, where the invasion paths converged, sill-like bodies of great complexity were formed.

Locally the gently-dipping bodies are intersected by steeply-dipping fault-fissures, some of which contain a little pyrite and/or chalcopyrite. In one instance a nearly vertical fissure branches considerably on passing from the underlying hornfels into a granitic sill and these branches die away rapidly on entering the overlying hornfels. The most complex "sill" composed of nearly horizontal bands of pegmatite and aplite is cut by a small, nearly vertical, replacement pegmatite.

In the simple pegmatite-aplite veins it is usual to find the pegmatite either entirely below the hanging-wall and underlain by aplite, or developed as hanging-wall and foot-wall bands which are separated by aplite. However, foot-wall pegmatites are never better developed than their hanging-wall counterparts, and usually inferior to them. In the complex sills, formed where the invasion paths converged, the largest and probably the earliest pegmatite, is invariably encountered immediately beneath the hornfels roof, and in it, and indeed in all other pegmatite bands encountered at Tremearne, the felspars, and tourmaline crystals when present, are so orientated that their longest axes are approximately at right-angles to the contact. Whenever structural traps existed in which volatile-rich portions of the magma could accumulate, unusually marked pegmatite development occurred.

Certain aplitic and granitic zones of the intrusives are characterised by the presence of irregular masses of hornfels which are, at least in the vast majority of cases, partially detached portions of the roof and not true xenoliths. The under-surfaces of these "xenoliths" are frequently fringed with pegmatite. Similarly, lateral fractures occurring in the "xenoliths" have frequently been sealed with pegmatite. Later magmatic fractions sometimes split a "xenolith" along a pegmatite-sealed fracture, and then by isolating the lower portion, produced a "xenolith" with both an upper and a lower pegmatite fringe. That the hornfels was essentially plastic during the period of intrusion is indicated by the curved form of many of the partially detached roof-masses. The degree of alteration imposed upon the hornfels during the stages of pegmatite-aplite development was slight and was confined to a band seldom more than an inch wide.

In the opinion of the writer it is by no means certain whether these bodies were developed from a granite residuum, or whether they are the most peripheral parts of a granite mass which was injected into and beneath an earlier granite. If the latter is the case then they resemble the Porthmeor pegmatite and the Polkannuga miarolytic granite in that they all developed during the earliest stages of the emplacement of the granite with which they are genetically related.

The general characteristics of the Tremearne bodies have been described by Hall (1930) and the manner of their formation by Webb (1947).

Mineralogy of the Tremearne pegmatites and aplites.

(i) Pegmatites.

Locally the first mineral to be formed was white or pale-brown mica which was deposited as a narrow selvedge just beneath the roof and also invested curved tongues of partially detached roof hornfels. Elsewhere, and especially in the marked structural traps, tourmaline developed first as inch-long brown crystals immediately beneath the roof. These were followed by the formation of large potash felspar crystals with a Baveno habit which sometimes grew to a length of about six inches, and which were orientated, as were the tourmaline crystals, with their long axes approximately at right-angles to the contact. Quartz was deposited at the same time as, and after the felspars, and both these minerals invested the earlier tourmaline crystals. Towards the end of the felspar stage, dark-green tabular crystals of magan-apatite[1] developed and partially invest some of the felspar crystals. The apatite crystals are occasionally about three inches in "diameter". Colourless and pale-brown lithium-bearing micas were deposited during and after the phase of apatite development. Later the felspars were slightly replaced by sericite mica in the form of rosettes and plumose masses. The mica-developing agents moved along the cleavage planes of the felspars and also along the junctions between tourmaline crystals and the investing felspars. These latter paths, as a result of the unequal contraction of the felspar and tourmaline on cooling were comparatively wide and therefore much used. Mica rosettes border practically every tourmaline crystal that is situated in felspar in the uppermost pegmatite band of the most complex sill. Probably at about the same time as the sericite was forming, globular masses of gilbertite mica, and small, prismatic, pale-violet, blue and white crystals of fluor-apatite were crystallising in the druses. Still later small quantities of deep-

1. The apatite has been provisionally termed mangan-apatite because the manganese content is sufficiently high to cause a marked blue-green product to develop when the powdered mineral is fused with sodium peroxide.

purple fluorite and arsenopyrite or lollingite[1] were laid down. Finally a buff-coloured clay (montmorillonite ?) partially in-filled some of the druses. Topaz occurs in small quantity in the pegmatites and on account of its marked presence in the aplites, it was probably deposited fairly early. Table 4 indicates the mineral paragenesis of the Tremearne pegmatites.

TABLE 4.

THE MINERAL PARAGENESIS OF THE TREMEARNE PEGMATITES

Mineral	Duration of Deposition
Tourmaline	———
White and pale-brown mica	——
Felspar	————
Quartz	—————...........
Tabular apatite	———
White and pale-brown mica	———
Topaz	—?—
Sericite and gilbertite	——
Prismatic apatite	——
Arsenopyrite	——
(or loellingite ?)	— ? —
"Clay"	——

(ii) Aplites.

These rocks contain both potash and soda felspar, quartz, muscovite mica, much topaz and locally a considerable quantity of blue tourmaline.

The conditions appertaining to pegmatite deposition.

As the tourmaline and felspar crystals in the pegmatites are orientated with their long axes at right-angles to the roof it is probable that the magmatic fraction within the open spaces was static or nearly so during the period of their development. On the other hand, distinctly later minerals

1. Specimens of the "arsenopyrite," when immersed in sodium azide/iodine solution, caused only an extremely small liberation of nitrogen bubbles when compared with typical Cornish arsenopyrite. This indicates that the sulphide content in the Tremearne mineral is very small.

occurring in druses were obviously deposited from a moving agent.

As far as the Cornish pegmatites lacking notable quantities of heavy minerals are concerned, all the available evidence suggests that the early "granitic" minerals were deposited within what was essentially a closed system, whilst the "druse minerals" were developed in an open system.

FURTHER EXAMPLES OF PEGMATITES OCCUPYING, OR APPARENTLY OCCUPYING, MECHANICALLY FORMED SPACES

Numerous examples of pegmatites of the type under review could be described, but space will only permit of notes on the following small selection.

1. Prah Sands.

Near the granite-killas junction at the eastern end of the beach are several simple veins consisting of pegmatite border zones and aplite centres. These are very similar to the simpler veins encountered at Tremearne.

2. Rinsey Cove.

Apart from several interesting bodies noted earlier, numerous mineralogically simple pegmatite veins occur near the eastern junction of the granite and the hornfels roof-pendant in which the Cove has been developed.

A three to four feet thick, drusy pegmatite consisting of an interesting mineral assemblage, which includes arseno-pyrite and prismatic fluor-apatite is situated along the western granite-hornfels junction.

One pegmatite in the west-central portion of the hornfels cliff is of special interest in that it split a quartz-tourmaline vein longitudinally during its emplacement. In the adjoining hornfels platform there are further indications that early quartz-tourmaline veins, whose strikes are parallel to the joints in the hornfels, were later re-opened and the fissures infilled with pegmatite.

3. St. Michael's Mount.

On the western side of the Mount, several vertical pegmatite veins, consisting almost entirely of horizontally-orientated, white crystals of orthoclase felspar, occur in the granite.

4. Ponsanooth, (Carn Menellis granite).

Here pegmatite-aplite bodies occur. Frequently the pegmatite borders a central aplitic portion. The pegmatite consists of large crystals of perthitic felspar together with smaller quartz and acid plagioclase crystals which partially replace the perthite. Tourmaline, largely enclosed in quartz, is also present.

The aplite consists essentially of acid plagioclase together with quartz, tourmaline and a little muscovite and orthoclase.

5. Trelavour Downs, St. Dennis.

This pegmatite is not now exposed, but according to Davison (1927) it "shows exceptional banded structure, the margins consisting of medium-grained brown (lithia-bearing) mica and felspar, followed by massive fine mica and then massive coarsely crystallised mica with a centre of coarse mica, felspar and quartz."

6. Luxulyan Quarries. (St. Austell granite).

The pegmatites in these quarries are worthy of note because of the interesting mineral assemblages occurring in their druses. These have been described by Busz (1904) who noted on the faces of large perthitic felspar crystals small crystals of albite in parallel growth ; quartz prisms ; pale-blue and green apatites ; stellate aggregates of gilbertite ; tourmaline ; muscovite ; and fluorspar.

SIMPLE QUARTZ-FELSPAR VEINS

Some of the innumerable small felspar and quartz-felspar veins usually found in the hornfels near the granite contact, and noted earlier, were doubtless formed when the granite crust was solid, and most of them may have developed during the period of early lode development.

In the granite on the western side of St. Michael's Mount there is a vein consisting of two, well-developed felspar borders and a somewhat drusy quartz core. The architecture of this vein is very similar to the one occurring at Hawkswood Mine (North Hill), excepting that wolfram crystals are embedded in the quartz of the latter, to certain wolfram-bearing pegmatites of South Crofty Mine, and to cassiterite-felspar-quartz veins occurring in slate at Penberthy Croft. It seems probable, therefore, that the St. Michael's Mount vein was developed either during the phase of "heavy mineral" pegmatite formation or during the early stages of hypothermal lode formation.

Groups 5 and 6. Pegmatites characterised by the presence of marked quantities of heavy minerals, and hydrothermal and/or pneumatolytic veins containing mineral assemblages reminiscent of those in certain pegmatites.

Throughout Cornwall generally, comparatively large bodies containing appreciable quantities of heavy minerals, and also sufficient felspar to be termed pegmatites, are rare. Nevertheless, several interesting examples have been recorded from the eastern half of Bodmin Moor and from the Carn Brea area. On the other hand, lodes containing comparatively small quantities of felspar, and also small felspar and felspar-quartz veins containing heavy minerals are widely distributed. They have been noted, for example, near the killas-granite junctions of the Land's End, Godolphin and St. Michael's Mount masses and at a considerable distance from outcropping granite, at Penberthy Croft. On occasion, it is extremely difficult to decide whether a given body should be termed a pegmatite or a heavy-mineral vein containing felspar. Possibly to make such a division is to introduce an artificiality.

THE FELSPAR-WOLFRAM LODES OF SOUTH CROFTY MINE (CAMBORNE)

In the deeper horizons of South Crofty Mine, numerous pegmatite veins, which dip south at angles varying from 35-45°, form a complex network along an east-west zone. The veins reach a maximum width of about a foot and locally consist of quartz-wolfram, arsenopyrite, potash felspar and fluorite. They only contain traces of cassiterite excepting in the close vicinity of the steeply-dipping tin veins which intersect them. Whilst the granite adjacent to the tin-veins is chloritised and tourmalinised, that near the pegmatites is silicified and slightly greisened.

In depth, the fracture zone which determined the distribution of these pegmatites narrowed, and in this narrow portion and at about 900 feet below the granite-killas contact, the payable Complex Lode occurs. This pegmatite lode is locally about a yard wide, dips south and is intersected by several smaller veins. When traced west it splits up into numerous irregular veins. Its eastward extensions show increasing quantities of quartz, and its wolfram values appear to fall off rapidly below the 335 fathom level where the greatest quantities of wolfram occurred.

The mineral paragenesis of the Complex Lode appears in Table 5. Webb (1947, p.121) states that "in most cases the quartz felspar veins are fissure fillings but it is often apparent that at least some of the width is caused by intensive silicification of the adjacent granite . . . ; also, some of the open space was probably provided by early solution of the granite minerals in the shear zone . . ."

TABLE 5.

MINERAL PARAGENESIS IN WOLFRAM LODES OF THE COMPLEX TYPE (After J. S. Webb)

	Time →
QUARTZ	
FELSPAR	
Cassiterite[1]	
WOLFRAM	(Scheelite[2])
ARSENOPYRITE	
Chalcopyrite	
Chlorite[3]	
Pyrite	
FLUORITE	
Calcite	

Essential minerals in capitals ; occasional accessories in small letters ; a dotted deposition range denotes irregular, local deposition.

1. Cassiterite only in very small quantity in the vein ; a possible accessory in the wall rock.

2. Scheelite is of very minor importance, occurs intergrown with wolfram.
3. Only sparingly present except where the vein is cut by younger chloritic veins. The latter also frequently carry cassiterite in notable proportions.

Wolfram, associated with chalcopyrite, etc., also occurs in normal veins in the higher horizons of the mine where it was deposited after the cassiterite in the veins which intersect the Complex Lode. The present writer has shown (unpublished Studies) that the Fe/Mn ratio of the wolfram from the normal lodes differs appreciably from that of the wolfram in the Complex Lode. A further point of importance to note is that the spatial distribution of "pegmatite" wolfram is in no way related to the primary zones which characterise the distribution of the minerals in the earlier, normal vein systems.

This fact suggests that primary zoning may not be due to a temperature gradient set up between a hot granite intrusive and a cold land surface. If such a gradient existed during the period of lode formation, then the temperature prevailing at the horizon at which the earlier Complex Lode was deposited, would be far too great for the development of wolfram. It might be argued that the pegmatite fraction was impounded and not until the temperature of the granite had dropped considerably was the wolfram deposited. If this were so, then at the time when the cassiterite in the intersecting lodes was being laid down, the wolfram in the pegmatites would have not yet been deposited. Therefore, considerable intermingling of the liquid pegmatite fraction with the mineral-developing agents ascending the tin-lode fracture systems would almost certainly have taken place. There is no evidence of this having happened. On the other hand, there is no good reason for suggesting that the pegmatite wolfram crystallised at an appreciably higher temperature than did the wolfram in the normal lodes.

The simplest explanation appears to be that the hot pegmatite fraction migrated to the peripheral zone of a fracture system developed in an already cool granite crust. Here the fraction lost heat quickly and pegmatite developed as a result of wall-rock replacement and crystallisation within open spaces. Later, when the wolfram-bearing pegmatites were completely developed, a series of steeply-dipping fractures were initiated which extended beyond the granite and far into the killas. Hot mineralising agents (liquids and/or gases) ascended along the fissures, and by progressive loss of heat to the adjacent wall-rock, a temperature gradient was established from the granite core outwards towards the land surface. At appropriate temperature levels, cassiterite, wolfram, etc., were deposited.

If this theory is correct, then the time interval between the emplacement of the granite and the establishment of the normal lodes must have been considerable. Hulin (1945, p.9), utilising the age determinations made by Urry, of rocks from Grass Valley, California, came to the conclusion that "between the crystallisation of that part of the batholithic body there exposed and the beginning of the mineralisation, an interval of time elapsed, which was not less than 3,000,000 to 5,000,000 years and which may have been on the order of 8,000,000 to 12,000,000 years."

OTHER SELECTED EXAMPLES OF METALLIZED PEGMATITES

1. East Pool Mine (Redruth) and the Roskear Section of Dolcoath Mine (Camborne).

In both these mines metallized pegmatites occurred which were very similar to those encountered at South Crofty, and specimens examined by the author suggest that in some cases their mineral paragenesis is the same as that of the Complex Lode. In others, e.g. E. Pool, the wolfram-arsenopyrite precedes felspar and quartz. In the Roskear Section of Dolcoath Mine, at the 2,000 foot level, a pegmatite of the type under discussion occurred which was clearly earlier than the normal cassiterite lodes there, and Davison (1929, p.7) noted "a lenticular vein of pegmatite in the lode itself running along the strike of the lode near the hanging wall." Davison (1929, p.6) also observed at Roskear "pegmatite composed of fairly crystallised quartz, idiomorphic perthite, lepidolite mica, pink garnet, and occasional molybdenite."

2. Williams Shaft, Dolcoath Mine (Camborne).

At 360 fathoms in Williams Shaft, Dolcoath Mine, a pegmatite was cut containing pink garnet, orthoclase and albite felspars, green muscovite and cassiterite. (Davison, 1922, p.31).

3. Bodmin Moor.

In the Altarnun area of Bodmin Moor, pegmatites containing wolfram and occasionally cassiterite occur, together with small, normal cassiterite and cassiterite-wolfram lodes.

At Cannaframe, according to Dewey and Dines (1923, p.27), the granite is traversed by "veins of pegmatite in which wolfram forms an original constituent, whereas cassiterite occurs only in the veins of later formation." Here then is yet another example of wolfram-bearing pegmatites preceding normal cassiterite veins.

4. Hawkswood Mine (North Hill).

Here in the granite, and not far from its junction with the killas, a pegmatite vein occurs which consists of pink felspar, quartz, wolfram and arsenopyrite. This is cut by numerous parallel, tourmaline-rich stringers, which coincide in dip and strike with the pegmatite, and which contain a little molybdenite. These stringers are doubtless the product of one of the earlier phases of normal lode development.

DEPOSITS WITH PEGMATITE AFFINITIES OCCUPYING GRANITE JOINTS

In some of the granite masses, small bodies occur in the joints which are of considerable interest, not only because of the rare minerals which they sometimes contain, but also because their mineral assemblages resemble those of the pegmatites on the one hand and those of the normal lodes on the other. Doubtless their development not only involved deposition within the joint-fissures, but also some wall-rock replacement and/or wall-rock solution followed by deposition.

Some of these bodies may have developed early and be equivalent to the later mineral deposits in the druses of the Trolvis pegmatites, whilst others may be early bodies which were re-opened, and in which further deposition took place during the phase of normal lode development. Most of them, however, probably commenced development during the early stages of normal lode formation, as is strongly indicated by certain examples at St. Michael's Mount described below. In some cases, the large number of minerals present indicates that they constituted passage-ways for mineralising agents over a long period of time. The mineralogical similarities between certain granite-joint deposits, normal lodes and mineral assemblages in pegmatite druses is indicated by the examples in Table 6.

TABLE 6.

Minerals in granite joints		Minerals in normal lodes (in slate) Wheal Metal, Breage.		Minerals in a pegmatite druse Mean Qy., Constantine.
Gold-diggings Qy., Linkinhorne	Cheesewring Qy., Linkinhorne.	Specimen 1	Specimen 2	
Bertrandite	Phenacite	Bertrandite	Cassiterite	Bertrandite
Purple fluorite	Bertrandite	Blende	& wood-tin	Pale-violet apatite
Pink orthoclase	Quartz	Chlorite	Gilbertite	Albite
(adularia habit)	Chlorite	Orthoclase	Bertrandite	Quartz
Pyrite	Purple fluorite	Quartz	Colourless apatite	Muscovite
Red blende				Chlorite
				Tourmaline
				Orthoclase

[Based on descriptions by Sir A. Russell (1913, pp.15-21 and 1911, pp.52-62)]

FELSPATHIC VEINS CONTAINING HEAVY MINERALS

In Cornwall, many felspathic veins containing heavy minerals exist, but these veins are usually small. The quantity of felspar is very variable, and an offshoot from a given vein may contain sufficient felspar to be termed a pegmatite whilst the amount present in the parent vein does not warrant the application of the term to it.

The following selected examples, together with others noted elsewhere, will serve to indicate the major characteristics of these felspathic veins.

1. Wheal Edward Mine Dump. (St. Just).

The killas on this dump, which was derived from the near vicinity of the granite, contains numerous small felspathic veins. These veins contain, besides felspar, variable amounts of quartz, cassiterite and chalcopyrite. Many of them are sufficiently rich in felspar to be termed pegmatites.

2. St. Michael's Mount.

In some of the greisen-bordered veins, clots of felspar occur in a matrix of quartz in which cassiterite, wolfram and apatite are also embedded.

Certain of the St. Michael's Mount veins vary considerably in width when traced along their strike, and locally any given one may be only a few millimetres wide over a strike length of about a metre. These narrow parts often contain an unusually rich mineral assemblage which is to some extent reminiscent of the mineral varieties occurring in some pegmatite druses. Thus, Davison (1920, p.317) noted the following minerals on the face of one such narrow portion of a vein which had been laid open by the sea :— Quartz, mica (mostly a lithium-bearing variety), pinite[1], orthoclase, tourmaline, topaz, fluorspar, beryl, apatite, albite, chalcopyrite and oxidation products, blende, cassiterite and wolfram.

The writer hopes to establish in a subsequent paper, that the extremely narrow portions of the St. Michael's Mount veins were the first portions of the vein systems, apart from the greisen, to be developed. None of the St. Michael's Mount veins described above contain sufficient felspar to be termed pegmatites.

3. South Crofty Mine.

Cronshaw (1921, pp.39-40) described an interesting felspathic lode in killas which occurs in Hosken's stope at the 50 fm. level of the New Cook's Kitchen Section of the mine and which "appears to represent a long period of continuous infiltration, undisturbed by serious movements. In the course

1. The occurrence of pinite, an alteration product after cordierite, is of special interest as the genesis of the original mineral is a mater of speculation. Furthermore, cordierite, or its pseudomorph, not only occurs in the Land's End granite mass at several localities, and in the Prah Sands porphyry dyke, but also in the felspar-rich, pegmatite at Castle Inch Quarry.

of this, the mineralogical character of the infiltration underwent a gradual change." A series of offshoots from the lode, containing felspar, fluorspar and arsenopyrite traverses the killas on the south side of the lode. The lode itself presents a symmetrically banded structure, and is composed of two narrow outer zones, two narrow intermediate zones and a comparatively wide central zone. "These . . . grade ore into the other without any visible sign of disturbance." The outer zones consist of felspar enclosing a few arsenopyrite crystals. The intermediate bands consist of intimately associated arsenopyrite and chalcopyrite from which grows out long quartz crystals arranged at right-angles to the walls and which make up most of the central zone. Spaces occurring between the quartz crystals near their bases are infilled with arsenopyrite and chalcopyrite. Wolfram crystals are also found in the central zone. These lie with their long axes parallel to those of the quartz crystals and are sometimes enclosed in fluorspar.

The felspathic offshoots may well be replacement veins, developed by the action of mineral agents moving along micro-fissures. A point in favour of this possibility is the occurrence of felspar, together with brown and colourless mica, chlorite and iron ores in the killas adjacent to the stringers. The fact that these offshoots are largely composed of parallel crystals of felspar which often extend from wall to wall, reminds one of the much larger, highly felspathic bodies which occur on the western side of St. Michael's Mount, and which have been described earlier. This example also suggests that at least some of the felspathic veins carrying cassiterite, chalcopyrite, etc., described earlier, may also be offshoots of veins similar to the type described above.

DISCUSSION CONCERNING THE GENESIS OF BODIES WITH GROUPS 5 AND 6 CHARACTERISTICS

The following major points emerge from the considerations of bodies with groups 5 and 6 characteristics :—

(i) The heavy-mineral pegmatites were developed before the normal lodes.

(ii) Whilst wolfram and arsenopyrite are common constituents of heavy-metal pegmatites, cassiterite is comparatively rare.

(iii) Where strong cassiterite and/or wolfram lodes are developed, heavy-mineral pegmatites are either comparatively poorly developed or absent, and vice versa.

(iv) The earlier representatives of the normal lodes may contain variable quantities of felspar.

The following alternative theories are advanced to account for these facts :—

Theory 1. With progressive crystallisation of the granite core, isolated "pools" of residuum, rich in volatiles and heavy-metal components, accumulated. During this stage there was a steady increase in vapour-pressure and if and when this exceeded the pressure exerted by the over-lying rocks, the later were fractured. If fracture occurred at comparatively early stage, when the components essential for the formation of felspar were still present in the unconsolidated magmatic fraction, then the fissures would be infilled with material capable of producing heavy-metal pegmatites. It is probable that the most volatile fractions would tend to accumulate just beneath the roofs of the residuum chambers and would, therefore, be amongst the first components to enter fissures. Because of the common occurrence of wolfram and arsenopyrite in heavy-metal pegmatites, it is probable that extremely volatile compounds of the elements necessary for the formation of these elements existed in the residuum. On the other hand, cassiterite is a much rarer pegmatite mineral in Cornwall, and when it occurs in a pegmatite unaccompanied by either wolfram or arsenopyrite, as at Dolcoath, it must be assumed that either the residual fraction had always been devoid of the very volatile components necessary for the formation of "pegmatitic" wolfram and arsenopyrite, or that it had already lost them as the result of an earlier stage of pegmatite development. The loss of volatiles during pegmatite formation would, of course, reduce the vapour-pressure of the residuum. With still further crystallisation of the silicates within the chamber, the vapour-pressure would again tend to increase and might become once more sufficiently great to fracture the roof and so permit of the formation of normal lodes. Obviously, in a given area, the chances of normal lodes developing are greatest when the vapour-pressure has not been decreased by the development of heavy-mineral pegmatites. If this is indeed the method by which fracture systems are initiated along which normal lodes develop, as suggested by Emmons (1940, p.189), then the presence or absence of felspar in lodes depends on whether the vapour-pressure was sufficiently great to fracture the roof at a comparatively early or comparatively late stage.

Theory 2. It is possible that the residuum was so deep-seated that at no time was its vapour-pressure sufficiently great to fracture the roof. If this were so, then the fractures associated with the formation of the heavy-metal pegmatites might well have been due to the partial collapse of the roof due to the weight of the overlying rocks. The fractures associated with the development of the normal lodes may have been due to regional stress, as suggested by Ghosh (1934, pp.273-275), or to the contraction of the granite and overlying rock, as suggested by Hulin (1945), or to a combination of both.

The fact that wolfram occurs in both pegmatites and normal lodes may be because the tungsten exists as a volatile and a non-volatile component in the residuum. Any other assumption would make it difficult to explain why wolfram occurs in pre-lode pegmatites and yet is always preceded by cassiterite in the lodes themselves.

Two alternative reasons can be advanced to account for the slight development or absence of cassiterite and/or wolfram-bearing pegmatites in areas where normal cassiterite-wolfram lodes are strongly represented. If it is thought that vapour-pressure is responsible for roof fracture, then, if fracturing takes place at an early stage, so that pegmatites form, it follows that because of the loss of volatiles, the vapour-pressure may never exceed the roof-pressure at a later period, or only exceed it for a short space of time. Therefore, normal lodes would not develop, or their developmental stage would be of short duration. On the other hand, if pegmatite development is dependent on whether or not there is a partial-collapse of the roof, then the lack of good cassiterite-wolfram lodes in areas rich in pegmatites containing these minerals, may simply be due to the fact that most of the tin and tungsten which accumulated in the residuum entered the pegmatites.

A SUMMARY OF CORNISH PEGMATITE DEVELOPMENT

The writer visualises a great wedge of granitic magma which invaded the Cornish sedimentaries from the south, and by so doing, metamorphosed and possibly folded them. The vanguard of this advancing magma was rich in silica and boron, which by reacting with the invaded rock, caused the local development of tourmaline-slate-hornfels, quartz and quartz-tourmaline veins. Possibly some of this early fraction contained the necessary components for the development of pre-granite pegmatites. This silica-rich differentiate was followed by a granitic fraction rich in volatiles, which tended to migrate to the uppermost portions of the magma and to accumulate in structural traps. Within the traps pegmatite developed immediately beneath the roof, and locally the roof itself was felspathised. Sometimes, as a result of resurgent boiling, followed by rapid consolidation of the magma, miarolytic granite was formed. Pools of entrapped residuum developed in each cupola during the time when the "granite minerals" were crystallising there and the vapour-pressure exceeded the roof-pressure, the overlying rocks were invaded by agents which, by occupying mechanically or chemically formed spaces, and/or by reacting with the wall-rock, resulted in the development of pegmatites which lack notable quantities of heavy minerals.

It is possible, that as a result of successive waves of magma moving into the cupolae, that roof and "vein" pegmatites of the type described above, together with miarolytic granite, were formed on more than one occasion.

Later, pressures exerted by the deep-seated magma were sufficiently great to permit of the penetration of the overlying rocks along lines of weakness by magmatic wedges, which on consolidation became the porphyry dykes.

As a result of the progressive crystallisation of the comparatively deep-seated, major portion of the intruded magma, several large pools of residuum collected. This residuum, having "been derived from a great mass of magma" contained considerable quantities of elements which only occurred in extremely small amounts in the residuum resulting from the development of the comparatively small volume of granite in any given cupola. This deep-seated residuum supplied the components for the development of heavy-mineral pegmatites, lodes and certain replacement pegmatites which contain relict felspar.

ECONOMICS

The Cornish pegmatites have contributed very little to the County's mineral output.

The Tresayes pegmatite has ben worked intermittently for felspar which has been used in the manufacture of glass, whilst the mica of the Trelavour pegmatite was once used as a source of lithium, as it contains 1.5 per cent. lithium oxide.

Some of the pegmatites in the Altarnun area have been exploited, together with closely associated normal lodes, for their cassiterite and wolfram content.

At the present time wolfram is extracted from the pegmatite at Hawkswood Mine and from the pegmatitic Complex Lode at South Crofty Mine.

CONCLUSIONS

In Cornwall and elsewhere, many problems concerning the pegmatites still await solution. A great deal of field and laboratory work still remains to be done. Much that has been written in this survey is of a tentative nature, but the paper will have achieved its purpose if it causes some who read it to attack some of the problems revealed there.

ACKNOWLEDGMENT

The writer wishes to express his appreciation and thanks to Dr. Webb of the Imperial College for generously allowing him access to his observations on certain Cornish pegmatites which are contained in his unpublished doctorate thesis.

References :—

BUSZ, K., "On the Granite from Gready, near Luxullian" : Rep. Brit. Assoc., p.563, 1904.

CRONSHAW, H. B., "The Structure and Genesis of some Tin-Lodes occurring in the Camborne District of West Cornwall" : Trans. Inst. Min. Met., Vol. XXX, pp.408-449, 1921.

DAVISON, E. H., "The Geology of St. Michael's Mount" : Trans. Roy. Geol. Soc. Cornwall, Vol. 15, pp.311-321, 1920.

,, "Note on the pegmatite from Carn Marth" : Trans. Roy. Geol. Soc. Cornwall, Vol. 15, pp.333-336, 1921.

,, Section on the Examination of Veinstones in Rep. Tin and Tungsten Research Board. H.M.S.O., 1922.

,, "The Cornish Pegmatites": Rep. Brit. Assoc., p.327, 1927.

,, "The Geology of Roskear Section Dolcoath Mine": Mining Mag., pp.3-7, March, 1929.

DEWEY, H., and DINES, H. G., Tungsten and Manganese Ores. Mem. Geol. Surv., 1923.

EMMONS, W. H., The Principles of Economic Geology : McGraw-Hill Book Co. Inc., 1940.

GHOSH, P. K., "The Carnmenellis Granite : its Petrology, Metamorphism and Tectonics" : Q.J.G.S., Vol. XC, pp.240-276, 1934.

HALL, S., "The Geology of the Godolphin Granite" : Proc. Geol. Assoc., Vol. XLI, pp.117-147, 1930.

HOSKING, K. F. G., "Fissure Systems and Mineralisation in Cornwall" : Trans. Roy. Geol. Soc. Cornwall, Vol. XVIII, pp.9-49, 1949.

HULIN, CARLTON D., Factors in the Localization of Mineralized Districts. Mining Tech., pub. by the Amer. Inst. Min. Met. Eng. Inc., pp.7-17, Jan., 1945.

MOREY, G. H., "Development of pressures in magmas as a result of crystallisation" : Washington Acad. Science Jour., Vol. 12, pp.219-230, 1922.

NIGGLI, P., Ore Deposits of Magmatic Origin, transl. by H. C. Boydell, pp.1-93, London, 1929.

REYNOLDS, D. L., "Observations Concerning Granite" : Geologie en Mijnbouw, pp.241-243, Aug., 1949.

RUSSELL, Sir A., "On the occurrence of Phenacite in Cornwall" : Min. Mag., Vol. XVI, pp.52-62, 1911.

,, "Notes on the occurrence of Bertrandite at some new localities in Cornwall" : Min. Mag., Vol. XVII, No. 78, pp.15-21, Dec., 1913.

,, "The Wherry Mine, Penzance, its history and its mineral productions" : Min. Mag., Vol. XXVIII, No. 205, pp.517-533, June, 1949.

SEDERHOLM, J. J., On Migmatites and Associated Pre-Cambrian Rocks of South-Western Finland. Memoir No. 77 of the Commission Géologique de Finlande. 1926.

WEBB, J. S., "A Replacement 'Pegmatite' Vein in the Carn Brea Granite" : Geol. Mag., Vol. LXXXIII, No. 4, pp.177-185, July-Aug., 1946.

,, "The Origin of the Tin Lodes of Cornwall" : A thesis submitted for the Degree of Doctor of Philosophy in the Faculty of Science of the University of London. June, 1947.