The metamorphic petrology and structure of the district north west of Clifden, CO Galway

Cobbing, E. J.

THE METAMORPHIC PETROLOGY AND STRUCTURE OF THE DISTRICT NORTH WEST OF CLIFDEN, CO. GALWAY.

BY E.J. COBBING B.SC.

ABSTRACT

In the course of the present study the area has been mapped in detail on the six inch scale and a stratigraphical succession has been suggested.

The regional metamorphism has been investigated and found to be of amphibolite facies. Metamorphic zones demarcated in pelitic rocks by staurolite, staurolite + sillimanite, and sillimanite + muscovite, have been recognised and the zonal isograds have been mapped.

Two post-kinematic granites were intruded into the metasediments, they are adamellitic in composition and are, together with several other small granite bodies, related to the Galway Granite. The metasediments have been thermally metamorphosed and zones of thermal metamorphism have been mapped, an inner zone of andalusite hornfels, (hornblende hornfels facies), and an outer zone of spotted schist, (epidote actinolite hornfels facies).

Fourteen chemical analyses of the metasedimentary rocks were made with the purpose of investigating the question of metasomatism in the regional and thermal metamorphism, and

for comparing the metasediments with unmetamorphosed sedimentary rocks.

It has been concluded that metasomatism did not occur during either the regional or thermal metamorphism.

Chemically the metasediments compare closely with sediments carried into a shelf sea from an adjacent land mass of moderate or low relief and it is concluded that the metasediments were deposited under similar conditions.

Three periods of folding have been recognised:

1. East - West, syn-metamorphic
2. East - West, post-metamorphic
3. North - South, post-metamorphic.

The first east-west folding resulted in the formation of recumbent, isoclinal nappes. These were subsequently cross folded about an east-west axis to give the present Connemara anticline which was then deformed by gentle folding about a north-south axis.

A swarm of north-south trending dykes was intruded in association with the granite emplacement, and at the same time the area was fractured by a system of faults striking north west - south east, and north east - south west.

The area was finally subjected to sub-aerial erosion and glaciated in Pleistocene times.

PREFACE

The research work for this thesis was carried out at the Durham Colleges between July 1956 and July 1959 under the tenure of a D.S.I.R. Research Studentship. The work was begun under the supervision of Professor F.H. Stewart and, on his translation to the chair of Geology at Edinburgh, continued under Professor K.C. Dunham.

My interest in the area was first aroused during an expedition of the Durham University Exploration Club to Connemara in the summer of 1954 of which I was a member. The leader of the party S.R.J. Woodell was a botanist, and at the time was interested in a heath, Daboecia cantabrica which is found in Spain, Brittany and Connemara. The patron saint of this thesis might be said to be St. Dabeoc after whom the plant was named.

I was left with a sharpened curiosity about Connemara and, when Professor Dunham suggested the detailed mapping of the area as a research topic, I accepted most gratefully the opportunity of revisiting this wet but beautiful land.

During the course of the field work my task was eased by the hospitality of the many people I met, the interest they showed and the equanimity with which they viewed my hammering the rocks in their back gardens. I would here record my great appreciation to a singularly courteous and hospitable people.

My thanks are also due to:-

The Department of Scientific and Industrial Research for a Research Studentship which enabled the work to be done.

The Geological Survey of Eire which made available air photographs of the area.

Professor K.C. Dunham F.R.S. under whom the bulk of the work was done, for his unfailing interest and stimulating suggestions, and who has followed the work closely both in the field and in the laboratory.

Professor F.H. Stewart under whom the work was begun and who set my foot in the direct way.

Professor R.M. Shackleton for providing facilities for study at Liverpool University, much valuable discussion of the geology of Connemara and opportunity to study his own maps and field slips.

Dr. B.E. Leake for his continued interest and many valuable suggestions about the scope of the work; for conducting me over his own ground at Cashel and Ballyconneelly, and for providing me with a chemical analysis of one of my own rocks.

Mr. B. Evans for conducting me over his ground at Toombeola and giving a most stimulating account of it.

Mr. J. Starkey for valuable discussion about the structural elements.

Mr. C. Kilburn for having the courage to take the piece of ground lying between myself and Professor Shackleton and for assistance with the structural stereograms.

Dr. C.H. Emelaus for accompanying me in the field and for petrographic assistance.

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Mr. W. Layton with whose co-operation the chemical analyses were completed.

Dr. B.K. Welch for commendable tolerance during our peaceful co-existence in the same laboratory and much stimulating discussion.

Dr. G.A.L. Johnson for critically reading part of the manuscript.

Mr. O.L. Oyawoye for help with the photomicrographs.

Mr. R.P. Hollingsworth for his many invaluable suggestions about the chemical analyses.

The laboratory staff of the Durham Colleges for the preparation of thin sections, maps and photographs.

Lastly to my wife who has typed the script and in many ways been a constant source of help to me during the final stages of preparation of the thesis.

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CHAPTER I

INTRODUCTION

Location.- The area studied is in the Western District of Ireland known as Connemara. It faces onto the Atlantic Ocean and is approximately 160 miles west of Dublin. It is most clearly seen on the Geological Survey of Ireland 1 inch to the mile map, sheet 94, and is there seen to lie directly to the north west of Clifden, the capital of Connemara, being bounded on the south by Clifden Bay, the north by Cleggan Bay, the east by the Clifden - Lough Fadda fault and the west by the Atlantic Ocean. It is divided into two unequal portions by Streamstown Bay, a narrow, fjord-like inlet four miles long and only 200 yards across at the seaward end. Throughout this account the northerly area will be referred to as the Aughris Peninsula, while the southerly area will be called the Ballymaconry Peninsula; The islands out to sea in line with this land mass also form part of the area studied; High Island, Friars Island, Cruagh, Inishturk, Eeshal Island and Turbot Island being the only ones of any consequence. There are numerous other rocks and breakers but it is generally impossible to visit these on account of the high seas.

The area is part of the terrain of the Connemara schists, believed to be of pre-Cambrian age, a series of metasedimentary rocks into which at the seaward end the Omey Island granite is intruded. This granite is one of several in Connemara all of which are most probably subsidiary stocks of the immense mass of the Galway granite which forms most of Southern Connemara.

<u>History of Research</u>.- The first serious work in Connemara was done during the last century by the Geological Survey of Ireland. Mapping was done by Warren, Cruise, Leonard and Nolan under Kinahan and the Memoir was published in 1878. This work was done at great speed and many years before the introduction of the petrological microscope into general use. Although these workers made mistakes and misinterpretations they recognised the major lithological types and also the Connemara anticline. They divided the region into two main areas, N. and S. of the Clifden-Galway Railway approximately. The northern portion composed of marbles, quartzites and schists is folded to form the Connemara anticline. The southern part is made up of lavas and agglomerates with small granite intrusions all truncated by the huge mass of the Galway granite. There were also one or two basic bodies recognised on the northern side of the anticline. Considering the speed at which they worked and the state of knowledge at the time, the production of this map must be regarded as a fine achievement for it still remains the basis of all modern work.

No further work was done until 1932 when L.R. Wager published an account of the ultramafic mass of Errisbeg Hill just behind the small harbour of Roundstone. In 1937 Ingold described the basic mass of Currywongaun on the north side of the Connemara anticline. These publications showed that the basic and ultrabasic rocks were not lavas but were plutonic in origin.

Since then R.M. Shackleton has spent several years mapping parts of the Connemara anticline. B.E. Leake did a Ph.D. thesis on the Cashel district and B. Evans is doing a similar thesis on the Toombeola district. Both areas are in South Connemara and within the lava-agglomerate zone of the survey. The lavas are now shown to be hornblende gneisses and the agglomerates to be agmatites. Ultrabasic layered intrusions were also recognised and two periods of feldspathization, first one of andesine (An_{40}) followed by one of microcline. The microcline feldspathization produced migmatitic granite which had been recognised by the survey as granite. B.E. Leake is continuing work in the Ballyconneelly district which is also in the hornblende gneiss migmatite zone, due south of the area now described and abuts onto it. Shackleton's work in the Connemara anticline is being supplemented by C. Kilburn and J. Starkey who are working east and west of him respectively. The present work is in the Connemara anticline at its most westerly point where it disappears into the Atlantic.

Nature of the Problem;- From all this work, most of it unpublished, many problems have become apparent. The Connemara anticline is marked chiefly by a series of quartzites and marbles. The quartzites are disposed in two main blocks. The Twelve Bens and the Maamturks, the two mountain ranges of Connemara, both range up to 2000 feet and display magnificently the core of the anticline. The quartzites are separated by the marbles which wrap round them and recur three or four times. The precise number is not known because the original mapping is not very definite on this point. It has been thought that both the quartzites are at one stratigraphical horizon and that all four marbles are also one horizon. Evidence will be produced later to support this contention.

Within the Connemara anticline, recumbent folding is present showing that the anticline is a secondary feature. The suggestion is that the Connemara anticline is a complex rather than a simple structure.

Over most of Connemara the linear elements pitch eastwards. There is a pitch culmination about 3 miles to the east of the area now studied and to the west of this culmination the pitch is predominantly westerly. The actual anticline itself however is an easterly plunging structure over the whole of Connemara, the culmination being roughly over the site of the Omey Island granite.

The regional metamorphism is known to increase from garnet grade in north Connemara to sillimanite grade in the south.

Purpose of research.- The area was chosen because it covers a fair, though not complete, section across the anticline. The lack of completeness is however offset by the fact that it is near the culmination and there was therefore some hope of tracing the stratigraphy round the structure should it prove possible to establish a sequence of beds.

It was thought that a metamorphic isograd probably crossed the area somewhere and the tracing of this would be a considerable advance in knowledge of the region. Finally there was the emplacement of the Omey Island and Turbot Island granites to be studied together with the associated thermal metamorphism if any.

Topography.- The area is of a fairly rugged nature, but not particularly high relief, the highest point situated in the centre of the Ballymaconry Peninsula about 2 miles west of Clifden being 587 feet. The high central portion of this peninsula is covered by bog to a depth of about 7 feet and exposure here is poor. The relief drops rapidly away to the coast on either side; on the south side exposure is excellent while on the north side there is a fairly continuous cover of drift and exposure is again poor. The Aughris Peninsula provides some contrast in that the relief is much more gradual, the highest point being 500 feet. There is a broad belt of excellently exposed ground running along the south side of the peninsula while on the north side the exposure is not so good and again there are large expanses of drift. The central part of the area, a broad plateau-like region, is a large expanse of bog through which rock outcrop is very sporadic.

The area as a whole is well served by roads which follow the coast providing easy access to the most distant regions, but the only way to get to the interior is on foot. The whole area has an exceptionally large amount of coastline for its size and here the exposure is nearly always complete, apart from a few instances where a cover of drift has obscured the geology.

Work Done.- The area was mapped in detail on the 6 inch scale, portions of 6 inch sheets 21, 22, 34 and 35 being used to cover the area. The bulk of the mapping was done on sheets 22 and 35. A total of eight months was spent in the field, two months in 1956, 4 months in 1957 and 2 months in 1958. Four hundred and fifty samples were collected and 260 thin sections have been made and described. Altogether, 150 modal analyses and 14 chemical analyses were made.

Field Methods.- The method known as strike mapping was employed; this consists of drawing an accurately orientated strike line at the position of every exposure. One of the advantages of this method is that considerable clarity and accuracy are retained where exposure is very dense. This was particularly found to be the case on the southern side of the Aughris Peninsula where exposure is considerable and the stratigraphy very confused and difficult. Air photographs were used to supplement the 6 inch maps which were often obsolete. They were also invaluable as aids in position finding in the large featureless expanses of bog which cover the central portions of both peninsulas. Mode of transport was by bicycle and foot on the mainland and by curragh to the islands. The latter was slightly unreliable on account of the vagaries of the Connemara boatmen. On one occasion the engine caught fire and on another, a day of glassy calm was judged too rough to risk landing on the rocky shore. For these reasons it was not possible to visit Cruagh and Friars Island, though all the other islands were visited.

Laboratory Methods.- Modal analyses were done with the Swift point counter on the basis of at least 2000 points per slide. Since much of the plagioclase in metamorphic rocks is untwinned, the presence or absence of potash feldspar is often uncertain, Sodium cobaltinitrite was used as a stain for potash feldspar to assist its determination in some rocks and to confirm its absence in others. This proved an invaluable aid, particularly in the modal analyses. Stained slides were prepared by etching in hydrofluoric acid fumes for 1 minute and then standing in a concentrated solution of sodium cobaltinitrite for 20 minutes after which they were washed and mounted in the usual way. Refractive indices were determined by oils of .005 interval. On the result being obtained the liquid was redetermined using an Abbé refractometer for minerals up to 1.680. Above this figure the Leitz Jelly refractometer was used. The sodium lamp was used for all determinations.

The chemical analyses were done in collaboration with W. Layton and in addition to the 14 rocks analysed, 10 amphibolites and 10 amphiboles were analysed in connection with his work. The methods used were the rapid methods of Shapiro and Brannock (United States Geological Survey Bulletin 1036 C, 1956) and all determinations were done in duplicate. There are however slight differences of method upon the advice of R.P. Hollingworth and these are given below with the relevant page of the Bulletin.

Solution A, page 32. This was prepared using 13 NaOH pellets instead of solution.

SiO_2, page 33. 1 ml. of tartaric acid was added instead of 4, as with 4 ml. the reaction is too fast whereas with 1 ml. the reaction is slowed down and the silico-molybdate complex is enabled to form properly.

Al_2O_3 was determined as in the Bulletin.

Solution B, page 32 - 33. The solution was prepared as directed in the Bulletin except that rocks which were known to contain staurolite were digested on a steam bath with HF and $HclO_3$ until the residue was dissolved, generally about 3 days, and was then made up directly to 200 mls.

Total iron was determined as in the Bulletin.

TiO_2 was determined as in the Bulletin.

P_2O_5 was determined as in the Bulletin.

MnO was determined as in the Bulletin.

CaO, page 39 - 40. The method was changed as the Geology Department did not have the requisite piece of aparatus. The scale was reduced by a factor of 5 to a microscale enabling the spectrophotometer to be used.

1. Add 1 ml in 10 ml aliquot of solution B to the photoelectric cell.
2. Add 0.3 ml sodium potassium tartrate solution.
3. Add 0.1 ml murexide indicator solution.
4. Add 1 ml NaOH solution or until solution becomes alkaline.
5. Titrate with 1 gram litre E.D.T.A. using microburette and spectrophotometer.

MgO was determined as in the Bulletin except that the titration was done with ordinary burette which was found in the event to be very effective.

FeO was determined as in the Bulletin.

H_2O was determined by the Penfield method which was considered on the whole to give low results.

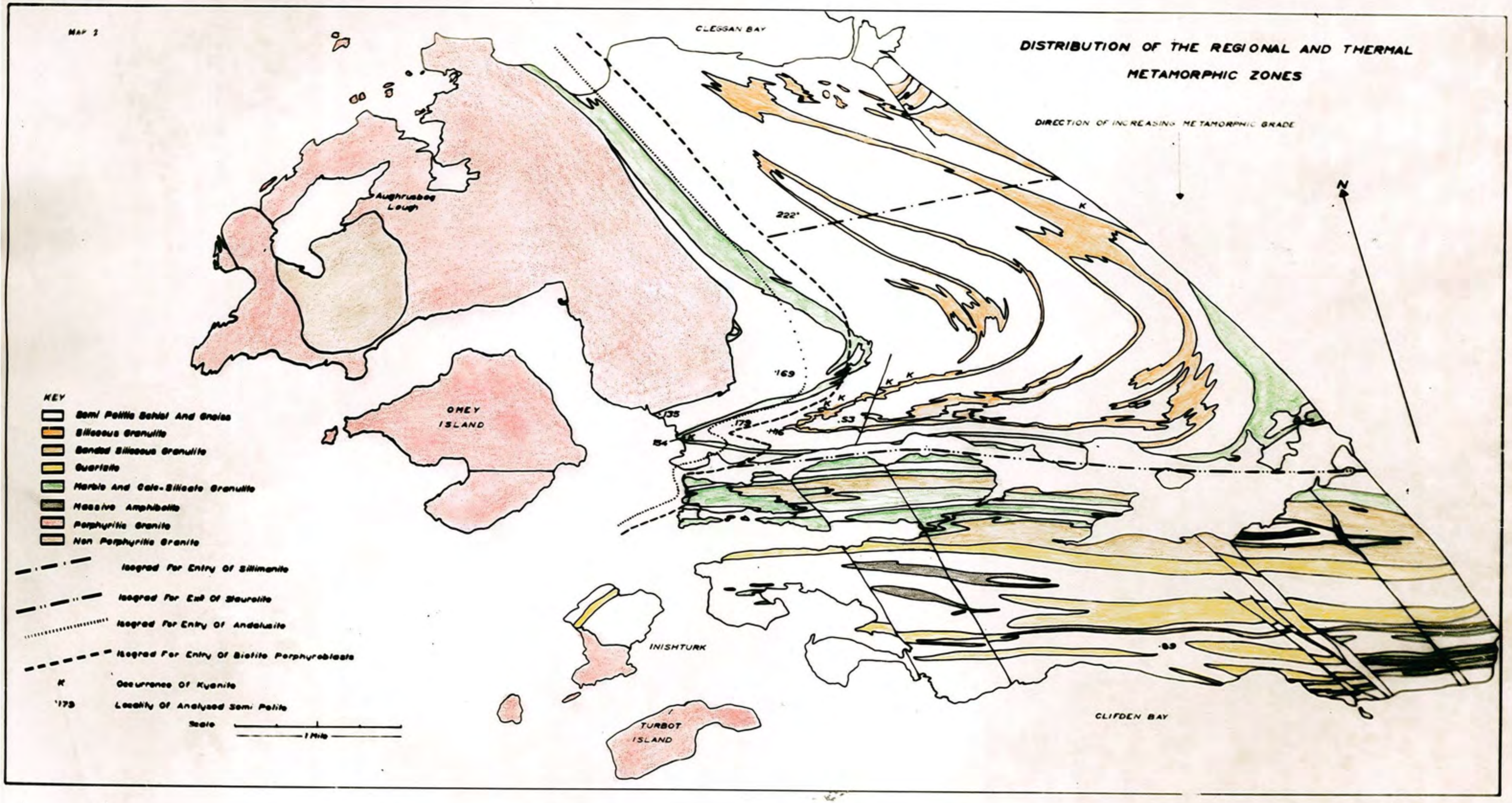
Co_2 was determined as in the Bulletin.

The accuracy of the rapid methods of analysis used is thought to be sufficiently good for bulk rock analyses, as in the present investigation. The results obtained for W. Layton's amphibolites agree closely with those found by the Geological Survey of Ghana using classical methods. During the present work a granite from Nigeria was analysed at the request of M.O. Oyawoye and this too was in close agreement with the results obtained by the Geological Survey of Nigeria, also using classical methods.

Their real value however lies in the fact that by using rapid methods 14 rocks were analysed whereas if it had been necessary to use classical methods only two or three rocks could have been done and the amount of useful information obtained would have been correspondingly smaller. This fact alone justifies the use of rapid methods. The accuracy of the methods has been investigated and found to be adequate for all normal purposes (Mercey 1956).

Terminology.- The term granulite is used throughout this account in a textural and not a genetic sense. It does not refer to rocks of granulite facies but rather to point the difference between rocks of granular texture as opposed to schistose texture. The one exception to this rule will occur in the chapter dealing with metamorphic facies and its use then will be clear from the context.

All other terms, where they are different from normal geological usage, will be defined as they are met with.


MAP 2
DISTRIBUTION OF THE REGIONAL AND THERMAL
METAMORPHIC ZONES
DIRECTION OF INCREASING METAMORPHIC GRADE
N
CLEGGAN BAY
Aughrusbeg Lough
OMEY ISLAND
INISHTURK
TURBOT ISLAND
CLIFDEN BAY
222°
169
135
154
173
116
53
83
K
KEY
Semi Pelitic Schist And Gneiss
Siliceous Granulite
Banded Siliceous Granulite
Quartzite
Marble And Calc-Silicate Granulite
Massive Amphibolite
Porphyritic Granite
Non Porphyritic Granite
Isograd For Entry Of Sillimanite
Isograd For Exit Of Staurolite
Isograd For Entry Of Andalusite
Isograd For Entry Of Biotite Porphyroblasts
K Occurrence Of Kyanite
173 Locality Of Analysed Semi Pelite
Scale
1 Mile

CHAPTER II

THE METAMORPHIC ROCKS

DISPOSITION OF THE REGIONAL AND THERMAL METAMORPHIC ZONES

The regional metamorphic zones traverse the area from east to west while the increase in grade is from north to south (see Map 2). Progressing from the north the first rocks encountered are in the staurolite zone. The first change seen is the entry of sillimanite in the form of lineated mats of fibrous crystals concentrated along the quartz segregations commonly present in the semi-pelitic schist. The delineation of this isograd is shown in Map 2 to be on a roughly E.W. line just inside the northern half of the Aughris Peninsula.

From this point staurolite and sillimanite continue together, the sillimanite gradually extending its influence so that it is found within the main body of the rock as well as in fibrous mats in the segregation veins. Within this zone of staurolite and sillimanite there are occasional occurrences of kyanite. These are very sporadic indeed and occur in the same way as the first sillimanite as crystals in segregation veins. They are usually associated with sillimanite. There is no kyanite zone in the accepted sense.

The second change noted is the loss of staurolite. This change is not actually seen in the field but it is very apparent that the rocks north of Streamstown Bay contain staurolite while those south of it do not. The isograd for the exit of staurolite is accordingly drawn along the line of Streamstown Bay. From this point onward sillimanite continues alone except for garnet which is present in all the zones.

The thermal metamorphic zones are disposed concentrically about the Omey Island granite and truncate the regional zones. There is an inner zone of andalusite hornfels and an outer zone of biotite porphyroblast hornfels.

CLASSIFICATION OF THE METASEDIMENTS

The metasediments can be readily classified into three main groups.

1. Siliceous.
2. Aluminous.
3. Calcareous.

There is continuous variation between the siliceous and aluminous groups, and also between the calcareous and aluminous groups. In the case of the calcareous group however the mineralogy is always distinctive and there is never any difficulty about grouping rocks of this category together even when the silico-aluminous admixture is considerable.

The present classification is based on recent work in Connemara. Both B.E. Leake and B. Evans have used this system and it is considered desirable to retain it as the Connemara metasediments are in some respects rather different to comparable rocks elsewhere.

The classification is based on the contrast between salic minerals, quartz and feldspar and femic minerals, micas, sillimanite, staurolite, garnet etc., the latter tending to impart schistosity to a rock, the former, granulosity. This is most important, for it is by differences of this nature that the rocks are distinguished in the field.

TABLE I

CLASSIFICATION OF THE METASEDIMENTARY ROCKS

SILICEOUS GROUP	QUARTZITE	>	80% quartz
	SILICEOUS GRANULITE		50-80% quartz
ALUMINOUS GROUP	FELDSPATHIC GRANULITE	>	66% quartz + feldspar < 50% quartz.
	SEMI-PELITE		33-66% quartz + feldspar
	PELITE	<	33% quartz + feldspar
CALCAREOUS GROUP	MARBLE	>	35% calcite
	CALC-SILICATE GRANULITE	<	35% calcite

Within the area described, pelite of the prescribed composition is of comparatively rare occurrence, it is however dominant in other parts of Connemara and for this reason has been included in the series. It is realised that what are here called semi-pelites have been described by other authors as pelite. The term has never been defined, however, it being customary to simply call the most pelitic member present pelite. In view of this lack of definition, of the priority of recent workers in Connemara and of its widespread application over other districts of Connemara, the present system is retained. Within the calcareous group pure marbles are rare, there is generally an admixture of tremolite or diopside while with increasing impurity plagioclase becomes important and finally ousts calcite completely. Between these two end members, the one a marble, the other a calc-silicate granulite, there is every gradation and an arbitrary grouping is necessary. The criteria chosen has in this case again been mineralogical; if the main impression of the rock is dominantly calcite it is grouped among the marbles, but if calcite is seen to be subordinate it is grouped among the calc-silicate granulites. The figure of 35% free calcite has been chosen, for it has been found by modal analysis that those rocks which were mapped in the field as marbles in general have calcite in excess of this, while those which are mapped as calc-silicate granulites have it in smaller quantity. This grouping is therefore primarily subjective but is nevertheless felt to be reasonable since another person's subjective decision could only move the dividing line by 5 - 10%. It is also felt that over rigid classifications tend to become unrealistic when applied to rocks of rapidly varying character.

PETROLOGY

Metasediments of the Regional Metamorphism

Semi-Pelites.- The semi-pelites form the major background unit of the whole area. They are generally schistose in character but occasional gneissose varieties do appear largely due to the concentration of feldspar into augen and veinlets. On the Ballymaconry Peninsula they are intimately mixed with siliceous and feldspathic granulite and it is impossible to separate them into stratigraphic units. On the Aughris Peninsula however, the admixture is not so intimate or continuous and stratigraphical separation of the two rock types is possible, albeit sometimes with difficulty.

On the Aughris Peninsula the semi-pelites present on the whole a more uniform aspect than elsewhere. They are coarse well-crystalline schists occasionally becoming so coarse as to have a gneissose character. This gneissosity is further emphasised by an abundance of garnet and staurolite, both minerals of granular habit, which tend to interrupt the foliation and give a more granular appearance to the rock. Weathered surfaces of these rocks are extremely handsome with pink garnets and resinous brown staurolites sticking out like peas. Segregations of quartz and plagioclase are frequent. These are extremely elongate, thin, lenticular units contorted and microfolded with tiny folds parallel to the regional lineation. The rock immediately surrounding the segregations is generally much darker than the rock as a whole giving the impression of having been leached of salic minerals. The biotites are much coarser and more densely packed and very frequently there are considerable accumulations of very coarse garnet and staurolite. Garnets of up to ½" diameter are not uncommon at these localities while staurolites of similar dimensions may also be found though more rarely.

It is at these points of mineral segregation and coarse growth that kyanite and sillimanite appear. Kyanite is extremely rare and sporadic and occurs as nests of crystals up to 1" in length in the quartz veins. Sillimanite is very common indeed and occurs as felted mats of whitish grey fibres mixed in with and frequently surrounding the quartz segregation veins. It has a very strong preferred orientation which is parallel to all other linear elements in the rock.

The rocks as a whole have a very strong fabric, feldspar

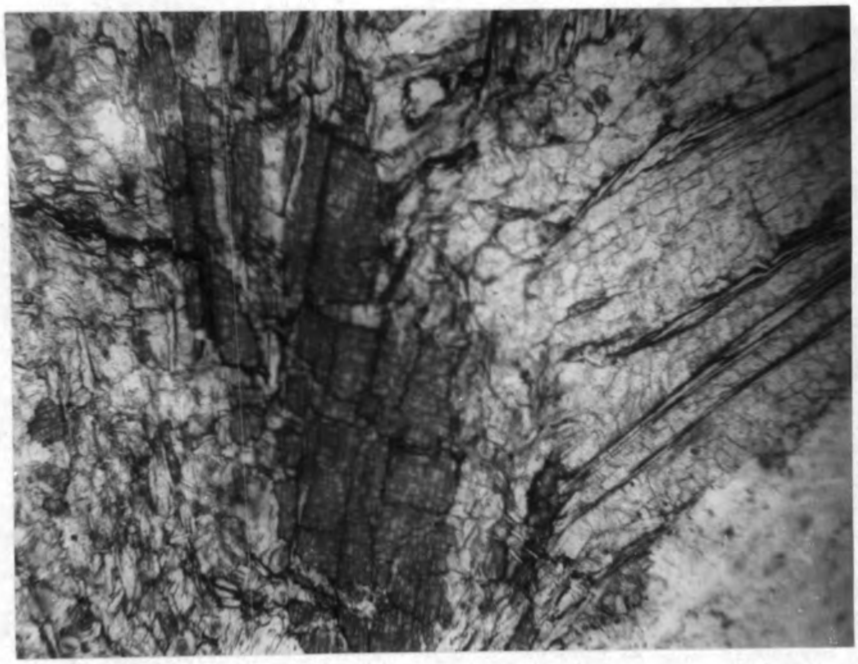


Plate 1. X 70. Kyanite in segregation veinlet. The remainder of the field is muscovite which has partly replaced the kyanite.

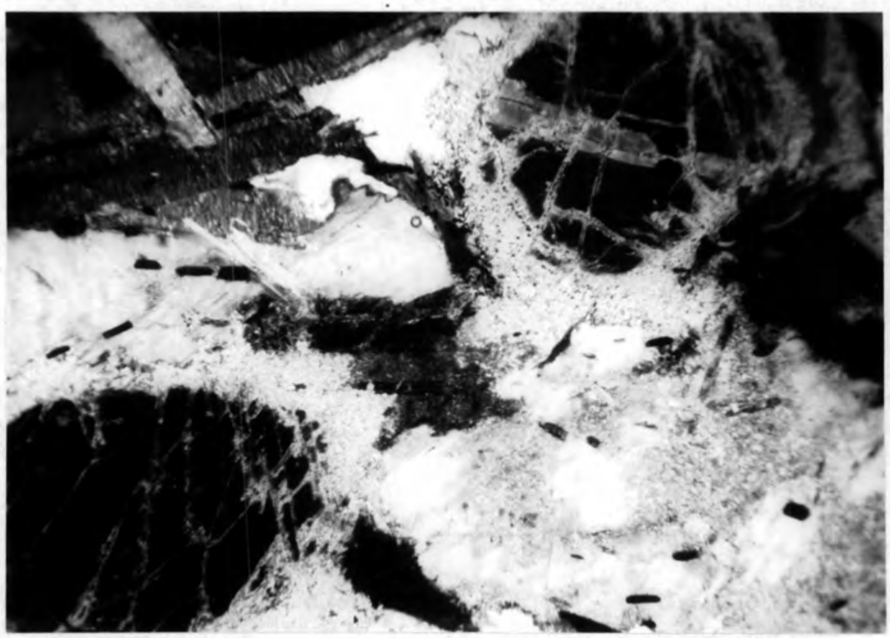


Plate 2. X 70. Staurolite crystals surrounded and penetrated by fine grained shimmer aggregate.

augen in particular being elongated to give a coarse lineation, while sometimes garnets and staurolites are arranged in columns and grooves which tend to enhance the linear character.

On the Ballymaconry Peninsula the semi-pelites present a somewhat more subdued aspect as they are frequently intermixed with very sober looking siliceous granulite and eye catching minerals are on the whole poorly developed. Segregation lenses of quartz and plagioclase are still much in evidence and at some horizons where potash feldspar is present in the body of the rock it is also present in the quartz veins as slightly pinkish blebs and crystals, occasionally swelling into knots and augen. The whole effect is of a micropegmatite permeating and invading the rock and some writers would no doubt describe this as lit-par-lit injection. This however is thought not to be the case for potash feldspar is only found in the veins when it is also present in the surrounding rock. Other minerals present are muscovite tourmaline and ilmenite, all of which are present in the parent semi-pelite. Further, the features which were noted in segregation veins on the Aughris Peninsula are also seen here; in particular the dense packing up of the femic minerals, in this case largely biotite, along the edges of the veins makes a strong suggestion of metamorphic differentiation (cf. Ramberg 1952, p. 217).

The semi-pelites on this peninsula are only gneissose when very feldspathic and transitional to feldspathic granulite; more typically they are constantly schistose. Staurolite is completely absent and garnet, though consistently present throughout, is more modest than its flamboyant cousin across the bay and is often difficult to detect in hand specimen, though a section will usually reveal its presence. Sillimanite is now totally different in occurrence, it is completely absent from the veinlets and is seen as lensoid ovoids of a rather pearly colour up to ½" in length. They are greasy to the touch and will scratch easily due to the fact that they are composed largely of sericite formed during retrograde metamorphism.

Following are 5 analyses of typical semi-pelites in Table II overleaf.

TABLE II

CHEMICAL AND MODAL ANALYSES OF THE SEMI-PELITES

SPECIMEN NO.	S_3	222	89	169	H16
SiO_2	52.35	56.40	56.10	54.29	53.00
Al_2O_3	19.00	19.77	18.71	18.10	19.17
TiO_2	0.20	0.16	0.69	0.80	0.17
Fe_2O_3	1.20	2.01	1.20	3.65	1.53
FeO	8.96	8.50	5.60	2.96	8.60
MnO	0.29	0.10	0.18	0.14	0.18
MgO	3.23	2.23	2.02	6.60	1.82
CaO	4.48	2.79	3.65	1.66	3.35
Na_2O	1.38	1.89	2.36	1.91	2.17
K_2O	4.81	4.21	6.20	7.66	5.90
P_2O_5	0.26	0.02	0.30	0.24	0.35
H_2O	1.45	1.90	2.07	1.51	3.18
TOTAL	99.40	99.97	99.07	99.43	99.39
NIGGLI VALUES					
Si	155	182	189	161	166
Al	33	37	37	30	36
Fm	40	39	29	45	35
C	14	10	13	5	11
ALK	13	14	21	20	18
K	0.69	0.60	0.63	0.72	0.64
Mg	0.36	0.28	0.34	0.65	0.24
MODAL ANALYSES					
QUARTZ	28.4	21.2	32.5	15.1	16.3
PLAGIOCLASE	19.8	18.8	11.5	25.0	24.7
ORTHOCLASE				5.9	
MUSCOVITE	3.4	16.2	15.4	31.2	13.0
BIOTITE	20.4	26.2	22.9	21.4	26.0
CHLORITE					3.9
SERICITE					1.3
GARNET	11.7	0.2	1.9		3.7
STAUROLITE	1.6	14.3			8.8
SILLIMANITE	14.4		15.7		1.2
TOURMALINE					0.8
OPAQUE	1.0	2.7		1.3	0.2
TOTAL	100.7	99.9	99.9	99.9	99.9

The localities of these specimens can be seen on Map 2 but localities are also given here.

S_3 30 yds. N.W. of Cushatrough school.

222 600 yds. E.S.E. of Lough Courhoor.

89 S. side of the Ballymaconry Peninsula, 2 miles W. of Clifden.

169 Just N. of Barnahallia Cottage.

H16 600 yds. W. of Cushatrough school.

Analysts - E.J. Cobbing and W. Layton.

The modal similarity of these 5 rocks is fairly clear. 222 is outside the sillimanite zone and this mineral is absent but in other respects it is very similar to H16; No. 89 is well beyond the zone of staurolite and this also is absent but instead sillimanite is very abundant. The one rock shown which is in some contrast to the others is 169. This is an orthoclase-bearing semi-pelite. It is present as a distinct formation in the Barnahallia district and its limits are shown on Map 6. Some affinities are shown with the Ballymaconry semi-pelites in that there is an intimate admixture of siliceous granulite which is not separable. It has no garnet, staurolite or sillimanite, the necessary iron, magnesia and alumina being combined with the excess potash present in biotite and muscovite. Chemically the difference is not marked except for the rather higher K_2O and lower iron.

Petrographically all the semi-pelites display essentially similar characters. Quartz is generally xenoblastic, sometimes tabular and is very frequently in lensoid segregations composed entirely of quartz; but a proportion of plagioclase is occasionally present. Quartz generally shows strain extinction.

Quartz-rich bands are also seen but in these there is usually some proportion of plagioclase.

Plagioclase over the whole area ranges from An_{25} to An_{45} but the more extreme members are relatively rare and the strong overall impression is of constant composition at An_{30}. There is no variation from north to south, the composition being exactly the same in the staurolite zone as it is in the sillimanite zone. Plagioclases were determined by measuring refractive indices on cleavage fragments and plotting them on the curves prepared by Tsuboi (1923). This was supplemented by the Michel Levy method using thin sections and substantial agreement was found between the two. Plagioclase is largely untwinned but in some places twinning on the albite and pericline laws is seen. Carlsbad twins are never seen. Poikiloblastic augen up to 2 mm. in length are common, the most frequent inclusions in these being quartz, biotite and muscovite. These inclusions are generally parallel to the prevailing foliation but sometimes there is an angular relationship between the two which must mean either that an earlier foliation has been overprinted by a later one or that the plagioclase crystals have been rotated during or after growth. Since there is no sign of a sigmoidal disposition of the inclusions and the crystals show no trace of cataclasis the former possibility is considered most likely. Plagioclase texture may be porphyroblastic or granular but is most commonly a combination of both. Crystals are generally fresh but alteration is not uncommon taking the form of light sericitization round the edges spreading to the interior of the crystals.

In some cases alteration is complete giving dense masses of disoriented sericite. Where orthoclase is present it is associated with plagioclase which it sometimes seems to replace. The orthoclase is clear xenoblastic with occasional microcline twinning and no sign of development of perthitic texture. It is generally fresh but a slight dusty brown alteration is occasionally seen.

Biotite, which together with muscovite defines the prominent foliation, may be brown or green in colour. There is a suggestion, but no more than this, that green biotite is found in the more feldspathic types while brown biotite is prevalent in the more pelitic varieties. Certainly wherever epidote is found it is always associated with green biotite and frequently the rock has free orthoclase in addition. Biotite is idioblastic and is intergrown with muscovite in laminae which separate the granular elements of the rock and wrap round porphyroblasts of garnet, plagioclase and staurolite which form augen. Biotite is frequently altered to chlorite which may be green, yellow or grey in colour, often showing anomalous blue interference colours. The chlorite occasionally contains either clusters of rutile needles or tiny crystals of magnetite as by-products of the change from biotite.

Garnet poikiloblasts are characteristic. Where garnet is in small quantity the texture is skeletal and ramifying but usually the habit is euhedral, though inclusions are always present. Quartz is by far the most common material included though muscovite and biotite are frequently present. These inclusions are sometimes beautifully sigmoidal showing that

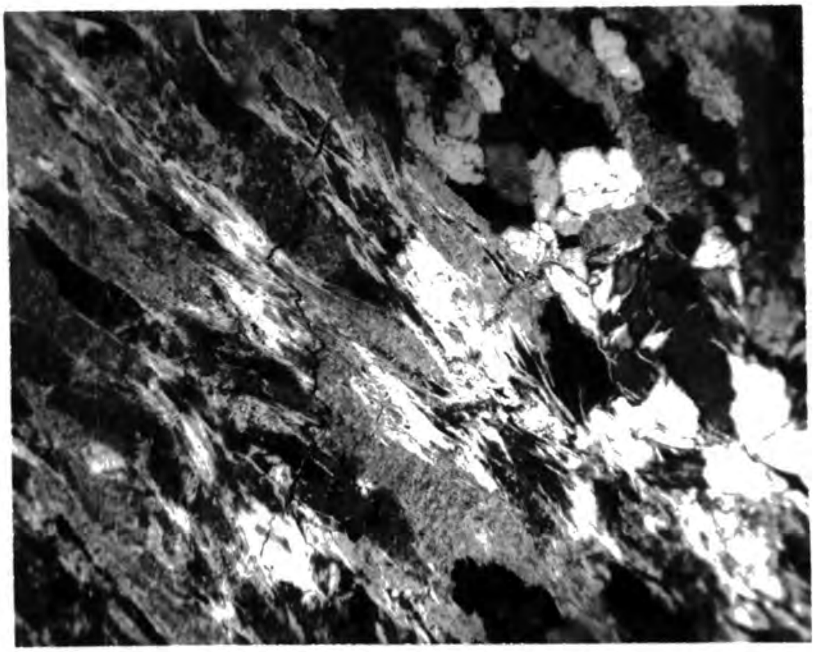


Plate 3. X 70. Fibrous sillimanite (white) developing from biotite (pale grey).

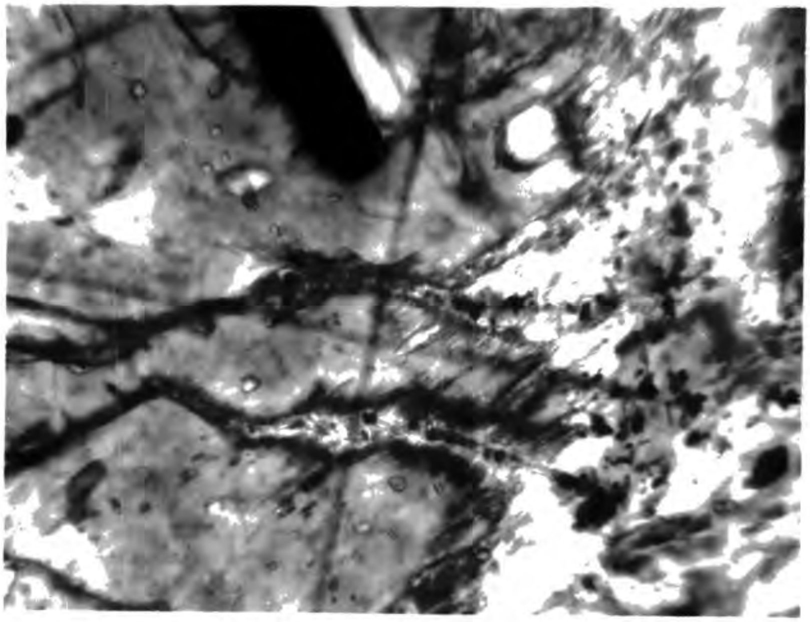


Plate 4. X 500. Fibrous sillimanite replacing staurolite along fractures. Fine grained magnetite is deposited in the fractures.

the garnets were rotated during growth. Unfortunately no oriented specimens were collected and so the sense of this movement is not known. Garnet is sometimes altered to green chlorite and very occasionally to brown biotite.

Staurolite occurs as stubby prismatic poikiloblasts which may enclose quartz and small rods of pyrite; frequently, however, it is completely free from inclusions. Very occasionally sigmoidal inclusions are seen but this is rare. It is pleochroic in shades of light yellow X < Y < Z and is very frequently altered to coarse disoriented sericite so that commonly a tiny central relic of staurolite is seen in a mass of shimmer aggregate. Kyanite is only present in two slides and in both cases it is in small prismatic crystals with no inclusions. In one case the kyanite is rimmed by coarse sericite but in the other it is fresh; associated minerals are garnet, staurolite and sillimanite but none of them is very abundant.

Sillimanite is most commonly seen to be developing from biotite in close packed sheaves of convoluted fibrolite; rimming of biotite by fibrolite and relics of biotite within fibrolite masses are frequent. This mode of occurrence is usual on the Aughris Peninsula but on the Ballymaconry Peninsula the situation is rather different; here the sillimanite is in lensoid masses of closely packed fibres but in this case they are seen to be developing from muscovite and not biotite, while substantial alteration by sericite is common.

Tourmaline is present in nearly all sections as euhedral crystals, often zoned and pleochroic in shades of olive green. Apatite is a sporadic accessory. Occasionally there are bands rich in fine grained apatite and these are interpreted as original heavy mineral concentrations. Zircon is also seen at these points.

Metamorphic reactions in the semi-pelites.- A series of metamorphic reactions are now described.

(a) High-grade reactions. Development of sillimanite from biotite marks the beginning of the sillimanite zone while deeper within the zone development from muscovite becomes the characteristic mode of formation. The actual destruction of staurolite by high grade minerals is not seen in spite of careful search except at one point where under high power sillimanite is seen to be fringing and penetrating staurolite. It is concluded that this must be the means of its replacement, particularly since it is seen on the south side of the Aughris Peninsula near the point of ultimate disappearance of staurolite.

(b) Low-grade reactions. These are the reactions of the retrograde metamorphism which are widespread throughout the area. Chloritization of biotite is common while alteration of garnet is also sometimes seen. Sericitization of staurolite is extremely common and is often the only retrograde change visible; in the more thoroughly altered rocks plagioclase is altered as well. It is possible to find rocks which consist of quartz, sericite, muscovite and chlorite, the only trace of the original mineralogy being in the form of pseudomorphs.

The Siliceous Granulites.- The siliceous granulites represent one of the most important rock groups in the area. In the classification they have been divided into a feldspathic and a siliceous group, but since their mineralogy is so similar and because they cannot be separated in the field they are here treated as one, and examples of both types are given.

On the Ballymaconry Peninsula the feldspathic type is most common interbanded, sometimes on a very minute scale, with semi-pelite. It is a dark coloured, fine grained granulose rock with little structure apart from a widely spaced foliation. The colour is due to finely divided biotite. In fact the rock possesses a strong fabric but this is often very difficult to see although occasionally a faint mineral lineation may be distinguished.

On the Aughris Peninsula however there is every gradation between this type and siliceous granulite which is sometimes a white quartzitic-looking rock. It is separated from quartzite however on the grounds that it contains both biotite and plagioclase which is absent in a true quartzite. It does in any case vary laterally into feldspathic granulite with which it is most naturally grouped. The rock is white or greyish white, mottled looking, often of a rather sugary texture due to the weathering out of the feldspars which leaves holes. It has a very strong fabric the feldspars being elongated in groups up to 5 or 6 inches in length, giving the rock an almost stripey appearance on the foliation planes.

The rock which is marked as banded granulite on the north side of the Ballymaconry Peninsula is a variant of the siliceous type. Originally mapped as quartzite it is now recognised as a siliceous granulite; occasionally feldspathic in nature its chief characteristic is the strong banding encountered everywhere along its outcrop, to the extent that it makes a definite stratigraphic unit, possibly of use in correlation beyond the area. The fabric is not so marked as in other types of siliceous granulite but is nevertheless visible on inspection as a constant mineral lineation. The formation is so strongly banded that the possibility of finding graded or current bedding should not be excluded. Careful search failed to yield anything definite but there were several suggestions of both these structures. In Table III overleaf are two analyses, one of a typical feldspathic type and one a typical siliceous type.

TABLE III

CHEMICAL AND MODAL ANALYSES OF THE SILICEOUS GRANULITES

SPECIMEN NO.	170	240
SiO_2	69.00	81.70
Al_2O_3	14.34	7.56
TiO_2	0.62	0.00
Fe_2O_3	1.46	0.60
FeO	2.73	0.53
MnO	0.18	0.00
MgO	2.02	1.43
CaO	1.70	2.66
Na_2O	2.66	0.95
K_2O	3.62	4.00
P_2O_5	0.16	0.19
H_2O	0.89	0.89
TOTAL	99.38	100.50
NIGGLI VALUES		
Si	289	600
Al	38	33
Fm	32	21
C	8	21
Alk	22	25.
K	0.47	0.73
Mg	0.46	0.72
MODAL ANALYSES		
QUARTZ	37.0	69.0
PLAGIOCLASE	32.5	2.1
ORTHOCLASE		15.3
BIOTITE	28.8	1.0
MUSCOVITE		12.6
GARNET	1.1	
OPAQUE	0.5	
TOTAL	99.9	100.0

Localities.

170 100 yds. E. of Barnahallia Cottage.

240 600 yds. S. of Cleggan.

Analysts - E.J. Cobbing and W. Layton.

These two examples are fairly characteristic of the two types. In 170 the lack of orthoclase and muscovite is in strong contrast to 240, while the dominance of biotite and the presence of a little garnet is another typical mark.

Petrographically quartz is dominant providing a xenoblastic mosaic of quite variable grain size in which the other minerals are set. The mineral is generally elongated and usually shows undulose extinction. In rocks which have less than 40% quartz it is sometimes found segregated into lenses.

Plagioclase is idioblastic and of rather granular habit with little development of porphyroblasts or poikiloblasts; in composition it ranges from An_{29} to An_{35} with a mean value of An_{32}. Crystals are most commonly untwinned but twinning is nevertheless not infrequent. In the banded granulites the banding is often partly produced by the plagioclase together with the micas. Where a very strong lineation is present this is caused by an elongate lensoid aggregation of plagioclase crystals together with orthoclase and mica into a stout lineation of very prominent character. Alteration to sericite is very common.

Orthoclase when present is in dispersed xenoblastic crystals, very clear with the occasional appearance of microcline cross-hatching. Perthitic segregation is not seen. Orthoclase is generally interstitial in character.

Biotite is either dispersed as single idioblastic crystals or grouped in bands with muscovite giving the rock a pronounced foliation. It is generally green or browny-green in colour, the light reddish-brown tint common in the semi-pelites being quite absent. Chloritization, partial or complete, is common.

Muscovite is similar in mode of occurrence to biotite but tends to be evenly dispersed throughout the rock as idioblastic crystals in parallel orientation.

When garnet is present its mode of occurrence is either as small, scattered, dense crystals or as large feathery crystals of skeletal habit enclosing large areas of quartz, poikiloblasts in fact except that there is usually more inclusion than crystals. No sigmoidal inclusions indicative of rotation are present in the garnet. Alteration of garnet to biotite and chlorite is sometimes seen.

Accessory minerals may be tourmaline, apatite, zircons, zoisite, epidote and calcite. Tourmaline, apatite and zircon are of fairly ubiquitous occurrence in the same manner as in the semi-pelites, only rather more obviously so. Epidote is more sporadic in occurrence and is generally associated with biotite which it has partly replaced. It is granular in habit with irregular margins. Zoisite and calcite occur in one or two rather peculiar granulites in which there is a slight calcareous admixture.

Metamorphic reactions in the siliceous granulites.-

(a) High-grade reactions. The composition of the siliceous granulites is much less responsive to physico-chemical changes than that of the semi-pelites. The only zonal mineral formed is garnet and that rarely, so that the high-grade changes of the semi-pelites are totally absent here.

(b) Low-grade reactions. The reactions characteristic of low-grade retrograde metamorphism are fairly common. Chloritization of biotite and sericitization of feldspar are both frequently present.

The Quartzites.- The quartzites are the most striking formations in Connemara, forming the huge mass of the Twelve Bens and the Maamturk mountains, so that in the area described although much attenuated, they are of great interest and vital importance to problems of Connemara geology as a whole. The quartzites are found only on the Ballymaconry Peninsula and they chiefly occur as two formations, one running along the southern margin of the banded granulite formation mentioned in the last chapter, which, continuing out to sea is found again on the island of Inishturk before finally disappearing; the other forms the backbone of the peninsula, a striking formation of startling white colour visible for miles and forming the highest point in the area. Several other smaller formations of quartzite are present in the southern half of the peninsula.

The quartzite is a white rock with visible flakes of white muscovite speckled through it. There is a frequent micaceous parting giving a slabby structure to the rock. A very perfect lineation is present provided largely by the parallel growth of the quartz crystals. This is clearly seen either on the fresh or weathered surface. There is also

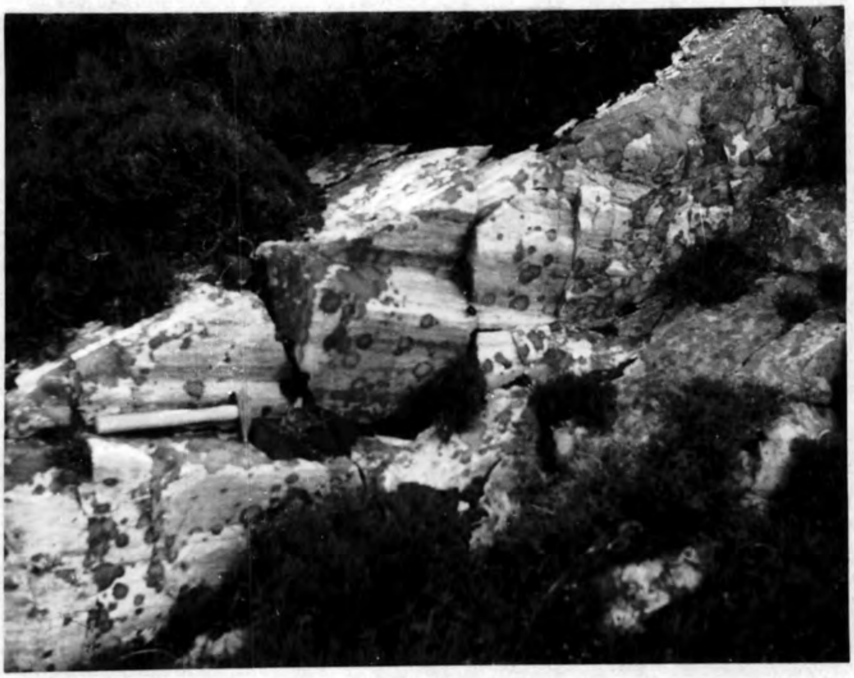


Plate 5. Westerly plunging mullion in quartzite.

Plate 6. X 70. Tremolite marble. Nest of radiating tremolite set in granoblastic calcite.

a large-scale lineation caused by the intersection of foliation and bedding planes and the presence of numerous microfolds which gives the rock a very characteristic fluted or mullioned appearance which is recognisable from a fair distance.

TABLE IV

CHEMICAL AND MODAL ANALYSES OF QUARTZITE

SPECIMEN NO.	35
SiO_2	93.00
Al_2O_3	2.30
TiO_2	0.00
Fe_2O_3	0.17
FeO	0.32
MnO	0.00
MgO	0.50
CaO	0.50
Na_2O	0.07
K_2O	3.36
P_2O_5	0.00
H_2O	0.62
TOTAL	100.84

MODAL ANALYSIS

QUARTZ	84.4
ORTHOCLASE	11.3
MUSCOVITE	5.0
TOTAL	100.7

NIGGLI VALUES

Si	1780
Al	29
Fm	21
C	9
ALK	41
K	0.97
Mg	0.61

Locality.

N.E. of Kingstown Orphanage.

Analysts - E.J. Cobbing and W. Layton.

The petrography is so straightforward as to be almost tedious. The rock is almost entirely composed of quartz which is of ultra-xenoblastic texture forming a lobed and sutured base for the other minerals. It shows frequent strain extinction and a constant elongation within the foliation.

The orthoclase is scattered in single crystals, often idioblastic, evenly throughout the rock; it is quite clear, with no signs of microcline twinning and little alteration other than a slight brown dustiness at the edges of some crystals. Muscovite is scattered throughout the rock in trains of idioblastic grains giving the rock whatever foliation it possesses.

Accessory minerals are rarer than they are in either the siliceous granulites or the semi-pelites. Tourmaline is absent and apatite nearly so while a little zircon is very occasionally seen. Any opaque mineral is generally seen to be euhedral pyrite frequently with a rim of hematite or some other iron oxide.

Neither high or low-temperature reactions are seen in this rock.

The Marbles.- The marbles form one of the major stratigraphic markers in Connemara and are therefore of considerable interest. They are in fact in close association with the calc-silicate granulites, a single mappable unit being generally composed partly of one rock and partly of the other. The marbles are rarely pure and generally contain some proportion of silicate material, nearly always tremolite and phlogopite with sometimes a very little diopside. These silicate minerals are commonly altered to a yellowy greenish serpentine. It is this mineral which, running in green bands through a white calcite matrix and highly folded and convoluted has given the Connemara marble its individual character, recognised in many an altar and reredos throughout the British Isles.

The silicate minerals occur both concentrated in bands and dispersed through the rock. Phlogopite of a shiny bronze colour seems often to be dispersed while pale green tremolite is generally in bands. Tremolite may be radiating or in parallel orientation but where there is any quantity of it the former habit seems to be the rule. This is in strong contrast to the general mineral habit in all other formations, a very puzzling fact since the tremolite must have formed under the same conditions of movement and pressure which caused the strongly oriented mineral growth elsewhere. Perhaps the explanation may be that limestone is such a plastic formation that it can sometimes move into "pressure lows", thus permitting radiating tremolite to form. The marbles weather very characteristically, calcite being preferentially dissolved giving a buff-coloured base in which the resistant silicates are set. As a result of this, minor structures, particularly folds, are often beautifully displayed.

TABLE V

CHEMICAL AND MODAL ANALYSES OF A MARBLE

SPECIMEN NO.	17
SiO_2	13.40
Al_2O_3	2.35
TiO_2	0.00
Fe_2O_3	0.47
FeO	0.56
MnO	0.04
MgO	16.90
CaO	35.00
Na_2O	0.31
K_2O	1.68
P_2O_5	0.50
H_2O	1.67
CO_2	27.40
TOTAL	99.83

MODAL ANALYSIS

CALCITE	64.4
TREMOLITE	31.2
PHLOGOPITE	4.3
OPAQUE	0.4
TOTAL	100.3

NIGGLI VALUES

Si	2
Al	2
Fm	39
C	57
ALK	2
K	0.70
Mg	0.96
CO_2	51

Locality

N. shore of Kingstown Bay.

Analysts - E.J. Cobbing and W. Layton.

The rocks are dominated by calcite which forms a granular base for all other minerals. It is generally idioblastic, twinned and frequently shows a rough preferred orientation. It encloses other minerals poikiloblastically and is sometimes seen to be in reaction-relation with serpentine but never with quartz, it being quite clear that the association quartz calcite is stable throughout the area. In some specimens there is a little dispersed quartz probably of detrital origin.

Tremolite is quite colourless with no tinge of green in any orientation; its extinction angle Z - C is 28°. From the analysis it is clear that this must be a fairly pure tremolite since there is very little iron in the rock while a good deal of the alumina must go into the phlogopite. The habit is generally radiating, often convoluted and finely fibrous in much the same way as sillimanite in the semi-pelites. Alteration of tremolite by serpentine has not been seen in thin section but it is thought that it must occur since tremolite is the only mineral present in sufficient quantity to account for the amount of serpentine in some of the marbles.

Diopside occurs in some marbles in quantities up to 17% but this is rare and smaller amounts are more usual. It is generally present in stubby idioblastic crystals with no inclusions and is easily distinguished from tremolite by its very much higher refractive indices. This is fortunate for it is usually inextricably mixed in with tremolite, only occasionally being found in individual groups and clusters.

There is no apparent preferred orientation among diopsides. An interesting reaction is occasionally evidenced by the rimming of diopsides by tremolite and what can only be described as spearing of diopside by lance-like blades of tremolite. This can occur across cleavages or parallel to them; there are some very fine examples of a cleavage being common to the two minerals; along part of its length it will have the high extinction angle of the original pyroxene while along the remainder the low extinction angle of the replacing amphibole is found.

Phlogopite is generally dispersed through the mass of the rock, only occasionally being concentrated along certain bands. It is generally slightly coloured and is pleochroic from colourless to pale brown. The crystals are idioblastic with no inclusions and when the rock is altered they are themselves altered to a pale grey chlorite which sometimes shows anomalous prussian blue interference colour.

Forsterite has not been found in any of the marbles; an experience which has been shared by some, though, not all other workers in Connemara. Cronshaw (1924) originally described the occurrence of this mineral and since then R.M. Shackleton has found other occurrences, but as far as is known at present, none has been found by the other workers. Serpentine is often in rather ovoid aggregates of fibrous grey crystals, the shape of which is suggestive of former forsterite or diopside, but this rather indefinite evidence is the only indication that the olivine may have been present.

Accessory minerals in the marbles are very rare. The opaque mineral generally takes the form of dispersed perfect cubes of pyrite.

Metamorphic Reactions In The Marbles.-

(a) High-grade reactions. There are no pro-grade reactions in this class of rocks since the expected conversion of tremolite to diopside is not seen in thin section. The retrograde reaction however has occurred and is in fact the only example of a high-grade retrograde reaction seen. It is thought that this has occurred due to incomplete expulsion of water given off during the forward reaction, which has then been able to recombine with diopside when the temperature fell sufficiently for the back reaction to take place. Evidence of this particular phenomenon is of very minor and sporadic occurrence.

(b) Low-grade reactions. These are the chloritization of phlogopite and the serpentinization of diopside, tremolite (and possibly forsterite) due most probably to the addition of water at the lower temperatures of metamorphism.

The Calc-Silicate Granulites.- These rocks are closely related to the marbles and are interbedded with them but on the whole they tend to be more abundant. They are in fact the characteristic expression of the calcareous facies. They may occur as parts of major formations or as tiny strips and lenses of isolated material whose present position may be due to original deposition, intense isoclinal folding, or both.

In field character they are very hard banded rocks of a patchy green and brown colour. The green colour is due to tremolite and diopside while the brown is due to phlogopite or biotite. These bands are thrown into numerous small isoclinal folds and it is the presence of these which give the very strong linear structure of the rock, often very prominent even at a distance. The rock is in general fine grained and individual minerals are often difficult to pick out, with the exception in some places of mica, but the rock as a whole is easily distinguished from other types. It is extremely variable in composition but this variability is not obvious in the field where homogeneity seems to be its chief character. In thin section, however, considerable disparity in the proportion of minerals present is seen. In Table VI overleaf is an example of a rather siliceous type.

TABLE VI

CHEMICAL AND MODAL ANALYSES OF A CALC-SILICATE GRANULITE

SPECIMEN NO.	5
SiO_2	64.60
Al_2O_3	10.22
TiO_2	0.42
Fe_2O_3	0.61
FeO	0.21
MnO	0.50
MgO	4.70
CaO	10.38
Na_2O	1.53
K_2O	5.25
P_2O_5	0.15
H_2O	0.67
TOTAL	99.24

MODAL ANALYSIS

ORTHOCLASE + PLAGIOCLASE	55.5
PHLOGOPITE	8.6
TREMOLITE	15.1
DIOPSIDE	12.6
QUARTZ	8.1
TOTAL	99.9

NIGGLI VALUES

Si	213
Al	20
Fm	26
C	38
ALK	16
K	0.69
Mg	0.73

Locality.

S. shore of Streamstown Bay, 300 yds. from the western end.

Analysts - E.J. Cobbing and W. Layton.

The same poverty of iron seen in No. 17 is again noted here and the corresponding deduction that the ferro-magnesian minerals are poor in iron is drawn.

The ground mass of these rocks is provided by a mixture of plagioclase and orthoclase with plagioclase dominant. This mixture is difficult to resolve, and generally the only possible way of distinguishing potash feldspar from plagioclase is by staining. The plagioclase is xenoblastic, in shapeless areas and may be twinned or untwinned. It is normally rather basic, An_{36} to An_{45}, but is generally extensively saussuritized, being filled with clouds of epidote and iridescent blue zoisite. In many places it includes diopside and tremolite. Potash feldspar has the same general characters as plagioclase and is intimately mixed with it, but is usually clear and fresh with little alteration. Very fine microcline twinning may be seen. Included minerals are diopside, tremolite and phlogopite.

Diopside is always idioblastic in stubby, prismatic, often slightly rounded crystals with no inclusions, dispersed in single crystals, or aggregated in clusters. Some rocks are almost entirely composed of diopside. As in the marbles it is occasionally fringed by fine tremolite. Sometimes there is intimate intergrowth of diopside and tremolite but neither mineral appears to be replacing the other. The diopside has been optically determined and found to be Salite Di 57.

Tremolite is idioblastic in stout crystals or small fibres radiating, convoluted and sometimes in parallel orientation,

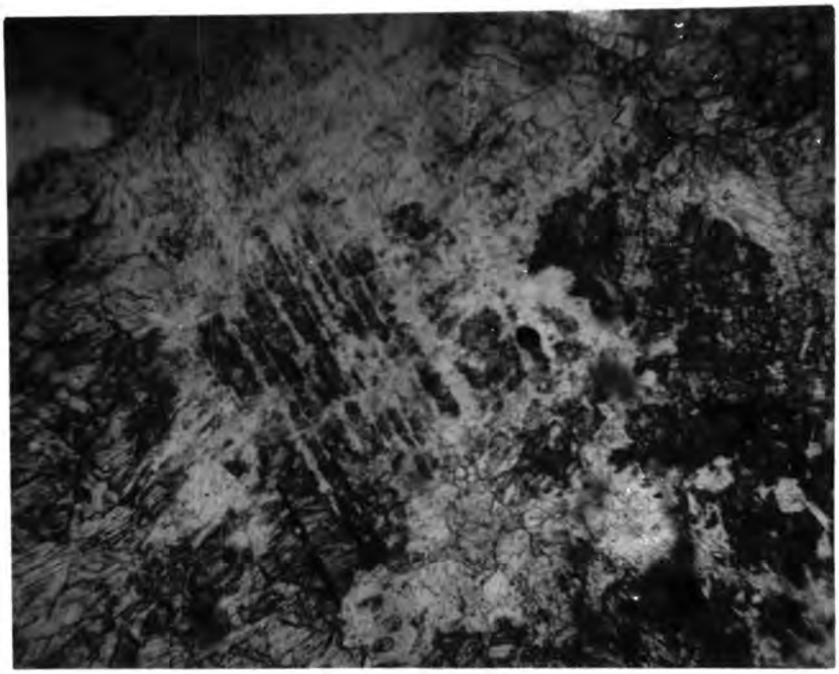


Plate 7. X 70. Calc-silicate granulite, ordinary light. Relic of diopside (dark grey) enclosed within and cut by lance like blades of tremolite.

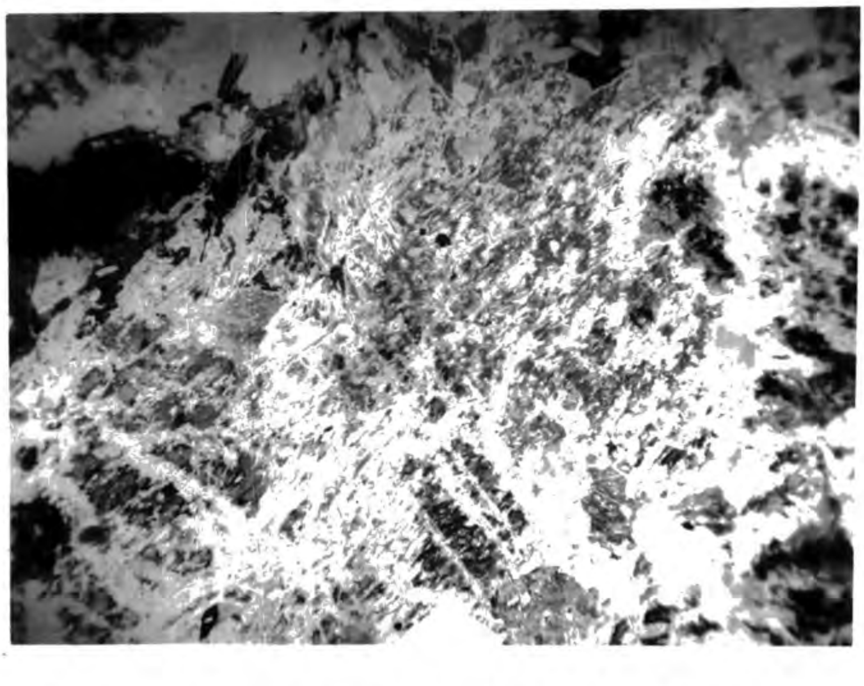


Plate 8. X 70. The same field as Plate 7 under crossed nicols.

with extinction angle Z - C 25°. The tremolite is again quite colourless and is possibly a fairly pure variety. Phlogopite is pleochroic, colourless to light brown, but in some examples the colour is rather deeper and these may be transitional to biotite. It may be dispersed or concentrated in rough foliae. Occasionally a light chloritization is seen. Quartz and calcite may be present either together or exclusive of the other in quantities up to 10%. Sphene is a constant accessory in small rounded crystals pleochroic in shades of light pink.

Opaque minerals present are generally pyrite in dispersed cubes.

Metamorphic Reactions In The Calc-Silicate Granulites.-

(a) High-grade reactions. These are the same as in the marbles, a rimming of the diopside by tremolite.

(b) Medium-grade reactions. Saussuritization of plagioclase is the chief manifestation of these with the production of zoisite, epidote and sericite together with other indeterminate minerals. This change is possibly on the border of medium and low grade changes.

(c) Low-grade reactions. The only reaction marked is the occasional slight chloritization of phlogopite.

The Striped Amphibolites.- These rocks form a very characteristic type, possibly of great stratigraphical importance in Connemara. They are composed of alternating dark and light bands parallel to the foliation which give the rock a pronounced stripey appearance, hence the name. The rock is composed of diopside-plagioclase stripes which are light in colour, sometimes with a slight greenish tinge, and hornblende-plagioclase stripes which are dark in colour, the hornblendes being in strong parallel orientation giving their stripes a pronounced lineation. The stripes are remarkably regular and do not seem to be microfolded which is unusual, for all other rocks, including the strongly banded ones, are intensely folded.

The striped amphibolites occur only on the Aughris Peninsula and are always associated with a siliceous granulite tending to appear on one side only of the band. This mode of occurrence is precisely similar to that observed elsewhere in Connemara. B.E. Leake has done 28 chemical analyses of striped amphibolites including one from the area now studied and has come to the conclusion that they are igneous rocks, the chemistry, particularly the trace elements being characteristic of basic rocks. If they are igneous rocks they could only be tuffs. This would account for the fact that they are banded and associated with a particular member of the sedimentary succession. They are therefore likely to be of prime geological importance in Connemara for there is a strong suggestion that there was only one phase of volcanic activity represented by only one tuff band, always associated with the same sedimentary member. Thus there is a possibility that the striped amphibolites will give a unique marker horizon, enabling the structure and stratigraphy to be worked out. In this account the striped amphibolites are grouped among the metasediments for convenience and because their main significance lies in this group.

TABLE VII

CHEMICAL ANALYSIS OF A STRIPED AMPHIBOLITE

SPECIMEN NO.	B.L. 2404
SiO_2	47.20
Al_2O_3	16.19
TiO_2	1.20
Fe_2O_3	2.71
FeO	10.35
MnO	0.33
MgO	8.12
CaO	7.94
Na_2O	3.60
K_2O	0.23
P_2O_5	0.04
H_2O	2.01
TOTAL	99.92

NIGGLI VALUES

Si	106
Al	21
Fm	52
C	19
ALK	8
K	0.25
Mg	0.53

No modal analysis was done on account of the strong banding of the rock.

Locality.

S.E. corner of Aughris Peninsula, 400 yds. W. of large porphyry dyke.

Analyst - B.E. Leake.

The rocks are best described in terms of stripes. The amphibolite stripes are composed largely of plagioclase and hornblende. The hornblende has been optically determined and found to be a Magnesio-hastingsite. α 1.6500, β 1.6600, γ 1.6670. Birefringence .0170. 2V 82°. It is pleochroic, light green - dark green - bluey green, Z > X > Y, Z - C 26° with a very strong parallel orientation. The amphibole is idioblastic with sharp crystal outlines and no inclusions. Plagioclase is of rather granular habit, quite clear and generally untwinned, but does occasionally show twinning. In composition it is An_{42}, a fairly basic plagioclase for this terrain. The plagioclase is quite fresh except where it adjoins the diopside-plagioclase stripes where it becomes saussuritized.

Sphene occurs as idioblastic crystals very frequently with a core of ilmenite. This conversion of ilmenite to sphene is a well-known reaction and it is of interest that we are here able to locate it just within the lowermost sillimanite isograd.

The diopside-plagioclase stripes are composed largely of plagioclase of exactly the same mode of occurrence as is seen in the calc-silicate granulites. It is always strongly saussuritized containing blebs of epidote and zoisite and it is impossible to determine the composition of the original feldspar. The contrast in condition of the feldspar between adjacent stripes is very striking. Diopside is evenly scattered in idioblastic stubby crystals usually colourless but occasionally with a tinge of green. It is similar in composition to that in the calc-silicate granulites; Salite Di 60. Sphene is not so prominent as in the amphibolite stripes but is occasionally present as euhedral crystals, usually rimming ilmenite.

The Metamorphic Reactions In The Striped Amphibolites.-

(a) High-grade reaction. The only reaction of note here is the partial conversion of ilmenite to sphene which we are here able to observe in the lower part of the sillimanite zone. Since the reaction is only partly completed it may be that the point of initiation is not far away and further workers may be able to fix this isograd relative to the sillimanite isograd should suitable rock types occur.

(b) Medium and low-grade changes. The saussuritization of feldspar in the diopside-plagioclase stripes is the only change of this nature. This is probably due to the fact that diopside has no water in the lattice whereas hornblende has up to 2%. As the temperature peak is reached and begins to fall there may be sufficient excess water in the diopside bearing stripes to react with the plagioclase whereas in the amphibolite stripes all the water is chemically bound. This is therefore recognised as a medium to low-grade retrograde metamorphic change.

Metasediments of the Thermal Metamorphism

The thermal metamorphism has been most carefully studied in the south west part of the Aughris Peninsula at the granite contact just opposite Omey Island because the exposure at this point is very much better than elsewhere around the granite. As can be seen from Map 6, the rocks of this area are disposed in an easterly plunging fold which closes to the west. The core of the fold is composed of the typical semi-pelite of the Aughris Peninsula; a rather gneissose rock with abundant garnet, staurolite and sillimanite, and is separated by a discontinuous band of calc-silicate-granulite from a rather atypical semi-pelite which contains orthoclase. This atypical semi-pelite has an intimate admixture of siliceous granulite which it is impossible to map separately. Thus at all points near the granite there is a potash-rich formation while at points away from the granite there is a potash-poor formation.

The isograds of the thermal metamorphism may be seen on Map 2. Where the dotted andalusite isograd crosses the potash-rich formation the dots are spaced widely apart. This is because the potash-rich formation shows very little sign of thermal alteration. In the field all the regional characters are preserved, even up to the edge of the granite, and there is no sign of the strong hornfelsing seen elsewhere. Very occasional crystals of andalusite can, however, be seen on a foliation plane, enabling the isograd to be drawn. The formation is strongly hornfelsed from the corner of the granite to the sea, but where it is again seen on the north shore of Streamstown Bay it is free of all marks of thermal metamorphism . This lack of response to thermal metamorphism is peculiar to this formation; other groups beyond it are affected, grossularite being developed in calc-silicate granulite just north west of Lough Nawarawaun. Clearly the formation was capable of conducting heat even if it was not itself affected by it. It must be confessed that this odd behaviour remains a puzzle and no satisfactory solution is offered. The suggestion that the granite may have an irregular sub-surface sending out subsidiary stocks is considered inadequate to meet the facts, for it remains true that at some points within two yards of an exposed granite contact the rocks show no sign of thermal metamorphism. It is suggested that the solution may lie in some form of structural control for it can be seen that within the formation which is responsive to thermal metamorphism the isograds tend to conform to the outline of the structure. This is considered to be based entirely on objective evidence for at the time that the isograds were mapped it was not realised that the structure existed. The precise nature of such a structural control is, however, difficult to imagine. Four types of rocks only are described for only these types come within the aureole of the granite.

<u>The Semi-Pelites</u>.- The first visible sign of change in the semi-pelites in the core of the structure is the development of disoriented biotite porphyroblasts. At first few, these

rapidly develop until a zone of spotted schist is produced. The regional texture is partly lost and a type of texture characteristic of hornfels is developed. Some of the regional characters of the rock are, however, preserved, and even enhanced. The lineations and microfolds are recrystallized and re-emphasised and this feature becomes progressively more striking towards the granite. Progressing through the spotted schist zone, garnet is seen to become less common and staurolite disappears entirely. Garnet can occasionally be seen to be crowded with biotite and the dark greasy look characteristic of cordierite is first seen here. With the appearance of andalusite there is a fairly rapid loss of the spotted character and true hornfelses are seen. Andalusite is ubiquitous, generally disoriented or radiating and sometimes in crystals up to 10 or 12 cm. in length. Garnet still occurs sporadically but is obviously much diminished in importance.

The changes in the orthoclase-bearing semi-pelite are essentially similar where any sign of hornfelsing is seen. Spotting by biotite porphyroblasts is sporadically developed but no true hornfels is seen until the corner of the granulite is reached. From this point onwards andalusite hornfelses are continuously present. Garnet and staurolite are in any case absent in this formation so no relict garnet is seen, andalusite being the only macroscopically important mineral present. This is very plentiful in stubby disoriented prisms studding the foliation planes of the rock. The recrystallization of the linear elements is again well developed. In Table VIII overleaf are chemical analyses of hornfels produced from both types of semi-pelite.

TABLE VIII

CHEMICAL AND MODAL ANALYSES OF THE SEMI-PELITIC HORNFELSES

SPECIMEN NO.	179	154	135
SiO_2	55.09	54.00	51.65
Al_2O_3	18.40	19.00	19.19
TiO_2	0.72	0.68	0.24
Fe_2O_3	2.29	2.25	1.89
FeO	5.10	5.20	7.50
MnO	0.08	0.04	0.05
MgO	2.37	1.62	2.53
CaO	4.41	5.02	3.35
Na_2O	2.20	2.70	2.16
K_2O	7.15	5.31	8.45
P_2O_5	0.17	0.20	0.35
H_2O	1.72	1.90	2.20
TOTAL	99.70	99.27	99.56
NIGGLI VALUES			
Si	171	175	173
Al	34	37	38
Fm	29	27	25
C	16	17	12
ALK	21	19	25
K	0.68	0.56	0.72
Mg	0.37	0.28	0.49
MODAL ANALYSES			
QUARTZ	16.1	11.9	4.5
PLAGIOCLASE	30.7	29.4	29.2
ORTHOCLASE			1.8
MUSCOVITE	20.6	24.3	14.6
BIOTITE	26.0	23.1	42.1
ANDALUSITE		1.5	4.4
CORDIERITE	4.3	4.2	3.2
GARNET	1.8	4.8	
OPAQUE	0.1	0.7	0.1
TOTAL	99.6	99.9	99.9

Analysts - E.J. Cobbing and W. Layton.

Plate 9. Eastward plunging structures preserved in hornfelsed calc-silicate granulite and semi-pelite.

Plate 10. X 70. Hornfelsed semi-pelite. Andalusite with pleochroic rose pink central area (dark grey) bordered by clear orthoclase. Muscovite and biotite form the remainder of the field.

The localities are shown on Map 2 and on Map 6; Nos. 179 and 154 are from the orthoclase-free band while No. 135 is from the orthoclase-bearing band. No. 169 described with the regional semi-pelites is an example of a non-hornfelsed semi-pelite from this band. The analyses are very similar, the main difference being the much higher potash in No. 135. The chief contrast in mineralogy is the presence of orthoclase in No. 135 and the absence of garnet while in the other two rocks the reverse is the case.

In general quartz retains its regional disposition, being segregated in lenses and ribs but recrystallized into equidimensional crystals. It is frequently poikiloblastically enclosed in plagioclase as rounded blebs. The plagioclase itself shows a greater tendency towards a decussate texture and many poikiloblasts grow across the foliation enclosing other minerals, chiefly micas and quartz. Twinning in the plagioclase is more prevalent in the hornfelses than in the regional rocks. The composition varies from An_{27} to An_{36} the most common value being An_{32}. Orthoclase when present is associated with plagioclase in xenoblastic irregular crystals frequently bordering quartz lenses. Very occasionally signs of microcline cross-hatching are present. The mineral is generally clear and fresh but slight alteration is sometimes seen.

Biotite during thermal metamorphism gradually lost its parallel orientation and small crystals began to grow across the foliation, increasing in size and abundance with advancing grade. The original regional orientation is not, however, completely lost even in the higher grades. In the orthoclase-free rocks the biotite is always brown, acquiring a slightly reddish tinge on hornfelsing. In the orthoclase-bearing band the biotite is green or browny green and it remains this colour in the high grades. Hall (1941) showed that the colour of biotites was due to the relative concentration of TiO_2, those with more titania being brown and those with less green. The present biotites have not been analysed so it is impossible to confirm this, but the titania in the rocks seems to show no significant variation. Biotite is occasionally replaced by chlorite but more often by cordierite which makes semi-circular teeth-like embayments into it and in other cases replaces it along cleavages.

Muscovite is intergrown with biotite in the regional foliation and, like it, first responds to the hornfelsing by the growth of small elongate crystals across the foliation. With increasing grade, large ragged porphyroblasts appear also cutting the foliation and the muscovite in the muscovite biotite intergrowth recrystallizes to a fine granular mass. It is generally in these granular masses of muscovite that andalusite develops as sieve-like poikiloblasts enclosing quantities of muscovite. This association of andalusite and muscovite is extremely common but in the higher grades stout crystals of andalusite may be found which are quite free of inclusions. These are pleochroic in rose pink $X > Y > Z$.

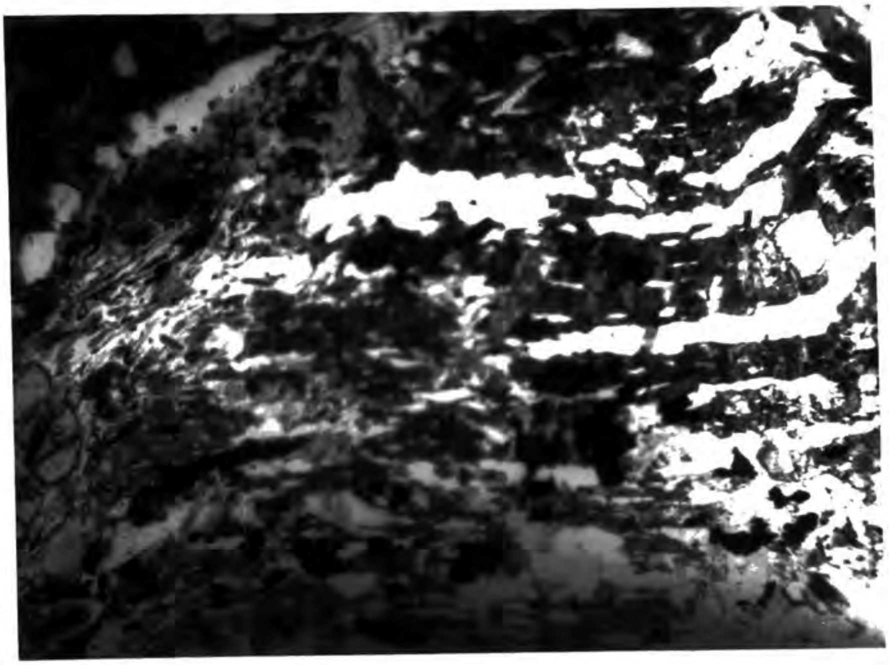


Plate 11. X 70. Hornfelsed semi-pelite. Garnet with sigmoidal inclusions of quartz. The garnet is replaced partly by disoriented biotite and partly by cordierite.

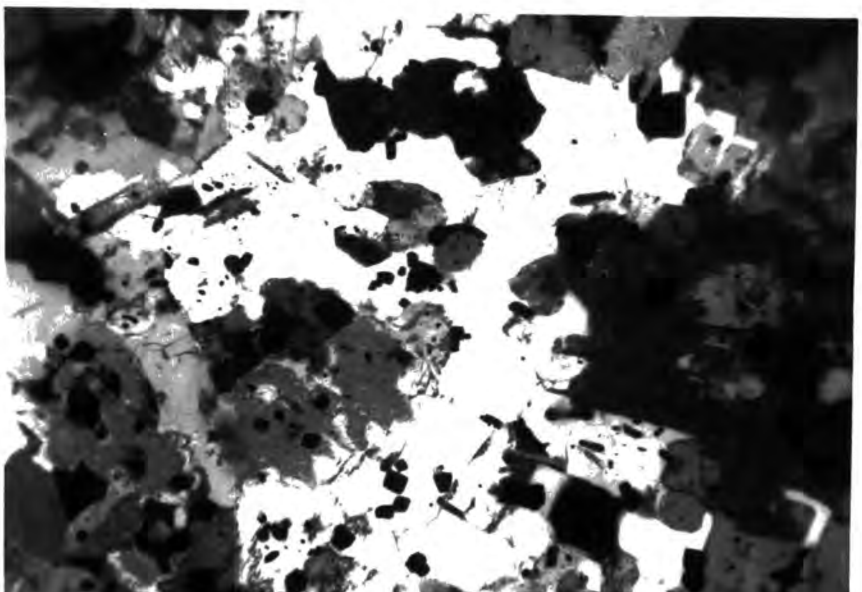


Plate 12. X 70. Hornfelsed semi-pelite. Euhedral crystals of cordierite with magnetite inclusions (grey) enclosed in quartz (white).

Garnet is unstable in the hornfelses and is progressively attacked first by biotite and later by cordierite and is generally present as groups of relics set within the replacing minerals. Cordierite appears after the recrystallization of biotite for biotite which has attacked garnet is itself corroded by cordierite. It replaces biotite, garnet and staurolite and frequently forms an indeterminate base in which other minerals are set. Poikiloblasts are common, very often perfectly round in shape and set with numerous inclusions. In some cases, these large crystals press out the surrounding micas in the same way as garnets do in the regional rocks. Cordierite is frequently pinitized to a yellow structureless mass occasionally set with small birefringent fibres. Cordierite may occasionally be detected in thin section beyond the biotite porphyroblast isograd shown on Map 2. In these cases it is replacing biotite. This is so sporadic as to be of little importance in drawing the isograds which are primarily field boundaries.

The opaque mineral may be pyrite, ilmenite or magnetite and is often well crystallized.

Metamorphic Reactions in the Semi-Pelitic Hornfelses.-

(a) High-grade reactions. These were numerous in this group of rocks and, apart from recrystallization, were involved in the production of andalusite and cordierite. Andalusite is formed by reaction from muscovite while cordierite is formed by reaction from biotite, garnet and staurolite.

Plate 13. X 70. Cordierite hornfels from the zone of spotted schist. Irregular porphyroblast of cordierite (black) with sericite inclusions. The crystal has grown in a dense cluster of sericite produced by retrogression of staurolite.

Plate 14. Calc-silicate hornfels. Grossularite and wollastonite (white) set in a matrix of diopside (pale grey).

(b) Medium-grade changes. The first attack of garnet by biotite may be grouped in this class. It was one of the first reactions produced by the granite emplacement. As the heat gradually built up it was in turn replaced by the formation of cordierite.

(c) Low-grade changes. The sporadic chloritization of biotite is the only one of these changes seen.

Siliceous Granulites.- There is little macroscopic change in this group of rocks apart from the recrystallization and consequent enhancement of the fabric. The original granulosity of texture is increased and a hard rock breaking with a conchoidal fracture is produced.

Microscopically the same is true. Quartz has recrystallized losing its tabular elongation and becoming equigranular; similarly plagioclase ovoids have disappeared being replaced by granular aggregates, very frequently twinned. Biotite tends to behave in the same way as in the semi-pelites, first a few small crystals grew across the foliation increasing in number and size with increasing grade. Frequently an original regional folia will be pseudomorphed by a matt of crystals growing at right angles. Muscovite is likewise affected though the last mentioned feature has not been noted. Neither andalusite nor cordierite are present in the siliceous granulites.

There are no reactions involved in the hornfelsing, only recrystallization.

Calc-Silicate Granulites.- These rocks are disposed in a series of lenticular bodies at the margin between the orthoclase-bearing and orthoclase-free semi-pelites. They occur often in very intimate association with the semi-pelite, frequently being down to the scale of an inch or so in width. Within the zone of biotite porphyroblasts the rock is always strongly hornfelsed, but this condition disappears rapidly beyond the zone, the only apparent difference from normal calc-silicate granulite being a rather powdery appearance due to extensive alteration of the feldspar. On the south side of Streamstown Bay at the extreme tip of the small peninsula, a slight development of hornfelsing in the calc-silicate granulite is seen, only visible at low tide. The mica-rich bands in the granulite are seen to pass into grossularite-idocrase bands in the hornfels while the feldspar-tremolite-diopside bands become feldspar-diopside bands.

The hornfelses themselves are very spectacular and are of very varied mineralogy; a frequent type is a fine grained calc-flinta rock in which masses of green diopside are set in a ground mass of feldspar. More strikingly, grossularite, idocrase and wollastonite are developed in varying proportions. Grossularite is frequently developed to the exclusion of all other minerals and on the well exposed coastal section may be commonly found in crystals up to 5cm. in diameter.

Idocrase is generally associated with grossularite but may be found by itself, occurring in lustrous brown crystals of beautiful shape. Cavities are frequently developed in these rocks, showing that they must have recrystallized under no great confining pressure and in these cavities well-shaped crystals of garnet and idocrase are found. A green variety of idocrase is seen in the core of the major anticline at Barnahallia Lough. Wollastonite is developed as a dead white mass of radiating fibres generally associated with grossularite. Common associations are:

Grossularite.

Grossularite wollastonite calcite ± diopside.

Grossularite idocrase diopside feldspar + accessory sphene.

Diopside feldspar + accessory sphene.

In thin section grossularite is frequently seen to be birefringent though not always so, and generally including large numbers of other minerals particularly diopside and plagioclase. Idocrase is idioblastic frequently in single crystals in association with idioblastic grossularite. There is no sign of zoning in the idocrase and in ordinary light it is an even brown colour. Wollastonite is in close packed masses of radiating fibres deeply penetrating grossularite and frequently set with small diopsides. The diopside is idioblastic in small prismatic crystals but is often in small rounded crystals. It is generally evenly dispersed and is included in plagioclase and grossularite and dispersed through masses of wollastonite. It has been optically determined and is a Salite Di 55 of similar composition to that found in the calc-silicate granulite and the striped amphibolite. Orthoclase is xenoblastic, interstitial to other minerals, clear and unaltered, mixed with

Plate 15. Calc-silicate hornfels. Grossularite and wollastonite lying as bands in a matrix of black calcite and diopside.

Plate 16. Segregation of plagioclase in massive amphibolite showing pinch and swell structure and packing up of amphibole at the margin of the vein.

plagioclase which is idioblastic, sometimes twinned but generally not and frequently clouded and heavily charged with black powdery material. The clouding is almost certainly implicit saussuritization.

Sphene is fairly ubiquitous in some types and is seen as rather shapeless rounded crystals often pleochroic in light shades of pink.

Unfortunately insufficient sections were made to trace the sequence of changes from unhornfelsed to hornfelsed types. The change can be seen in the field to be very abrupt in any case and where the formations are discontinuous as is the case in the Aughris Peninsula, it is often impossible to obtain specimens from the desired position.

The Marbles.- These are of very subsidiary importance occurring as tiny lenses within the calc-silicate granulites. The calcite is very often dark grey or black in colour, presumably due to finely disseminated carbon though no trace of this is seen in thin section. The accessory minerals are grossularite and green idocrase with very occasional plagioclase and diopside.

The Metamorphosed Igneous Rocks

The Massive Amphibolites.- The massive amphibolites occur as lenses and discontinuous bodies, in some instances of considerable size, on the Ballymaconry Peninsula only. They are found principally at one horizon, the northern side of the main central quartzite and are to be seen irregularly disposed along its length. At the western end of the quartzite two major bodies are found, one just over the other, just under a mile in length and up to 220 feet thick. They are massive in structure with little sign of the intense microfolding seen in other formations. Hornblendes are dark green or black and are commonly lineated but not sufficiently to give the rock a dominantly linear structure. A very rough indefinite foliation is present. Feldspar is dispersed through the rock as small, white weathering granules and also as large porphyroblasts frequently parallel to the foliation, but not always so. Segregation veins are common and these are generally parallel to the foliation. They are composed of plagioclase showing pinch and swell structure while the rock on either side of the vein is very dark being almost entirely composed of very coarse amphibole. The whole impression is of a redistribution of material, salic material being concentrated within the vein and femic material on the margin. The rock in general is massive and gneissic in character. Table IX overleaf is an analysis of a typical example.

TABLE IX

CHEMICAL AND MODAL ANALYSES OF MASSIVE AMPHIBOLITE

SPECIMEN NO.	51
SiO_2	46.60
Al_2O_3	14.60
TiO_2	1.90
Fe_2O_3	1.81
FeO	7.40
MnO	0.12
MgO	7.09
CaO	15.45
Na_2O	2.23
K_2O	2.65
P_2O_5	0.45
H_2O	0.91
TOTAL	100.61

MODAL ANALYSIS

PLAGIOCLASE	40.2
HORNBLENDE	54.4
SPHENE	5.4
TOTAL	100.0

NIGGLI VALUES

Si	98
Al	18
Fm	39
C	35
ALK	8
K	0.43
Mg	0.57

Analysts - E.J. Cobbing and W. Layton.

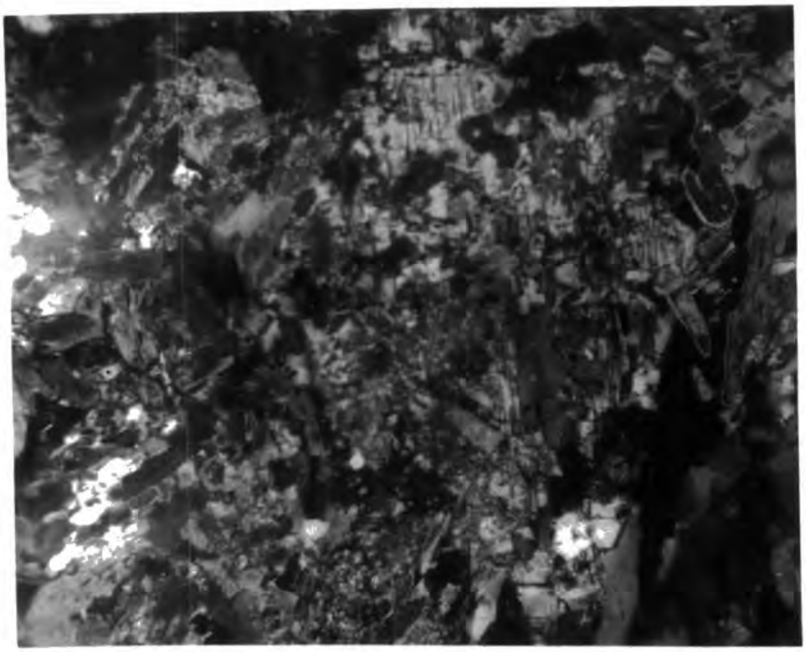


Plate 17. Twinned plagioclase porphyroblast in massive amphibolite. Possibly a relic of primary igneous ophitic texture. Inclusions of sphene and hornblende within the feldspar.

Hornblende has been optically determined from three rocks and found to be Magnesio-hastingsite α 1.6570, β 1.6630, γ 1.6720. Birefringence .0173. 2V 80. It is in idioblastic prismatic crystals pleochroic from light green to dark olive green Z > X > Y. Extinction angle Z - C 15 - 20°. There are no inclusions and the crystals are oriented though poorly so. In some sections there is an indication of two generations of hornblende with large irregular crystals enclosing small euhedral ones, both generations being of the same colour and extinction angle. Plagioclase is quite clearly present in two generations. The base is of granular untwinned plagioclase generally clear but sometimes cloudy, the composition being An_{30} to An_{36}. In addition to this there are large crystals very reminiscent of igneous phenocrysts. These are usually twinned but the twinning is interrupted by numerous inclusions of clear feldspar of the groundmass and sometimes small hornblendes. This may be a relict ophitic texture. In some instances small blebs of quartz are exsolved. These large crystals are sometimes saussuritized with numerous flecks of zoisite and epidote but this saussuritization is patchy in development. Some of these rocks have been found to have plagioclases of An_{32} and An_{58}, the latter value being middle labradorite and strongly suggesting an igneous origin. Plagioclases from the segregation veins have a composition of An_{30} which agrees well with the regional values of the other rocks.

Sphene is dispersed in idiomorphic crystals and along the main outcrop of the amphibolites there is no trace of relict ilmenite at all, but from a small amphibolite lens within the quartzite on the north side of the Ballymaconry Peninsula small ilmenite cores were observed within the sphenes. The isograd for the completion of this reaction must run somewhere between these not very widely separated points.

Metamorphic Reactions In The Massive Amphibolites.-

(a) High-grade reactions. The only high-grade reaction is the development of sphene from ilmenite, the significance of which has already been noted (page 44).

(b) Medium and low-grade reactions. Saussuritization of plagioclase is the only retrograde reaction seen.

This group is recognised to be composed of meta-dolerites on several lines of evidence. The presence of large angular plagioclase porphyroblasts gives a texture extremely like that of a porphyritic igneous rock. The appearance of these in thin section tends to confirm the impression as does the presence of labradorite An_{58}. The chemical analysis is very suggestive of an olivine-basalt type. The calcium is very high but it is thought that this may be due to the method used. In the procedure of Shapiro and Brannock (1956) alumina and iron are liable to interfere in the titration thus giving a high value. (Personal communication B.E. Leake). If this is taken into account, then very favourable comparison may be made with olivine-basalts and certain of the alkali differentiates. (Turner and Verhoogen, 1952, pages 127, 134, 137, 144, 150, 153, 157, 159, 193.)

<u>The Granite Sills and Dykes</u>.- A series of synkinematic sills and dykes parallel to the regional foliation of granitic composition and of foliated character are to be found on the Ballymaconry Peninsula. They are generally thin, rarely more than 5 or 6 feet thick, and frequently less. They occasionally transgress the foliation for short distances but this tendency is usually quickly corrected. They can rarely be followed for any distance. In some cases the rocks adjacent to the sills seem to be impregnated with muscovite. The sills themselves are strongly foliated, micas in particular being oriented to give a fairly strong lineation.

Quartz is allotriomorphic, interstitial in character and shows undulose extinction while plagioclase which is idiomorphic is generally strongly sericitized. Some unaltered relics remain and composition is found to be An_{10}. Orthoclase is in allotriomorphic interstitial crystals which often show perthitic development. Biotite is dark brown, dispersed in idiomorphic oriented crystals and is generally strongly chloritised while some crystals show slight fibrolitization at the margins. A little accessory apatite is present together with orthite.

The fact that the dykes are foliated together with the slight fibrolitization of the biotite suggests that the granite sills were intruded at the peak of the metamorphism or in the early stages of decline. Associated with the granite sills, there are extremely coarse pegmatites which show no sign of foliation whatever. They are obviously coeval with the granite sills for in the Lough Animma district a granite is seen to pass directly into a pegmatite. It is thought that the extreme coarseness of the pegmatites has enabled them to resist deformation. Some orthoclase crystals are up to 12 inches in length. The pegmatites are basically composed of orthoclase perthite and quartz in coarse graphic intergrowth, with both biotite and muscovite in books of an inch or so in size. These bodies tend to be more persistent than the granites and of slightly larger dimensions. One in particular south of Lough Animma may be traced along the edge of a calc-silicate band which it alters in no way whatever for 500 yards.

The High-Grade Reactions in the Metamorphic Rocks.

In the regional and thermal metamorphism a number of high-grade changes have been noted.

(a) Conversion of biotite to sillimanite.

(b) Conversion of muscovite to sillimanite.

(c) Conversion of staurolite to sillimanite.

(d) Conversion of muscovite to andalusite.

(e) Conversion of garnet to biotite.

(f) Conversion of garnet to cordierite.

(g) Conversion of biotite to cordierite.

Only in the cases of (c) and (f) can chemical equivalence be said to have been reasonably maintained during the reaction. All the other reactions involve mica and the access or departure of potash and water. Various writers have described reactions indicating that excess water is driven off and excess potash converted into orthoclase (Francis 1956).

MUSCOVITE + QUARTZ = ORTHOCLASE + ANDALUSITE + WATER

MUSCOVITE + QUARTZ = ORTHOCLASE + SILLIMANITE + WATER

BIOTITE + QUARTZ = ORTHOCLASE + SILLIMANITE + MAGNETITE + WATER

Thus in all cases an association of orthoclase + aluminium silicate is the product of the reaction and this is certainly found to be the case in many regions. In the area studied however this is not the case for orthoclase cannot be found at or near the site of the observed evidence of reaction or indeed in the rock at all in many instances. This point has been proved by the use of sodium cobaltinitrite. It is clear from the literature that this condition is by no means unique (Tozer 1955, Francis 1956).

Since the excess potash does not enter into a recognisable phase it may be suggested that it migrates from the site of reaction in company with water. This is an interesting possibility and many geologists would undoubtedly be glad of such a source of universal potash.

The converse of the above argument applies in the case of (e) where an addition of potash and water is necessary to effect the reaction. In this case a migrant source of potash and water is very welcome. Similarly for many of the reactions of retrograde metamorphism the addition of potash and water is required.

It is felt that the only answer to this problem is a very carefully controlled chemical investigation. Such analyses as have been done during the present project indicate no difference in water and potash-content between the staurolite zone and the sillimanite zone and thus seem to offer evidence against the migration of these oxides due to the above metamorphic reactions.

CHAPTER III

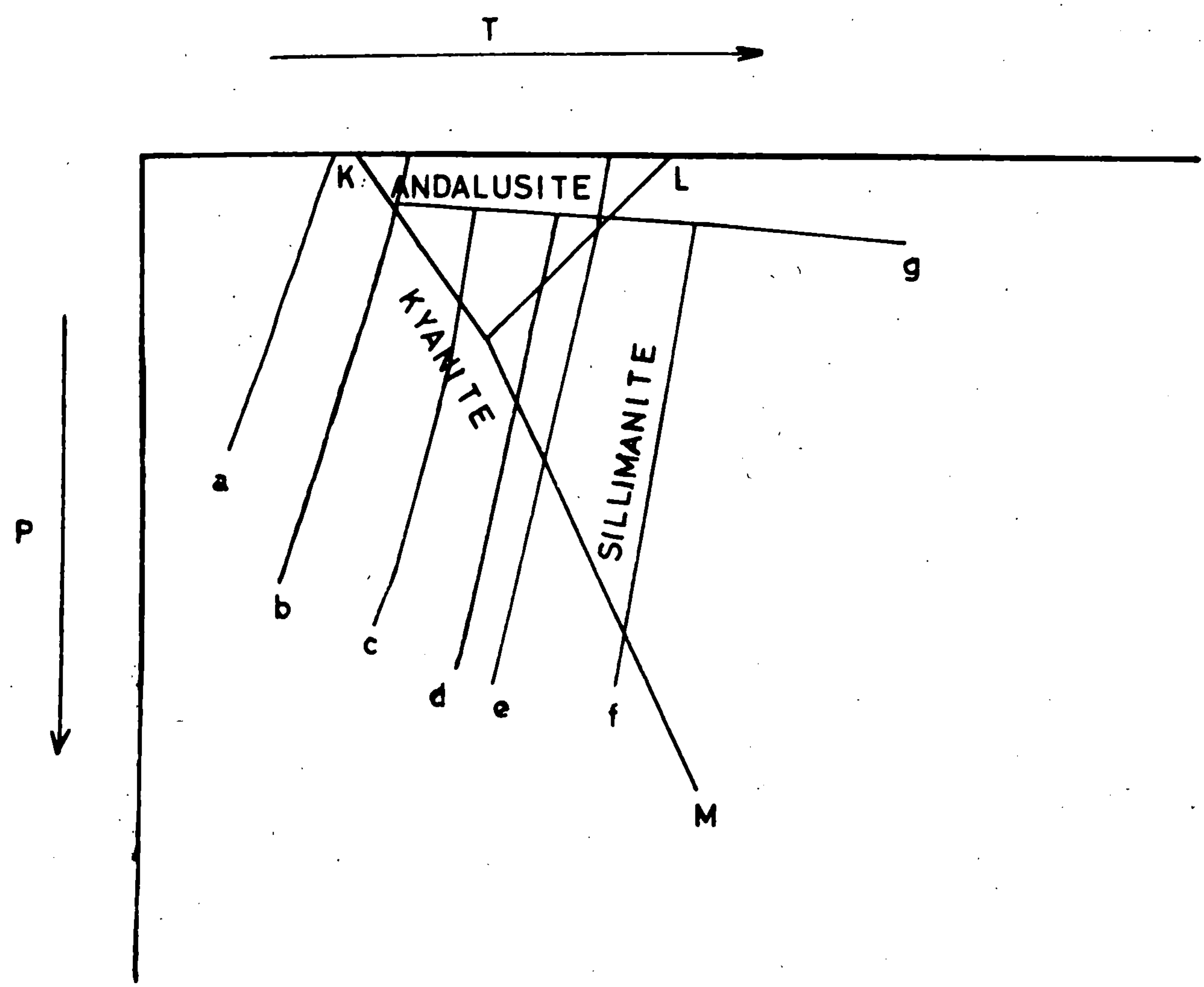
THE METAMORPHIC ZONES AND FACIES

COMPARISON OF THE REGIONAL METAMORPHIC ZONES IN CONNEMARA WITH THE BARROVIAN ZONES.

A complete series of metamorphic zones is not seen in Connemara as rocks of only staurolite or possibly garnet grades upwards are exposed. The zones seen are in contrast with Barrow's type sequence in the Scottish Highlands (1893 and 1912), for the kyanite zone is not present. The sequence is staurolite - sillimanite + staurolite - sillimanite as opposed to the Barrovian case of staurolite - kyanite - sillimanite. It can be seen from Map 2 that the only occurrences of kyanite are within the sillimanite + staurolite zone.

It has been long known that the Barrovian zones are of general but not universal application, the best known exception being the cordierite - andalusite gneisses of Banffshire. The area which agrees most closely with the present case is New Hampshire (Billings, 1941). Here however the analogy is not complete for the rocks are at least bi-metamorphic. Until recently these variations in mineral assemblage have not been well understood but now, following the work of Myashiro (1949), Thompson (1955) and Francis (1956), it has become possible to make tentative correlations. In Fig. 1. a, b, c, d, e and f mark the thermodynamically plotted curves of a series of dehydration reactions in pelitic rocks which correspond to Barrow's zones.

FIG 1



DISPOSITION OF THE METAMORPHIC ZONES IN A PRESSURE-TEMPERATURE FIELD

(AFTER G.H.FRANCIS 1956)

a. MUSCOVITE + FERROMAGNESIAN CHLORITE = BIOTITE + ALUMINOUS CHLORITE + WATER.

The curve defines the upper limit of the chlorite zone.

b. FERROMAGNESIAN CHLORITE + QUARTZ = ALMANDINE + WATER.

The curve defines the upper limit of the biotite zone.

c. GENERATION OF STAUROLITE FROM CHLORITOID.

The curve defines the upper limit of the almandine zone.

d. STAUROLITE + QUARTZ = ALMANDINE + SILLIMANITE (kyanite, andalusite) + WATER.

The curve defines the upper limit of the staurolite zone.

e. MUSCOVITE + QUARTZ = POTASH FELDSPAR + SILLIMANITE + WATER.

The curve defines the upper limit of the kyanite zone.

f. BIOTITE + MUSCOVITE + QUARTZ = POTASH FELDSPAR + ALMANDINE + WATER.

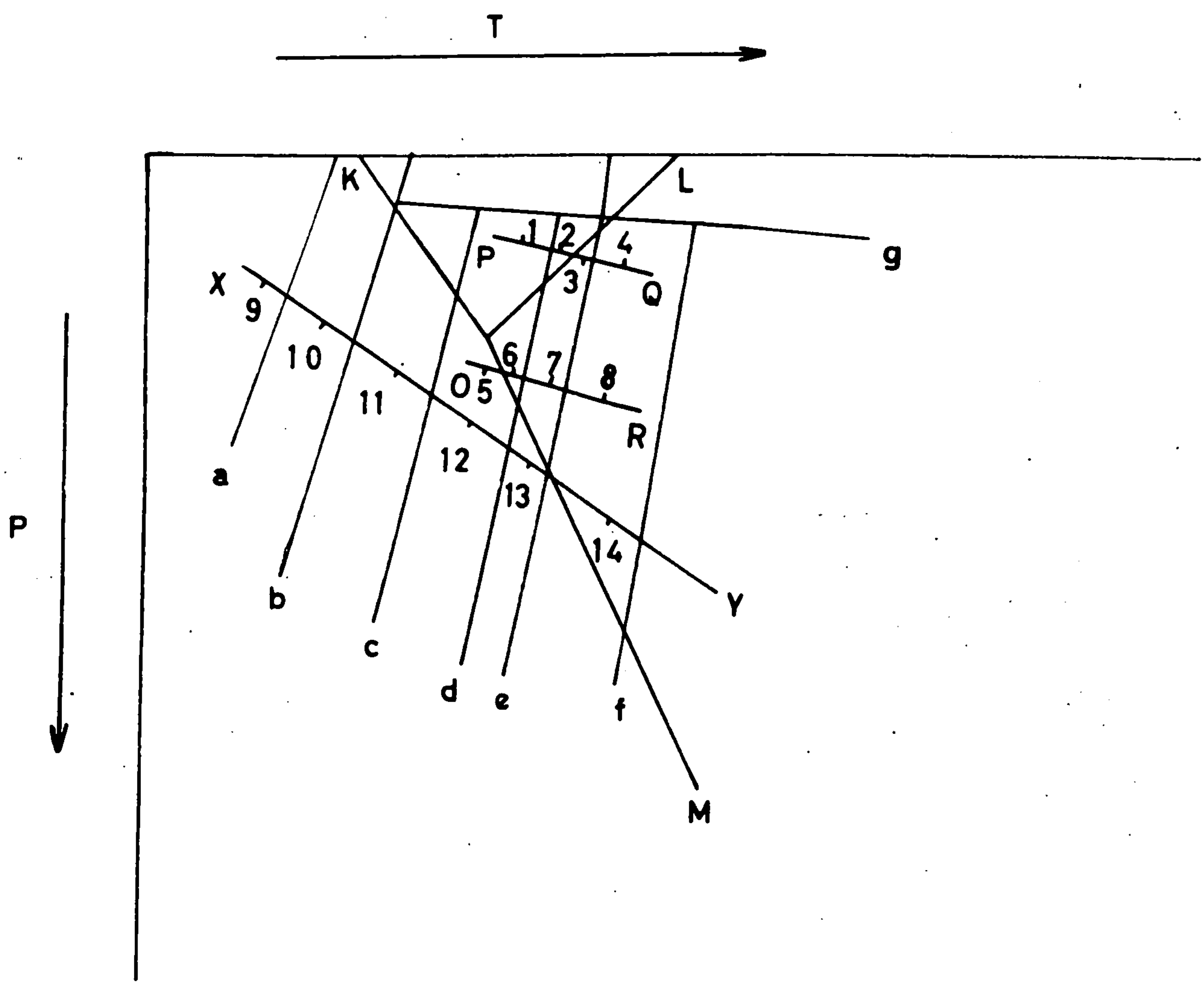
The curve defines the upper limit of the sillimanite zone and the lower limit of the granulite facies.

g. This curve delimits the field of cordierite.

The lines KLM are the stability fields of the aluminium silicate minerals. These cross obliquely the curves of the reactions and this may be the cause of much variation e.g. a reaction along curve d. may at various points result in the associations andalusite - muscovite, sillimanite - muscovite or kyanite - muscovite.

In Fig. 2 the rocks of Banffshire, Connemara and the Grampians are plotted on the graph according to their parageneses:-

FIG 2



LOCATION OF METAMORPHIC SERIES FROM BANFFSHIRE (P-Q), CONNEMARA (O-R) AND THE GRAMPIAN HIGHLANDS (X-Y) WITHIN A PRESSURE-TEMPERATURE FIELD

P.Q. Banffshire.

1. andalusite - staurolite.
2. andalusite - muscovite.
3. sillimanite - muscovite.
4. sillimanite - potash feldspar.

O.R. Connemara.

5. staurolite.
6. staurolite - sillimanite.
7. sillimanite muscovite.
8. sillimanite - potash feldspar.

X.Y. Grampian Highlands.

9. chlorite.
10. biotite.
11. almandine.
12. staurolite.
13. kyanite - muscovite.
14. sillimanite - potash feldspar.

In this graph we see that the parageneses of the rocks are accounted for by the differences in the pressure-temperature conditions under which they were formed; thus if a wide kyanite - muscovite zone is seen, as in the Grampians, metamorphism must have taken place at greater pressure than if such a zone is thin or absent. In this connection, the puzzling parageneses of the Banffshire coast are readily explained, Harker's original notion (1932) of metamorphism under deficient shearing stress being remarkably near the truth.

The field of the Connemara metamorphism is fairly near the aluminosilicate invariant point and it is now becoming clear that rocks from many different regions plot in a similar pressure-temperature field. (cf. Hietanen (1956), Streckeisen (1928), Billings (1941).) It may be objected that on the line representing the Connemara metamorphism it is quite possible for kyanite to form on the kyanite side of the aluminosilicate stability curve giving way to sillimanite on crossing the line. This is quite true and it is suggested that this is also the case in Dutchess County. (Balk and Barth, 1936). However, a similar argument may be advances for every point within the staurolite field that crosses the aluminosilicate line. Since kyanite does not occur it is suggested that the reason may be a chemical one; the ratio of combined iron and magnesia/alumina being too high to permit the existence of kyanite as well as staurolite until reaction d. has been initiated (Clifford, 1958). The sporadic occurrence of kyanite within the sillimanite zone does indicate close proximity to the conditions represented by the aluminosilicate stability curve. It is significant that kyanite occurs mainly in the segregation veins which are not only the areas of the greatest chemical activity but may also be subject to local fluctuations in pressure due to the presence of pore fluids in greater abundance. As sillimanite is forming from biotite and is being concentrated in veinlets it would need very little change in the physical conditions for the stability line to be crossed locally and for kyanite to crystallize instead. All these factors together reinforce the conclusion that the line representing the Connemara metamorphism is fairly accurately placed on Fig. 2.

DISCUSSION OF THE LOWER BOUNDARY OF THE AMPHIBOLITE FACIES.

Metamorphic facies were intended by Eskola (1915) to describe all rocks within certain pressure-temperature fields. Pelitic or semi-pelitic rocks are fairly easy to work with as they seem to have reacted very vigorously to advancing grade of metamorphism giving rise to the zones described by Barrow. The problem is to extend these zones into other less reactive rocks such as quartzo-feldspathic gneisses which in some cases are the dominant unit in a metamorphic terrain.

Eskola defined his facies system with reference to the hornblendic rocks of Orijarvi and as a result the subject has been saddled with an unsuitable nomenclature. Eskola's terms were greenschist facies, epidote-amphibolite facies, amphibolite facies, granulite facies. The strongest argument against these terms is that they do not accurately define anything; epidote for example may be found in hornblendic rocks of all facies. In recent years there have been attempts to define the epidote-amphibolite/amphibolite boundary in terms of the stable feldspar present and there can be no doubt that this is a soundly based idea. At present however there are two schools of thought on the subject. Turner (1948 - 1951) has redefined the epidote-amphibolite facies as the albite-epidote-amphibolite facies, while Ramberg (1952) and Barth (1952) define it as covering amphibolites in which the stable feldspar is more sodic than An_{30}. Thus there is a considerable gap between the two systems. In Turner's system the facies corresponds roughly with the garnet zone of Barrow while with Ramberg and Barth it is equivalent to the garnet + staurolite + kyanite zones; the base of the amphibolite facies being in the one case the staurolite zone and in the other the sillimanite zone.

Ramberg laid great stress on two points when fixing An_{30} as a suitable boundary:

(1) That staurolite-bearing and associated rocks always had a feldspar composition more sodic than An_{30}.

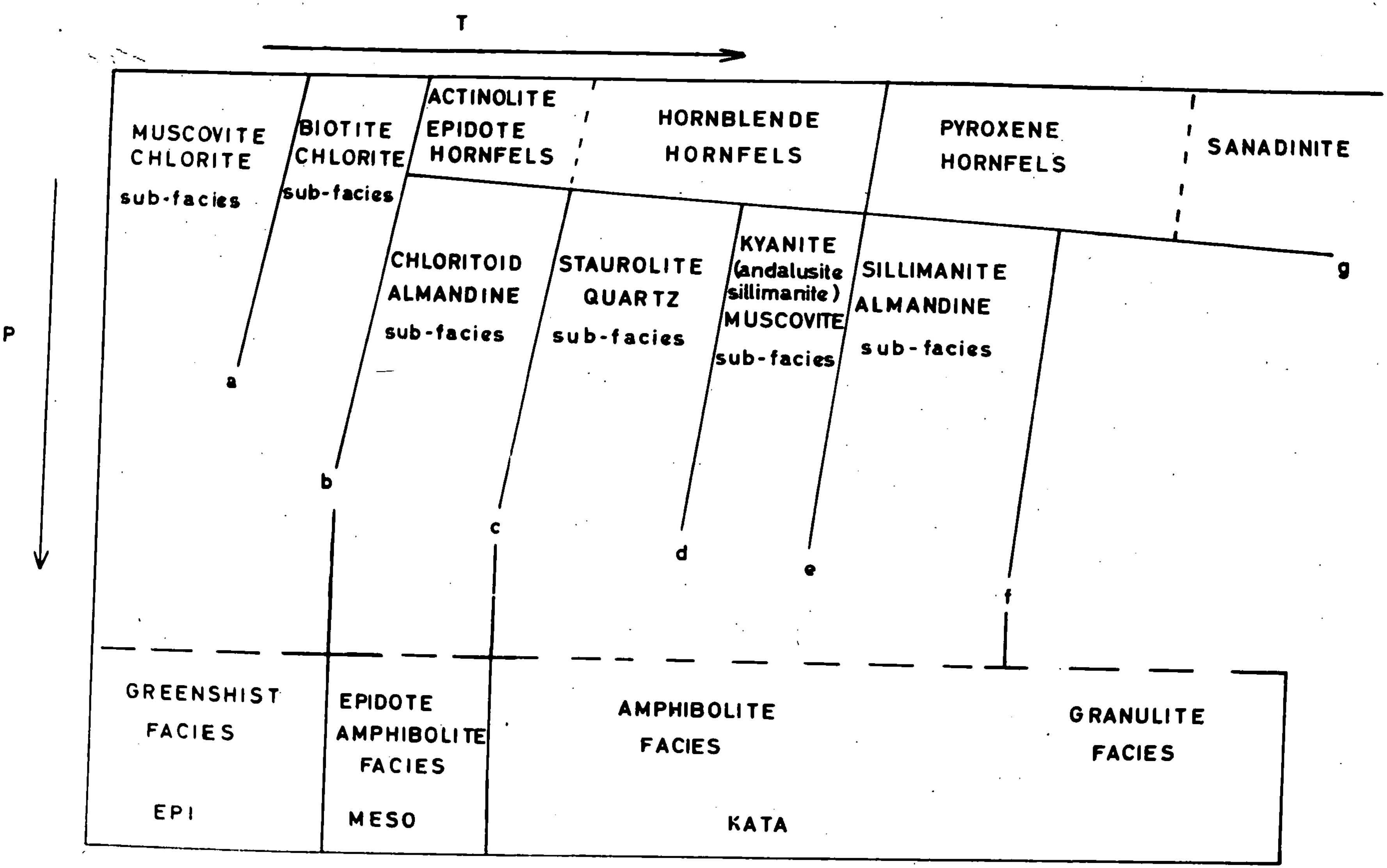
(2) That the conversion of tremolite to diopside takes place under the same pressure-temperature conditions that stabilize plagioclase of composition An_{30}.

During the present study it has been shown that the average stable plagioclase over the whole area from staurolite zone to sillimanite zone over a distance across the isograds of some 4 miles is plagioclase An_{30}. It has also been shown that diopside is stable in marbles which are isograde with staurolite-bearing rocks and that there is no evidence of its development from tremolite. In this case then Ramberg's argument does not hold.

It appears therefore that the stability field of plagioclase An_{30} is quite unsuitable for use in defining this important boundary and it is here proposed to follow Turner.

It is felt that there is a great need for defining this boundary in an accurate and useful manner and in particular the work of Kennedy and Read in the Highlands may be of some interest here. Read (1931) described a zone of veins in the higher grades of metamorphism which he then regarded as being connected with migmatization and granitization while Kennedy (1948) correlated non-injected rocks with the garnet zone and injected rocks with the kyanite and sillimanite zones. They thus recognise an important break in metamorphic style marked by the incoming of quartz and quartzo feldspathic veinlets frequently ptygmatically folded. It is considered that this veining is due to metamorphic segregation and differentiation which probably begins to operate under fairly universal pressure-temperature conditions and should be of universal application. Should this prove to be the case it is suggested that the epidote-amphibolite/amphibolite facies boundary be drawn at this point. Should this prove not to be the case then it is considered that Turner's present definition should stand and that in pelitic rocks the upper limit of the garnet zone should be the defining boundary. The rocks of Connemara are within the zone of veins and also Turner's definition and are therefore considered to be of amphibolite facies.

FIG 3



CORRELATION OF METAMORPHIC FACIES WITH METAMORPHIC ZONES

Finally it is recommended that the terms greenschist, epidote-amphibolite and amphibolite facies be superseded by the terms epi-facies, meso-facies, kata-facies proposed by Niggli (1924) which eliminate the disadvantages of having universal boundaries defined in terms of a particular rock type.

A CORRELATION OF METAMORPHIC ZONES AND FACIES

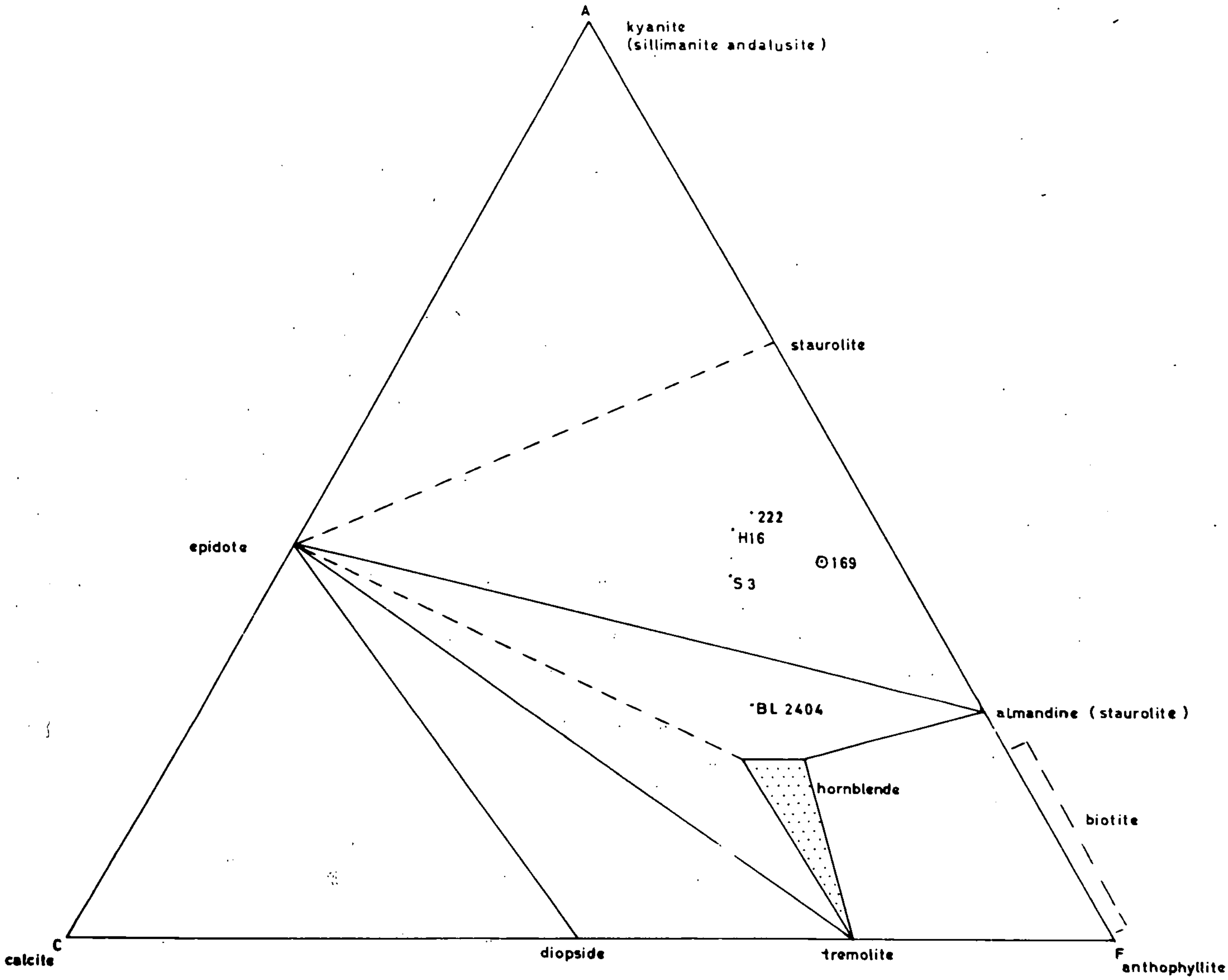
The reactions of Fig. 1. can now be correlated to give an integration of zones and facies and the result is seen in Fig. 3. The reactions which divide the pelitic rocks into zones are used to define sub-facies within the major facies. The scheme followed is that of Turner (1951) with the exception that, following Francis (1956), the kyanite-staurolite sub-facies is divided into a staurolite-quartz sub-facies and a kyanite-muscovite sub-facies. This regrouping is recognised by Turner (1958). As we have seen the kyanite-muscovite sub-facies may produce the paragenses kyanite-muscovite, sillimanite-muscovite, and andalusite-muscovite corresponding to the various possible positions of the Al_2SiO_5 stability curve within the sub-facies.

DESCRIPTION OF THE FACIES DISPLAYED

The Regional Metamorphism

The regional metamorphic rocks of the region studied fall within the staurolite-quartz sub-facies and the kyanite (sillimanite)-muscovite sub-facies of the amphibolite (kata)

FIG 4



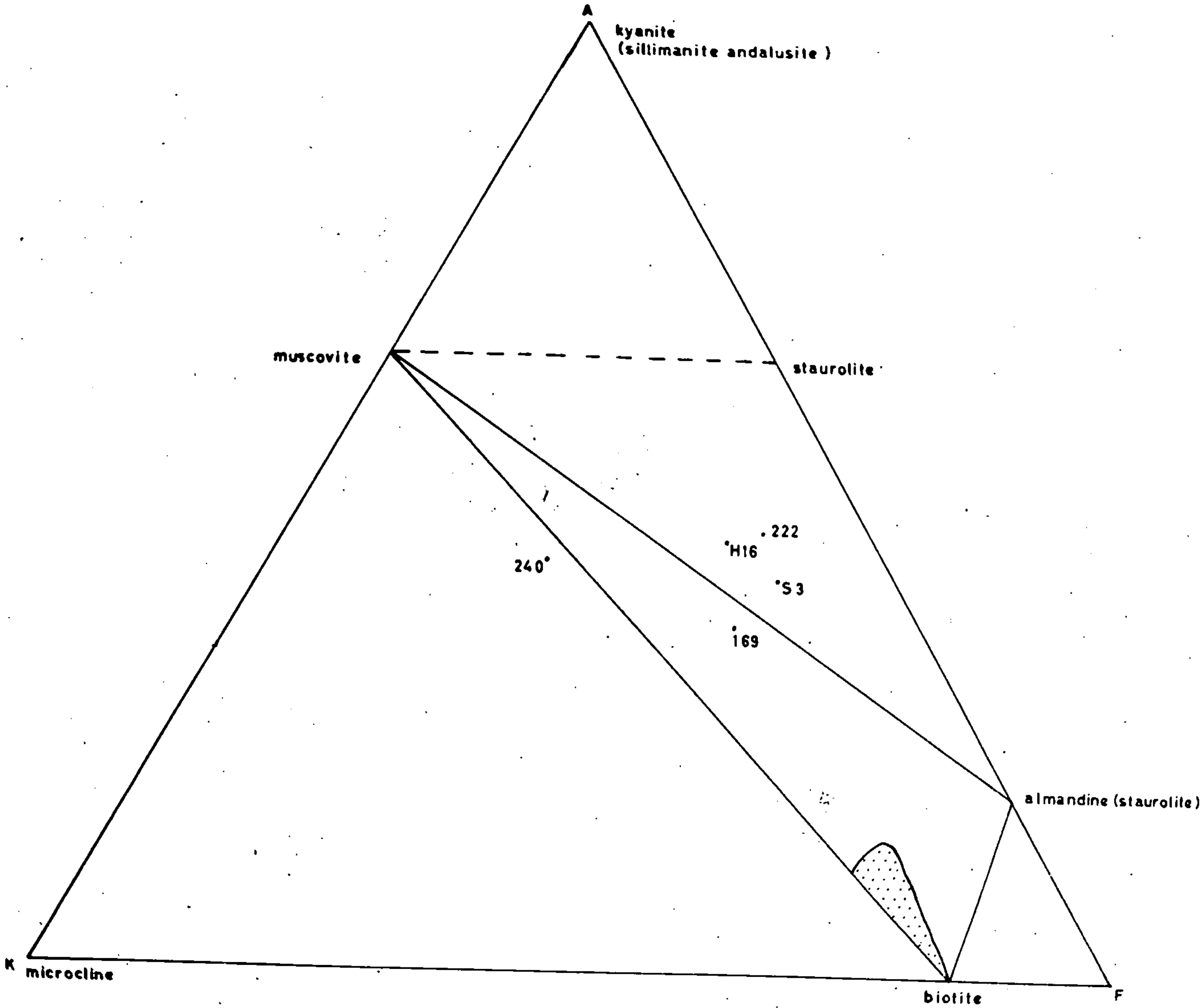
ACF DIAGRAM FOR THE STAUROLITE QUARTZ sub-facies

facies. The isograd for the entry of sillimanite falls within the staurolite-quartz sub-facies (see Fig. 2), while the curve of reaction d. (Figs. 1, 2 and 3) marks the final disappearance of staurolite and the commencement of the kyanite (sillimanite) sub-facies. It is clearly seen on Fig. 2 that points 7 and 13 fall within the same sub-facies and therefore that the sillimanite-muscovite zone of Connemara is equivalent to the kyanite-muscovite zone of the Highlands. To the south of the area studied muscovite is resorbed (Leake 1958) i.e. reaction e. takes place; and over much of South Connemara the sillimanite-almandine sub-facies is developed.

The Staurolite-Quartz Sub-Facies.- This is the sub-facies of the Aughris Peninsula and is demonstrated in Figs. 4 and 5. It will be seen that the staurolite line is dotted; this is because the observed association is staurolite-sillimanite, whereas the analyses plot in the staurolite-epidote-almandine field. It is clear that sillimanite and staurolite are stable over the whole of the sillimanite-epidote-almandine field and therefore that the staurolite line should coincide with the almandine line. Staurolite is added in brackets to the almandine line.

In rocks which have modal potash feldspar staurolite and sillimanite are not developed. This is well shown by No. 169 which although falling into the staurolite field on Fig. 4 is separated from it on Fig. 5. The A.K.F. diagram is therefore the proper place for pelitic and quartzitic rocks

FIG 5

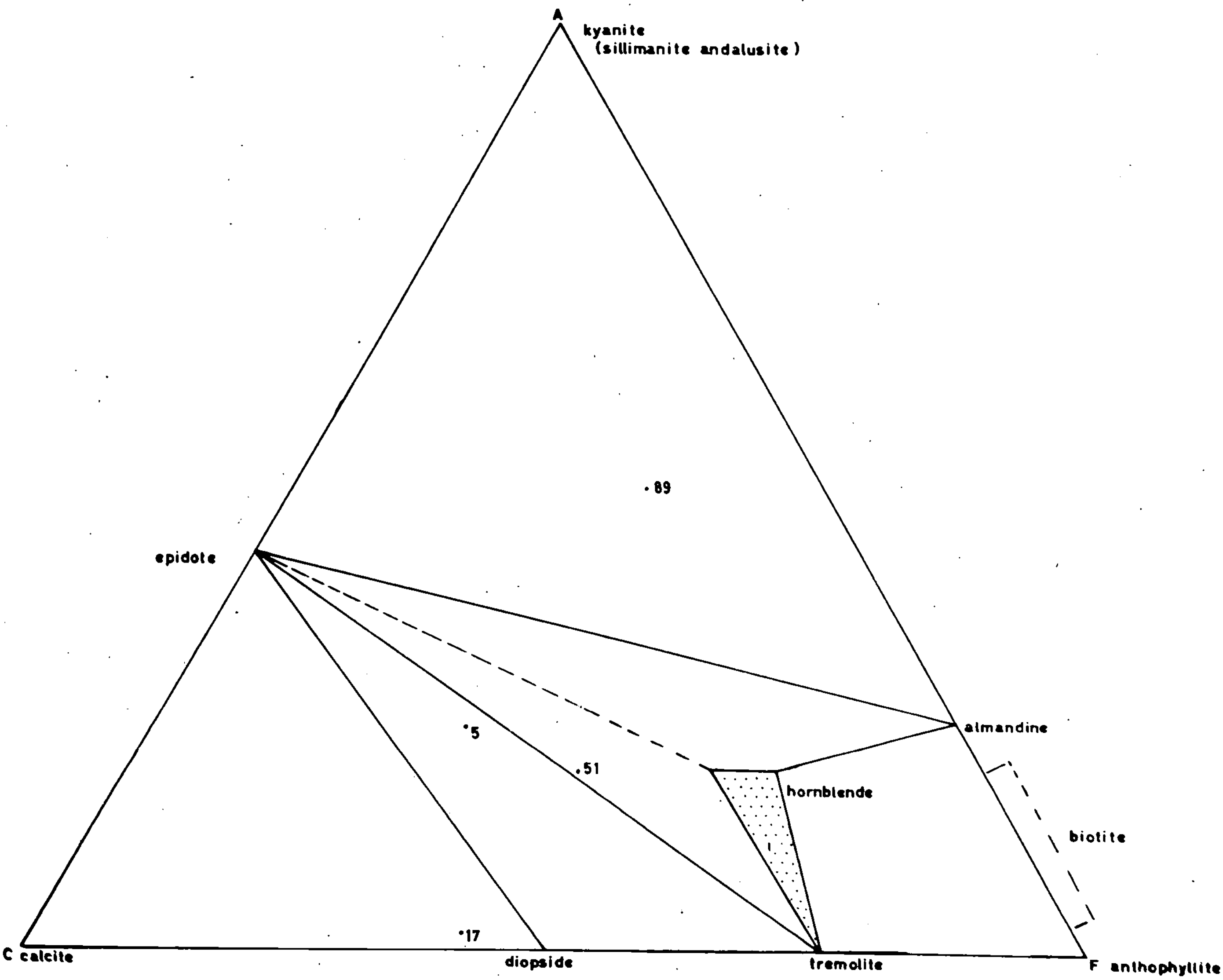


AKF DIAGRAM FOR THE STAUROLITE QUARTZ sub-facies e.g. No. 240 with excess K_2O. Below the epidote almandine join Fig. 4 is identical to Fig. 6. This confirms field and petrographic experience that the calcareous and amphibolitic rocks are the same for both the staurolite quartz and kyanite muscovite sub-facies, the only variation being in the pelitic members. The line epidote-hornblende is dotted since the striped amphibolite analysis falls into the almandine-epidote-hornblende field whereas in fact it does not crystallize almandine at all. This line was inserted by Turner in an attempt to subdivide the smphibolite group into garnet-bearing and garnet-free; but since it does not satisfactorily accommodate the striped amphibolites it is considered to be unjustified.

The Kyanite-Muscovite Sub-Facies.- This is the sub-facies of the Ballymaconry Peninsula. In fact, sillimanite is crystallized rather than kyanite for reasons given above and it is considered to be equivalent to the kyanite-muscovite zone of the Highlands. In Figs. 6 and 7 it is seen to differ from the staurolite-quartz sub-facies only in the absence of staurolite. Petrographically muscovite is replaced by sillimanite though the reaction is not very far advanced. This is reaction e. of Figs. 1, 2 and 3 and indicates that the sillimanite-almandine sub-facies is fairly close.

There is only one analysed semi-pelitic rock from this sub-facies, No. 89, which is seen in both Figs. 6 and 7 to fall in the sillimanite-almandine field. The necessity of using an A.K.F. diagram to illustrate the pelites, siliceous

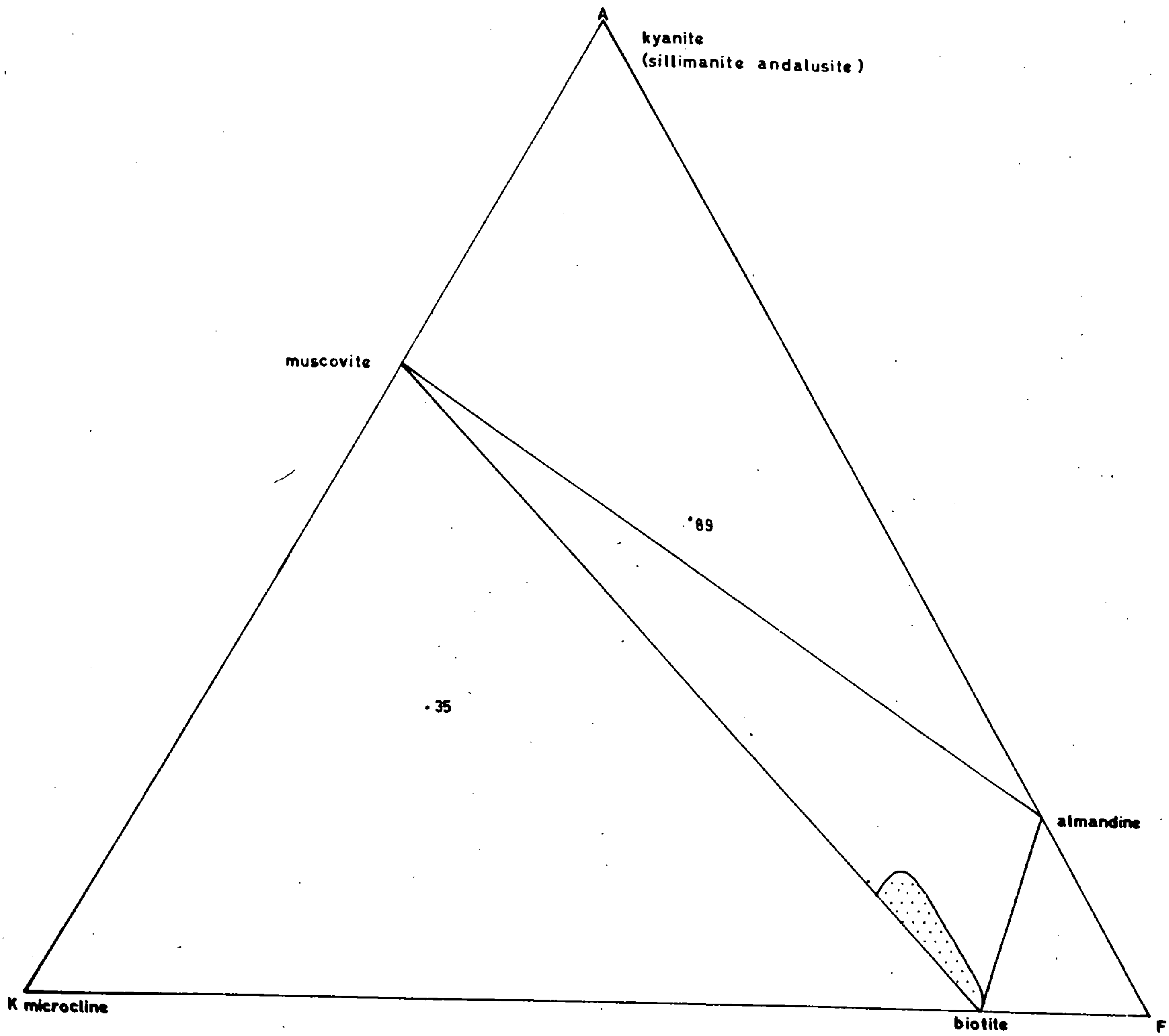
FIG 6



ACF DIAGRAM FOR THE KYANITE MUSCOVITE sub-facies granulites and quartzites with excess K_2O is again demonstrated, No. 35 being well into the muscovite-biotite-microcline field. Though no potash feldspar bearing semi-pelites have been analysed from this zone the analogy with No. 169 in Fig. 5 is clear, since it would plot in exactly the same place in this sub-facies.

The lower part of Fig. 6 is identical to Fig. 4 and in fact specimens plotted here may be put on Fig. 4 to illustrate the mineral paragenses of that sub-facies. The massive amphibolite No. 51 falls into the appropriate field as does No. 17, the tremolite marble. The calc-silicate granulite No. 5 is also in the correct field but as has been noted above, it contains modal potash feldspar and therefore excess K_2O. It is seen that the presence of excess K_2O has no modifying effect upon the phases crystallized, as in the case of the semi-pelitic rocks, and therefore this part of the diagram may be regarded as suitable for illustrating calcareous rocks. It is considered unnecessary to use two separate A.C.F. diagrams to illustrate rocks with deficient K_2O and excess K_2O since in the first case only the lines above the epidote-tremolite join are seen while in the second case the lines below the epidote-almandine join are used. In combining the two the whole triangle is used and there is no vacant space. It is suggested that in amphibolites the presence of sphene and absence of ilmenite be considered as diagnostic of the kyanite-muscovite sub-facies, since the isograd for this reaction lies very near to that for the disappearance of staurolite.

FIG 7



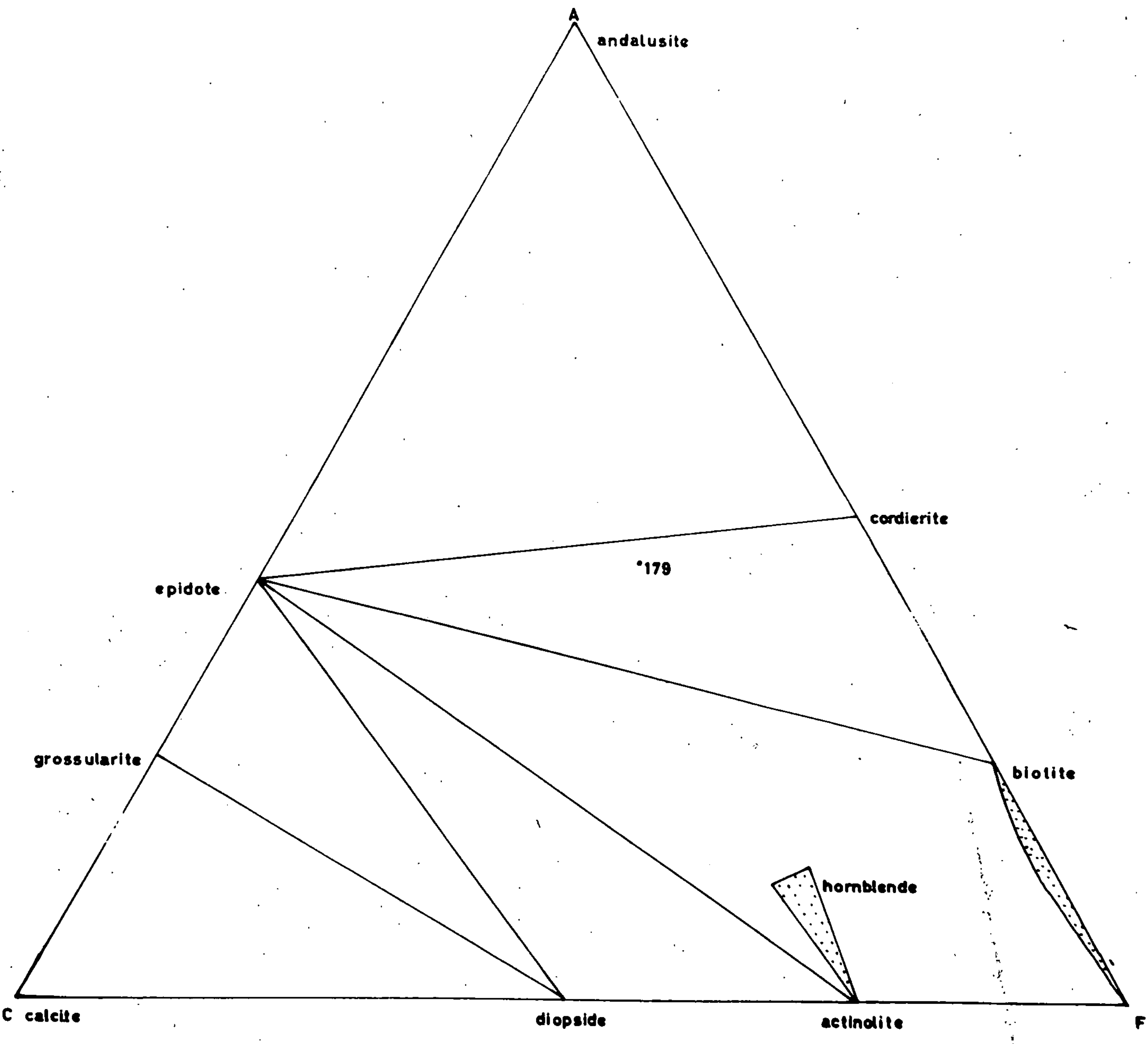
AKF DIAGRAM FOR THE KYANITE MUSCOVITE sub-facies

Unfortunately one cannot show this on an A.C.F. diagram.

The Actinolite-Epidote-Hornfels Sub-Facies.- The outer part of the aureole of the Omey Island granite must be assigned to this sub-facies of the epidote-amphibolite facies even though the diagnostic criteria are not evident. The conversion of almandine to biotite is a reaction probably initiated in this sub-facies as is the conversion of biotite and staurolite to cordierite. The difficulty is that the rocks as a whole tend to preserve the regional aspect apart from spotting due to biotite and cordierite. The plagioclase present is always the regional andesine An_{30} sometimes slightly recrystallized but never converted to albite + epidote. The reason for the poor development of this sub-facies is undoubtedly the coarse crystallinity due to the regional metamorphism which makes the rock less susceptible to reaction at lower grades. The association of epidote and albite in place of the original plagioclase feldspar in the calc-silicate granulites is prevalent in this sub-facies but since this is the normal result of saussuritization in these rocks it cannot be held to be diagnostic of this sub-facies. It is however particularly intense at this level which may be an indication of relation to thermal metamorphism.

The sub-facies is illustrated in Fig. 8, No. 179 being the only analysed example of this grade. It contains cordierite but no andalusite. The incoming of andalusite into rocks of similar composition may mark the transition to the

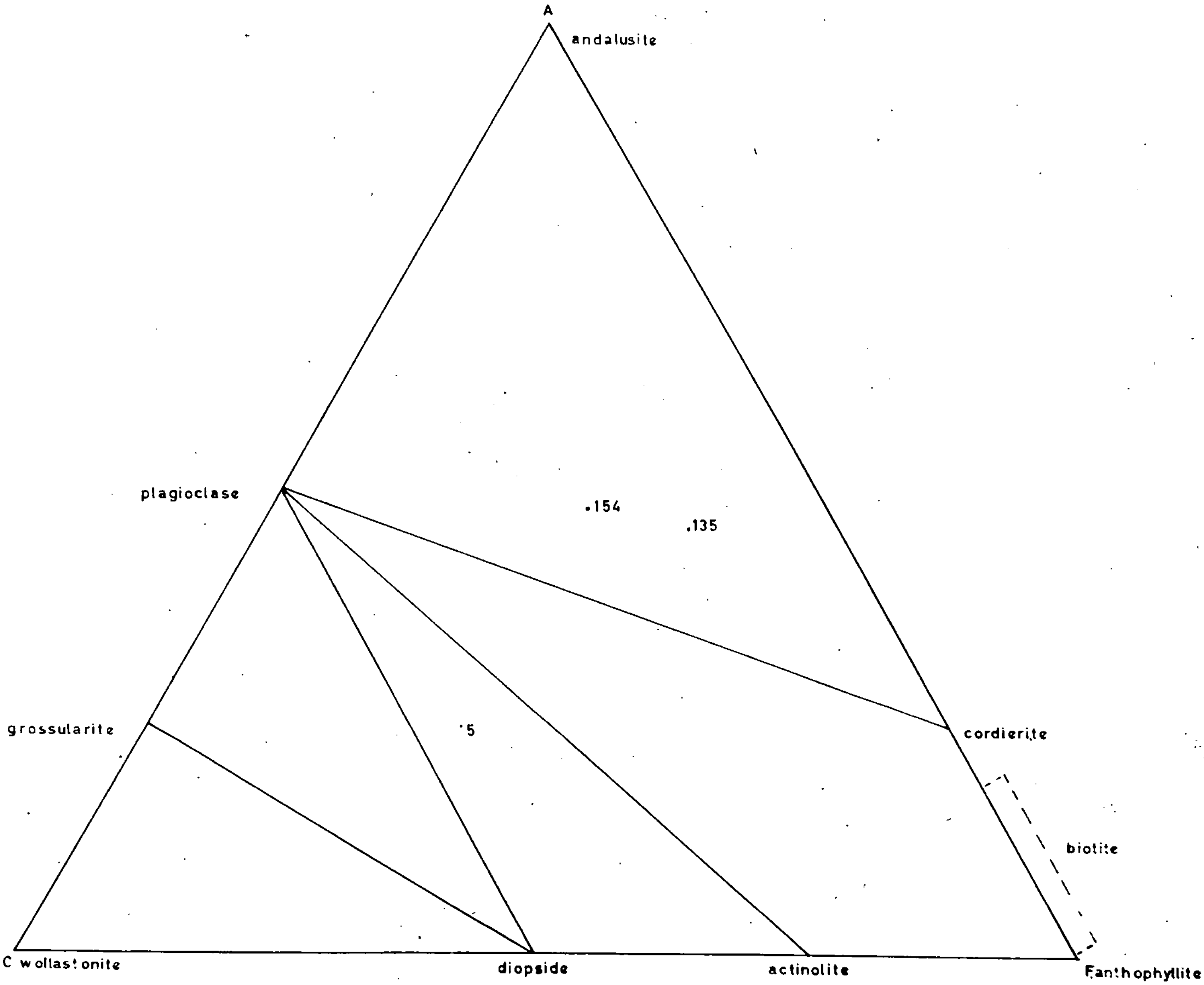
FIG 8



ACF DIAGRAM FOR THE ACTINOLITE EPIDOTE HORNFELS sub-facies hornblende-hornfels sub-facies. The assemblages in the calc-silicate hornfels are essentially similar to those in the hornblende-hornfels sub-facies and distinction of the two sub-facies in these rocks would be difficult.

The Hornblende-Hornfels Sub-Facies.- This sub-facies of the amphibolite facies is well developed in the Omey Island granite aureole and corresponds approximately to the andalusite zone of thermal metamorphism. Cordierite and andalusite crystallize together in rocks of the same composition as No. 179 and the cordierite boundary on Fig. 9 is accordingly shifted to include this paragenesis. It is interesting to note here the fact that the presence of excess K_2O does not interfere with the crystallization of andalusite and cordierite as it does with the formation of staurolite and sillimanite in the staurolite-quartz sub-facies. No. 135, for example, has orthoclase, andalusite and cordierite in the same rock and there are numerous other thin sections demonstrating this paragenesis from the area. This association of orthoclase with cordierite and andalusite is normally a characteristic feature of the Pyroxene-hornfels facies, which is further characterised by the absence of micas, except possibly a little biotite. This latter feature is certainly not shown in the present region for both muscovite and biotite are frequently present in considerable quantity throughout the aureole. In fact the only associations of orthoclase with cordierite and andalusite are found in the orthoclase-bearing formation next to the

FIG 9



ACF DIAGRAM FOR THE HORNBLENDE HORNFELS sub-facies granite (see Map 6). In the case of hornfelsed semi-pelites of normal composition, orthoclase is not found e.g. No. 154, although there is abundant muscovite present and its formation as a product of the reation

MUSCOVITE + QUARTZ = ANDALUSITE + ORTHOCLASE + WATER

might be expected.

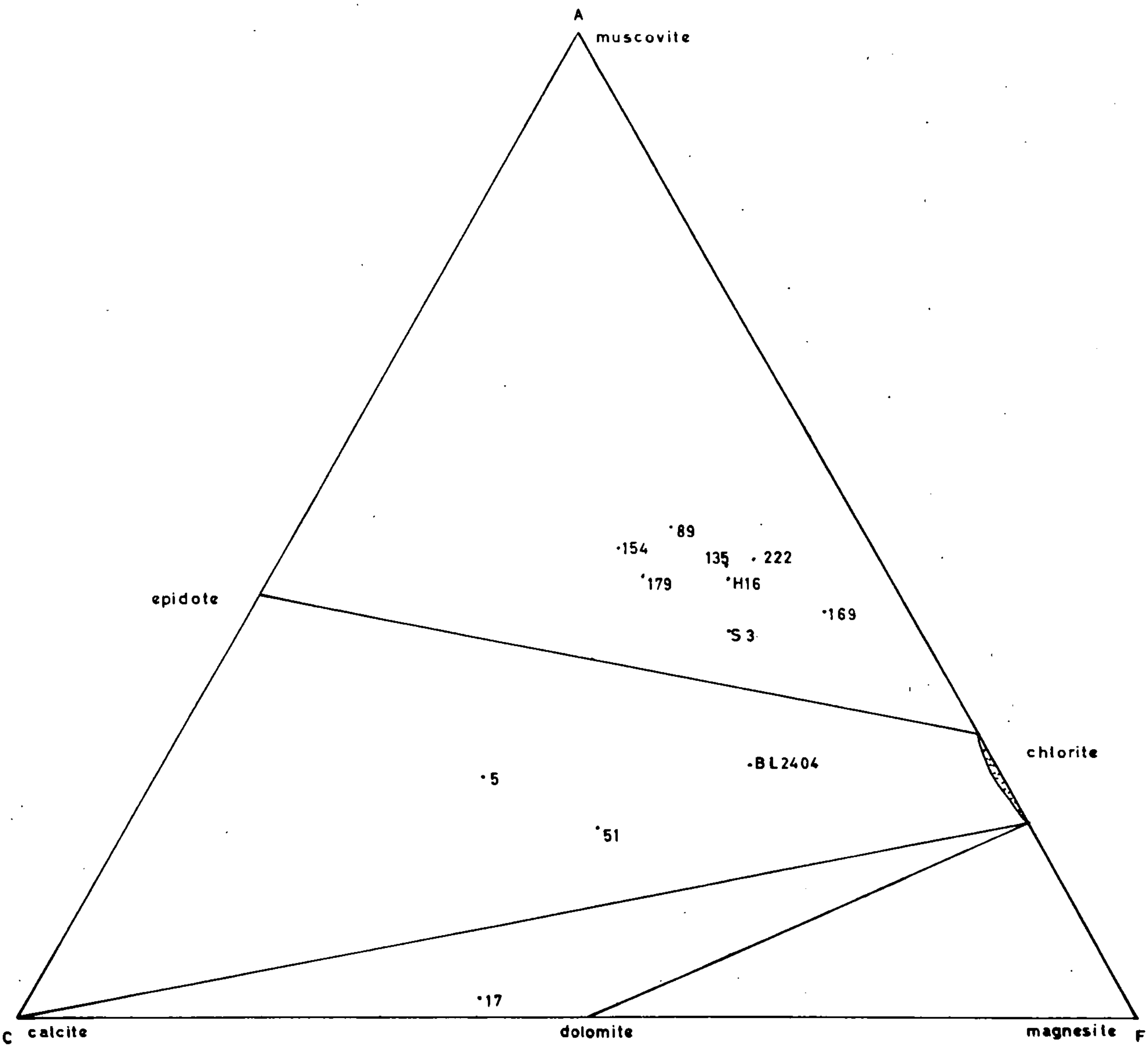
It is concluded therefore that these rocks are properly considered within the hornblende-hornfels sub-facies and that the anomalous presence of orthoclase in association with cordierite and andalusite is due to simple recrystallization of a semi-pelite of rather unusual composition.

Accordingly, it is not necessary to draw a separate A.K.F. diagram for this sub-facies since the excess K_2O does not materially alter the parageneses in either the pelitic or calcareous members.

The calcareous assemblages are well shown in Fig. 9. By superimposing the calcareous analyses from Fig. 6 a good idea of the parageneses found is provided, considering that only two analyses from this group were done.

<u>The Greenschist Facies</u>.- This is the facies of the retrograde metamorphism. There is sporadic retrogressive metamorphism of biotite grade, i.e. biotite-chlorite sub-facies, but this is on so small a scale that it is not worth giving a diagram to demonstrate it. The bulk of the retrograde metamorphism is of chlorite grade, muscovite-chlorite sub-facies as illustrated on Fig. 9. All the analysed rocks are plotted on this

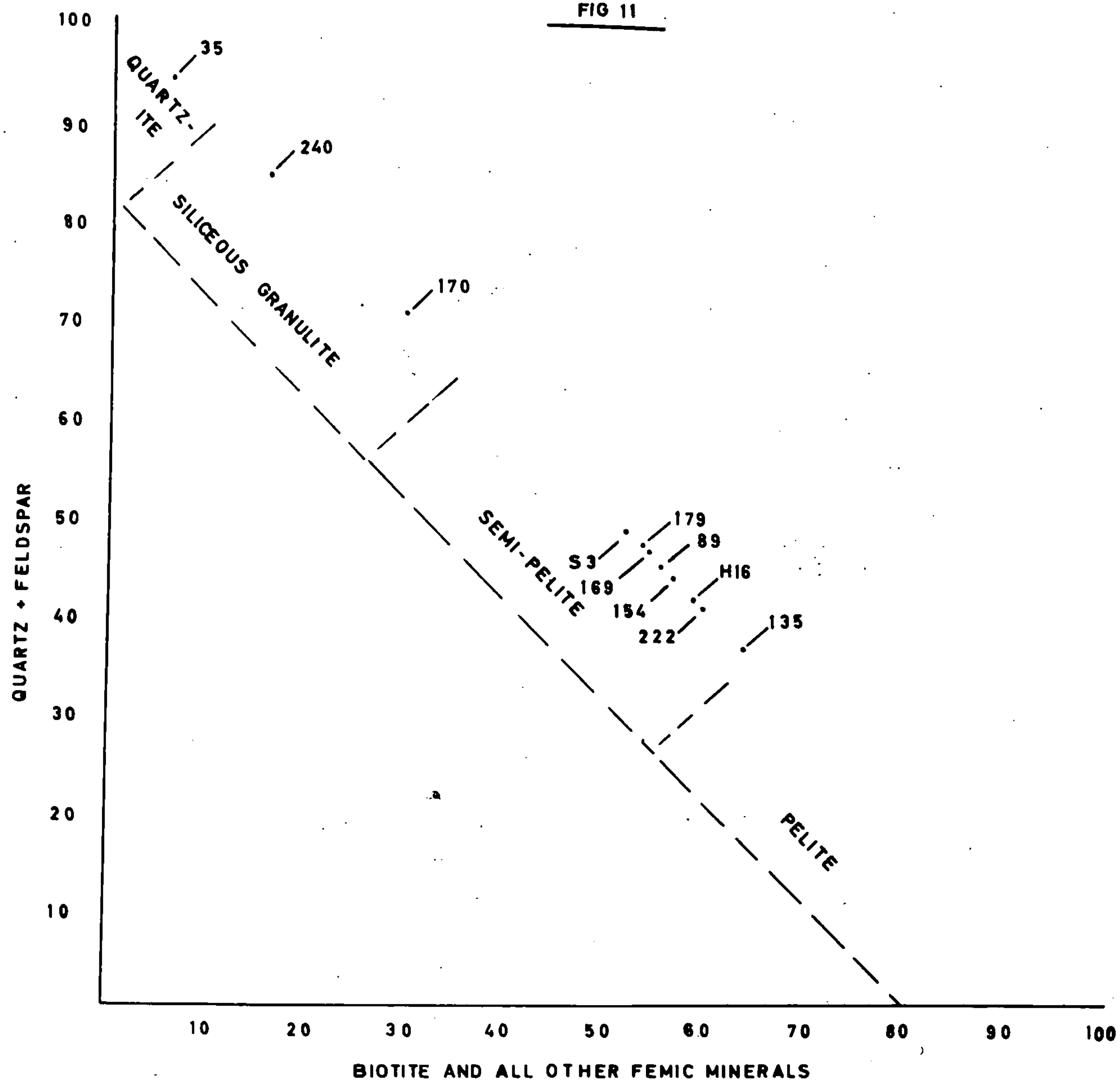
FIG 10



ACF DIAGRAM FOR THE MUSCOVITE CHLORITE sub-facies diagram which gives a good idea of what their parageneses would be if the retrogression were complete, and perhaps of the original mineralogy of some of the sediments.

<u>The Use of A.C.F. and A.K.F. Diagrams</u>.- The use of these has proved somewhat more difficult in practice than was anticipated. Considerable adjustment of joining lines had to be made in many instances to make the diagram comprehensible; hence, the supposed universality of these diagrams is not supported by the present area. This is almost certainly due to the fact that rocks remain stubbornly complex, largely due to minerals like hornblende which have a wide range of composition. It seems that the use of triangular diagrams may be too simple to meet the case or, more likely, that the mineral boundaries themselves are considerably more diffuse than suggested in the diagrams. It may be that tetrahedral diagrams would be more effective but they would certainly be very cumbersome and difficult to follow. For the present it seems that the most satisfactory method is simply to define the sub-facies in terms of the pelitic rocks and describe the associated lithological variations within these sub-facies. This is the procedure which has been followed, A.C.F. and A.K.F. diagrams being used chiefly for illustration.

FIG 11



RELATION OF THE SPECIMENS SELECTED FOR CHEMICAL ANALYSIS TO THE MODAL COMPOSITION IN THE QUARTZITE SEMI-PELITE SERIES

CHAPTER IV

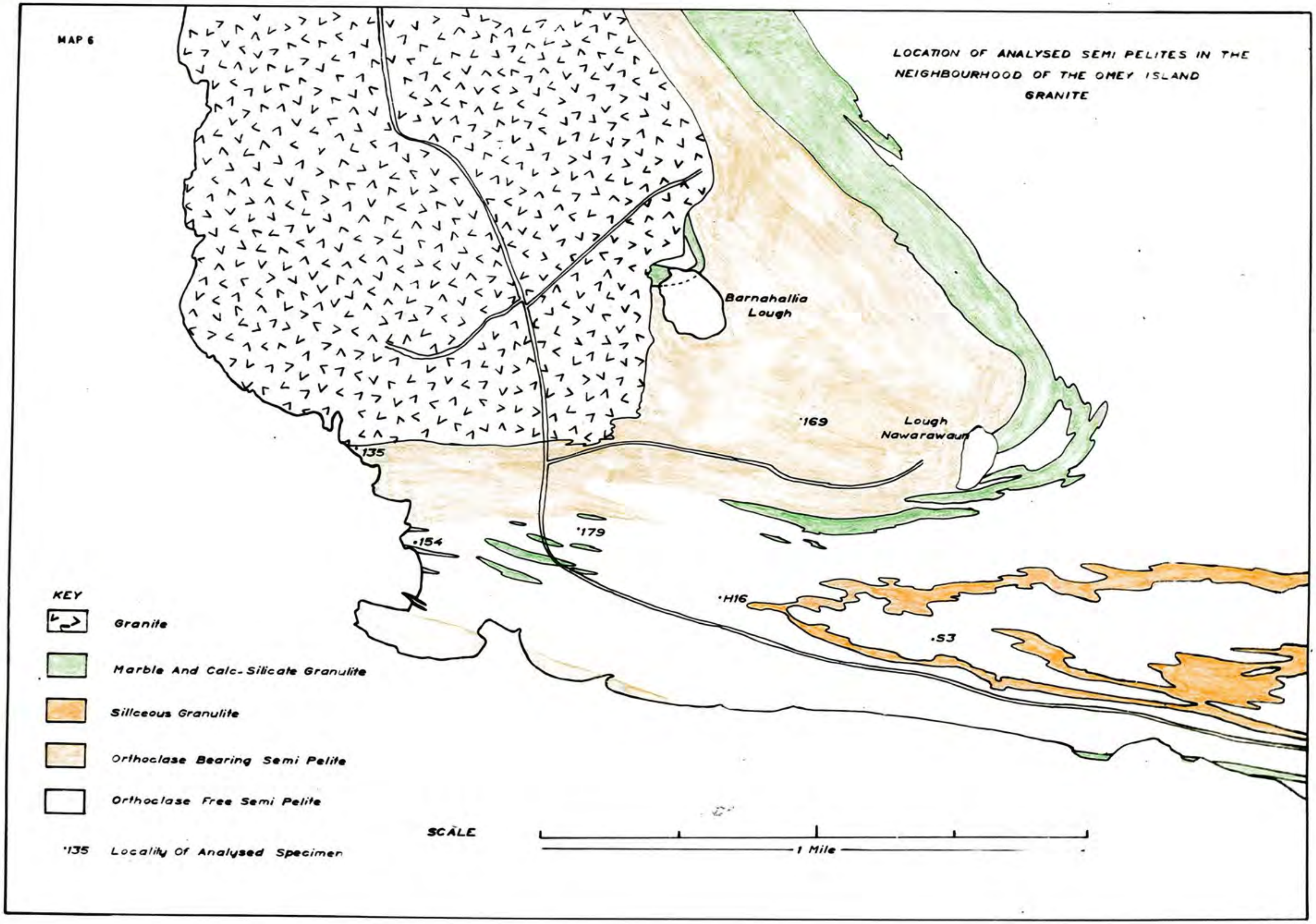
GEOCHEMISTRY OF THE METASEDIMENTS

GEOCHEMISTRY OF THE METAMORPHISM.

The Regional Metamorphism.- In order to investigate the possibility of Na or K-metasomatism in relation to the increasing metamorphism, it was decided to take specimens of semi-pelite for analyses from the several metamorphic zones. The metamorphic zones traverse the area parallel to the strike of the stratigraphy and therefore no single formation can be traced from lower grade to higher grade (see Map 2). There is thus no strict natural control of composition relative to increasing metamorphism; in fact the Aughris Peninsula has a higher proportion of semi-pelite than the Ballymaconry Peninsula. To make the analyses as strictly comparable as possible, selection of specimens was made on the basis of modal composition. The most typical semi-pelites were found, by making many modal analyses, to be those which contained between 36 per cent and 50 per cent combined quartz and feldspar and the rocks analysed were selected from within these limits. Thus a strict compositional control was established within the framework of which it was hoped to observe any chemical changes due to metasomatism.

Three specimens were selected; No. 89 from the sillimanite muscovite zone; No. S3 from the sillimanite-staurolite zone and No. 222 from the staurolite zone. Their location may be seen on Map 2. These analyses are presented in Table II (page 17). Silica and alumina are very constant, indicating that the modal method of selection is effective. No. 89 is slightly higher in potash and soda and is lower in iron than No. S3 and No. 222. It is possible that this difference indicates an increase in alkalis and a decrease in femics, i.e. alkali metasomatism with increasing grade, but on the other hand No. H16 (page 17) analysed in connection with the thermal metamorphism but in fact a regional rock, has very similar alkali values to No. 89 and comes from a lower metamorphic grade. Leake (1958) analysed 16 rocks from north and south Connemara and found that the alkalis remained constant throughout. His range of potash and soda values were very similar to those given here, which suggests that the variation seen is due to sampling differences and sedimentary variation rather than to alkali metasomatism. It is concluded that no alkali metasomatism has been connected with the regional metamorphism at the grades investigated. Any chemical differences between these rocks and sedimentary rocks in general are due either to original sedimentary differences or to alkali metasomatism in the lower grades of metamorphism. This latter factor, though not considered to be important, cannot be altogether dismissed. Since unmetamorphosed strata and those of low metamorphic grade are not present in Connemara, it will not be possible to investigate this point, which must therefore be left unanswered.

Alkali metasomatism is known to occur in the

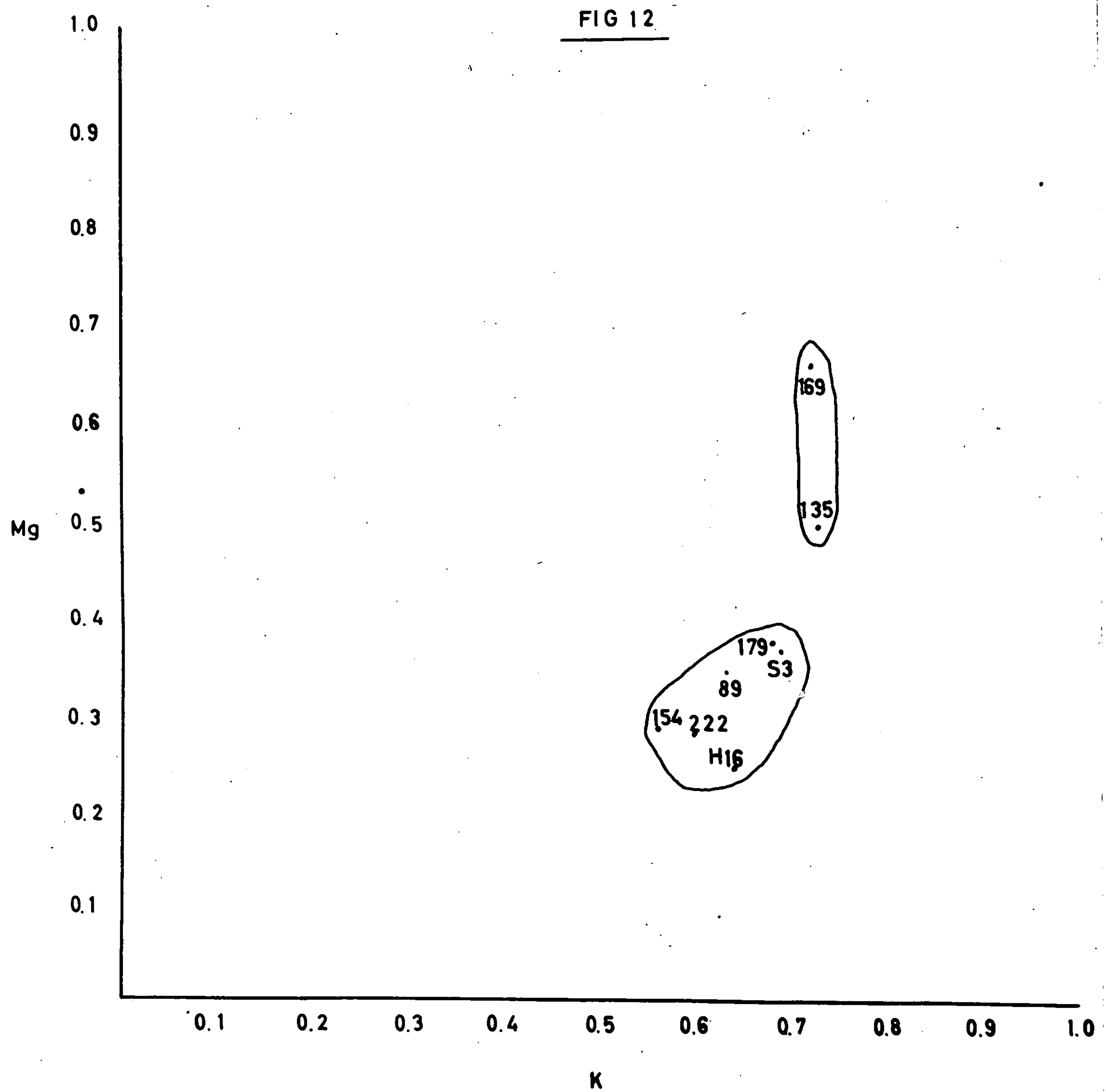

MAP 6
LOCATION OF ANALYSED SEMI PELITES IN THE NEIGHBOURHOOD OF THE OMEY ISLAND GRANITE
Barnahallia Lough
Lough Nawarawaun
·135
·154
·179
·169
·H16
·S3
KEY
Granite
Marble And Calc-Silicate Granulite
Siliceous Granulite
Orthoclase Bearing Semi Pelite
Orthoclase Free Semi Pelite
·135 Locality Of Analysed Specimen
SCALE
1 Mile

migmatite zone where a large scale microcline feldspathization has been demonstrated (Leake 1954).

The Thermal Metamorphism.- Samples for this investigation were again selected from the semi-pelites on the basis of modal composition. The study here was complicated by the fact that the rocks at this point are disposed in a fold closing towards the granite (Map 6), the core of which is composed of orthoclase-free semi-pelite while the mantle is orthoclase-bearing semi-pelite. It is very easy to pass from one band to another while walking towards the granite along the strike, so that without very careful sampling a strong potash metasomatism would almost certainly be recorded.

In order to determine the presence or extent of metasomatism during thermal metamorphism it was necessary to select a series within the orthoclase-free semi-pelite and a series within the orthoclase-bearing semi-pelite. The localities selected can be seen on Map 6. The orthoclase-free series is numbered H16, 179, 154. The chemical and modal analyses are presented in Tables II and VIII (pages 17 and 48). The series passes from unmetamorphosed No. H16 through spotted hornfels No. 179 to andalusite hornfels No. 154. There is an increase in potash in the case of No. 179, but this is not shown in No. 154. There is no appearance of potash feldspar within this series. Soda is constant throughout while H16 is rather higher in iron than the two hornfelsed rocks. Within this series it seems that there is no change in bulk

FIG 12



PLOT OF THE NIGGLI VALUES K AND Mg
FOR THE SEMI-PELITES

composition. The potash/soda ratio is similar in all three specimens as is the Fe/Mg ratio.

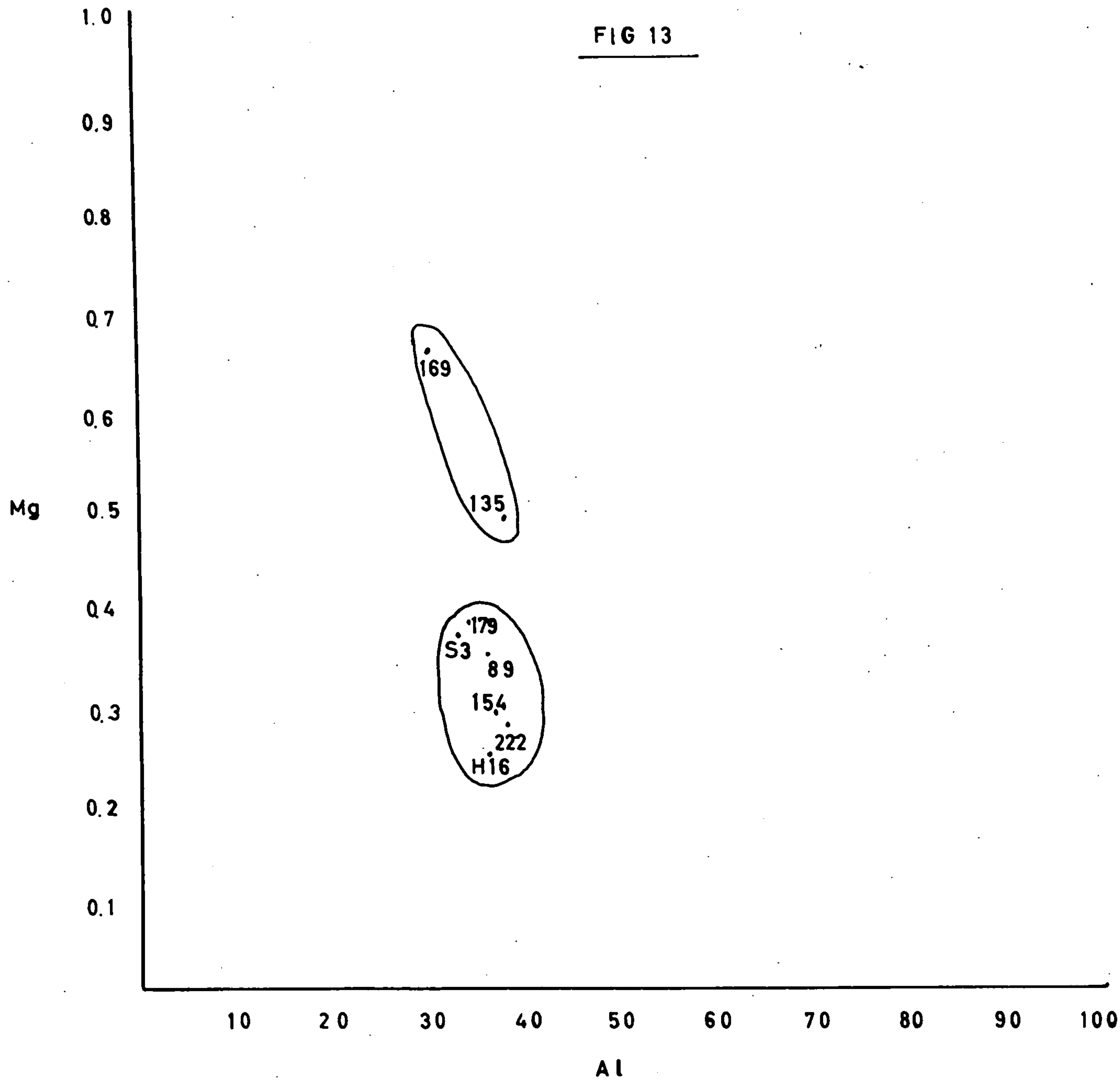
There are only two specimens in the orthoclase-bearing series; No. 169, an unaltered regional rock and No. 135, a thoroughly recrystallized andalusite hornfels. The chemical and modal analyses may be seen in Tables II and VIII (pages 17 and 48).

Within this series No. 135 has slightly more potash and soda than No. 169 but this may be due to the fact that it is the most pelitic specimen taken (see Fig. 11), and is relatively deficient in silica. The potash/soda ratio is again similar in the two specimens.

It seems that within the two series there is little, if any concrete evidence to demonstrate alkali metasomatism. There are slight suggestions of increases in potash but these are so indefinite and can be explained so easily on other grounds that it is here concluded that alkali metasomatism has not occurred in this case.

The Niggli values K, Mg and Al for all the semi-pelites are plotted on Figs. 12 and 13. These graphs therefore demonstrate the chemistry of the semi-pelites with respect to these oxides in both the regional and the thermal metamorphism. In both cases the rocks are divided into two groups. The larger group contains all the rocks analysed in the investigation of the regional metamorphism and, in addition, that series connected with the thermal metamorphism which was taken from the formation lacking

FIG 13



PLOT OF THE NIGGLI VALUES K AND Al FOR THE SEMI-PELITES potash feldspar.

Quite clearly these rocks are chemically one group. Inspection of the bulk analyses reinforces this conclusion. They are in fact typical representatives of those semi-pelitic rocks which are quantitatively most important in this part of Connemara.

Since there is no chemical change in this group, it follows that the thermal metamorphism was isochemical and that contact metasomatism did not take place in this case.

The smaller group consists of the two rocks taken from the orthoclase-bearing band Nos. 169 and 135. The fact that these two rocks, one regionally metamorphosed and the other thermally metamorphosed, fall into the same group confirms the conclusion that the thermal metamorphism was isochemical.

Further, the fact that in Figs. 12 and 13 the only chemical separation shown is one which is dependent on stratigraphic factors, draws attention forcibly to the extent to which these factors control the chemistry of a complex even at a high metamorphic grade. The way in which delicate chemical differences, stratigraphically determined, are maintained at a high level of metamorphism is striking; and the suggestion is strong that these differences could be maintained only in the case of isochemical metamorphism.

It is concluded that there has been no alkali metasomatism in either the regional or the thermal metamorphism. While it is realised that the number of analyses is too small to be conclusive it is at least as large as those used by previous investigators to demonstrate metasomatism (Barth, 1952, page 361).

The Relation of the Metasediments to Other Sedimentary Terrains.- Analyses of the major types of metasediments were made in order to compare the chemistry of the major types with those of unmetamorphosed sedimentary rocks. Direct comparison is not possible for the metasediments have a much lower water content but it is easy to make allowances for this.

The semi-pelites in comparison with unmetamorphosed average shales are markedly lower in silica and higher in alumina; allowing for the small proportion of water and consequent relative increase of all other oxides this difference is even more marked. This must mean that in the original sediment there was a high proportion of clay minerals relative to the silty fraction.

Potash is dominant over soda indicating that they are true shales and not greywackes. The semi-pelites are very rich in potash and in this respect are quite unlike most shales. The potash content in a shale is generally introduced during its formation by the adsorption of potash ions from sea water into the lattice of the clay minerals, thus a fine grained shale with a high proportion of clay mineral to silt is liable to be richer in potash than a rock with a greater proportion of silt. This is borne out by the fact that in varved clays the fine grained winter varves are richer in potash while the silty summer varves are correspondingly poorer. The present analyses are strikingly similar to that of a winter varve, (Pettijohn, 1957, page 345) and also to the potash rich Glenwood and Dacorah shales from the Ordovician of Minnesota (Pettijohn, 1957, page 370).

Fineness of grain and a high proportion of clay mineral fraction to silt is thus indicated on two grounds.

(a) The low silica and high alumina.

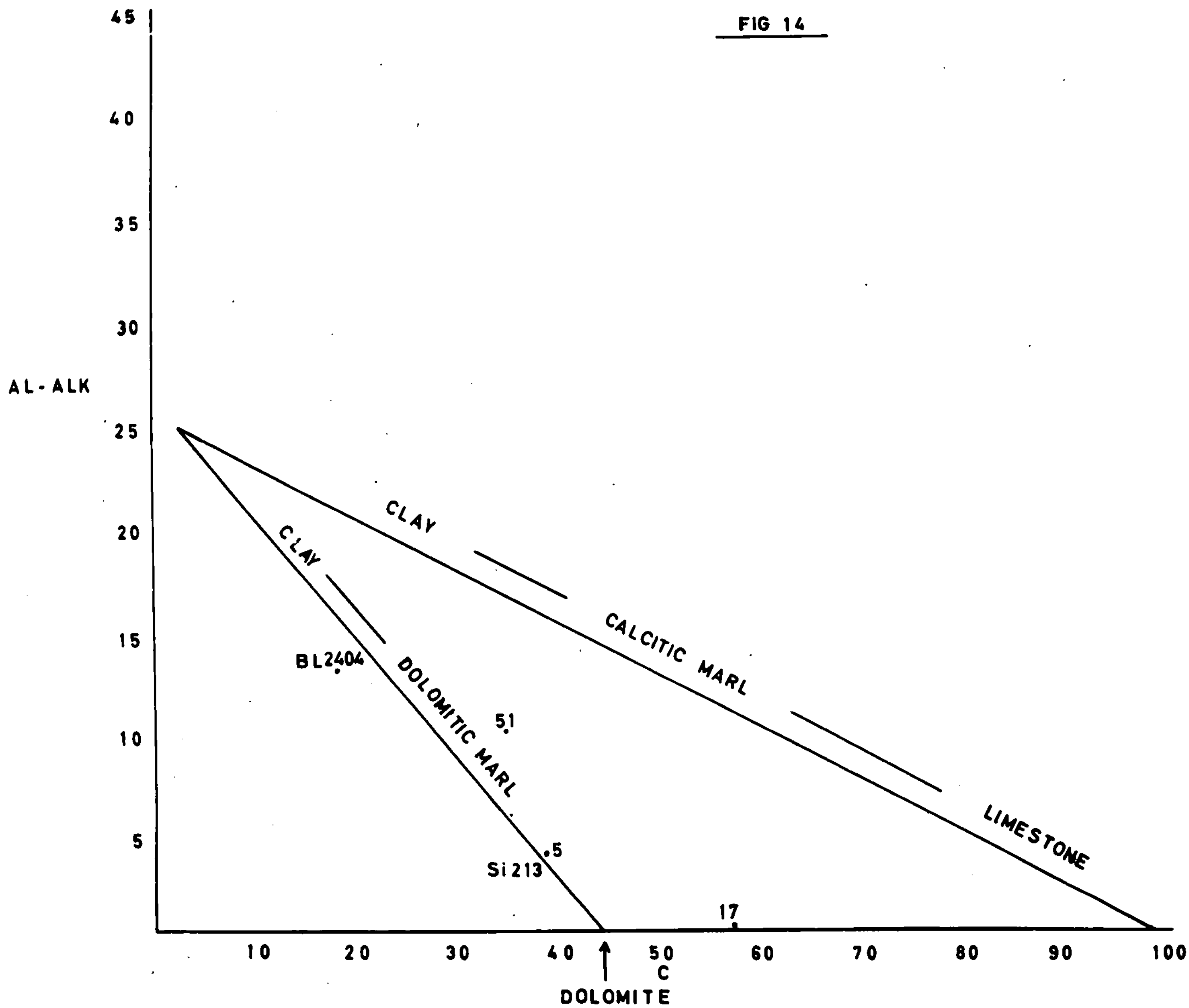
(b) The high potash.

The semi-pelites therefore are the metamorphosed equivalents of fine grained shales which must have accumulated under fairly quiet conditions to allow such complete winnowing of the clay mineral fraction from the silty fraction.

The feldspathic siliceous granulite No. 170 (Table III, page 25) is similar chemically to many greywackes (Pettijohn, 1957, page 306) with the exception that potash is dominant over soda. Since this is the most characteristic feature of greywackes it cannot belong to this group. Alternatively, however, it is quite similar to analyses of silty clays from the Mississippi delta (Pettijohn, 1957, page 344) in which potash is dominant over soda. This interpretation is more consistent with the field relations particularly on the Ballymaconry Peninsula where the intimate mixture of siliceous granulite and semi-pelite well simulates the constant variation between shale and silty shale seen in deltaic and other shelf deposits, (Pettijohn, 1957, page 366). A fairly stable sedimentary environment is indicated in which silt and shale are formed rather than undifferentiated greywackes. Leake (1954) has reported a siliceous granulite from the Cashel district which has soda dominant over potash and this may be a true greywacke.

The very siliceous granulite No. 240 (Table III, page 25) is chemically quite similar to arkosic sandstones, like the Torridonian of Scotland and the Sparagmition of Norway, (Pettijohn, 1957, page 324). There is, however, no way of knowing whether the present feldspar proportion is original or due to reorganization of intergranular pelitic material on metamorphism. If the latter is the case then these rocks are simply a siliceous variant of the feldspathic granulites and are equivalent to sedimentary proto/quartzite (Pettijohn, 1957, page 291). This interpretation is preferred since it conforms with the field evidence. Siliceous granulites of this type are frequently seen to pass laterally into feldspathic siliceous granulites and are clearly a more siliceous expression of the same trend. This also avoids the difficulty of having high relief and extreme climatic conditions to produce the arkose and low relief and moderate conditions for the formation of the associated rocks.

The quartzite No. 35 (Table IV, page 30) is a very pure quartzite, the greatest quantity of impurity being potash and alumina. Chemically it compares closely with other orthoquartzites (Pettijohn, 1957, page 298) but it is perhaps just slightly too impure to be put in this group and may more properly be equated with a protoquartzite. This



PLOT OF NIGGLI VALUES FOR THE CALCAREOUS ROCKS AGAINST MIXTURES OF CLAY LIMESTONE AND DOLOMITE (AFTER NIGGLI) certainly fits the sedimentary setting quite well. The quartzites are persistent lithological types which, together with their extreme composition, suggests that they represent a period of widespread, uniform conditions, as for example the shallowing of a sea in a shelf area.

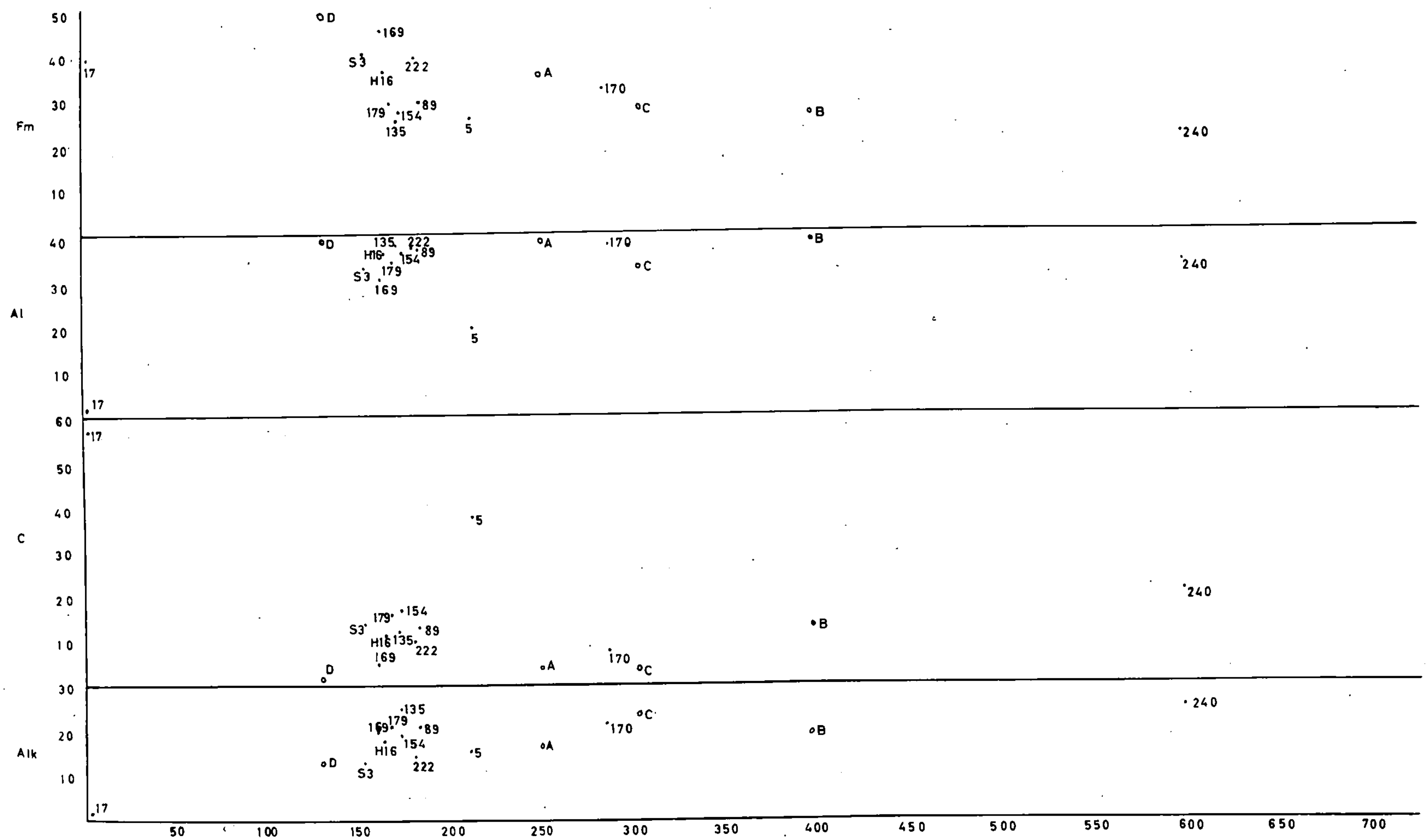
The marbles and calc-silicate granulites also tend to indicate such conditions. They are persistent over considerable areas and are sometimes up to 500 feet thick. In general, they tend to be confined to particular horizons and can thus be cited in the same way as the quartzites as representing widespread uniform conditions.

They cannot be compared directly with sedimentary calcareous rocks for during metamorphism any dolomite present has decomposed allowing the magnesia to combine with silica in various ways. However, the analysed rocks Nos. 17 and 5 indicate that the rocks were dolomitic limestones and dolomitic marls. Some pure lime-stones are present but they are of relatively little importance and none were analysed.

Since the massive amphibolites and striped amphibolites are now considered to be metamorphosed igneous rocks and have been dealt with in Chapter II, they are not described here.

Niggli values of calcareous rocks from Connemara are plotted on Fig. 14 against artificial mixtures of clay, limestone and dolomite. The parameters are Al - ALK and C. The tremolite marble No. 17 falls slightly on the calcareous side of true dolomite. It does in fact have alumina, femic

FIG 15



PLOT OF THE NIGGLI VALUES FOR THE METASEDIMENTS and alkalis but these are not effectively shown on this graph since alumina and alkalis are self cancelling. The original rock must have been a slightly impure dolomite.

The calc-silicate granulite No. 5 falls within the field of dolomitic marl while the high Si figure indicates a considerable siliceous fraction. More analyses of the calcareous rocks would probably reveal a continuous series from dolomitic marl to dolomite and limestone.

When the hornblendic rocks are plotted on the diagram, the striped amphibolite No. B.L.2404 and the massive amphibolite No. 51 fall in or near the field of dolomitic marl. The bulk chemical analyses are therefore ambiguous for on their sole evidence these rocks could either be igneous or sedimentary. In fact it has been decided that they are igneous; in one case on the evidence of trace elements and in the other on the evidence of relict igneous textures. However, if they were not igneous this would be their place in the sedimentary series.

Niggli values of the series semi-pelite to quartzite are shown on Fig. 15. In fact the Si value of the quartzite No. 35 is so high, 1780, that it cannot be shown on a reasonably sized piece of paper. However, the trend of the series is adequately demonstrated by No. 240 which is a very siliceous rock. Al, ALK, C and Fm are all plotted against Si, thus the effective means of separation is the relative quartz content. An average clay analysis, A, is plotted (Pettijohn, 1957, page 344) and is found to be considerably more siliceous than the group of semi-pelites analysed which reinforces the previous conclusions drawn about these rocks. There is a considerable separation between this group and the feldspathic granulite No. 170, which reflects the field recognition. An average analysis of silts from the Mississippi delta is also plotted, B, and is found to be midway between No. 170 and No. 240. There are undoubtedly many rocks in Connemara of this composition since the series is continuous. The actual silica content of this rock is the same as No. 170. The reason for its higher Niggli value is the lower alumina 10 per cent as against 14 per cent which thus allows a high proportion of uncombined silica to appear in the Niggli value. Thus the rock is in fact more quartzose than No. 170. A selected greywacke (Pettijohn, 1957, page 306) rather more siliceous than average and of very similar composition to No. 170 is plotted. It falls at very nearly the same spot as No. 170. In contrast, however, it has soda dominant over potash and it is this difference which has been previously stressed.

The siliceous granulite No. 240 is seen to be a near end member of a series from silica-poor clay through normal clay and siltstone of increasing silica content to quartzite.

An analysis of a true pelite from south Connemara (Leake, 1958) is plotted at D. This shows all the properties of the semi-pelites from the present area but is even more extreme in composition.

CHAPTER V

STRATIGRAPHY.

BASIS OF DIVISION INTO TWO SEDIMENTARY FACIES.

In previous chapters the difference in lithological type between the Aughris Peninsula and the Ballymaconry Peninsula has been strongly emphasized. It has been noted that there is a great contrast in the condition of the semi-pelite siliceous granulite series. On the Ballymaconry Peninsula semi-pelite is intimately mixed with siliceous granulite while on the Aughris Peninsula they are more clearly differentiated with semi-pelite dominant and siliceous granulite forming thin marker bands. Further the Ballymaconry Peninsula is distinguished by the presence of persistent pure white quartzites along its length which are not present on the Aughris Peninsula. The main Connemara marble horizon is also confined to the Ballymaconry Peninsula for although there are calc-silicate granulites and marbles on the Aughris Peninsula they belong to one thin, impersistent horizon which only gives a broad outcrop where the dip is moderate in the core and on the northern flanks of the Connemara anticline. The striped amphibolite only occurs on the Aughris Peninsula and is always associated with a band of siliceous granulite.

Thus the rocks of the two peninsulas are strikingly different. Those of the Aughris Peninsula are dominantly semi-pelitic with differentiated siliceous granulites and associated striped amphibolites, while a thin, discontinuous but persistent band of calc-silicate granulite is present at a single horizon. Those of the Ballymaconry Peninsula are dominated by undifferentiated semi-pelite and siliceous granulite in which are set pure quartzites and, along the northern margin a series of thick continuous marbles and calc-silicate granulites referred to as the Connemara marble.

It is clear therefore that two contrasted sedimentary facies are present. The sequence of the Aughris Peninsula is herein called the striped amphibolite facies while that of the Ballymaconry Peninsula is called the Connemara marble-quartzite facies.

It will be realised that tabulating a succession in a terrain of this nature is always difficult and often impossible. The intense nature of the isoclinal folding makes it inevitable that in some instances the same bed will be counted twice, while thickening of a formation at crests of folds will often be attributed to an original sedimentary condition. This is further complicated by the fact that in Connemara there is no good "way up" evidence apart from layered ultrabasic intrusions which are not present in the area studied. Working therefore on the basis that a dominance of clay represents deeper water conditions than the presence of thick, continuous sandstones and limestones, and that the usual observed sedimentary progression is from deep water to shallow water, it is assumed that the striped amphibolite facies is older than the Connemara marble quartzite facies. It is realised that sedimentary progression from shallow water to deep water is also often seen and therefore the hypothetical nature of the foregoing conclusion is emphasized. It is in fact little more than a convenient way of presenting the succession and in the light of future evidence may have to be inverted.

The danger of including the same horizon twice is particularly acute in the case of the striped amphibolite facies of the Aughris Peninsula where huge isoclinal folds are seen to wrap round the Connemara anticline. Indeed the prime difficulty here is finding a convenient point for the base of the succession for the same beds are repeated on both sides of the anticline.

Since the same calc-silicate granulite horizon is present at both the western end of the sedimentary series at Lough Nawarawaun and at the eastern end against the Clifden fault, it has been decided to fix the base of the succession arbitrarily at a mid point between the two at the source of the stream which enters Streamstown Bay at Doon Castle.

From here the succession passes across Streamstown Bay into the Ballymaconry Peninsula. The top of the succession is arbitrarily fixed in the middle of the main quartzite in the centre of the Ballymaconry Peninsula. This is done because it is believed to be the core of a large isoclinal fold closing to the west. The series of thin quartzites and marbles on the south side of the Ballymaconry

Peninsula are thought to have been brought in by drag folding and in all probability are the equivalents of parts of the succession already described, for example they may be the divided equivalent of the quartzite which runs into Kingstown Bay. Much of this however, is hypothesis and the tenuous nature of the suggested stratal sequence must be emphasized. The stratigraphical succession (Table X) follows overleaf.

TABLE X

STRATIGRAPHICAL SUCCESSION

CONNEMARA MARBLE QUARTZITE FACIES

QUARTZITE	900	feet	(This thickness may be doubled by folding of a bed 450 feet thick.)	
SEMI-PELITE + SILICEOUS GRANULITE	1,200	"	(With interbedded meta-dolerites up to 200 feet thick.)	
QUARTZITE	300	"		
BANDED GRANULITE	900	"		
CALC-SILICATE GRANULITE	20-100	"		
SEMI-PELITE	150	"		
MARBLE + CALC-SILICATE GRANULITE	500	"		4,000 ft.

STRIPED AMPHIBOLITE FACIES

SEMI-PELITE (ORTHOCLASE-BEARING)	200-500	"		
CALC-SILICATE GRANULITE	0-100	"		
SEMI-PELITE	200	"		
STRIPED AMPHIBOLITE	0-50	"		
SILICEOUS GRANULITE	100-300	"		
SEMI-PELITE	900	"		
SILICEOUS GRANULITE	200	"		
SEMI-PELITE	300	"		
SILICEOUS GRANULITE	0-200	"		
SEMI-PELITE	900	"		3,600 ft.
			TOTAL THICKNESS	7,600 ft.

The succession just given is of limited value for its base and top are both too indefinite and the complexities of folding make correlation within such a small area difficult. However, the recognition of the striped amphibolite facies, and the Connemara marble quartzite facies, is an important contribution which may prove useful during future work in the area.

In the striped amphibolite facies semi-pelite forms the base in which the other members are set. The siliceous granulites are sometimes discontinuous but in many cases a particular band may be traced for considerable distances. They do, in fact, form markers which help to elucidate the structure. These bands are shown on Map 1 and are seen to lie in tight isoclinal folds which pass from recumbency over the core of the anticline, to verticality on the limbs. The striped amphibolite is intermittently present at the top of the uppermost siliceous granulite and this combination is an invaluable horizon throughout the area. The constancy with which the succession siliceous granulite, striped amphibolite, semi-pelite, calc-silicate granulite is seen is remarkable and it is therefore considered that these are true stratigraphical horizons. This similarity in succession confirms the correlation of the calc-silicate granulite at the Clifden fault with that at Lough Nawarawaun even though exposure between the two areas is limited or absent. This particular formation, though inconstant, is traceable from Sellerna Bay in the north and west, over the crest of the anticline at Lough Nawarawaun, round the fold closure opposite Omey Island and thence along the north shore of Streamstown Bay until, as it is disappearing from the area, it begins its second sweep around the core of the anticline.

In this behaviour, it exactly duplicates that of the siliceous granulite bands which are seen to cross and recross the anticline several times.

This particular part of the stratigraphy therefore has proved invaluable in demonstrating the major structure though the complexity of folding may yet be too great for the true succession to be determined.

Within the Connemara marble-quartzite facies the marble itself is the basal and possibly the most important member. It is present along the complete length of Streamstown Bay. In the east it abuts against the Clifden fault and is here seen at its greatest uninterrupted thickness of 500 feet. It passes out into the Bay and under the drumlin of Boolard Island until at its next appearance it is seen to straddle the Bay at Doon Castle. From here onwards the Bay is eroded out along its length giving the extremely narrow strip of water called a fjord by the original survey. At the end of the peninsula it passes out to sea and around the nose of a fold, reappearing on the south side of Kingstown Bay. There is here another fold complementary to the previous one and its contour is shown on Map 1. This is the last appearance of the Connemara marble in the area.

Associated with the marble, and separated from it by a band of semi-pelite, is a persistent calc-silicate granulite which follows faithfully the outcrop of the marble. At the nose of the fold on the small peninsula between Kingstown Bay and Streamstown Bay it is greatly thickened, but is speedily separated by the interpolated banded granulite into two thinner bands which pass regularly eastwards and out into Streamstown Bay under a depressing heap of small drumlins. During this eastward passage it can be seen enclosed as a large tectonic inlier within the banded granulite. This repetition is due to the very tight folding. The two bands are seen to reappear on the east side of the bay but some changes have occurred. The most northerly band has been thinned tectonically and is now represented as a row of large boudins just south of the main marble outcrop; the southerly band however remains strong and passes eastwards to the Clifden fault where it closes round the nose of a fold. This closure is on the same axis as that seen in Kingstown Bay and its trace may be seen on Map 3. From this closure it passes continually westwards, across Streamstown Bay once more, just north of the ruined church until it eventually disappears into Kingstown Bay.

Associated with this band, and conforming to the same structure is the thick banded granulite. It is seen in the west as the core of a fold whence, passing eastwards over Streamstown Bay, it wraps round the calc-silicate granulite and from here turning westwards finally enters the sea at Kingstown Bay sandwiched the while between calc-silicate granulite and quartzite.

This quartzite is present along the whole length of the Ballymaconry Peninsula and is unique in that having vanished into the open sea it is again found on an island; Inishturk, the strike having changed considerably meanwhile. This change of strike is one of many indications that the Ballymaconry Peninsula is the core of a hugh isoclinal fold closing westwards; this particular quartzite is thought to close round the nose of the fold and reappear in Connemara further southwards. This at any rate should be easily proven or otherwise by future mapping.

The main quartzite in the centre of the peninsula is thought to be the core of this structure and for this reason it closes on itself before reaching the end of the peninsula. It has present along its northern flank a series of lenticular massive amphibolites of varying size. These may represent a series of lava flows at a particular horizon or a dolerite sill broken up by boudinage.

South of this quartzite a series of thin quartzite and marbles are developed and it is now considered that they form another subsidiary fold closing westwards. The two marbles near Clifden should close in the region of Clifden Castle but this is obscured by faulting. The three thin quartzites to the south are thought to be equivalent to the one thin one which runs along the southern margin of the central quartzite. This identity is apparent at the point above the words CLIFDEN BAY, Map 1, where the three quartzites are thrown out by a cross fold and on reappearance one quartzite only is seen. This continues westwards but its final destiny is concealed beneath drift. It is now thought that it joins up with its thin northern partner, here much thickened and that together they form a fold hinge in the bay above Ardmore. This fold can be considered as a relatively minor fold within the major structural unit of the Ballymaconry Peninsula.

The place in the stratigraphical column of these thin quartzites and marbles is not known and cannot be known until more information is available. For the present, the top of the succession is placed within the main central quartzite but this is on the whole unsatisfactory and in fact the question remains open.

It will be noted that in spite of the limitations of size and complex structure we have erected a sedimentary column of some 7,600 feet, no small achievement for an area of 35 square miles. This may well indicate that the Connemara schists represent a very considerable sedimentary series. It is perhaps better to regard the succession as being in itself of limited value, but certain of its members of considerable value. Within the striped amphibolite facies the siliceous granulite band with the associated striped amphibolite is a valuable marker, as is the band of calc-silicate granulite. Within the Connemara marble quartzite facies the Connemara marble itself is of prime importance and, closely associated with it, the thick banded granulite. The two thick quartzites are of major importance.

By following these formations eastwards it should be possible to establish a more definite stratigraphy. Their importance at this stage however is more likely to be in differentiating the structure.

The Sedimentary Environment.- In Chapter IV the conclusion was reached that the semi-pelites were originally fine grained shales relatively rich in clay minerals and relatively poor in silt. The dominance throughout the metasediments of potash over soda indicated that there was little, if any, greywacke present. These conclusions are complementary and indicate that sedimentation took place slowly enough for sedimentary differentiation of the alkalis to be effective. The fine-grained semi-pelite must have been deposited under quiet, stable conditions and it is suggested that a shelf sea deep enough to be beyond the influence of wave base would provide these. Alternatively, a deep trough of Euxinic type bordered by a low lying land mass could be envisaged. Pyrite is always present as an accessory but is never found in local concentrations as might be expected if it were formed under reducing conditions. This fact could perhaps indicate that the strata were not deposited under Euxinic conditions as suggested. The absence of greywacke type rocks indicates that conditions of rapid erosion and deep burial were not effective, rather, a picture of moderate relief and even sedimentation into a shelf sea is presented. The dominance of semi-pelite in the striped amphibolite facies is interpreted as indicating deep water conditions while the development of the siliceous granulites marked a short phase of shallowing. A second phase of shallowing is indicated by the thin calc-silicate granulite (dolomitic marl) which acts as a precursor to the main Connemara marble, (limestone-dolomite-dolomitic marl) 500 feet in thickness. This must have indicated either shallow water conditions, or a long period of little sedimentation, or both, and is strongly indicative of shelf as opposed to geosynclinal conditions.

Within the Connemara marble-quartzite facies it is considered that the lithology is representative of a shallow shelf sea. The various quartzites of extreme purity indicate widespread shallow water conditions while the condition of the semi-pelite in this facies, intimately mixed with feldspathic and siliceous granulites is strongly reminiscent of the interbanded siltstones and clays characteristic of deltaic deposits.

The whole picture then is of a shelf sea or trough being gradually enfilled with the onset of shallow water and deltaic conditions.

It is unfortunate that there are no sedimentary structures preserved within the area to provide "way up" evidence. The sequence of events envisaged here is similar to that demonstrated in Donegal in recent years, but in that region abundance of current bedding and other sedimentary structures confirms the sedimentary sequence. In the present region it is mainly a case of deduction with little corroborative evidence.

The metasediments are similar in character to the Dalradian of Donegal where an analogous sedimentary environment has been postulated (McCall, 1954). Although direct equivalence of the Connemara schists with the Dalradian cannot be proven, there is a strong possibility that they are of Dalradian age.

CHAPTER VI

STRUCTURE.

STRUCTURAL ELEMENTS PRESENT

Bedding.- This may be regarded as the primary structural element. Though often it cannot be directly seen, as in homogeneous semi-pelites for example, its presence and direction can generally be inferred from the directions of the boundaries between contrasting formations which are taken to be original bedding planes. In banded rocks, however, the bedding is directly visible between the different composition bands within the rock. The banded granulites are the most striking example of this, being divided into quartzose and feldspathic bands, with the mica preferentially concentrated in the latter. Careful search was made for current and graded bedding. A few very indeterminate examples were seen but nothing which was unequivocal. In most cases the supposed current bedding could easily have been due to slight distortion within one of the many micro-folds present. In all the examples seen the indication was that the beds "younged" southwards. Bedding may occasionally be seen in some quartzites and also in the striped amphibolites but in other formations it is not obvious.

Foliation Schistosity.- This is the dominant structural feature in Connemara. It was imparted with the first isoclinal recumbent folding and consists of a strong parallelism of the tabular elements within the rock to the axial planes of the folding. Since the folding is isoclinal the bedding is generally parallel to the axial planes of the folds and so bedding and schistosity largely coincide. Exceptions occur in the hinges of folds for when the beds swing round a closure the foliation continues in its own direction and intersects the bedding, generally at a high angle. This is particularly well seen on Inishturk and also on a small scale at the hinges of microfolds.

The schistosity is a parallelism of all elements in the rock but certain minerals show it more effectively than others. The micas and amphiboles give a strong schistosity but rocks in which these are deficient have poor schistosity and in these cases, as for example the quartzites, a slabby, widely spaced foliation is present instead.

Mullions.- These are chiefly to be seen in the banded rocks such as the quartzites, banded granulites and calc-silicate granulites. They are chiefly caused by intense micro-folding which gives the bedding plane an undulating fluted appearance. This is particularly evident in the quartzites. Due to this undulation the foliation frequently intersects the bedding and a strong sharp line is produced parallel to the direction of fluting. It is a "b" lineation and is parallel to the plunge of the microfolds. The whole structure, fluting plus lineation, is termed a mullion and its primary agency of production is the microfolding.

Microfolding.- Microfolding is seen in all the rocks and is frequently on a very intense scale. It is usually a miniature reproduction of an isoclinal fold with long parallel limbs and a sharp crest which often shows thickening. Quartz veins and segregations are generally puckered by small folds which plunge in the same sense as the other microfolds but are not otherwise similar, being slightly more open in character. The amplitude of the folds may be from several inches up to several feet but the latter case is uncommon. The axial planes of the microfolds are generally at a low angle to the schistosity, but in the case of the larger folds the angle may be somewhat larger.

Lineation.- This is present in all rocks though sometimes not macroscopically. It consists basically of an orientation of the linear elements of the rock (e.g. hornblende) which run in parallel lines across the foliation planes in the same direction as the plunge of the microfolds. Some minerals are more responsive than others to this influence. Micas and hornblende are generally much lineated while quartz frequently shows a striking parallel growth which is very evident upon weathered surfaces. On the Aughris Peninsula the fibrous mats of sillimanite are all strongly lineated. When feldspar is porphyroblastic in the semi-pelites and siliceous granulites it is often arranged in trains of elongate augen parallel to the regional lineation. In quartzites the parallel orientation of the quartz grains is very evident in the hand specimen. In short, the rocks as a whole have a strong linear fabric which is parallel to the plunge of the microfolds. The other linear elements, mullions and cleavage intersections also plunge in the same sense. In general the mineral lineations are regarded as "b" lineations but in at least one case there is the possibility that they are "a" lineations. True "a" lineations such as slickensides are minor in occurrence and obvious in character.

Boudinage.- This is generally seen on a small scale only but when developed it is extremely perfect in character. The length of an individual boudin is usually 1 or 2 feet. It is generally seen within the banded granulites where, presumably, the difference in competency of the bands provides suitable conditions. Small lenses of amphibolite are also sometimes seen to be boudinaged and in the tension gaps between boudins small pockets of quartz appear. In the case of the rocks at the east end of Streamstown Bay the calc-silicate granulite band immediately south of the Connemara marble is represented by a small cluster of boudins. These can be seen in the field to be boudins and are up to 30 feet in length. The plunge of boudins, where it can be determined, is parallel to the microfolds and other lineations.

Cleavage.- Cleavage is associated with all the periods of folding. It is in all cases an axial plane cleavage of the associated folding, or is so close to parallelism with

Plate 18. X 70. Strain-slip cleavage in semi-pelite. Foliae of intergrown muscovite and biotite sharply folded giving sweep extinction. Porphyroblasts of sericitized staurolite on flanks of the fold.

the axial plane that divergences may be disregarded. In the case of the isoclinal folding the cleavage has matured to a true schistosity which has already been described, but with later folding the cleavages cut the pre-existing structures in various ways. In the semi-pelites it is present as a strain-slip cleavage consisting of numerous tiny puckers or microfolds, the axial planes of which lie parallel and produce the cleavage. In thin section the original schistosity can be seen to be thrown into small folds, the micas being bent and broken in the apices and dragged down along the limbs to provide a new incipient schistosity. This can be well seen where the cleavage is at a large angle to the schistosity but where it is parallel or nearly so it is difficult or impossible to detect.

When the cleavage is present in harder rocks such as siliceous granulite or quartzite it is more widely spaced and is fault-like rather than fold-like in character. The foliation is cut and the lineations bent and displaced.

STRUCTURE TIME SEQUENCE

The First East-West Folding.- This is the most profound folding in Connemara. It took place during the metamorphism for the minerals were affected by the movements as they grew. Sillimanite, for example, is oriented in the same sense as quartz and other minerals and is not sericitised, altered or deformed in any way, as it would have been if the folding had taken place during the waning phases of the

Plate 19. Recumbent fold on the Clifden - Cleggan road lying approximately in the core of the Connemara anticline.

Plate 20. Recumbent fold on the Clifden - Cleggan road showing well developed "b" lineations on the left of the photograph.

metamorphism or subsequent to it. This applies to all minerals, sillimanite merely being used as an example. Similarly the folding did not take place before the metamorphism for, though the crystallizing minerals could have grown parallel to the pre-existing directions in the rocks it is unlikely that they would have done so as perfectly as is the actual case. Also the quartz-feldspar segregation veins would have been structureless whereas they are strongly microfolded and lineated in the same sense as the isoclinal microfolds and the mineral lineations. For these reasons it is concluded that the isoclinal folding occurred during the metamorphism, the metamorphic reactions and recrystallization taking place under the stresses of intense folding; and the secretion veinlets of quartz and feldspar were deformed as they were sweated out from the parent rock.

The majority of the structural elements seen are considered to have been produced by this folding. Mineral lineations, mullions and boudinage all plunge in the same sense as the microfolds which in turn plunge in the same sense as the major folds as observed on the small peninsula between Kingstown Bay and Streamstown Bay. They are therefore "b" lineations. The plot of these lineations from the whole area is shown on Map 4.

It is believed that the original folding resulted in the production of essentially horizontal nappes on a large scale, the present vertical position of some folds being due to distortion during the later formation of the Connemara anticline. The original attitude of the folds may be seen in the core of the anticline at Barnahallia Lough where a superb cliff face is exposed in which layer upon layer of recumbent isoclinal folds are piled on top of one another. The amplitude of each fold here is three to five feet while the distance from hinge to hinge is generally some hundreds of feet. There is little sign of shearing along the limbs which testifies to the extreme plasticity of the rock at the time of folding.

This piling up of the recumbent folds had the effect of reproducing the sedimentary succession several times. One of the major problems of Connemara geology is to assess the extent to which this has occurred.

The mechanism which could have produced such a pile of recumbent folds is difficult to envisage and one is again faced with the recurrent Alpine problem. Did they gradually subside or were they pushed? In Connemara there is no root zone, but the region is after all only a relatively small window exposed through younger rocks so roots might be concealed. Nevertheless, I do not personally favour a root hypothesis.

Since the "b" direction in the core of the anticline, where the original attitude is preserved, is roughly east-west it follows that the point of origin or transport must have been approximately either north or south. The picture envisaged, therefore, is of a land mass rising either to the north or south of the present area and the superincumbent sediments sliding off under the influence of gravity into the flanking trough where, they were piled up as a great stack of recumbent folds and regionally metamorphosed by the upward rise of geoisotherms concurrent with the mountain building.

An alternative hypothesis based on a suggestion by Dr. F.R.S. Henson, is that the recumbency of structure is due to primarily plutonic causes. Shearing of the deep basement along geosutures and lateral movement of the basement along wrench faults might make possible an under-riding movement of the basement beneath its sedimentary cover. This under-riding movement and the resulting drag upon the burden of sediment should be capable of forming large recumbent folds within the overburden while the heat from the friction of basement and sediment would be a possible contributory cause towards the metamorphism. This is not susceptible of proof within the area studied, but, bearing in mind the frequency of recumbent structures in metamorphic terrains it is worth serious consideration. In the present case the basement movement would have to be northwards or southwards along north-south trending wrench faults.

Whatever the mode of formation, however, the fact remains that during metamorphism, large scale isoclinal recumbent folds were produced and these are now described in more detail.

The folding is seen at its simplest in the belt of marble, calc-silicate granulite and banded granulite which occupies the south shore of Streamstown Bay. The beds here are almost vertical but have a slight southerly dip. The regional plunge of the lineations over this area is at approximately 30° to the west; these are illustrated on Map 4 and here it is shown that within the westerly part of the belt there is a good concentration at 20° - 30° while in the eastern portion the lineations decrease in plunge to 10° or less and a few cases of easterly plunging lineations are seen. This is symptomatic of a general tendency throughout the area for the lineations to become steeper towards the west and shallower towards the east. This shallowing tendency is completed somewhat to the east of the area now under study where there is a pitch culmination and the lineations begin to plunge in an easterly direction.

The dominant feature of this belt is the antiform which occupies the small peninsula between Kingstown Bay and Streamstown Bay, the trace of the axial plane of which is shown on Map 3.

This fold closes to the west with the same plunge as that of the regional lineations and microfolds; the core is of banded granulite, the closure of the other formations taking place out to sea. Inspection of the map shows that the closure of the calc-silicate granulite band is very nearly completed, since several infolds of the succeeding semi-pelite are seen which are in fact drag folds at the nose of the structure. The identity of the succession to the north and south of the banded granulite core leaves no doubt that the structure is a fold of considerable proportions. The extremely isoclinal nature of the folding may be gathered from the tightness of the fold itself and also from the large infolds of exotic material, for example the tectonic inclusion of calc-silicate granulite within the banded granulite terminated by a fault and, fairly close to, the semi-pelite inclusion within the calc-silicate granulite. These are the apices of associated isoclinal drag folds infolded within the major members and preserved by erosion.

Immediately south of this westward closing antiform, the same succession is thrown into an eastward closing synform the trace of which is shown on Map 3. The effect of this is that the beds which closed from the north round the nose of the antiform are now on the south of it and march eastwards where they close once more, and again passing westwards are finally disgorged into Kingstown Bay. This is best illustrated by the semi-pelite band between the Connemara Marble and calc-silicate granulite which is repeated three times within the distance of half a mile in the succession. The banded granulite makes a similar sigmoidal journey as do the other bands but here they become more difficult to follow.

The eastward closing synform is most clearly seen at the east end of Streamstown Bay; here the rather attenuated calc-silicate granulite bands close eastwards surrounded by a mantle of banded granulite. The closure is not actually seen because the bands eventually thin out to nothing but they get close enough to demonstrate their impending juncture. The ultimate disappearance is probably due to tectonic pulling and boudinage or perhaps merely to the normal confusion of the Clifden fault zone.

The centre of the synform is occupied by an isoclinally folded antiformal ridge of calc-silicate granulite. This may be regarded as an antiformal pucker along the base of the synform. Its antiformal shape can be demonstrated in a stream section at its eastern extremity; it continues in the centre of the structure until its final disappearance on the north side of Kingstown Bay. The Connemara marble itself having completed its westerly closure out to sea is seen on the series of small islands on the north side of Kingstown Bay and actually has its eastward synformal closure within the Bay itself. This is indicated by dotted lines on Map 1.

Both the eastern and western closures are very well exposed and their authenticity is in no doubt. It is extremely fortunate that this perfect sequence of complementary antiform and synform can be so clearly demonstrated, for the role of folding in Connemara has hitherto not been well understood and therefore any concrete knowledge of it in one place may well be capable of application elsewhere.

Immediately to the south of the structures just described lies the remainder of the Ballymaconry Peninsula and here it must be admitted that the structure is by no means obvious. It can be seen from Map 4 that the lineations

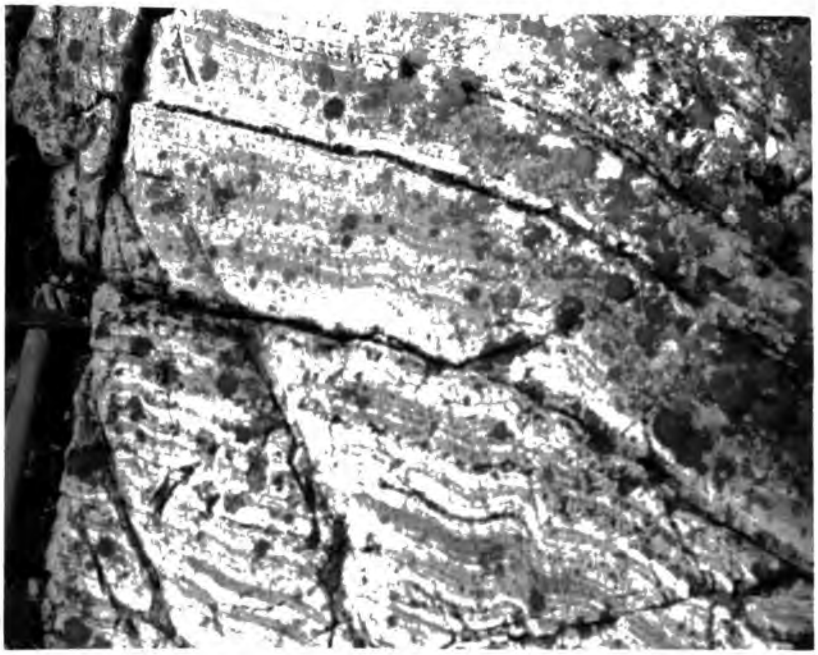


Plate 21. The quartzite on Inishturk. The banding gives the direction of bedding which is cut at a high angle by the prominent regional schistosity.

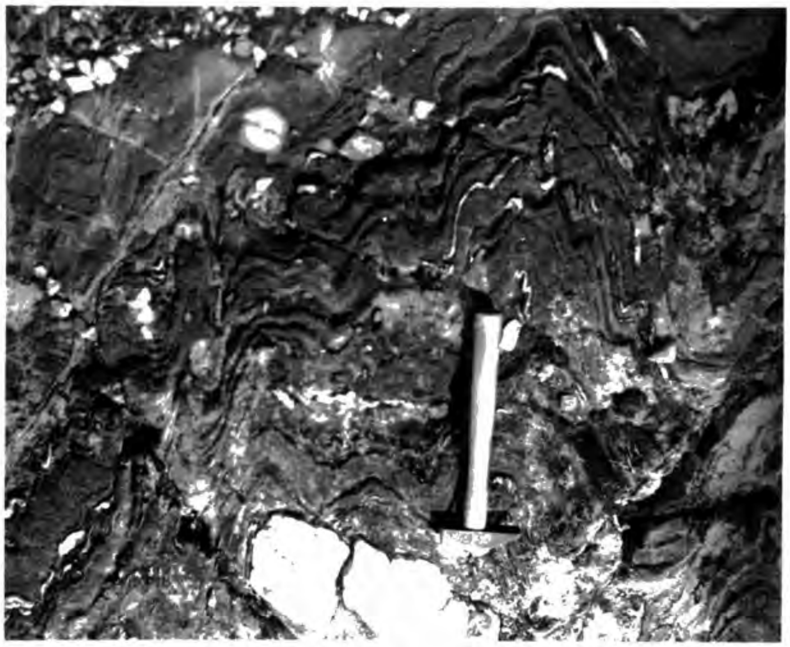


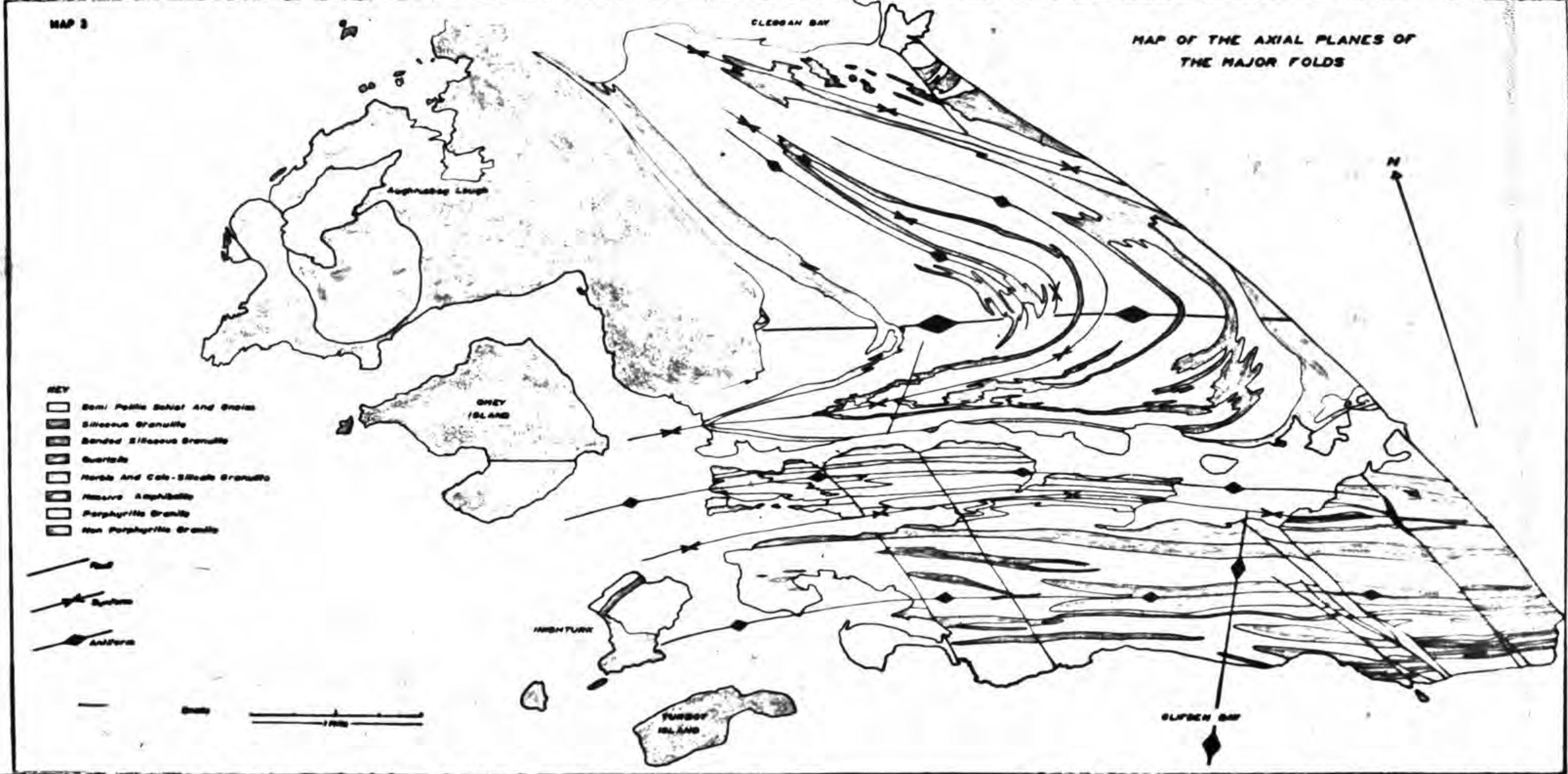
Plate 22. The Ballymaconry Peninsula opposite Inishturk. Secretion veinlets of quartz sweated out along bedding planes and strongly microfolded. The axial planes of the folding are parallel to the regional schistosity which cuts the bedding.

in the western part of the peninsula are strongly concentrated in very much steeper attitudes than in the belt to the north. This change is very rapid, for in the southward passage from banded granulite to quartzite there is an immediate change of 20° in the plunge of the lineations. The pattern of lineations decreasing in steepness eastwards is repeated here but with some interruption from a north-south cross fold shown on Maps 3 and 4.

The most striking feature about the peninsula is the central quartzite and its curious westward termination reminiscent of a fish's tail. Within these twin prongs the lineations steepen rapidly until they are at 80° or more in the noses. This is taken to indicate the closure of a fold, and indeed there must be something of that nature here or otherwise the quartzite would continue uninterrupted.

The northern quartzite, on its reappearance on Inishturk, has radically changed its strike, and is now most suggestive of a fold closure. In addition the regional schistosity now cuts the bedding at a high angle on a very large scale. This is well shown in one of the photographs from Inishturk and is firm evidence of a fold closure. The lineations on Inishturk also steepen up to nearly vertical and corrobate the interpretation of this feature in the central quartzite.

There is therefore strong evidence of a major fold closing westwards. Since the plunge is also westwards it can only be an antiform. The axial plane of this fold is


MAP 3
MAP OF THE AXIAL PLANES OF
THE MAJOR FOLDS
N
CLEGGAN BAY
OMEY ISLAND
INISHTURK
TURBOT ISLAND
CLIFDEN BAY
KEY
Semi Pelitic Schist And Gneiss
Siliceous Granulite
Banded Siliceous Granulite
Quartzite
Marble And Calc-Silicate Granulite
Massive Amphibolite
Porphyritic Granite
Non Porphyritic Granite
Fault
Syncline
Antiform

accordingly drawn through the central quartzite which is taken as being the core of the fold. It is thought that the northern quartzite closes round and eventually reappears in south Connemara possibly on the Erislannan Peninsula. The previously described antiform and synform affecting the Connemara marble are interpreted as the drag folds of a relatively incompetent formation mantling the antiformal structure of a competent formation.

The chief criticism of this interpretation is that whereas in the Connemara marble fold the succession was repeated, in the case of the present structure it is not, for the beds on the north side of the central quartzite bear no relation to the beds on the south side. This objection may be answered on one of the following grounds:-

(a) The central quartzite is not necessarily the true core of the antiform.

(b) The central quartzite is the true core but the southern part is complicated by subsidiary drag folding.

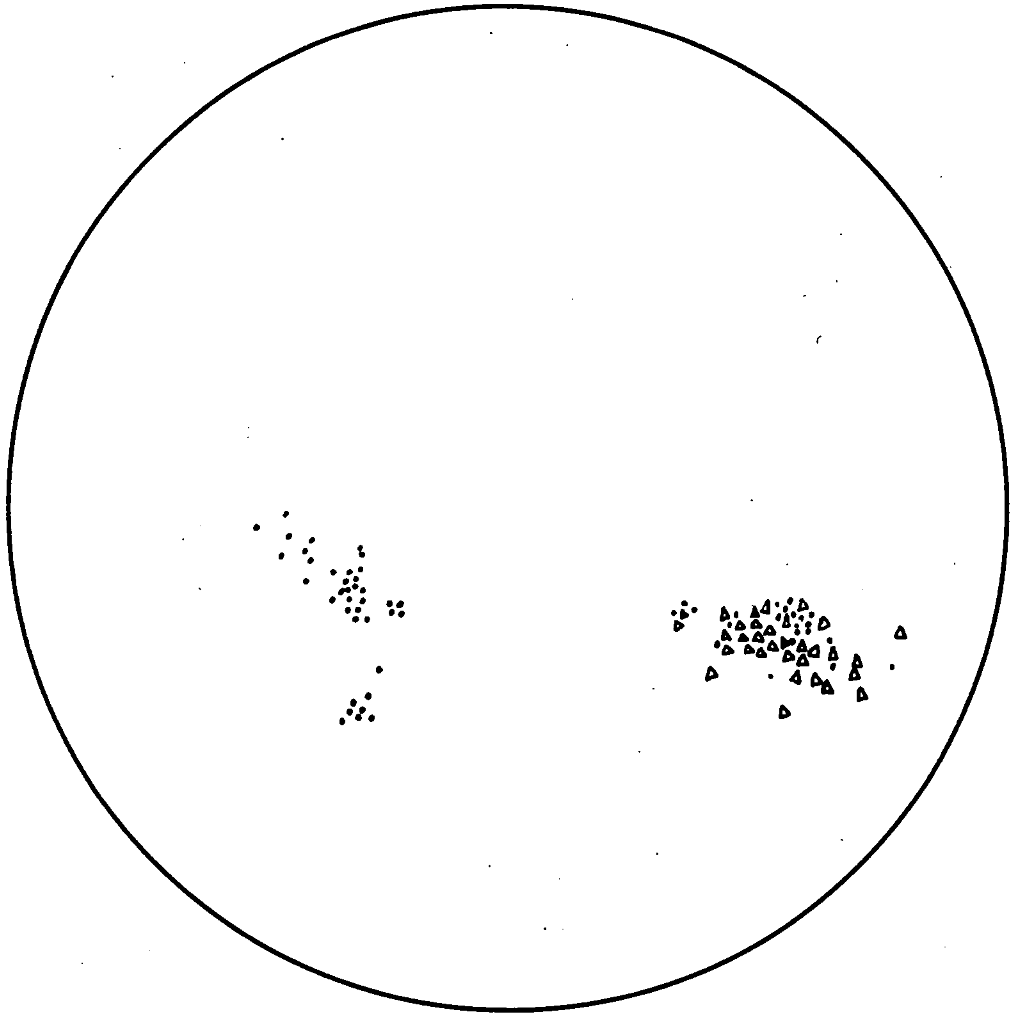
The central quartzite is not necessarily the core of the structure because only a part of the structure is seen; a considerable portion of it must lie in Clifden Bay and is probably partially represented on the Erislannan Peninsula (Map 5). The quartzite has been chosen as the core chiefly on account of its spectacular termination. It must be remembered that this formation is the chief of those forming the Twelve Bens, a considerable mountain mass for the British

Isles, the abrupt termination of which calls for some explanation. Such an explanation is provided by regarding it as the core of a westward closing antiform.

As noted in the previous chapter the series of thin quartzites and marbles lying to the south of the central quartzite is now regarded as a westward closing antiform. Here at least the criteria of repetition of the succession is satisfied, the two marbles are same one repeated while the three thin quartzites are the equivalent of the single thin quartzite running along the length of the central quartzite. These fuse into one to the west of the north-south cross fold (Map 3), and the identity is more obvious. At the time Map 3 was constructed, however, this structure had not been recognised and for that reason is not shown. It is now thought that the most southerly quartzite, shown terminated by a dotted line on Map 1, should in reality be joined to the quartzite immediately north of it which terminates in the bay above Ardmore. At the western extremity of this quartzite within the bay, the lineations are again very steep at 80° or more and by analogy with the central quartzite and Inishturk represent a fold closure. For these reasons the two quartzites should be joined in the hinge of a westward closing antiform in the bay just above Ardmore.

This structure may be the true core of the major structure or it may be a subsidiary drag fold within it, but at present it is impossible to say which.

FIG 16



• MINERAL LINEATION

▲ MICROLDS

LOWER HEMISPHERE PLOT OF THE LINEATIONS AND MICROFOLDS FROM THE BARNAHALLIA DISTRICT

Thus we have concrete evidence of westward closing structures on Inishturk, in the central quartzite and in the quartzites north of Ardmore. The cumulative evidence of a major antiform is therefore impressive and in no matter what way the detailed geometry may be eventually solved it will almost certainly be within this major framework.

Turning now to the area north of Streamstown Bay we notice that the dominating feature is the westward closing synform in the Barnahallia district. It will be remembered that this structure was considered in connection with the thermal metamorphism in this area. The question is immediately asked, why is this westward closing structure a synform whereas previously all westward closing structures have been antiforms? The answer to this is given on Map 4, in the stereogram for the Barnahallia district and also in Fig. 16 which is the same enlarged. In Fig. 16 it is seen that the lineations plunge westwards at about 50° while the microfolds plunge eastwards at 30°. It must be stated that at present the reason for this is not understood; two immediate possibilities are:-

(a) That the westward plunging lineations are "a" lineations.

(b) That two periods of folding are represented.

The lineation plunging west at about 50° is the strong mineral lineation characteristic of the whole area while the eastward plunging microfolds are the steep-limbed isoclinal folds elsewhere associated with the lineations.

Although very careful search was made over the area it was not possible to see if either of these structures was later than the other but the possibility of finding such evidence should not be ruled out. Where the rocks are hornfelsed the lineations are destroyed and the eastward plunging microfolds emphasized.

The possibility that the granite had moved the country rock so that the westward plunging structures became eastward plunging was considered, but rejected on the grounds that the westward plunging lineations were in fact still present and, if anything, in a steeper attitude than in the marble belt.

Since the microfolds are very prominent it is considered that they play the dominant part in the structure particularly so as the adjacent Connemara marble antiform also closes westwards and if the lineations were considered definitive we would be faced with the fact of two adjacent antiforms and no intervening synform. By regarding the eastward plunging microfolds as "b" lineations the Barnahallia structure becomes a synform, and this course has been followed.

As can be seen from Map 4 the eastward plunging structures die out towards the east and the overall westerly plunge again becomes dominant though at a much reduced value.

It is apparent from Maps 1 and 3 that the Barnahallia structure is the dominating one on the Aughris Peninsula for the secondary folding of it and its associated folds by the

Plate 23. East-west folds in quartzite on the south side of the Ballymaconry Peninsula. The horizontal plunge is caused by the north-south cross folding rotating the plunge from west 50° to 0°.

Plate 24. East-west folds of rather open style in quartzite. The horizontal plunge is due to the north-south cross folding as in Plate 23.

Connemara anticline produces the complex pattern of folds which is the chief feature of the area. The associated folds will therefore be described in relation to the Connemara anticline.

<u>The North-South Folding</u>.- During the past two years B.E. Leake has mapped the Ballyconneelly dome, a north-south trending structure lying to the south of the present area within the migmatite belt. This structure is demonstrably later than the isoclinal folding for these folds are distorted by the dome and its associated cleavages. Its relation to the second period of east-west folding, i.e. the formation of the Connemara anticline, is less clear but it has been shown that the north-south cleavages associated with the dome are traversed by a set of east-west cleavages which are possibly associated with the Connemara anticline. If this is so then a period of north-south folding intervenes between two periods of east-west folding. Within the area studied over most of the Ballymaconry Peninsula a strong north-south cleavage is developed which is particularly well seen in the quartzites. On the south side of the peninsula the lineations rapidly become horizontal and for a short distance plunge eastwards at a shallow angle before resuming the regional westward plunge. This is illustrated in Map 4, while Map 3 shows how the transverse buckling of the rocks causes the temporary pitching out of three thin quartzites. There is also a slight deflection in strike of the central

Plate 25. The mineral lineation of the quartzite plunging west at 20° is cut and deformed by the prominent vertical strain-slip cleavage associated with the north-south cross folding.

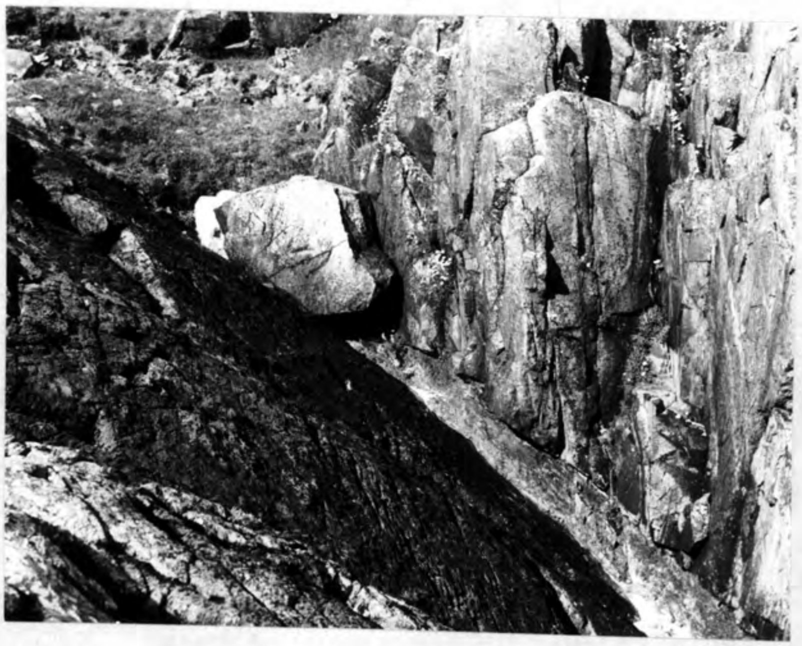


Plate 26. Small thrust plane with gouge near the southern contact of the Omey Island granite.

quartzite and the thin quartzite on its southern margin, and it is quite clear that all this is the effect of the northward prolongation of the Ballyconneelly dome which is rapidly dying out. North of the central quartzite few effects are seen apart from cleavage but on the south shore of Streamstown Bay the lineations are horizontal over a short distance. This is the last effect seen of this structure; on the other side of the Bay east-west structures prevail.

It is possible that the culmination east of the area studied is produced by a similar mechanism and may be another axis of north-south folding. At present however there is little positive evidence for this.

The Second East-West Folding.- This period of folding is considered to have produced the dominating feature of the area, the Connemara anticline, a considerable structure of some 30 or 40 miles observed length and one which may continue out to sea. Its culmination is approximately over the Omey Island granite so that it presumably extends a similar distance westwards. It can be recognised on High Island some 5 miles out into the Atlantic which is structurally in the core of the anticline. Here the foliation dips west at about 30°. The structure as a whole probably continues for a further 10 or 15 miles and is among the larger single structural units in the British Isles.

The isoclinal folds of the first east-west folding are bent like sedimentary strata about this second east-west axis and are disposed as steeply plunging folds on the flanks and horizontal recumbent folds in the core. The subsequent effect of erosion upon this complicated geometry produces the structure of Connemara as we see it today.

Within the area studied the fold is assymetric and appears to be almost a monocline with its shallow limb facing north and its steep limb facing south. This impression is, however, gained partly because an incomplete section across the anticline is seen at this point; north of the area studied the rocks dip just as steeply as those of the southern limb.

A very strongly developed set of cleavages are seen in the core of the anticline where they cut the recumbent isoclinal folds at a high angle. This cleavage is also present along the limbs but is difficult to detect for it is then parallel to the general foliation. It can, however, occasionally be seen as small folds of about 1 inch in amplitude bending the foliation.

Microfolds are associated with the folding and, though few, they are quite large when they occur. They are generally present in or near the core of the anticline as cylindrical folds 10 - 20 feet in length which plunge at 10° - 20° east and bend the foliation, lineations and microfolds. They too have an associated cleavage identical to that within the main structure. We have evidence, therefore, that the anticline plunges eastwards at 10° - 20° at this point, probably increasing in plunge beyond the area.

The effect of the second east-west folding upon the pre-existing isoclinal folding is most clearly seen on the Aughris Peninsula which is now described.

The manner in which the isoclinal folds are secondarily disposed about the axis of the anticline may be seen on Map 1 where their recumbent nature in the core and steeply dipping attitude on the flanks is well illustrated. The antiform complementary to the Barnahallia synform is folded about the axis of the Connemara anticline and is therefore now seen as a synform (Map 3). A similar process operates for all the other structures, the axial planes of the isoclinal folds are folded about the anticline and structures which are synforms on one side are antiforms on the other.

Since the anticline plunges at 20° the eastward plunging lineation at Barnahallia (Fig. 16), is simply rotated about this axis and is seen on the northern side of the anticline as an eastward plunging lineation at 10° - 20°. This is only possible because the plunge of the secondary folding is similar but not coincidental to the plunge of the primary folding. For this reason we are able to see westward closing synforms on both sides of the anticline. The objection that these are in fact "b" lineations associated with the Connemara anticline is answered by the fact that they are different in style of folding to the anticline and its associated folds and that they are recumbent in the core and steep on the flanks and further, are cut by cleavages associated with the anticline.

The westward plunging lineation seen at Barnahallia is moved to the horizontal position as it is rotated about the axis of the anticline until, gradually increasing its angle as the beds become steeper, it eventually assumes an easterly plunge. This lineation therefore is westerly plunging on the south side of the anticline and easterly plunging on the north side. On the north side of the anticline then there are two easterly plunging lineations, one at a high value and one at a low value; the one of a high value is on the whole dominant but does not completely obscure the other which becomes more evident when intense microfolding is seen in the siliceous granulites.

These various changes in orientation of the lineations can be seen on Map 4. In the core of the anticline where the foliation is at a low angle the lineations have a correspondingly low plunge and are located on the periphery of the stereogram on the same strike, or trend as those seen at Barnahallia. Thus the westerly plunging mineral lineation seen at Barnahallia moves to the periphery in the south west quadrant in the core of the anticline. It then appears on the periphery in the north east quadrant and from there moves to the interior of the stereogram as the dip increases northwards. Similarly the eastward plunging lineation is brought to the periphery in the core of the anticline but on passing to the north of the anticline it remains in very nearly the same place. The stereogram on the north west of Map 4 shows it to be absent and here the other mineral lineation is quite dominant.

The interplay of these two lineations is therefore complex. It is felt that in all probability they represent two periods of folding but, as previously stated, it has not so far been possible to prove this.

The most northerly structure seen, a westward closing synform in siliceous granulite has its northern limb much broken and boudinaged. This may merely be the consequence of extreme plasticity during folding, i.e. normal boudinage, or it may be disruption due to interference of one set of structures with a pre-existing set; in other words, folding of the shallow easterly plunging structures by the steep easterly plunging structures. This is no more than a suggestion for a future line of enquiry.

A further feature which should be mentioned at this point is that on the northern limb of the anticline a very strong strain-slip cleavage is present dipping north at about 35° and cutting the foliation at a moderate angle. It is the axial plane cleavage of a set of assymetric microfolds which plunge to the east north east at about 10°. This must represent yet a further phase of east-west movement but as far as is known at present no similar structures have been reported elsewhere in Connemara.

Emplacement of Granites.- After the various periods of folding a series of post-kinematic granites were intruded; these will be described in the chapter following.

Faulting.- Two directions of faulting are present, one striking N.W.-S.E. and the other N.E.-S.W. and of these the former is by far the most important.

The faulting occurs at least after the formation of the Connemara anticline for the Clifden fault traverses the structure and displaces the axial plane somewhat. The precise degree of displacement is not known partly because of poor exposure but chiefly because the evidence lies outside the area studied. The faulting is probably also post-granite emplacement for there are at least two faults within the granite showing the north west trend.

The north west direction seems to be dying out northwards for while it is strongly represented on the Ballymaconry Peninsula the only representative on the Aughris Peninsula is the Clifden fault. In particular, two very clear faults on the western half of the Ballymaconry Peninsula fail to make the small jump across Streamstown Bay. Here, however, two members of the north east set take over and it is fairly clear that the two sets are complementary.

It will be noticed that in the fault-zone near Clifden Castle there are three closely spaced north east trending faults which, it is thought, are release fractures complementary to the dominant north west faulting.

The angle between these two directions of faulting, 45° - 50°, suggests that they are normal faults, the result of tension applied in an east-west direction. That there is a considerable vertical component is demonstrable in certain cases, for example, the Clifden fault itself at Streamstown.

Here beds which would normally dip east actually dip west and this displacement is due to drag against the fault plane which hades to the west. Elsewhere evidence of vertical movement is difficult to find and in fact at close quarters the faults seem to be tear or wrench faults, almost always with a sinistral throw. However, the angle between the two sets of faults does not favour this hypothesis for if east-west compression was operative the north east trending set should run east north east to west south west at a very much more acute angle to the compression direction. The hypothesis of tension is favoured by the facts that dykes are often found along the faults and that the strike direction of the swarm of lamprophyre and porphyry dykes is not dissimilar to that of the north west faulting. Since the dykes could only be intruded under conditions of tension these same conditions may have been the controlling factor during the faulting.

Compression and wrench faulting is favoured by the fact that on the coast section opposite Omey Island a very beautiful small thrust is seen, the strike direction of which is that of the north west striking faults.

Arguments for both normal faulting and wrench faulting can therefore be found and it is not impossible that both these processes were operative. The displacement of formations along many of the faults appears insignificant; many of the more prominent faults in the field show hardly

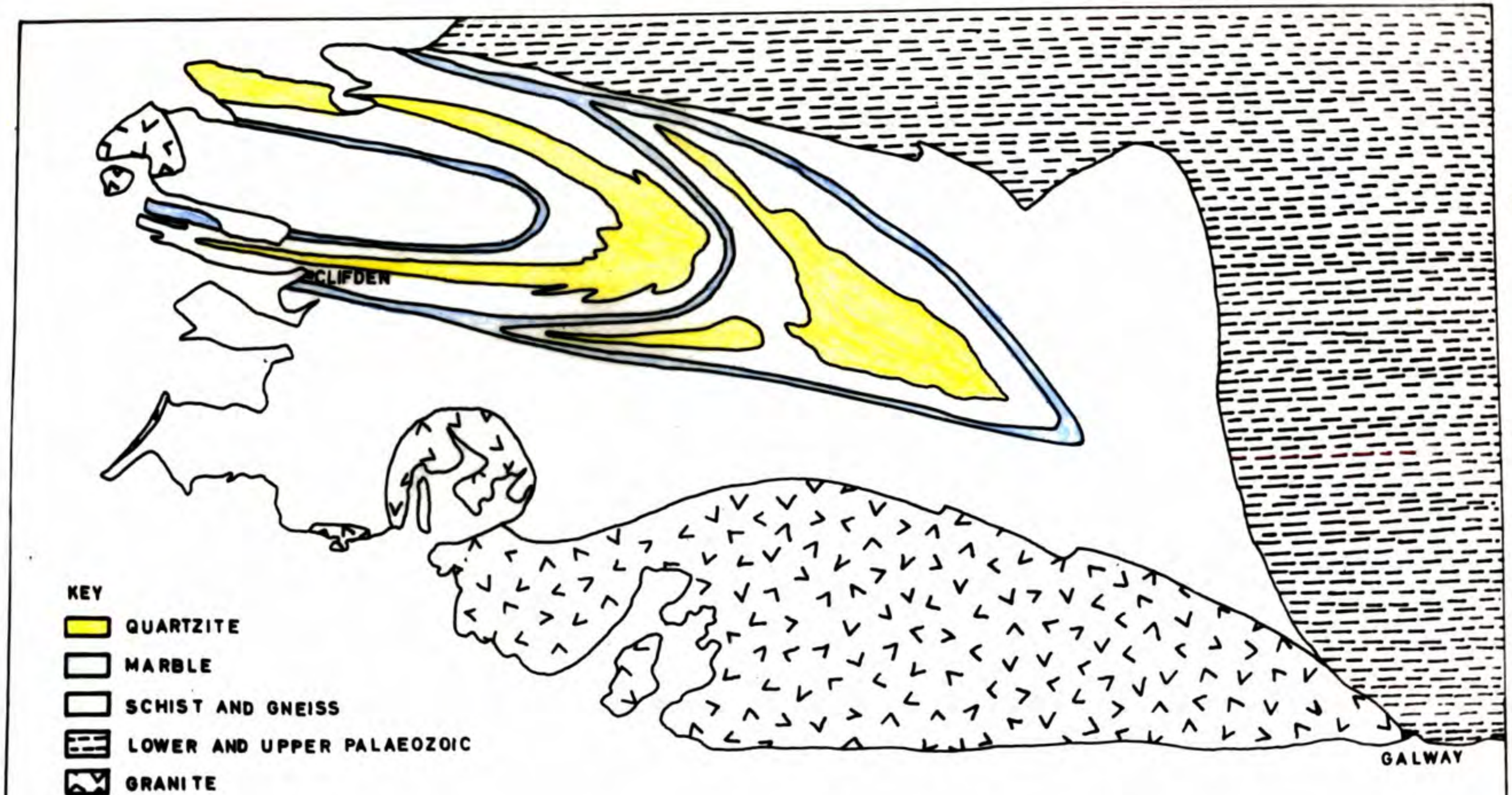


FIG 1.7
SKETCH MAP OF THE GEOLOGY OF CONNEMARA

any displacement. The greatest seen is along the Clifden fault itself where the Connemara marble is thrown ½ mile to the north to the vicinity of Streamstown.

Mineralization.- Both sets of faults are in places mineralised. Networks of hydrothermal quartz recement and vein the fault gouge and in these veins small pockets of pyrite and chalcopyrite can be found. These are of no economic importance. The Irish in their unbounded optimism have in the past attempted to work these and considerable shafts remain as monuments to their energy but it is difficult to imagine that these veins ever could have been economic and now all the workings are abandoned.

MODEL OF THE CONNEMARA ANTICLINE

The small map Fig. 17 is a generalized map of Connemara based on that of the original survey and showing the distribution of the major formations. The most striking feature is the presence of the two large quartzite masses, the Twelve Bens and the Maamturks, and the fact that they seem to be completely enveloped by formations of marble.

The coloured plate, Fig. 18a, shows two recumbent folds one lying above the other. The upper one has overridden the lower so that its "b" direction is at a markedly divergent angle. In Fig. 18b these recumbent sheets are cross folded about an east-west axis and a plane of erosion

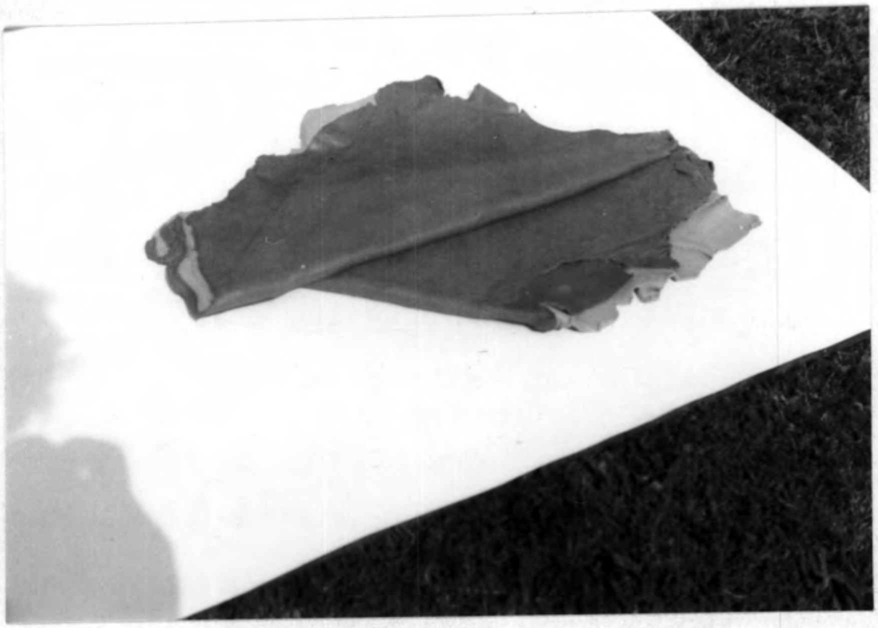


FIG 18a

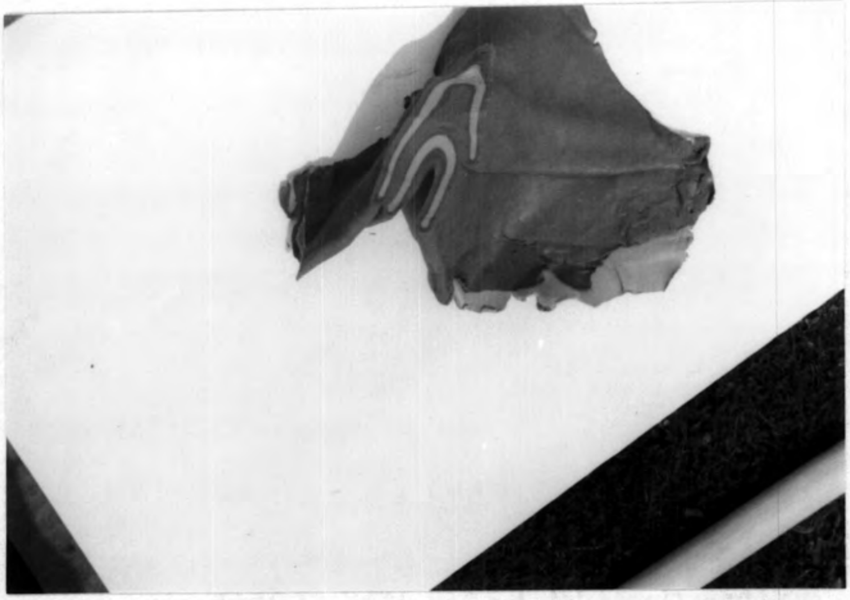


FIG 18b

- Quartzite
- Connemara marble
- Striped amphibolite facies

MODEL OF THE CONNEMARA ANTICLINE

is produced. The resulting sectiom across the secondary fold gives a disposition of formation strikingly similar to that seen on Fig. 17.

In spite of this similarity the correspondence between the model and the map is by no means exact. On the basis of the model for example one should expect to find at least two marbles lying between the Twelve Bens and the Maamturks while the striped amphibolite horizon should also be present at this point. At the time of writing it is not known whether this is the case but further investigation at this point may prove fruitful.

Lack of correspondence between model and map is also seen in the Maamturks. Here there is a considerably body of quartzite which the map shows to be detached from the main mass and this is now known to be true (personal communication J. Starkey). The model shows a continuous connection at this point. There are in addition probably many other discrepancies of varying magnitude between the model and actual fact. It would, however, be expecting too much for a simple model of this nature to agree exactly with the structure as shown at present. Only two periods of folding are shown whereas certainly three and probably four periods are really present. The fact that such a comparatively simple model can produce a relatively close semblance of reality is in itself a recommendation of its value.

There is therefore some degree of correspondence between hypothesis and fact, a correspondence that is sufficiently close to merit the serious consideration of the hypothesis during further work. A recommendation of the validity of the hypothesis is the fact that it is an application of the process discovered during the present study, namely cross folding of recumbent isoclinal folds. While it is by no means propounded as a final solution it is the first working model to be produced of the structure of Connemara, and for this reason if no other, it may be of some value.

CHAPTER VII

POST-KINEMATIC IGNEOUS ROCKS

THE GRANITES OF WEST CONNEMARA

Subsequent to the formation of the Connemara anticline a number of granites were intruded. These are all very similar in petrography and composition and in all probability are related to the main Galway granite which they closely resemble. At the western end of the area studied two granites are intruded, the Omey Island granite and the Turbot Island granite. The Omey Island granite is itself intruded by a finer grained granite which is situated virtually in the centre of the main body. This second granite is better considered with the Omey Island granite as it is obviously closely related and is structurally continuous with it.

The Omey Island Granite

Field Relationships.- This granite is emplaced within the core of the anticline approximately at the culmination. It is essentially a round pluton but in detail its surface configuration is determined by the enclosing country rock. This is extremely well seen in the Barnahallia district. On the coast opposite Omey Island the granite contact runs due east-west parallel to the strike of the metasediments, while it dips south at 70°. Thus the strike and dip of the granite contact is the same as the country rocks at this point. The granite then turns north towards Barnahallia Lough and at the corner of the turn it can be seen to make teeth-like indentations into the country rock whose strike is now abruptly halted by the granite. This "nibbling" action of the granite shows that the metasediments must have been in this attitude before the granite was intruded. From Barnahallia Lough to Sellerna Bay the granite contact is not well exposed but it can nevertheless be traced parallel to the strike of the metasediments which, now being on the northern limb of the anticline, is north-west. There is a suggestion here that the granite has slightly bowed out the country rock in order to accommodate itself. It would be interesting to know here the dip of the granite contact. Owing to poor exposure it cannot be seen except at Sellerna Bay where it is conformable to that of the metasediments which are here quite steep. In the core of the anticline though, where shallow dips prevail, the contact is poorly exposed and one wonders whether the dip of the granite contact is also low. The contact is again seen on the island of Cruagh and Friars Island and although landings were not made on these, the contact could be clearly seen from the boat in beautifully exposed cliff faces. On both these islands the contact is conformable with the country rock.

Thus in the case of the Omey Island granite the country rocks at nearly every point are parallel to the

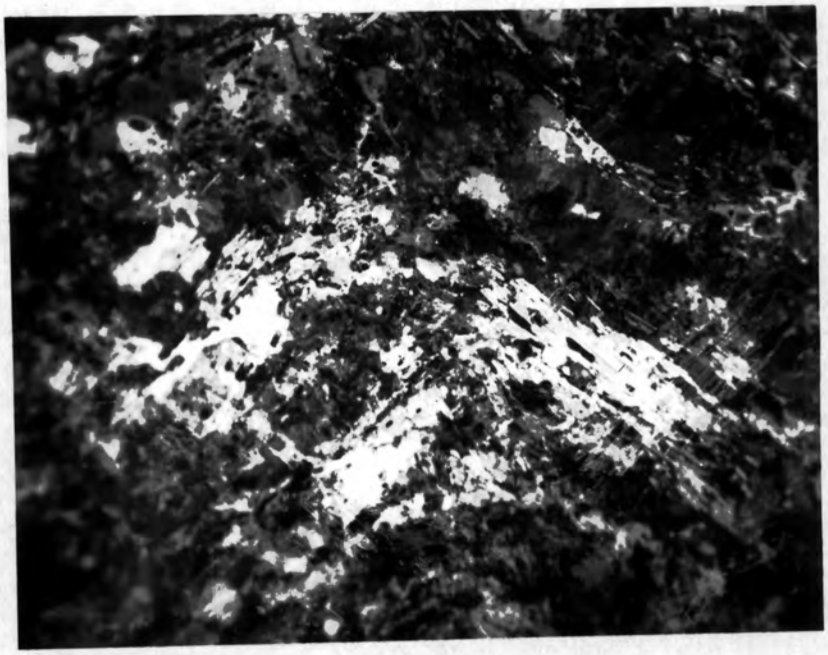


Plate 27. X 70. The strain-slip cleavage produced during the formation of the Connemara anticline preserved in a recrystallized cordierite - orthoclase hornfels.

Plate 28. Contact of the Omey Island granite. Sheets of country rock rafted off as xenoliths from the steeply dipping strata on the right of the photograph.

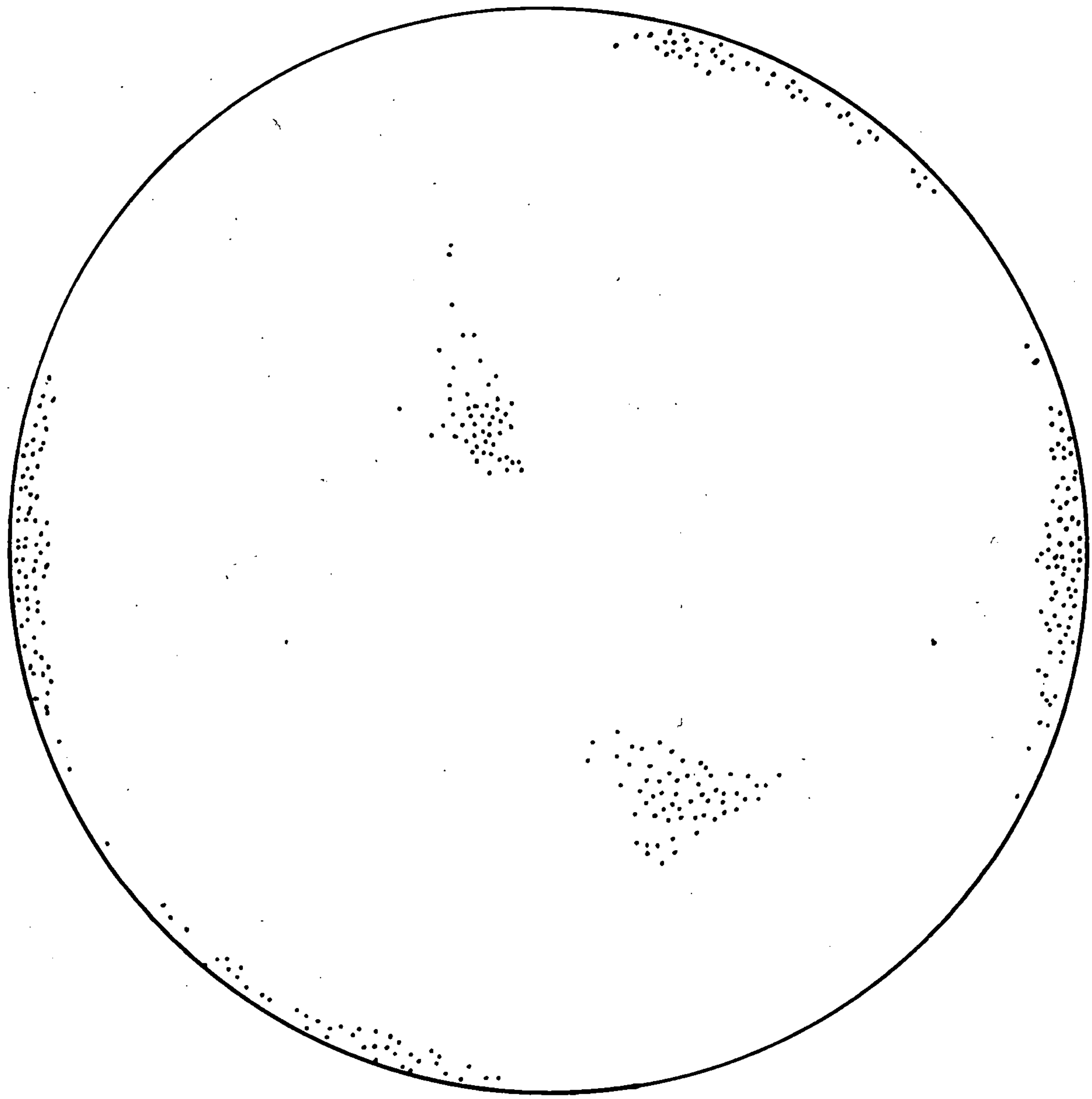
granite contact. This is due not to moulding of its carapace by diapirism during intrusion, but simply to the fact that it is intruded into the pitch culmination of the Connemara anticline which forms an ideal accommodation structure for an intrusive granite.

The contact itself is pencil sharp against the metasediments which are strongly hornfelsed. There is no zone of permeation and hybridization but there are many xenoliths of country rock. In places where the contact is parallel to the strike these are fairly large and are simply rafted off and held in their original orientation or only slightly displaced. Where the contact has a cross-cutting relation to the country rocks the xenoliths tend to be more numerous and smaller; and here they are in every possible orientation. It is quite clear that they have floated in a liquid medium and there can be no doubt that the granite is a magmatic one.

In the vicinity of Barnahallia Lough the rocks are brecciated on a large scale and in places the breccia is recemented with granite veinlets. A chilled marginal facies is developed at Barnahallia Lough and also at Sellerna Bay. In character it closely resembles quartz-feldspar porphyry for it contains quartz and plagioclase phenocrysts set in a fine grained matrix of quartz and potash feldspar. It is very similar to some of the local dyke rocks.

There is therefore overwhelming evidence of the magmatic state of this granite at the time of its emplacement.

FIG 19



LOWER HEMISPHERE PLOT OF THE POLES OF THE JOINTS OF THE OMEY ISLAND AND AUGHRUSBEG LAKE GRANITES

This is almost certainly true of the other small granites in Connemara and probably true of the Galway granite itself.

Within the Omey Island granite a smaller fine grained granite is intruded in the neighbourhood of Aughrusbeg Lake. It is approximately circular in form and is very near the centre of the Omey Island granite. The contact between the two granites is not well seen but there does not seem to be any sensible alteration in either of the granites. One curious fact is that the granite is relatively coarse grained on the margins and fine grained towards the centre where it resembles a quartz porphyry. It may be that the inner granite was intruded while the outer granite was still hot. This would account for the coarse margin and lack of alteration. The fine grained central part is more difficult to explain. If, however, it were the feeder of a volcanic pipe, eruption at the surface and the consequent loss in volatiles and lowering of pressure may have resulted in the rapid cooling of the liquid central part. This is pure hypothesis and no proof is offered.

Structure.- Both the Omey Island granite and the Aughrusbeg Lake inner granite are jointed throughout in the same fashion. Three sets of joints are present and these are shown on the accompanying stereogram, Fig. 19. These three directions of jointing are remarkably constant throughout both granites and may be found equally strongly developed both at the margins and in the centre. There is no suggestion of radial jointing at the margins as described by Cloos (1925).

The joint faces are often coated with sheets of terminated quartz crystals and where there is much hydrothermal activity the granite is reddened on either side of the vein. This hydrothermal activity is confined to certain directions of jointing, being most common in the direction which strikes due east-west. It is confined to two sectors, one along the south shore of Aughrusbeg Lake and one along the south shore of Omey Island. These are shown on Map 1 and the Omey Island set dip north at 70° while the Aughrusbeg Lake set dip south at 30°. They therefore dip to a focus in the centre of the granite. The veins at Aughrusbeg Lake cut both the Omey Island granite and the Aughrusbeg Lake granite.

The veins themselves are up to 4 inches thick and are primarily composed of quartz with quantities of muscovite and are generally greisen like in character; pyrite and chalcopyrite are sporadically distributed in euhedral crystals but molybdenite is by far the most common sulphide mineral. This is unevenly dispersed in the veins in small nests and pockets. Individual crystals are possibly up to ¼ inch in size but are generally much smaller.

The other joint directions occasionally have quartz veins associated with them but these are always completely barren.

The nature of the jointing indicates that its formation is due to regional forces rather than to those produced during the cooling of the magma. These forces must have been operative after the formation of the Connemara anticline and at present little is known about them. The fact that the joints cut both the Omey Island and the Aughrusbeg Lake granites indicates that they both cooled under the same system of stresses. In all probability they both cooled together, the Aughrusbeg Lake granite being intruded before the Omey Island granite had become solid enough to fracture into a joint system.

Aplite veins are sparsely distributed throughout the granite. They are generally thin, an inch or two in thickness, but may sometimes be up to 5 feet thick. They occur associated with the various joint directions and also cutting the rock haphazardly. Pegmatites are totally absent both from the granite and about its margins.

The granite is faulted in the north west - south east direction which is dominant in the area. The granite is shattered and crushed along the fault zones and huge gullies and caves are eroded in them in the coastal sections. The only known occurrence of an east-west fault occurs on Omey Island where a wide shatter belt some 10 yards in thickness of crushed granite traverses the island. The line of this fault can be seen on Map 1. It is suggestively opposite the opening to Streamstown Bay and may indicate that the bay may also be eroded along a line of east-west fracture. The evidence here is ambiguous. The narrow bay may be due to erosion along a fault line or it could equally be due to erosion along the outcrop of the Connemara marble. East-west faults would be extremely difficult to detect in the metasediments since this is the prevailing strike direction and the presence of this fault within the granite may indicate a direction of general faulting.

The granite was undoubtedly intruded prior to the faulting which is therefore one of the later phases in the structural evolution of the area.

Petrography of the Omey Island Granite.- In hand specimen the Omey Island granite is a coarse grained leucocratic rock. Clear round crystals of quartz are set in a matrix of white plagioclase crystals. The quartz and plagioclase are equigranular, in the size-range 2 to 5 mm. Large phenocrysts of pink perthitic orthoclase are dispersed in rectangular crystals up to 25 mm. in length but are generally much smaller. These crystals frequently show Carlsbad twinning. Biotite is evenly dispersed throughout the rock.

The rock is an adamellite in composition and shows very little variation over its outcrop. Whatever variants are seen tend to be granitic in composition and in general these tend to be found towards the margins of the body. This tendency, however, is sporadic and it is not suggested that there is any zoning within the granite. Table XI overleaf is a modal analysis of a typical example.

TABLE XI

MODAL ANALYSIS OF THE OMEY ISLAND GRANITE

QUARTZ	41.0
PLAGIOCLASE	25.0
ORTHOCLASE	26.6
BIOTITE	5.9
HORNBLENDE	0.7
OPAQUE	0.8
TOTAL	100.0

Where there is any change in composition the quantity of plagioclase remains stable and the proportions of quartz and orthoclase vary.

In thin section quartz is seen to be equidimensional with allotriomorphic margins interlocking with the surrounding grains. The quartzes in general are strained and show wavy or patchy extinction; they occur either singly or as groups of two or three crystals.

Plagioclase crystals are rectangular in shape and are idiomorphic in character, showing well-defined albite twinning. They are frequently zoned and the composition varies from oligoclase in the core to albite on the margins of the crystals; normal igneous zoning is in fact displayed. The crystals are frequently altered to sericite and this alteration seems to pick out the zoning in some cases, the basic cores being more strongly altered than the acid margins.

In contrast to the plagioclases in the metamorphic rocks these igneous plagioclases never contain any inclusions.

The large crystals of orthoclase though apparently euhedral in hand specimen are seen in thin section to have extremely allotriomorphic margins penetrating between other crystals and enclosing them within the feldspar crystal. They are very strongly perthitic and the veins of perthite are frequently arranged tangentially to the plane of the Carlsbad twinning in a herring-bone effect. Interstitial orthoclase perthite is also present within the ground mass. It is always allotriomorphic in character and has the appearance of having come from an interstitial liquid filling in the space between the crystals.

An interesting microscopical relationship is developed between the feldspars. Where plagioclase is in contact with orthoclase a thin rim of thread like myrmekite is developed around the margin of the plagioclase crystal. The myrmekite is rounded towards the orthoclase and is clearly developing at the expense of that mineral. Cases of euhedral rectangular plagioclase with a rim of myrmekite are common. Myrmekitic relationships between plagioclase and quartz are not seen or are only very minor in importance.

Biotite is dispersed through the rock in single crystals but is sometimes seen in groups of crystals. It is generally euhedral, pleochroic light to dark greeny brown in colour and is frequently chloritised.

Plate 29. X 70. Omey Island granite. Rim of myrmekite surrounding zoned plagioclase which is enclosed in a perthite crystal.

Plate 30. X 70. Omey Island granite. Chilled marginal facies. Large zoned plagioclase phenocryst embayed by small quartzes of the ground mass at its margin.

Hornblende is very occasionally present in small euhedral crystals and is generally dark green or greeny brown in colour. Accessory minerals include apatite, epidote and sphene. Apatite is most frequently seen as inclusions within the biotite; epidote is also associated with biotite while sphene is associated with the opaque minerals but not always so. The opaque mineral present is nearly always pyrite but magnetite and ilmenite are also present.

The chilled marginal facies has phenocrysts of rounded quartz and euhedral plagioclase set in a matrix of orthoclase and quartz. There is the same quantity of plagioclase in the chilled rock as in the unchilled rock - 20 to 30 per cent - and the modal composition of the two facies is virtually identical. The plagioclase is zoned in the same way as that just described and in some instances the plagioclase phenocrysts are embayed by the surrounding matrix showing some degree at least of magmatic corrosion. Biotite is present in the same way as the main granite, as are epidote and apatite. Hornblende and sphene are absent.

There is thus fairly clear evidence that a magma of adamellitic composition was intruded. The condition of the magma at the time of intrusion is considered to have been a suspension of plagioclase and quartz crystals in a fluid of potassium-rich composition. The slow cooling afforded by the plutonic conditions allowed the development of coarse orthoclase crystals which, during the later phases of cooling and solidification underwent exsolution, developing perthitic textures. The perthite also reacted with the pre-existing plagioclase to give rims of fine myrmekite.

Petrography of the Aughrusbeg Lake Granite.- This rock is much finer grained in hand specimen than the Omey Island granite and its chief mark of contrast is that it is not markedly porphyritic. Generally it is an evenly coarse grained rock with rounded clear quartzes set in a mottled matrix of feldspar which is dominantly pink in colour but flecked through with white. In the fine grained examples the overall pink colour is more pronounced. Biotite is evenly dispersed in single crystals throughout the rock. This granite is again an adamellite in composition and a modal analysis of a typical example is given in Table XII.

TABLE XII

MODAL ANALYSIS OF THE AUGHRUSBEG LAKE GRANITE

QUARTZ	39.2
PLAGIOCLASE	27.5
ORTHOCLASE	31.6
BIOTITE	1.4
MUSCOVITE	0.7
TOTAL	100.1

In thin section quartz is in rounded equidimensional crystals of about 1 mm. diameter which have fairly well defined margins; but in some cases it shows allotriomorphic margins and can be seen to embay plagioclase crystals. The plagioclase is nearly always euhedral and strongly twinned. It is generally in the range 1 to 2 mm., but is occasionally large enough to have a porphyritic texture relative to the surrounding grains. Zoning is common and well developed, a central core of oligoclase being rimmed by a thinner zone of albite. Myrmekite rims to the plagioclase are rare and poorly developed but may occasionally be seen where plagioclase and perthite are adjacent to one another. Sericitization of the plagioclase is common and is nearly always dense in the cores of the crystals and absent at the rims.

Orthoclase is generally interstitial in character and seems to have a coarse poikilitic texture enclosing both quartz and plagioclase. Carlsbad twinning is developed in the larger crystals and perthite segregations are arranged in a herring-bone pattern about the twin plane.

Biotite is scattered in sporadic single crystals, often rather ragged-looking and nearly always chloritised. Muscovite occasionally fringes biotite but is more usually dispersed in very occasional small crystals.

Accessory minerals are epidote, sphene and apatite. The relationships of these are identical to those within the Omey Island granite; apatite occurs as inclusions in biotite, epidote very often adjacent to biotite and sphene associated with the opaque mineral which is usually pyrite.

A very little tourmaline has also been detected in this rock.

The chief mark of contrast between this inner granite and the outer Omey Island granite is the finer grained non-porphyritic texture and the presence of muscovite. The interstitial and poikilitic nature of the perthite crystals indicates that they may have been part of the residual magmatic liquid. The corrosion of plagioclase by quartz crystals is also an indication of the magmatic history of this granite.

The fact that it contains muscovite as well as biotite shows that relative to the Omey Island granite it is enriched in volatiles and this suggests that it is probably a later differentiate from the main granite body at depth. Thus the Aughrusbeg Lake granite is in all probability a later member of the granite series than the Omey Island granite.

The Turbot Island Granite

<u>Field Relationships</u>.- The Turbot Island granite is seen on the islands of Inishturk, Turbot and Eeshal, in several inconspicuous reefs and breakers and is intruded approximately at the nose of the westward closing structure on the Ballymaconry Peninsula previously discussed. The margin is seen on Inishturk only and is extremely complex. There is no question of conformability of the margin to the surrounding

structure as with the Omey Island granite for the metamorphic rocks and structures are truncated abruptly and absolutely by the granite. Since this is one of the most westerly parts of Europe, no further exposure of the country rock is seen.

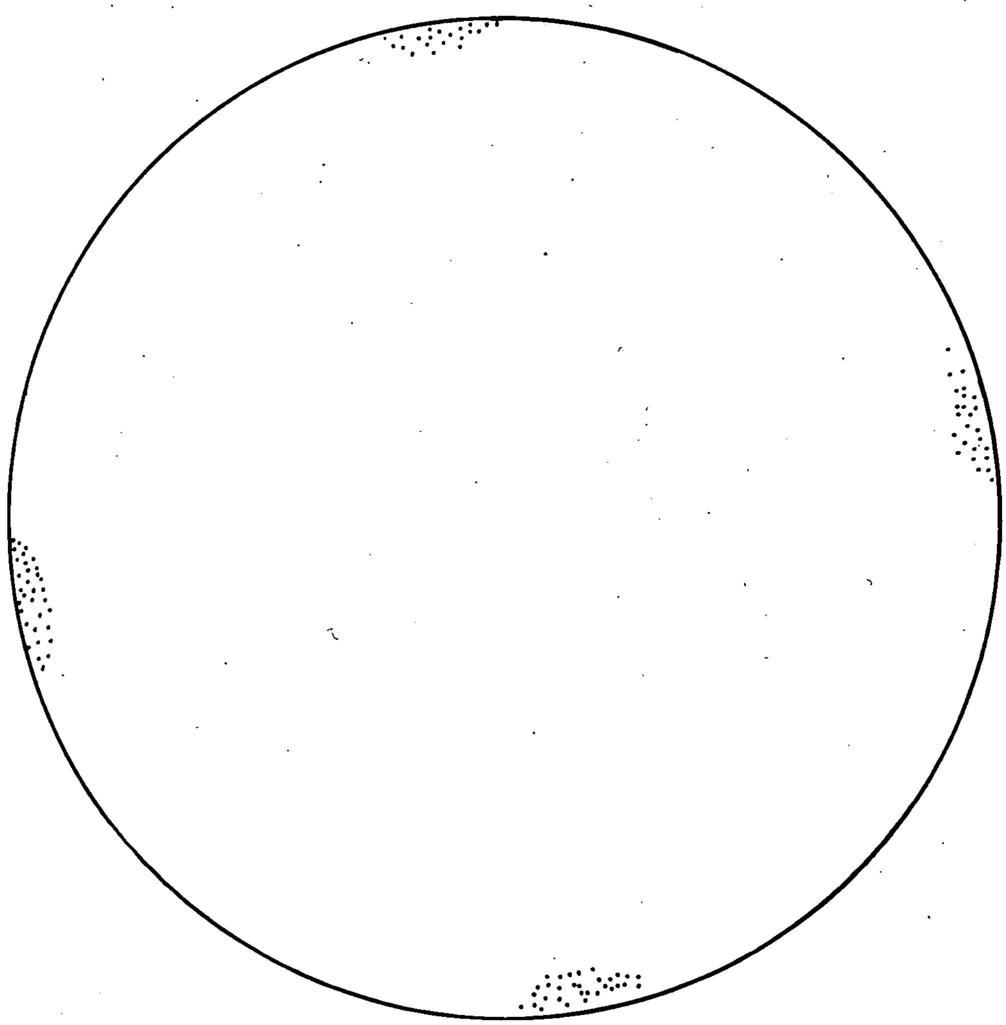
A broad aplitic margin is developed around the granite and it is this which forms the actual contact with the country rock. The aplite was emplaced later than the granite which it intrudes with numerous sills. Sill injection is in fact the major feature of the contact area. Numerous sills of varying sizes are intruded into the country rock on one side and the granite on the other. Exposure here is well nigh perfect and an excellent three-dimensional picture of the contact phenomena is obtained along the rugged coastal section. Large blocks of country rock can be seen to be wedged off by the mechanism of sill injection which extends for a considerable distance into the country rock. The contact is therefore extremely complicated, for the rugged topography successively exposes aplite sill or country rock. Thus windows of aplite within country rock are common, as are rafts of country rock in aplite. Map 1 gives some idea of the irregularity of the contact.

The country rock is strongly hornfelsed but it has not been studied in the same detail as has that around the Omey Island granite, partly because this was one of the last areas to be mapped and time was running out, and partly because the rocks at this point are granulitic rather than semi-pelitic and are consequently deficient in sensitive indicators of thermal metamorphism. The semi-pelites collected have considerable quantities of cordierite, but only small quantities of andalusite were seen in thin section, and none in the field. This, however, may have been due to composition rather than to any differences in the type of thermal metamorphism. The hornfelses are as thoroughly recrystallized as those from the inner part of the Omey Island granite aureole and it is thought that they can be grouped in the same metamorphic facies, namely the hornblende hornfels sub-facies of the amphibolite facies.

The aplite is remarkable for the strong development of horizontal features of peculiar type. Layers of coarse perthite three or four inches thick can be seen. These sometimes have large plates of biotite associated with them but are more frequently barren. Sills and layers of white aplite within pink aplite may also be seen. In fact the dominant character of this marginal aplite is the intense development of horizontal structures both within itself and branching from it into the granite on one side and the country rock on the other.

<u>Structure</u>.- The granite is everywhere jointed in the same pattern. Two sets of joints are developed nearly at right angles and in addition a set of horizontal joints is frequently seen. The joint pattern is the same both in the granite proper and in the marginal aplite. Thus the same features

FIG 20



LOWER HEMISPHERE PLOT OF THE POLES OF THE JOINTS OF THE TURBOT ISLAND GRANITE as those seen in the Omey Island and Aughrusbeg Lake granites are duplicated here though the actual directions of jointing are slightly different; these directions are shown in Fig. 20. Presumably, therefore, the granite cooled under a system of regional stress which controlled the development of the joints. The granite would appear to have been solid at the time of aplite injection so that the joints seen in the aplite, though similar in direction, must have been formed after those seen in the granite. The same stress field must therefore have persisted for a considerable period of time.

No faults can be seen to cut the granite but this may well be due to the fact that a much smaller proportion of it than the Omey Island granite can be seen.

It is thought that this granite, by analogy with other granites of Connemara, is probably circular in cross section and is in all probability a vertical plug or boss passing downwards into a granitic batholith below.

Petrography.- The Turbot Island granite is strikingly similar to the Omey Island granite with the exception that it has large and extremely abundant phenocrysts of perthitic orthoclase which are the dominant feature of the rock. This exceptional development of orthoclase phenocrysts is the most striking feature of the Turbot Island granite and distinguishes it from all the other granites of Connemara. In other respects, however, it bears a strong family resemblance and in particular resembles the Omey Island granite.

In hand specimen the large orthoclase phenocrysts, up to 40 mm. in length, are set in a matrix of white plagioclase, orthoclase and large rounded quartzes while, as in the other granites, biotite is evenly dispersed in single crystals. The rock is again an adamellite and a modal analysis is given in Table XIII below.

TABLE XIII

MODAL ANALYSIS OF THE TURBOT ISLAND GRANITE

QUARTZ	35.8
ORTHOCLASE	30.2
PLAGIOCLASE	30.1
BIOTITE	2.9
OPAQUE	1.0
TOTAL	100.0

In thin section quartz is in large rounded crystals, in the range 2 to 5 mm., with allotriomorphic margins, generally in clusters of two or three crystals and with the smaller crystals included in perthite. Plagioclase is euhedral and strongly twinned. It is often zoned, usually with a core of oligoclase and a rim of albite but in several cases the reverse condition has been noted. Sericitization of the plagioclase is common and is generally confined to the centre of the crystal. This is the case both in normal and reversed zoning, thus suggesting hydrous potash-metasomatism at an early stage followed by re-deposition of feldspar at the margins of the crystals.

Orthoclase is present both as large phenocrysts and as interstitial material which sometimes encloses quartz and plagioclase poikilitically. The phenocrysts are twinned on the Carlsbad law and though the shape is well defined the actual crystal margin is very often irregular. Perthite segregations are strongly developed in the same way as the other granites. Where plagioclase is in direct contact with perthite a thin rim of thread like myrmekite is developed. This is an extremely common phenomenon and very similar to the same feature in the Omey Island granite.

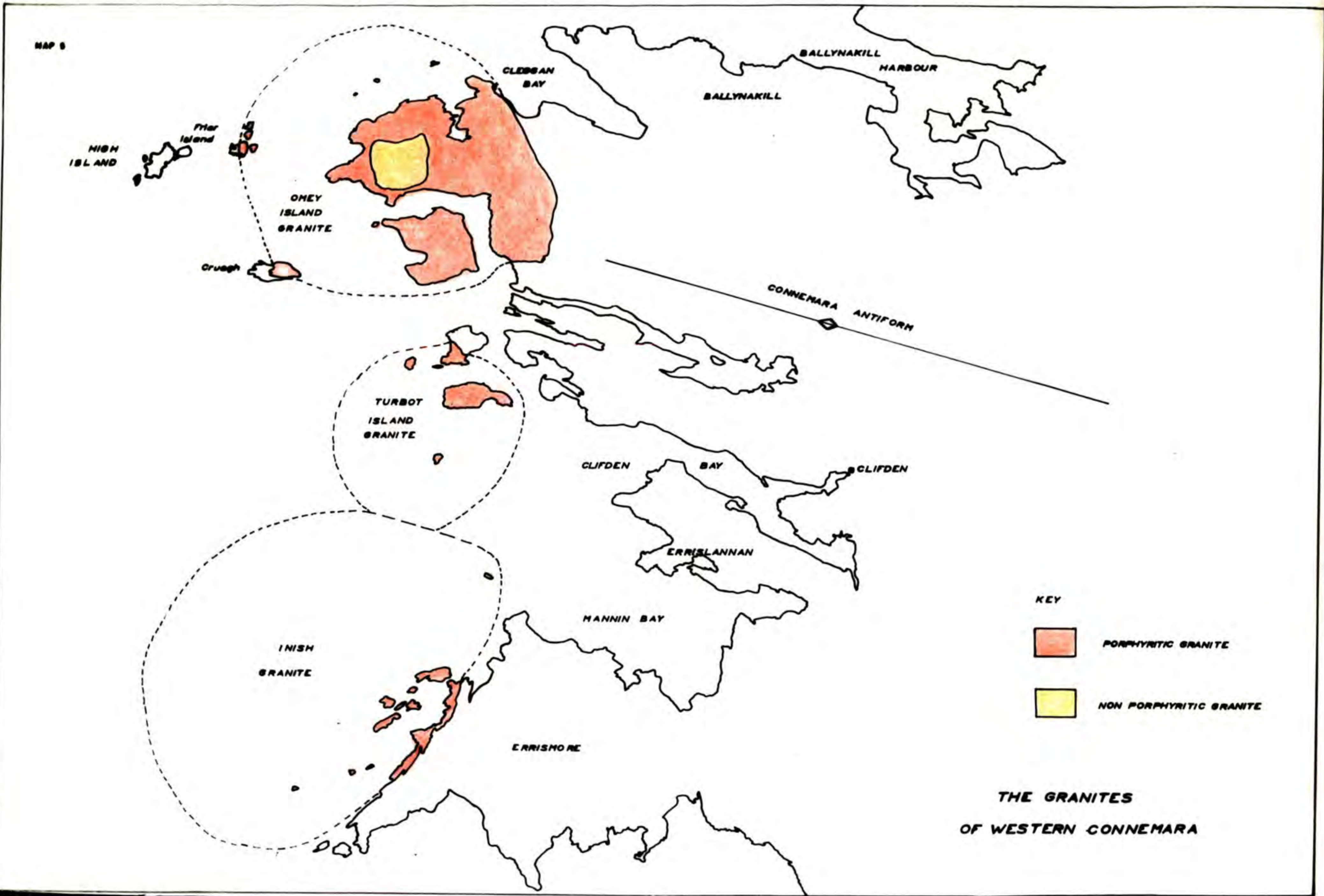
Biotite is dispersed in single crystals and is light browny green to dark green in colour. It is generally strongly chloritized. Apatite is found as inclusions in the biotite and the opaque mineral, usually pyrite, is also frequently closely associated.

The plutonic history of the rock would appear to be very similar to that of the Omey Island granite for the mineral relationships are virtually the same in both cases. A magmatic history is envisaged with orthoclase as the latest forming fraction. This has developed as phenocrysts where it had room and where it had not, it enclosed quartz and euhedral plagioclase in a coarsely poikilitic base. The perthite and myrmekite development are later features related to subsolvus conditions (Bowen and Tuttle, 1950) occurring during the final cooling of the solid rock.

RELATIONSHIPS OF THE GRANITES OF WEST CONNEMARA

The distribution of the granites is shown on Map 5. The Omey Island and Turbot Island granites lie within the area studied and have been discussed, the Inish granite has been mapped by B.E. Leake and has been visited by the present writer. It has been so called because it is chiefly exposed on the numerous islands. The map shows the proportion of actual granite exposed and how much must be covered by the Atlantic Ocean. It will be realised in the case of the Turbot Island and Inish granites how conjectural the margins really are.

The Omey Island granite is fairly clearly defined as a circular boss by its fortunate exposures on Cruagh and Friars Island but the margins of the other granites are less definite. It was at one time thought that the Inish and Turbot Island granites were one body but close inspection indicated that this was probably not so. As previously mentioned, the main feature about the Turbot Island granite is the striking development of orthoclase perthite phenocrysts. The Omey Island granite has far fewer phenocrysts while over the whole of its visible outcrop the Inish granite has hardly any orthoclase phenocrysts at all. It is common experience in Connemara that any individual granite is remarkably uniform in appearance over the whole of its outcrop but that there may be considerable textural differences between


MAP 5
HIGH ISLAND
Friar Island
Cruagh
OMEY ISLAND GRANITE
CLEGGAN BAY
BALLYNAKILL
BALLYNAKILL HARBOUR
CONNEMARA ANTIFORM
TURBOT ISLAND GRANITE
CLIFDEN BAY
CLIFDEN
ERRISLANNAN
MANNIN BAY
INISH GRANITE
ERRISMORE
KEY
PORPHYRITIC GRANITE
NON PORPHYRITIC GRANITE
THE GRANITES
OF WESTERN CONNEMARA

closely adjacent but similar granites. This is the case with the Roundstone, Errisbeg Townland and Murvey granites from the Roundstone district. It has been concluded, therefore, that the Inish and Turbot Island granites are two separate granites and are not one single body. Since the Omey Island and Roundstone granites are circular in form it is assumed that these are also, particularly since the Inish granite at its exposed contact gives a definite impression of an arcuate section. The conjectural outline of these granites is shown on Map 5. It will be seen that the Turbot Island and Inish granites have a common boundary over a short distance. They were probably intruded at slightly different times and quite probably one granite takes a large bite out of the other, but which one is undecided. Geochemical evidence may help here for presumably the granite which is most enriched in volatiles is the later and is intrusive towards the other one.

The boundary will probably be modified in the light of such evidence, but meanwhile Map 5 is useful in that it shows the number, form and extent of the granites in this highly dissected and poorly exposed district of West Connemara.

THE DYKES

Field relationships of the dykes

A swarm of lamprophyre and quartz feldspar porphyry dykes traverses the area in an approximately north-south direction. These dykes are small in the area studied, rarely exceeding 10 feet in thickness and usually less than 5, indeed some of the lamprophyres are only six inches thick. Further eastwards, however, and outside the present area the dykes, particularly the porphyries, assume considerable dimensions.

The dyke swarm is in no sense radial with respect to the Omey Island and Turbot Island granites but it does bear a radial relationship to the main Galway granite lying to the south of the area.

Both porphyry and lamprophyre dykes have been intruded along the north west and north east faults, but though association of dykes and faults is common they are not always so associated. The Omey Island granite is cut by both lamprophyre and porphyry dykes but the Turbot Island granite is not; indeed the Turbot Island granite encloses blocks of lamprophyre as xenoliths.

The dykes intrude the rocks quite sharply with no dislocation or brecciation, and they have no apparent metamorphic effects upon the metasediments. This is the case even where they intrude calc-silicate granulites and limestones.

An east-west swarm of olivine-dolerite dykes traverses the area and these vary from 5 to 20 feet in thickness. They cut the north-south dyke swarm and also the Omey Island granite but are not seen to cut the Turbot Island granite which, however, may well be due to the insufficient exposure of this granite.

These dykes are strongly jointed in columnar fashion, perpendicular to the margins; they have prominent chilled margins and are generally bordered by a dyke breccia or gouge some few inches in thickness. They are medium to fine grained in texture and frequently have amygdales filled with zeolites and chlorite.

Petrology

The lamprophyres.- These are dark medium grained melanocratic rocks, sometimes with small phenocrysts of biotite and hornblende 2 to 3 mm. in length, and in some cases a slightly pinkish colour in the ground mass. These rocks are dominantly hornblendic but biotite is common and pyroxene is occasionally seen. They are rather variable in composition and a modal analysis of a typical example is given in Table XIV below:-

TABLE XIV

MODAL ANALYSIS OF A LAMPROPHYRE

GREEN HORNBLENDE	22.0
TREMOLITE	6.2
ORTHOCLASE	55.0
BIOTITE	3.2
CHLORITE	13.1
OPAQUE	0.8
TOTAL	100.3

Plate 31. X 70. Lamprophyre. Ordinary light. Green hornblende rimmed by tremolite in optical continuity. The remainder of the field is occupied by chlorite, orthoclase, plagioclase, sphene and apatite.

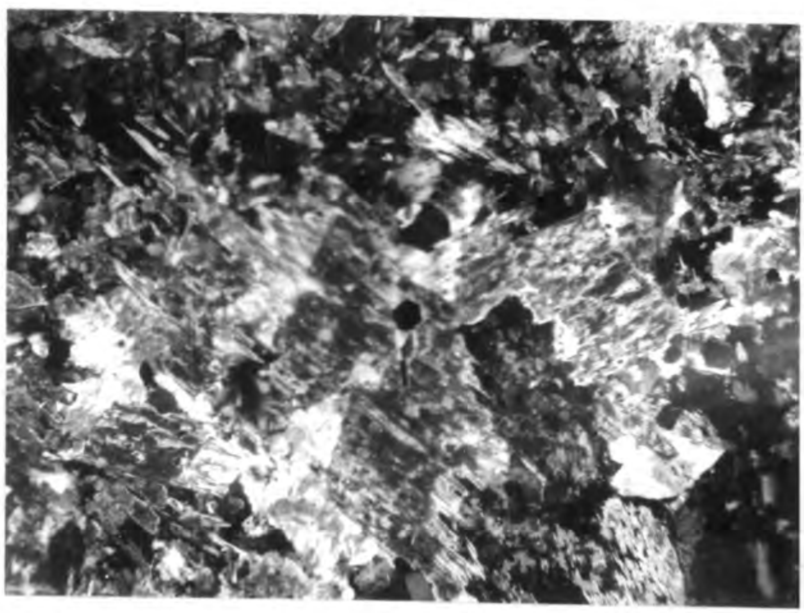


Plate 32. X 70. The same field as Plate 31 under crossed nicols.

The chief characteristic of these rocks in thin section is the dominance of amphiboles. These are always euhedral and the most striking thing about them is that they are frequently zoned. A core of green hornblende will be mantled by a rim of colourless amphibole. Separate euhedral crystals of colourless amphibole are also present and euhedral crystals of both coloured and colourless amphiboles may be present together with the zoned crystals. The colourless amphibole is clearly of later formation than the green one for it mantles it in all cases. Both these amphiboles have been optically determined. The green amphibole is a Magnesio-hastingsite, α 1.6530, β 1.6650, γ 1.6690. Birefringence .0160. It is pleochroic, light browny green - dark olive green $X > Y > Z$ with extinction angle Z - C 10° to 20°. The colourless amphibole is tremolite, α 1.6195, β 1.6400, γ 1.6450. Birefringence .0255. 2V 85. Extinction angle Z - C 20° to 25°. It is optically identical to that seen in the calc-silicate granulites.

This rimming of green hornblende by iron-poor tremolite indicates that at this stage the melt was low in iron, or that iron-bearing amphiboles were not stable. The indication is that the last suggestion is the case, for in many of the colourless crystals small euhedral cubes of magnetite are present showing that plenty of iron was available if it was needed. This is certainly an unusual conclusion for magnesium-rich minerals are generally formed in the earlier rather than the later stages of a cooling magma.

However, lamprophyres are very odd rocks and it may well be that at some stage in their complex cooling history the normal sequence of events was reversed.

Biotite is the other dominant dark mineral and is present in all the rocks in some quantity. It is pleochroic in shades of brown, euhedral and is frequently chloritised, sometimes completely so, the chlorite being charged with fine needles of rutile.

Pyroxene is occasionally present but is rare and inconspicuous. It is seen as short stubby prisms up to ½ mm. in length, scattered and in groups; it is colourless with extinction angle Z -,C 45° and is most probably a diopsidic augite.

These dark minerals are set in a base of feldspar which is very variable. Orthoclase or plagioclase may be the only feldspar present but more frequently the two feldspars are present together. Orthoclase is always shapeless, interstitial in character and very indeterminate. The use of sodium cobaltinitrite stain as an aid to its identification is virtually the only means of positive identification. The orthoclase may be fresh but is most often slightly clouded with a light dusty brown alteration. Plagioclase may be present in exactly the same way as orthoclase described above, untwinned and interstitial, or it may be present in euhedral twinned crystals the composition of which is sodic oligoclase An_{15}. The plagioclase may be fresh but is usually strongly altered to coarse sericite. Analcite is sometimes present in small quantity and is associated with the plagioclase.

Quartz is rarely present as single scattered interstitial crystals of rounded outline and may occasionally be seen as phenocrysts.

The accessory minerals, epidote, sphene and apatite are common and in some cases assume the status of an important constituent of the rock. One case is recorded where epidote forms 12 per cent of the rock, but this is unusual.

Epidote is in scattered, stubby, euhedral prisms showing no particular preference or association. Where epidote is an important mineral patches of the rock are rich in epidote while other patches are rich in hornblende.

Sphene is distributed evenly in very small euhedral crystals throughout the feldspar base.

Apatite is present in long needles, frequently radiating and penetrating both biotite and amphiboles. Calcite is present in fair quantity in some examples and is probably the result of hydrothermal alteration.

The opaque minerals present are pyrite in large cubes and either irregular shapeless masses of non-reflecting oxide, or small cubes of magnetite.

The impression given by the petrography of these rocks is of a magma rich in crystals of dark minerals, hornblende, pyroxene and biotite, carried in a fluid of feldspathic composition which cooled when the magma was intruded along fissures as a dyke. Flow textures may sometimes be seen in the form of streaking-out and parallelism of the dark minerals which may also sometimes be broken and fractured, but these are microscopic rather than macroscopic phenomena.

The rocks are basically hornblende lamprophyres in which the composition of the feldspar may be either orthoclase or plagioclase or both and they are therefore classified as Vogesites and Spessartites.

The Porphyries.- The porphyry dykes tend to be somewhat larger than the lamprophyres and no very small dykes were found. They average about 5 feet in thickness and are extremely tough, leucocratic structureless rocks in which are set phenocrysts of quartz and white feldspar. Sometimes a slight foliation and flow texture may be seen at the margins of the larger dykes. Unlike the lamprophyres these are fairly constant in composition though in some rocks euhedral hornblende crystals are present, representatives of both the green and colourless varieties being seen. These instances show fairly certainly the linkage and relationship between the porphyry and lamprophyre dykes and are of intermediate character between the two, being approximately monzonitic in composition. Most of the porphyry dykes, however, are of constant composition and a typical modal analysis is given in Table XV overleaf.

TABLE XV

MODAL ANALYSIS OF A PORPHYRY

QUARTZ	26.0
ORTHOCLASE	31.2
PLAGIOCLASE	29.3
BIOTITE	9.6
MUSCOVITE	0.4
CHLORITE	3.5
TOTAL	100.0

They are roughly adamellitic in composition and consist of phenocrysts of quartz and plagioclase feldspar up to 2 mm. across, set in a matrix of orthoclase and quartz.

The plagioclase phenocrysts are euhedral with sharp outlines which show signs of incipient corrosion. They are generally twinned and are frequently zoned having cores of oligoclase and rims of albite. Sometimes crystals are very markedly corroded and broken into by the fine grained matrix. The plagioclase is generally fresh but may sometimes be very strongly altered to a mass of sericite.

The quartz phenocrysts may be euhedral but are more frequently rounded and give clear evidence of magmatic corrosion, being broken into and penetrated by branching fingers of the fine grained matrix.

Biotite is present as phenocrysts and is pleochroic from light brown to dark green. Most frequently it has been partly or wholly converted to green chlorite.

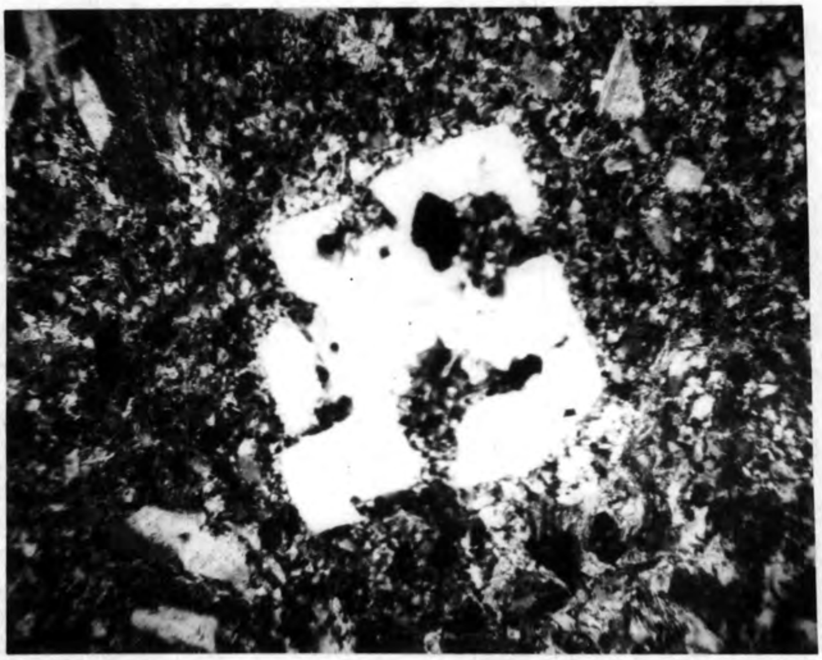


Plate 33. X 70. Quartz Porphyry. Euhedral quartz has been broken and embayed by the fine grained matrix of quartz and alkali feldspar.

Plate 34. X 70. Olivine Dolerite. Augite interstitial to and moulded round idiomorphic labradorite laths. Euhedral olivine in discrete crystals.

Muscovite is dispersed in tiny shreds throughout the rock and epidote is present as an accessory.

The matrix is composed of approximately equal amounts of quartz and orthoclase but the grain is so fine that it is impossible to distinguish them without staining, which brings out beautifully the textures in these rocks.

The thin sections demonstrate clearly that a suspension of euhedral quartz plagioclase and biotite crystals in a liquid corresponding to orthoclase + quartz in composition was intruded along fissures as dykes. The liquid corroded the phenocrysts probably prior to intrusion for cooling must have been fairly rapid to achieve so fine a grain size. The magma was probably rich in volatiles for hydrothermal alteration of biotite and plagioclase is common and extensive while, in contrast to the porphyritic granites, but in common with the Aughrusbeg Lake granite, muscovite is present in small quantity.

<u>The Olivine-Dolerites</u>.- These are melanocratic tough, structureless rocks breaking with a conchoidal fracture with visible specks of honey yellow olivine and amygdales filled with fibrous and structureless zeolites. The amygdales tend to be present in the centre rather than the margin of the dykes. The rocks are very constant in composition and a modal analysis of a typical example is given in Table XVI overleaf.

TABLE XVI

MODAL ANALYSIS OF AN OLIVINE DOLERITE

LABRADORITE	43.7
AUGITE	22.6
OLIVINE	20.4
ANALCITE	2.5
THOMSONITE	5.5
OPAQUE	4.5
TOTAL	99.2

The rock is an alkaline olivine-dolerite of Teschenitic type.

In thin section the olivine is seen to be euhedral though sometimes it seems to be slightly rounded and is generally about ½ mm. across. Inclusions are rare but a little magnetite is occasionally seen within the olivines. Crystals are nearly always fresh but serpentinization does occur along fractures and is in some cases extensive.

The pyroxene is a lilac-coloured, slightly pleochroic augite of the variety often described as titanaugite, which is in ophitic intergrowth with labradorite. The labradorite is the dominant member of the intergrowth and augite is allotriomorphic towards it. Groups of augite fragments are sometimes in optical continuity and this may be an early stage in the development of a coarse poikilitic texture. In one rock the pyroxene was zoned; a clear core of diopsidic augite crowded with magnetite octahedra was mantled by coloured augite; this, however, is unusual.

Labradorite is euhedral in bladed lath-like crystals up to 2 mm. in length and is intergrown with augite. Twinning is universal and pronounced and there is an occasional indeterminate tendency towards zoning. An intergrowth texture occurs also with the opaque mineral present, probably ilmenite or ilmeno-magnetite. This is very skeletal in habit and is frequently seen in intergrowth both with augite and labradorite. Sometimes it appears to be later than both these minerals and cuts transversely across the crystallographic directions.

It seems that labradorite, augite and ilmeno-magnetite all crystallized at approximately the same time or very closely following one another. Of these components ilmeno-magnetite was probably the last.

Analcite is present and is associated with labradorite where it is found in interstices and cracks. It is also found more spectacularly in amygdales. The most characteristic occupant of the amygdales, however, is thomsonite which occurs in radiating sheaf like fibrous crystals. The thomsonite is almost always fresh but a light brown dusty alteration may sometimes be seen. The margins of the amygdales may be bordered by a thin rim of chlorite or they may pass straight into the surrounding rock. Small pockets of thomsonite occur which have not assumed a circular shape and these are generally in the neighbourhood of the circular amygdales.

Calcite is present in small quantity in some rocks both in the amygdales and in the rock itself as irregular patches.

The thin sections show that a magma of alkaline olivine-basalt composition in which crystals of olivine were suspended was intruded into the country rock. On cooling, an ophitic intergrowth of labradorite and augite crystallized, with subsidiary intergrown ilmeno-magnetite. Alkaline residual liquors crystallized in interstitial spaces and amygdales in the last stages.

TIME RELATIONSHIPS OF THE POST-KINEMATIC IGNEOUS ROCKS

Time relationships of the igneous rocks to each other have been touched upon at points throughout this chapter and will now be treated all together.

The Omey Island granite was intruded after the formation of the Connemara anticline and it is itself intruded by the Aughrusbeg Lake granite. The granite is cut by faults of the north west - south east trend and also by porphyry and lamprophyre dykes of the north-south swarm and olivine-dolerite dykes of the east-west swarm.

The Turbot Island granite is not cut by dykes of either the north-south or the east-west swarm but instead it contains blocks of lamprophyres as xenoliths.

The north-south swarm of dykes intrudes the prevailing fault directions and this episode of dyke formation is therefore either closely associated with the faulting or later than it.

The east-west swarm of dykes cuts both the north-south swarm and the Omey Island granite.

The emplacement of the Omey Island granite was the first phase of post-kinematic igneous activity and the intrusion of the Aughrusbeg Lake granite may be regarded as part of this phase. Subsequent to the intrusion of these granites, faulting occurred which was possibly associated with dyke intrusion. Emplacement of the north-south dyke swarm of lamprophyres and porphyries occurred either at this time or shortly after it. Both faults and dykes cut the Omey Island granite.

Intrusion of the Turbot Island granite is the next recognisable phase. This must have taken place after the intrusion of the dykes for the dykes are included as xenoliths in the granite and are therefore pre-granite in age.

The east-west swarm of olivine-dolerite dykes cuts the north-south swarm of dykes and also the Omey Island granite. It is not demonstrably younger than the Turbot Island granite for no dykes are seen to cut this body. Nevertheless, since this dyke swarm has a direction so radically at variance with the north-south swarm and is in composition so different from other igneous rocks in the area, it is felt that it is unlikely to be related to the dominantly granitic igneous suite of the area. It is much more probably connected with one of the centres of Tertiary vulcanism which are so well displayed in Northern Ireland. Alternatively, they could be connected with the Carboniferous suite of alkaline igneous rocks in the Midland Valley of Scotland. Since the Hercynian alkali suite is not well represented in Ireland whereas there are numerous centres of Tertiary vulcanism, the likelihood is that these dykes are of Tertiary age. In either case, however, they are very much later than all previous igneous activity and, after a considerable time lag, represent the last major phase of igneous activity recognisable in the area.

CHAPTER VIII

CONCLUSION

GEOLOGICAL HISTORY

Sedimentation.- A series of sandstones, dolomitic limestones and clays were deposited in a shallow sea or a restricted trough bordered by a land mass of moderate relief. Deep water conditions in which fine grained clays dominated were succeeded by shallower water conditions under which the sediments deposited became more psammitic in character and during which thick bodies of pure quartzite and dolomitic limestone were formed.

First East-West Folding and Regional Metamorphism.- The sedimentary succession was thrown into a series of huge recumbent isoclinal folds and at the same time was regionally metamorphosed under amphibolite facies conditions.

Second East-West Folding.- The recumbent folds were refolded about an east west axis giving the Connemara anticline.

North-South Folding.- This could have occurred either in between the two periods of east-west folding or subsequent to them for evidence at present in ambiguous. The Bally-conneelly Dome was formed about a north-south axis and the pre-existing structures were deformed by the folding.

Emplacement of the Omey Island Granite.- This granite and the associated Aughrusbeg Lake granite was emplaced after the formation of the Connemara anticline. It thermally metamorphosed the cold regional metamorphic rocks giving zones of hornfelses round the granite.

Faulting.- The region was then faulted. Two prominent sets of faulting were produced, one striking north west - south east, the other north east - south west. Evidence of both normal and wrench faulting can be seen. The faults cut all the previous structures and also the Omey Island granite.

Injection of Lamprophyre and Porphyry Dykes.- A north-south swarm of thin lamprophyres and porphyry dykes was intruded either at the time of faulting or shortly afterwards. These dykes are intruded along the fault planes and also into the Omey Island granite.

Emplacement of the Turbot Island granite.- This granite was emplaced after the phase of dyke formation for it encloses lamprophyre as xenoliths. Like the Omey Island granite it thermally metamorphoses the regionally metamorphosed country rock.

East-West Swarm of Olivine-Dolerite Dykes.- These are believed to be either Hercynian or Tertiary with a strong preference for a Tertiary age. They cut the north-south dyke swarm and the Omey Island granite but cannot be seen to intrude the Turbot Island granite. Their very much later age is therefore suspected rather than proven.

Pleistocene Glaciation.- The area was covered by a considerable ice sheet centred on the Twelve Bens which moved westwards to the Atlantic. The surface of the country was stripped bare and strongly scoured; the hard metamorphic rock surfaces were eroded to give roches mouttonées the characteristic outcrop in the area and, in the areas of uniform relief both drumlins and a thick continuous layer of boulder clay were deposited. After the retreat of the ice, peat began to form and has continued to do so up to the present time. It forms equally well on boulder clay or bare rock and for that reason it is virtually impossible to delineate the extent of the drift deposits. The peat is cut for fuel by the Irish crofters and thanks to their industry a considerable extent of the Aughris Peninsula is now well exposed. The latest effective event in the geological calendar can thus rightly be said to be the advent of man.

DISCUSSION OF THE WORK COMPLETED AND SUGGESTIONS FOR FUTURE WORK

The basis of the present study has been the detailed mapping of the area. This has been effective in that it has suggested a general mechanism of formation for the Connemara anticline and has in general given a very much clearer picture of the stratigraphy and structure than previously existed. Further problems, however, have been raised. In particular the question of the two lineations plunging in opposite directions in the Barnahallia district and the Aughris Peninsula in general need further investigation. The present view is that these represent two quite separate periods of isoclinal folding and it is therefore important to establish

(a) whether this is true

(b) which period of folding is first

(c) the extent of overprinting of later structures upon earlier ones.

Understanding of these points will greatly help our knowledge and interpretation of the many peculiarly shaped outcrops with which Connemara abounds.

The other main aspect of the work has been the chemical analyses of which the most important were those of the semi-pelites. An attempt was made to discover whether there was any change in bulk composition during regional and thermal metamorphism. The conclusion reached was that there was no such change but there are several riders to this. In the case of the regional metamorphism the formations are parallel to the metamorphic isograds and it is not possible to trace one band through a series of metamorphic zones. An attempt to overcome this difficulty was made on the basis of selecting samples for analysis according to a standard modal composition but the effectiveness of this method is not really known at present. It should be tried in an area where metasomatism is known to occur and if it does show a change in bulk composition then it is effective and could be used elsewhere. If it does not, it means that the method of selection is masking actual changes and should be discontinued.

In the case of the thermal metamorphism the situation is rather different for it is possible to follow the same bed from lower to higher grade. Again the conclusion was reached that there was no change in bulk composition and, since more analyses were done and it was possible to work on two different formations, the conclusion is correspondingly more valid than is the case with the regional metamorphism.

However, although there are strong indications that metasomatism in the area is at a discount it would be profitable to pursue the point with more analyses using the method of bulk sampling described by Pitcher and Sinha (1957). This would require a considerable number of analyses, perhaps twenty, but it might settle the question definitely.

A further interesting line of chemical enquiry would be the analysis of staurolite, garnet and sillimanite throughout the grades of regional metamorphism with particular attention to the trace elements. A similar investigation with biotite would be most useful but here the separation from muscovite and chlorite would be very difficult.

Although there is no apparent metasomatism, there must have been a considerable movement of material involved in simple recrystallization and such an investigation as that suggested above would be fundamental to understanding this process at differing levels of metamorphism.

During the course of the present study various ideas about the origins of quartzo feldspathic and other veinlets within the metamorphic rocks have been entertained. Eventually the conclusion was reached that they represent the sweating out of the salic minerals from the parent rock. It is thought that a chemical investigation should be able to prove or disprove this point. Since movement of such material in relation to such veins has been the source of much controversy in the past, this study would be of value.

Chemical analysis of the granites with a view to determining their relative age might well be undertaken. Assuming that a granite which is enriched in volatiles relative to another is younger, the determination of trace elements could be of great value in suggesting the relative ages of granites where field evidence is poor or ambiguous. In particular, it could be used to verify the deduction that the Turbot Island granite is younger than the Omey Island granite.

Further suggested chemical work therefore falls under four headings.

1. More bulk analyses to confirm or disprove current conclusions.
2. Analysis of individual minerals within the

metamorphic framework.

3. An investigation of quartzo feldspathic and other veinlets to determine their origin.
4. Chemical analysis of the granites determining the abundance of volatiles and thereby their relative age.

In the field of petrology and mineralogy there is a vast amount of profitable work to be undertaken. In a terrain of this nature there is a great variety of different rocks and in the course of mapping the area a number of things have been noted which would be worthy of future study. In particular, the granite contact at Barnahallia Lough is of great interest. Here the granite directly intrudes a small limestone band. The limestone is veined by granite and blocks of limestone have been incorporated in the granite. The limestone has been converted to a coarse fibrous green amphibolite and the granite strongly contaminated with hornblende. The detailed study of this contact both mineralogically and chemically could not fail to be of the greatest interest.

Similarly the tabular structures in the complex aplitic margin of the Turbot Island granite might well repay detailed investigation for some of them are odd in the extreme and the tendency to tabularity has clearly played an important part in the mechanics of intrusion.

The detailed mineralogy of some of the calc-silicate hornfelses may repay investigation. These are very coarse rocks and separation of material should present no difficulty. It has been noticed that within these hornfelses both green and brown idocrase is liable to occur. They have very slightly different refractive indices and the pursuance of their mineralogy could well be a micro study of some interest.

Within the field of regional metamorphism the method of petrofabric investigation has not been used. This omission was deliberate for it is felt that before petrofabrics can give useful results it is necessary to know a great deal about the various deformations to which the rocks have been subject. At present, although the position is much better than it was, we do not possess sufficient knowledge for a general petrofabric investigation. In particular, the problem of the diverging lineations in the Barnahallia district, and the importance and relationship of this to the general structural picture, has not been solved. If it is possible to do this by petrofabric methods then a very real contribution to the geology of Connemara will have been made.

Other structural problems remain, the shallow strain-slip cleavage and associated eastward plunging folds on the northern limb of the anticline, for example. It is considered that with the rapid completion of the basic mapping of Connemara now under way many of these problems will be solved, for what may seem puzzling and inconsistent when seen within one small area may no longer present any real difficulty when seen in relation to the whole. The basic necessity therefore is the completion of the mapping of Connemara. When this is done it will be possible to review the geology as a whole and select the problems of fundamental importance for detailed and intensive study.

Suggestions for future work upon the area studied are resolved into two main groups; structural and chemical. In this ancient region devoid of fossils these, allied with petrology, must be our main tools. In using them we may yet hope for an ultimate solution of the many outstanding problems remaining in Connemara.

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