DATA ON THE MINERALOGY AND PETROLOGY OF THE DOLOMITE-BEARING NORTHERN CONTACT ZONE OF THE QUÉRIGUT GRANITE
FRENCH PYRENEES

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INTRODUCTION

This thesis comprises the results of a mineralogical and petrological study on the dolomite-bearing contact zone of the granite massif of Quérigut in the French Pyrenees. The thermally metamorphosed carbonate country rock as well as the border zone of the granite have been investigated. Special attention has been paid to the many contact minerals and their alteration phenomena.

The region investigated is situated in the eastern part of the French Pyrenees, roughly on the boundary of the departments Aude and Ariège. Geologically it lies in the northern part of the axial zone of the Pyrenees, near the large North Pyrenean fault.

During the summers of 1951 and 1952 some tectonical field-work was done in the Paleozoic area N of the granite, roughly bounded by the villages of Rouze, Campagna, Fontanès, Gesse and the Col de la Malagrède (fig. 1). Detailed fieldwork on the contact zone between the village of Usson and the Col de la Malagrède was carried out in the summers of 1955 and 1956.

As topographic map that of the "Etat major", sheet 254 Quillan SO, scale 1: 50.000 (revised in 1936) was used. The region is shown on the geological map, sheet 254, Quillan, scale 1:80.000, issue 1938 (second edition).

Dr. V. S. Colter and Dr. A. T. Thompson kindly corrected parts of the English manuscript.

For technical assistance I am grateful to Messrs. J. Bult, M. Deyn Jr., J. Hoogendoorn and A. Verhoorn.

I wish to express my sincere gratitude for the financial aid and the many facilities given by the N. V. Bataafsche Petroleum Maatschappij.

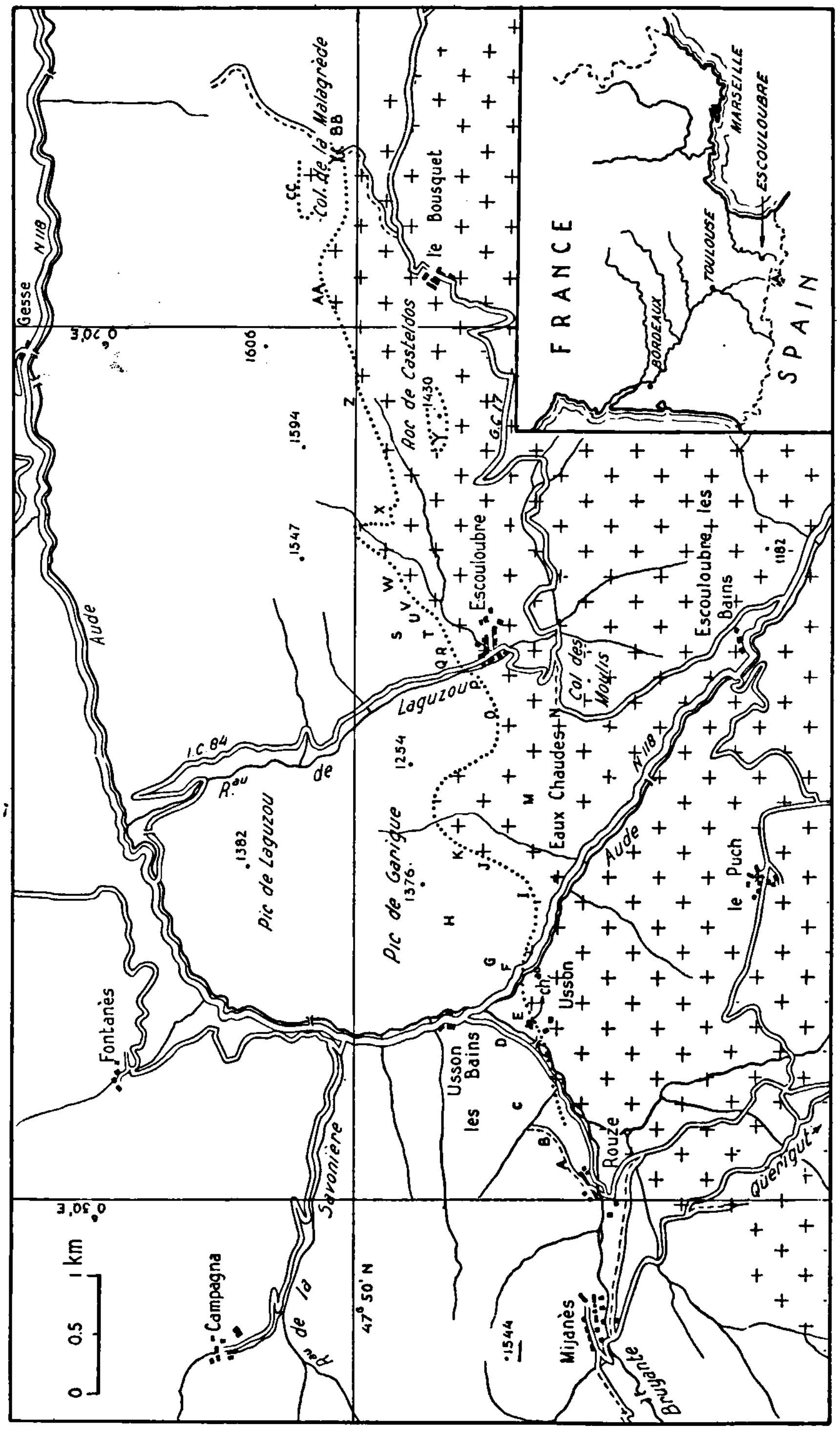


Fig. 1 — Map of the surroundings of Escouloubre, showing the extension of the granite and the location of a number of localities mentioned in the text.

PART I

GEOLOGY

PREVIOUS WORK

More elaborate accounts concerning the stratigraphy and the tectonics of the Paleozoic area around the massif of Quérigut were given by **Caralp** (1888), **Carez** (1908) and **Roussel** (1904). With the exception of some very concise papers (a. o. **Dalloni** 1930), no modern literature dealing with the area N of the granite is known to the author. In 1938, however, a new edition of the sheet Quillan of the Geological map 1:80.000 was published, incorporating some new data.

Concerning the granite massif itself, more is known and the published papers deal with the petrology, the contact phenomena, the tectonics and the evolution of the massif.

In a study of the granites of the Pyrenees and their contact phenomena, **Lacroix** paid special attention to the granite of Quérigut. In two well known papers (1898, 1900) he revealed his ideas and theories concerning the felspathization, the intimate connection between endo- and exomorphism and the "mise en place" of granites in general and of the granite of Quérigut in particular. In the first paper (1898) **Lacroix** treated the extreme SW part of the massif, sometimes called "the classical area of **Lacroix**", where he claims that an extensive felspathization of the pelitic sediments has taken place, as a consequence of imbibition and injection. Extensive assimilation of calcareous and dolomitic rocks is said to have produced rocks more basic than the granite, ranging from hornblende-granites to norites and locally even to ultrabasic rocks in small masses. In the second paper (1900) the whole massif was described, but only brief mention was made of the northern contact zone between Mijanès and Counouzouls (pp. 13—17). Reference was also made (pp. 13—14) to that part of the contact zone studied by the present author. Without doubt **Lacroix** did not investigate the whole northern contact very accurately, otherwise he would have seen the silicate skarns and the dolomitic marbles with their many interesting minerals, exposed at several localities between Eaux Chaudes and Le Bousquet.

Erdmannsdörffer (1914) investigated part of the so-called classical area of Lacroix, but this author did not support the views of **Lacroix** concerning the extensive felspathization.

More recently **Raguin** published some articles on different aspects of the granite of Quérigut. These deal with new localities of basic rocks and the occurrence of a lamprophyre (1933a), the tectonics of the massif (1933b), as well as with the genesis of the basic and ultrabasic rocks and the evolution of the whole massif (1949, 1950). According to **Raguin**, the massif of Quérigut might represent a combination of a "granite d'anatexie" (the heterogeneous S and SW part of the massif with migmatitic character) and a "granite en massif circonscrit" (the much larger homogeneous part of the

TABLE I

Stratigraphic table of the area situated between the granite of Quérigut and the villages of Rouze, Campagna, Fontanès, Gesse and the Col de la Malagrède (according to the explanatory note of the Geological map sheet Quillan, 1:80.000, issue 1938).

TRIASSIC	UPPER TRIASSIC (Keuper)	Multicoloured marls, generally reddish and frequently containing gypsum.
	MIDDLE TRIASSIC (Muschelkalk?)	Grey or yellow limestones and dolomitic limestones, grey or variegated marls.
	PERMOTRIASSIC	Conglomerates containing calcareous or siliceous elements, sandstones and red marls.
CARBONIFEROUS		Black or greyish green clayey shales with subordinate layers of quartz-sandstone and limestone, and lenses of conglomerate with components often of local provenance and containing Devonian limestone, lydite and further locally much milky quartz. At the base a thin bed of lydite may occur.
DEVONIAN	UPPER SERIES	Thick layers of dense limestone, the top being nodular (so-called "griottes"), with Goniatites.
	LOWER SERIES	Dolomites and fossiliferous limestones, probably representing the Eifelian.
GOTHLANDIAN		Black graphitic shales ("schistes carburés") with a.o. *Monograptus,* often including nodules and lenses of black pyrite-bearing limestone which may contain a. o. *Orthoceras bohemicum* and *Cardiola interrupta.*

massif). In his book on the geology of the granite, **Raguin** (1946) refers several times to the granite of Quérigut.

Very recently **Termier** and **Termier** (1956) devoted some pages (pp. 466—469) to the granite of Quérigut in their treatise on the evolution of the lithosphere (part I), without mentioning any new points of view.

No comments will be made in this thesis on the views of **Lacroix** and **Raguin**, mainly concerning the SW part of the massif. The author's study will be restricted to the petrology and mineralogy of a part of the northern contact zone.

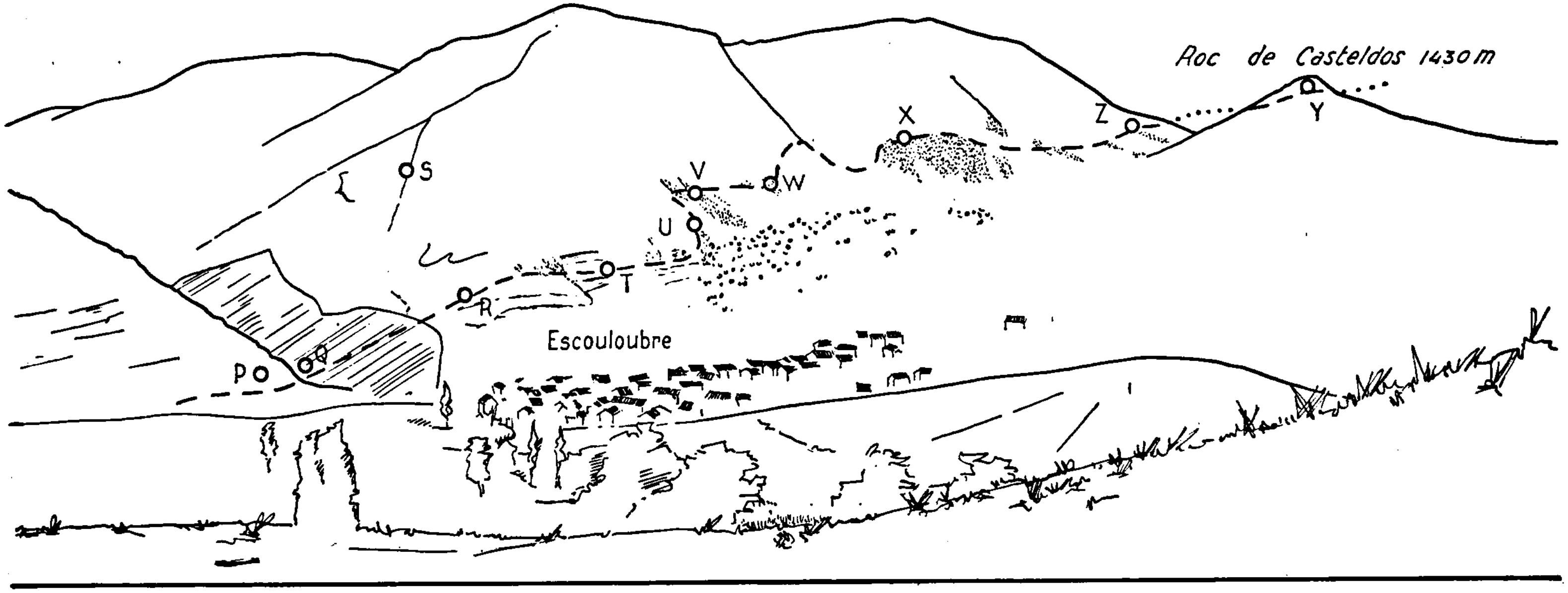
GENERAL GEOLOGICAL OUTLINES

Since this thesis is principally concerned with the petrology and, more especially, the mineralogy of part of the northern contact zone of the granite of Quérigut, the geology of the whole massif and of the surrounding sedimentary rocks will be dealt with only briefly.

STRATIGRAPHY

As has been pointed out already, the present author did some tectonical field-work in the area N of the granite previous to his investigations in the northern contact zone. The area that was roughly examined is situated between the granite boundary and the villages of Rouze, Campagna, Fontanès, Gesse and the Col de la Malagrède (see fig. 1). In discussing the stratigraphical sequence reference will be made to the geological map sheet Quillan, 1:80.000, and to some observations by the present author. According to the map Gothlandian, Devonian, Carboniferous and Trias are exposed, bordered in the N by the Mesozoic. In table I the lithological sequence for this area is summarized, according to the legend of the geological map Quillan 1938. The Gothlandian, consisting of black shales ("schistes carburés") and limestones similar to those found elsewhere in the Pyrenees, is but locally exposed. Graptolites have not been found in these beds. The Devonian which makes up the largest part of the area is characterized by thick beds of calcareous and dolomitic rocks. Locally (e. g. N of Escouloubre near loc. Q) it is clearly apparent that the dolomitization did not follow the bedding of the limestone, but rather, broke irregularly through it. At several places (e. g. near Usson and N of Escouloubre near loc. Q) almost pure as well as very impure quartzitic layers and lenses, up to several dm. thick, alternate with the limestone. Marly limestone may occur locally. Among the various fossils found ammonoids (goniatites), nautiloids (e. g. *Orthoceras*), and fragments of crinoids and corals may be mentioned. The preservation of the fossils is almost invariably poor. In contrast to the Devonian, the Carboniferous shows much variation in lithology, a sequence consisting of a bed of lydite (of very restricted occurrence) overlain by alternating beds of shales, limestones and sandstones passing vertically as well as laterally into conglomerate. The latter forms remarkable units, in places attaining a thickness of up to 40 metres. The matrix of these rocks is mainly argillaceous but may also be sandy. The components are well rounded and consist predominantly of quartzite and milky quartz. Lydite may be of frequent occurrence. Pebbles of gneissic, granitic and rhyolitic composition occur in lesser amounts and are found near Campagna and E of Fontanès. In no case do these rocks resemble one of the igneous types found in this area. The calcare-

Fig. 2 — Panorama of part of the area investigated, viewed from the Col de Moulis, with granite on the foreground, the contact with the country rock being indicated in the sketch. The letters refer to localities mentioned in the text.


Roc de Casteldos 1430 m
P
Q
S
R
T
U
V
W
X
Z
Y
Escouloubre

ous rocks of the Carboniferous sequence mentioned above occur mainly in its older parts. The Trias, which unconformably overlies the Carboniferous and Devonian, consists of multicoloured shales and slates, as well as of calcareous and dolomitic rocks similar to those seen in other parts of the Pyrenees.

Lithologically the Devonian resembles that of the so-called satellite massifs of the Pyrenees, situated N of the North Pyrenean fault (see e. g. De Sitter 1953, Keizer 1953) and the Catalanean Pyrenees which are comprehensively described by Dalloni (1930). The Carboniferous also shows a close resemblance to that of the Catalanean Pyrenees.

In outline the mapping as depicted on the geological map can be accepted as correct. It is the author's opinion, however, that the boundary between the Devonian and Carboniferous in several instances is rather arbitrarily chosen.

THE IGNEOUS ROCKS

In a broad sense it is known that there are two distinctly different types of granites in the Pyrenees, namely a group of gneissic leucocratic granites and a group of granitic to granodioritic batholiths and stocks. Both are considered to belong to the Hercynian orogeny of the Pyrenees, the former probably being syn-tectonic and the latter late- or post-tectonic (see e. g. Raguin 1946, Hupé 1947, 1951 and De Sitter 1951, 1956). According to Raguin (1949) the origin of the granite of Quérigut is somewhat complicated, it being a combination of a "granite d'anatexie" (the heterogeneous S and SW part of the massif) and a "granite en massif circonscrit" (the main part of the massif which is homogeneous). Since the northern contact zone described in this account belongs to the latter, with its intrusive diapiric character (Raguin 1950), nothing will further be said about the anatexitic part of the massif.

As has been pointed out already, an area of the granite extending to some km. from the contact has been roughly investigated. In addition to a short review of the data given by the geological map, Quillan 1:80.000, some of the observations made by the author will follow below. According to this map the western part of the massif mainly consists of medium-grained biotite-granite. Unlike the eastern part of the massif, the porphyritic granite is restricted here to some separate masses. Small masses of "granulite" are irregularly scattered throughout the normal granite. Large dislocations are revealed by mylonite zones or thick quartz-veins (Raguin 1933b). The former have a roughly E—W strike and a steep dip to the S.

Every visitor to the area under discussion will be struck by the high degree of weathering of the granite, particularly near the contact. At the surface the granite has largely been decomposed into a coarse-grained sand-like mass. Relics of comparatively fresh granite in the form of large rounded or slightly angular blocks occur separately or in huge piles. They give a peculiar aspect to the landscape (fig. 3). Good exposures of fairly fresh to fresh granite are seen along the main road (N 118) which follows the valley of the Aude. The chief constituents of the common biotite-granite which forms the bulk of the granite massif of Quérigut s.s. are quartz, potash-rich felspar, fairly soda-rich plagioclase and biotite. The porphyritic granite in the vicinity of Escouloubre-les-Bains shows conspicuous megacrysts (up to 5 cm. in length) of potash-rich felspar, which are often twinned according to the Karlsbad law. The other main constituents are quartz, soda-rich plagioclase and highly chloritized biotite. At a distance of a few km. from the contact aplitic dikes as well as dark inclusions are occasionally found. Both become quite common, however, nearer to the contact. There, hornblende becomes conspicuous, too, while there are also porphyritic dikes (see further below).

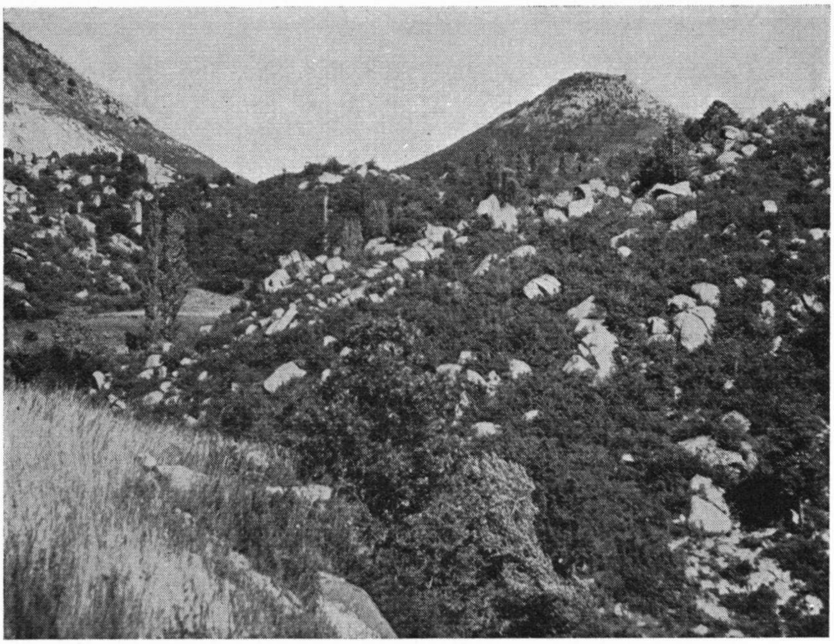


Fig. 3 — Piles of large rounded blocks of granite, innermost border zone, NE of Escouloubre. The Roc de Casteldos is seen on the background.

The main constituents of the rather fine-grained leucocratic granite near Le Puch are quartz, potash-rich felspar, very soda-rich plagioclase and biotite (brownish green in section). As only an occasional flake of secondary muscovite is seen the term "granulite" in the French sense is not strictly correct.

In the mylonite zones all stages from a slightly laminated granite to a mylonite proper may be recognized. Apart from these zones, the granite often shows signs of mechanical deformation which are expressed in a slightly laminated texture and many slickensides. This is clearly shown along the main road (N 118). Here the many joint planes which are steeply dipping to the S, are also well displayed.

GEOLOGY OF THE CONTACT ZONE

Introduction

As has been mentioned above, the part of the northern contact zone of the granite of Quérigut studied by the present author, is roughly limited by the village of Usson in the W and the Col de la Malagrède in the E. The term contact zone has been used in a broad sense, embracing both the metamorphosed country rock and the border zone of the granite. This border zone has been subdivided in a wide innermost zone and a very narrow outermost zone. As compared with the common biotite-granite, the former is characterized by the development of some hornblende, a much increased proportion of dark inclusions and aplitic dikes, and finally by the occurrence of porphyritic dikes. The outermost border zone of the granite is conspicuous by virtue of marked differences in mineralogical composition as well as in texture.

The lowermost point of the contact is about 800 m. above the sea-level and situated beside the main road (N 118) E of Usson, whilst the highest elevation is estimated to be about 1370 m., on the slope of the Roc de Casteldos. At most places the contact between the granite and the country rock is not exposed, it being covered by young sediments. A further disadvantage of the study of the contact is the almost invariably high degree of weathering of the granite near to the country rock. Over long intervals the granite may be completely decomposed into a coarse sand-like mass. According to LACROIX (1900, p. 13) this decomposed granite even extends from Mijanès to Counouzouls, over a distance of nearly 18 km. A careful investigation along the contact line nevertheless revealed several localities (I, J, K, T—U, V) where the granite in contact with the sediments is comparatively fresh. This fresh zone, however, is usually very limited in width, varying from a few dm. to a few metres. Here, we may also observe narrow bands of silicate skarn that are exclusively localized between the granite and the country rock. Considered at a large scale the contact is regular (fig. 1 and 2) but in detail it may be very irregular with many curves and small tongues (fig. 5 and 6).

The sediments that have been thermally metamorphosed and partly also subjected to pneumatolytic action consist mainly of alternating layers of earlier limestones and dolomites, now being calcite and dolomitic marbles with strongly varying amounts of contact minerals. Metamorphosed pure as well as impure quartzitic and argillaceous rocks are of much less frequent occurrence. Only metamorphosed dolomites have been found in direct contact with fresh granite. Sharp contacts with calcite marbles do not seem to be exposed in the area under consideration, but they may be encountered E of it as well as in the southern contact zone of the massif. The calcareous rocks as well as the intercalated quartzitic rocks most probably belong to the Devonian, whereas spotted slates that were locally observed are possibly of Carboniferous age. The rare black schists doubtless represent metamorphosed so-called "schistes carburés" of the Gothlandian. In a broad sense all the metamorphosed strata have an E—W strike and a steep dip to S. The thickness of the contact zone is considered to vary from about 100 to 150 metres. Subsequently some of the main features of the various contact rocks and the border zone of the granite will be described.

THE METAMORPHOSED COUNTRY ROCK

The dolomite marbles and dolomitic marbles

Pure and almost pure dolomite marbles as well as dolomitic marbles rich in magnesium-bearing contact minerals are of frequent occurrence in the investigated contact zone. The layers of the pure marbles predominate and they may attain a thickness of several tens of metres. Dolomitic marbles with a large content of contact minerals are well exposed NW of Eaux Chaudes (loc. I), in the vicinity of Escouloubre (loc. O, P, R, T—U and V) and N and NE of Le Bousquet (loc. AA and BB). The thickness of these rocks may attain a few tens of metres. The chief primary contact minerals are forsterite, phlogopite, clinohumite and spinel, whilst serpentine, chlorites and hydrotalcite are the most common alteration products. Fresh and highly altered marbles may be found close together. Layers rich in contact minerals and those almost devoid of them grade into each other or are sharply defined. Further, beds rich in forsterite and phlogopite alternate with beds in which the assemblage spinel-clinohumite prevails. Highly altered forsterite-phlogopite marbles are rendered conspicuous by virtue of the yellow to green colours of the serpentine. Beautiful fresh marbles rich in orange and orange-brown coloured crystals of clinohumite and numerous dark specks of spinel are exposed at loc. V and AA. Humite-bearing marbles appear to be of much less frequent occurrence (loc. V and Z) than the rocks mentioned above, whilst the minerals chondrodite and fluoborite have been encountered at one locality only, in a small mass of marble NNE of the Roc de Casteldos (loc. Z). In contrast with the calcite marbles, hornfelses do not appear to be intercalated between the dolomitic marbles.

The calcite marbles

Well bedded pure and almost pure calcite marbles make up the bulk of the metamorphosed country rock, the layers attaining a thickness of many tens of metres. In the vicinity of the Col de la Malagrède the pure calcite marble is locally very coarsely crystalline, the grain-size being up to 0.5 cm. By the side of the road N of Escouloubre (loc. Q) pure fairly coarsely crystalline marble, partially perfectly white, is quarried for sculpture purposes. Calcite marbles rich in calc- and calc-magnesian-silicates are locally exposed adjacent to the walls of the Chateau d'Usson (loc. E), near Escouloubre and on the Roc de Casteldos, especially on its western slope. There the several minerals stand out on the rock surface as a result of the selective action of weathering. The last mentioned locality displays well bedded marbles, which are particularly rich in grossular, idocrase and diopside. In addition to the minerals mentioned the most common contact minerals of the marbles are generally clinozoisite-epidote, prehnite, tremolite and wollastonite. At several localities marbles alternate with lenses and layers of hornfels, which vary in thickness between some mm. and a metre. Usually these hornfelses contain the same contact minerals as the surrounding marbles.

The calc-silicate and calc-magnesian-silicate hornfelses

As already mentioned above the hornfelses occur as lenses and layers, intercalated between the strata of the calcite marbles. Their thickness varies from a few mm. to a metre. Generally the hornfelses are well banded and multicoloured, the banding clearly representing the original bedding. In a broad sense the hornfelses can be divided into low and high grade types, both consisting of rather similar contact minerals to those found in the surrounding marbles. The low grade types are of frequent occurrence W and NW of Usson and are well exposed near the hairpins of an abandoned road under construction (loc. D). When crossing the river Bruyante higher grade hornfelses, in layers up to 1 m. thick, are seen close to the walls of the Chateau d'Usson. These rocks, as well as the surrounding marbles, are particularly rich in grossular, idocrase and diopside. ENE of Usson by the side of the main road (N 118) and also some tens of metres higher up hidden under the trees, there are some small outcrops of hornfels. There wollastonite makes its appearance. NW of Eaux Chaudes (loc. I) well banded hornfelses are seen as large lumps slipped from above, but also in situ. In these rocks prehnite and potash felspar may be notable constituents, whereas wollastonite is lacking. The latter, however, is present in considerable amounts more to the E, along the gentle slope of the mountain ridge N of Escouloubre, between loc. Q and S. There the progressive transformation of quartzitic lenses and layers into coarsely crystalline wollastonite rocks can be followed clearly. Boudins of quartzite lenses are seen to be completely surrounded by wollastonite, whilst cracks in these lenses are also filled up with this mineral. These phenomena indicate that important mechanical deformation took place prior to or during the thermal metamorphism. The selective action of weathering excavates the wollastonite felses, whereas the diopside-rich hornfelses stand out prominently (fig. 4). Some small scattered masses of hornfels occur in the vicinity of Escouloubre (loc. T). E of this locality exposures of hornfelses become very scarce and apart from a few small masses there is only one important occurrence of these rocks, viz. on the summit of the Roc de Casteldos, especially on its western side. There, over a distance of many tens of metres, multicoloured, well-banded hornfelses alternate with marbles rich in the contact minerals wollastonite, idocrase,

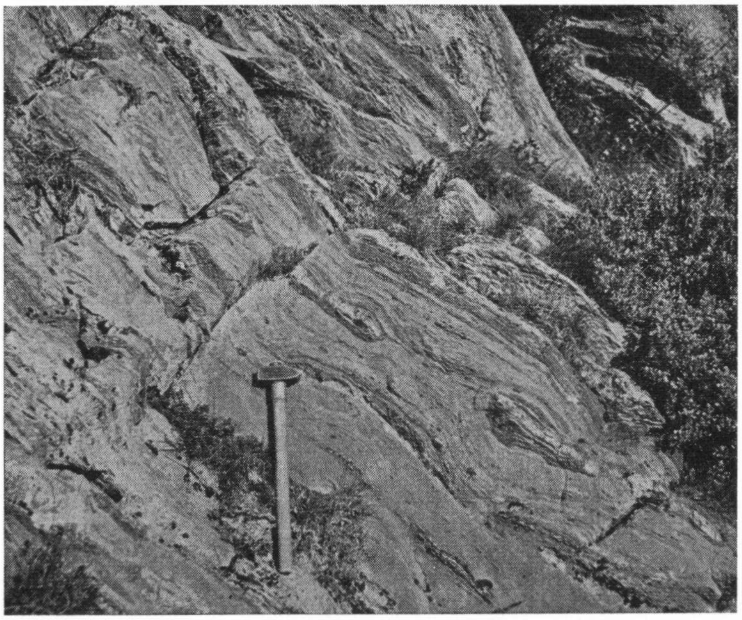


Fig. 4 — Boudinage of calc-magnesian-silicate hornfelses and wollastonite rocks, the former standing out prominently on the rock surface, the latter being excavated.

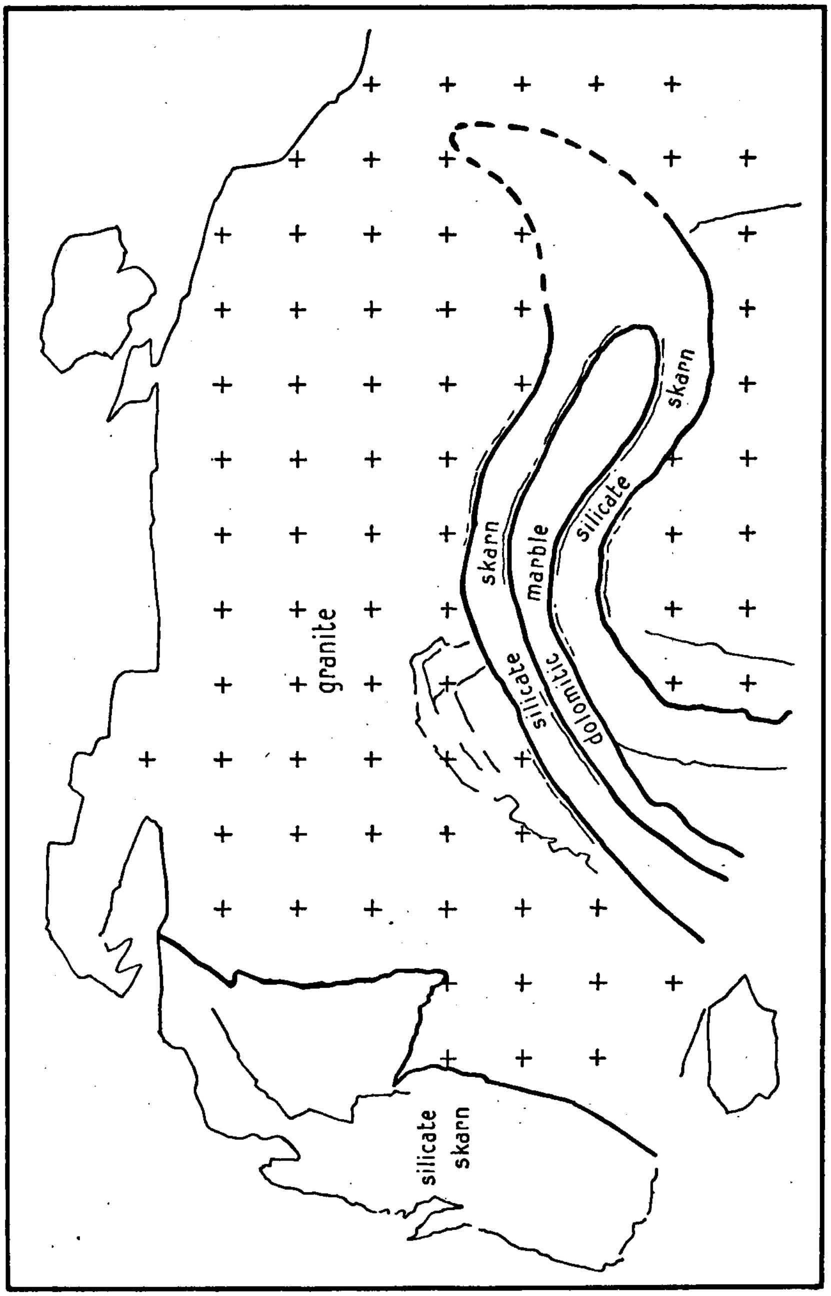
grossular and diopside. Finally a small mass of almost pure wollastonite fels NW of the Col de la Malagrède is worth mentioning (loc. CC). SW of this pass thick lenses of pure quartzite are seen, which stand out more than a dm. on the rock surface. These lenses have apparently not reacted with the surrounding marble to form wollastonite rocks as encountered elsewhere.

The silicate skarns

Silicate skarns have been found at a few localities where the granite adjacent to the dolomitic marble is comparatively fresh. These skarns occur exclusively as narrow zones between the granite and the dolomitic marbles, usually 4—7 cm. wide. They follow exactly the curves of the irregular contact line. Between the granite and the dolomitic marble in some instances only a decomposed pale green powdery mass was seen, the character of which could not be ascertained any more. Skarns in the form of veins, pockets or irregular masses, well known in contact zones from other areas, have not been encountered. The marble immediately adjacent to the skarns is in most cases pure or almost pure, but in some instances may also contain a large proportion of contact minerals. A zonal arrangement of different mineral

Fig. 5 — Pseudo-dike of partly pegmatitic granite in the dolomitic marble. In fact it is a protuberance of the granitic body itself, bordered by a well-developed skarn and transition zone. The talc-rich zone of the skarn, zone V, is deeply excavated by the action of weathering (on the left). Relics of the milky white calcite zone, zone VI, are clearly distinguishable, especially on the right. On path SSE of the Pic de Garigue (loc. J).

Fig. 6 — "Peninsula" of dolomitic marble, surrounded by a zone of silicate skarn, enclosed by the granite. Zone VI, the narrow white calcite zone, is clearly distinguishable along part of the contact between the marble and the skarn. NE of Escouloubre (loc. T).


granite
skarn
marble
silicate
skarn
silicate
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assemblages is often clearly distinguishable in the rocks under discussion. A diopsidic clinopyroxene invariably makes up the bulk of the skarns, whilst the remainder of the rock mainly consists of lilac mica, zoisite, clinozoisite, spinel, xanthophyllite, talc, serpentine and calcite. Some of the skarn zones are conspicuous by virtue of their remarkable mineral assemblage (the spinel-xanthophyllite zone) or because of a contrasting colour (the green serpentine zone and the milky white calcite zone).

Features of interest are the pseudo-dikes of granite in the marble and the pseudo-inclusions of marble in the granite. Both phenomena are due to irregularities of the contact and of the topography. The pseudo-dikes which at first glance may be considered as true dikes are merely small protuberances of the granite itself. They can be well observed near the hairpins of a footpath on the SE slope of the Pic de Garigue (fig. 5, loc. J). On the photograph relics of the former silicate skarn are visible on both sides of the "dike". Pseudo-inclusions of the marble in the granite are well exposed NE of Escouloubre (loc. T and V). On fig. 6 a peninsula of dolomitic marble in the granite is depicted, the marble being surrounded by a narrow zone of silicate skarn.

THE BORDER ZONE OF THE GRANITE

The outermost border zone

This zone is situated between the country rock and the innermost border zone of the granite. In the case that a band of silicate skarn borders the granite, there still occurs a peculiar very narrow zone (a few mm. to 5 cm. wide), the so-called transition zone, between these. This zone, which at first sight seems to belong to the skarn (the wall-rock), is considered to represent a highly transformed border facies of the igneous body.

In contrast with the innermost border zone the outer one is very limited in width, varying from a few dm. to a few metres. Further the outermost border zone in many cases differs markedly from the common biotite-granite and this holds true for the mineralogical composition as well as the texture. The latter is characterized by the local occurrence of pockets and irregular masses of pegmatite, as well as of concentrations of mafic or felsic minerals. Indeed, a more or less irregular distribution of the several constituents is displayed almost everywhere in the outermost border zone. Immediately adjacent to the contact the common mafic constituents biotite and hornblende locally give place to a dark green clinopyroxene, which is generally altered into uralite and hydrous iron-ore. The width of the clinopyroxene-bearing granite zone varies from a few cm. to a few dm. The larger proportion of accessories in the granite close to the contact is conspicuous. Orthite is often easily perceptible with the aid of a hand-lens.

At a locality NE of Escouloubre (loc. T) a small mass of a completely different type of rock has been encountered, a highly pneumatolyzed potash-rich granitic rock carrying abundant little flakes of colourless mica, scattered nests of tourmaline and minor amounts of anatase.

The innermost border zone

The innermost border zone of the granite is bounded at the one side by the outermost border zone and at the other by the common biotite-granite.

The limits are not sharply defined but rather gradational, especially with the latter, this limit being situated at a few hundreds of metres from the contact with the country rock. Apart from an occasional crystal of hornblende, the granite of this zone is usually not markedly different from the common biotite-granite, its main constituents being quartz, potash-rich felspar, fairly soda-rich plagioclase and biotite, with orthite among the common accessories. Nearer to the contact the proportion of the hornblende usually increases somewhat and locally a granodioritic composition of the rock is suggested. In contrast with both the common biotite-granite and the porphyritic biotite-granite, aplitic dikes as well as dark inclusions are of frequent occurrence in the hornblende-bearing granite of the innermost border zone. Furthermore, porphyrite dikes, usually much altered and weathered, are also present here, as well as a rare, extremely hard, dark lamprophyre. The aplitic dikes are a few cm. to somewhat more than a metre wide, whilst the porphyrites may attain a thickness of several metres. Both types of rocks may occur close together. In contrast with the aplites, which appear to be almost exclusively localized in the granite itself, porphyrites have been encountered in the country rock as well, and they occur in some instances even at a distance of more than a hundred metres from the contact. In only one case an aplitic vein has been found in the metamorphosed country rock, it being surrounded by low grade hornfelses (loc. D). Apart from this vein, containing a clinopyroxene, prehnite and comparatively much titanite, neither the aplites nor the porphyrites show many features worth mentioning. The porphyrites mostly are of quartz-dioritic composition, with hornblende and biotite as the main dark constituents,

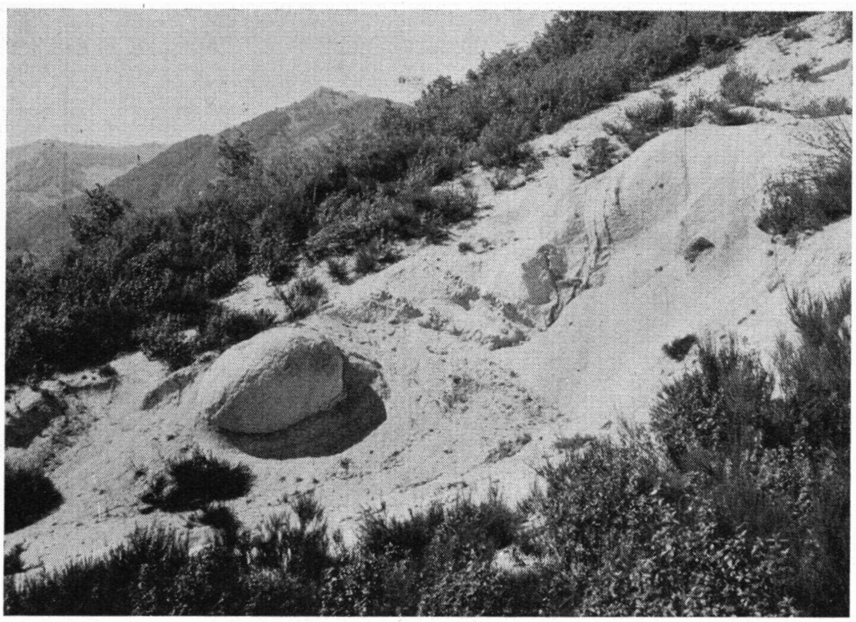

Fig. 7 — Relic of fresh granite, wholly surrounded by a white coarse sand-like mass of granite. Eaux Chaudes.

but some granodiorite-porphyries have also been noted. The lamprophyre contains a pink-lilac pyroxene, probably a titanium-bearing variety, and completely altered phenocrysts, possibly of earlier olivines.

The dark inclusions in the granite, almost exclusively of ellipsoidal or rounded shape, mostly vary in size between a cm. and a few dm., larger ones being of rare occurrence. It may be emphasized that these inclusions are neither clustered together, nor do they show a preferred orientation. The limits with the surrounding granite are invariably sharp. Mineralogically the inclusions consist of the same minerals as the granite, but the size and proportion of some of these minerals differ markedly. Most of the inclusions appear to be porphyritic melanocratic granodiorites, those of quartz-dioritic composition being of rarer occurrence. Usually these bodies stand out clearly on the surface of the granite because of the action of selective weathering.

At the surface the high degree of weathering of the granite has often resulted in the total decomposition of the rock into a coarse sand-like mass. The colour is either perfectly white or brownish stained. In some cases large rounded relics of sharply defined granite are completely surrounded by a sand-like mass and at first glance they seem to have been transported from elsewhere (fig. 7). Both diaclase planes and aplitic veins that run from the fresh granite into the sand-like mass, however, point to a decomposition in situ.

PART II

MINERALOGY

Introduction

In this chapter a number of interesting minerals from the contact zone and from the border zone of the granite will be described, while the results of comparative studies of some minerals from other areas will also be mentioned. The following minerals have been recognized in the area under discussion:

- actinolite
- albite
- anatase*
- apatite
- biotite*
- calcite
- chalcopyrite
- chiastolite
- chlorite*
    - pennine
    - clinochlore
    - amesite
- chondrodite*
- clinohumite*
- clinopyroxene*
    - diopside
    - augite
- clinozoisite*
- diaspore*
- dolomite
- epidote*
- fluoborite*
- fluorite (?)
- forsterite*
- garnet* (a. o. grossular)
- graphite
- goethite
- haematite
- hornblende
- humite*
- hydrotalcite*
- idocrase*
- ilmenite
- ludwigite (?)
- magnetite
- manasseite*
- muscovite (and lilac mica)*
- orthite*
- phlogopite*
- plagioclase (Ca-bearing)
- potash-rich felspar (a. o. adularia and microcline)
- prehnite*
- psilomelane
- pumpellyite*
- pyrite
- pyrrhotite
- quartz
- rutile*
- sericite
- serpentine
    - antigorite
    - chrysotile
- spinel*
- szaibelyite (?)
- talc*
- thulite-like clinozoisite*
- titanite*
- tourmaline*
- tremolite*
- wollastonite*
- xanthophyllite*
- zircon

The minerals indicated with an asterisk will be separately described in the following paragraphs.

The minerals of the humite group will be described together, as will those of the epidote group. The manasseite will be jointly described with hydrotalcite. The mineral resembling szaibelyite is dealt with in the fluoborite paragraph. In the xanthophyllite section some new occurrences of clintonite from other areas will be mentioned.

ANATASE

Anatase has been found at one locality only, NE of Escouloubre, where it occurs as an accessory constituent in a small mass of highly pneumatolyzed potash-rich granitic rock. This mass is situated close to the contact with the dolomitic marbles.

The mineral, which is only visible in thin section, occurs in aggregates or as scattered crystals (fig. 8). The anatase crystals measuring up to 0.2 mm. in length show euhedral forms as well as rounded outlines. The characteristic transverse striation is occasionally clearly visible. The crystals are usually transparent, with an occasional weak yellow or blue tinge, but a number of almost opaque sections have also been observed. The anatase is characterized by its extremely high refringence and birefringence. Lozenge-shaped sections show negative elongation whilst square cross sections give a uniaxial, optically negative interference figure. In some cases anatase forms mixed aggregates with rutile.

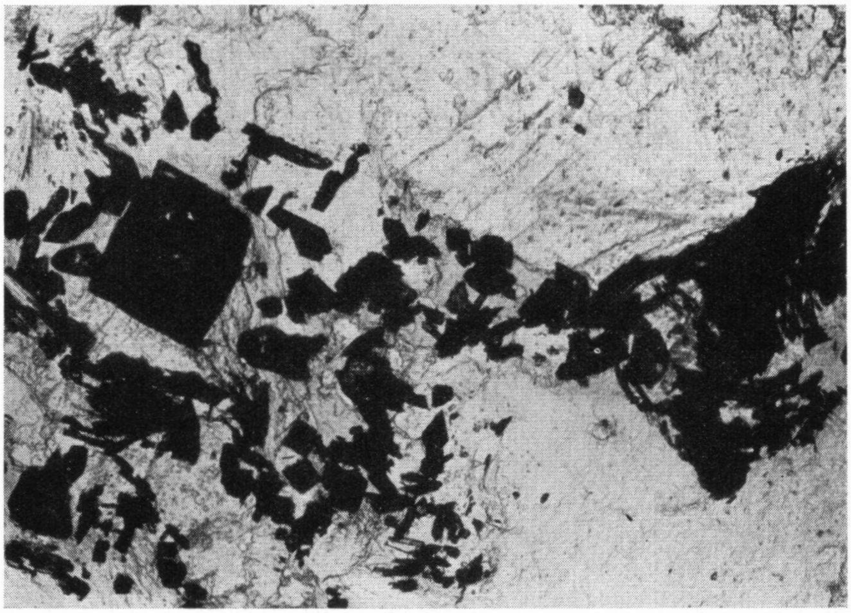

Fig. 8 — Aggregates consisting of translucent or almost opaque crystals of anatase. Truncated as well as complete lozenge-shaped sections are seen. Highly pneumatolyzed potash-rich granitic rock, NE of Escouloubre (loc. T).
sl. 1487 one nicol × 145

BIOTITE

In the investigated area this mineral is present in all kinds of igneous rocks except in some aplitic dikes and in some parts of the pyroxene-bearing granite. In the country rock biotite has only occasionally been observed, in metamorphosed argillaceous rocks and in marbles (Chateau d'Usson) as well as in some calc-silicate hornfelses NE of Escouloubre (loc. T).

Besides some aplitic dikes with brown-green biotite, almost all the igneous rocks contain a variety of biotite that is pleochroic from dark brown to weak brownish yellow. The biotite in the pyroxene-bearing granite may show a reddish brown colour which possibly is due to a comparatively large TiO_2 content.

In the granite close to the contact, intergrowths of biotite, hornblende and clinopyroxene (presumably diopsidic augite) may be present. In some cases biotite is distinctly seen to be bordered by either a hornblende crystal or several pyroxene crystals. Exceptionally, biotite is bordered by a hornblende crystal which in its turn is surrounded by several pyroxene crystals.

Primary inclusions of the biotite include apatite (occasionally with a pleochroic halo), zircon and orthite (both with pleochroic haloes) and finally magnetite. Titanite is either primary or originated by alteration of the biotite.

Many different alteration products have been observed and some of these are of special interest. Besides chlorites and rutile, several calcium-bearing products are present such as clinozoisite-epidote, titanite, prehnite, pumpellyite and garnet. The chlorites, represented by optically negative and optically positive pennine, and the sagenitic rutile show no special features. The calcium-bearing products commonly form lenticular crystals arranged parallel to the lamellar cleavage. Several of these may be enclosed in the same biotite crystal (fig. 9).

The alteration products clinozoisite-epidote (commonly pleochroic from dark to weak yellow), titanite and prehnite are of frequent occurrence in the granite, especially close to the contact, as well as in its dark inclusions.

Pumpellyite as an alteration product of biotite seems to be rare in the granite itself but widespread in the dark inclusions.

Garnet, originated by alteration of biotite and of a peculiar lenticular shape, has also frequently been observed in the dark inclusions but is of rare occurrence in the granite itself.

For a more detailed description of the alteration products the reader is referred to the relevant paragraphs.

In order to obtain a rough idea about the frequency of the similar calcium-bearing alteration products of biotite in other regions, a study was made of thin sections of granitic to dioritic rocks from many localities in the world. Again clinozoisite-epidote, commonly pleochroic, as well as titanite and prehnite appeared to be the most widely distributed alteration minerals. Unlike the first two minerals mentioned, prehnite is comparatively little recorded. Apparently this mineral has often been described as epidote. Titanite was never seen to occur together with rutile. So the liberated TiO_2 content of the earlier biotite seems to be represented either by rutile or by titanite. Though pumpellyite seems to be present less often, the mineral was nevertheless observed in altered biotite of rocks from more than ten localities (see p. 285). In particular, samples from the Vosges (France), the Odenwald (Germany) and the Bergamo Alps (Italy) were seen to contain notable amounts of pumpellyite. More than ten lenses of this mineral may be enclosed in a single biotite crystal (fig. 23). Besides by Erdmannsdörffer (1943), who mentioned briefly similar occurrence of pumpellyite, the mineral has possibly hitherto not been correctly identified, but has been confused with other minerals such as pennine, clinozoisite or prehnite.

Garnet, originated by alteration of biotite and occurring in single or several closely packed lenses (fig. 13), has been observed in rocks from many different parts of the world, especially in quartz-diorites and diorites. It should be emphasized that this type of commonly turbid and slightly anisotropic garnet generally is difficult to distinguish. Compared with ordinary garnet, well known in some granitic rocks (Raguin 1957) and occasionally also enclosed in biotite, it has quite a different appearance. This peculiar type of garnet has apparently not yet been recorded in literature and may have been confused with zoisite. Zoisite, on the other hand, was not definitely recognized by the author as an alteration product of biotite.

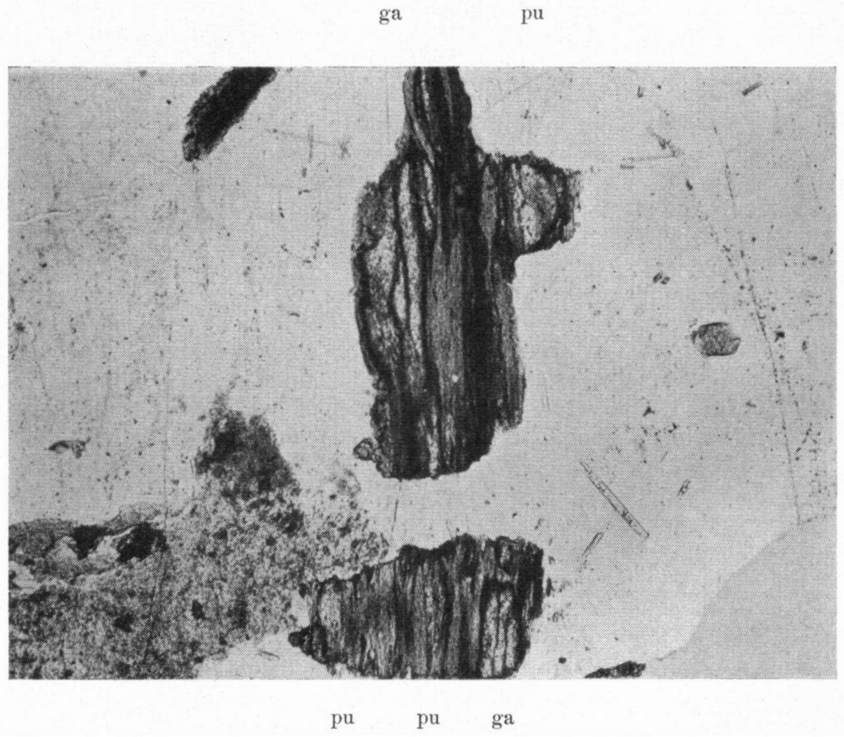

Fig. 9 — Chloritized crystals of biotite enclosing lenses of pumpellyite (pu) and garnet (ga). Dark inclusion of the granite, NE of Escouloubre (loc. T).
sl. 793 — 1 one nicol × 87

CHLORITES

In the investigated area this group of minerals is represented by optically positive pennine, optically negative pennine, clinochlore with low to moderate birefringence and at least two varieties of amesite. In most cases the various types of chlorites are alteration products of earlier minerals and they usually have been mentioned in the paragraphs dealing with these minerals. Some features of interest may still follow below, however.

An optically almost isotropic pennine in a number of samples of the dolomitic marbles exhibits a peculiar type of pseudo-pleochroism, viz. from dark reddish brown or black-brown parallel to the lamellar cleavage to much weaker brown at right angles to it. In most cases only part of the chlorite flakes show this colour, which often varies in intensity within the same crystal. The dark brown colour is considered to be caused by the alteration of the former phlogopite. With very high magnification it is clearly seen that numerous enclosed brown specks cause the false colour of the pennine, the specks being pleochroic themselves. The clinochlore of many of the marbles may even show a still darker colour. In this case the pleochroism or pseudo-pleochroism is from brownish black or black parallel to the cleavage to almost colourless or pale grey at right angles to it. The cause of this type of colour is not clear, though it might be due to the inclusion of numerous extremely small particles of graphite. It can easily be understood that these chlorites are also intensively coloured in the hand-specimen, the pennine being dark violet-brown, the clinochlore being black. The latter, resembling graphite in appearance, recalls the black serpentines from Passau (Bavaria) and St. Philippe (Vosges) that show a similar pseudo-pleochroism (LINDEMANN 1904, p. 211).

Amesite

A peculiar mica-like mineral has been observed in minor amounts in quite a number of thin sections of the silicate skarns. Apart from its elongation, which is negative, the mineral closely resembles a colourless mica. The birefringence ranging from moderate to rather strong, has been estimated to be up to 0.025 and possibly is even higher. The mineral is an alteration product of the spinel as well as of the xanthophyllite. An X-ray powder pattern of the mineral appeared to be almost identical with that of amesite from the type locality, Chester, Massachusetts (BRINDLEY, OUGHTON and YOUELL 1951). Aggregates consisting of fine flaky interlocking lamellae of a clinochlore-like alteration product of the spinel that may occur in the same sections as the amesite have also been subjected to X-ray investigation. The X-ray powder pattern was seen to be identical with that of the amesite described above. So there are probably two types, or eventually more types of amesite, the differences in birefringence probably being due to differences in chemical constitution. It must be emphasized, however, that a careful chemical analysis is wanted to reveal the proper character of both types of amesite. The refringence of both varieties of amesite is distinctly higher than that of the clinochlore that often occurs in juxtaposition.

Sections of rocks from other areas containing magnesium-rich spinels in several cases also exhibited alteration of this mineral into amesite (see p. 292).

CLINOPYROXENES

Clinopyroxenes have been found in several different types of igneous and metamorphic rocks. The igneous rocks are those of the border zone of the granite including the so-called transition zone, the dark inclusions of the granite, an aplitic vein and a lamprophyre. The metamorphic rocks which carry clinopyroxenes include the calc-magnesian-silicate hornfelses and marbles, and the silicate skarns.

In view of differences in appearance, optical properties and mode of occurrence, the clinopyroxenes of each group of rocks will be dealt with separately.

The clinopyroxenes in the igneous rocks

At the localities where silicate skarns have been found, the border zone of the granite and the narrow transition zone between it and the skarn almost invariably contain clinopyroxenes. In the hand-specimen the clinopyroxene can be fairly easily distinguished from the hornblende by its frequent alteration into hydrous iron-ore. A further point of distinction between the two minerals is their colour, the hornblende being black, and the fresh clinopyroxene dark green. In thin section the clinopyroxene is seen to be pale green to colourless, the birefringence strong, the optic axial angle positive ($+ 2V = $ ca. 60°) and $c/n\gamma$ ca. 47°. Twinning, often polysynthetic, has frequently been observed. The shape of the crystals may occasionally be euhedral to subhedral, but very irregular outlines are much more common, especially in the transition zone. The mode of occurrence and the optical properties suggest that the pyroxene is a diopsidic augite. It is possible that the clinopyroxene found in the transition zone, which is usually rather pale green in the hand-specimen and colourless in thin section, is nearer to diopside. Unlike that of the transition zone, the clinopyroxene found in the granite is generally accompanied by the common mafic constituents biotite and hornblende, often forming intricate intergrowths with these minerals. In other cases the biotite and the hornblende crystals are distinctly surrounded by a fringe of several clinopyroxene individuals (fig. 10). A further mode of occurrence is as separate crystals scattered throughout the rock. Enclosed accessories are orthite, ore, apatite and titanite, the latter two often being present in large proportions. Strongly pleochroic uralite and hydrous iron-ore are the most frequent alteration products, calcite, chlorite and serpentinous matter being less commonly met with.

In the dark inclusions clinopyroxene appears to be a rare constituent, only one of the many inclusions investigated being seen to contain it in significant amounts. The mineral, probably a diopsidic augite or a common augite, is in most cases intricately intergrown with biotite, but not with hornblende. In some sections of the dark inclusions, however, an occasional small core of clinopyroxene was seen in the hornblende.

In a mechanically deformed aplitic dike surrounded by low grade calc-silicate-hornfelses, NW of Usson, a pale green-brown clinopyroxene was seen in the rock, forming its only femic constituent. Another occurrence of clinopyroxene is in a dark, very hard lamprophyre by the side of the main road to Escouloubre (I. C. 84), SW of the Col de Moulis. There a weakly pleochroic pink-violet clinopyroxene has been observed. Its birefringence is strong, $+ 2V$ ca. 55° and $c/n\gamma = $ ca. 48°. Probably the mineral has a slight titanium content.

The clinopyroxene in the calc-magnesian-silicate hornfelses and marbles

In these rocks clinopyroxene is of widespread occurrence and often occurs in considerable amounts. According to its optical properties (strong birefringence, c/nγ = 40° and + 2 V = ca. 60°) and mode of occurrence the mineral is most probably a common diopside with a slight hedenbergite content. Megascopically the mineral is not readily recognizable, as it occurs in fine-grained dense green masses. Under the microscope, however, it is easily distinguished. Whilst it occasionally shows a tendency to idiomorphism, it occurs most frequently as highly rounded or oval-shaped grains. In the hornfelses skeletal outlines may be seen. Under the microscope the diopside is in most cases colourless or turbid brownish. An occasionally observed pale green colour is possibly due to an increased hedenbergite content.

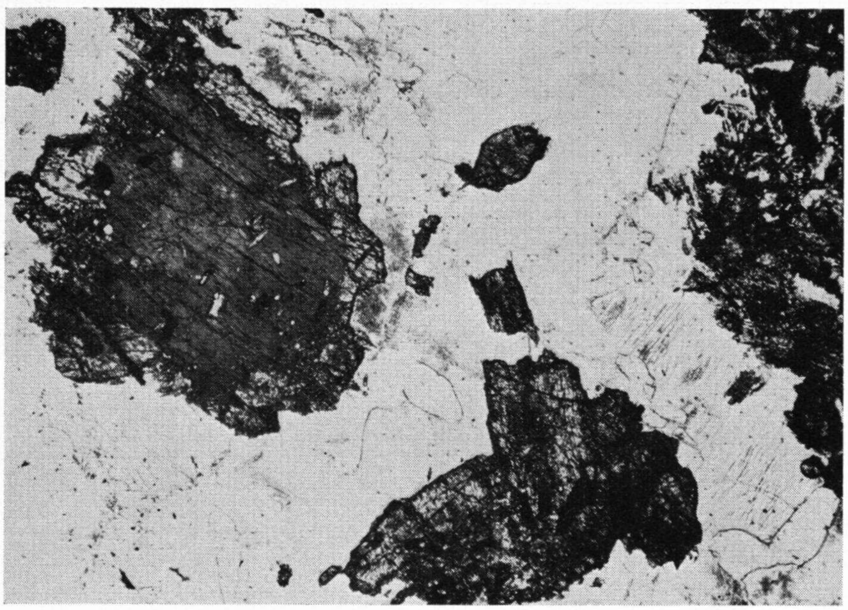

Fig. 10 — Small crystals of clinopyroxene surrounding a large crystal of hornblende in a clinopyroxene-bearing granite of the outermost border zone. NE of Escouloubre (loc. U).
sl. 890 one nicol × 87

The clinopyroxene in the silicate skarns

These rocks are built up mainly of clinopyroxenes. These vary from zone to zone, however, in shape, grain-size and presumably also in chemical constitution. The variation in dimensions is considerable, masses of extremely small rounded granules (ca. 0.01 mm. diam.) sometimes occurring in adjacent position to crystals measuring several mm. in length. The grain-size of the clinopyroxene in the colourless clinopyroxene zone (zone IV) is invariably distinctly larger than elsewhere in the skarn. In this zone crystals up to 1 cm. in length have been observed.

The colour of the clinopyroxenes grades roughly from green in zone I through pale green in zone II to very pale green or colourless in zones III and IV. According to their mode of occurrence and optical properties (c/nγ diminishing from ca. 43° to ca. 38°, + 2 V being ca. 60°) we might be dealing here with common diopsides with a slight hedenbergite content, diminishing from zone I to zone IV. By analogy with dark and pale green clinopyroxenes of a similar skarn zone described by TILLEY (1951), however, the green clinopyroxene of the first zone, and to a less extent the pale green one of the second zone, may contain not only a notable amount of iron, but also rather much alumina. Further, the paragenesis spinel-clinopyroxene suggests a certain aluminium content of the latter (TILLEY 1938). According to their dispersion phenomena, however, none of our clinopyroxenes seems to be highly fassaitic (see KNOPF and LEE 1957 and TRÖGER 1957). Since X-ray powder patterns of diopside and of fassaite from the type locality were found to be identical, only a set of chemical analyses can definitely establish the identity of our clinopyroxenes.

The alteration products include serpentine and calcite.

DIASPORE

This mineral has frequently been recognized among the alteration products of the green spinel of the silicate-skarns. Spinels that occur in the dolomitic marbles, however, were but seldom found to be altered into diaspore (fig. 28 and 29). In these rocks hydrotalcite appears to be the most common alteration product.

Generally the diaspore is only present in very small amounts, in cracks or along the borders of the spinel crystals. In some rocks, however, spinels have been observed that have been almost completely altered into aggregates of diaspore, amesite and magnetite (fig. 26 and 27). Unlike the magnetite, which is commonly highly limonitized, amesite appears to be a common associate of the secondary diaspore.

The diaspore, which is generally in very small crystals (0.05 mm diam.), has high refractive indices, strong birefringence, varying elongation and a very large positive optic axial angle. Sections with negative elongation dominate. In a few cases comparatively much larger crystals up to 0.2 mm. diameter have been observed (fig. 11).

Though the mineral is sufficiently characterized by its optical properties, its identity was checked by means of an X-ray powder pattern.

A few records of rocks which contain both spinel and diaspore have been found in the literature (TILLEY and FLETT 1930; TILLEY 1935 and EGELER 1948), but no descriptions of spinels which are altered into diaspore are known to the author.

A study of thin sections of rocks containing magnesium-rich spinels from different localities in the world revealed similar alteration into diaspore to be quite a common phenomenon (see p. 292). It seems fairly evident therefore, that the secondary diaspore has hitherto not been recognized as such and has doubtless been confused with other minerals such as epidote, prehnite or micaceous minerals.

EPIDOTE GROUP

In the investigated area this group of minerals is represented by α- and β-zoisite, clinozoisite-epidote, orthite and a thulite-like variety of clinozoisite.

Zoisite is among the main constituents of the silicate skarns. In the hand-specimen its colour is greyish lilac to lilac. Because of its peculiar shape and appearance the mineral is not so readily recognized in thin section.

Almost invariably this zoisite displays a short prismatic habit with frayed borders. It generally occurs in aggregates. Anomalous interference colours have been but very seldom observed, and even then they are only slightly anomalous. Both α- and β-zoisite appear to be present, the latter probably in much larger proportion.

In some samples of the silicate skarns reddish-violet spots and small irregular masses are seen that in section appear to consist of a mineral with a pleochroism from pale reddish (α) to very pale reddish (β) and yellowish (γ). Though the pleochroic scheme is similar to that of thulite, the manganese-bearing variety of the orthorhombic zoisite, its X-ray powder pattern points to clinozoisite. The habit and outlines of the crystals of this thulite-like variety of clinozoisite closely resemble those of the zoisite described above.

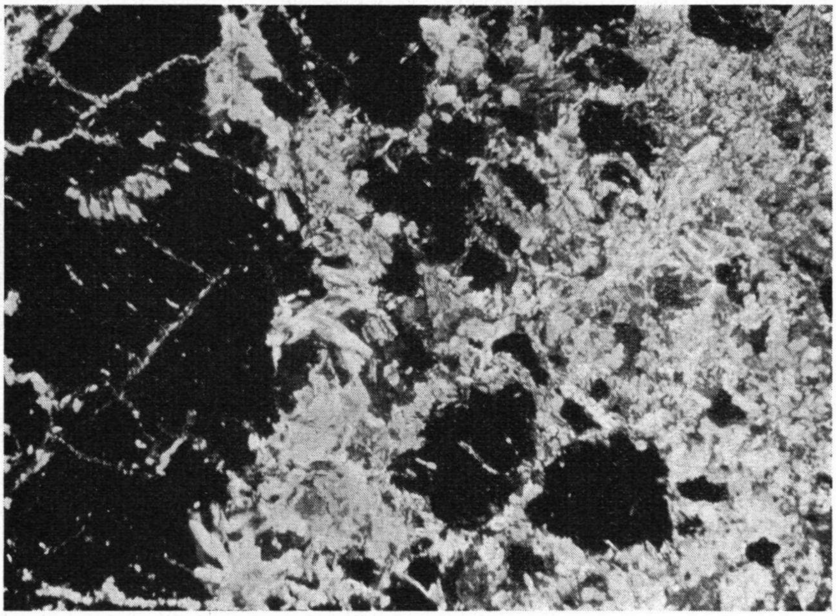

Fig. 11 — Spinel of the spinel-xanthophyllite zone which is partly altered into comparatively coarse diaspore. Zoned silicate skarn, NE of Escouloubre (loc. T).
sl. 906a — 1 crossed nicols × 87

Members of the clinozoisite-epidote series have been encountered in many different kinds of rocks, igneous as well as metamorphic. The minerals are either primary or secondary.

Orthite is a common accessory in most of the granitic rocks as well as in some aplitic dikes. In the outermost border zone of the granite the mineral is present in much larger proportion. In some cases even five crystals have been observed in a single thin section of normal size. The colour of the orthite varies in shades of brown.

In some sections of the narrow veinlets that penetrate from the granite into the silicate skarns, a radioactive orthite-like mineral has been observed. Its properties, however, are not quite the same. The birefringence is moderate, the optic axial angle fairly small and *positive*, whilst the pleochroism is in greenish and yellow-brownish colours. Most of the sections show anomalous bluish or anomalous yellow-brownish interference colours.

FLUOBORITE

Fluoborite — $Mg_3(F, OH)_3BO_3$ — has been observed at one locality only, near the pass NNE of the Roc de Casteldos. The host-rock is a highly altered dolomitic marble with comparatively large amounts of ore. Only three specimens of the marble were seen to contain notable amounts of fluoborite. In other samples the mineral is only among the minor constituents.

In the hand-specimen the fluoborite is difficult to recognize. With the aid of a binocular microscope little hair-like aggregates with a silky lustre may be seen. The chief associated contact minerals in the dolomitic marble are highly chloritized phlogopite, strongly serpentinized chondrodite, much partially limonitized magnetite and chalcopyrite. Minor constituents are forsterite in small rounded crystals, apatite and rare clinohumite. Hydrotalcite is generally also very subordinate, although in one case notable amounts of this mineral were seen.

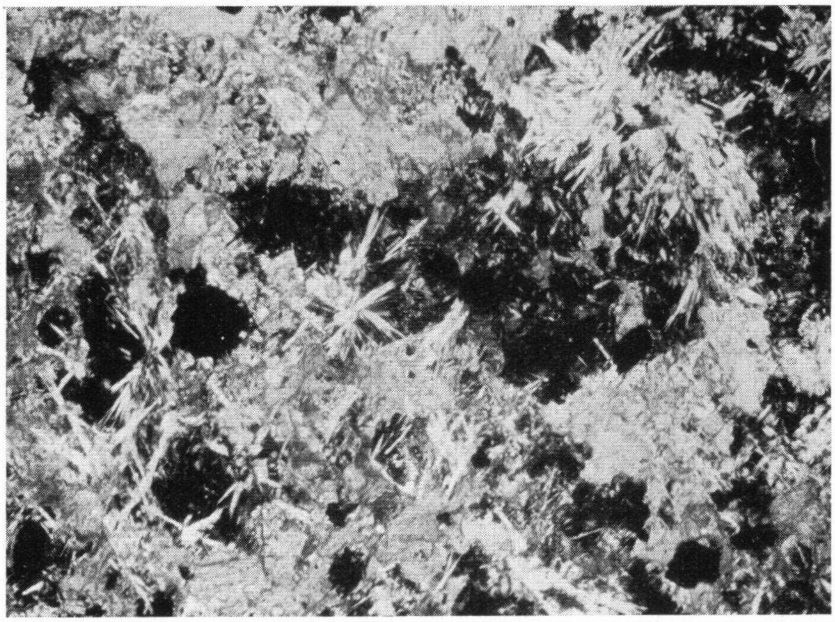

Fig. 12 — Aggregates consisting of little prisms and needles of fluoborite embedded in serpentine and chlorite. Highly altered dolomitic marble,NNE of the Roc de Casteldos (loc. Z).
sl. 213 — 3 crossed nicols × 87

Under the microscope the fluoborite, which is nearly always in aggregates, is seen to occur in two different forms, grading into each other.

The first is as aggregates consisting of many small slender prisms or needles which have a more or less parallel arrangement or which show a radiating structure (fig. 12). These prisms may measure up to 0.5 mm. in length and 0.05 mm. in width. With high magnification and the diaphragm almost closed, cross-sections of the fluoborite may be recognizable which show more or less distinct hexagonal outlines.

The second type is in rounded aggregates, up to 0.3 mm. in diameter, consisting of several bent mica-like lamellae which show undulatory extinction. Every mica-like lamella in its turn consists of a great number of closely packed, very thin, hair-like needles which have a parallel arrangement.

In both types the prisms or needles have straight extinction, negative elongation, low refringence and strong birefringence. The mineral is colourless or has a faint brownish tinge.

The fluoborite is uniaxial and optically negative. Its refractive indices are:

$$n_{\varepsilon} = 1.524$$
$$n_{\omega} = 1.556.$$

According to the diagram in SCHALLER's paper (1942) these properties point to the presence of about equal amounts of the (OH) and (F) end-members of the fluoborite series.

That fluoborite has hitherto been but comparatively infrequently recorded may in part be due to its generally inconspicuous appearance in the hand-specimen, and its possible resemblance to mica-like minerals in the slide.

Though the mineral was already adequately identified by means of its optical properties, an X-ray powder pattern was prepared, which appeared to be identical with that of the fluoborite from the type locality Norberg in Sweden.

In addition to the needle-like fluoborite, and commonly intergrown with it, another fibrous mineral with much resemblance to fluoborite but having a distinctly higher birefringence, was observed in some sections. Its properties such as the negative elongation, the high birefringence and the fibrous habit point to szaibelyite, a not unknown associate of fluoborite at several localities, but the refringence of the mineral seems to be lower than recorded for szaibelyite. Since this mineral is present in very small quantities, however, its identity could not be stated with certainty.

Fluoborite is now known to occur at the following localities:

Hsiang-Hwa-Ling and Jelutan, Hunan, China [1] (AHLFELD, MOSEBACH and OEMICHEN 1938).
Pitkäranta, Finland (ESKOLA and JUURINEN 1952).
NNE of the Roc de Casteldos, Aude, France.
Campania, Nocera, Italy [2] (BRISI and EITEL 1957).
Hol-Kol Mine, Suian distr., Korea (WATANABE 1939, 1943).
Beatrice Mine, Selibin, Malaya (JOHNSTON and TILLEY 1940).
Skye, Scotland (TILLEY 1952).
Norberg distr., Sweden (GEIJER 1926, 1927).
Lincoln County, Nevada, U. S. A. [3] (GILLSON and SHANNON 1925 and GEIJER 1927).
Franklin and Stirling Hill, Sussex County, New Jersey, U. S. A. (BAUER and BERMAN 1929).

[1] The mineral was not described as fluoborite but was shown to be identical with the "magnesium-borate" from the Beatrice Mine at Selibin in the Federated Malay States described by WILLBOURN (1926). Later on JOHNSTON and TILLEY (1940) stated the true identity of this "borate" to be fluoborite. The descriptions of the Chinese mineral are comprehensive enough and the optical properties are exactly those of fluoborite so that the name fluoborite is fully justified.

[2] Very recently BRISI and EITEL (1957) proved that the mineral "nocerite" which has originally been described as a complex oxyfluoride of calcium and magnesium is in reality an intimate mixture of fluorite and the pure fluorine end-member of the fluoborite series.

[3] The mineral was described as an unknown by GILLSON and SHANNON, but its identity was made clear by GEIJER (1927).

FORSTERITE

Forsterite is among the most widespread contact minerals of the dolomitic marbles. With the exception of some specimens carrying humite or chondrodite, almost all samples of these rocks were seen to contain forsterite, and commonly notable amounts of it. In the silicate skarns, however, forsterite has never been found.

In the hand-specimen fresh forsterite is colourless or weak yellow to brownish and therefore not readily seen. Rocks containing serpentinized forsterite, however, readily attract attention by virtue of their bright yellow to green colours.

The crystals are often strongly rounded and measure up to 3 mm. in length. They are either scattered in the rock as separate grains or concentrated in aggregates.

In thin section the forsterite is colourless and easily recognized by its rounded outlines, irregular cracks, high refringence, strong birefringence, positive sign and very large optic axial angle. Partly altered crystals show the well known mesh-structure. Intricate intergrowths with the carbonate matrix such as recorded for clinohumite are quite common. When separated from the marble by treatment with hydrochloric acid the crystals may show similar skeletal outlines. Intergrowths with other contact minerals such as clinohumite, phlogopite (chlorite), apatite, spinel and magnetite are frequently met. For a detailed description of the intricate homoaxial intergrowths of forsterite and clinohumite the reader is referred to page 271. Swarms of small spinel crystals and rounded magnetite granules may be enclosed in a single forsterite crystal.

Among the various alteration products encountered serpentine is the most common. Other secondary products that were frequently observed are optically negative and optically positive pennine, clinochlore, calcite, talc and fibrous yellow to brownish products. In some rocks the forsterite is altered into pale brownish to greenish serpentine-like products with higher birefringences ranging from 0.015 to 0.030. Unlike the alteration of clinohumite the serpentinization of forsterite is never seen to be accompanied by the liberation of small magnetite granules. Incipient alteration into serpentine or chlorites starts along irregular cracks and poor cleavage planes as well as along the periphery, producing the well known mesh or sieve structure.

A single slide may show different types of alteration of the forsterite. A zonal arrangement of the alteration products such as that described for clinohumite may be observed in several samples. Here, however, dust-like iron ore is absent.

GARNET

Minerals belonging to the garnet group have been found in the calc-magnesian-silicate hornfelses and marbles, the silicate skarns, the so-called transition zone, the granite and the basic inclusions of the granite. The garnets are either primary minerals or alteration products of biotite.

In view of characteristic differences in appearance and in the mode of occurrence, the garnet of each group of rocks will be dealt with separately.

The garnet in the calc-magnesian-silicate hornfelses and marbles

The garnets found in these rocks are members of the grossular-andradite series, as indicated by the dimensions of their unit cells. According to the comparatively low refringence (1.73—1.76) their content of grossular should be much larger than that of andradite and therefore they will be called grossular in the sequel.

Grossular is of widespread occurrence in the rocks referred to above. At some localities (loc. E and loc. Y) the marbles may contain perfectly idioblastic dodecahedrons, as well as irregularly bounded crystals. The garnets may vary in dimensions between 2 mm. and 2 cm. in diameter and may range in colour from yellow-brownish to dark reddish brown. In the hornfelses the grossular is commonly of xenoblastic habit, but in some of these rocks subhedral crystals may occur. Several hornfelses show dark brown idioblastic idocrase crystals which are embedded in a dense matrix of weak reddish grossular.

In thin section the garnet is pale brownish yellow or pale reddish to colourless. A weak birefringence was seen in many cases. Irregular cracks are frequent. Garnet porphyroblasts are generally crowded with inclusions of small rounded crystals of diopside. Enclosed calcite, clinozoisite-epidote and prehnite may be either of primary or of secondary origin. Intergrowths with these minerals as well as with idocrase, potash-rich felspar and wollastonite are frequent.

The garnet in the silicate skarns

In these rocks garnet is a rare constituent. According to the comparatively low refringence (1.745) it is an almost pure grossular. Xenoblastic aggregates as well as subhedral crystals are present. The colour is weak brownish pink to almost colourless.

In all the slides examined the grossular was seen to be optically anisotropic. Some crystals show an alternating pattern of hardly birefringent and distinctly birefringent zones.

The garnet in the transition zone

Some samples of the contact between the granite and the silicate skarns show the development of a xenoblastic grossular ($n = 1.745$) in the transition zone. The colour is weak, varying from yellowish pink to almost colourless.

In thin section the mineral is colourless. Optically isotropic crystals as well as crystals showing a weak birefringence were seen.

The garnet in the granite and its dark inclusions

In many samples of the basic inclusions as well as in some samples of the granite close to the contact a peculiar type of garnet has been observed in fresh or chloritized biotite. It should be emphasized that this garnet differs quite considerably in appearance from ordinary garnet. It occurs in single lenses as well as in aggregates consisting of several flat closely packed lenses parallel to the lamellar cleavage of the biotite or the chlorite. Most of the lenticular garnet crystals are weakly birefringent, show a straight extinction and a positive elongation. The colour may vary from pale reddish brown to darker brown. Very turbid crystals are common. In several cases no sharp limits were seen between the garnet lenses and the surrounding biotite or chlorite, and indeed they seem to merge into each other.

A noteworthy thing is that the refringence of the garnet seems to be much lower in the slide (estimated to be about 1.70) than it is in fact (1.78—1.79). Therefore we are probably not dealing with hydrogrossular. The combination of this refringence and the dimensions of the unit cell (12.00 Å) points to a rather peculiar member of the grossular-andradite series (FRIETSCH 1957). However, the comparatively low refringence suggests that the proportion of grossular is larger than that of andradite, whereas the comparatively large size of the unit cell points to the reverse. Therefore, a careful chemical analysis is wanted to reveal the proper composition of this garnet.

Aggregates consisting of very flat parallel lenses resemble closely single crystals of a mineral that has a distinct cleavage direction parallel to the elongation. At first glance the weak birefringence of these suggests that they are longitudinal sections of zoisite. It should be emphasized, however, that such sections of α-zoisite have negative elongation and those of β-zoisite alternating elongation whereas the garnet lenses have positive elongation. In plane-polarized light, turbid lenses of the garnet may resemble titanite.

The garnet is considered to be an alteration product of the biotite, and its formation may be compared with that of other calcium-bearing products such as clinozoisite-epidote, titanite, prehnite and pumpellyite (see p. 257). Some of these products may accompany the garnet in the same rock and may even be enclosed in the same chloritized biotite crystal (fig. 9). In exceptional cases small biotite crystals were seen to be almost completely converted into garnet.

A study of many sections of granitic to dioritic rocks from various localities in the world, revealed alteration of biotite into lenticular crystals of garnet to be a widespread phenomenon (see p. 258). Usually the garnet is only present in very subordinate amounts. In some rocks, however, especially in diorites and quartz-diorites (e. g. from the Vosges in France and from the Odenwald in Western Germany) it was seen to be a main constituent. There, the biotite crystals may be almost completely converted into aggregates of garnet (fig. 13).

Since in many granitic to dioritic rocks the lenticular garnet is only a very subordinate constituent, the mineral will be more easily found in the heavy translucent fraction. This type of garnet may also be more easily recognized by immersion in liquids than in the slide were it is "hidden" in the biotite. Further it is supposed, that many sands which owe their origin to the decomposition of granitic to dioritic rocks will contain some garnet of the type described here.

As far as known to the author the peculiar lenticular garnet has not yet been recorded in literature. Probably it has been confused with zoisite in several cases. Further, it may be of interest to note that the presence of the orthorhombic zoisite in biotite has never been observed by the author.

HUMITE GROUP

In the region under investigation three members of this group are represented but only clinohumite is of widespread occurrence. Humite and chondrodite are but locally developed whereas norbergite has not been found.

Clinohumite

After forsterite and phlogopite, clinohumite and spinel are among the most frequent primary contact minerals in the dolomitic marbles. Unlike the colourless forsterite, clinohumite readily attracts attention in the samples by means of its striking yellow to brownish colours. The crystals measure up to 3 mm. in length and commonly show rounded and irregular outlines. They are either scattered through the marble as separate grains or concentrated in aggregates of up to 1 cm. in diameter.

In thin section confusion with forsterite is not possible because all varieties of clinohumite, the pale yellow included, are seen to show a distinct pleochroism. The darker coloured varieties have α = dark yellow to golden yellow, β = pale yellow and γ = pale yellow to yellow; absorption $\alpha > \gamma \geqslant \beta$.

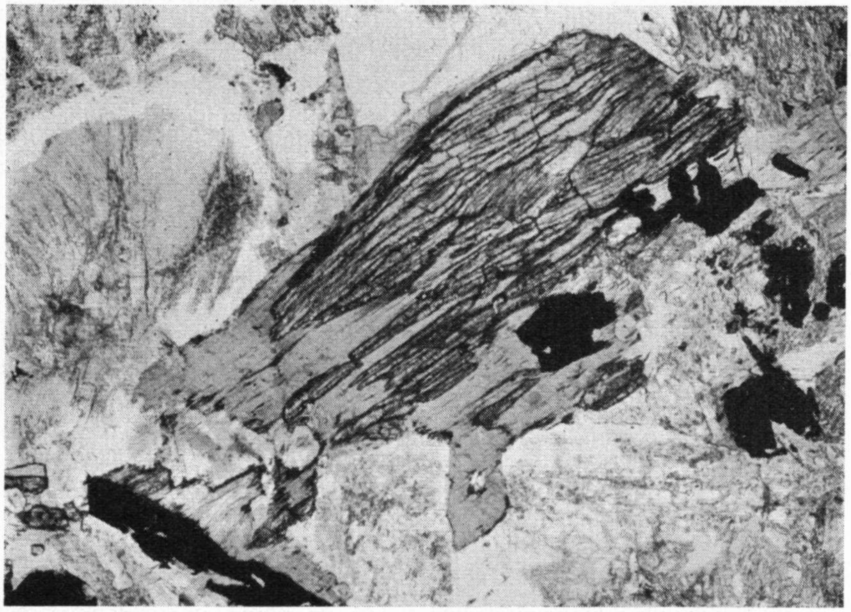

Fig. 13 — Lenses of a peculiar type of garnet, both closely packed and separate, enclosed in highly chloritized biotite, and arranged parallel to the lamellar cleavage. Spessartite, Spessart, Western Germany.
sl. D 340 one nicol × 87

The yellow clinohumites have α = pale yellow, β and γ colourless; absorption $\alpha > \beta = \gamma$.

In marbles collected at different localities but especially in those occurring N of Le Bousquet clinohumite may build (very) intricate intergrowths with the carbonate matrix, which commonly consists of calcite. In this case the slides may show numerous small clinohumite sections of rounded or irregular shape, separated from each other by carbonate grains, but showing simultaneous extinction (fig. 14 and 15). Actually these separate sections belong to a single large crystal with very irregular skeletal outlines as revealed by treating the sample with dilute hydrochloric acid. Though these crystals have

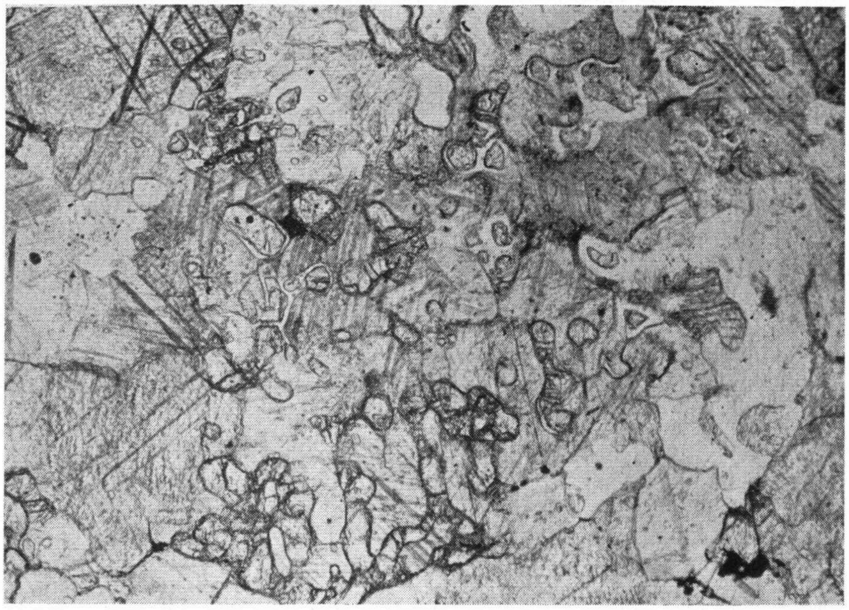

Fig. 14 — Partially serpentinized crystal of clinohumite forming an intricate intergrowth with the carbonate matrix. Forsterite-clinohumite-spinel marble, N of le Bousquet (loc. AA).
sl. 228 one nicol × 87

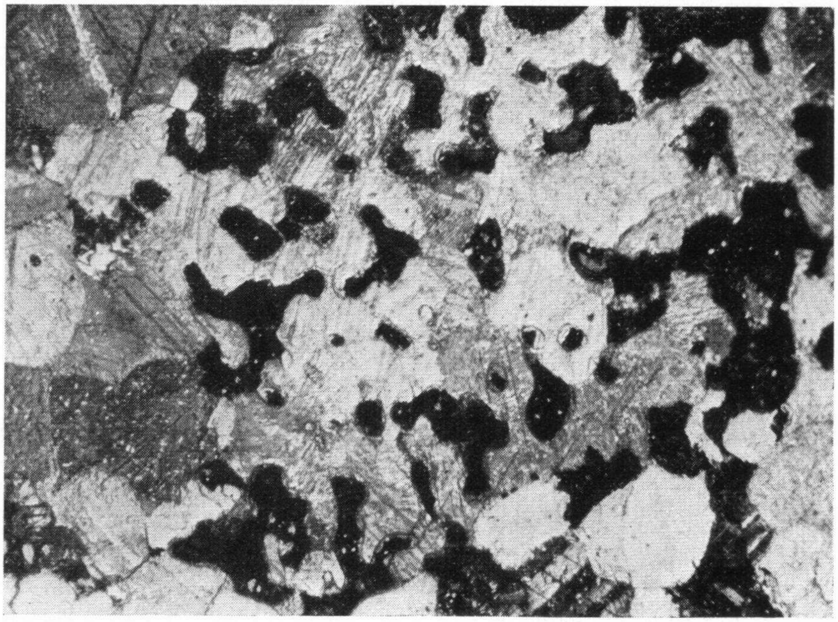

Fig. 15 — The same as fig. 14 with crossed nicols. The numerous sections of the clinohumite, which are separated from each other by carbonate, are seen to show simultaneous extinction.

the appearance of being strongly corroded, the intricate intergrowths, also those with other contact minerals, are considered to be of primary origin. In the slides the clinohumite-carbonate intergrowths may show strongly variable amounts of each constituent.

A noteworthy feature is the intricate homoaxial (not zonal) intergrowth of clinohumite and forsterite. As seen in section the amount of each mineral may vary in all proportions, forsterite crystals speckled with some yellow spots of clinohumite ranging to clinohumite crystals enclosing some little colourless spots of forsterite. The genetic relationship between forsterite and humite minerals as suggested by other investigators (Du Toit 1919, De Quervain 1928, Read and Double 1935, Watanabe 1943, Tilley 1951) is fully confirmed in the present study. In the investigated area moreover all the stages of progressive replacement of forsterite by clinohumite are met with. In a contact rock from Serranía de Ronda (prov. Andalusia, Spain) similar intergrowths of forsterite and humite were observed by the author[1]).

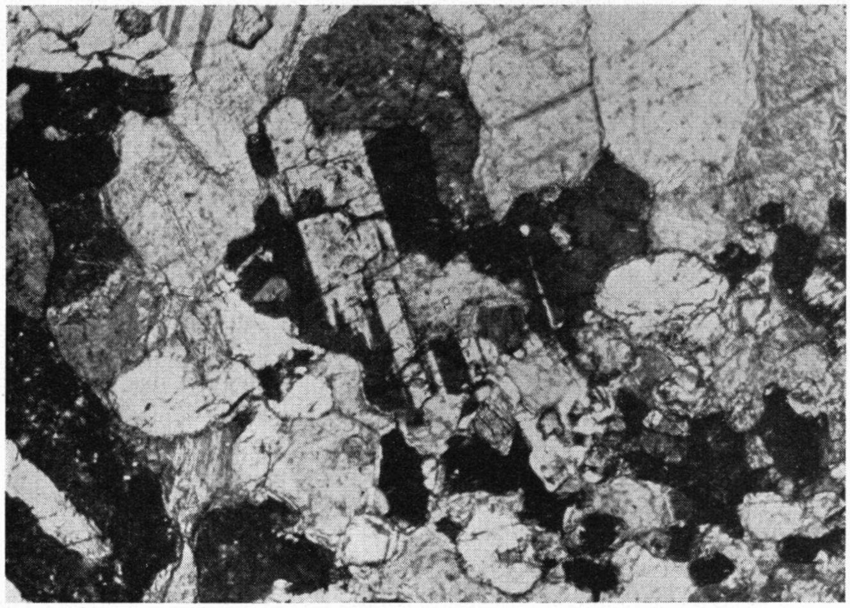

Fig. 16 — Clinohumite showing polysynthetic twinning on (001). Forsterite-clinohumite-spinel-marble, N of Eaux Chaudes.
sl. 690 — 1 one nicol × 145

Polysynthetic twinning on (001) is frequently observed (fig. 16); in addition twinning on other planes may occur more scarcely.

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[1]) It may be noted here that Michel-Lévy and Lacroix (1886) and Michel-Lévy and Bergeron (1889) described homoaxial intergrowths of colourless humite and yellow clinohumite from rocks of the same locality, the humite making up the mantle and the clinohumite being the core.

In a specimen presented to the Geological and Mineralogical Institute at Leiden by Professor Lacroix, the colourless olivine-like material of the mantle, however, was seen to be forsterite, the identification of which was checked by means of its X-ray powder pattern.

In section some of the darker coloured crystals of clinohumite were seen to show different colour intensities within the same crystal, sometimes in patches, most frequently, however, with a more weakly coloured core and a darker mantle. The refractive indices of the more strongly coloured parts appear to be a little higher. It may be mentioned that we are not dealing here with intergrowths of two different humite minerals, both varieties showing the X-ray pattern of clinohumite without admixture of other minerals. Humite minerals from other regions (Sparta and Amity, U. S. A.) were seen to show similar differences in colour intensity to those described above.

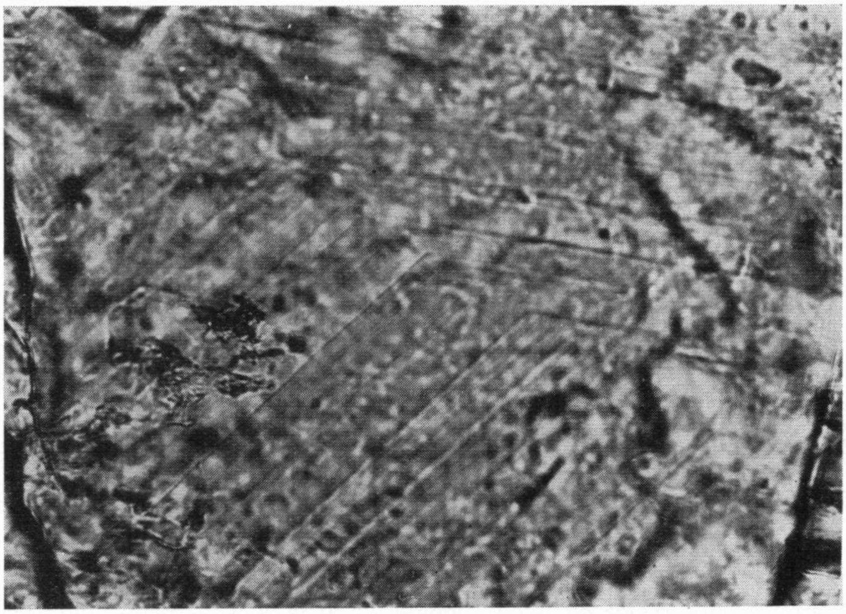

Fig. 17 — Part of a clinohumite crystal showing a distinct zonal pattern of alternating, sharply defined, paler and darker yellow zones. Forsterite-phlogopite-clinohumite-spinel marble, NW of Eaux Chaudes (loc. I).
sl. 179 — 2 one nicol × 740

Another feature of the clinohumites of Escouloubre may be worth mentioning. Some slides, when viewed at high magnification, show a distinct zonal pattern of alternating, sharply defined, paler and darker yellow zones (fig. 17).

Among the various alteration products observed serpentine and fine lamellar clinochlore are the most common. Unlike the alteration of forsterite, the chloritization and serpentinization of the clinohumite is always seen to be accompanied by the liberation of numerous very small granules of magnetite. Incipient alteration starts along irregular cracks and indistinct cleavage planes (001) as well as along the crystal boundaries, producing the well known mesh-structure. All stages of alteration may be observed in slides of a single hand-specimen. Other secondary products that were frequently observed are optically negative and optically positive pennine, calcite, fibrous yellow to brownish products and brownish to blackish cloudy undetermined material. Of less frequent occurrence are pale brownish to greenish serpentine-like products with higher and much higher birefringence, showing interference colours up to red of second order in slides of normal thickness (about 0.03 mm.). In this case no separation of magnetite granules was observed.

A single slide may show different types of alteration of the clinohumite. In some samples collected at different localities a distinct zonal arrangement of the alteration products is seen. In this case a relic core of clinohumite, eventually partially altered into yellowish brown fibrous products, is seen to be bordered by a narrow zone of optically negative pennine with anomalous bluish interference colours merging through a very thin isotropic zone into optically positive pennine with brownish yellow interference colours. This latter zone passes into clinochlore showing very low, greyish interference colours, eventually merging into higher yellowish ones. The chloritic fibro-lamellae are always speckled with dust-like iron-ore and are seen to be arranged more or less perpendicular to the boundaries of the zones. The completely altered clinohumite crystals of these rocks consist only of clinochlore, eventually including some little spots of negative pennine mantled by positive pennine. It seems likely that the clinochlore is the ultimate product of progressive alteration, the positive and negative pennine representing intermediate steps.

Chondrodite

This member of the humite group has been observed at one locality only, near the pass NNE of the Roc de Casteldos. Its chief associates are strongly chloritized phlogopite, partially limonitized pyrite, fluoborite, and much serpentinous and chloritic products presumably derived from olivine-like minerals. In some samples apatite, hydrotalcite, forsterite, clinohumite and rutile may be observed as minor constituents.

In the hand-specimen the chondrodite is difficult to distinguish, partly due to its very weakly yellowish colours but especially to its high degree of alteration.

In the slide the strongly rounded grains, which are separate or in aggregates, measure up to 2 mm. in diameter. The colour is much weaker than that of the clinohumites and humites ($\alpha =$ very pale yellow and β, $\gamma =$ colourless). Another valuable diagnostic feature is the markedly lower refringence. In one slide only, indistinct polysynthetic twinning was observed with an extinction angle characteristic for chondrodite. Before the observation of the twins the identity of the mineral was already established by means of its X-ray powder pattern.

Among the alteration products serpentine and translucent brownish to opaque blackish material have been observed.

Humite

The orthorhombic humite has been observed in rocks from two localities, near the chondrodite-bearing marbles NNE of the Roc de Casteldos and NE of Escouloubre (loc. V).

In the hand-specimen the minerals vary from yellowish to dark orange in colour, in section the darker coloured varieties have $\alpha =$ dark yellow and

β, γ = pale yellow, whereas the weakly coloured have α = very pale yellow and β, γ = colourless; absorption $\alpha > \beta = \gamma$.

The associated minerals are spinel and a little clinochlore. In one sample a mineral resembling ludwigite was observed as a minor constituent. Some sections may show intricate intergrowths of humite and carbonate. The alteration products are yellow to brownish fibrous products.

General remarks on the humite group

When coloured, a mineral of the humite group may be easily recognized as such. Colourless humite minerals, however, are also known, so that these might be confused with forsterite. The orthorhombic norbergite being characterized by its comparatively low refringence and small optic axial angle, this holds especially true for the orthorhombic humite, if this mineral does not show a well-developed cleavage on (001), but also for monoclinic members devoid of twinning or cleavage on (001).

Within the humite group itself it is again norbergite that is sufficiently characterized by its refringence and optic axial angle. The refringence of the other members, however, overlaps over a considerable range, so that, if a distinct cleavage on (001) is lacking, humite and untwinned chondrodite or clinohumite often cannot be optically identified.

A complete chemical analysis of purified material may then reveal the true identity of the species but may meet with severe difficulties and even lead to incorrect results if two or more humite minerals occur in the same rock.

The identification by means of the X-ray powder pattern, however, gives reliable and quick results, as already stated by Sahama (1953, p. 47) [1]. Although there is much similarity in structure each species has a pattern markedly different from that of the others and from that of forsterite (fig. 18). Further, if two members of the group occur in the same rock, an X-ray pattern indicates the presence of both of these and may even give a rough estimation of the amounts of each mineral. According to Sahama (1953, p. 6) an admixture of 5 per cent of another humite mineral may easily be detected in the pattern. The possibility must not be overlooked, however, that different members of the humite group may occur in different parts of the same specimen. To enlarge the reliability of a statement of the content of humite minerals of a rock, the sample for the X-ray pattern is therefore to be taken from an intimate mixture of grains taken from various parts of the sample.

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[1] On the assumption that humite minerals in museum collections might be incorrectly labelled a number of specimens was checked by the author with the aid of their X-ray powder patterns. Indeed several of these were found to contain other members of the humite group than indicated on the label. This holds good especially for the rocks from the Vesuvius; further, it may be of interest to note that a specimen from Katveltorp (Sweden) labelled as chondrodite appeared to contain humite, whereas that mineral, as far as known to the author, has not yet been recorded from this well known locality of humite minerals.

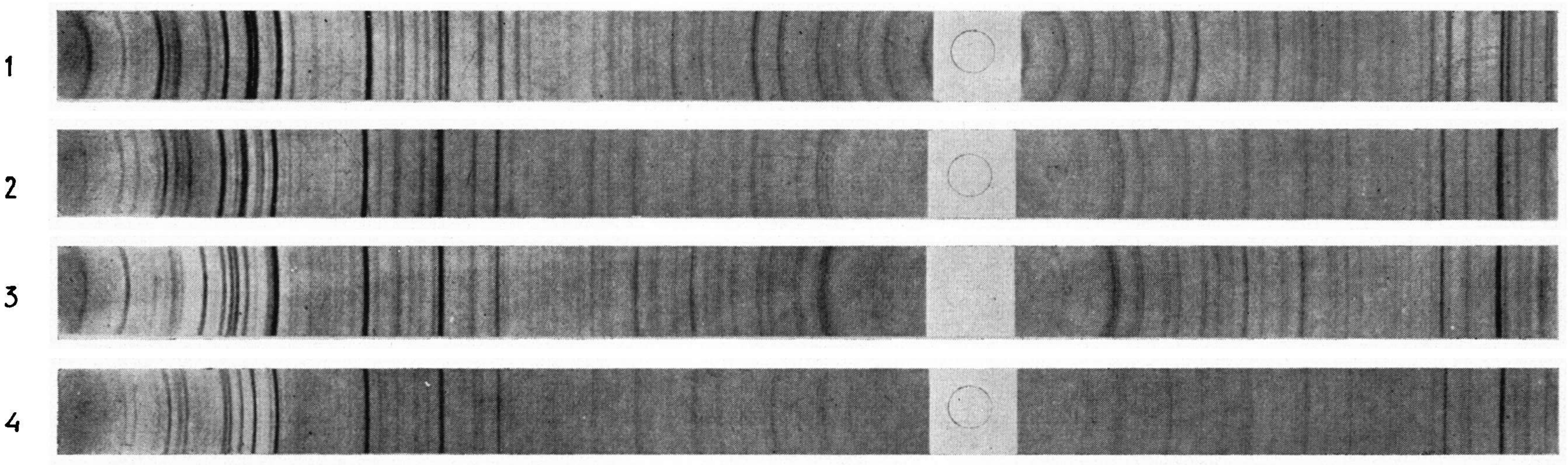

Fig. 18 — X-ray powder photographs of forsterite and three of the humite minerals. (Fe Kα radiation, camera diameter 9 cm.)

No. 1 Forsterite, Eaux Chaudes (loc. I), Pyrenees. m* 1867
No. 2 Clinohumite, Le Bousquet (loc. AA), Pyrenees. m 1843
* Number X-ray photograph.

No. 3 Chondrodite, NNE of the Roc de Casteldos (loc. Z), Pyrenees. m 1824
No. 4 Humite, Katveltorp, Sweden. m 1978

HYDROTALCITE
AND
MANASSEITE

As **Frondel** (1941) pointed out, almost all specimens of hydrotalcite — $Mg_6Al_2(OH)_{16}CO_3 . 4 H_2O$ — are not homogeneous but are intimate mixtures of an hexagonal and a rhombohedral substance which have very similar physical and identical chemical properties. The rhombohedral substance has been called hydrotalcite and the hexagonal manasseite. The polymorphs can easily be distinguished by means of their X-ray powder pattern.

In the investigated area both minerals are present, X-ray powder patterns which were taken from samples from different localities showing almost pure patterns of hydrotalcite with only little admixture of manasseite. Though we may therefore expect that in the whole area manasseite is present in much lesser amounts than hydrotalcite, one should be careful to judge, since according to **Frondel** (1941, p. 305) the hydrotalcite-manasseite ratio may vary greatly from point to point, even in the same hand-specimen.

For the sake of convenience in the following account the name hydrotalcite is used when the hexagonal or rhombohedral character of the mineral or the degree of admixture has not been determined by X-ray investigation. The pure rhombohedral substance will be indicated with hydrotalcite s.s. (= sensu stricto).

In the investigated contact zone hydrotalcite is of very widespread occurrence in the dolomitic marbles as an alteration product of magnesium spinel.

The mineral is, however, difficult to distinguish in hand-specimen. In some cases it may be observed with the aid of a strong hand-lens or a binocular microscope as small white spots up to a diameter of 3 mm. consisting of foliated and contorted platy to fibrous masses showing a silky lustre.

Although the alteration of magnesium spinel into hydrotalcite was early recorded in literature, this phenomenon is of special interest in the investigated area. The fact is that all steps in the progressive alteration are present. This even holds true for sections of a single hand-specimen.

Under the microscope the hydrotalcitization of the spinel is seen to start along cracks and poor cleavage planes as well as along the borders of the crystal. The type of alteration may recall the well known mesh-structure of olivine-like minerals. In an advanced stage of alteration relics of the spinel are seen to be embedded in a dense matrix of contorted hydrotalcite lamellae and fibres (fig. 19 and 20).

Commonly the hydrotalcite shows a conspicuous resemblance to serpentine in its general appearance, birefringence, sign of elongation and optic axial angle. It can be distinguished, however, by its lower refringence, though this is only distinctly visible when both minerals are adjacent to each other. Further, hydrotalcite lamellae have a $n\gamma$ (about 1.51) distinctly lower than the refractive index of Canada balsam (n about 1.54).

In an incipient stage of the alteration of the spinel the hydrotalcite may show peculiar anomalous bluish interference colours. These colours, as far as known to the author not yet recorded in literature, have also been observed in rocks from other areas (e. g., Amity, New York in the U. S. A. and the Massif de l'Arize in the Pyrenees). The anomalous bluish interference colours may closely resemble those typical of optically negative pennine and confusion with this mineral might be expected.

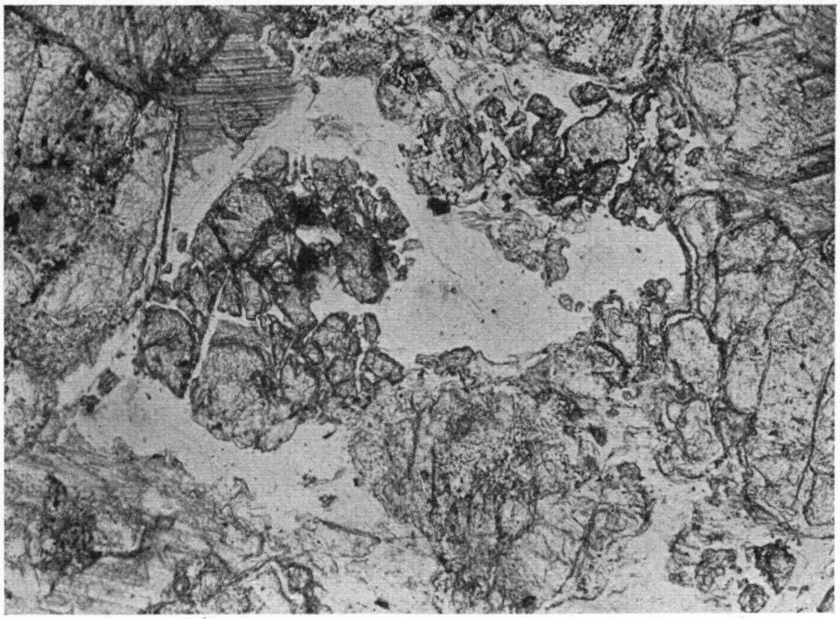

Fig. 19 — Crystals of spinel partially altered into masses of foliated and contorted hydrotalcite lamellae. Forsterite-phlogopite-clinohumite-spinel marble, NE of Escouloubre (loc. T).

sl. 58 — 4 one nicol × 87

Fig. 20 — The same as fig. 20 with crossed nicols.

Hydrotalcite aggregates originated by the total alteration of spinels in addition to the common serpentine-like contorted lamellae may also show more chlorite-like lamellae. These have a more distinct lamellar cleavage and show interference colours up to dark yellow of the first order. Lamellae of this type may measure up to 0.4 mm. along the cleavage and 0.3 mm. perpendicular to this direction.

The different appearances of the hydrotalcite might be expected to be due to the presence of different polymorphs or, if both minerals are present, to a different proportion of these. X-ray powder patterns taken from little altered and completely altered spinels in all cases, however, revealed the same pattern of hydrotalcite s.s. with very little admixed manasseite.

The coarser aggregates of hydrotalcite are frequently turbid due to a very finely divided brownish pigment. Small opaque black and dark brownish granules which are embedded in aggregates of hydrotalcite may in part represent primary inclusions of the earlier spinel and in part also the liberated poor iron content. Enclosed translucent flakes of haematite or goethite are doubtless of secondary origin.

The hydrotalcite is uniaxial and optically negative. Its refractive indices are:

$$n_\varepsilon = 1.496$$
$$n_\omega = 1.510.$$

An occasionally observed small optic axial angle may be due to mechanical deformation. The measured indices of refraction point to hydrotalcite s. s.

Modern textbooks (e. g. DANA 1944) mention only three countries (U.S.A., Norway and Russia) where hydrotalcite has been found and the mineral has hitherto been considered as fairly rare. Further, hydrotalcite is reported as pseudomorphs after spinel from the Grenville district in Quebec, Canada (OSBORNE 1938). That hydrotalcite is noticed comparatively seldom may in part be due to its close resemblance to talc in the hand-specimen and to serpentine or optically negative pennine in the slide. As a matter of fact serpentine is reported in textbooks (DANA 1944, p. 695 and WINCHELL II 1951, p. 84) as being among the alteration products of spinel. Several authors described alteration of spinel into serpentine or serpentinous products (TILLEY 1920, p. 465; THOMAS 1922, p. 248, GEIJER 1927, p. 22; JOPLIN 1935, p. 391; DREVER 1939, pp. 510—511 and KEITH 1946, p. 977).

It is striking, however, that in a study of many thin sections of rocks containing magnesium-rich spinels serpentine has never been observed among the alteration products of these minerals. On the other hand some new occurrences of hydrotalcite have been detected in addition to those of the investigated area (see p. 290). It seems fairly evident now that hydrotalcite has often been described as serpentine. The present author even thinks hydrotalcite to be a quite common mineral.

The process of hydrotalcitization may be comparable with other well known alteration processes such as chloritization and serpentinization. Further it is supposed that hydrotalcite in all cases owes its origin to the conversion of magnesium spinels although relics of these will not always be present. Highly altered dolomitic marbles and calcified serpentines with spinels are considered to be the rocks most likely to contain hydrotalcite.

IDOCRASE

This mineral is a common constituent in the calcite marbles and the calc-silicate and calc-magnesian-silicate hornfelses.

In the hand-specimen, the larger idocrase crystals may easily be distinguished by their stout prismatic habit, square cross sections and brown to green colour. In the marbles the mineral may be either dark olive-green (resembling epidote) or display varying shades of brown. Marbles carrying much green idocrase are well exposed on the western slope of the Roc de Casteldos (loc. Y). In the hornfelses of several localities (loc. E and Y), dark brown idocrase crystals showing a strong tendency to idioblastic development, are embedded in a dense matrix of pale reddish xenoblastic grossular.

Under the microscope, the idocrase crystals, showing a poor cleavage (100), are generally intersected by many cracks, roughly perpendicular to the elongation. Porphyroblasts of idocrase may enclose calcite and numerous minute rounded granules of diopside. Intergrowths with the calcite matrix and potash felspar as well as with grossular, its common associate, are frequently observed. The intergrowths with grossular may be intricate and in several cases the idocrase seems to have grown at the expense of the grossular. In thin section the idocrase is colourless or weakly pleochroic with a patchy colour distribution. Green varieties may be distinctly pleochroic, with ω = lemon yellow and ε = very pale yellow to colourless. Occasionally, a zonal arrangement of pale and darker colour intensities is distinguishable. Anomalous bluish, as well as anomalous greenish grey and brownish green interference colours have been frequently observed for the green varieties of idocrase.

Among the various alteration products, calcite is the most common. Clinozoisite-epidote and prehnite are occasionally developed along cracks and cleavage planes. In one section pale brownish idocrase is partially converted into a weak brown fibrous product. The fibres have a straight extinction, positive elongation and a weak to rather strong birefringence (about 0.025). In other instances idocrase is partially replaced by a dense brownish sericitic mass.

MUSCOVITE,

LILAC MICA AND SERICITE

Colourless mica is not of frequent occurrence in the igneous rocks. Besides in a small mass of a highly pneumatolyzed rock close to the contact (loc. T), where colourless mica occurs as a main constituent, it has only been observed in some of the aplitic dikes. In the aplites it is probably a common muscovite.

A pale lilac mica, in most cases largely replaced by a much finer flaked mica, is among the main constituents of the silicate skarns. The X-ray investigation of this mineral met with difficulties, but vaguely indicated that it is not a muscovite. The dense character of the masses of mica in the hand-specimen is due to the fine flaky character of this mica which is also pale lilac in colour.

Sericite and sericite-like minerals have been observed in different kinds of rocks, usually as alteration products of plagioclase.

PHLOGOPITE

Phlogopite has been found in the dolomitic marbles and in the silicate-skarns. The phlogopite of the skarns is pale green to colourless in thin section and is easily recognized because of its common alteration into different types of chlorite.

The phlogopite in the marbles will be somewhat more elaborately described. This mineral is among the most widespread constituents of the dolomitic marbles. The mica is scattered through the rock or builds lenses, layers or irregular aggregates of a thickness of up to several centimetres. The dimensions of the crystals may vary between 0.1 mm. and 1 cm. but are commonly about 3 mm. Fresh phlogopite is pale brown to golden brown in colour whereas the chloritized crystals are dark brownish to blackish, colourless, or, more rarely, green. The dark colours are due to much finely divided enclosed material. At first glance the very dark types may resemble graphite lamellae.

Under the microscope the fresh phlogopite always shows a very weak pleochroism, with α = colourless to very pale yellow-brownish and β, γ = pale brownish.

The crystal outlines may vary from perfectly pseudohexagonal to irregular. Intricate intergrowths of phlogopite with the carbonate matrix are common. In this case many small sections of phlogopite, in optical continuity, are seen to be separated from each other by carbonate. When separated from the marble by means of hydrochloric acid these crystals show very irregular skeletal outlines. Other contact minerals such as forsterite, clinohumite and spinel show similar intricate intergrowths with the carbonate matrix.

In some samples crystals of phlogopite have been found which are very strongly elongated along the c-axis, the length of these crystals being up to five times the width (fig. 21). Similar elongated crystals are known from other regions such as the famous Franklin locality in N. Jersey, U. S. A. (PALACHE 1935, p. 116). Crystals of phlogopite which are slightly elongated along the c-axis are rather common in the investigated area.

Phlogopite, like all micas (except the brittle) very susceptible to mechanical deformation, is often in strongly bent flakes that show a wavy extinction. In some cases completely ragged flakes are seen with the interspaces filled by fine grains of turbid carbonate material.

The alteration products include chlorites, serpentine, rutile and dark translucent to opaque products. Different products commonly occur in the same phlogopite crystal. The chlorites, which are the most common alteration products, may show a distinct zonal arrangement. In this case a relic core of phlogopite is seen to be bordered by a zone of optically negative pennine with anomalous bluish interference colours merging through a narrow isotropic zone into optically positive pennine with anomalous yellowish brown to brownish green interference colours. This zone changes into clinochlore with very low, dark grey interference colours that may merge into yellow, and occasionally even into dark yellow.

PREHNITE

This mineral is of very widespread occurrence in the investigated area and is present in many different kinds of rocks, igneous as well as metamorphic.

In most cases the prehnite seems to have been developed during a late stage of the metamorphism, as the mineral is frequently seen to replace earlier minerals or to be among the alteration products of some. Further it may occur in veinlets.

The prehnite of the igneous rocks and that of the metamorphic rocks will be dealt with separately because of characteristic differences in their mode of occurrence and their paragenetic relationships.

Prehnite in the igneous rocks

These rocks include the granite itself, especially near the contact, the basic inclusions of the granite and finally the porphyritic and aplitic dikes.

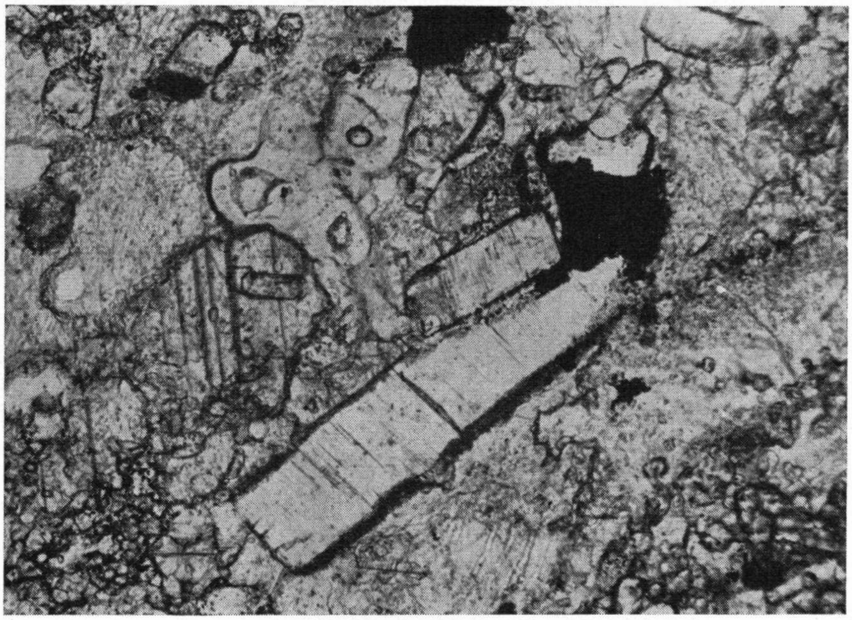

Fig. 21 — Phlogopite crystal very much elongated along the c-axis. Forsterite-phlogopite marble, N of Escouloubre (loc. R).
sl. 280 — 1 one nicol × 230

Commonly the prehnite is among the subordinate constituents but some rocks contain notable amounts of it. The prehnite is particularly abundant in a narrow zone (0.5—3 cm. in width), called in this work "the transition zone" which may occur between the granite and the silicate skarn. In some samples of the granite-skarn contacts this zone is seen to be dark yellow in colour due to abundant prehnite. Other samples of similar rocks, however, have much colourless prehnite. Thin sections of these rocks show the mineral in the well known sheaf-like masses, ragged aggregates and more or less fibrous mica-like tufts. The prehnite is in most cases anhedral but subhedral to euhedral sections may be seen in veins and small geodes. Intimate intergrowths of prehnite and other minerals, such as potash-rich and albitic felspar as well as strongly corroded quartz, are common. The last mentioned mineral commonly appears to be replaced by aggregates of prehnite and calcite.

Prehnite when fan-shaped or radially arranged shows a characteristic wavy extinction. The birefringence is strong and the elongation negative; if the (001) cleavage is visible, the extinction appears to be straight against this direction. Most of the prehnite is turbid, due to a finely divided brownish pigment, but clear crystals may occur in veinlets.

In the border zone of the granite, which is adjacent to the transition zone or the silicate skarn and in which pyroxene is a common constituent, much prehnite may be present in small veinlets and among the alteration products of the plagioclase and biotite. In some cases these minerals were even seen to be completely replaced by prehnite. In granitic rocks collected at a distance of more than about ten metres from the contact prehnite has also frequently been found, though in much smaller amounts.

In the aplitic and porphyritic dikes prehnite was but seldom observed and the mineral, except in one case, was only among the subordinate constituents. In a pyroxene-bearing aplitic dike NW of Usson much colourless prehnite was seen to be present, the content increasing towards the contact, whilst this mineral is also among the main constituents of the surrounding hornfelses.

Development of prehnite in fresh or chloritized biotite was observed in thin sections of the granite, especially that close to the contact, of the dark inclusions and of some porphyritic dikes.

The cross sections of the biotite commonly show long, thin lenses of prehnite which are arranged parallel to the lamellar cleavage direction of the mica (fig. 22). Short, thick lenses, as well as lenses which are thickened at one of the ends, may also occur. Most of the larger prehnite lenses which show a wavy extinction are seen to consist of a number of small lenses which differ slightly in optic orientation. A biotite crystal may contain a single prehnite lens or several of these bodies and in exceptional cases the mica is even seen to be completely replaced by aggregates of prehnite. In this case, inclusions of the earlier biotite, such as apatite and zircon may be seen to be enveloped by the secondary prehnite.

In addition to the prehnite, other calcium-bearing alteration products of the biotite may occur in the same slide. These minerals which build more or less lenticular crystals or aggregates include titanite, clinozoisite-epidote, garnet and pumpellyite. Several of these may occur in the same biotite crystal, especially when this mineral is highly chloritized.

A study of thin sections of granitic to dioritic rocks from many localities in the world (see p. 257) revealed alteration of biotite into lenticular aggregates of prehnite to be a widespread phenomenon. It has comparatively seldom been recorded in literature, however. As far as known to the author the earliest reports of secondary prehnite lenses are from **Read** (1931) who speaks of "prehnite splitting up biotite". **Hjelmqvist** (1937) reports prehnite lenses in biotite-chlorite from many different Scandinavian igneous rocks. Other records include those of, e. g., **Drever** (1936) and **Kimpe** (1944). The prehnite has frequently been described as epidote, but in some cases as phenacite.

Prehnite in the metamorphic rocks

The mineral occurs in both low and high grade calc-silicate hornfelses as well as in the silicate skarns.

In many hornfelses prehnite is among the main constituents. In the hand-specimen the mineral is colourless to greenish yellow. Under the microscope it is commonly in xenoblastic aggregates which are often turbid, due to a brownish pigment. The (001) cleavage is less distinct than that of the prehnite in the igneous rocks. In several instances the prehnite appears distinctly as a replacement product of earlier minerals such as grossular, potash-rich felspar and calcite. In other cases the mineral seems to be of primary origin. Subhedral clear crystals of prehnite may be present in veinlets.

In the silicate skarns prehnite is generally among the minor constituents. Larger quantities of the mineral, however, may be present in that part of the rock which is adjacent to the transition zone or the granite itself. Veinlets may contain clear prehnite which is often associated with clinozoisite, adularia or calcite.

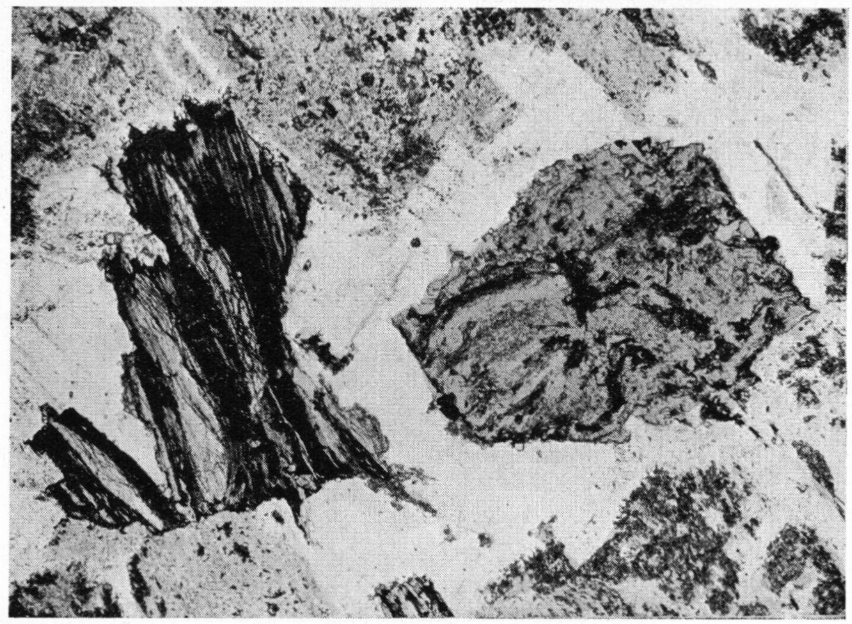

Fig. 22 — Lenses of prehnite arranged parallel to the lamellar cleavage of chloritized biotite. Hornblende-biotite-granite close to the contact, NE of Escouloubre (loc. T).

sl. 731a — 2 one nicol × 35

PUMPELLYITE

Green varieties of this mineral have been recognized as very subordinate constituents in some granitic rocks, mainly from very near the contact, and in many of the dark inclusions.

Under the microscope the mineral is seen to occur as more or less lenticular inclusions in partly or completely chloritized biotite (fig. 9). The pumpellyite which is elongated along the b-axis ($\beta // b$) is distinctly pleochroic with β = dark bluish green to pale green and α, γ = pale yellowish brown to colourless; absorption scheme $\beta \gg \alpha, \gamma$. Examined between crossed nicols longitudinal sections show either anomalous bluish to purple interference colours and positive elongation (resembling optically negative pennine) or anomalous brown-yellowish interference colours and negative elongation (resembling optically positive pennine). As the optic character of the pumpellyite is biaxial and positive with a small to rather small axial angle, the sections with negative elongation are predominant. From pennine the pumpellyite can be distinguished by its higher refringence. Weakly coloured varieties, however, may be confused with clinozoisite.

The pumpellyite is considered to be an alteration product of the biotite, and its formation may be compared with that of other secondary calcium-bearing products of biotite, such as clinozoisite-epidote, garnet, titanite and prehnite. Several of these products may accompany pumpellyite in the same slide and they may even be present in the same chloritized biotite crystal.

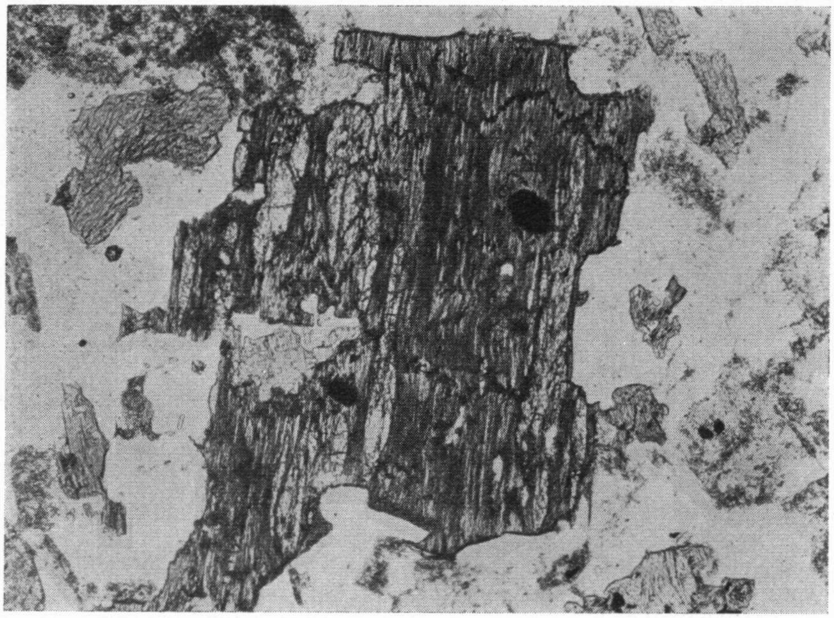

Fig. 23 — Partially chloritized biotite crystal enclosing many lenses of green pumpellyite as well as some lenses of yellow epidote. Hornblende-biotite-quartz-diorite, Val Marcia, Bergamo Alps, Italy.
sl. 3252 one nicol × 87

On the assumption that pumpellyite might occur in similar conditions in rocks from other areas, the sections of a number of granitic to dioritic rocks from many different localities were subjected to a search for this mineral. Though pumpellyite lenses in biotite seem to be of rarer occurrence than masses of the other calcium-bearing alteration products referred to above, they were nevertheless rather frequently observed. Some examples of rocks containing pumpellyite lenses are listed below. The biotite of hornblende-quartz-diorites and diorites seems to be especially liable to contain pumpellyite lenses. Many lenses may be enclosed within the same biotite crystal (fig. 23) and occasionally some pumpellyite was also observed in cracks and among the alteration products of plagioclase.

A thorough search through the literature revealed only one article (ERDMANNSDÖRFFER, 1943) briefly mentioning similar lenses of pumpellyite in biotite. Presumably this briefness and the war-time publication of this paper are the reasons why this mode of occurrence of pumpellyite has escaped the notice of most petrographers.

Summarizing, it may be stated that to the well known occurrence of pumpellyite in glaucophane-schists, green-schists and altered basic igneous rocks, now another type of occurrence may be added, that of the granitic to dioritic rocks.

As pumpellyite seems to be a very subordinate constituent of these rocks, the mineral will be more easily found in their heavy translucent fraction. Further, it is supposed that many sands that owe their origin to the decomposition of granitic to dioritic rocks will contain some pumpellyite. It may be emphasized that this may hold true for many parts of the world. In fact this mineral, formerly designated as "chloropite" has been recognized as forming up to 4 per cent of the heavy translucent minerals in samples of Quaternary sands from more than a hundred different localities in the Netherlands (EDELMAN, 1933). Very recently LANGENBERG and DE ROEVER (1955) stated that the "chloropite" was in fact pumpellyite. Said authors considered the pumpellyite of these sands to be most probably derived from pumpellyite-bearing diabases in Germany. It is clear from the above that any pumpellyite-bearing granitic to dioritic rock might also be a suitable source-rock for this mineral. In this regard we may mention such rocks from Western Germany (e. g. the "Odenwald") and the Vosges (see below).

Pumpellyite-lenses in biotite were found to occur a. o. at the following localities:

Andlau, Vosges, France.
Hohwald, Vosges, France.
St. Blaise, Vosges, France.
Gross Bieberau, Odenwald, Western Germany.
Weinheim, Odenwald, Western Germany.
Silindung near Pagaran Pisang, Sumatra, Indonesia.
Adamello, Italy.
Klausen, Tirol, Italy.
Val Marcia, Bergamo Alps, Italy (fig. 23).
Pulau Ubin near Singapore, Malaya.
Lyttelton, New Zealand.
Bon Ave Quarry, Scotland.

RUTILE

Rutile has been found as an accessory constituent in dolomitic marbles, granitic rocks and hornfelses.

In some samples of the dolomitic marbles small rounded crystals of dark yellow to brownish rutile have been observed. Some rocks from the fluoborite locality were seen to contain comparatively large crystals of rutile measuring up to 1 mm. in diameter. Further, in some dolomitic marbles needles of rutile with sagenitic structure have been observed as an alteration product of the phlogopite. Similar secondary sagenitic rutile in chloritized biotite was seen in some slides of the granite and its basic inclusions. Commonly, however, the liberated titanium content of the earlier biotite is represented by secondary titanite. Granitic rocks from very close to the contact which frequently contain comparatively large amounts of titanite may contain titanite crystals with a core of ilmenite, rutile or both.

Highly rounded grains of rutile, doubtless of clastic origin, have occasionally been observed in low grade calc-silicate hornfelses NW of Usson.

SPINEL

Spinel has been found in the silicate skarns and in the dolomitic marbles. Though the spinels of both groups of rocks are rich in magnesium, they will be dealt with separately in view of characteristic differences in their mode of occurrence, paragenesis and alteration phenomena.

The spinel in the silicate skarns

In nearly all the silicate skarns studied, spinel is of frequent occurrence. The mineral is almost exclusively localized in lenticular and irregular aggregates of a thickness of up to 1.5 cm., occurring in the characteristic spinel-xanthophyllite-zone. Separate crystals may attain sizes of up to 0.5 cm. and commonly show irregular or strongly rounded boundaries; more or less distinct octahedral outlines are very rare. The colour of the skarn spinels as seen in the hand-specimen varies from green to bluish green.

A distinct pattern of two perpendicular cleavage directions was only seldom observed, but irregular fractures are common. Under the microscope, colourless spinel with irregular fractures may resemble grossular. There are, however, some characteristic differences in appearance.

The spinel of the silicate skarns often builds intricate intergrowths with other minerals such as diopside and xanthophyllite. The comparatively low refringence (about 1.73) indicates that we are dealing with an almost pure magnesium spinel, with a very low content of iron.

Along the periphery as well as along the cleavage cracks and the irregular fractures there is commonly some slight alteration into two types of amesite and into diaspore. The most common type of amesitic chlorite has a weak birefringence and resembles clinochlore. In fact, the mineral was considered as such until an X-ray powder pattern revealed its true identity. The other type is an amesitic chlorite with high interference colours, resembling a colourless mica, but showing a negative elongation (fig. 24 and 25). Samples from two localities (loc. T and V) show all stages of alteration from spinel into diaspore and amesitic chlorites (fig. 11, 26 and 27). Almost fresh and entirely altered crystals may be seen close together in one slide. In the masses of completely converted spinels, some magnetite (now highly limonitized) may be seen, possibly representing the liberated iron content of the earlier spinel. The most common alteration products always appear to be closely associated, showing commonly a core of diaspore surrounded by a mantle of amesitic chlorite. For further details on the alteration products the reader is referred to the relevant paragraphs.

The spinel in the marbles

Spinel is among the most widespread contact minerals of the dolomitic marbles. The mineral occurs either as an accessory or as a main constituent

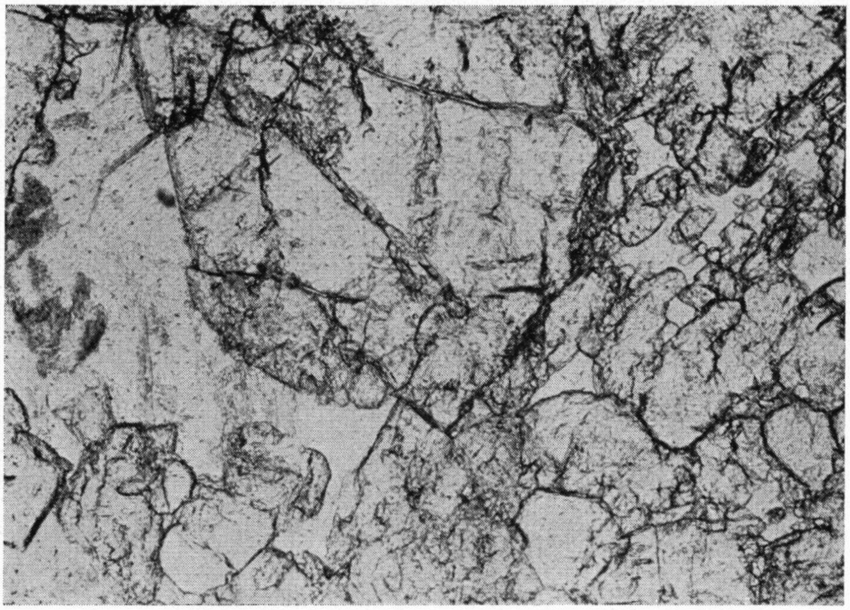

Fig. 24 — Spinel partially altered into diaspore and some flakes of amesite (am) with rather strong birefringence. Zoned silicate skarn, NE of Escouloubre (loc. T).
sl. 884b — 1 one nicol × 87

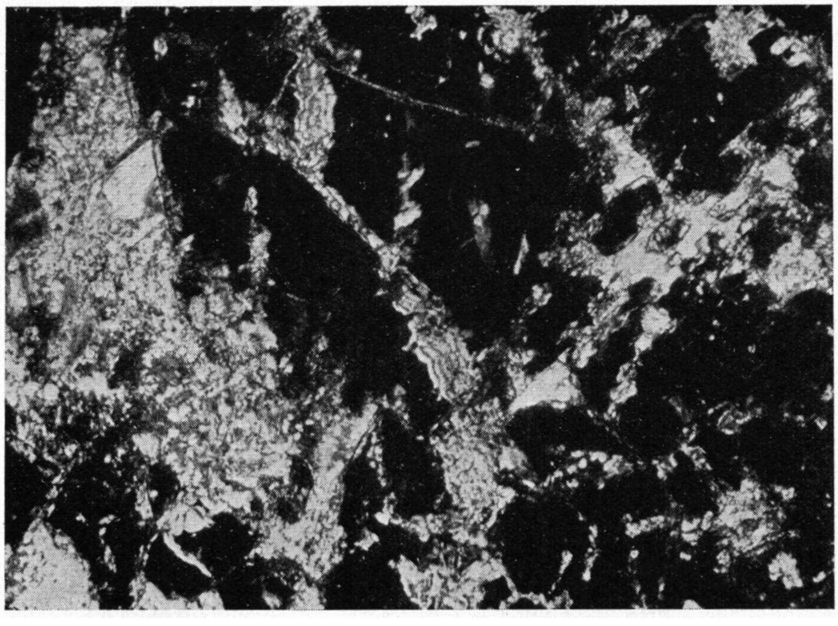

Fig. 25 — The same as fig. 24 with crossed nicols.

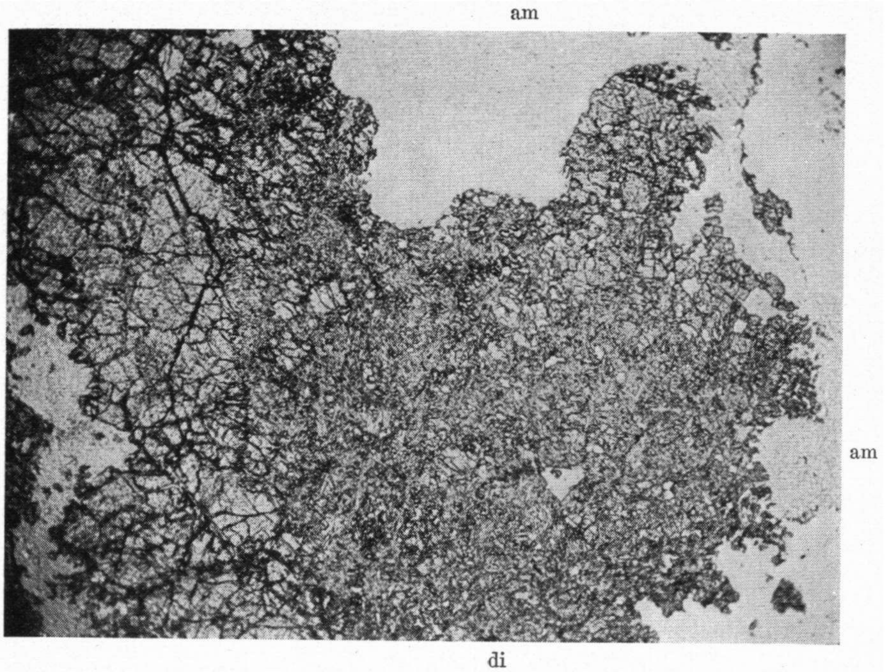

Fig. 26 — Spinel crystals almost completely altered into aggregates of diaspore (di) which are partly surrounded by aggregates of fine flaky amesite (am) with weak to moderate birefringence. Zoned silicate skarn, NE of Escouloubre (loc. T).
sl. 906a — 1 one nicol × 23

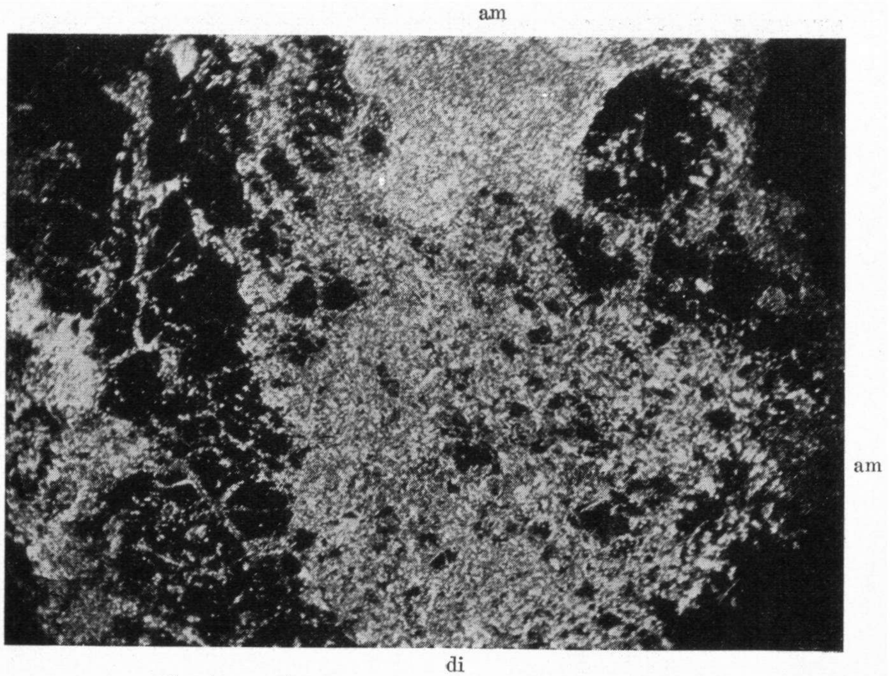

Fig. 27 — The same as fig. 26 with crossed nicols.

and is always accompanied by other contact minerals. This holds good up to the dimensions of a single slide. Commonly the spinel is scattered throughout the rock, but occasionally it may build aggregates of a thickness of several mm. The dimensions of the single crystals vary between 0.02 mm. and 3 mm. but they are commonly about 0.1 mm.

In the hand-specimen the small or very small crystals of spinel are usually difficult to recognize. In fresh and slightly altered light coloured marbles like those N of Le Bousquet, however, the spinels may be easily recognizable as small dark speckles. The colour of the smaller crystals is difficult to distinguish in the hand-specimen. For that reason the spinels were separated from the marbles by treatment with hydrochloric acid and studied under the binocular microscope. The colours include shades of pale violet, pale green, pale greyish green and occasionally more intense shades of these colours. Very small crystals may be perfectly colourless. In a few cases, purple spinels have also been observed. In thin section the same colours were observed, but with lesser intensities. Spinels of different colour may be present in the same specimen. Conspicuous spinels showing different colours (not zonally) within one crystal have been found in rocks NE of Escouloubre (loc. T and V). In thin section these crystals commonly show a pale greenish part merging into a pale violet part. In some samples (loc. T) comparatively large spinels (2 mm. diam.) were seen with a green and a purple part, the boundaries being sharply defined. Other crystals in the same slide show brownish purple and green parts. In addition to the pale greenish and pale violet spinels, some samples from loc. V contain small, dark brown spinels. As seen in section these crystals are reddish brown and tend to be localized in certain zones. In most cases only a part, commonly the core, of the crystal is brown and the remainder very pale green or very pale violet. With very high magnification the brown colour is seen to be due to an extremely finely divided brownish pigment. A very weak pleochroism is occasionally distinguishable. This pigment is possibly of secondary origin and resembles the spurious colour of the pseudo-pleochroic pennine described on p. 259. There, however, the pigment granules are much larger and the pleochroism much stronger. To the authors knowledge spinels showing different colours within the same crystal are fairly rare. A thorough search through the literature revealed only one article (WEINSCHENK 1897, p. 147) mentioning multicoloured spinels, viz. deep violet spinels with a sharply defined green core from Passau (Bavaria, W. Germany).

In thin section the spinels show a complete optic isotropism. Perfectly idioblastic octahedrons of spinel, as well as spinels showing rounded or very irregular outlines are present. Intricate intergrowths of spinel and the carbonate matrix are frequent in rocks N of Le Bousquet. When separated from the marble by treatment with hydrochloric acid these spinels show skeletal outlines similar to those of the accompanying forsterite and clinohumite. Though the crystals have the appearance of being strongly corroded, the intricate intergrowths of these minerals with the carbonate matrix are considered to be of primary origin. Spinels with irregular or skeletal outlines are not rare and indeed have been recorded by several authors, e. g. DU TOIT (1919, pp. 127 and 131) and LAITAKARI (1916, p. 30).

Many pale coloured crystals of spinel are turbid due to the inclusion of many small speckles of magnetite. Other spinels enclose a small number of larger granules of magnetite which may be highly limonitized.

The refringence of the spinel varies from 1.72 to 1.74. These comparatively low values suggest that we are dealing with pure, or almost pure magnesium spinels containing only a very small proportion of iron.

Among the various interesting alteration products observed, hydrotalcite seems to be by far the most common. Other secondary products include diaspore, chlorite (possibly amesite), magnetite and goethite (or haematite).

All steps in the progressive alteration of the spinel into aggregates of hydrotalcite are present and this holds true even for sections of a single hand-specimen. Highly and completely altered spinels are common in the marbles NE of Escouloubre (loc. T), NW of Eaux Chaudes (loc. I) and N of Le Bousquet (loc. AA). Translucent flakes of goethite (or haematite) enclosed within hydrotalcite masses and occasionally bordering relics of the spinel are supposed to be of secondary origin. Enclosed granules of magnetite are possibly partially of primary origin and partially of secondary origin, representing the liberated poor iron content of the earlier spinel.

Diaspore and chlorite (amesite?), frequent alteration products of the spinel in the silicate skarns, were only seen in a small number of sections of the marbles (fig. 28 and 29). In one sample from loc. P (NW of Escouloubre), green spinels occur which are highly altered into fine masses of diaspore and chlorite (amesite?). A core of diaspore, enclosing some granules of magnetite, is bordered by the chlorite. In some sections of the marbles N of Le Bousquet the spinels were seen to be converted into masses of either hydrotalcite, or hydrotalcite together with chlorite (amesite?) or diaspore.

For an extensive description of the interesting alteration products hydrotalcite and diaspore, the reader is referred to the relevant paragraphs.

Alteration phenomena of magnesium-rich spinels in rocks from other areas.

The alteration of spinel into hydrotalcite has been comparatively rarely recorded in literature and as far as known to the author the alteration of spinel into diaspore and amesite has hitherto not been mentioned at all. On the assumption that the alteration products described above might occur in similar conditions in rocks from other areas, a number of sections of regionally or thermally metamorphosed rocks containing magnesium-rich spinels from many different localities were studied. The host-rock of the spinels is in most cases a marble, a calc-magnesian-silicate hornfels or an aluminium-rich schist or rock. The results of the microscopical investigation are listed below.

Highly altered dolomitic forsterite-clinohumite marble; NE of Orus, Massif des Trois Seigneurs, Ariège, France.
Aggregates of hydrotalcite are considered to represent totally converted spinels.

Dolomitic forsterite-clinohumite-spinel marble; 1.5 km. WNW of Saurat, Massif de l'Arize, Ariège, France.
Colourless spinels show incipient alteration into hydrotalcite along cracks as well as along the borders.

Dolomitic forsterite-spinel marble; S Borgafjäll, Jämtland, Lapland, Sweden.
Green spinels show very little alteration into hydrotalcite along the periphery.

Forsterite-phlogopite-spinel-pargasite marble; Orus, Massif des Trois Seigneurs, Ariège, France,

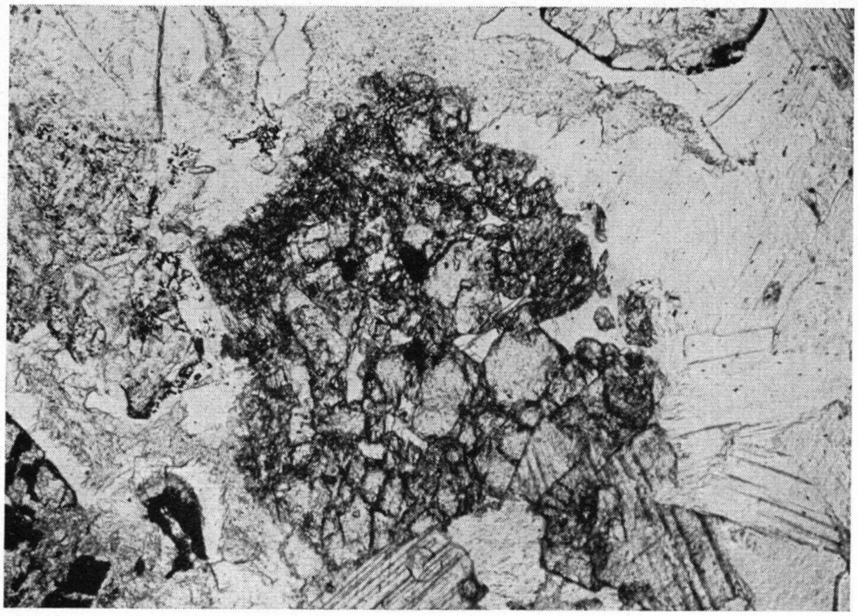

Fig. 28 — Spinel crystal partially converted into aggregates of fine granular diaspore, some flakes of chlorite (amesite?) and a few granules of magnetite.
Forsterite-phlogopite-clinohumite-spinel-apatite-ore marble,
NW of Escouloubre (loc. P).
sl. 357 — 2 one nicol × 87

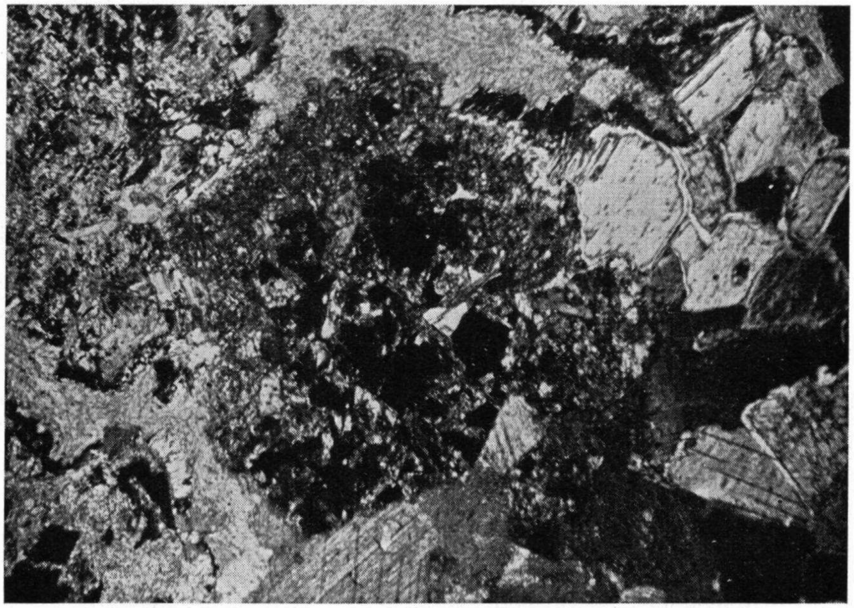

Fig. 29 — The same as fig. 28 with crossed nicols.

Pale green spinels are partially or completely altered into diaspore, magnetite and chlorites (possibly including amesite with weak birefringence).

Forsterite-clinohumite-spinel-pargasite-phlogopite-clinochlore rock; S of Lapège, Massif des Trois Seigneurs, Ariège, France.
Very pale green spinels show incipient alteration into diaspore along cracks as well as along the periphery.

Forsterite-spinel-phlogopite marble; Rauenthal, Vosges, France.
Very pale green spinels show incipient and advanced stages of alteration into diaspore and chlorites (possibly including amesite with weak birefringence).

Cordierite-gedrite-pleonaste-biotite-hornblende rock; Gèdres, Vallée de Héas, Ht. Pyrenees, France.
Green spinels (pleonaste) are highly altered into diaspore, magnetite (highly limonitized) and a little chlorite (optically positive and optically negative pennine and possibly amesite with low birefringence).

Plagioclase-cordierite-sillimanite-spinel-garnet rock; 15 km. S of Carballo, La Coruña, Spain.
Green spinel (pleonaste) shows very little alteration into diaspore.

Fassaite-spinel-phlogopite-carbonate rock; Toal della Foja, Monzoni, Tirol, Italy.
Green spinels (pleonaste) show very little alteration into amesite (with weak to rather strong birefringence) along cracks as well as along the borders.

Anorthite-fassaite-spinel-carbonate rock; Pesmeda, Monzoni, Tirol, Italy.
Pale green spinels show very little alteration into amesite (with weak to rather strong birefringence) along the borders.

Highly altered forsterite-dolomite marble; Snarum, Norway.
Aggregates of a little diaspore and amesite (with weak to rather strong birefringence) are supposed to represent completely converted spinels.

Gahnite-phlogopite-pargasite marble; Franklin, New Jersey, U.S.A.
Colourless gahnite (weak blue in the hand-specimen) shows incipient alteration into diaspore and amesite (with weak to moderate birefringence), along cracks as well as along the borders.

In the investigated rocks diaspore and chlorites (among which is amesite) appear to be the most frequent alteration products of the spinel and they may occur in different kinds of rocks. The alteration into hydrotalcite, however, seems to be restricted to spinels occurring in marbles. It may be mentioned here that in several samples studied, no alteration of spinel was seen at all. These are not listed above.

It may be emphasized that serpentine, frequently described as an alteration product of spinel in literature (see p. 278), has not been observed in the slides examined. Possibly, hydrotalcite which may closely resemble serpentine, has been confused with serpentine in several cases. Colourless micaceous alteration products of spinel are often recorded in literature. They have not been observed, however, in the sections examined. The possibility should not be overlooked, that in some cases amesite with rather strong birefringence, and diaspore, have been confused with colourless micaceous minerals. Further, talc, mentioned in very old literature (e.g. SILLEM 1852) as an alteration product of spinels has never been seen in the slides examined. In the hand-specimen, talc may closely resemble hydrotalcite and therefore confusion with this mineral seems likely.

TALC

This mineral has been found both in the dolomitic marbles and in the silicate skarns.

Some samples of the dolomitic marbles contain rounded aggregates of fine flaky talc which are doubtless derived from forsterite.

In the silicate skarns talc, presumably of primary origin, may be a main constituent of the talc-serpentine-chlorite zone. Further it may occur in small amounts in the spinel-xanthophyllite zone of these rocks.

Under the microscope the talc, which has high birefringence and a very small (to zero) negative optic axial angle, is commonly seen to build fine flaky aggregates. In the same slide talc, colourless phlogopite and another colourless mica (lilac in the hand-specimen) may occur together and they may be difficult to distinguish. Generally, however, the phlogopite is seen to be more or less altered into chlorites, whilst the other mica which is commonly in much larger crystals frequently is replaced by sericitic material.

SE of the Pic de Garigue talc has been observed to occur in narrow veins in the dolomite-marble, very close to the contact. This talc is always separated from the dolomite by a thin white calcite zone. Possibly in a late stage of metamorphism silica-bearing solutions from the granite entered cracks of the marble giving rise to the formation of talc according to the following reaction:

$$3\,CaMg(CO_3)_2 + 4\,SiO_2 + H_2O \rightarrow Mg_3(Si_2O_5)_2(OH)_2 + 3\,CaCO_3 + 3\,CO_2$$

TITANITE

Titanite occurs in the igneous rocks as well as the metamorphic rocks in this region. It may be primary, secondary, or occur as a recrystallized detrital mineral.

The titanite in the igneous rocks

These rocks comprise the granite, the dark inclusions of the granite, the so-called transition zone (see p. 321), the aplitic and porphyritic dikes and the pegmatites.

In the ordinary biotite-granite, titanite may be among the accessory constituents and it occurs usually in very subordinate amounts. Close to the contact, however, especially in the pyroxene-bearing granite, and also in the basic inclusions, titanite may be present in much larger amounts. Titanite showing the well known "diamond-shape" as well titanite with irregular rounded outlines have been seen. The titanite may occur within the mafic as well as in the felsic constituents. With hornblende it occasionally builds intricate intergrowths. In the chloritized biotite, secondary titanite is often developed and may be accompanied by other calcium-bearing alteration products. Occasionally, titanite crystals have a core of ilmenite, or rutile, or both. Titanite, showing very irregular skeletal outlines and being present in cracks, has been possibly developed during a late stage of consolidation of the granite.

In the dark inclusions titanite is of rather frequent occurrence. Comparatively large crystals (up to 3 mm. in length), cut into pieces by plagioclase laths, were seen in a few thin sections. Secondary titanite in chloritized biotite is common.

In the transition zone titanite is seldom absent. Weakly pleochroic yellow brownish crystals of titanite showing a perfect "diamond-shape" were seen in sections of the transition zone of granite-skarn contacts SE of the Pic de Garigue (loc. J). At other places swarms of small titanite crystals may be enclosed within the clinopyroxene. In some cases the titanite as well as the accompanying apatite show a pleochroic aureole, if enclosed in uralitized parts of the clinopyroxene.

Some samples of the aplitic and porphyritic dikes and pegmatites have titanite in very subordinate amounts. Here, no special features were noted.

The titanite in the metamorphic rocks

In several samples of the silicate skarns and in some samples of the calc-silicate hornfelses titanite is present in subordinate amounts. The mineral may be colourless or weakly pleochroic in various tinges of yellow, brown and pink. In some sections of low grade calc-silicate hornfelses and also of a high grade hornfels, distinctly pleochroic titanite (yellow to wine-reddish) was seen. The strongly rounded titanite crystals of the low grade hornfelses NW of Usson are supposed to be of clastic origin.

TOURMALINE

This mineral is not of widespread occurrence in the investigated area. In the granite itself it has been found at one locality only (loc. T), NE of Escouloubre, in some pegmatitic pockets and in a small mass of highly pneumatolyzed potash-rich granitic rock. Both occurrences are very close to the contact. In addition, tourmaline was found in subordinate amounts in some aplitic dikes and in low grade metamorphic rocks E of Rouze (loc. A, C and D).

In geodes of the pegmatitic pockets, nests of stout, prismatic, black coloured tourmaline crystals are visible. In thin section tourmaline appears to build narrow veins as well as intimate intergrowths with potash-rich felspar. The mineral is highly pleochroic with ε = greenish brown and ω = very dark brown (with a bluish tinge).

In samples of the potash-rich granitic rock described on page 326, nests of black tourmaline crystals may be present. In section very small needle-like almost colourless tourmaline crystals are visible as well as much larger and darker crystals (up to 0.5 cm. in length). Radiating groups as well as groups arranged in parallelism occur. The colour may vary in a single crystal. Considerable differences in the intensity of the colours, occasionally very irregularly distributed, may be seen in some aggregates. In the tourmaline aggregates as depicted in fig. 30, ε varies from nearly colourless through brownish green to brown, and ω from pale green through darker brownish green to brownish black.

In some aplitic dikes subordinate amounts of small greenish blue tourmaline crystals are also seen.

The low grade metamorphic rocks carrying tourmaline include the mica-rich schists and quartz-rich hornfelses. In several slides, small fragments of greenish brown tourmaline, doubtless of clastic origin, were easily distinguished.

TREMOLITE

Tremolite, both in the pure form and with a slight actinolite content (the amount being considered to be related to the intensity of the pale green colour) has been found in the igneous as well as the metamorphic rocks.

In a number of thin sections of the granitic rocks and the porphyritic dikes, tremolite has been observed as an alteration product of green-brown hornblende. Aggregates consisting of calcite, chlorite and small crystals of tremolite, which occur in some of the porphyritic dikes and in a lamprophyre, may possibly represent completely converted olivine crystals.

Some thin sections of the so-called transition zone contain notable amounts of very fibrous tremolite, resembling sericite in appearance.

Very pale green tremolite as well as colourless tremolite are common constituents of the calc-magnesian-silicate hornfelses and marbles.

Occasional fairly large crystals of colourless tremolite have been found in the clinohumite-spinel-bearing dolomitic marbles ($n\gamma/c$ = about 18°; $-2V$ = very large).

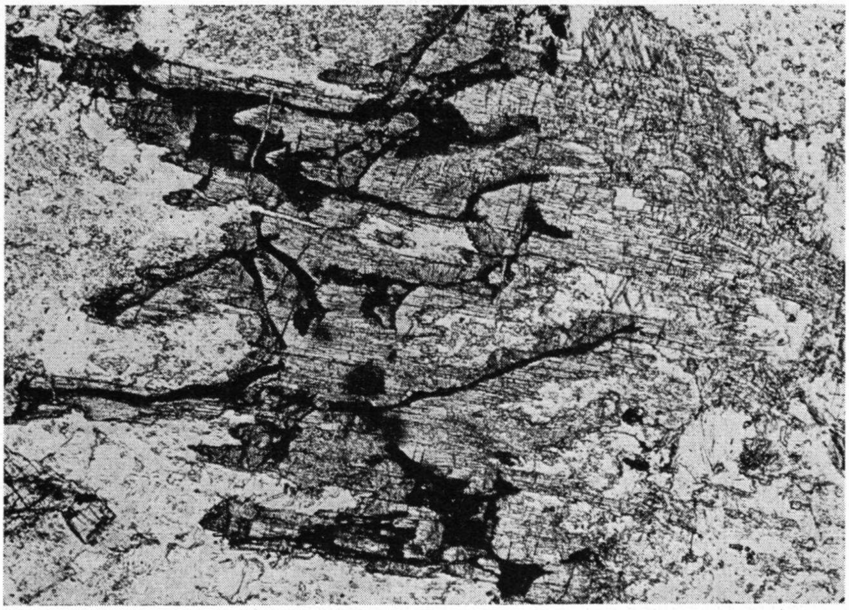

Fig. 30 — Aggregate of tourmaline consisting of an irregularly bounded very dark brown part with a number of brownish green prisms as well as almost colourless needles. The whole aggregate is optically continuous.
sl. 1228 one nicol × 35

WOLLASTONITE

Wollastonite is of widespread occurrence and has been found in the calc-silicate hornfelses as well as in the calcite marbles. It is the only contact mineral found which may build up almost pure monomineralic rocks. Rocks of this type are especially common near Escouloubre, on the lower slopes of the ridge N of Escouloubre (loc. Q—S). Here, on approaching the contact one can follow the progressive formation of wollastonite, originating from the reaction of quartzitic layers and lenses with the surrounding calcareous rocks. The first appearance of wollastonite is in the form of thin skins bordering quartzite lenses. Nearer to the contact, mixed quartz-wollastonite rocks are seen to be embedded in the calcite marble. Relic cores of quartzite may be found in lenses of wollastonite which in turn are surrounded by the calcite marble. Close to the contact, rocks consisting of pure, or almost pure, coarsely crystalline masses of wollastonite with a diameter of up to 20 cm. may be observed. Other occurrences of wollastonite include those NW of the Col de la Malagrède and on the top of the Roc de Casteldos.

Under the microscope wollastonite is commonly seen to occur in its well known slender prisms, forming aggregates which show a radiating structure. In the slides of some calc-silicate hornfelses, however, the wollastonite shows a short prismatic habit. In both cases the mineral is readily distinguished by its optical properties, namely its moderate refringence, moderate birefringence, rather small (± 40°) optically negative axial angle and its pyroxene-like appearance in cross sections.

In some cases alteration of wollastonite into calcite has been observed.

XANTHOPHYLLITE

INCLUDING REMARKS ON THE CLINTONITE GROUP

Introduction

In this paper the term clintonite group is used in the restricted sense of comprising the calcium- and magnesium-bearing brittle micas only, viz. clintonite, brandisite and xanthophyllite. In several cases, particularly in older literature, the name has been used in a broader sense embracing all the so-called brittle micas, which include margarite, chloritoid and ottrelite as well.

According to several authors there are no reasons to make a distinction between clintonite, brandisite and xanthopyllite and only the name clintonite, which has priority, should be retained (LAITAKARI 1921, GOSSNER 1924, KOCH 1935, WINCHELL and WINCHELL 1951). According to the present author brandisite is identical with xanthophyllite, and the former name should be dropped. Xanthophyllite and clintonite, however, seem to show characteristic differences, so that these two variety-names should be retained. The term clintonite s. s. then could be restricted to the brown fluorine-bearing members.

Only xanthophyllite has been found in the area investigated. Further, clintonite s. s. is described from two new localities in other areas. Some general remarks concerning the clintonite group as a whole will be added.

Xanthophyllite in the investigated area

Xanthophyllite is one of the main constituents of the silicate skarns. The mineral is not scattered randomly throughout the rock, but almost exclusively localized in a special zone, the spinel-xanthophyllite zone. In the hand-specimen it occurs as pearly white plates which are often arranged in fan-shaped groups that are usually easily distinguished with the naked eye. Occasionally the mineral shows pale green and brownish colours due to alteration into clinochlore and cloudy chlorite-like products, respectively. The dimensions commonly vary from 0.2 to 0.5 cm., but in exceptional cases plates up to 2 cm. in diameter have been found. It is noteworthy that the xanthophyllite is almost invariably associated with green spinel, the spinel-xanthophyllite ratio being highly variable. As seen in the hand-specimen as well as under the microscope the brittle mica seems to replace the spinel.

In thin section the xanthophyllite is perfectly colourless. Intergrowths with spinel and clinopyroxene are often seen. The latter, probably a slightly fassaitic diopside, appears to be partially replaced by xanthophyllite. In many cases the plates of xanthophyllite are crowded with very small oval-shaped granules of clinopyroxene which are probably of a later generation than the diopside mentioned above. Unlike the common micas, the lamellar cleavage of the brittle mica is not so well developed (fig. 31). Other characteristics to be employed in distinguishing the xanthophyllite from ordinary colourless or pale coloured micas are the distinctly higher refringence and much lower birefringence of the former. The pertaining properties of the xanthophyllite are:

Fig. 31 — Spinel (lower left), xanthophyllite (distinct cleavage) and diopside (smaller grains) of zone III, the conspicuous spinel-xanthophyllite zone. Zoned silicate skarn, SE of the Pic de Garigue (loc. K).
sl. 410 one nicol × 35

$$n\alpha = 1.644 \qquad n\gamma - n\alpha = 0.012$$
$$n\beta, \gamma = 1.656$$

The mineral is nearly uniaxial. Because of the high refringence, basal sections of the mineral show typical shagreened surfaces. At first glance sections perpendicular to the cleavage may easily be mistaken for an orthorhombic amphibole. X-ray powder patterns of the mineral are identical with that of xanthophyllite of the type locality, Schischimsk in the Urals.

Occasionally the xanthophyllite is interleaved with a colourless phlogopite and then both minerals may be partially or completely altered into clinochlore. In some cases the phlogopite appears to replace the brittle mica.

In addition to the clinochlore (birefr. ca. 0.010), which is the most common alteration product, clinozoisite, brownish chlorite-like substances, amesite (with rather strong birefringence) and prehnite have been produced by alteration of the xanthophyllite. Several different alteration products and in exceptional cases even all the products mentioned above may be observed in sections of a single hand-specimen. The alteration into clinochlore and clinozoisite is often developed in such a manner that flat lenticular bodies of the latter lie parallel to the cleavage of the former. In the hand-specimen this clinozoisite is greyish white in colour and the clinochlore pale green to colourless. Unlike prehnite, which is rare, amesite with moderate to rather strong birefringence appears to be a fairly common alteration product. Usually, however, it occurs in small amounts only. In samples from several localities in the area under discussion the xanthophyllite is largely replaced by various types of brownish chlorite-like material. One type is a fairly dark brown cloudy substance with a weak birefringence. Other types are fibrous products in shades of brown with weak to moderate birefringence and varying elongation.

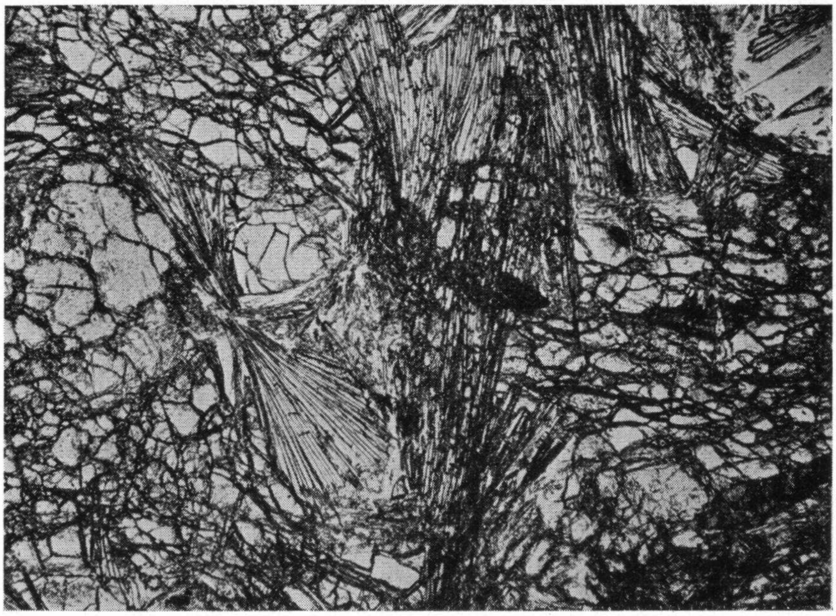

Fig. 32 — Sheaf- and fan-shaped aggregates of clintonite. Forsterite-spinel-clinohumite-clintonite rock. Llanos del Juanar, Serranía de Ronda, Spain.
sl. 2229a one nicol × 35

The clintonites from other areas

In a study of rocks carrying minerals of the humite group from various localities, two samples were seen to contain clintonite s. s. As far as known to the author, both occurrences, one in Spain and the other in the United States (Franklin), have not yet been recorded in the literature.

The sample from Spain (Llanos del Juanar, Serranía de Ronda, Andalusia) was presented about thirty years ago to the Geological and Mineralogical Institute at Leiden by professor A. LACROIX. The rock is made up almost exclusively of contact minerals, main constituents being forsterite [1]), clinohumite, spinel and clintonite (fig. 32). The alteration products include serpentine and clinochlore. Large accessory crystals of titanite enclose ilmenite, rutile or both. In the hand-specimen the pale violet-brownish plates of clintonite (2 mm. diam.) can be rather easily distinguished, though confusion with phlogopite is possible. In most cases the clintonite is arranged in fan-shaped groups. Under the microscope the brittle mica is weakly pleochroic with α = colourless and β, γ = pale brownish. The clintonite is optically nearly uniaxial with negative character. The refractive indices are:

$$n\alpha = \text{ca. } 1.643$$
$$n\beta, \gamma = 1.655$$

Incipient alteration into fine-flaky clinochlore is occasionally seen.

Rocks from the same locality have been studied by MAC-PHERSON (1879), MICHEL-LÉVY and BERGERON (1889, pp. 184—190), and DE ORUETA (1917, pp. 445—464). Most probably DE ORUETA noticed the clintonite but confused it with pargasite, also a common constituent of these rocks. He mentions that in addition to the normal pargasite, there are very slender crystals of this mineral in sheaf-like arrangement while sections of "pargasite" showing straight extinction suggest it to be an orthorhombic amphibole.

The other sample containing clintonite is a very small piece of marble from Franklin (New Jersey, U. S. A.), a locality renowned for its extraordinary variety of minerals. The chief contact minerals in the rock are norbergite, pargasite, clintonite and lilac spinel, with graphite in subordinate amounts. The plates of clintonite which measure about 3 mm. in diameter are brown in colour with a bronze lustre. Because of its shape and colour the mineral highly resembles phlogopite. Under the microscope the clintonite is distinctly pleochroic with α = very pale brownish and β, γ = pale brown. The optic axial angle appears to be very small and the optic character is negative. The refractive indices are somewhat lower than those recorded for clintonite, viz. $n_\alpha = 1.622$ and $n_{\beta,\ \gamma} = 1.634$. Some of the crystals show an incipient alteration into clinochlore.

X-ray powder patterns of the clintonite from both localities are very similar to that of clintonite from the type locality Amity, New York, U. S. A. (see below).

General remarks on the clintonite group

Many brief and a few rather comprehensive articles concerning one of the members of this group have already been written. Papers dealing with the whole clintonite group, however, are very scarce (TSCHERMAK 1879, KOCH 1935). The latter author contributed four new analyses, two of xanthophyllite and two of brandisite, the specimens coming from known localities. The most recent analysis of clintonite is that made by VON SIPÖCZ (in TSCHERMAK 1879). Because of the close similarity in optical, chemical and crystallographical properties several authors have proposed to group xanthophyllite, brandisite and clintonite together under a single name, viz. clintonite (see above). On the assumption that X-ray powder patterns of the three so-called varieties might

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[1]) See also footnote on p. 271.

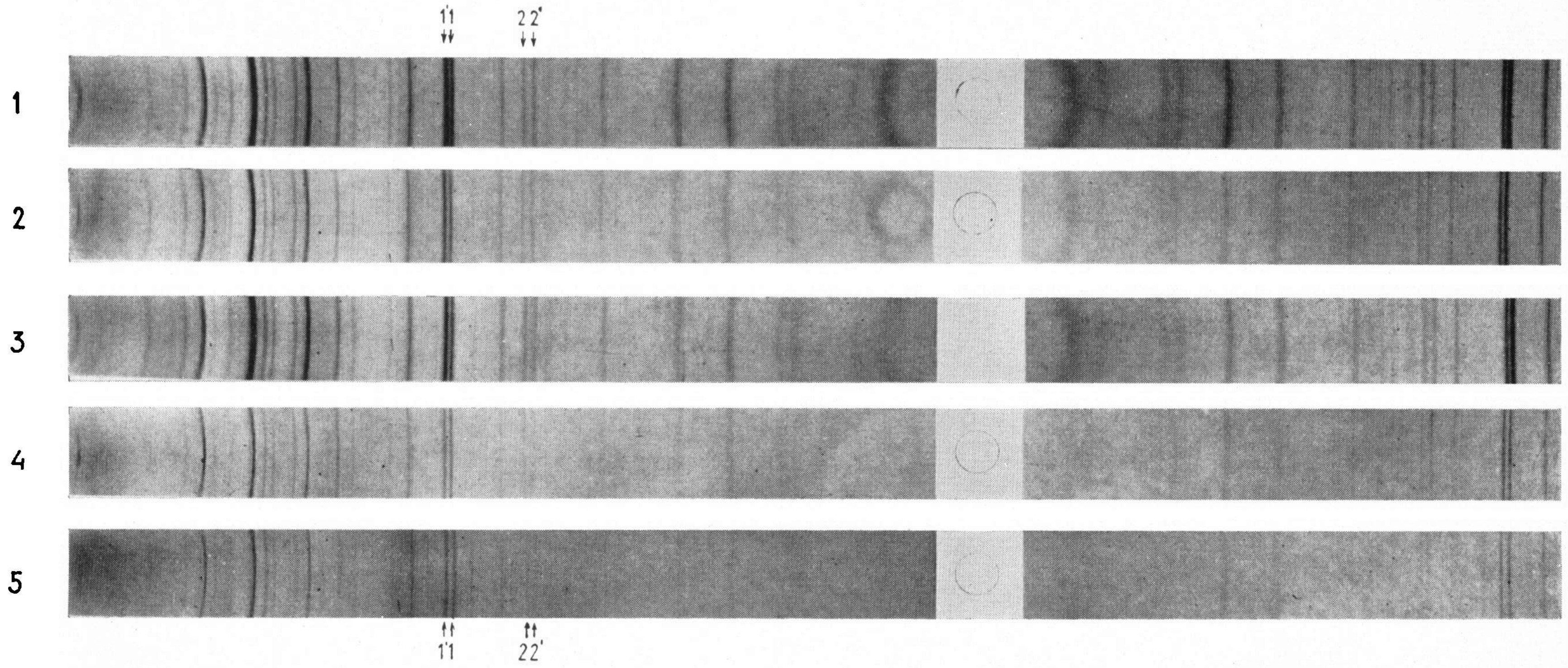

Fig. 33 — X-ray powder photographs of the minerals of the clintonite group. (Fe Kα radiation, camera diameter 9 cm.)

No. 1 Xanthophyllite, Schischimsk, Urals. m 1380
No. 2 "Brandisite", Monzoni, Tirol. m 1375
No. 3 Xanthophyllite, Escouloubre, Pyrenees. m 2121
No. 4 Clintonite, Warwick, New York, U.S.A. m 1377
No. 5 Clintonite, Franklin, New Jersey, U.S.A. m 2078

show characteristic differences, all samples of clintonite minerals available to the author were X-rayed. The patterns of a number of xanthophyllites from Schischimsk, Achmatowsk, Crestmore, Adamello, Scotland, Alaska and Escouloubre, and of brandisite from Monzoni — the only locality where brandisite occurs in fairly fresh crystals — in every instance were seen to be identical. The optical properties of xanthophyllite and brandisite are similar. Since the slight differences between the chemical analyses of xanthophyllite and those of brandisite neither justify the use of two variety names, the name of brandisite should be dropped, xanthophyllite having priority.

The patterns of the clintonites from Amity, Warwick, Spain and Franklin, however, show slight but distinct differences when compared with the pattern of xanthophyllite-brandisite as well as amongst themselves. This is expressed in the inward shifting of at least two lines (indicated in fig. 33 with 1 and 2). Compared with xanthophyllite the distance between the reflection pair 1 and 1′ is larger, that between 2 and 2′ is smaller. It is a noteworthy feature, that the degree of shifting varies for the clintonites from the different localities, those of Amity and Warwick, however, being identical. It would be interesting if it could be established that the degree of shifting is proportional to the fluorine content of the clintonites reported by RICHARDSON (1836) and VON SIPÖCZ (1879). If this were true the clintonite from Franklin would have the largest proportion of fluorine. It is remarkable in any case that this mineral is associated with norbergite, the member having proportionally the highest fluorine content of the humite group. Careful analyses, however, are necessary before the tentative suggestion made above can be confirmed. A further matter of interest in the connection is that the clintonites in every case are brown in colour (resembling phlogopite) and invariably associated with minerals of the humite group. Moreover, the plane of the optic axes is said to be parallel to (010) in xanthophyllite-brandisite, whereas it is reported to be perpendicular to (010) in clintonite (a. o. HINTZE 1897). Finally, the pleochroic scheme of clintonite s.s. is apparently α (colourless to very pale brownish) $< \beta, \gamma$ (pale brown), whereas that of coloured xanthophyllite is α (pale yellow-brownish to brownish) $> \beta, \gamma$ (colourless to very pale greenish). It is therefore suggested to retain the variety names of xanthophyllite and clintonite s. s. ¹), the latter being used for the brown fluorine-bearing variety and the comprehensive mineral species being designated as clintonite.

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¹) The clintonites described by KNOPF (1953, 1957) may possibly belong to the variety xanthophyllite as defined in the present paper, in view of the colours of their pleochroic schemes.

PART III

PETROGRAPHY

Introduction

In this chapter the different types of rocks encountered in the contact zone will be described, together with the main features of the igneous body. Much more attention has been paid to the dolomitic marbles and the silicate skarns with their interesting mineral content than to the other metamorphic rocks. For details concerning the different minerals the reader is referred to the relevant paragraphs.

THE DOLOMITIC MARBLES

Pure dolomite marbles:		
198 and 1148	NE of Escouloubre	(loc. T).
Almost pure dolomite marbles with very subordinate amounts of contact minerals:		
733	NE of Escouloubre	(loc. T).
836 and 1486	NE of Escouloubre	(loc. U).
1458a	SE of the Pic de Garigue	(loc. K).
Dolomitic forsterite-phlogopite marbles:		
260	NW of Eaux Chaudes	(loc. I).
283 and 285	N of Escouloubre	(loc. R).
663, 665 and 670	NE of Escouloubre	(loc. U).
Dolomitic forsterite (serpentine)[1])-phlogopite (pennine) marbles:		
444a, 445 and 448	W of Escouloubre	(loc. O).
320a	NW of Escouloubre	(loc. P).
277, 280, 323 and 331	N of Escouloubre	(loc. R).
69, 73a and 75	NE of Escouloubre	(loc. T).
651 and 659	NE of Escouloubre	(loc. U).
229	N of Le Bousquet	(loc. AA).
Dolomitic forsterite-phlogopite-apatite-ore[2]) marbles:		
1116a, 1152 and 1152a	NE of Escouloubre	(loc. T).
Dolomitic forsterite-phlogopite-spinel marbles:		
295, 669 and 672	NE of Escouloubre	(loc. U).
842	N of Le Bousquet	(loc. AA).
Dolomitic forsterite-phlogopite-spinel-apatite marbles:		
70587	NE of Escouloubre	(loc. T).
796	NE of Escouloubre	(loc. U).
Dolomitic forsterite-phlogopite-clinohumite-spinel marbles:		
853, 863 and 864	N of Le Bousquet	(loc. AA).

[1]) The minerals between brackets represent the alteration products.

[2]) When apatite and ore are mentioned in the name of the rock, these minerals are among the main constituents.

Dolomitic forsterite-phlogopite (clinochlore)-clinohumite-spinel marbles:

245	NW of Eaux Chaudes	(loc. I).
1013b and 1472	NE of Escouloubre	(loc. V).
1318a	NE of Le Bousquet	(loc. BB).

Dolomitic forsterite (serpentine, chlorites)- phlogopite (chlorites)-clinohumite (chlorites, serpentine, magnetite)-spinel (hydrotalcite) marbles:

112, 165, 166, 178a, [illegible], 183 and 186	NW of Eaux Chaudes	(loc. I).
690	N of Eaux Chaudes	
1409a	SE of the Pic de Garigue	(loc. K).
59, 1289a and 1290e	NE of Escouloubre	(loc. T).
33, 879a, 881a and 1348a	NE of Escouloubre	(loc. V).
223a, 228, 846, 848a, 865, 866b and 870a	N of Le Bousquet	(loc. AA).
1319 and 1321e	NE of Le Bousquet	(loc. BB).

Dolomitic forsterite (serpentine)-phlogopite (chlorites)-clinohumite (serpentine, chlorites, magnetite)-spinel (hydrotalcite)-apatite-ore marbles:

357	NW of Escouloubre	(loc. P).
1289	NE of Escouloubre	(loc. T).

Dolomitic humite-spinel marbles:

32, 937 and 1341	NE of Escouloubre	(loc. V).
210	NNE of the Roc de Casteldos	(loc. Z).

Dolomitic "forsterite"[1] (serpentine)-phlogopite (chlorites)-chondrodite (serpentine)-ore marbles:

1118c, 1118e, 1118h, 1129c, 1131 and 1131b	NNE of the Roc de Casteldos	(loc. Z).

Dolomitic "forsterite" (serpentine)-phlogopite (chlorites)-chondrodite (serpentine)-"spinel" (hydrotalcite)-ore marbles:

215 and 1126	NNE of the Roc de Casteldos	(loc. Z).

Dolomitic "forsterite" (serpentine)-phlogopite (chlorites)-chondrodite (serpentine)-fluoborite-ore marbles:

212a, 213 and 70586	NNE of the Roc de Casteldos	(loc. Z).

These rocks comprise the dolomites and highly dolomitic limestones that have been thermally metamorphosed and partially subjected to pneumatolytic action. The dolomite-calcite ratio of the different marbles varies considerably, depending on the original proportion of impurities in the earlier dolomites (see p. 337). Theoretically, in extreme cases metamorphism produces pure dolomite marbles on the one hand, and on the other calcite marbles carrying considerable quantities of magnesium-rich contact minerals, without any residual dolomite. The latter are regarded as having originally been dolomites, with such a proportion of impurities, that on metamorphism the available dolomite reacted completely with the impurities, leaving no residual dolomite. Such rocks are of widespread occurrence in the region described in this paper, but restricted to small masses, patches and narrow zones not more than a few cm. in thickness, enclosed within dolomite-bearing marbles. A hand-specimen of marble of normal dimensions in all cases will contain a certain

[1]) The minerals between quotation marks are almost completely converted.

amount of recrystallized dolomite. The pure or almost pure dolomite marbles, however, may occur in beds, up to several tens of metres in thickness.

The calcite content of the marbles has been determined by staining the rocks and slides with solution of copper nitrate, according to the method described by Rodgers (1940). Although in most cases the various contact minerals were seen to be partially or completely bordered by the newly formed calcite, occasional grains of contact minerals may be completely surrounded by dolomite. Almost without exception the newly formed calcite is turbid, whereas the recrystallized dolomite is limpid. This feature has already been noted in similar rocks from other regions (Tilley, 1920, p. 453).

In the dolomitic marbles the following contact minerals have been found:

primary minerals

apatite
chalcopyrite
chondrodite
clinohumite
fluoborite
forsterite
graphite
humite
ludwigite?
magnetite
phlogopite
pyrite
pyrrhotite
rutile
spinel
szaibelyite?
tremolite

secondary minerals

chlorites (amesite?, pennine, clinochlore)
diaspore
goethite
haematite
hydrotalcite
magnetite
manasseite
serpentine
serpentinous products with higher birefringence than serpentine
rutile
talc

The pure and almost pure (733, 836, 1458a, 1486) dolomite marbles are generally white to dark blue-grey or pale brown in colour, ranging in grain-size from fine to medium. On weathered surfaces the colour of these rocks may be brownish or grey-black. Some types of dolomite marbles are loosely coherent, easily decomposing into separate grains by the blow of a hammer.

Under the microscope the crystals are seen to form an interlocking pavement pattern. Polysynthetic twinning is common. Mechanically distorted crystals are frequently observed.

In the dolomitic marbles forsterite and phlogopite are by far the most common primary contact minerals and they may occur in considerable amounts. It is noticed that the two minerals occur nearly always in close association with one another. They occur either in the form of discrete crystals or as monomineralic aggregates (up to several cm. across), the latter predominating in the case of phlogopite. Fresh forsterite-phlogopite marbles, which are of rare occurrence, are not readily recognized in the field, especially if the carbonate is dark in colour and the minerals are of small dimensions (295, 669, 1152a). When much altered, however, these rocks are very conspicuous by virtue of the vivid yellow to green colours of the serpentinized forsterite and the dense greenish black masses of the fine-flaked chloritized phlogopite (75, 323, 970c). These chlorite masses occur as thin irregular layers or lenses, that occasionally show boudinage structure (fig. 34).

Under the microscope the forsterite is generally in rounded individual crystals being separated from each other by the carbonate. Occasionally the forsterite crystals are grouped together in aggregates. Serpentinized forsterite, set in a matrix of calcite, forms masses of ophicalcite (229, 659).

Unlike forsterite the fine-flaked phlogopite frequently builds monomineralic aggregates of interlocking crystals. The chloritized masses of the phlogopite often include scattered spots of a blackish material, which is responsible for the dark colour of these masses in the hand-specimen (970c). It is worthy to note that the chlorites in the forsterite-phlogopite marbles consist almost exclusively of optically positive and optically negative pennine. Clinochlore appears to be very rare in these rocks, contrasting with its very common occurrence in the clinohumite-bearing marbles. Spinel, apatite and magnetite are common accessories.

In some specimens spinel, apatite and magnetite are among the main constituents (295, 796, 842, 1152a, 70587). The apatite commonly is in prisms with very rounded outlines and intersected by many irregular cracks.

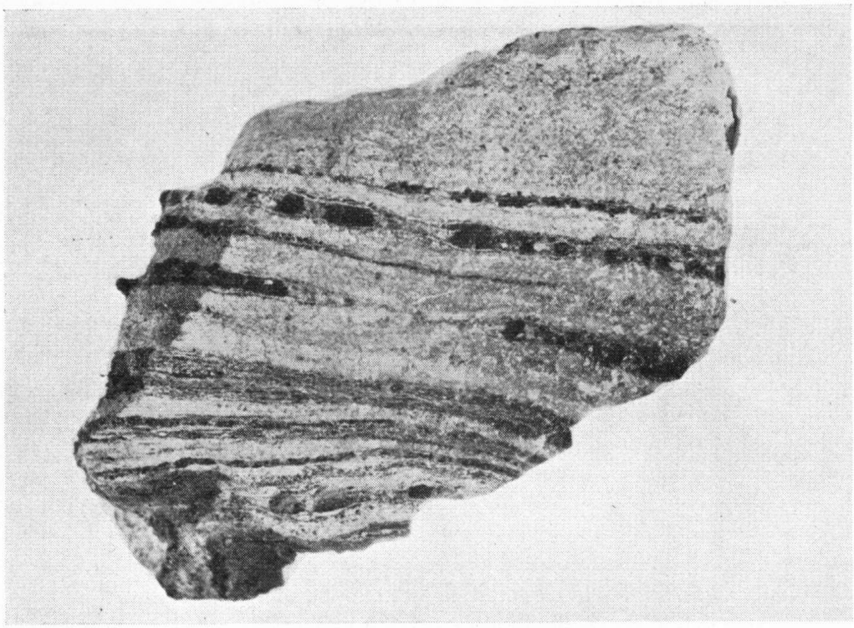

Fig. 34 — Narrow blackish layers and boudins consisting of completely chloritized fine-flaked phlogopite, in a highly altered banded forsterite (serpentine)-phlogopite (chlorite) marble. NE of Escouloubre (loc. R).
Sample 1113a Natural size

After forsterite and phlogopite, clinohumite and spinel are the most common primary contact minerals, both in quantity and distribution throughout the area. Clinohumite in every case appears to be accompanied by spinel, but the latter may occur without the former as is noted above. The assemblage forsterite-phlogopite-clinohumite-spinel was found to be very common in this zone. Apatite, rutile, magnetite and pyrrhotite are the common accessories. Tremolite is only found as an occasional fairly large crystal. The rocks show varying stages of alteration, entirely fresh specimens being extremely rare. Such rocks, however, are exposed N of Le Bousquet, where a light grey marble (853, 863, 864) with conspicuous dark specks of spinel, spots of orange clinohumite and yellow forsterite was seen. Some scattered phlogopite and pyrrhotite was also plainly visible. In thin section most of the contact minerals of these rocks build intricate intergrowths with the carbonate matrix, whilst forsterite and clinohumite also may be intimately intergrown with each other.

In similar marbles from other localities (loc. I, V and BB) the phlogopite may be highly altered into white clinochlore though all the other contact minerals show virtually no sign of alteration (245, 1013b, 1318a, 1472, fig. 35). The samples 1013b (fig. 36) and 1472 are representatives of the most beautiful clinohumite-bearing marbles of the whole investigated region. The irregular masses and strings, consisting of orange-brown clinohumite, pale yellow forsterite and dark speckles of spinel and up to 1 cm. thick, are very conspicuous. The secondary greyish calcite surrounding the contact minerals appears to be more easily eroded by the action of weathering than the pale greyish to white dolomite of the matrix. In thin section polysynthetic twinning of the clinohumite was frequently observed.

Fresh marbles, as described above, are of very limited occurrence, however, and more commonly the different minerals show various stages of alteration even in a single section. They may consist of forsterite (serpentine or chlorites)[1], phlogopite (chlorites), clinohumite (chlorites or serpentine) and spinel (hydrotalcite). In some rocks apatite and ore minerals form notable constituents (357, 1289). The various contact minerals are either randomly scattered throughout the rock or they may be concentrated in patches, lenses and irregular masses. In section the well rounded crystals of forsterite and clinohumite, some up to several mm. in diameter, again show occasional intimate intergrowths with the carbonate matrix. Further, the two minerals are commonly intricately intergrown with each other. In addition intergrowths of forsterite and phlogopite or its alteration products were also seen. Spinel commonly occurs as separate crystals but may occasionally be aggregated in strings. In some samples pyrrhotite can easily be recognized with the naked eye (865, 1283f).

Marbles containing humite have been found at two localities only (loc. V and Z). Scattered, pale orange to yellow spots of humite are embedded in a medium-grained white (32, 937, 1341) or greyish blue rock (210). In section, colourless spinel proves to be the only accompanying contact mineral of importance. Accessory constituents include apatite, phlogopite, talc, ore, clinochlore and a mineral resembling ludwigite (1341).

Finally, near the pass N of the Roc de Casteldos (loc. Z), a small mass of marble is exposed with a mineral assemblage that differs from all the above-described types. In addition to most of the minerals previously mentioned, chondrodite and fluoborite are also present. The host rock is a rather fine-grained grey to dark greyish blue marble. The most important contact minerals, almost invariably highly altered, are forsterite (serpentine), phlogopite (chlorites), chondrodite (serpentine, brownish products), spinel (hydrotalcite), fluoborite and partly limonitized magnetite, pyrite and chalcopyrite. Accessory constituents include clinohumite, apatite, rutile and a mineral resembling szaibelyite (see p. 265). Many of the minerals mentioned may occur together in a single hand-specimen. With the naked eye, the highly

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[1] The minerals between brackets represent the alteration products.

Fig. 35 — Fresh forsterite-phlogopite (clinochlore)-clinohumite-spinel marble, the mica being the only mineral that has been almost completely converted, viz. into colourless clinochlore. NE of Escouloubre (loc. V).
Sl. 1472 one nicol × 35

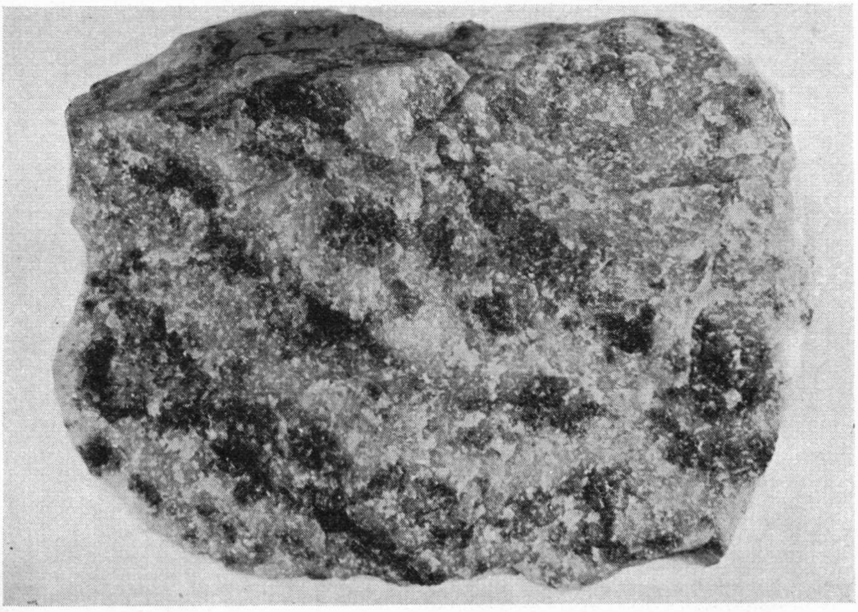

Fig. 36 — Dolomitic marble, with patches and streaks consisting of intergrown forsterite, clinohumite and spinel. NE of Escouloubre (loc. V).
Sample 1013b Natural size

chloritized phlogopite (up to 0.5 cm. diam.), the serpentine and the ore minerals can easily be distinguished; in a few cases little hair-like aggregates of fluoborite may be seen with the aid of a binocular microscope. The other minerals can only be recognized under the microscope. Fresh forsterite is present in little rounded crystals only, but aggregates of serpentine that have much larger dimensions may possibly represent completely converted larger forsterite crystals. Very pale yellow chondrodite, commonly altered into serpentine is present in almost all sections of these rocks. Comparatively fresh crystals occur in the samples 1118e and 1118h. The refringence of the chondrodite is distinctly lower than that of the clinohumite. This latter mineral has only rarely been observed, as small rounded crystals (1118h, 1131). Distinct pseudomorphs after clinohumite were not seen (see p. 266). Fresh little octahedrons of spinel are rare, aggregates of hydrotalcite rather common (215, 1126). Fluoborite is occasionally present, usually in subordinate amounts (1118h, 1118e, 1129c), but in three samples it is present as a major constituent (212a, 213, 70586). It may be of interest to note that the fluoborite aggregates are almost never embedded in the carbonate, being almost exclusively intergrown with masses of serpentine or chlorite. The partially limonitized ore minerals (magnetite, chalcopyrite and pyrite) are present in comparatively large amounts. Apatite is a fairly common accessory, occurring as rather large, well rounded prisms (1129c). Rutile is also common in comparatively large irregular crystals (1131b).

THE CALCITE MARBLES

60	Calcite marble	N of Escouloubre	(loc. Q).
24	Calcite marble (coarse-grained)	NE of Le Bousquet	(loc. BB).
148	Potash felspar-chlorite-epidote-actinolite-tremolite-ore marble	NE of Escouloubre	(loc. X).
262	Tremolite-ore marble	N of Escouloubre	(loc. R).
81	Quartz-diopside-ore marble	Roc de Casteldos	(loc. Y).
595	Potash felspar-actinolite-tremolite marble	N of Escouloubre	(loc. R).
596	Quartz-actinolite-epidote-diopside marble	N of Escouloubre	(loc. R).
649	Potash felspar-diopside-prehnite-ore marble	NE of Escouloubre	(loc. T).
149	Quartz-potash felspar-epidote-diopside-grossular marble	NE of Escouloubre	(loc. X).
1008a	Diopside-grossular marble	NE of Escouloubre	(loc. V).
547	Grossular-biotite-clinozoisite-epidote marble	Chateau d'Usson	(loc. E).
1382	Diopside-grossular-idocrase marble	Roc de Casteldos	(loc. Y).
84	Potash felspar-diopside-prehnite-idocrase marble	Roc de Casteldos	(loc. Y).
85	Potash felspar-diopside-idocrase marble	Roc de Casteldos	(loc. Y).
93	Diopside-grossular-idocrase marble	Roc de Casteldos	(loc. Y).
95	Diopside-grossular-idocrase marble	Roc de Casteldos	(loc. Y).
83	Diopside-prehnite-wollastonite marble	Roc de Casteldos	(loc. Y).
138a	Magnetite marble	NE of Escouloubre	(loc. V).

These rocks comprise the pure and impure limestones and slightly dolomitic limestones transformed by thermal metamorphism into pure calcite marbles and marbles with a varying proportion of contact minerals. With the exception of water, virtually no extraneous material from the granite is thought to have been introduced. The contact minerals present in the marbles are considered to owe their origin entirely to the reaction between the different kinds of impurities and the calcite matrix. Recrystallized clastic minerals may be present in notable quantities in some of the rocks, especially in the low grade marbles.

Among the various minerals listed below, all of which have been found in the marbles, none was found to belong to a rare species or to be of special interest.

primary minerals

actinolite
apatite
biotite
calcite
chlorite
clinozoisite-epidote
diopside
grossular
hornblende
idocrase
magnetite
plagioclase
potash felspar
prehnite
quartz
titanite
tremolite
wollastonite
zircon

secondary minerals

calcite
clinozoisite-epidote
chlorite
limonite
prehnite

Pure and almost pure calcite marbles form the most common rocks in the investigated contact zone. In most cases the rocks are fine- to medium-grained, but coarsely crystalline marbles with a grain-size of 3 mm. are of local occurrence (loc. BB). The colour of the various types of marble is commonly a shade of blue, blue-grey, green or perfectly white. Small masses of pink, reddish yellow and violet coloured marble are locally exposed. As seen in section, the calcite grains are generally of irregular shape with sinuous or zig-zag boundaries. Distorted crystals as well as polysynthetically twinned crystals are frequently seen.

Low grade calcite marbles, often vaguely banded, may contain various amounts of one or more of the following minerals: quartz, potash felspar, chlorite, actinolite-tremolite, clinozoisite-epidote, prehnite, diopside (in small well rounded granules) and ore minerals (81, 148, 262, 595 and 649). Accessory constituents include apatite, biotite, titanite and zircon. Some of the constituent minerals are considered to be of clastic origin.

The marbles that contain varying amounts of grossular and idocrase in addition to the minerals mentioned above, are considered to have reached a somewhat higher degree of thermal metamorphism (149, 596). Sample 1008a contains numerous small dodecahedrons of grossular, no more than a few mm. across, and extremely small rounded granules of diopside. Conspicuous crystals of grossular up to 1 cm. in diameter are present in the marbles (547) that alternate with thick bands of calc-magnesium-silicate hornfelses near the walls of the Chateau d'Usson. Under the microscope, diopside in the form of rounded granules is seen to be the most common associate. The porphyroblasts of almost colourless grossular, intersected by many irregular cracks, may enclose calcite, diopside, clinozoisite-epidote and some prehnite. Accessory quartz appears to be in stable coexistence with the calcite.

Another important occurrence of grossular-rich marbles is on the summit of the Roc de Casteldos, especially at its western side. There, green idocrase is a very common associate of the weakly reddish or pinkish brown grossular. The two minerals are often intimately intergrown. Some marbles are extremely rich in green idocrase (1362). Pale yellow brownish idocrase seems to be of less frequent occurrence here (84, 85). On the rock surface the several minerals stand out prominently as a result of the action of weathering. The presence of wollastonite in some of the samples indicates that we are dealing here with rocks that have reached a fairly high stage of metamorphism. The mineral may be either a minor (84, 85) or a major constituent (83). The most common and outstanding type of occurrence of wollastonite, however, is in the coarsely crystalline wollastonite rocks which are described on page 313. In the marbles the mineral is usually white and may display its well known lustrous radial aggregates. Occasionally, however, the wollastonite has a pale pinkish brown colour.

Calcite marbles rich in ore minerals appear to be rare in this area. They may be seen at loc. V where thin (a few cm.) indistinctly defined bands rich in magnetite occur (138a). In thin section no mineral other than magnetite was seen in the calcite matrix.

THE CALC-SILICATE AND CALC-MAGNESIAN-SILICATE HORNFELSES

70588	Quartz-calcite-potash felspar-clinozoisite-epidote-sericite-chlorite-ore hornfels	NW of Usson	(loc. D).
70589	Quartz-calcite-potash felspar-clinozoisite-epidote-ore hornfels	NW of Usson	(loc. D).
498	Quartz-potash felspar-clinozoisite-epidote-actinolite-ore hornfels	NW of Usson	(loc. D).
494	Quartz-calcite-potash felspar-clinozoisite-epidote-diopside-ore-titanite hornfels	NW of Usson	(loc. D).
508	Quartz-calcite-potash felspar-clinozoisite-epidote-prehnite-diopside-grossular-titanite-ore hornfels	NW of Usson	(loc. D).
123	Quartz-calcite-potash felspar-clinozoisite-prehnite-diopside-biotite hornfels	NW of Eaux Chaudes	(loc. I).
122	Quartz-potash felspar-clinozoisite-epidote-prehnite-biotite-titanite hornfels	NW of Eaux Chaudes	(loc. I).
696	Quartz-potash felspar-clinozoisite-epidote-prehnite-diopside-grossular-idocrase hornfels	NW of Eaux Chaudes	(loc. I).
70603	Potash felspar-clinozoisite-epidote-diopside-grossular-idocrase hornfels	Chateau d'Usson	(loc. E).
70597	Diopside-grossular hornfels	NE of Escouloubre	(loc. T).
70	Clinozoisite-plagioclase-diopside hornfels	NE of Escouloubre	(loc. T).
71a	Quartz-potash felspar-clinozoisite-hornblende-diopside-biotite-ore hornfels	NE of Escouloubre	(loc. T).
70596	Calcite-potash felspar-clinozoisite-prehnite-diopside-grossular hornfels	NE of Escouloubre	(loc. T).
87	Calcite-potash felspar-diopside-grossular-idocrase hornfels	Roc de Casteldos	(loc. Y).
91	Calcite-potash felspar-diopside-wollastonite-hornfels (marble)	Roc de Casteldos	(loc. Y).
78	Calcite-potash felspar-prehnite-diopside-idocrase-wollastonite hornfels (marble)	Roc de Casteldos	(loc. Y).
334	Quartz-calcite-potash felspar-diopside-wollastonite hornfels	N of Escouloubre	(loc. S).
70612	Quartz-calcite-bearing wollastonite rock	NE of Le Bousquet	(loc. CC).
1110	Coarsely crystalline wollastonite rock	N of Escouloubre	(loc. S).

These rocks have been produced by the thermal metamorphism at the expense of the pure and impure quartzitic rocks which were intercalated as lenses and layers between the original limestones. They are now very hard dense rocks, often well banded and occurring in layers with a thickness between a few mm. and a metre. Mineralogically, the different types of rocks consist mainly of calc-silicates and calc-magnesian-silicates. Recrystallized clastic minerals may form notable constituents in the lower grade hornfelses. The contact minerals are considered to owe their origin to the reactions between the quartz, the impurities and the surrounding and intermixed carbonate. With the exception of water, virtually no introduction of material from the granite is suggested.

Hornfelses with comparatively large amounts of calcite, grade into marbles rich in contact minerals. Rocks consisting of very thin (a few mm.) alternating bands of hornfels and marble may be considered as forming a transitional suite between the hornfelses and the marbles (78, 91).

Among the many different minerals, listed below, all of which have been found in the hornfelses, none was found to be very rare or of special interest.

primary minerals

actinolite-tremolite
apatite* 1)
adularia
biotite
calcite
chalcopyrite
clinozoisite-epidote
diopside
grossular
hornblende
idocrase
ilmenite
magnetite
plagioclase
potash felspar*
prehnite
pyrite
quartz** 1)
titanite*
tourmaline**
wollastonite
zircon**
zoisite

secondary minerals

actinolite
calcite
chlorite
clinozoisite-epidote
limonite
prehnite
sericite

The hornfelses that contain variable amounts of the minerals quartz, calcite, potash felspar, clinozoisite, actinolite and ore minerals are considered to be of low grade (70588, 70589 and 498). Accessory constituents include rounded grains of titanite, tourmaline and zircon. The clinozoisite-epidote occurs as small shapeless grains. This mineral and the fibrous actinolite are considered to be the only newly formed products. In addition, subordinate amounts of prehnite may occasionally be seen (70589). The rocks under discussion are of frequent occurrence NW of Usson. Here, they are generally well banded and display shades of grey, green and grey-blue. At the same

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1) The minerals indicated with an asterisk may be either contact or clastic minerals. Those with two asterisks are considered to be of exclusively detrital origin.

locality somewhat higher grade hornfelses are also common (494, 508). In addition to the minerals mentioned above, these rocks contain diopside, prehnite and grossular in the form of sieved irregularly bounded crystals. The various minerals in these rocks have larger dimensions and show more distinct crystal outlines than in the very low grade hornfelses. Titanite, which is often a notable constituent, is either a contact mineral or a recrystallized clastic product. Very narrow veins, roughly perpendicular to the banding of the rocks, consist mainly of calcite, quartz, prehnite, clinozoisite and adularia.

NW of Eaux Chaudes, well banded, multicoloured hornfelses containing many different contact minerals are exposed (122, 123, 696). The layers vary in thickness from a few cm. to almost a metre. Pale reddish bands are rich in grossular, dark green ones in diopside, whilst a grey-yellow colour is caused by a predominance of prehnite and white bands are built up of quartz and potash felspar. Further important minerals are calcite, clinozoisite-epidote and biotite. Subordinate constituents include titanite, zircon, apatite, soda-rich plagioclase, rutile, sericite and ore minerals. Small veins filled mainly by calcite and prehnite are occasionally seen. It would seem that in these rocks quartz and calcite are still in stable coexistence.

Near the walls of the Chateau d'Usson, bands up to a metre in thickness of calc-magnesian-silicate hornfels are intercalated between grossular- and diopside-rich marbles. The dense dark green masses consist almost exclusively of diopside. Pale reddish masses with dark brown spots consist of xenoblastic grossular enclosing idioblastic crystals of idocrase (70603). Under the microscope potash felspar and clinozoisite-epidote are seen to form notable constituents. Accessory minerals include prehnite, titanite, ore, colourless mica and some residual calcite. Narrow veins contain adularia and quartz.

The samples 70597, 70 and 71a are from an extremely hard, dense, fine-grained lens-shaped body of hornfels which is intercalated between the calcite marbles NE of Escouloubre (loc. T). Varying colours ranging through shades of green, grey-green, pink and black-violet indicate different mineral assemblages. The main constituents, only recognizable in thin section, are quartz, potash felspar, plagioclase (strongly sericitized), clinozoisite, hornblende, diopside, grossular, biotite and ore minerals. In subordinate amounts calcite, apatite, rutile, tourmaline, zircon, prehnite and titanite are also present, the latter occasionally in larger amounts. Narrow veins contain chlorite and a fibrous actinolitic amphibole. In sample 70597 the grossular appears to have a fairly large andradite content and the diopside (pale green in section) a distinct hedenbergite content. The weathered parts of this rock are of a rusty colour. At the same locality (loc. T) a hornfels with green and reddish pink patches (70596) consists mainly of calcite, potash felspar (partially albitized), clinozoisite-epidote, prehnite, diopside and grossular. The xenoblastic masses of potash felspar and grossular seem to be partially replaced by prehnite. Accessory constituents include apatite, chlorite, ore (partly limonitized), zircon and fairly large diamond-shaped crystals of titanite.

Beautiful multicoloured banded hornfelses, alternating with marbles rich in contact minerals, are exposed on the summit of the Roc de Casteldos, especially at its western side. There, in addition to all minerals previously mentioned wollastonite is also present, indicating a fairly high degree of metamorphism. It may be a subordinate or a main constituent, occurring in parallel or radial white lustrous aggregates. Green to dark green bands or irregular masses are rich in diopside; dense white masses consist mainly of potash felspar. Brown idioblastic crystals of idocrase (87) are often embedded in pale reddish masses of xenoblastic grossular (cf. the hornfelses of the Chateau d'Usson). Locally, very thin bands (a few mm.) of hornfels alternate with bands of marble of equal thickness (78, 91). Minerals like clinozoisite-epidote and prehnite occur generally in only subordinate amounts and are in several cases alteration products of earlier minerals. Accessory constituents include titanite, ore minerals and an optically isotropic mineral with low refringence, possibly fluorite.

Rocks with varying amounts of wollastonite, calcite and quartz are especially abundant on the lower slopes of the ridge N of Escouloubre (loc. Q—S). There, the gradual transformation of mechanically deformed quartzitic layers and lenses into pure wollastonite rocks can be clearly followed. At a certain distance from the granite the quartzitic lenses are seen to be enveloped by a thin skin of needle-like wollastonite (334). Nearer to the contact one can observe quartzitic cores which are surrounded by zones of wollastonite of varying thickness. The phenomenon that the boudins of quartzite are entirely surrounded by wollastonite and that the cracks occurring in the quartzitic masses are filled with wollastonite, indicates that mechanical deformation of these rocks must have taken place prior to or during the thermal metamorphism. On weathered surfaces the quartz-cores stand out prominently (up to a few cm.), due to their greater hardness, whilst the areas of wollastonite may be deeply excavated. Close to the contact, almost pure coarsely crystalline wollastonite rocks are seen, occasionally enclosing some residual calcite and quartz, these two minerals not being in contact with one another. In thin section potash felspar and diopside are seen to be present, generally in subordinate amounts, but occasionally in larger quantities. Residual quartz displays a striking mosaic structure. Similar almost pure wollastonite rocks (70612) occur NE of Le Bousquet (loc. CC).

THE SILICATE SKARNS

These rocks comprise the narrow zone of calc-magnesian-silicates which is exclusively localized at the contact between the granite and the metamorphosed pure and impure dolomites.

The silicate skarns are considered to have arisen from the direct local metasomatism of the dolomitic country rock at the granite contact. Although the contact line may be very irregular, the width of the silicate skarns does not show very much variation, averaging between 4 and 7 cm. (see fig. 5 and 6).

The hand-specimens of the silicate skarns are listed below. They include representatives of the complete sequence from the granite to the dolomitic country rock as depicted in fig. 37. None of the specimens, however, spans this complete range, each consisting of but a part of the sequence. The samples whose numbers are on the same line as well as those grouped together by a bracket were collected very near to each other and in many cases actually represent one very large sample.

The abbreviations used below are as follows: DM = dolomitic marble, SS = silicate skarn, TZ = transition zone (see p. 321) and G = granite. The different zones of the silicate skarns are also indicated:

I The green clinopyroxene zone
II The pale green clinopyroxene-zoisite-lilac mica zone

III The spinel-xanthophyllite zone
IV The colourless clinopyroxene zone
V The talc-serpentine-chlorite zone
VI The calcite zone.

The transition zone shows three different types:
1) The prehnite-rich type, 2) The clinozoisite- and zoisite-rich type and 3) The grossular-bearing type.

257 and 258	G-TZ(2)-SS(I—IV)	NW of Eaux Chaudes	(loc. I).
373 and 373a	„	SSE of the Pic de Garigue	(loc. J).
404, 684, 685, 687, 1254, 1259, 1260, 1262, 1272, 1277, 1278 and 1414	„	SE of the Pic de Garigue	(loc. K).
734a, 736, 1035, 1038, 1039, 1053, 1065, 1067, 1072, 1082 and 1485	G-TZ(3)-SS(I—V)	NE of Escouloubre	(loc. T).
733, 1068, 1069, 1070, 1071, 1084, 1091, 1092, 1093 and 1098	SS(V—VI)-DM		
884, 884c, 887, 889, 896 and 900	G-TZ(3)-SS(I—V)	NE of Escouloubre	(loc. T).
884a, 884b, 892 and 906	G-TZ(3)-SS(I—IV)		
53, 54 and 430	G-TZ(1)-SS(I—IV)	NE of Escouloubre	(loc. T).
1193, 1194 and 1197	G-TZ(2)-SS(I—V)	NE of Escouloubre	(loc. T).
1162 and 70594	G-TZ(3)-SS(I—IV)	NE of Escouloubre	(loc. T).
1164 and 1168	SS(V—VI)-DM		
289, 290 and 1468a	G-TZ(1)-SS(I—IV)	NE of Escouloubre	(loc. U).
290c, 1468b and 1468e	SS(III—IV)		
757	G-TZ(1)-SS(I—IV)	NE of Escouloubre	(loc. U).
1336 and 1338	„	NE of Escouloubre	(loc. U).
769, 814, 825, 829, 830, 835, 837, 838, 1477, 1480, 1500, 1600, 70592 and 70593	G-TZ(1)-SS(I—IV)	NE of Escouloubre	(loc. U).
70611	SS(I—IV)		
810 and 832	SS(III—IV)		
1466	SS(I—IV)	NE of Escouloubre	(loc. U).
738	SS(IV—V)	NE of Escouloubre	(loc. U).
1467	SS(I—VI)-DM	NE of Escouloubre	(loc. U).
1423 and 1423a	G-TZ--SS(I—V)	NE of Escouloubre	(loc. V).
1424 and 1424a	SS(V—VI)-DM		
725 and 959	SS(II—IV)	NE of Escouloubre	(loc. V).
1443	SS(V—VI)-DM	NE of Escouloubre	(loc. V).

As the skarns consist predominantly of diopsidic clinopyroxene, they may be regarded in a broad sense as silicated dolomitic marbles. Later metamorphism, however, resulted in the production of lower grade water-bearing minerals (e. g. clinozoisite, zoisite, lilac mica, prehnite and talc) as well as alteration products of earlier minerals.

Among the many minerals, listed below, all of which have been found in the silicate skarns, several are of special interest.

earlier minerals	*later minerals*
apatite	actinolite-tremolite*
calcite	calcite
clinozoisite	chlorites (amesite, pennine and clinochlore)
diopside 1)	clinozoisite-epidote
grossular	diaspore
lilac mica	limonite
phlogopite	magnetite
plagioclase	lilac sericitic mica
spinel	orthite*
talc	prehnite
thulite-like clinozoisite	quartz*
tremolite	serpentine
xanthophyllite	
zoisite	

The samples of the silicate skarns from all localities examined show a more or less pronounced zonal arrangement of different mineral assemblages. Though this zoning is not always readily distinguished in the hand-specimen, it becomes immediately apparent under the microscope. Some of the zones show sharp limits, others grade into each other. In a broad sense the skarns at the several localities consist of the same minerals. The proportions of the minerals in the different zones, however, may vary markedly. This holds true not only for samples collected at widely scattered localities, but also for almost adjacent samples from the same locality. Some of the zones, which are distinctly recognizable in one sample, may be almost absent in another. It may be of interest to note, however, that the sequence of the different zones in all the silicate skarns investigated, invariably was seen to be the same. This sequence is depicted in fig. 37, the most characteristic minerals occurring in each zone being indicated.

Before describing successively the six zones, it should be mentioned that a diopsidic clinopyroxene invariably makes up the bulk of the rock. From zone to zone, however, this mineral varies in shape, size, and probably also to a certain extent in chemical constitution. The so-called transition zone, which is considered as a very narrow strongly converted border zone of the granite, will be described on a later page (p. 321).

Zone I: **The green clinopyroxene zone**

This innermost zone of the silicate skarn, which is green (pale to fairly dark) in colour, almost always abuts sharply against the granite or the transition zone, but passes gradually into the adjacent skarn zone (see e. g. fig. 38 and 39). The contact of the skarn and the igneous rock may be called "knife-sharp".

The main constituent of zone I is a clinopyroxene, which according to its optical properties is probably a diopside with a slight hedenbergite content. In several cases the colour of the diopside is dark green immediately adjacent to the granite and becomes lighter as the marble is approached. Under the microscope the mineral is often seen to occur in the form of

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* The minerals indicated with an asterisk are found exclusively in narrow veins, penetrating the skarn from the granite.

1) The diopside of at least several zones may have a certain aluminium content (fassaite).

peculiar fan-shaped or radiating aggregates. Apart from the inclined extinction these aggregates resemble those of prehnite. Masses of very small, turbid brownish crystals are also common. Many crystals have corroded, skeletal outlines. In a very few cases the colour is pale green in thin section.

Calcite, occurring in varying amounts in this zone is not considered to be a primary mineral, but rather of secondary origin. Other minerals present include brownish sericitic material, prehnite, clinozoisite, zoisite and lilac mica (colourless in section), generally in subordinate amounts. The last three minerals are more common in the adjacent zone.

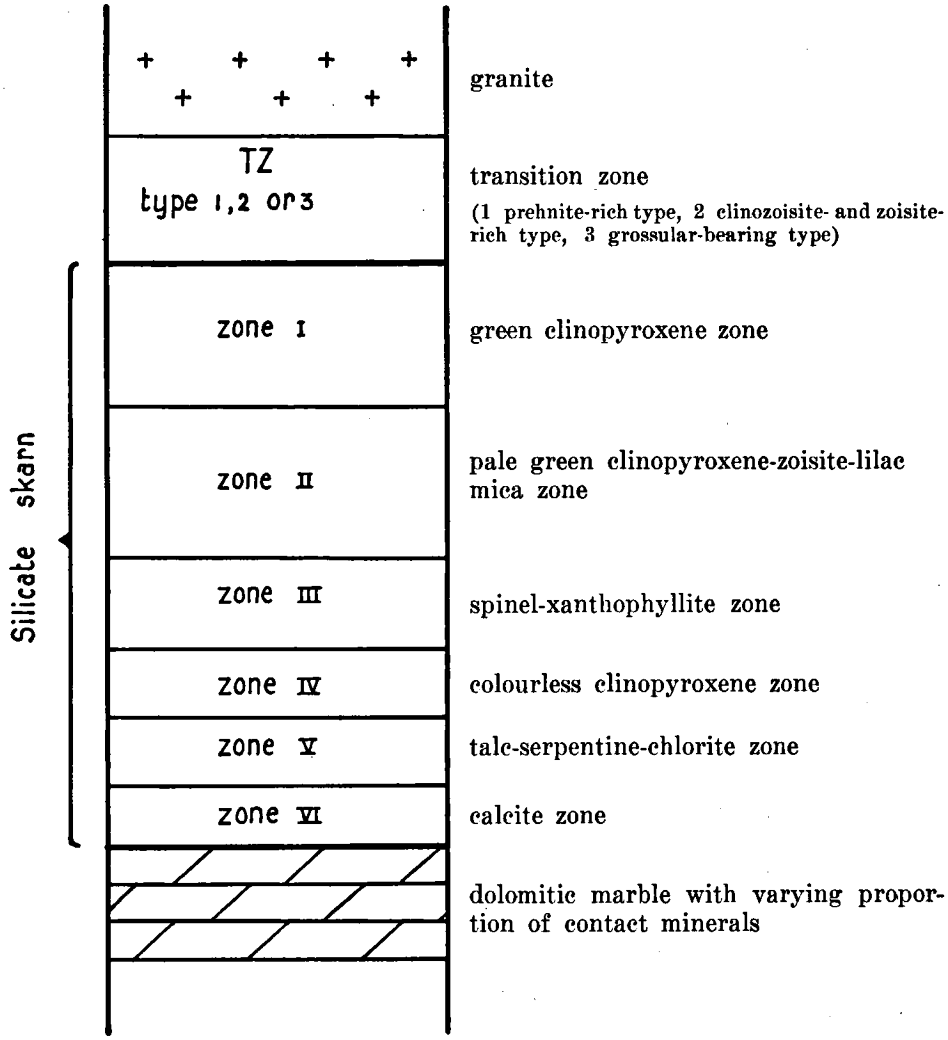

Fig. 37 — Scheme of the complete sequence of silicate skarn between the so-called transition zone and the dolomitic marble.

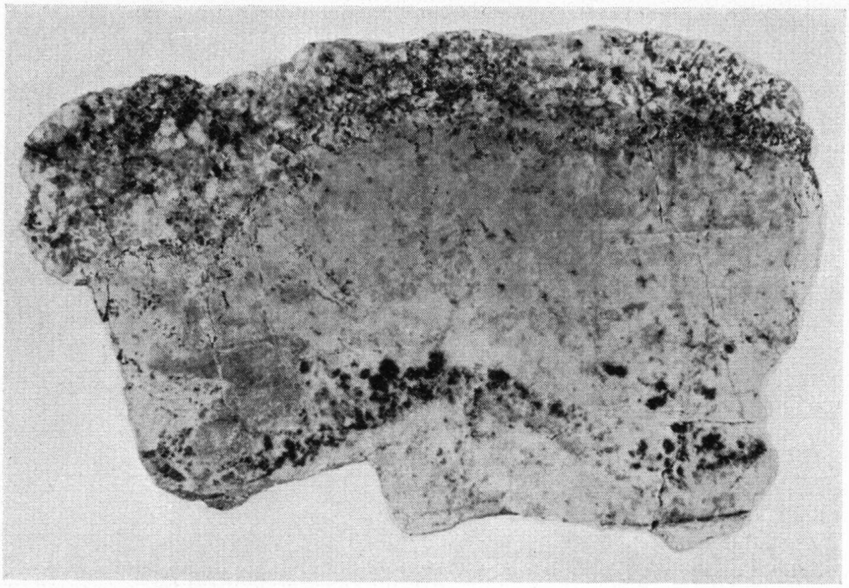

Fig. 38 — Contact of granite and zoned silicate skarn with a well-developed spinel-xanthophyllite zone (dark spots). In the lower left part of the skarn a dense aggregate of zoisite and lilac mica is seen. The transition zone (type 1) in this sample is very narrow and becomes apparent only under the microscope. NE of Escouloubre (loc. U).

Sample 1600 × 4/5

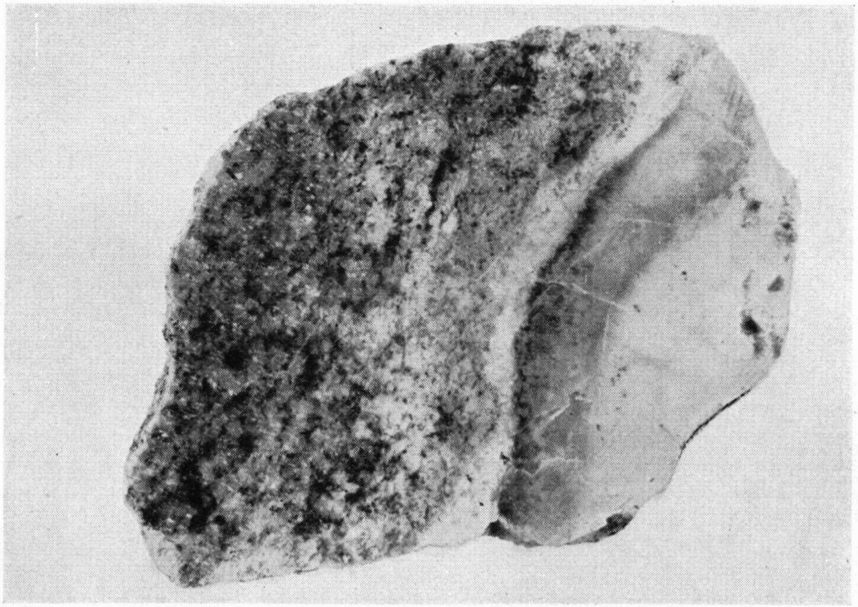

Fig. 39 — From left to right: clinopyroxene-bearing granite, light coloured transition zone (TZ), silicate skarn with distinct dark clinopyroxene zone (I), pale green clinopyroxene-zoisite-lilac mica zone (II) and spinel-xanthophyllite zone (III). NE of Escouloubre (loc. U).

Sample 757 × 9/10

Zone II: **The pale green clinopyroxene-zoisite-lilac mica zone**

As mentioned above, the green clinopyroxene zone (zone I) passes gradually into this zone. Similarly this zone generally shows a gradual transition into the next zone, zone III. In comparison with zone I the chief characteristic of zone II is an increase of zoisite and mica and a notable decrease of calcite. If the proportion of zoisite and mica, both of which are lilac coloured, is very large, this zone is distinctly recognizable in the field (fig. 40). In this case both minerals, which usually occur as separate crystals scattered throughout the rock, form dense, lenticular, or irregular aggregates (up to 1 cm. across) whose boundaries are sharply defined (769, 70592).

Under the microscope the clinopyroxene shows the optic properties of a common diopside and often exhibits strongly corroded outlines. The lilac mica, colourless in section, is generally partially or completely replaced by aggregates of much finer flaked mica, which cause the dense character of the masses of mica in the hand-specimen. The zoisite, which is not readily recognized as such, occurs as aggregates or as separate crystals that show a peculiar short prismatic habit with frayed borders. Both α- and β-zoisite appear to be present, the latter probably predominating. Small violet-reddish spots, present in some samples of the skarn rocks, consist of clinozoisite with a similar habit (810, 70592). This mineral, however, is distinctly pleochroic, the colour scheme resembling that of thulite.

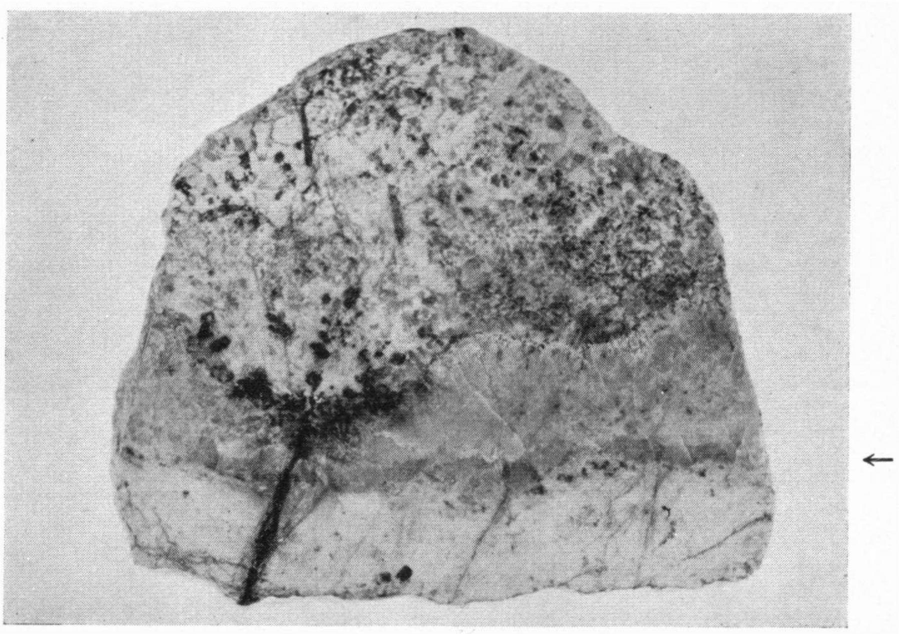

Fig. 40 — Contact of granite and zoned silicate skarn with a well-developed pale green clinopyroxene-zoisite-lilac mica zone, the latter two minerals forming dense aggregates (arrow). The dark veinlet contains much actinolite.
NE of Escouloubre (loc. U).

Sample 769 Natural size

Zone III: **The spinel-xanthophyllite zone**

This zone is characterized by two conspicuous minerals, green to blue-green spinel and colourless xanthophyllite, both of which occur as spots, patches and irregular masses of up to 1 cm. in diameter. The remainder of the zone consists predominantly of very pale green to colourless clinopyroxene, possibly a slightly fassaitic diopside, but it also includes small amounts of zoisite, lilac mica, phlogopite and residual calcite with apatite as a common accessory. Pleochroic clinozoisite is also present in a few samples (1193, 1194). If the proportion of spinel and xanthophyllite is large, the zone becomes very conspicuous (fig. 38 and 41). In some rocks, however, only small aggregates or a few scattered crystals of one or both minerals are seen (fig. 39 and 40). There seems to be a close genetic connection between the spinel and the brittle mica, which are often intergrown. Probably the xanthophyllite is derived from the spinel. In many cases, the xanthophyllite flakes are crowded

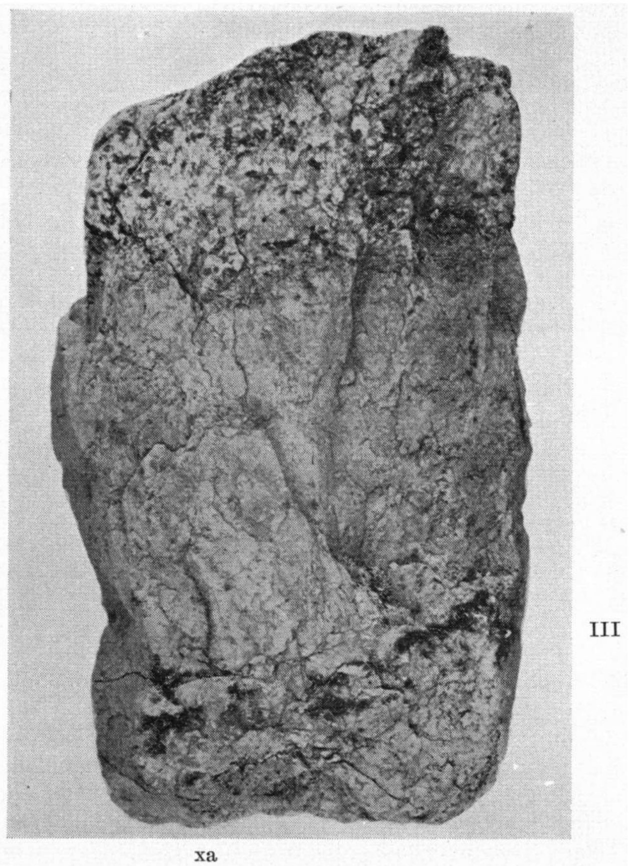

Fig. 41 — Contact of granite and silicate skarn with a well-developed spinel-xanthophyllite zone (III). xa = aggregate of xanthophyllite. NE of Escouloubre (loc. U).

Sample 835 Natural size

with very small rounded granules of diopsidic clinopyroxene, that possibly represent a later generation of this mineral. The spinel-xanthophyllite masses in some samples appear to be partially replaced by intergrowths of greyish white clinozoisite and pale green clinochlore (887, 900). Thin sections indeed show the alteration of xanthophyllite into clinochlore and lenticular clinozoisite. Incipient alteration of spinel into diaspore and amesite is common; advanced stages are but locally observed (884, 887, 895, 900, 906). The habit of the lilac mica and zoisite is similar to that in zone II. Phlogopite, being colourless or only weakly pleochroic, may occur as an occasional flake. This mineral, however, is more common in the next zone, zone IV.

Zone IV: **The colourless clinopyroxene zone**

A comparatively coarse-grained (a few mm. diam.), perfectly white or very pale green clinopyroxene is by far the most common constituent of this zone. The mineral is a diopside with possibly a slight fassaite content. The crystals of the clinopyroxene in this zone are markedly larger than in the preceding zones. A perfect decussate texture is often seen. Other minerals scattered throughout this zone include lilac mica, talc and phlogopite, which is often converted into clinochlore. This phlogopite, unlike that present in the marbles, is green or almost colourless. Apatite is a common accessory.

The limits of this zone with the two adjacent zones may be either sharp or gradational. In a number of cases no zone of colourless clinopyroxene is present, and then zone III is directly succeeded by zone V. The absence of zone IV is due to the complete alteration of the clinopyroxene into serpentine and of the phlogopite into chlorite.

Zone V: **The talc-serpentine-chlorite zone**

The minerals comprising this zone include as main constituents, talc, serpentine and chlorite, their proportion varying considerably. Generally the zone consists mainly of talc, but in some instances as much as 90 % of serpentine has been recorded, the zone then being conspicuously green in colour (fig. 42). The high content of talc means that the zone is frequently excavated, because of the susceptibility of the mineral to the action of weathering.

Under the microscope it is clearly seen that the serpentine is derived from the clinopyroxene, all stages in the alteration process being visible. The bulk of the calcite which was simultaneously released by this process has migrated outwards and now forms zone VI, but a small part has remained in this zone. The chlorite, represented by optically positive pennine, optically negative pennine and clinochlore is an alteration product of phlogopite. This mineral, seldom found fresh in this zone, is pale green to colourless. If the zone is very rich in serpentine and chlorite, the thickness may vary considerably, even over a very small distance.

The talc, which is in fairly large flakes as well as in small fibrous masses, seems to be a primary mineral.

The boundary between zone V and zone VI, the calcite zone, is generally sharp.

Zone VI: **The calcite zone**

White, fine-grained calcite makes up the bulk of this outermost zone of the skarn. Small masses of fine-flaky talc may be present in some instances.

The limit with the adjacent medium-grained dolomitic marble is invariably sharp, as shown by staining tests, and this boundary is accentuated by the contrasting grain-size. The difference between the milky white calcite zone and the dark weathered dolomitic marble is very clearly seen on weathered surfaces (fig. 5 and 6). In thin section the calcite is turbid (brownish), whereas the dolomite is limpid. The calcite zone owes its existence to the outward migration of the lime that was released during the serpentinization of clinopyroxene similar to that of zone IV, as well as to the newly formed calcite released during the formation of the talc.

An almost colourless grossular with a pinkish tinge has been found in three specimens of the silicate skarn. It appears to be an uncommon constituent, being restricted to zones I and II. In the transition zone, however, grossular is a rather common constituent.

Plagioclase, of a rather lime-rich variety and highly altered into sericitic material, has been found in one sample only, namely in zone I.

Narrow veins may contain actinolite, calcite, clinozoisite-epidote, prehnite, quartz and an orthite-like mineral. The last three minerals are restricted to the dark green veinlets that penetrate the skarn from the granite (fig. 40).

THE TRANSITION ZONE

Samples of granite-skarn contacts with a more or less distinct transition zone are listed on p. 314, the type of zone to which the sample belongs being indicated.

In this zone the following minerals have been found:

adularia
apatite
calcite
clinozoisite-epidote
diopsidic augite
grossular
ore minerals (e. g. magnetite and ilmenite)
orthite
plagioclase (albite and oligoclase)
potash-rich felspar
prehnite
quartz
rutile
sericite
titanite
tremolite
zircon
zoisite
fibrous undetermined constituents, e. g. a mineral resembling hydromagnesite.

The name transition zone is proposed by the author to describe the peculiar zone that occurs between the granite and the silicate skarn. This transition zone in most cases differs markedly from the adjacent granite as well as from the silicate skarn, both in appearance and in mineralogical composition. In hand-specimen the zone still seems to belong to the zoned silicate skarn, but under the microscope it becomes apparent that it is better considered as a strongly converted border zone of the granite. It is not impossible, however, that on closer examination some types of transition zone might indeed belong to the skarn.

Unlike the skarn, the transition zone varies considerably in width (a few mm. to 5 cm.), as well as in mineralogical composition. The contacts with the adjacent granite and the skarn are either sharp, or gradational over a short distance. The mineralogical content varies, as already noticed, and on a broad basis permits the recognition of three distinct types, each being characterized by a special mineral assemblage.

1. The prehnite-rich type

Of the three types, this type of transition zone shows the closest similarity to the granite. The zone, varying in thickness from a few mm. to a cm., is characterized by an abundance of prehnite.

In some hand-specimens virtually no transition zone is seen, the contact between the granite and the skarn appears to be "knife-sharp" (e.g. sample 1600, depicted on fig. 38). Under the microscope, however, the narrow zone becomes clearly visible. When the prehnite is yellow, the zone is distinctly perceptible in the sample as a yellowish band, especially on polished surfaces (fig. 39). In other cases, the mineral is perfectly colourless and then gives rise to a white zone (290). In thin section, the zone is seen to consist of some or all of the following minerals: quartz, potash-rich felspar, very soda-rich plagioclase, clinopyroxene, prehnite and calcite. Accessory constituents include apatite, titanite, orthite and zircon. It is noteworthy that biotite and hornblende are virtually absent.

The quartz is invariably strongly corroded and partially replaced by prehnite and to a lesser degree also by calcite. Small, scattered relics of quartz, which are in optical continuity, may be embedded in a dense mosaic of fine-grained and turbid brownish xenoblastic prehnite. The perthitic potash-rich felspar may also be replaced by prehnite. All stages of the progressive replacement of potash felspar by chess-board albite can be observed. The polysynthetically twinned plagioclase invariably is very rich in soda, being generally albite or occasionally oligoclase. Often the crystals are crowded with inclusions of clinozoisite, prehnite and sericite. The clinopyroxene ($c/n\gamma$ = ca. 47°) is probably a diopsidic augite and is present in widely varying proportions. The outlines of the mineral are often very irregular. Alteration into uralite and hydrous iron-ore is common. Prehnite is generally present in great abundance, both as a replacement mineral and as a primary mineral, being developed in small cavities in the form of limpid sheaf-like or fan-shaped aggregates. It may also occur in veinlets, together with adularia, calcite, clinozoisite and chlorite. The calcite may be a notable constituent and is seen to replace quartz and potash-rich felspar. Titanite, often present in comparatively large amounts, occasionally encloses ilmenite, rutile or both.

2. The clinozoisite- and zoisite-rich type

This type of zone (1—5 cm. thick) is not so readily identified as a highly converted border zone of the granite. In the hand-specimen it appears as a dense white, white-greyish or olive-greenish zone (685, 373) with dark green flecks, apparently belonging to the skarn.

Its chief constituents, varying in proportion, are clinopyroxene, clinozoisite, zoisite, prehnite, tremolite, calcite and brownish fibrous masses of a sericite-like material. Potash felspar and quartz, if present, generally occur as small, scattered, corroded crystals. Possibly part of the sericite-like matter represents completely converted plagioclase. Indeed in one case small relics of twinned plagioclase were observed in the sericite-like masses. The pale greenish or colourless clinopyroxene is presumably a diopsidic augite and is often clustered together into aggregates. The frequent polysynthetic twinning (100) is conspicuous. The crystals, often showing very irregular or rounded outlines, are generally partly altered into uralite and hydrous iron-ore. In many cases the pyroxene encloses swarms of small crystals of titanite and some apatite. The other accessories include zircon, orthite and ore, minerals absent from the adjacent silicate skarn.

3. The grossular-bearing type

This zone is generally distinctly visible in the hand-specimen where it occurs as a dense, greenish to pinkish white band varying in thickness from a few mm. to 3 cm. The width may vary rapidly, even in the same sample. A feature of the zone is the rather frequent occurrence of pale brownish to pink spots which consist of grossular (887, 1072, fig. 42). Further, in thin section the zone is seen to be composed of some corroded crystals or fine-granular masses of quartz, some potash felspar, a varying number of crystals of clinopyroxene and much fibrous material. Prehnite is in some cases present as a fine granular mosaic or as coarser grained aggregates. Titanite is a common accessory. The grossular occurs in the form of fairly large poikilo-

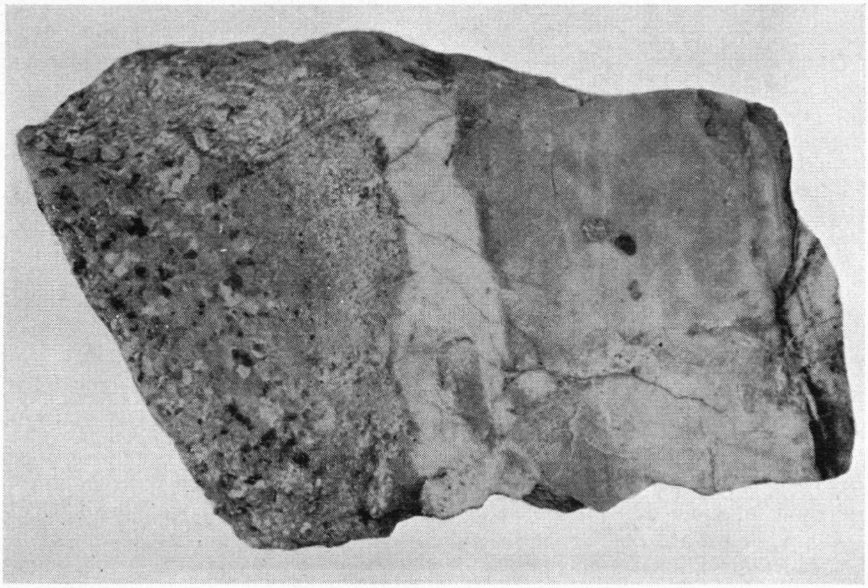

Fig. 42 — From left to right: granite, dense white transition zone with pink patches of grossular (type 3), silicate skarn with at the extreme right the conspicuous green serpentine of zone V. NE of Escouloubre (loc. T).
Sample 1072 Natural size

blasts which have very irregular outlines, as well as in clusters of very small (about 0.03 mm. diam.) rounded grains and idioblastic dodecahedrons. The identity of the various types of fibrous constituents, which are generally intimately intergrown with the above-mentioned minerals, could not be established. One type shows considerable resemblance to hydromagnesite both in appearance and optical properties. An X-ray powder pattern of the fibrous matter, however, did not confirm this tentative identification.

The action of weathering on the zone is selective and results in a spongy porous mass.

THE GRANITIC ROCKS

As already mentioned in the introduction to this chapter, the several types of igneous rocks encountered in this region will be touched upon only briefly. It may be of interest, however, to mention a few characteristics of some of them and to give a more detailed description of the dark inclusions in the granite.

The various primary and secondary minerals observed in the granitic rocks are listed below.

actinolite-tremolite
adularia
albite (e. g. chess-board albite)
anatase
apatite
biotite
calcite
chlorites (pennine and clinochlore)
clinopyroxene
clinozoisite-epidote
colourless mica
garnet
hornblende
ore minerals (e.g. ilmenite and magnetite)
orthite
plagioclase
potash-rich felspar, a. o. microcline
prehnite
pumpellyite
quartz
rutile
sericite
titanite
tourmaline
uralitic hornblende
zircon

An elaborate description of the granitic and locally also granodioritic rocks which occur at a distance of more than ca. ten metres from the contact is beyond the scope of the present paper. Quartz, rather acid plagioclase, potash-rich felspar and biotite as well as hornblende in lesser amounts are the chief constituents, whilst the accessories include apatite, zircon, titanite and orthite, the latter being quite common (fig. 43). Clinopyroxene has never been encountered in these rocks.

The outermost border zone of the granite, the part up to ca. ten metres from the contact, is in most cases clearly distinguishable from the ordinary biotite- or hornblende-bearing biotite-granite, on account of such features as a differing proportion of some of the minerals, the texture of the rock and the overall mineralogical composition. The same minerals are found in this granite as in the biotite-granite, apart from the local occurrence of clinopyroxene at the immediate contact. The strongly zoned plagioclase, however, tends to be slightly richer in anorthite and the hornblende is much more common, so that the quantity of hornblende is equal to that of the biotite, or even larger (fig. 44). Only at the immediate contact (a few cm. to a few dm. from the skarn) these common mafic constituents give place to a clinopyroxene. A notable feature of the border zone of the granite is the irregular distribution of the minerals in several places. Melanocratic and

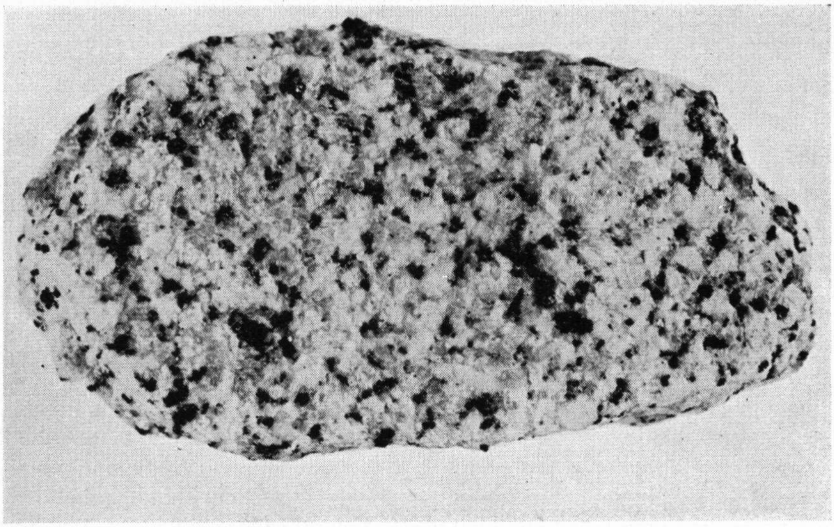

Fig. 43 — Medium-grained hornblende-bearing biotite-granite, 30 metres from the contact. NE of Escouloubre (loc. T).

Sample 416 Natural size

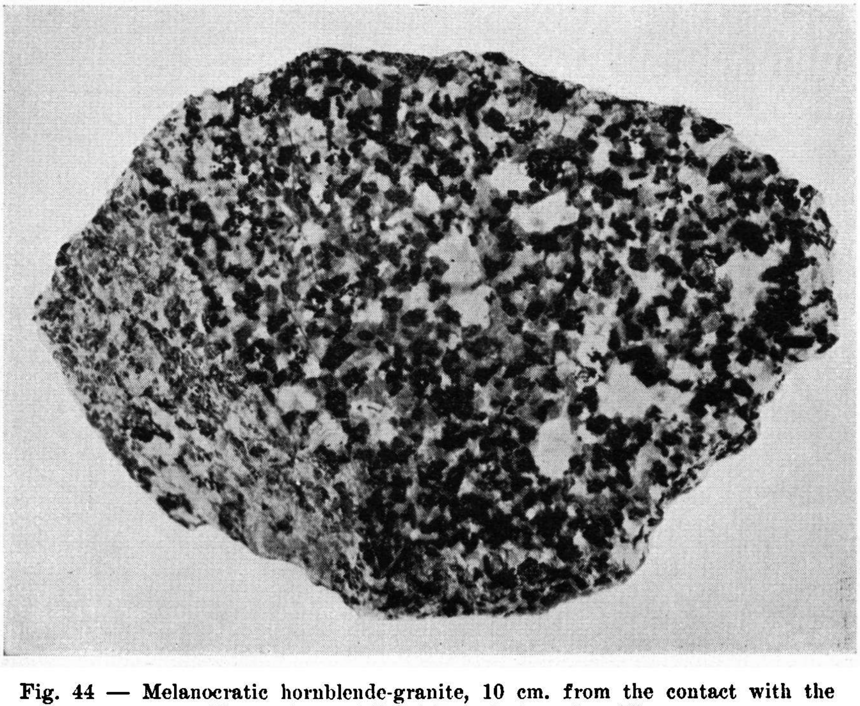

Fig. 44 — Melanocratic hornblende-granite, 10 cm. from the contact with the silicate skarn. NE of Escouloubre (loc. T).

Sample 187 Natural size

leucocratic parts may occur almost in juxtaposition (fig. 45). Pegmatitic pockets and irregular masses, containing graphically intergrown quartz and potash-rich felspar, together with a very soda-rich plagioclase, occur at several localities. The potash-rich felspar crystals may attain a size of as much as 4 cm., whilst the hornblende is generally a few cm. in length. In an exceptional case very large crystals (flat prisms) of an amphibole have been found that are even up to 10 cm. in length. The accessory constituents are present in comparatively large amounts, ore being among them. In the clinopyroxene-bearing granite, biotite and hornblende in varying amounts are also generally present, where they often occur as "cores" surrounded by a mantle of several individuals of clinopyroxene. In one case a hornblende crystal enclosing biotite, was seen to be surrounded in its turn by the clinopyroxene. Elsewhere, the three mafic constituents are intimately intergrown. In the hand-specimen the hornblende and the clinopyroxene can be fairly easily distinguished by the frequent alteration of the latter into hydrous iron-ore. Furthermore, the fresh clinopyroxene is dark green in colour, whereas the hornblende is black (fig. 44 and 46).

It may be emphasized that in this border zone of the granite, prehnite is a very common alteration product of plagioclase. Prehnite is also among the alteration products of biotite and it forms a common constituent in veinlets. Very close to the contact, especially in the pyroxene-bearing granite, orthite may achieve significant proportions. In several instances a single slide was seen to contain as many as five crystals of orthite. The mineral occurs in perfectly euhedral as well as in irregular form. Unlike in the dark inclusions, garnet and pumpellyite appear to be rare as alteration products of the biotite.

In cracks and little veinlets the most frequent constituents are adularia, clinozoisite, prehnite and calcite. Veinlets of adularia may occur in the original potash-rich felspar, the latter clearly showing higher refractive indices than the former.

A highly pneumatolyzed potash-rich granitic rock has been found at one locality, NE of Escouloubre (loc. T) where it forms a small mass (ca. 1 metre diam.) close to the contact (736, 737, 755, 756, 1228, 1229, 1232c, 1234 and 1487). In the hand-specimen, the rock is immediately seen to differ markedly from the ordinary granite, both in its irregularly distributed white and greyish green colours and its abundant content of a fine lamellar (0.5 mm. diam.) colourless mica. Nests of black tourmaline are irregularly distributed throughout the rock-mass.

Under the microscope the chief constituents are seen to be potash felspar, which is the dominant mineral, colourless mica, quartz, calcite and tourmaline. The accessory constituents include anatase, apatite, rutile and zircon, while there are also minor amounts of olive-green pennine. The potash felspar which is never perthitized, occurs as fairly large (up to 6 mm. across) anhedral individuals. The mineral is strongly altered into kaoline and is largely replaced by masses of an extremely fine-flaky clinochlore-like mineral. Quartz is present in rather small quantities and may be almost absent in some samples. It occurs as strongly corroded crystals, which occasionally show a slight tendency to idiomorphism. The colourless mica, having a comparatively small and variable optic axial angle, is abundant, mostly in fan-shaped groups but also scattered throughout the rock as separate flakes. The

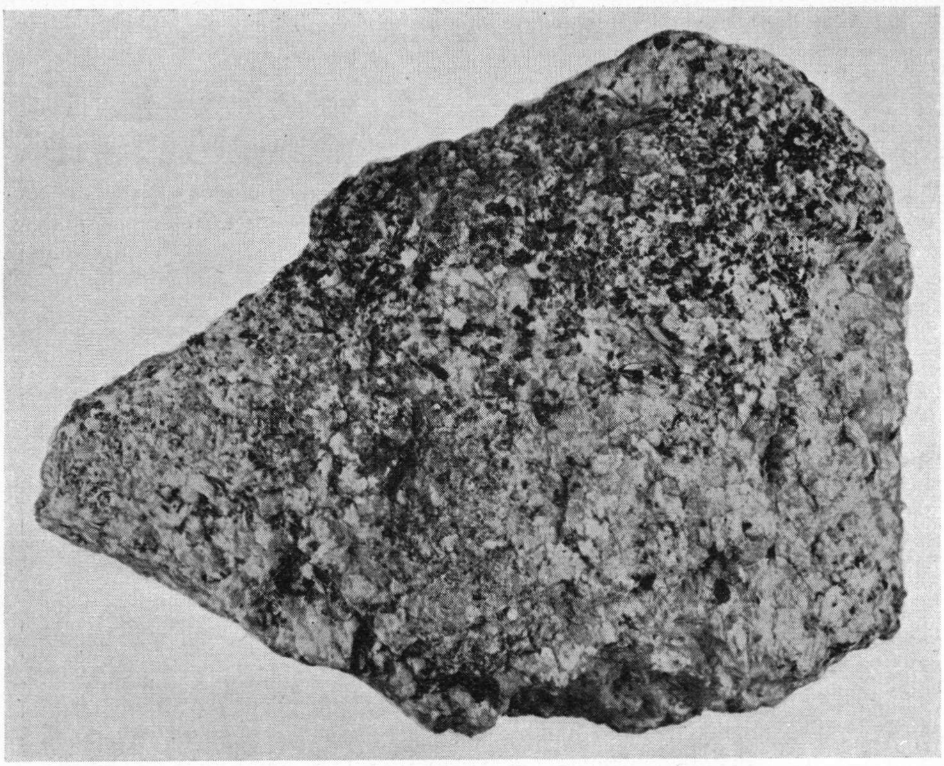

Fig. 45 — Heterogeneous granite, showing melanocratic and leucocratic parts in juxtaposition. Most of the quartz and the potash felspar are graphically intergrown. NE of Escouloubre (loc. V).

Sample 1453 × 4/5

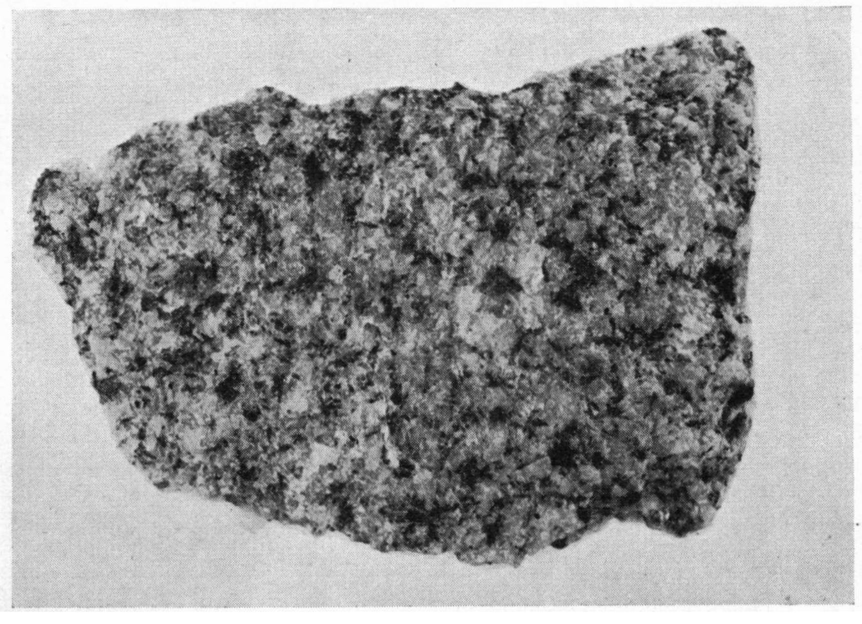

Fig. 46 — Clinopyroxene-rich granite, 20 cm. from the contact. NE of Escouloubre (loc. U).

Sample 1468g × 10/9

mineral is doubtless of later origin than the potash felspar and the quartz. The calcite which occurs in irregular masses as well in veinlets is considered to be of secondary origin. It partially replaces both the quartz and the felspar. As mentioned above, the tourmaline is irregularly scattered throughout the rock. The larger crystals may be arranged in parallelism, whilst the very small almost colourless prisms are invariably randomly oriented. Titanite which is a common accessory in nearly all the granite rocks, is completely absent. In these rocks the titanium content is represented by the following minerals, arranged in order of abundance: anatase, rutile and possibly brookite. The small crystals of anatase are generally grouped together into aggregates (fig. 8). The origin of the green pennine aggregates could not be established.

The dark inclusions of the granite

70575	Melanocratic porphyritic biotite (chlorite)-quartz-diorite	Escouloubre-les-Bains.
Melanocratic porphyritic hornblende-biotite-quartz-diorites:		
139		500 m. SE of Escouloubre.
70576		Escouloubre-les-Bains.
793 and 794		NE of Escouloubre (loc. T).
110		WNW of the Col de Moulis (loc. M).
107	Melanocratic porphyritic clinopyroxene-hornblende-biotite granodiorite	WNW of the Col de Moulis (loc. M).
Melanocratic porphyritic hornblende-biotite granodiorites:		
38, 417, 759, 70577 and 70580		NE of Escouloubre (loc. T).
109		WNW of the Col de Moulis (loc. M).
871		Le Bousquet.

Among the minerals, listed below, all of which have been found in these rocks, some of the alteration products are of special interest.

primary minerals	*secondary minerals*
apatite	actinolite-tremolite
biotite	albite
clinopyroxene	calcite
hornblende	clinozoisite-epidote
ore minerals	garnet
orthite	prehnite
plagioclase	pumpellyite
potash felspar	rutile
quartz	sericite
titanite	titanite
zircon	zoisite

These rocks comprise the dark blue-black inclusions in the granite, which are of most frequent occurrence in a zone, extending a distance of up to some hundreds of metres from the contact. The diameter of these bodies varies from a centimetre to a metre, averaging about 10 cm. across. The shape is almost invariably well rounded, often approaching that of a triaxial ellipsoid. Slightly angular outlines have occasionally been observed. The limits with the surrounding granite are invariably sharp. In some cases the granite adjacent to the inclusions was observed to be particularly rich in dark minerals up to a distance of a few cm. (794). The inclusions, varying in composition from granodiorite to quartz-diorite, are composed of exactly the same minerals as the granite. The dimensions and proportion of these, however, differ markedly. All the inclusions investigated appear to be porphyritic in structure, though this is usually only clearly discernible under the microscope. The sizes of the megacrysts of quartz, potash felspar and plagioclase are of the same range (3—4 mm.) as in the enclosing granite. The dimensions of the crystals comprising the groundmass, however, are much smaller (ca. 0.5 mm.), main constituents being plagioclase, biotite and hornblende. It is the abundance of the femic constituents in the groundmass which is responsible for the dark colour of the rock.

The quartz and potash felspar megacrysts occur generally as anhedral crystals, which are crowded irregularly with many minerals of the groundmass. If the proportion of the enclosed crystals is very large, the quartz and the potash felspar merely fill up the interspaces between the minerals of the groundmass. It can easily be understood why these crystals are not readily distinguished in the hand-specimen. Aggregates of cataclastic quartz without inclusions are comparatively rare. In some samples the potash felspar may be completely lacking, or occur as small anhedral masses and veins replacing plagioclase.

The plagioclase megacrysts, unlike those of the quartz and the potash felspar, tend to display an idiomorphic shape with only a few very small inclusions of biotite and hornblende. Generally the mineral shows oscillatory zoning with the core invariably richer in lime than the margin. Most crystals are twinned according to the albite and Karlsbad laws. Prehnite, and in rare cases also pumpellyite, have been observed among the alteration products. The plagioclase of the groundmass shows somewhat lath-like sections. Most of the crystals are almost completely converted into sericite and saussuritic material.

The biotite and the hornblende occur generally as separate crystals but may occasionally be clustered together in aggregates, having the appearance of dark megacrysts in the hand-specimen. The biotite has been rendered conspicuous by its many alteration products, which include optically positive and optically negative pennine, rutile, clinozoisite-epidote, titanite, garnet, prehnite and pumpellyite. Generally the calcium-bearing minerals show lenticular outlines. Green-brown hornblende, occasionally partially bleached, is present in all the rocks investigated except in one of the rare inclusions (70575) found in the porphyritic granite. In some cases an occasional rather large hornblende crystal (2 mm. in length) was seen in a slide (70577). Intergrowths of hornblende and biotite are common, the latter appearing to be an alteration of the former.

Clinopyroxene in appreciable quantity, has been found in only one, rather large (about 30 cm. across) inclusion (107). It forms intricate intergrowths with biotite, but not with hornblende. According to its optical properties this clinopyroxene is probably a common augite or a diopsidic augite. In some samples (70580) a small core of clinopyroxene may be observed within the hornblende.

Orthite, a common accessory in the granite, has also been found in several of the dark inclusions. In one case it could be clearly established that the mineral is of comparatively late crystallization, because a fairly large crystal of orthite partially enclosing biotite and laths of plagioclase was observed (70577). The other accessories, including apatite, titanite, zircon and ore minerals, occur in somewhat larger proportions than in the surrounding granite. Calcite, adularia and prehnite form the most common constituents in the narrow veinlets.

PART IV

PETROLOGY

Introduction

In this chapter the contact zone under discussion will be compared with similar contact zones in other areas, whilst an attempt will be made to explain its main features. Consecutively, the border zone of the granite, the zone of silicate skarns and that of the hornfelses and marbles will be discussed, special attention being paid to the contrasting genesis of the silicate skarns and the other metamorphosed country rocks.

THE BORDER ZONE OF THE GRANITE

The opinion of Raguin (1950), that the northern part of the granite massif of Quérigut can best be considered as an intrusive granite of diapiric character, is fully supported by the observations of the present author, the granite having produced a well-developed contact aureole of limited dimensions.

Within the region occupied by the granite, a wide innermost and a very narrow outermost border zone of the granite can be recognized. The former, except the local development of some hornblende crystals, does not differ much in mineralogical composition from the ordinary biotite-granite. This innermost zone, however, is characterized by a much increased proportion of dark inclusions and aplitic dikes, as well as by the occurrence of dikes of porphyrites of granodioritic to quartz-dioritic composition. Contrary to the innermost border zone the outer one is very limited in width, whilst it differs markedly from the ordinary biotite-granite in mineralogical composition as well as in texture.

The outermost border zone is characterized by a much larger content of hornblende, the development of clinopyroxene immediately adjacent to the contact, and a distinctly larger proportion of accessories. Other differences are the occurrence of pegmatitic masses and pockets, and the almost invariably heterogeneous distribution of the different minerals. Similar heterogeneous character of a narrow outermost border zone is shown by many other massifs of granite (e. g., Raguin 1957, p. 51, Hieke 1945, Bianchi and Dal Piaz 1952). The occurrence of hornblende in the border zone of a biotite-granite may either be due to the assimilation of calcareous sediments or to the development of a dark marginal facies, irrespective of the kind of wall-rock. If in such a border zone, adjoined by calcareous rocks, the proportion of hornblende is large and the amount of lime-bearing accessories much increased, however, many authors assume some assimilation of limestone or dolomite to have taken place. This is especially the case if the hornblende and biotite give place to a diopsidic clinopyroxene. A clinopyroxene-bearing border zone, generally very limited in width, has been described from many massifs of granite or granodiorite bordered by calcareous rocks and appears to be of quite common occurrence (see, e. g. Umpleby 1917, Eskola 1922, Agar 1923, Roggeveen 1929, Osborne 1932, 1949, Joplin 1935, Kimpe 1944, Hieke 1945 and several other investigators of the Adamello massif, Tilley 1949, 1951 and Knopf 1957). Broadly speaking there are two contrasting opinions concerning the genesis of this clinopyroxene. Some authors favour the direct crystallization of the pyroxene from a melt enriched in CaO and MgO, others consider this pyroxene to have been produced by metasomatic replacement of earlier biotite and hornblende after the consolidation of the border zone of the granite. According to the present author the absence of homoaxial intergrowths of hornblende and clinopyroxene in the area under discussion constitutes an important argument against a metasomatic origin of the latter. So the clinopyroxene which occurs in separate crystals as well as in small crystals surrounding earlier crystallized biotite and hornblende has apparently grown from a magmatic melt enriched in lime and magnesia.

An alkaline border facies of the granite characterized by the occurrence of soda-pyroxenes as described by Doelter (1903), Du Toit (1919), Watanabe (1943), Tilley (1949, 1951) and Nockolds (1950), has not been found.

The so-called transition zone which has been observed as a very narrow zone between the granite and the silicate skarns is represented by several different types, each with a characteristic mineral assemblage, viz. a prehnite-rich type, a clinozoisite- and zoisite-rich type and a grossular-bearing type. Characteristically a number of low grade metamorphic lime-bearing minerals such as zoisite, clinozoisite, prehnite and tremolite, accompanied by sericite-like products, invariably are notable constituents. The distribution of the different minerals seems to be rather irregular. Earlier minerals like quartz, albite and potash felspar are in several cases clearly replaced by prehnite, illustrating the original granitic character of the transition zone. Probably this zone owes its origin to the intense local action of lime-bearing solutions of a rather late origin. Equivalents of this transition zone in other areas have been described under the same name or under other names such as "highly contaminated zone", "hybrid zone", "reaction zone" (e. g. Joplin 1935) or by purely descriptive names. Though a real garnetized border zone of the granite as recorded by a. o. Bergeat (1910), Knopf (1942) and Barth (1951) appears to be absent in the Escouloubre area, grossular is among the main constituents in one of the types of our transition zone.

The dark rounded inclusions of mela-granodioritic to quartz-dioritic composition are probably similar to inclusions reported from many other granitic and granodioritic massifs. In general, the origin of dark inclusions may either be due to early segregation of mafic minerals or to incorporation of fragments of the country rock. In view of various properties of the inclusions of the Escouloubre area, listed below, an origin by segregation of early minerals seems to be the most acceptable theory. These properties are:

1. The invariably highly rounded outlines.
2. The absence of transitions between inclusions of igneous appearance and fragments of distinctly sedimentary origin.
3. The absence of minerals characteristic of metamorphosed limestones and dolomites; the inclusions are made up of the same minerals as the surrounding granite, which only differ in proportion and dimensions of their crystals. Clinopyroxene is nearly always absent.
4. The absence of zonal structure and the absence of relict bedding.

5. The type of zoning of the plagioclase megacrysts, pointing to an igneous origin.
6. The accessory constituents enclosed within the mafic and felsic minerals are similar in shape and character to those in the surrounding granite.
7. The inclusions are broadly of the same size and are rather regularly distributed.

Though not belonging to the border zone proper, an aplitic vein occurring in the low grade hornfelses NW of Usson may be mentioned in this paragraph because of its deviating characteristics. The clinopyroxene, prehnite and abundant titanite found in this vein suggest the incorporation of quite a large proportion of wall rock material. The rock is a "dissogénite" in the sense of A. Lacroix (1923, p. 374, see also Raguin 1946). Similar aplitic veins have been reported from the SW part of the massif of Quérigut by Lacroix (1898, 1900).

THE SILICATE SKARNS

At the scarce localities where comparatively fresh granite is adjacent to dolomitic country rock, a narrow zone of silicate skarn has been encountered between these two. Though calcite marbles are the most common country rocks, sharp contacts between the granite and the calcite marbles are apparently not exposed in the area under discussion. Silicate skarns between granite and calcite marble, however, have been very locally observed by the present author, E of the investigated area (near Buillac) as well as at the southern contact of the granite massif (a. o. near Puyvalador).

Before discussing the possible origin of the silicate skarns, the most conspicuous properties of the silicate skarns of the Escouloubre area will be listed:

1. The skarns are exclusively localized between the granite and the dolomitic marble.
2. The width of the narrow skarn zone, regardless of the very irregular shape of the contact, is characteristically nearly the same (4—7 cm.).
3. The limits with the adjacent transition zone and the adjacent dolomitic marble are nearly always very sharp.
4. The skarns show an invariably similar succession of different zones, that may be more or less distinctly developed:

	(granite)
	(transition zone)
zone I	green clinopyroxene zone
zone II	pale green clinopyroxene-zoisite-lilac mica zone
zone III	spinel-xanthophyllite zone
zone IV	colourless clinopyroxene zone
zone V	talc-serpentine-chlorite zone
zone VI	calcite zone
	(dolomitic marble)

It may be emphasized that zone III, the spinel-xanthophyllite zone, too, is rich in clinopyroxene, whilst the minerals of zone V and VI have grown at the expense of a clinopyroxene-rich assemblage. Clinopyroxene, therefore, was originally the main constituent of all the zones of the silicate skarns.

5. Broadly speaking, the skarns of different localities consist of the same minerals.

6. One of the zones (zone III), which is situated somewhat nearer to the dolomitic marble than to the so-called transition zone, is characterized by the occurrence of conspicuous aluminium- and magnesium-rich minerals, spinel and xanthophyllite.
7. No undersilicated minerals like forsterite or humite minerals have been found. Forsterite and members of the humite group are, however, common constituents is the dolomitic marbles.
8. Ore-minerals of later origin appear to be totally absent (small concentrations of ore have been found in some of the other metamorphic rocks).
9. There are various phases of metamorphism that caused the development of many different minerals.

Since the silicate skarns are mainly made up by diopsidic clinopyroxene or its alteration products, and the adjacent dolomitic marbles being generally almost pure, the formation of the skarns obviously implied a considerable amount of metasomatic exchange. If the silicate skarns would have been formed by the action of solutions percolating along fissures after the consolidation of the border zone of the granite, the distribution of the skarns would have been very irregular, i. e., as a border zone of strongly varying width along many pre-existing fissures, some of which would extend deeply into the dolomitic marbles. The silicate skarns, on the contrary, are exclusively localized along the contact of the granite and the dolomitic marbles. Furthermore, the zone of the silicate skarns is conspicuously constant in width, regardless the irregularities in the shape of the contact. It may therefore be concluded, that we are dealing here with a reaction zone between the dolomitic marbles and the granite, the latter being either in a liquid or in a solid state, and that the transport of the metasomatic agencies most probably took place by diffusion along crystal boundaries. The very limited width of the zone of the silicate skarns is in harmony with such an origin.

As to the question whether the immediately adjacent granite was in a liquid or in a solid state during the formation of this front of diffusion, it may first be stated that in the skarn zone silica obviously was the main substance added, the main reaction involved in the production of the skarns being the transformation of dolomite into diopsidic clinopyroxene. The width of the skarn zone varying between 4 and 7 cm., the quantity of silica added may be roughly estimated as being equal to that contained in a zone of granite of a thickness of about 10 cm. If this silica would have been derived, by diffusion, from solid granite bordering the present skarn zone, the border zone immediately adjacent to this skarn could be expected to be conspicuously poor in quartz or even devoid of this mineral. Since no such conspicuous irregularities in the distribution of the quartz in the border zone have been observed, the conclusion is drawn that during the formation of the silicate skarns the adjacent granite was still in a liquid state, i. e., that the zone of the silicate skarns represents a reaction zone between the granitic magma and the dolomitic marbles.

During its formation by diffusion of material derived from the adjacent granitic magma, the zone of the silicate skarns is supposed to have consisted essentially of clinopyroxene and spinel, all the other minerals being of younger age. Since it is not known whether the oldest among the younger minerals — such as xanthophyllite, zoisite, lilac mica and phlogopite — were formed when the adjacent granite was still liquid, our deductions concerning the elements diffused from the magma into the adjacent skarn zone will be mainly based upon the behaviour of the elements necessary for the formation of the clinopyroxene and the spinel. The former differs in colour in the different zones, the colour nearest to the granite being green of appreciable intensity, merging through pale green into almost colourless or perfectly colourless in zone IV. This difference in colour is apparently due to a larger content of iron in the green variety. The spinel according to its refractive index is almost pure $Mg_2Al_2O_4$. In the absence of any indications that the iron and aluminium contained in these minerals was derived from original impurities in the dolomite, it is concluded that besides a large amount of silica, some aluminium and iron was also added to the skarns, the former probably in excess of the latter. This conclusion is supported by the repartition of these elements in the different zones, iron obviously being essentially restricted to the zones I and II nearest to the granite, and the alumina-rich spinel being restricted to zone III. In view of the fact, however, that according to analyses given by TILLEY (1951, p. 663) similar green clinopyroxenes not only are richer in iron than the lighter coloured clinopyroxene of an adjacent zone, but also show a larger content of aluminium, the aluminium content of the clinopyroxenes probably decreases together with their iron content from zone I towards zone IV. Since the younger minerals are also mainly localized in special zones, the content of aluminium and iron contained in the zoisite and lilac mica of zone II, and the content of aluminium of the xanthophyllite of zone III may also largely represent material that was introduced during the original formation of the skarns. If the above conclusions are warranted, aluminium is mainly concentrated in the first three zones, i. e., in zone I in the green clinopyroxene, in zone II in the pale green clinopyroxene (less than in the pyroxene of zone I), and further in the zoisite and lilac mica, and in zone III in the spinel and the xanthophyllite. The aluminium content of zone III could not apparently be incorporated in the pyroxene. Whether some iron is needed for this incorporation, or whether it mainly depends on temperature, is not clear. Zone IV is obviously less rich in aluminium, though a very small proportion of this element may be present in its colourless pyroxene.

Iron being essentially restricted to zones I and II, and aluminium to zones I, II and III, the iron has apparently migrated over a smaller distance than the aluminium during the diffusion process that produced the original zonal structure of the skarn; aluminium, however, in its turn has migrated less far than silicon.

Hitherto the zones V and VI have been left out of consideration. The serpentine, chlorite and part of the calcite of these zones are considered as alteration products of material similar to that of zone IV, the colourless clinopyroxene zone. The lime liberated by the alteration of an original colourless clinopyroxene has here, apparently, been expelled from the original mixture, so that it now builds a separate zone, zone VI, zone V being exceedingly rich in magnesia. The talc may have been produced together with part of the calcite by the action of silica-bearing solutions on dolomite, since talc was also seen to have been produced in cracks in the dolomitic marble, up to 1 metre from the contact. It may be emphasized that this talc is not pseudomorphous after an olivine-like mineral. The virtual absence of clinopyroxene in zones V and VI and the corresponding strong alteration shown by these zones may be due to the circulation of younger solutions along the contact of the less permeable skarn and the dolomitic marble.

As to the age of the different minerals contained in the various zones of the silicate skarns, at least three assemblages of different age may be recognized:

I the oldest minerals: clinopyroxene and spinel.
II minerals corroding and surrounding the former, but not building distinct pseudomorphs: xanthophyllite, zoisite, lilac mica and phlogopite.
III younger pseudomorphous alteration products of the minerals of groups I and II: chlorites (including amesites), serpentine, fine flaked lilac mica, diaspore, prehnite, clinozoisite, calcite and magnetite.

Talc probably is contemporaneous with the third and youngest group of minerals.

THE MARBLES AND HORNFELSES

Since the calcite marbles and hornfelses differ in several important aspects from the dolomitic marbles, these groups will be separately dealt with.

The calcite marbles and hornfelses

In contrast with the silicate skarns described above, the calcite marbles and hornfelses are considered to have been almost exclusively generated from earlier compounds, i. e., with almost no addition of material from the granite. Impurities of siliceous and aluminous composition in the original material of the calcite marbles and hornfelses reacted with the surrounding rock and gave rise to the production of lime-silicates or magnesian-lime-silicates, the proportion of the residual calcite depending on the original proportion of impurities. The calcitic limestones and hornfelses do not show many features of special interest.

Broadly speaking, the calcite marbles and hornfelses may be divided into low and high grade types, though several transitional stages may be encountered. No sharply defined zones showing a different grade of metamorphism have been observed. The low grade rocks, however, have been found at relatively large distances from the contact. The low grade types carry newly formed contact minerals like clinozoisite-epidote, chlorite, actinolite and prehnite, whereas quartz and calcite are present in stable coexistence. Somewhat higher grade types in addition show development of fine granular masses of diopside and xenoblastic grossular. In the high grade types wollastonite was produced by the reaction of quartz and calcite, accompanying minerals being diopside, idocrase, potash felspar, and further some epidote minerals and prehnite that partly are distinctly of secondary origin.

The source rocks of the usually distinctly banded hornfelses are doubtless the pure and impure quartzitic layers and lenses that are intercalated between the limestone beyond the limits of the contact aureole. The pure quartzitic layers and lenses gave rise to the production of pure wollastonite rocks, lime migrating inwards along cracks and fissures.

The rocks dealt with in this paragraph are similar in mineralogical constitution and genesis to corresponding rocks in many other areas. Although the dolomitic marbles show the results of widespread pneumatolytic action, no fluorine, boron or chlorine-bearing minerals have been found in the calcite marbles and hornfelses. It may be emphasized that the metamorphosed limestones and dolomites are invariably seen to be in alternating position. It is clear, therefore, that the dolomites were more suitable to fix the pneumatolytic compounds than the limestones. It must be kept in mind, however, that fluorine might be found in a mineral in which its presence cannot be proved without a chemical analysis, e. g. in idocrase.

The dolomitic marbles

Dolomitic marbles with varying proportions of contact minerals have been encountered at many localities along the contact. In the Escouloubre area, regardless of the locality, there are only four common main constituents, viz. forsterite, phlogopite, clinohumite and spinel. Humite, chondrodite and fluoborite seem to be of very rare occurrence in the investigated contact zone. Apatite and ore (magnetite, pyrrhotite) are also of widespread occurrence but usually only in subordinate amounts. The most frequent alteration products are serpentine, chlorites and hydrotalcite. Forsterite-phlogopite marbles represent the most common type of rock, whilst spinel is often present as a minor constituent. Forsterite-phlogopite-clinohumite-spinel marbles also are not rare. Clinohumite-spinel marbles with subordinate amounts of forsterite and phlogopite, however, appear to be scarce, whilst clinohumite-spinel marbles devoid of forsterite and phlogopite have not been found at all.

Periclase or brucite marbles have not been encountered in the area under discussion. Apparently at the prevailing pressures the temperature was not high enough to cause dedolomitization of the pure dolomite rocks since these have recrystallized merely to medium-grained pure dolomite marbles. It is known, however, that at a given pressure the dolomite reacts at considerably lower temperatures in the presence of silica or alumina (TILLEY 1920, p. 457). TEALL's dedolomitization principle that impurities present in dolomitic rocks react with the magnesian in preference to the calcic carbonate is clearly demonstrated, dominant lime-bearing minerals being completely absent in the dolomitic marbles (TEALL 1903, TILLEY 1920, HARKER 1939). Broadly speaking, we may say that generally, and also in the Escouloubre area, impurities and dolomite have reacted, with the production of magnesium-rich minerals, calcite and carbon dioxide. In most cases the secondary calcite surrounds the newly formed contact minerals. Most probably forsterite, phlogopite and part of the spinel owe their origin to reactions of earlier impurities like alumina, silica and sericite with their dolomitic matrix, as described by TILLEY (1920). Clinohumite, however, has clearly been developed during a later stage of the metamorphism, at the expense of earlier contact minerals, viz. during the pneumatolytic stage, and with incorporation of fluorine and water. The intricate intergrowths of forsterite and clinohumite, the proportion of each being highly variable, clearly demonstrate the progressive replacement of the forsterite by the clinohumite. Similar genetic relationships between forsterite and humite minerals have been already reported by several authors (see p. 271). In not one case, however, does this replacement seem to have been completed, as in all samples a variable proportion of forsterite has still been left. Moreover, the pneumatolytic products appear to be very irregularly distributed, clinohumite-rich marbles being found in juxtaposition which marbles almost devoid of this mineral, but rich in forsterite. In some of the clinohumite-rich samples no separate crystals of forsterite are seen, this mineral only being represented by intimate intergrowths with the clinohumite. A noteworthy feature is that the clinohumite-rich marbles in all cases are much richer in spinel than the forsterite-phlogopite marbles, whereas phlogopite (or its alteration product chlorite) is present in small amounts only. The possibility must not be overlooked that part of the clinohumite and the spinel might have been originated at the expense of earlier phlogopite. The reaction might be similar to that of chondrodite and spinel simultaneously originating from phlogopite, as described by VON ECKERMANN (1922). Another matter of interest is that the clinohumite-rich marbles, unlike the forsterite-phlogopite marbles, often carry a pseudo-primary clinochlore with comparatively high birefringence (ca. 0.010) and absolutely colourless in the sample. In many cases not one trace of the original mineral, the phlogopite, is left. This even holds true for samples of very fresh marbles, the phlogopite being the only mineral which was transformed into secondary products. It is clear that such a chlorite can easily be mistaken for a primary mineral, or, at any rate for a mineral that does not owe its origin to alteration of an earlier mineral. The association clinohumite-clinochlore is conspicuous, however, and points to a simultaneous generation of these minerals during a later, pneumatolytic stage in the history of the rock, clinochlore therefore being a secondary mineral. Similar colourless chlorite, sometimes called leuchtenbergite, has often been reported to be associated with minerals of the humite group (e. g. TSCHERMAK 1879). Some authors consider such a chlorite to be a primary mineral, generated simultaneously with the earlier contact minerals. According to others the flakes have grown as independent crystals during the pneumatolytic stage, i. e. not as a pseudomorphous replacement product of phlogopite. In very fresh and unaltered marbles of the Escouloubre area, however, the clinochlore sometimes still contains relics of phlogopite, illustrating its secondary origin. It is clear, therefore, that in many, if not in all cases we have to deal with a clinochlore that owes its origin to alteration of an earlier phlogopite.

The formation of apatite in the dolomitic marbles may possibly indicate that there has been an introduction of phosphorus in some volatile form. Some authors, however, consider the presence of apatite in such rocks to be due to recrystallization of original phosphatic substance in the sediment, e. g., of detrital apatite (TILLEY 1920, p. 460; OSBORNE 1931, p. 309).

The presence of small scattered concentrations of pyrrhotite, chalcopyrite and magnetite — the latter often intimately intergrown with the carbonate matrix — suggests addition of iron in the form of iron sulphides and possibly also iron fluorides. The magnetite present in the forsterite-phlogopite marbles as well as in the calcite marbles may possibly be due to recrystallization of detrital material. During the formation of the clinohumite at the expense of forsterite, some iron must have been incorporated, since magnetite granules are invariably seen to have been liberated during later serpentinization and chloritization processes of the clinohumite, whereas the alteration of forsterite in the Escouloubre area never gives rise to the production of similar magnetite granules.

As has been mentioned above, humite and chondrodite appear to be of rare occurrence in the area under discussion. Probably they also owe their origin to the transformation of earlier forsterite by the action of fluorine- and water-bearing volatiles.

In the dolomitic marbles at least three stages of metamorphism may be recognized, viz.:

1. formation of forsterite, phlogopite and part of the spinel.
2. formation of the humite minerals, fluoborite, clinochlore, and ore minerals (pneumatolytic stage).
3. formation of the alteration products serpentine, chlorites, magnetite (as granules), hydrotalcite and goethite.

SUMMARY

The northern part of the contact aureole of the biotite-granite of Quérigut contains limestones and dolomites, which have been metamorphosed over a distance of about 100 to 150 metres. Further, a wide innermost border zone of the igneous body is characterized by the development of some hornblende and the occurrence of many dark inclusions, as well as aplitic and porphyritic dikes. A narrow outermost border zone of the granite is conspicuous by a much larger proportion of hornblende and accessories, the development of clinopyroxene in the immediate vicinity of the contact, and finally by a heterogeneous texture. Scarce localities where comparatively fresh granite is in direct contact with the dolomitic country rock, revealed the presence of a narrow zone of silicate skarn, developed exactly at the junction. Adjoining the skarn, the granite of the outermost border zone shows a very narrow and highly modified border facies over a distance of a few mm. to 5 cm., the so-called transition zone. Three types of this zone are distinguished: a prehnite-rich type, a clinozoisite- and zoisite-rich type and a grossular-bearing one.

Though the contact is very irregular, the zone of the silicate skarns follows all its curves and is remarkably constant in width (4—7 cm.). The adjoining country rock being almost pure dolomitic marble, the zone of the silicate skarns has apparently been formed by extensive metasomatism over a very limited distance. Within the skarn zone itself, a zonal structure is also apparent, with six different mineral assemblages, the spinel-xanthophyllite zone being the most conspicuous. Since the skarn consists mainly of a diopsidic clinopyroxene, it is broadly speaking a silicated dolomite. According to the mineralogical composition of the different zones, however, a certain amount of iron and aluminium has also been introduced by diffusion from the adjacent granitic magma, the proportion of both elements diminishing towards the marble. Among the various earlier and later minerals observed in the skarns, a thulite-like clinozoisite, amesite and diaspore may also be mentioned.

Alternating layers of pure and impure limestones and dolomites, making up the bulk of the country rock, have been subjected to thermal metamorphism and partly also to pneumatolytic action. The pure limestones and dolomites were recrystallized to pure marbles. Impure limestones were transformed into calcite marbles with varying proportion of contact minerals, such as clinozoisite-epidote, prehnite, diopside, grossular, idocrase and wollastonite. Pure and impure quartzitic layers and lenses intercalated between the earlier limestones are now calc-silicate hornfelses, composed mainly of the minerals just mentioned. The impure dolomites were converted into dolomitic marbles with magnesium-rich minerals such as forsterite, phlogopite and spinel, while pneumatolytic action superimposed on the thermal metamorphism partly transformed the forsterite into clinohumite. Besides these four widespread minerals, chondrodite, humite and fluoborite have been found locally. Some of the spinels display two differ-

ent colours within the same crystal. All steps in the progressive alteration of spinel into hydrotalcite are visible.

Of the more than sixty minerals encountered in the rocks of the contact aureole and the border zone of the granite (listed on p. 255), six are probably new for France, viz. amesite, fluoborite, hydrotalcite, manasseite, xanthophyllite and a thulite-like clinozoisite. The alteration phenomena of some of the earlier minerals are of special interest and we may mention here that of spinel into diaspore, hydrotalcite and two types of amesite; of xanthophyllite into a. o. amesite, prehnite and clinozoisite; and finally of biotite into a. o. pumpellyite and garnet. Comparative studies of rocks from several other areas revealed similar alteration phenomena. The secondary garnet of a peculiar, flat, lenticular shape is probably of hydrothermal origin and appears to be a quite common mineral which has apparently hitherto been confused with other minerals such as zoisite.

Finally, two new localities of clintonite have been found, one in Spain (Serranía de Ronda) and the other in the U.S.A. (Franklin).

RÉSUMÉ

Le granite de Quérigut est essentiellement un granite à biotite. Dans la partie septentrionale de l'auréole de contact des calcaires et des dolomies ont été métamorphisés sur une épaisseur de 100 à 150 m. Une large zone de bordure du massif granitique est caractérisée par la présence de hornblende et de nombreuses enclaves de couleur foncée, de même que de filons d'aplite et de porphyre. Une zone beaucoup plus étroite, nettement marginale, se distingue par une plus grande teneur en hornblende et minéraux accessoires, tandis que la structure devient plus hétérogène; enfin on trouve du clinopyroxène au voisinage immédiat du contact. Ce n'est que rarement que le granite non altéré se trouve en contact direct avec les sédiments dolomitiques; dans ce cas-ci, une mince bande de „skarn" est intercalée entre ces deux roches. Immédiatement à côté de cette bande le granite montre une zone fortement modifiée (dénommée „zone de transition") épaisse de quelques mm à 5 cm. On y distingue trois types différents, dont le premier est riche en prehnite et le deuxième riche en clinozoïsite et zoïsite, tandis que le troisième est caractérisé par la présence de grossulaire.

La zone de skarn silicaté, dont l'épaisseur constante (4—7 cm) est remarquable, suit nettement toutes les courbes irrégulières du contact. Les sédiments originels étant des dolomies presque pures, le skarn a dû être formé par une métasomatose intense sur une distance limitée. Au sein même du skarn on peut distinguer six zonules de paragénèse différente, dont la plus remarquable est celle à spinelle et xanthophyllite. Le skarn étant essentiellement constitué par un clinopyroxène-diopside, on peut dire qu'il s'agit d'une dolomie silicatée. En considérant la composition minéralogique des différentes zones, on peut constater qu'une certaine quantité de fer et d'aluminium, provenant du granite, y a aussi été introduite par diffusion. La quantité de ces deux éléments diminue quand on s'approche du marbre. Parmi les minéraux observés dans les skarns on peut mentionner la clinozoïsite ressemblant à de la thulite, de même que l'amèsite et le diaspore.

Les couches alternantes de calcaires et de dolomies plus ou moins purs, formant la majorité des roches encaissantes, ont été affectées par le métamorphisme thermal et localement aussi par une pneumatolyse. Les calcaires et les dolomies purs ont été récristallisés en marbres purs. Les calcaires impurs ont été transformés en marbres contenant des proportions variables de minéraux de contact tels que la clinozoïsite-épidote, la prehnite, le diopside, le grossulaire, l'idocrase et la wollastonite. Les bancs et les lentilles quartzitiques intercalés au milieu des calcaires originels sont devenus des cornéennes principalement formées des minéraux mentionnés ci-dessus. Les dolomies impures ont été changées en marbres dolomitiques à minéraux riches en magnesium comme la forstérite, le phlogopite et le spinelle, tandis que la pneumatolyse a partiellement transformé la forstérite en clinohumite. Des roches à humite et des roches à chondrodite et fluoborite ont été observées rarement. Parfois le spinelle montre deux couleurs différentes dans le même cristal. On peut observer également tous les stades d'altération du spinelle en hydrotalcite.

Parmi les plus de soixante minéraux décrits de l'auréole de contact et de la zone de bordure du massif granitique (voir la liste de p. 255) on peut signaler probablement six premières descriptions pour la France, à savoir d'amésite, de fluoborite, de hydrotalcite, de manasseïte, de xanthophyllite et de clinozoïsite ressemblant à de la thulite. Les phénomènes d'altération de quelques minéraux sont très intéressants. Nous signalons particulièrement l'altération du spinelle en diaspore, hydrotalcite et deux types d'amésite, du xanthophyllite en amésite, prehnite et clinozoïsite, et finalement celle de la biotite en pumpellyite et grenat. L'étude de roches comparables d'autres régions a révélé des phénomènes d'altération identiques. Surtout le grenat secondaire mentionné ci-dessus, d'aspect lenticulaire et probablement d'origine hydrothermale, paraît être largement répandu; il a dû être confondu avec d'autres minéraux comme par exemple la zoïsite.

Pour terminer, on notera que deux nouveaux gîtes de clintonite ont été découverts, l'un en Espagne (Serranía de Ronda), l'autre aux États-Unis (Franklin).

SAMENVATTING

De kalkstenen en dolomieten der noordelijke contacthof van het hoofdzakelijk uit biotietgraniet bestaande massief van Quérigut werden tot op een afstand van ongeveer 100 tot 150 m van het contact door de metamorfose beïnvloed. Verder is een brede binnenste randzone van dit massief gekenmerkt door het optreden van geringe hoeveelheden hoornblende, van vele donkere insluitsels en van aplitische en porphyritische gangen. Een smalle buitenste randzone vertoont duidelijker opvallende kenmerken, nl. een veel groter gehalte aan hoornblende en accessoria, de ontwikkeling van clinopyroxeen in de naaste omgeving van het contact, en een heterogene structuur. Op de weinige plaatsen waar onverweerde graniet in contact met het dolomitische nevengesteente werd aangetroffen, is een smalle zone van silicaatskarn ontwikkeld, die het contact nauwkeurig volgt. De aangrenzende graniet vertoont in een zone met een breedte van enkele mm tot 5 cm zeer sterke vervangingsverschijnselen. Deze zone, welke als „overgangszone" wordt aangeduid, heeft drie verschillende verschijningsvormen, hetgeen leidde tot het onderscheiden van een prehniet-rijk type, een clinozoisiet- en zoisiet-rijk type en een type gekenmerkt door het optreden van grossulaar.

Hoewel het contact zeer onregelmatig verloopt, volgt de skarnzone alle bochten hiervan, terwijl de dikte dezer zone bovendien opvallend constant blijft (4—7 cm). Daar het nevengesteente uit vrijwel zuivere dolomiet bestaat, is de vorming der skarnzone blijkbaar te wijten aan intensieve metasomatose over een korte afstand. De zone der silicaatskarns vertoont zelf weer een opbouw uit zes zones met verschillende mineraalgezelschappen; de spinel-xanthophylliet-zone kan hier wegens zijn opvallende uiterlijk speciaal worden vermeld. Daar de zone der silicaatskarns in hoofdzaak uit diopsidische clinopyroxeen bestaat, is deze ruwweg als een gesilicateerde dolomiet te beschouwen. De mineralogische samenstelling der verschillende zones duidt echter aan, dat ook een zekere hoeveelheid ijzer en aluminium door diffusie aan het naburige granitische magma werd ontleend, doch dat het gehalte aan deze elementen in de richting der dolomietmarmers vermindert. Van de diverse generaties van mineralen, die in de skarns werden waargenomen, dienen amesiet, diaspoor en een thulietachtige clinozoisiet speciaal te worden vermeld.

Het nevengesteente bestaat in hoofdzaak uit met elkander afwisselende lagen van zuivere zowel als onzuivere kalksteen en dolomiet, die thermisch werden gemetamorfoseerd en ten dele ook pneumatolytisch werden beïnvloed. De zuivere kalkstenen en dolomieten rekristalliseerden tot zuivere marmers. De onzuivere kalkstenen werden gemetamorfoseerd tot calcietmarmers met een wisselend gehalte aan contactmineralen als clinozoisiet-epidoot, prehniet, diopsied, grossulaar, vesuviaan en wollastoniet. Zuivere zowel als onzuivere kwartsitische lagen en lenzen, die inschakelingen tussen de oorspronkelijke kalkstenen vormden, worden nu vertegenwoordigd door kalksilicaathoornrotsen, die in hoofdzaak uit de hierboven genoemde mineralen bestaan. De onzuivere dolomieten werden door de thermische metamorfose getransformeerd in dolomitische marmers met magnesiumrijke mineralen als forsteriet, phlogopiet en spinel, terwijl een latere pneumatolytische beïnvloeding de gedeeltelijke omzetting van forsteriet in clinohumiet ten gevolge had. Behalve het voorkomen van deze vier zeer verbreide mineralen valt nog het plaatselijke optreden van chondrodiet, humiet en fluoboriet in deze samenvatting te vermelden. Sommige spinellen vertonen twee verschillende kleuren binnen éénzelfde kristal. De omzetting van spinel in hydrotalciet is in al zijn verschillende stadia waar te nemen.

Van de meer dan zestig mineraalsoorten, die in de gesteenten der contacthof en der granitische randzone werden waargenomen (zie lijst op pag. 255), werden er zes waarschijnlijk nog niet eerder in Frankrijk aangetroffen, nl. amesiet, fluoboriet, hydrotalciet, manasseïet, xanthophylliet en een thulietachtige clinozoisiet. De wijze van omzetting van verscheidene mineralen verdient verder speciale vermelding, en wel de omzetting van spinel in diaspoor, hydrotalciet en twee soorten amesiet, die van xanthophylliet in o. a. amesiet, prehniet en clinozoisiet, en die van biotiet in pumpellyiet en granaat. Soortgelijke omzettingsverschijnselen werden ook in gesteenten van andere gebieden waargenomen. De secundaire granaat vertoont een merkwaardige platte lensvorm en is waarschijnlijk van hydrothermale oorsprong. Dit type van granaat blijkt vrij algemeen voor te komen en is vermoedelijk steeds voor een ander mineraal aangezien.

Tenslotte kan hier nog het vinden van twee nieuwe clintonietvindplaatsen worden vermeld; één hiervan is in Spanje gelegen (Serranía de Ronda), de andere in de U. S. A. (Franklin).

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Received during the printing:

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