Petrology. — *On glaucophane-bearing rocks from Corsica.* By C. G. EGELER. (Communicated by Prof. H. A. BROUWER.)

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During a sojourn on Corsica in the summer of 1947, some geological investigations were carried out by Prof. H. A. BROUWER and the writer in the eastern part of the island, with the main object of studying the relationship between the granitic rocks occurring there and the metamorphic series of the schistes lustrés nappe [1]). In many places the granitic rocks were found in contact with glaucophane-bearing schists of varying composition and at the contacts phenomena of injection and imbibition were found to be of widespread occurrence (see also PILGER, Lit. 8). Examples of these composite glaucophane-bearing rocks as well as a considerable number of more normal glaucophane-schists — partly from localities more remote from the intrusions — were collected at various points along the road from Bastia to the Col de Teghime, at Cardo and near Punta del Cepo, W of the Bay of St. Florent [2]). Though the writer is well aware that this collection is in no way representative of all the various types of glaucophane-bearing rocks occurring in the eastern part of the island, several interesting features of some of the types investigated and specially of the composite varieties, seem to justify a short description.

Several groups and subgroups were distinguished.

I. Lawsonite-bearing glaucophane-schists.

This group, which is only scantily represented in the collection investigated, comprises all varieties containing lawsonite as an important lime-rich silicate. Subdivision may be made into the garnet-free and the garnet-bearing types.

a. *Lawsonite-glaucophane-schists* — Only two non-garnetiferous varieties were examined, both collected along the road at Cardo. Megascopically they are markedly schistose rocks of a bluish to greyish-blue colour. Under the microscope they show a considerable variation with respect to the relative amount and kind of minerals present besides the mutual constituents glaucophane and lawsonite, the one rock being mainly characterized by a high content of muscovite [3]) and the other by the presence of biotite.

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1) For the main results of these investigations refer to Lit. 1.

2) For the location of the contact zones refer to PILGER (Lit. 8, Table II).

3) The mica in the various glaucophane-bearing rocks investigated varies from entirely colourless to very pale greenish. No distinction is made and the mineral is always designated as "muscovite".

In the muscovite-lawsonite-glaucophane-schist the abundance of colourless mica has given rise to a tabular schistosity. The muscovite appears to be associated with a considerable amount of green chlorite. Glaucophane is developed in elongated prisms of a slender habit, showing the normal pleochroism from blue (n_γ) to violet (n_β) and almost colourless (n_α); the optic axial plane lies according to (010). Especially the larger crystals occasionally show a zonary structure; in one or two cases the glaucophane crystals in their cores are found to pass more or less gradually into crossite. The latter mineral is mainly characterized by the transverse position of the optic axial plane; the colour is almost the same as that of the glaucophane, though somewhat deeper. Lawsonite is fairly abundant locally, developed in more of less idioblastic crystals which are tabular according to the base. Besides lawsonite the rock also contains a considerablee amount of epidote and evidently grades into the muscovite-rich epidote-glaucophane-schists described below. Some calcite occurs, especially concentrated in particular chlorite-rich bands. Albite is a subordinate constituent. Titanite is the principal accessory mineral, abundantly scattered throughout the rock; apatite is present in fairly large crystals.

In the other variety, a biotite-rich albite-lawsonite-glaucophane-schist, both muscovite and epidote are absent; their place is taken by a yellowish brown biotite. Further albite occurs as an important rock-forming constituent, developed in untwinned, poiciloblastic crystals. Glaucophane is again developed in slender needles, which here show a strictly parallel orientation, giving rise to a linear schistosity. Lawsonite is much more abundant than in the muscovite-rich variety. The mineral occurs in fairly large (several tenths of a millimeter), more or less idioblastic crystals, tabular according to the base and generally orientated parallel to the general direction of schistosity; an intensive polysynthetic twinning on (110) is observed. Epidote appears to be less abundant than in the variety described above and is distinctly subordinate to lawsonite. Some titanite is found and further a small amount of iron ore, considered as magnetite.

b. *Garnet-bearing lawsonite-glaucophane-schists* — This group is represented by a single specimen collected along the road from Bastia to the Col de Teghime, NE of the Serra di Pigno. Glaucophane is again the principal constituent, developed in parallel-ranged, pale blue, fibrous crystals, showing the normal characteristics. Often the amphibole is associated with green chlorite; together these minerals form a felty aggregate. Lawsonite is abundantly developed in more or less idioblastic tabular individuals, which may attain sizes up to 0,5 mm. Besides glaucophane and lawsonite, garnet is the most conspicuous constituent. The mineral occurs in pale reddish crystals of a small size (up to 0.4 mm) showing a tendency towards an idioblastic development; minute grains of titanite are often enclosed, sometimes together with some ore. In particular bands, which may contain a considerable amount of colourless mica, untwinned albite is

abundant. Some granular epidote occurs locally, sometimes in close association with the lawsonite. Titanite is arbitrarily scattered through the rock in small, often spindle-shaped grains. Further apatite is found and also a minor amount of finely granular iron ore. The rock is intersected by veinlets of albite.

II. Epidote-bearing glaucophane-schists.

Non-injected types.

Under this head all the glaucophane-schists are described which contain epidote minerals as principal lime-rich silicates and which show no signs of injection or imbibition either in the hand-specimen or in the thin section. The group is well-represented in the collection investigated. Subdivision may be made into types especially rich in chlorite, types especially rich in muscovite and types mainly consisting of glaucophane together with epidote and with only minor amounts of the other minerals.

a. *Chlorite-rich epidote-glaucophane-schists* — Examples of the chlorite-rich type were collected at Cardo and along the road from Bastia to the Col de Teghime. They are markedly schistose rocks of a bluish green colour, which, on account of the high content of sodic felspar, may be termed chlorite-albite-epidote-glaucophane-schists. Besides the chlorite, they may contain a considerable amount of colourless mica. The alkali-amphibole is developed in slender, parallel-ranged prisms, of varying length though generally smaller than a millimeter. Epidote occurs in greenish yellow crystals of a strongly varying size; swarms of fine glaucophane needles are observed to pass undisturbedly through porphyroblastic epidote individuals. Chlorite is mainly represented by a green, intensely pleochroic variety, showing anomalous brown interference colours and a negative elongation. Some calcite may occur, sometimes concentrated in particular bands. The main accessory constituent is always titanite or leucoxene, while further apatite is found. Ore is represented by magnetite, sometimes together with some pyrite and limonite.

b. *Muscovite-rich epidote-glaucophane-schists* — This group may be subdivided into a type rich in albite and a type in which albite is very scarce or absent.

The felspar-rich type is represented by a muscovite-albite-epidote-glaucophane-schist, collected along the road from Bastia to the Col de Teghime. It is a highly schistose, fairly coarse-grained rock of a dark greenish blue colour. The crystals of glaucophane are sometimes larger than 1 millimeter whereas the mica is developed in individuals of several millimeters, giving rise to a well-marked tabular schistosity. The poicilo-blastic development of the large mica flakes is very striking. The mineral shows a faint greenish tinge. Besides the main constituents glaucophane, muscovite, albite and epidote, a considerable amount of chlorite occurs; evidently this rock is closely related to the chlorite-rich type described

above. Titanite is again the main accessory mineral. Further it should be mentioned that some parts of the rock are very rich in tourmaline, developed in idioblastic crystals evidently of pneumatolitic origin. The mineral is of a deep blue colour, sometimes with greyish or brownish rims. According to HARKER (Lit. 3, p. 117) this blue colour may indicate a noteworthy content of soda.

Examples of the albite-poor variety of muscovite-epidote-glaucophane-schists were collected along the same road as the felspar-rich type described above, though somewhat nearer to the Col. As mentioned already, these rocks may be entirely devoid of felspar. The pale blue glaucophane is generally developed in more of less thick-set crystals, in several cases with relict cores of a brownish green amphibole. The larger individuals often contain abundant minute inclusions of titanite. The epidote-group is sometimes represented by low-birefringent members, in finely granular aggregates or swarms of small prisms. Larger crystals may show orthitic cores.

c. *Epidote-glaucophane-schists* — Representatives of the group of epidote-glaucophane-schists containing neither chlorite nor muscovite as important rockforming constituents, were collected both at Cardo and along the road from Bastia to the Col de Teghime. A considerable amount of albite may be present and in one case some biotite is found. The alkali-amphibole is again developed in rather thick-set crystals and on the whole these rocks seem closely related to the albite-poor muscovite-epidote-glaucophane-schists described above. Most representatives of these two last types appear to be of a rather massive habit, notwithstanding the fact that the schistosity may still be clearly distinguishable in the hand-specimen. This massive habit is mainly due to the shape and more or less arbitrary orientation of the amphibole crystals.

Types changed by injection or imbibition.

This group comprises all glaucophane-bearing varieties in which phenomena of injection or imbibition were observed. The various samples were collected at several points along the road from Bastia to the Col de Teghime and at the contact at Cardo.

Generally speaking they form an interesting type of composite rocks of varying colour and of a more or less gneissic habit. The variation in colour arises from the fact that in some cases the greyish green or bluish green schist element predominates and in others the leucocratic igneous element. Sometimes a well-developed "eyed" structure is found, when quartz and albite occur in more or less rounded or lenticular concentrations. More often the quartzose and felspathic concentrations are flattened out to parallel discontinuous bands, giving the rocks a peculiar "streaked" appearance. The latter structure shows transitions to the normal banded structure, caused by lit-par-lit injection. Sketches illustrating the "eyed" and the "streaked" structure were published in Lit. 1, p. 303, fig. 1 and 2 respectively.

Under the microscope especially the igneous part of these rocks shows features of interest. Broader veins appear to consist mainly of a finely granular aggregate of quartz and albite. Sometimes the latter mineral is also developed in porphyritic crystals, containing abundant inclusions of epidote. Varying amounts of colourless mica and occasionally some biotite occur and on the whole the composition of these larger injective veins corresponds more or less to that of the intrusive rocks with which they are genetically connected. Smaller bands and lenticular concentrations may consist almost entirely of a finely granular aggregate of albite, while lenticles wholly consisting of quartz are abundant. Bands consisting of both quartz and felspar are sometimes observed to become more and more siliciferous, ending in bands of more or less pure quartz (see also Lit. 1, p. 304). A considerable part of the quartz present was apparently still mobile after crystallization of the sodic component of the invading material; when strained of, under the influence of continuing orogenic stress, this highly siliciferous solution gave rise to the formation of the characteristically elongated quartz concentrations, which may consist almost entirely of a single, flattened crystal, showing an intensely undulose extinction.

The origionally invaded rocks are always epidote-bearing glaucophane--schists, mostly of the micaceous type. As these have been extensively dealt with above, no separate descriptions need be given. It is sufficient to mention that there may be a considerable variation with respect to the relative proportions of the various minerals present and that glaucophane is sometimes only a subordinate constituent.

Though the injection of these rocks has in many cases been very intensive, causing a close alternation of the schist and the igneous layers, in general no closer intermixture of these two elements has taken place. In fact, even when the glaucophane-schist bands are narrow, they have often remained completely intact, showing no difference whatever to the non-injected varieties occurring nearby. In other cases, however, and especially in the varieties showing eyed structures, the impregnation appears to have been of a more intimate kind. Here imbibition of the soda--rich solutions has given rise to concentration of albite and quartz also within the glaucophane-schist element.

Bands rich in epidote minerals, frequently occurring in the igneous parts, are considered as schist intercalations which have been almost absorbed; some recrystallization appears to have taken place. At the junction of the invaded rock and the invading element chlorite may be concentrated in a considerable quantity.

III. Glaucophane-bearing mica-schists and quartzite-schists.

Examples of this group are scarce in the collection investigated. Two much divergent types may be distinguished, viz. the glaucophane-bearing mica-schists and the glaucophane-bearing calc-muscovite-quartzite-schists.

a. *Glaucophane-bearing mica-schists* — A rock of this type was collected directly West of Punta del Cepo, to the West of the Bay of St. Florent. Is is a considerably schistose greyish green variety, which on microscopical examination appears to consist mainly of fine-scaled muscovite, together with some chloritic material showing transitions to a deep green mica. Finely granular quartzitic lenses occur and it is especially in these that the alkali-amphibole is found. The latter mineral is developed in elongated prisms, generally of some tenths of a millimeter, which may show a distinct zonarity, especially in the larger individuals. It appears that in general the rims consist of glaucophane while the cores may be formed by crossite. It should be noted, however, that the zonarity may be irregular and that patches of crossite may also occur more or less arbitrarily in the glaucophane crystals. The glaucophane shows the usual characteristics with a pleochroism from blue (n_γ), to violet (n_β) and yellowish (n_α), while the colour of the crossite is somewhat more intense with a pleochroism from violet (n_γ) to deep blue (n_β) and yellowish (n_α). The crossite is mainly characterized by the position of the optic axial plane transverse to the longitudinal direction. A small amount of albitic felspar occurs, while titanite, leucoxene, apatite, zircon and limonitic iron ore are the accessory constituents.

b. *Glaucophane-bearing calc-muscovite-quartzite-schists* — This type is represented by a single specimen collected along the road SE of Cardo. Calcite, colourless mica and quartz are the main constituents; glaucophane, in pale blue prisms of a slender habit, is found in a subordinate amount in some parts of the rock.

Considerations on the metamorphism

With the treatment of the main petrographical features of the various glaucophane-bearing rocks occurring in the collection investigated, the subject of their origin and grade of metamorphism remains for discussion.

The fact that basic rocks not specially rich in soda may give rise to glaucophane-bearing rocks of much the same type as those originating out of alkaline varieties (see e.g. Harker, Lit. 3, and Joplin, Lit. 4) is again demonstrated in eastern Corsica, where diabasic and gabbroid rocks are abundantly represented among the ophiolites of the schistes lustrés nappe. Pilger (Lit. 8), in a short review of the basic eruptive rocks and their metamorphism, mentions diabase-porphyrites, mostly coarsely granular diabases showing all transitions to gabbros, tuffaceous rocks, peridotites and serpentines. He states that an increase in the degree of alteration of the diabasic and gabbroid varieties may be observed, when passing towards the base of the nappe; normal augite-diabases were changed to glaucophane-diabases and these to true glaucophane-schists in which all traces of the diabasic origin have disappeared; gabbros were changed to schists rich in chlorite, actinolite, albite and epidote.

Among the rocks dealt with in the present paper the lower grade types mentioned by PILGER do not occur. Almost all the varieties investigated appear to be entirely recrystallized. Structural relics, indicating an igneous origin, may, however, still be preserved. This is specially the case in the more massive types, which apparently have originated out of diabasic or gabbroid rocks. In other cases the alteration is so advanced that considerations on the origin become more speculative, especially as chemical analyses are wanting. The mineral assemblage of most of these higher grade types seems to indicate, however, that they too are the metamorphic representatives of basic igneous rocks, though the possibility should be taken into consideration of some varieties, relatively poor in lime-minerals, being formed out of alkaline rocks [4]).

The glaucophane-bearing mica-schists and quartzite-schists are widely divergent types of sedimentary origin. It is difficult to account for the presence of alkali-amphiboles in the quartz-rich schists otherwise than through metasomatic enrichment in soda (HARKER, Lit. 3, p. 132).

With regard to the grade of the metamorphism the following may be said. It has often been observed that in lawsonite-rich glaucophanitic rocks epidote minerals are scarce or absent, whereas an abundance of epidote generally seems to exclude the occurrence of lawsonite. HARKER (Lit. 3, p. 294) suggested that the development of lawsonite might mean a first step to the formation of the epidote minerals, the presence of epidote thus implying a somewhat higher grade of metamorphism [5]). ESKOLA (Lit. 2) distinguished a glaucophane-schist facies and pointed out the possible existence of several subfacies. DE ROEVER (Lit. 10, p. 161) found reasons to distinguish a lawsonite-glaucophanite subfacies, characterized by the stability of lawsonite and the instability of epidote and garnet, from at least one subfacies in which lawsonite is not stable.

The occurrence of lawsonite as an important constituent of some of the glaucophane-bearing rocks from Corsica is well known (see e.g. LACROIX, Lit. 5, NENTIEN, Lit. 7 and PILGER, Lit. 8). According to PILGER lawsonite is especially abundant in those varieties which show an advanced degree of alteration and are often considerably schistose, whereas epidote appears to be restricted mainly to the lower grade types, which are often characterized by the occurrence of relict minerals and in which relict diabasic structures still predominate. This is evidently not in concord with the theory that epidote represents a higher grade of metamorphism than lawsonite. Moreover, it is not confirmed by the results of our investigations. Most of the glaucophane-bearing schists of our collection contain epidote as an apparently stable constituent, notwithstanding the fact that they are

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[4]) More or less unchanged spilitic rocks are also represented in eastern Corsica.

[5]) See also QUITZOW (Lit. 9), JOPLIN (Lit. 4), LACROIX (Lit. 6) and DE ROEVER (Lit. 10).

generally entirely recrystallized and often highly schistose [6]). The mineral assemblage found in these rocks seems to indicate that they were metamorphosed in a subfacies of the glaucophane-schists facies, having alkali-amphibole-epidote as a critical association and i.a. albite, muscovite and chlorite as type-minerals, while lawsonite is unstable [7]).

In the few cases that lawsonite is present in the glaucophane-bearing rocks of our collection the mineral is always associated with epidote. One of the lawsonite-rich schists also contains a considerable amount of garnet. JOPLIN (Lit. 4, p. 536), referring to the association of lawsonite and garnet in a rock from California, suggests an unstable equilibrium; it seems likely that the same holds good in the present instance.

The abundant occurrence of lawsonite in glaucophane-bearing rocks from eastern Corsica, as described by other investigators, may point to the fact that here the glaucophane-schist facies is represented by more than one subfacies [8]).

When considering the problem of the glaucophanitic metamorphism, as developed in the investigated part of eastern Corsica, the question arises how far the formation of the alkali-amphiboles should be attributed to the contact action of the alpine granites. The occurrence of glaucophane and occasionally also of crossite in quartz-rich sedimentary schists which have been intruded by albite-granites, seems indeed to point to a certain amount of metasomatic exchange, resulting in an enrichment in soda [9]). The distribution of the glaucophane-bearing rocks, with regard to that of the granites [10]), shows, on the other hand, that alkali-amphiboles are also abundantly formed in rocks showing no apparent association with the granitic intrusions, so that no metasomatic processes due to contact action seem possible. The occurrence, in the contact zones, of rocks relatively poor in soda but rich in lime-minerals such as lawsonite or pumpellyite (see Lit. 1, p. 303), seems to indicate that metasomatic addition of soda has been only a local phenomenon.

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[6]) There is a strong resemblance, for instance, to varieties from the Val de Bagnes in Wallis, which also contain epidote minerals as characteristic lime-rich silicates, while lawsonite is absent (Lit. 11 and 12).

[7]) The glaucophanite subfacies with lawsonite unstable, distinguished by DE ROEVER (Lit. 10, p. 161), has the critical associations alkaliamphibole-epidote and alkaliamphibole-garnet and i.a. the typical minerals quartz, muscovite and chlorite. Though garnet was not found in the epidote-rich glaucophane-schists of our collection, it seems likely that the same subfacies is dealt with here.

[8]) Lawsonite was also found in considerable quantities in non-glaucophane-bearing rocks collected at the contact E of Barbaggio (Lit. 1, p. 303).

[9]) PILGER (Lit. 8, p. 6) mentions the occurrence of subordinate amounts of glaucophane in phyllitic rocks and calc-schists, especially in the neighbourhood of glaucophane-diabases, where a certain amount of exchange of material may have taken place during the metamorphism. The examples of glaucophane-bearing sedimentary schists occurring in our collection, however, show no association with glaucophanitic rocks of igneous origin.

[10]) Refer to PILGER (Lit. 8, Table II).

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