

ART. III.—*A Chemical Study of the Glauco-phane Schists*;
by HENRY S. WASHINGTON.

Introductory.—Among the metamorphic rocks the glaucophane schists are of special interest, on account of their peculiar mineralogical composition, as well as their comparative rarity. It is therefore somewhat remarkable that they have been only slightly investigated from a chemical point of view, especially as the characteristic mineral, glaucophane, has been analyzed from most of the localities. Indeed, as Rosenbusch* has remarked, our knowledge is far from sufficient for a proper understanding of their relations and origin. It is with the object of supplying partially this deficiency that the present chemical investigation has been undertaken. To supplement the analyses, some petrographical description is added, but the geological relationships will be only lightly touched upon, on account of the lack of opportunity for personal observations.

The material from Syra was collected by myself, several years ago, during a day's stay on the island. For the numerous specimens from the other localities I am deeply indebted to petrographers in different parts of the globe, and I gladly take this opportunity to express my hearty thanks to those mentioned in subsequent pages, in connection with the various specimens, for their kindness and generosity, which have made this investigation possible by supplying me with the requisite material.

Syra, Greece.

The glaucophane rocks of this island were first noticed by Virlet,† in 1833, who took the blue hornblende to be in part cyanite. Fiedler‡ in 1841, in a sketch of the geology and archaeology of the island, refers to this mineral as a hornblende, and mentions the abundance of epidote. Glauco-phane was indentified as a new mineral in these rocks by Hausmann§ in 1845. The rocks of the island were described by Luedecke¶ in 1876, from specimens collected by Fouqué and von

* Rosenbusch, *Elemente der Gesteinslehre*, 1898, p. 521; also *Sitzungsber. Akad. Wiss. Berlin*, 1898, p. 706.

† Virlet, *Expéd. Scient. de Morée*, vol. ii, p. 66, 1833.

‡ Fiedler, *Reise durch Griechenland*, vol. ii, p. 168, 1841.

§ Hausmann, *Gött. gel. Anzeigen.*, 1845, p. 193, Ref. in *Neues Jahrb.* 1845, p. 321.

¶ Luedecke, *Zeitschr. d. deutsch. geol. Gesellsch.*, vol. xxviii, p. 248, 1876.

Fritsch, and later the geology, as well as the rocks, were described by von Foullon and Goldschmidt.*

While the glaucophane schists of Syra vary considerably in appearance and composition, yet, according to von Foullon and Goldschmidt, (with whose conclusions my own observations agree, as far as they go), they may be referred to two main types, epidote-glaucophane schist and mica (quartz)-glaucophane schist. These are not divided with absolute sharpness, as some transition forms are found, but, with only one or two exceptions all my specimens may be referred to these two. The more numerous divisions of Luedecke may also be put in one or the other of these two groups, or regarded as transition varieties.

In association with these are found various metamorphic rocks, such as gneiss and epidote schist (which are especially abundant, according to von Foullon and Goldschmidt), omphacite rocks and eclogites, and various augitic and hornblendic schists. All these occur in connection with and interbedded with metamorphosed limestones, but the relations of the different members of the complex are far too intricate and little known as yet to permit of discussion.

Epidote-Glaucophane Schist.—It would seem that the rocks belonging here are rather more abundant than those belonging to the other main group. They vary from coarsely crystalline forms, in which either the glaucophane or the epidote is porphyritic in quite large individuals, to fine-grained varieties, in which the epidote occurs as small patches in the mass of dark blue, silky prismatic glaucophane, forming specimens of great beauty. Garnet is present only to a small extent, and mica, quartz and feldspar are not abundant in the most typical representatives of this type.

The specimen chosen for analysis is from near Kyperusa, a small hamlet about $2\frac{1}{2}$ kilom. north of Hermoupolis, in the northeastern part of the island. It is fine-grained, and shows to the naked eye small prisms of pale greenish yellow epidote with some white flecks of calcite and quartz, lying in a dark blue, silky groundmass of minute glaucophane needles. Under the microscope all these minerals are seen, the glaucophane highly pleochroic, the epidote nearly colorless, together with some chlorite (which is apparently derived in great part from the glaucophane), a few small titanite and rutile crystals, and a little feldspar, which, with the quartz and calcite, is interstitial.

* von Foullon and Goldschmidt, Jahrb. k. k. Geol. Reichsanst., vol. xxxvii, p. 1, 1887.

The analysis (No. I, below) shows a decidedly basic composition, with rather high Al_2O_3 and CaO , considerable Na_2O , and only a trace of K_2O . It will be seen later that it resembles the analyses of several other occurrences of these rocks.

As the mineralogical composition is quite simple, it may be calculated out quite readily as follows. The figures for glaucophane used here are those furnished by an analysis given further on, while those for epidote are based on the analysis by Luedecke.*

Glaucophane	37.2
Epidote	40.2
Chlorite	7.7
Quartz	6.1
Calcite	5.1
Feldspar	2.1
Titanite and rutile	1.6
	100.0

In II there is given an analysis of another specimen from Syra, an omphacite-zoisite rock, composed of bright, grass-green omphacite (diallage) in blades and large crystals, white mica (paragonite), and granular zoisite, with a little interstitial quartz. The content of mica varies considerably, being fairly abundant in the specimen analyzed, and much less so in others.

This resembles I very closely, though Fe_2O_3 is considerably higher than FeO . TiO_2 was not determined, and is included in the Al_2O_3 . Even thus the latter is high, but is to be attributed to the abundant zoisite and paragonite. The mineral composition of this calculates out approximately ;

Omphacite	31.7
Zoisite	31.7
Paragonite	31.0
Quartz	5.6

Mica-Glaucophane Schist.—The rocks which may be referred to this group are not abundant, but vary considerably in character, and, through decrease in the amount of mica tend to become quartz-glaucophane schists. The specimen which was chosen for analysis seemed to be fairly typical. It came from near the Café Škarbeli, on the east coast, a short distance to the north of Hermoupolis on the east coast.

It is markedly schistose, and shows megascopically glaucophane, white mica, greenish epidote and diallage, and small

* Luedecke, op. cit., p. 262.

red garnets, the whole being rather fine-grained and traversed by veins of quartz, which were carefully avoided in the pieces chosen for analysis.

Under the microscope the glaucophane appears in long crystals, with fringed ends, of the normal gray-blue color and pleochroism, the blue being deeper at the borders. The epidote is slightly greenish yellow, in elongated crystals, and much broken. It is sometimes difficult to distinguish it from the diallage, which occurs in generally larger crystals and less green in color. The garnets are almost colorless and much cracked. The flakes of mica present the usual characters of muscovite, but they must be referred to the soda-mica paragonite, on account of the mere trace of K_2O which the analysis reveals. Apart from the veins, grains of quartz are fairly abundant, scattered through the other constituents and interstitial. Small brown titanites are seen here and there, a little chlorite is present, and also grains of an apparently alkaline feldspar.

Through the kindness of Prof. Lawson and Dr. Ransome, I have been enabled to study specimens and sections of the lawsonite-bearing schists of California, but have been unable to find any of this interesting mineral in the rocks of Syra.

The analysis (No. III, below) shows a much higher percentage of SiO_2 than the preceding, slightly lower Al_2O_3 and Fe_2O_3 , the same MgO and FeO and K_2O , with lower CaO and higher Na_2O . In nearly all respects, with the notable exception of the Na_2O , it is transitional between the analyses of the more basic rock and that of the quartz-glaucophane schist to be given presently, and this intermediate character is quite consonant with its complex and transitional mineral composition. In its general features it resembles the analyses of many diorites, and it may be mentioned here that this analysis is quite unique among the dozen or so given in this paper.

The mineral composition being so complex, any satisfactory calculation of the relative amounts of the component minerals is difficult, and would be arbitrary.

Quartz-glaucophane Schist.—It has already been said that von Foullon and Goldschmidt divided the glaucophane schists of Syra into the two groups in which the blue hornblende was associated with either epidote or mica. While this is in general true, and in correspondence with the megascopical appearance of the rocks, yet it does not recognize fully enough the fact that the mica-glaucophane schists tend to become highly acid through the increase in quartz and decrease in mica. I have therefore referred some of my specimens to a third group of quartz-glaucophane schists, in which the mica, while present, and prominent in the hand specimen, yet is in

subordinate amount, and quartz very abundant. This division seems also to be in accordance with facts observed elsewhere.

Some of these schists resemble closely the preceding, and are rather bluish-gray, fine-grained, and highly schistose. The specimen taken for analysis differs from all these, and is a very striking rock, resembling (as far as can be told from the description) some of the quartz glaucophane schists of Angel Island, described by Ransome, to be mentioned later.

It is a highly schistose, shining white rock, from the north-west slope of Mt. Kappari. It is composed largely of quartz and less white mica, forming a fine-grained groundmass, through which are scattered blades of blue glaucophane, and some garnets about one cm. in diameter. Accessory epidote and apatite are also present in small amount.

The analysis (No. IV, below), it will be seen, differs radically from those of the other Syra rocks, being very acid, and with all other oxides much lower, except K_2O , which is quite high. In a general way it resembles those of the acid glaucophane schists of the Pacific coast.

	I.	II.	III.	IV.
SiO_2	46.39	46.76	58.26	79.43
Al_2O_3	17.34	22.65	16.21	12.68
Fe_2O_3	6.32	4.35	3.44	1.10
FeO	4.62	1.74	4.63	1.86
MgO	4.93	3.93	4.99	0.48
CaO	13.07	14.43	3.82	1.40
NaO	2.95	2.36	5.36	1.61
K_2O	0.25	0.15	0.39	0.76
H_2O 110° + ..	1.48	2.87	0.98	1.03
H_2O 110° — ..	0.08	0.16	0.22	0.12
CO_2	2.24	----	----	0.00
TiO_2	0.85	not. det.	1.37	0.17
MnO	trace	trace	trace	trace
	100.52	99.40	99.67	100.64

- I. Epidote-glaucophane schist. Kyperusa, Syra. Washington anal.
- II. Omphacite rock. Café Skarbéli, Hermoupolis, Syra. Washington anal.
- III. Mica-glaucophane schist. Café Skarbéli, Hermoupolis, Syra. Washington anal.
- IV. Quartz-glaucophane schist. N.W. slope of Mt. Kappari, Syra. Washington anal.

In connection with the glaucophane schists of Syra, it will be convenient to give the results of an analysis which I made of the glaucophane of the island. The mineral was very carefully separated by means of Thonlet's solution from a

rather coarse-grained specimen of quartz-mica-glaucophane schist, with a few accessory garnets. It just sank in a solution of sp. gr. 3.11, and was examined with the microscope and seen to be extremely pure.

My analysis (the mean of two) is shown in I, and for comparison are given the analyses of Luedecke (II) and Schnedermann (III), taken from the paper of Luedecke (p. 252), already cited. It is hoped to discuss this analysis, along with other new ones, in a subsequent paper.

	I.	II.	III.
SiO ₂	57.67	55.64	56.49
Al ₂ O ₃	11.07	15.11	12.23
Fe ₂ O ₃	3.20	3.08	----
FeO	9.68	6.85	10.91
MnO	0.06	0.56	0.50
MgO	9.85	7.80	7.97
CaO	0.95	2.40	2.25
Na ₂ O	6.80	9.34	9.28
K ₂ O	0.42	----	----
H ₂ O 110° +	0.36	----	----
H ₂ O 110° -	0.12	----	----
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	100.18	100.78	99.63

Attica.

The investigation of Lepsius* have shown that both the gabbros and the Cretaceous shales of Attica have been altered to glaucophane schists, through regional metamorphism.

	I.	II.
SiO ₂	48.00	45.97
Al ₂ O ₃	15.80	18.18
Fe ₂ O ₃	11.76	5.95
FeO	3.29	2.30
MgO	7.70	7.50
CaO	5.51	8.29
Na ₂ O	3.42	4.10
K ₂ O	0.46	0.75
H ₂ O	4.20	6.50
P ₂ O ₅	trace	trace
S	trace	----
MnO	trace	trace
	<hr/>	<hr/>
	100.14	99.54

- I. Gabbro. Kypriano, near Laurium. Lepsius anal., op. cit., p. 101.
 II. Gabbro. Malje Kuki, near Daskalio. Lepsius anal., op. cit., p. 102.

*Lepsius, Geologie von Attika, Berlin, 1893.

Unfortunately he gives no analyses of true glaucophane schists, but it seems worth while quoting the above two analyses of gabbros, which have partially undergone the transformation. Both are composed chiefly of plagioclase and diallage, which has been largely altered to fibrous green hornblende, with considerable glaucophane in needles. Chlorite and magnetite occur, but no olivine nor serpentine was seen.

Lepsius* also describes a blue gray, partially schistose rock, from west of Olimpos in Attica, composed of glaucophane needles lying in a groundmass of quartz and feldspar. A silica determination gave 87.43 per cent, and it is evident that this is a quartz-glaucophane schist, analogous to those of Syra, and, as will be seen later, of the Pacific Coast and elsewhere.

Croatia.

In 1887 Dr. Kišpatić† described a number of glaucophane schists, which occur chiefly as boulders or pebbles in various streams of Frnska Gora in Croatia. They vary to some extent, but it is of great interest to note that they may all be classed as either epidote-glaucophane schists, to which the majority belong, or as quartz-glaucophane schists, which are represented by only two occurrences. Garnet is sometimes present in abundance, sometimes quite wanting, and mica is rare, even in the more acid group.

I am indebted to Prof. Rosenbusch for one of Kišpatić's specimens from the Srnjevaciki Potok. It is of very simple composition, being composed chiefly of frayed, pleochroic glaucophane, and colorless or pale yellow epidote, in grains and prismatic crystals. Between these, but in very small amount is a colorless mineral, which occasionally shows multiple twinning lamellæ, and is referred to plagioclase. There are also rare rutile grains.

In thin section my specimen corresponds very well with Kišpatić's description. The rock is very fine-grained, composed of a pale glaucophane, in xenomorphic masses, with abundant grains and stout crystals of colorless or pale yellow epidote. A colorless mineral, apparently a plagioclase, as suggested by Kišpatić, is rare, in interstitial grains.

The analysis shows low SiO_2 , and resembles in a general way that of the Kyperusa rock. It differs, however, in having much higher MgO and lower CaO , as well as in the absence of CO_2 .

* Lepsius, op. cit., p. 104.

† Kišpatić, Jahrb. k. k. geol. Reichsanst., xxxvii, p. 35, 1887.

SiO ₂	47.36
Al ₂ O ₃	19.74
Fe ₂ O ₃	3.10
FeO	5.71
MgO	8.24
CaO	4.63
Na ₂ O	3.57
K ₂ O	0.51
H ₂ O 110° +	5.89
H ₂ O 110° -	0.16
CO ₂	trace
TiO ₂	1.36
MnO	trace
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	100.27

Epidote-glaucophane schist. Srnjevački Potok, Fruska Gora, Croatia. Washington anal.

Anglesey, Wales.

The occurrence of glaucophane schists on Anglesey was first observed by Blake* in 1888. The area is small and the composition apparently quite uniform, only epidote-glaucophane schist being mentioned. This occurs as local modifications of a hornblende schist which is probably derived from a diorite, which occurs in the vicinity.†

Through the kindness of Mr. Teall and Mr. E. B. Greenly I received specimens from the most typical locality, "The Monument," near Menai Bridge, on Anglesey, one of which was analyzed.

The specimens are very uniform, and are dense, compact, fibrous rather than foliated, schists, of a dark, blue-black color,

SiO ₂	47.47
Al ₂ O ₃	15.25
Fe ₂ O ₃	8.22
FeO	7.19
MgO	5.96
CaO	11.32
Na ₂ O	2.11
K ₂ O	0.56
H ₂ O 110° +	2.13
H ₂ O 110° -	0.04
TiO ₂	not det.
MnO	trace
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	100.25

Epidote-glaucophane schist. The Monument, Anglesey, Wales. Washington, anal.

* Blake, Geol. Mag., Decade III, vol. v, p. 125, 1888.

† Blake, Rep. Brit. Assoc. Adv. Sci., 1888, p. 406. Also op. cit., p. 125. Harker, Petrol. for Stud. 1897, p. 314.

and somewhat silky luster. Under the microscope they correspond with the plate given by Teall*, and are seen to be composed of a rather pale, prismatic glaucophane, with the normal pleochroism, rather less pale epidote, and small amounts of magnetite, quartz, mica and titanite. No calcite was seen.

Piedmont.

The occurrence of glaucophane schists in Piedmont is well known, and has been described by many geologists, but as I had no specimens from this region, I have passed it by in the preceding pages. Since they have been put in type, however, I have discovered an analysis of one of the rocks of this region, which is inserted here.

The occurrence of glaucophane schists and amphibolites ("prasinites") in the Val Maira, in southwestern Piedmont, is described by S. Franchi,† who also shows that they are both derived from diabases by metamorphism, apparently regional. The glaucophane schists are described as composed of glaucophane (gastaldite), with epidote and chlorite, and less albite, quartz, titanite and calcite. Analyses of this and of the amphibolite are given, and the very close correspondence between the two is evident. This is a strong point in favor of the view elsewhere expressed, that the formation of these two rocks is due, not to age distinctions, but to differences in conditions during metamorphism.

	I.	II.
SiO ₂	48·67	50·38
Al ₂ O ₃	18·36	17·65
Fe ₂ O ₃	10·30	10·02
FeO.....	-----	-----
MgO.....	5·49	4·77
CaO.....	11·03	10·95
Na ₂ O.....	1·12	2·52
K ₂ O.....	0·11	0·24
H ₂ O.....	4·20	2·52
TiO ₂	0·45	1·32
P ₂ O ₅	trace	trace
	99·75	100·37

- I. Glauco-phane schist, Val Maira, Piedmont. Aichino anal. S. Franchi, *Boll. Com. Geol. Ital.*, xxvi, p. 199, 1895.
- II. Amphibolite ("Prasinite"), Valle del Sangone, Piedmont. Aichino anal. S. Franchi, *op. cit.*, p. 199.

Corsica.

For the sake of completeness there may be mentioned two glaucophane rocks of Corsica, which have been analyzed.

* Teall, *Brit. Petrol.* 1888, pl. xlvii, fig. 1.

† S. Franchi, *Boll. Com. Geol. Ital.*, vol. xxvi, p. 192, 1895.

One is a gray-green schist from the neighborhood of a large serpentine dike, at La Barchetta, near Bastia, of which, not having access to the original paper by Oels,* I can give no description. It is, however, possibly the same as that described by Oebekke† from the same locality, as composed of prismatic glaucophane, partly altered to chlorite, granular epidote, plagioclase, quartz and calcite.

The analysis (No. I, below) shows low SiO_2 and CaO , with very high alkalis, and Fe_2O_3 largely preponderating over FeO . It does not correspond with the description given by Oebekke, nor, in fact, as far as the iron oxides and alkalis are concerned, with any other analysis of a glaucophane schist.

The other is a glaucophane schist from the gneiss of Bastia,‡ a dark, fine-grained, tough rock, composed of "orthoclase, some oligoclase, needles and prisms of glaucophane, sahlite, iron mica and chlorite, with other secondary products."

The analysis, given in II below, is unsatisfactory, and of little value, as FeO , alkalis and H_2O have not been determined. As far as it goes it is rather anomalous for a glaucophane schist, and resembles most that of the rock from Café Skarbéli, in Syra.

	I.	II.
SiO_2	50·17	55·94
Al_2O_3	13·88	18·06
Fe_2O_3	7·80	12·17
FeO	1·69	
MgO	4·53	2·75
CaO	10·90	5·95
Na_2O	7·31	5·13 (difference)
K_2O	2·16	
H_2O	1·56	not det.
Mn_3O_4	0·59	----
	100·59	100·00

I. Glaucophane schist. La Barchetta. Bastia. Corsica. M. Oels anal. Ref. in Neu. Jahrb. 1896, i, p. 47.

II. Glaucophane schist, near Bastia, Corsica. Busatti anal. Ref. in Neu. Jahrb., 1897, i, p. 281.

Japan.

Glaucophane schists are of quite common occurrence among the metamorphic rocks of Japan,§ and a number of them have been described by Kotô. From him I received several specimens of typical material, two of which were analyzed.

* M. Oels, Inaug. Diss. Erlangen. 1894, Ref. in Neues Jahrb. 1896. I, p. 47.

† Oebekke, Zeitschr. d. deutsch. geol. Ges., vol. xxxviii, p. 647, 1886.

‡ Busatti, Atti Soc. Tosc. Sci. Nat., Mem. xiii, p. 1-19, 1894: Ref. in Neues Jahrb. 1897, i, p. 281.

§ Kotô, Jour. of Sci. College, vol. i, Pt. i, p. 85, 1886. Harada, Die Japanischen Inseln, Berlin, 1890, pp. 54, 62.

Epidote-Glaucophane Schist.—One of these specimens is a rock of this character from Hongô, in Norimoto Village, Yana District, Province Mikawa. It is compact, of a rather dark, greenish gray color, and schistose with a silky luster. The specimen is traversed by a vein of calcite, which was avoided in the material chosen for analysis. The microscope, as well as the analysis, shows that this mineral is present throughout the rock to a considerable extent.

The structure of the rock as seen by the microscope differs from most of the other specimens examined, in the very finely fibrous character of the glaucophane, which is rather pale, but of the usual pleochroism. This forms streaks and bands through the rock, bringing out the schistose structure, and also occurs as a sort of felt. With it, but somewhat locally developed, is a pale green or bluish-green, not highly pleochroic, amphibole, also in needles, which seem to be an actinolite and to be derived from the glaucophane. A yellowish epidote occurs in small grains, chiefly intimately associated with the glaucophane.

Partly intermingled with these three, but generally forming the greater part of separate streaks, is a colorless mineral of rather high refraction and low birefringence, the polarization colors being grays and blue-grays. It is chiefly in long grains, not showing much cleavage, and is apparently orthorhombic. This must be referred to zoisite, as the low alkalies preclude the possibility of its being a feldspar. Calcite is quite common, and some grains of quartz are seen. Titanite is also present in small grains.

The analysis of this rock, given in I below, is that of a normal epidote-glaucophane schist, with high CaO. It calls for no special remark here.

A specimen of glaucophane schist from Otaki-san, near Tokushima, Shikoku Island, represents the rocks in which glaucophane was first discovered in Japan by Kotô, and which have been briefly described by him. The majority of them would seem to be epidote-glaucophane schist, some containing garnets, but the one in my possession is a quartz-glaucophane schist. Unfortunately it is seemingly so badly altered that no analysis was made of it, but a brief description may be of interest.

It is a highly fissile, schistose rock, of a general brownish color, glistening with mica scales, and with abundant dark blue glaucophane. Microscopically it is composed of stout prisms of dark glaucophane, white mica, and considerable interstitial quartz. Small crystals of colorless titanite, apatite and zircon (?) are numerous. Brown limonitic stains over all

the section indicate the decomposition of the specimen, but it is more fresh than the megascopic appearance would indicate.

“*Glaucophane Slate.*”—The second specimen which was chosen for analysis is one of a rock called by this name by the Japanese geologists. According to Kotô* they are extensively developed in the Paleozoic of Japan, and are really “schalsteins,” derived from diabase tuffs. The specimen in question, from Kamoi Kotan, Island of Hokkaido (Yesso), is a very fissile, slaty, fine-grained rock, of a general light, blue-gray color, but stained between the folia with limonite.

Under the microscope it is seen to be very fine-grained, and with the detrital, cataclastic structure of the original diabase tuff very well marked. There are irregular patches of a pale, fibrous glaucophane, with some rather large crystals and fragments of pyroxene, but the greater part is an indeterminate, very finely granular mass of colorless and yellow grains and fragments, mostly of augite, with some of glass, and possibly of plagioclase.

The analysis (No. II) resembles the preceding in many respects, but is lower in CaO, and higher in iron oxides, K_2O and $TiO_2 \cdot H_2O$ is high, but no CO_2 was found.

The analysis, on the whole, confirms the view that the rock is a metamorphosed diabase tuff, and for comparison, analyses of two of these are given in III and IV.

	I.	II.	III.	IV.
SiO ₂	47·89	48·88	47·25	49·13
Al ₂ O ₃	13·06	13·44	17·84	14·76
Fe ₂ O ₃	6·77	5·32	5·46	16·40
FeO	5·36	8·96	7·20	----
MgO	4·10	4·21	5·97	4·41
CaO	11·65	5·80	5·15	9·05
Na ₂ O	3·35	3·73	2·30	2·96
K ₂ O	0·57	1·71	0·29	1·81
H ₂ O 110° + ..	1·39	3·42	8·55	1·66
H ₂ O 110° — ..	0·12	0·36		
CO ₂	2·97	none	----	----
TiO ₂	2·14	3·90	in Al ₂ O ₃	----
MnO	0·09	----	0·14	----
	99·46	99·73	100·15	100·18

- I. Epidote-glaucophane schist. Norimoto, Yana Distr. Mikawa Prov. Japan.
 II. “Glaucophane slate.” Kamoi Kotan. Isl’d Hokkaido. Japan.
 III. “Schalstein.” Nogurizawa. Kanra Distr. Kozuke Prov. Japan. Harada anal. Harada. Die Jap. Inseln., p. 66.
 IV. “Schalstein.” Siebenhitz. NW of Hof. Bavaria. Schwager anal. Gümbel, Geogn. Beschr. Fichtelgeb. 1879, p. 227.

* Kotô, op. cit., p. 89.

California.

Coming to our own continent, we find glaucophane schists only in the extreme west, where they are extensively developed along the Pacific Coast, in California and Oregon, and possibly beyond these. They are very varied in character, and have been described in part by many geologists, but their relationships and origin are not yet fully understood. Some of them would seem to be the products of regional metamorphism, while in other cases they are due to contact metamorphism and are local in character.

They also vary widely in composition, but the researches already made by others, as well as the analyses given here, show that, just as in Syra, Croatia and Brittany, they belong to two groups, the basic and the acid. As the occurrences are somewhat widespread, they will be described under local headings.

Santa Catalina Island.—The geology of this island, which lies off the coast of Southern California, has been described by W. S. T. Smith.* It is composed largely of diorites and andesites, resting on a basement of quartzite and schists, in which also serpentine occurs.

Of the occurrence of the glaucophane schists he speaks as follows: "Besides the micaceous partings of the quartzites there were found at a number of points partings of blue amphibole, having frequently a silky luster. This amphibole also occurs in larger masses in a schistose condition. The occurrences of this rock are found particularly in the Little Harbor region, apparently confined to the neighborhood of areas of the amphibole, and talc-schists and serpentine. It is probable that here, as elsewhere in California, these blue amphibole schists are due to local contact metamorphism occasioned by the intrusion of basic eruptives."

Dr. Smith does not describe these rocks further, but in the petrographic collection of Yale University is a suite of rocks from Santa Catalina Island, collected by Prof. B. Silliman in 1867, among which are several specimens of the glaucophane schists from Little Harbor, on the west coast. I am indebted to Prof. Pirsson for the privilege of studying these, as well as material for analysis.

They all prove to be quartz-glaucophane schists, pale, blue-gray in color, rather ashy and dull, one fibrous, and the others (including the specimen analyzed), very schistose and fissile, though quite hard. One specimen shows thin bands of white quartz.

* W. S. T. Smith, Proc. Cal. Acad. Sci., (3), Geol., vol. i, p. 1, 1897.

Under the microscope the specimen analyzed shows a multitude of fine, pale blue glaucophane needles, and larger crystals fringing out into needles, embedded in granular quartz, with some minute zircons and a few grains of epidote. There is no carbonaceous matter present, but in another similar specimen this exists to a considerable extent, while a dark, compact rock, also from Little Harbor, is a black and apparently little altered, quartzose shale.

	I.	II.	III.
SiO ₂	74.48	80.21	74.16
Al ₂ O ₃	9.15	7.99	11.85
Fe ₂ O ₃	1.41		0.82
FeO	4.12	3.35	1.66
MgO	3.04	1.54	2.10
CaO	2.84	1.10	2.10
Na ₂ O	2.24	5.97	6.57
K ₂ O	0.43	0.22	0.15
H ₂ O 110° +	2.06	0.74	0.52
H ₂ O 110° —	0.08		
CO ₂	----	----	0.09
TiO ₂	----	----	0.37
P ₂ O ₅	----	----	0.08
MnO	----	----	0.06
C	----	----	0.18
	99.85	101.12	100.76

- I. Quartz-glaucophane schist. Little Harbor, Santa Catalina Island, Cal. Washington anal.
 II. Quartz-glaucophane schist. Angel Island, Cal. Ransome anal. Bull. Dept. Geol. Univ. Cal., vol. i, p. 231.
 III. Adinole, Mansfield, Mich. Steiger anal. Clements. This Journal, vol. vii, p. 88, 1899.

The analysis shows that quartz is very abundant, more so indeed than the microscopical examination would have led one to suppose. It is possible, to judge from the amount of Al₂O₃, that sillimanite is present, since Smith speaks of it as occurring in the neighboring quartzite. None was seen in the sections, though the dense felt of glaucophane needles would make its identification difficult.

It may be inferred from the presence of carbonaceous matter in some of the specimens, and from the apparent gradation to true shale shown by them, that these schists are derived from shales of a quartzose character, or from the quartzites as Smith suggests, possibly through the contact metamorphism of intruded igneous rocks.

It may be mentioned that the analysis corresponds very well with that of an adinole (III above), derived from a clay slate

by contact metamorphism of a dolerite, at Mansfield, Michigan, described by Clements.* The adinole carries abundant albite, and actinolite instead of glaucophane. This difference may be connected with the higher Al_2O_3 and Na_2O and lower FeO in the adinole.

Angel Island, Cal.—The occurrence just described seems to be analogous with that at Angel Island, in San Francisco Bay, described by Ransome,† the similarity being also remarked on by Smith (p. 57). At the latter locality radiolarian cherts have been altered into quartz-glaucophane schists by the intrusion of fourchite and serpentine. They vary rather more in character, as some are composed essentially of glaucophane and albite,‡ while others are made up of glaucophane and quartz. Brown mica and garnet also occur. Analysis II above, by Ransome, shows the essentially general similar character of the two, though it was made evidently of an albitic schist.

It is of interest to note that, just as carbonaceous matter is preserved in the Santa Catalina schists, so in these from Angel Island the radiolarian remains are not entirely obliterated by the metamorphism.

Mount Diablo.—Among the metamorphic rocks of this locality glaucophane schists occur,§ but unfortunately detailed petrographic descriptions seem to be wanting. One of them, a boulder from Pine Canyon, has been analyzed by Melville.|| It is briefly described as bluish with streaks of green, with well marked schistose structure, and containing innumerable cinnamon garnets. It is composed presumably chiefly of glaucophane, epidote and garnet, with few accessories, and is probably closely similar to some of the glaucophane schist of Tupper Rock, Oregon, or a specimen from Tiburon Peninsula, sent me by Prof. Lawson. The analysis is given on the next page.

In a recent paper¶ Turner throws some doubt on the interpretation of these schists as the product of contact metamorphism by basic intrusions, but discussion of this problem is outside the scope of this article.

Sulphur Bank.—Glaucophane schists from this locality, which lies east of Clear Lake (north of the preceding locality), have been described by Becker.** They vary much, as elsewhere, some being quartz-mica-glaucophane schists, and others

* Clements, this Journal, IV, vol. vii, p. 88, 1899.

† Ransome, Bull. Dept. Geol. Univ. Cal., vol. i, p. 211, 1894.

‡ Turner (17th Ann. Rep. U. S. G. S., i, p. 728, 1896) suggests that they may be in reality dike rocks.

§ Turner, Bull. Geol. Soc. Amer., vol. ii, p. 384, 1891.

|| Melville, Bull. Geol. Soc. Amer., vol. ii, p. 413, 1891.

¶ Turner, Jour. Geol., vol. vi, p. 490, 1898.

** G. F. Becker, Mon. XIII, U. S. G. S., p. 102, 1888.

SiO ₂	47.84
Al ₂ O ₃	16.88
Fe ₂ O ₃	4.99
FeO	5.56
MgO	7.89
CaO	11.15
Na ₂ O	3.20
K ₂ O	0.46
H ₂ O 105°+	1.81
H ₂ O 105°-	0.17
P ₂ O ₅	0.14
MnO	0.56
	100.65

Garnet-glaucophane Schist. Pine Canyon, Mount Diablo.
Melville anal. Bull. Geol. Soc. Amer., vol. ii, p. 413, 1891.

zoisite-glaucophane schists. One of the last was analyzed, and is described by Becker as follows.

“It is a greenish-gray, schistose rock, consisting chiefly of glaucophane and zoisite. The latter occurs in imperfect prismatic crystals. The zoisite is distinctly dichroic and has a faint olive-green tint when the prisms are parallel to the principal section of the nicols. Sections perpendicular to the main axis are square, often with one truncated corner. The extinctions are normal and the colors of interference are gray to yellow in the prisms, but more vivid in granular aggregates. The angle of the optical axes appears to be large. Glaucophane, in needles and long, imperfect, nearly parallel prisms, gives the rock its cleavage. Quartz, albite, muscovite and titanite are present.”

The occurrence of a purely zoisite-glaucophane schist, as described by Becker, is decidedly unusual, and the determination of all the supposed zoisite as such would seem to be somewhat problematical. It is true that some of the mineral was separated and analyzed,* the results corresponding fairly well with the determination as zoisite, but being not inconsistent with an epidote low in iron. The color and pleochroism are also unusual for zoisite. It would seem probable that both minerals exist in the rock, the granular form being probably especially referable to epidote.

Melville's analysis (I) shows a composition closely resembling the preceding one, and like other glaucophane schist analyses, with high CaO. It is of interest to compare with it an analysis of a diabase (Becker's pseudodiabase) from Mt. St. Helena, also by Melville. It will be seen that the two are almost identical.

* Becker, op. cit., p. 79.

	I.	II.
SiO ₂	49·68	49·08
Al ₂ O ₃	13·60	14·68
Fe ₂ O ₃	1·86	1·95
FeO	8·61	9·63
MgO	6·27	6·69
CaO	10·97	10·09
Na ₂ O	3·09	4·60
K ₂ O	0·12	0·20
H ₂ O 100°+	} 3·84	} 1·18
H ₂ O 100°-		
TiO ₂	1·31	1·72
P ₂ O ₅	0·21	0·23
MnO	0·04	0·15
	99·60	100·48

- I. Zoisite-glaucophane schist. Sulphur Bank. Melville anal. Becker, Mon. XIII U. S. G. S., p. 104, 1888.
 II. "Pseudodiabase." Mt. St. Helena. Melville anal. Becker, op. cit., p. 98.

While we are still in California, there may be quoted, for the sake of completeness, two analyses given by Rosenbusch. The first (I) is of a specimen sent him by Palache, of a "Grünschiefer with glaucophane, further stage of altered tuff. Hills north of Berkeley." This is calculated from two partial analyses and an alkali determination.* It shows a composition very low in SiO₂ and MgO, probably high in iron, and high in CaO and Na₂O, differing materially from others only in the lower SiO₂.

The second† (II) is of the albite-crossite rock described by Palache,‡ and which Turner§ thinks may be a dike rock.

	I.	II.
SiO ₂	42·59	65·2
Al ₂ O ₃	} 31·00	} 15·8
Fe ₂ O ₃		
FeO		
MgO	5·10	2·4
CaO	10·80	0·6
Na ₂ O	4·16	10·8
K ₂ O	1·01	0·1
H ₂ O, CO ₂	5·34	----
	100·00	100·0

* Rosenbusch, Sitzungsber. Preuss. Akad., 1898, p. 716.
 † Rosenbusch, op. cit., p. 712.
 ‡ Palache, Bull. Dept. Geol. Univ. Cal., vol. i, p. 181, 1894.
 § Turner, 17th Ann. Rep. U. S. G. S., i, p. 728, 1896.

Rosenbusch calculated the rock composition from the specific gravities of the rock and of the two minerals, and their known chemical composition. He gives two limiting results, but, as they differ but little, that corresponding to the mineral mixture Ab_7, Cr_3 , is here given. As Rosenbusch remarks, this composition is quite anomalous, whether for eruptive or metamorphic rocks, and it is to be desired that an analysis of the rock itself were available.

Oregon.

Glauco-phane schists, both acid and basic, occur along the coast in Oregon, and have been partially described by Diller,* who suggests that, as at Angel Island, they are the products of contact metamorphism. He very kindly sent me a number of typical specimens, three of which I have analyzed.

That from a ledge about one mile N.E. of Winston's bridge, near Roseburg, is a schistose, gray (scarcely blue) fine-grained rock, with many glistening flakes of white mica sprinkled through it. One specimen shows some small brown garnets. The other (analyzed) is wanting in them, and is composed of a felt of stout, rather short glauco-phane crystals, with grains of epidote, some chlorite, a few irregular quartz grains, and phenocrysts of colorless mica.

Chemically (I) it is the most basic of all these rocks which have been analyzed with the exception of the one partially analyzed by Rosenbusch. It is also very high in iron, low in CaO , and, for these rocks, high in K_2O , which indicates that the mica is a muscovite and not a paragonite, as in the Syria rocks.

Glauco-phane schists also occur southwest of Roseburg, in the neighborhood of Coos Bay. Those from Tupper Rock have been briefly described by Diller, and three specimens sent me indicate that they vary considerably in character. Two are composed essentially of glauco-phane embedded in granular quartz, with some white mica, and a little epidote. The chemical composition of these must be closely similar to that from Four Mile Creek, described later. The other (III) is much more basic, composed of glauco-phane with less granular epidote, or zoisite, in which lie many small garnets, around which are zones of white mica. This corresponds more nearly in chemical composition to the Mount Diablo occurrence.

The schist from Four Mile Creek, Coos County, is a rather coarser grained, schistose rock, of a general light gray color, showing considerable white mica and quartz. In general

* Diller. 17th Ann. Rep. U. S. G. S., i, p. 454, 1896; Geol. Atlas of U. S. Roseburg Folio, 1898.

appearance it is not unlike the intermediate mica-glaucophane schist from Cafe Skarbeli, Syra, already described. In thin section it is seen to be composed very largely of quartz, which shows clear evidence of crushing. In this lie well-formed glaucophane prisms, which are highly pleochroic, c blue, b violet, a pale yellow or colorless. With these, but in less amount, are thin flakes of colorless mica, which the analysis shows to be muscovite scales and plates of chlorite, and some small garnets.

The analysis (II) shows an exceedingly acid composition, being the highest in SiO_2 of any of the rocks so far examined by me. On calculation the mineral composition works out as follows:

Quartz	67.6
Glaucophane	14.2
Muscovite	10.4
Garnet	} 7.8
Chlorite	
	100.0

The relatively high K_2O in both these Oregon rocks is noteworthy, the nearest approach to them in this respect being the "glaucophane slate" of Kamoi Kotan in Japan.

	I.	II.	III.
SiO_2	46.07	82.53	49.15
Al_2O_3	15.35	6.88	15.87
Fe_2O_3	3.61	0.59	4.10
FeO	9.87	4.11	7.58
MgO	7.83	1.86	7.53
CaO	4.37	0.68	9.06
Na_2O	3.22	1.21	3.59
K_2O	2.68	1.24	0.54
H_2O 110°+	4.25	1.35	1.07
H_2O 110°-	0.16	0.07	0.16
CO_2	1.05	---	none
TiO_2	1.63	---	1.19
MnO	trace	trace	trace
	100.09	100.52	99.84

- I. Epidote-glaucophane schist. Near Winston's Bridge, Roseburg, Douglas Co., Oregon. Washington anal.
- II. Quartz-glaucophane schist. Four Mile Creek, Coos Co., Oregon. Washington anal.
- III. Garnet-glaucophane schist. Tupper Rock, near Brandon, Coos Co., Oregon. Washington anal.

General Conclusions.

It will be of interest to compare the foregoing analyses with each other, and for this purpose those which seem to be of most value are collected in the large table on page 55. It is at once evident that these rocks are divided into at least two main groups. One, the larger, is basic, with SiO_2 ranging only from 46 to 49.7, the other is very acid, with SiO_2 ranging from 74.5 to 82.5. These two seem to be very sharply separated, a possible third intermediate group being represented by only one analysis, with SiO_2 58.3.

Basic Group.—Taking up the basic group first, it is seen that they are of fairly uniform composition in most respects. Al_2O_3 in most of them is rather low, from 13 to 15, being higher only in II (17.34), III (19.74) and V (16.88) and VII (18.36). Iron oxides are high in all, and FeO uniformly surpasses Fe_2O_3 (molecularly), in two cases (I and X) very much so. MgO varies from 4.1 to 8.2, and there seems to be no correlation between it and any other oxide, though there are indications of a parallel variation of it and FeO.

CaO shows the most striking behavior, running from 4.4 to 5.8 in some, and then with a break from 11 to 13 in others. It would be natural to connect this behavior with some corresponding difference in mineral composition, but I have failed to find any trace of such. One would suppose that the rocks rich in CaO might be prone to carry garnets, but, while they are abundant in V and IX they are lacking in II, IV, VI and X. On the other hand they are quite wanting in I, III and VIII, in which CaO is low.

Na_2O remains very steady, varying only from 1.1 to 3.7, while K_2O is present, as a rule, only in traces, being above one per cent only in I (2.7) and VIII (1.7). H_2O is, of course, present in considerable, but varying, amount, and CO_2 likewise is irregular, being often quite absent, and again high. TiO_2 , when determined, is always high, a fact connected with the frequent occurrence of rutile and titanite as accessory minerals. P_2O_5 and MnO are present only in traces.

Acid Group.—Inasmuch as in this group SiO_2 constitutes 75 to 80 per cent of the rock, the distribution of the other oxides through the remaining 25 to 20 per cent allows of a comparatively small range in variation. It may be noted, however, that FeO is constantly higher than Fe_2O_3 , that MgO is rather high for such acid rocks, that CaO decreases regularly as SiO_2 increases, and that Na_2O is constantly higher than K_2O , which, except in XV, is present only in traces. The very high Na_2O in XIV is undoubtedly to be attributed to the presence of albite.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
SiO ₃	46·07	46·39	47·36	47·47	47·84	47·89	48·67	48·88	49·15	49·68	58·26	74·48	79·43	80·21	82·53
Al ₂ O ₃	15·35	17·34	19·74	15·25	16·88	13·06	18·36	13·44	15·87	13·60	16·21	9·15	12·68	7·99	6·88
Fe ₂ O ₃	3·61	6·32	3·10	8·22	4·99	6·77	10·30	5·32	4·10	1·86	3·44	1·41	1·10	-----	0·59
FeO	9·57	4·62	5·71	7·19	5·56	5·36	-----	8·96	7·58	8·61	4·63	4·12	1·86	3·35	4·11
MgO	7·83	4·93	8·24	5·96	7·89	4·10	5·49	4·21	7·53	6·26	4·99	3·04	0·48	1·54	1·86
CaO	4·37	13·07	4·63	11·32	11·15	11·65	11·03	5·80	9·06	10·97	3·82	2·84	1·40	1·10	0·68
Na ₂ O	3·22	2·95	3·57	2·11	3·20	3·35	1·12	3·73	3·59	3·09	5·36	2·24	1·61	5·97	1·21
K ₂ O	2·68	0·25	0·51	0·56	0·46	0·57	0·11	1·71	0·54	0·12	0·39	0·43	0·76	0·22	1·24
H ₂ O 110° +	4·25	1·48	5·89	2·13	1·81	1·39	3·42	3·42	1·07	-----	0·98	2·06	1·03	-----	1·35
H ₂ O 110° -	0·16	0·08	0·16	0·04	0·17	0·12	4·20	0·36	0·16	3·84	0·22	0·08	0·12	0·74	0·07
CO ₂	1·05	2·24	trace	-----	-----	2·97	-----	none	none	-----	-----	-----	none	-----	-----
TiO ₂	1·63	0·85	1·36	not det.	-----	2·14	0·45	3·90	1·19	1·31	1·37	-----	0·17	-----	-----
P ₂ O ₅	-----	-----	-----	-----	0·14	-----	trace	-----	-----	0·21	-----	-----	-----	-----	-----
MnO	trace	trace	trace	trace	0·56	0·09	-----	trace	trace	0·04	trace	trace	trace	-----	trace
	100·09	100·52	100·27	100·25	100·65	99·46	99·73	99·73	99·84	99·59	99·67	99·85	100·64	101·12	100·52

- I. Epidote-glaucophane schist. Winston's Bridge, near Roseburg, Oregon. Washington anal.
- II. Epidote-glaucophane schist. Kyperusa, Syria. Washington anal.
- III. Epidote-glaucophaneschist. Srnjocvacki Potok, Fruska Gora Croatia. Washington anal.
- IV. Epidote-glaucophane schist. The Monument, Anglesey, Wales. Washington anal.
- V. Garnet-glaucophane schist. Pine Canyon, Mt. Diablo, Cal. Melville anal.
- VI. Epidote-glaucophane schist. Norimoto, Mikawa, Japan. Washington anal.
- VII. Epidote-glaucophane schist. Val Maira, Piedmont. Aichino anal.
- VIII. Glaucophane "Slate." Kamoi Kotan, Hokkaido, Japan. Washington anal.
- IX. Garnet-glaucophane schist. Tupper Rock, Bandon, Coos Co., Oregon. Washington, anal.
- X. Zoisite-glaucophane schist. Sulphur Bank, Cal. Melville anal.
- XI. Mica-glaucophane schist. Cafe Skarbeli, Hermoupolis, Syria. Washington anal.
- XII. Quartz-glaucophane schist. Santa Catalina Island, Cal. Washington, anal.
- XIII. Quartz-glaucophane schist. Mt. Kappari, Syria. Washington anal.
- XIV. Quartz-albite-glaucophane schist. Angel Island, Cal. Ransome anal.
- XV. Quartz-glaucophane schist. Four Mile Creek, Coos Co., Oregon. Washington anal.

Comparisons with other rocks.—Rosenbusch* has already called attention to the fact that “certain glaucophane rocks are chemically identical with the igneous rocks belonging to the gabbro magmas, or their tuffs.” He bases this conclusion on the two analyses of Melville (Nos. V and X), admitting at the same time that it does not follow that all glaucophane rocks are so derived.

That this main conclusion is correct for the majority of glaucophane schists would seem to be borne out by the analyses in the table, and their comparison with typical analyses of diabase and gabbros quoted in the large works of Roth, Zirkel and Rosenbusch. It is undeniable that there is a remarkably close agreement between the two, and the conclusion is irresistible that a large part of the glaucophane schists are probably derived from diabases, gabbros or their tuffs.

That this is not true of all is rendered certain by the four analyses of acid glaucophane schists, which we have already seen are in all probability derived from cherts, quartzose shales or quartzites. The anomalous analysis No. XI corresponds with those of many rather acid diorites, and it is possible that it has been derived from a rock of this kind, though this is not certain.

Although outside the scope of this paper it will not be amiss to call attention to several cases which bear directly on the question of the derivation of some of the glaucophane schists from rocks of the gabbro family, and which are strongly confirmatory of this view.

Direct evidence of the change from undoubted igneous rocks was first given by Kotô† in the case of several Japanese occurrences, melaphyrs and diabase tuffs showing a gradual increase in the blue amphibole and final transition into true glaucophane schist, through “glaucophanization” of the diallage. Instances of the same thing are also mentioned by Harada.‡

Another instance is furnished in Greece by Lepsius, in his description of the metamorphic schist of Attica.§ He shows that some of the gabbros of this region, which have been intruded into the sedimentaries and have been subjected to the same regional metamorphism, contain glaucophane, often in large quantities, though there are apparently few instances of the final conversion into true glaucophane schist.

It may be noted that the gabbros from near the Isthmus of Corinth and from Argolis, according to Lepsius and my own observations, do not show any glaucophane, but are analogous

* Rosenbusch. *op. cit.*, p. 711.

† Kotô *op. cit.*

‡ Harada, *op. cit.*, p. 62.

§ Lepsius, *Geologie von Attika*. Berlin, 1893, p. 176.

to a more basic group of gabbros, also occurring in Attica, which furnish serpentine on alteration.*

The Attic Cretaceous shales, according to Lepsius,† also yield glaucophane schists as products of metamorphism. Unfortunately no analyses are given, but some of them, as that from Velaturi near Thoriko, must resemble closely the Kyperusa schist, being composed essentially of glaucophane and epidote. Others again are more acid and carry along with glaucophane abundant quartz, feldspar and white mica.

In this connection it is of interest to note that glaucophane schists are very common in the whole region of metamorphic rocks which runs along the eastern coast of Greece, and extends southward and eastward through the Archipelago. Rocks of this character have been described from Thessaly,‡ Euboea,§ Attica,|| Thermia,¶ Tinos,** Siphnos,†† Syra, Milos,‡‡ Samos,§§ Rhodes,||| and Smyrna.¶¶

We have already seen that the glaucophane schists of Anglesey are probably derived from diorite (possibly gabbro), since, according to Blake and Harker, gradual transitions are observed from massive diorite to hornblende schist, the glaucophane schist being locally developed. Serpentine also occurs on Anglesey, though not near the Monument, where diorite occurs.*** Though the whole district has been subject to regional metamorphism,††† it is uncertain whether the development of glaucophane schist is due to this or to contact metamorphism.

Another instance of derivation from basic igneous material is that given by Rosenbusch in the paper already cited. He describes specimens sent by Palache, labelled "altered tuff" from near Berkeley, Cal., and concludes that these diabase tuffs do in fact alter to true glaucophane schists.

In his monograph on the Quicksilver Deposits of the Pacific Slope Becker‡‡‡ briefly describes the alteration of diabase to glaucophane schist, and also speaks of the glaucophane schists of Mt. Diablo passing over into slightly altered shales.

* Lepsius, op. cit., p. 86.

† Lepsius, op. cit., pp. 133 and 136 ff.

‡ F. Becke, *Min. Petr.*, Mitth., vol. ii, p. 49, 1879.

§ F. Becke, op. cit., p. 71.

|| Lepsius, op. cit.

¶ Oebekke, *Zeitschr. d. d. Geol. Ges.*, vol. xxxviii, p. 644, 1886.

** Von Foulton and Goldschmidt, op. cit., pp. 24 and 31.

†† K. Ehrenburg, *Inselgruppe von Milos*. Leipzig, 1889, p. 101.

‡‡ I. Chelussi, *Giorn. di Min.*, vol. iv, p. 34, 1893.

§§ Foulton, *Sitzber. Akad. Wiss. Wien*, vol. c, p. 176, 1891.

||| Oebekke, op. cit., p. 651.

*** Cf. Blake, *Q. J. G. S.*, vol. xlv, pl. xiii, 1888.

††† Sir A. Geikie, *Anc. Volc. of Gr. Brit.*, vol. i, pp. 128, 220, 1897.

‡‡‡ Becker, op. cit., pp. 100 and 102.

Finally Barrois* regards the glaucophane schists of Île de Groix, in Brittany, as the product of the metamorphism of sedimentary rocks.

Comparison with amphibolites.—A point of some interest, already touched on by Rosenbusch,† is the general similarity in chemical composition between the basic glaucophane schists and many of the amphibolites, as may be seen on reference to the analyses of these last given by Roth, Zirkel and Rosenbusch. It was hoped that the present investigation would throw some light on this point, and possibly reveal some constant difference in chemical composition between the two, which would serve to explain the diverse mineralogic resultants of apparently identical metamorphic processes on similar original material.

The results are, on the whole, inconclusive, though as a rule, the amphibolites are higher in MgO, CaO and K₂O, and lower in Fe₂O₃, than the glaucophane schists. The eclogites approach, as a class, much more closely to the glaucophane schists, especially in low K₂O, though they also are apt to be higher in MgO and lower in Fe₂O₃.

As Rosenbusch remarks, the distinction between the amphibolites and the glaucophane schist lies in the fact that, while in the former the Na₂O has gone into feldspar, in the latter it has gone into glaucophane. He suggests that this may be connected with a difference in the age of the rocks.

With this view I cannot agree. It seems more reasonable to suppose that, just as in the consolidation of igneous magmas the eventual mineralogic composition of rocks derived from any given magma is chiefly dependent on the physical conditions of cooling, the presence of mineralizers, etc., so here physical or chemical conditions have determined whether the metamorphism of, for instance, a diabase tuff produces a normal amphibolite or an epidote-glaucophane schist.

This view is based partly on the general reasoning which has abolished the age distinction in igneous rocks, and partly on the following considerations:

In the first place, we find at many places, as Île de Groix, Greece, California, Anglesey, etc., amphibolites and glaucophane schists occurring together, the latter being often only locally developed.

In the next place glaucophane has been often developed at one locality by the metamorphism of such widely diverse original materials as cherts and diabase tuffs. This points clearly to the existence of some peculiar conditions, apart from

*Barrois, Ref. Neus Jahrb., 1884, ii, p. 72.

† Rosenbusch, op. cit., p. 711.

the composition of the original material, as necessary to the formation of the mineral.

Again we find glaucophane schists in the "Grundgebirge" or Lower Cambrian at Île de Groix, Neocomian among the Pacific Coast, Post Cretaceous in Attica, and probably of other ages elsewhere. Similarly amphibolites are found of various ages.

Lastly, the fact that these rocks are not found generally distributed over the earth, as are the amphibolites, but occur in well-defined zones or regions of metamorphic rocks, points to the existence of some peculiarity in the conditions of the metamorphic processes involved. This occurrence in strongly marked regions is exemplified by their presence in Greece and the Archipelago, the Piedmont Region in Italy, Japan and along the Pacific Coast of this country.

Summary.—The glaucophane schists belong to two main groups, sharply separated from each other. The larger one is basic, composed chiefly of glaucophane and epidote, often with abundant garnet, zoisite, diallage, and sometimes smaller amounts of mica, feldspar and quartz, and rutile and titanite as frequent accessories. Chemically these closely resemble the composition of the rocks of the gabbro family, and are apparently divisible into two subgroups, one high in CaO, the other low in it. These are in most cases almost undoubtedly derived from such igneous rocks or their tuffs, but also possibly in rarer cases from sediments or slates of similar composition.

These basic glaucophane schists scarcely differ in chemical composition from the amphibolites and eclogites, and the difference in their formation is probably to be ascribed to differences in the conditions of metamorphism.

A smaller, but widely spread, group is acid in composition, and these are composed largely of quartz and glaucophane, with mica and sometimes albite. These are derived from cherts, quartzites or quartzose shales and sandstones.

The existence is indicated of a third, still smaller, group of intermediate mineralogical composition, and chemically like the diorites.

The glaucophane schists are apparently the result of both regional and of contact metamorphism, and in many regions they occur together. This last seems to be the rule in glaucophane schist areas of any size, and where only the one kind is found the area is apt to be small.