

thin beds of flint, and the echinoderm *Holaster planus*. Where the Chalk has been cut into by the valley the upper portion is considerably disintegrated and discoloured. This rubble is about 6 feet in thickness in the lower part, and thins out towards the right; and where the Boulder-clay rests directly upon the Chalk it is missing altogether, having probably been planed off by the moving ice.

To the left of the section there is a wedge-shaped mass of fine, clean, angular chalk 'grut', which is about 6 feet thick at the left of the section and gradually tapers off towards the right. This 'grut' is evidently of very early date, as it contains a fairly large proportion of small well-rounded quartzite pebbles, such as occurred at the top of the Wolds in pre-Glacial times.¹ The chalk 'grut' at North Sea Landing is precisely similar to the deposit at Sewerby described by Mr. G. W. Lamplugh²; in fact, in general appearance it is precisely similar to that on the buried cliff, though unfortunately there is no beach material exposed at North Sea Landing, nor is this to be expected. The section just exposed at North Sea Landing therefore seems to indicate the position of a pre-Glacial outlet on Flamborough Headland, which has not previously been described. This had been partly filled in by chalk 'wash' in early Glacial times; the whole valley had subsequently been blocked by drift during the Great Ice Age, and had since remained hidden until exposed by the recent landslip.

VI.—THE DEVELOPMENT OF URALITE AND OTHER SECONDARY AMPHIBOLES: A BRIEF HISTORY OF RESEARCH IN THAT SUBJECT.

By ALBERT WILMORE, D.Sc. (Lond.), F.G.S.

IN the year 1831 the famous mineralogist and chemist, Gustav Rose, described a mineral which he had observed in his travels in the Urals the previous year.³ He pointed out that he had found in the greenstones of the Urals crystals with the cleavages and the prism angle of hornblende, but with the external form of augite. The porphyritic crystals of these greenstones are sometimes hornblende, sometimes augite.

In a greenstone near Bogoslawsk, 437 versts north of Ekaterinberg, there are large dark crystals of hornblende with perfect cleavage. They have also the crystal form of hornblende, showing typical symmetrical six-sided sections with two angles of $124\frac{1}{2}^\circ$ when the section is transverse to the ortho-axis, and angles of $156\frac{1}{2}^\circ$ when the section is parallel to that axis. There is often a core of augite, and in the larger crystals this core is surrounded by a comparatively narrow zone of dark hornblende. In the smaller crystals the augite core is very small and sometimes it is quite wanting. To these crystals of hornblende, so clearly derived from augite by some alteration, he gave the name of *Uralite*.

¹ See *The Naturalist* for 1904, pp. 54–6.

² *Quart. Journ. Geol. Soc.*, August, 1891, pp. 384–431.

³ *Pogg. Ann.*, 1831, Bd. xxii.

In giving reasons for the grouping of hornblendes and augites into one family, he called attention to the fact that when hornblende is fused in a platinum or graphite crucible, crystals result which have the form of augite. Augite crystals are found in slags, but never hornblende crystals. The melting-point of hornblende is lower than that of augite. In 1833 Rose gave further localities for uralite.¹

Meanwhile Professor Glocker had cast doubts on the secondary origin of this uralite; he had suggested that it might be due to hornblende enclosing, in crystallizing, a core of augite, or that an original crystal of augite had had a zonary growth of hornblende formed round it (Schwegger's *Jahrbuch*, Bd. v, p. 373). Rose replied to these suggestions, and insisted on the unity of the augite and hornblende families. He also gave further localities for secondary hornblende.² Rose then discussed the question whether hornblende and augite should be considered as two dimorphous substances, and he showed that though their chemical composition is very similar it is not identical. Later on he suggested the possibility of the change from augite to hornblende being due to the higher oxidation of the ferrous oxide of the augite.

These observations of G. Rose are the first systematic descriptions of a secondary mineral, and are the precursors of much important work in connexion with changes in the minerals of rocks which could only be carried out after the application of the microscope to petrological study.

The subject does not seem to have attracted much attention until the era of microscopic petrology had dawned, but from 1876 onwards one finds a continuous series of important papers dealing more or less directly with uralite.

In 1876 J. A. Phillips called attention to the "pseudomorphic origin" of many of the minerals of the greenstones of Western Cornwall.³ Some of the rocks are gabbros or dolerites, in which the original constituent minerals are occasionally, to a great extent, unchanged, but are sometimes almost entirely represented by "pseudomorphic forms".

In the same year S. Allport described the rocks surrounding the Lands End mass of granite.⁴ Allport made an interesting observation which shows that he regarded the process as almost entirely one of paramorphism. "The alteration that has taken place appears to be the result of internal rather than of external action; in other words, it must have been caused by a more or less complete decomposition and re-arrangement of mineral substances in situ, and not to any great extent by the introduction of new material from without."

This seems to have been one of the first suggestions, that the production of hornblende by change from augite is one of simple paramorphism, an idea which was afterwards developed more fully, especially by G. H. Williams. As will be seen later, it does not now seem feasible to regard the change as of so simple a nature, at any

¹ Pogg. Ann., Bd. xxvii, pp. 97-106.

² *Ibid.*, 1834, Bd. xxxi, pp. 609-22. Dana gives the date as 1831.

³ Quart. Journ. Geol. Soc., 1876, vol. xxxii, pp. 155-78.

⁴ *Ibid.*, pp. 407-27.

rate in the majority of cases. Rose's original suggestion, though only touching one aspect of the possible chemical changes, was nearer the truth.

In 1880 von John described Flysch gabbros from Bosnia ("Über Kryst. Gest. Bosniens": Jahrb. der k.k., etc., Vienna, 1880), and he stated that the kind of secondary hornblende produced depends upon the composition of the original pyroxene. Brown hornblende results from the alteration of dark diallage, but green hornblende from the alteration of green diallage. The secondary brown hornblende is very strongly dichroic, but the hornblende derived from the light-green diallage is fibrous and almost colourless. The hornblende passes by further change into chlorites.

Cohen (*Sammlung von Mikrophot. von Mineralien u. Gest.*, Stuttgart, 1884) illustrated the development of uralite in his pl. xlvii, figs. 1-4. Fig. 1 shows the beginning of uralitization in the periphery of a crystal, and is taken from a micro-section of the so-called uralite-porphyr from Predazzo in the Tyrol. Fig. 2 shows the beginning of uralitization in the central part of a crystal, and is from a 'proterobase' from near Audlan in the Vosges. Fig. 3 shows complete uralitization; section parallel to the vertical axis, and is again from the uralite-porphyr of the Tyrol. Fig. 4 shows complete uralitization; section nearly at right angles to the vertical axis. It is from the so-called uralite-porphyr of Miask in the Urals. The form is augite, the cleavage that of hornblende.

An important work is Lehmann's study of the crystalline schists of Saxony, etc.¹ In ch. xiii, p. 191, which deals with gabbros and amphibole rocks (Amphibolgesteine), he mentioned a series of secondary minerals, among which are amphibole, saussurite, magnesia-mica, etc. He described the change from pyroxene to amphibole as one of paramorphism. Later, p. 197, he described amphiboles of secondary origin, which are sometimes like smaragdite, sometimes like actinolite. The amphiboles and other secondary minerals are due in part to pressure. An important observation is that the formation of magnetite often accompanies that of amphibole derived from hypersthene rich in iron.

We now come to the very important series of contributions made by Professor Judd during the years 1885-90. Though not the earliest of the series it may be well to take first the Presidential Address to the Geological Society of London in 1887.² This address deals with the morphology, physiology, chorology, and ætiology of minerals. In the section treating of the physiology of minerals Professor Judd pointed out the importance of recognizing the different *structure-planes* of crystals. The most obvious of these are the *cleavage-planes*. These, however, are not the only latent structure-planes in crystals. Brewster, Reusch, and Pfaff had shown long ago that when crystals are subjected to pressure in certain directions their molecules appear to glide over one another along certain definite planes within the crystal, and if we examine optically a crystal which has been treated

¹ *Untersuchungen über die Entstehung der Atkrystallinischen Schiefergesteine*, Bonn, 1884.

² Quart. Journ. Geol. Soc., vol. xliii, p. 68 et seq.

in this manner it is actually found to exhibit a series of twin-lamellæ arranged parallel to the so-called *gliding-planes*.

There is still a third and even more subtle set of structure-planes in crystals, those, namely, for which the name of *solution-planes* has been proposed.

In the section dealing with the 'ætiology' of minerals (the causes by which the existing forms, capabilities, and position of minerals and rocks have been determined) Professor Judd compared the change from unstable monoclinic sulphur—by a pressure of 5000 atmospheres—to the stable rhombic form, and that of yellow mercuric iodide, by simply rubbing, into the stable red tetragonal form, with the "paramorphic change of pyroxene into hornblende, which is so frequently exemplified in the earth's crust".

In the next paper to be noticed he explained his now well-known theory of schillerization, and showed the connexion between this process and the planes of discontinuity in crystals.¹ This paper is of importance in connexion with uralitization, as it deals to some extent with augite, diallage, and the amphiboles, and the changes set up in the pyroxenes.

The difference between minerals found at great depths and the same minerals found near the surface is sometimes original—due to pressure and slow growth—sometimes secondary, such as the bands of fluid enclosures, the avaturine structure, and the chatoyant phenomena.

The same phenomena, but more closely connected with the subject of this paper, were further elucidated in a paper by Professor Judd in 1890.² In that paper he reviewed the work of Mügge on the diopsides of Ala, of Phillips and Teall on the Whin Sill augites, and showed that augites in the Tertiary basalts of Ardnamurchan present the same features, viz. lamellar twinning parallel to the basal plane (001) and not parallel to the orthopinacoid (100). According to the work of Mügge this may have been caused by pressure. The lamellar twinning or parting of diallage, parallel to the orthopinacoid (100), is due to solution acting along the solution-planes.

There is one other paper by Professor Judd which should be included in this important series.³ This paper deals with a pyroxene-felspar rock at Odegaarden, near Bamle, in Norway. This rock has been converted into hornblende-scapolite rock. M.M. Fouqué and Michel-Lévy had shown that by fusion (with a trace of sodium fluoride) and slow cooling this hornblende-scapolite rock is, in turn, converted into a pyroxene-felspar rock.

The change of felspar into scapolite may be followed step by step. The solvent which attacked the felspar crystals along their solution-planes, and which acted under statical pressure, contained sodium

¹ "On the relation between the Solution-planes of Crystals and those of Secondary Twinning, etc.: a contribution to the Theory of Schillerisation": *Min. Mag.*, 1887, vol. vii, pp. 81-93.

² "On the relation between the Gliding-planes and the Solution-planes of Augite": *Min. Mag.*, 1890, vol. ix, pp. 192-6.

³ "On the process by which a Plagioclase Felspar is converted into a Scapolite": *Min. Mag.*, 1889, vol. viii, pp. 186-98.

chloride. The felspars of this Oodegaarden rock evidently became saturated along their solution-planes with sodium chloride in solution, and the effect of the internal stresses in the rock masses was to “bring about those chemical reactions by which the felspar-molecules were broken up and their materials united with the sodium chloride to form scapolite”.

The pyroxene has undergone a precisely parallel series of changes. The original pyroxene was very nearly colourless, probably an enstatite. It was converted into a schillerized ‘bronzite’ by enclosures parallel to a pinacoid. This pale-coloured bronzite is, in places, found to be acquiring the characteristic colour, pleochroism, and absorption of brown hornblende.

The last stage in the change of the Oodegaarden pyroxene is seen in certain crystals which, around their edges and in certain patches in the middle, exhibit the full pleochroism, the absorption, and the characteristic cleavage of hornblende. This is often accompanied by ‘granulation’ of the broad plates of the original pyroxene. The original rock appears to have a perfectly granitic structure, but the derived hornblende-scapolite rock has a granulitic structure.

The effects produced are the results—

- (1) of chemical action resulting from statical pressure (schillerization) ;
- (2) of changes induced by the internal stresses set up in a rock during its deformation in the act of flowing (dynamo-metamorphism).

Professor Judd described the change from pyroxenes to hornblende as a ‘paramorphic’ one, but that from felspar to scapolite as a ‘pseudomorphic’ one.

Two important papers of a different type by Professor Judd may now be noticed. The first of these is his well-known paper on the Peridotites of Scotland.¹ In this paper he gave a classification of pyroxenes with ‘Schiller’ varieties, which is here reproduced.

	<i>Unaltered forms.</i>	<i>‘Schiller’ varieties.</i>	<i>More altered forms.</i>	
Enstatites (<i>Rhombic</i>)	{	Enstatite proper	Diaclastite ?	
		Proto-bronzite	Bronzite }	
		Proto-hypersthene	Hypersthene }	
			Talc ?	
Augites (<i>Monoclinic</i>)	{	Amblystegite	Hypersthene	Bastite
		Diopsides	Diallage and	Green diallage
		Augite proper	Pseudo-	and
		Hedenbergite	hypersthene	Smaragdite

An interesting alteration series is given on p. 381 of this paper—

Augite, diallage, green diallage	{	Smaragdite Actinolite and similar hornblendes.
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On p. 386 he distinguished ‘weathering’ changes which produce kaolinization, uralitization, serpentinization from the changes which produce schillerization. The latter is deep-seated, the others are not deep-seated.

The next paper of Professor Judd deals with the Tertiary Gabbros in Western Scotland and Ireland.² In it he emphasized most strongly

¹ “On the Tertiary and older Peridotites of Scotland”: Quart. Journ. Geol. Soc., 1885, vol. xli, pp. 354-418, pls. x-xiii.

² Quart. Journ. Geol. Soc., vol. xlii, p. 49 et seq.

the unstable nature of the minerals of the basic rocks. The felspars are found changed into saussurite, the augites into hornblende, the olivine into serpentine and magnetite. Still further changes may have taken place by which the rock is converted into hornblende schist or gneiss.

Almost contemporary with this important series of papers were several contributions by Dr. Teall. Of these the first was an oft-quoted paper on the Metamorphism of a Dolerite Dyke into a Hornblende-schist.¹ At Scourie in Sutherlandshire occurs a dyke of hornblende-schist, which is clearly the result of metamorphism of a dolerite. In this paper Dr. Teall made a number of very important observations relative to such questions as the various stages in the development of the secondary hornblende and the production of foliation.

Of the two minerals, augite and hornblende, the former appears to be the stable form at high temperatures, the latter at low temperatures, "so that any condition tending to facilitate molecular readjustment must necessarily tend to facilitate the change from augite to hornblende. The enormous pressures brought into operation in the process of mountain-making may not unreasonably be supposed to supply such conditions."

Analyses of the dolerite of the hornblende-schist are given, but apparently the only safe conclusions from percentages which are very similar in the two cases are—

- (1) That the change has almost been one of simple paramorphism.
- (2) That there may have been some conversion of ferrous into ferric oxide.

Dolerite	$\left\{ \begin{array}{l} \text{Fe O} \quad . \quad . \quad 14\cdot71 \\ \text{Fe}_2 \text{O}_3 \quad . \quad . \quad 2\cdot47 \end{array} \right.$	Hornblende- schist	$\left\{ \begin{array}{l} \text{Fe O} \quad . \quad . \quad 11\cdot71 \\ \text{Fe}_2 \text{O}_3 \quad . \quad . \quad 4\cdot35 \end{array} \right.$
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In a paper dealing with some minerals from the Lizard,² Dr. Teall described a (probably) secondary hornblende, a very pale variety occurring in a gabbro-schist at Pen Voose. This was analysed by Mr. J. H. Player.

Si O ₂ 48·8	Ca O 12·2
Al ₂ O ₃ 10·6	Mg O 18·6
Fe ₂ O ₃ 1·7	Ignition loss 1·8
Fe O 4·7	

On this analysis Dr. Teall remarks: "If this hornblende be secondary, then its composition does not bear out the view that secondary hornblende is derived from pyroxene by a paramorphic change."

In 1885 Dr. Hatch³ described gabbros passing into amphibolites, the alteration series being—

Normal gabbro, hornblende gabbro, amphibolite, epidote rock.

Another alteration series is suggested, as follows:—

Normal gabbro, uralite gabbro, actinolite or nephrite-schist, serpentine.

¹ Quart. Journ. Geol. Soc., 1885, vol. xli, pp. 133-45.

² "Notes on some Minerals from the Lizard": Min. Mag., 1888, vol. viii, pp. 116-20.

³ "Über den Gabbro aus der Wildschonau in Tyrol," etc.: T.M.P.M., 1885, Bd. vii, pp. 75-87.

Pressure is clearly seen to have been effective in converting the diallage into hornblende. The crystals of the former were bent, stretched, and partly destroyed. Hornblende is developed along the cracks in patches and round the edges. A large quantity of magnetite has been developed as the result of the change from diallage to hornblende. The extent to which secondary hornblende has been produced is a measure of the schistose character developed in the rock, until, with complete change of the original diallage to hornblende, an amphibolite or nephrite-schist is produced.

The next contribution to be noticed is that of Harker in his Sedgwick Prize Essay of 1888.¹ In ch. vi, on Diabase Sills, etc., it is pointed out that the augite has fringing growths of hornblende, these also traversing it in strings and sometimes extending into the decomposed felspar. This secondary amphibole is always in crystalline relation with the augite from which or in which it grows.

The pseudomorphic hornblende is for the most part truly secondary in the ordinary sense of the word. In one or two examples, on the other hand, there are appearances which suggest that the amphibolization may have begun before the final solidification of the rock, e.g. when a grain of augite is seen partly pseudomorphosed by hornblende which is in crystalline continuity with hornblende moulding the grain.

We now come to some of the more important papers from the pens of the American petrographers. First among these may be taken a paper by G. H. Williams.² This a very suggestive paper. It is pointed out that pyroxene and hornblende are two different crystallographic forms of essentially the same molecule. Some experimental work is reviewed. In 1824 Mitscherlich and Berthies melted *tremolite* at the Sèvres pottery works and found that augite resulted on slowly cooling. G. Rose in 1831 had performed a similar experiment with actinolite from the Zillerthal. Fouqué and Michel-Lévy have since corroborated. A second paper by Williams in 1890³ contains important suggestions upon the whole question of secondary amphiboles. This memoir is intended as a contribution to the study of dynamic or regional metamorphism.

Of the various types of alteration discussed, uralitization occupies a prominent place. It is made to include the derivation of any hornblende, fibrous or compact, from pyroxene. In discussing this process it is pointed out that though it has often been referred to as one of paramorphism it is more than that in many cases. Forehammer, Rose, and Svedmark have shown that when augite changes to fibrous hornblende, magnetite and often calcite are separated out between the needles.

Williams pointed out that Harrington, of Montreal, had analysed three stages in the alteration from pyroxene to a secondary fibrous hornblende, and found that during the change there was a loss of lime

¹ *Bala Volcanic Series of Caernarvonshire*, Cambridge University Press, 1888.

² "On the Paramorphosis of Pyroxene to Hornblende in Rocks": *Amer. Journ. Sci.*, 1884, vol. xxviii, No. 16, pp. 259-68.

³ "The Greenstone Schist Areas of the Menominee and Marquette Districts, Michigan": *Bull. U.S.G.S.*, 1890, No. 62.

and a gain of magnesia. (This change is, however, far from constant. See, e.g., Teall on the Scourie Dyke.)

It was further pointed out that the schistose structure of the rocks is largely due to the production of fibrous hornblende. This secondary fibrous hornblende does not remain in the area formerly occupied by the pyroxene; amphibole needles are even found along the cleavage cracks of the felspars. Some other points from this important memoir are—

(1) Brown hornblende passes into green hornblende by the reduction of its iron from the ferric to the ferrous state; afterwards loss of iron produces fibrous and less coloured hornblende.

(2) Very often there is a double hornblende zone round a pyroxene core; first (inner) brown and more compact hornblende, then green and more fibrous hornblende.

Another important United States monograph is that of F. D. Chester.¹ He distinguished between tremolite and fibrous green hornblende in his remarks on rocks at Iron Hill. Tremolite is evidently regarded as colourless or nearly so. Fibrous green hornblende surrounds hypersthene cores, and tremolite fibres are developed irregularly within the core. Much magnetite is set free as the result of the change, which Chester described as a paramorphic one.

It is pointed out that 'uralite' is used in an ambiguous way—

(1) To indicate a substance with the external form of augite, but the cleavage and optical properties of hornblende.

(2) Fibrous hornblende is loosely described as uralite.

The three papers by W. S. Bayley on the Basic Massive Rocks of the Lake Superior Region necessarily contain several references to uralite and uralitization.² The first of these papers gives an interesting history of the classification of the gabbros from the time of Haüy. The third article contains an account of the different structure-planes noticeable in some of the augites. Diagonal cleavages are accentuated by dark decomposition products, the most abundant of which are tiny irregular black and brown dots. These are scattered everywhere throughout the pyroxenes, but are accumulated most thickly in the neighbourhood of the cleavage lines. Peculiar platy inclusions characteristic of gabbro-diagonal are seen in some of the pyroxenes. These are often arranged in straight lines crossing the parting-planes. They are frequently so crowded that the line of inclusions appears as a dark bar crossing the diagonal at various inclinations to the cleavage.

In 1888 A. C. Lawson, of the Canadian Survey, made some contributions to our knowledge of the subject.³ In a chapter on the Petrography of the Keewatin Series he pointed out that the pyroxene of rocks of the gabbro type is more resistant to 'paramorphic change' than the augite of the diabases. Shreds of fibrous hornblende or actinolite derived from augite are observed to have been developed within the substance of the fresh plagioclase, and along its line of

¹ "The Gabbros and Associated Rocks in Delaware": Bull. U.S.G.S., 1890, No. 59.

² *Amer. Journ. Sci.*, 1893, vol. i, pp. 433, 587, 688.

³ Report on the Geology of the Rainy Lake Region: Geol. and Nat. Hist. Surv. of Canada, Montreal, 1888.

contact with the augite. In another part he noticed that secondary hornblende, chlorite, and epidote have been developed very extensively along cleavages and cracks of the fresh plagioclase.

The recent Survey memoir dealing with the north-west of Scotland¹ contains numerous references to the subject. It is shown that hornblende is sometimes compact and gives no evidence of secondary origin, but on the other hand *much* of the hornblende is evidently secondary after pyroxene. Some of the hornblende-felspar rocks of the Lewisian gneiss show hornblende with pyroxene cores (p. 62). The basic dykes and sills also show much secondary hornblende. The famous Scourie Dyke (*vide ante*) is quoted as an example.

The presence of pyroxene cores in hornblende, the occurrence of needles of hornblende in the felspars (p. 93), the extension of the hornblende individuals parallel to the direction of shearing are observations similar to others already noted. Granulation of pyroxene is also noticed.

The larger textbooks of mineralogy and petrology have, of course, devoted some space to a consideration of this subject. Zirkel, in his *Lehrbuch der Petrographie*,² discusses "Secundäre Amphibole" at some length. There is a good general summary of the chief observations followed by a discussion of the nature of the chemical changes involved. One observation is worth reproduction. Schwerdt (*Zeit. Geol. Ges.*, 1886, p. 225) records a case of Chinese diorite in which uralitization has commenced in the middle of the augite crystals so that green fibrous hornblende is seen to be surrounded by an envelope of compact augite.

In the chemical discussion it is emphasized that the passage from pyroxene to amphibole is more than a mere paramorphism; it is a change of augite substance into hornblende substance. The analysis of the Ottawa uralite by Harrington is given (*vide ante*). This shows a loss of CaO of 9 per cent. and a gain of MgO of $3\frac{1}{2}$ per cent. There is an increase of both ferrous and ferric oxides. There is also an analysis of a uralite derived from the pyroxene of a gabbro from Zwartekoppies (Dahms). This shows a *gain* of CaO of 6 per cent., a loss of MgO of 6 per cent., and a gain of FeO of 3 per cent. These results are obviously quite contradictory, but it is pointed out that the first case concerns a basic rock rich in lime (24.44 per cent.), while the second deals with a rock poor in lime and rich in magnesia and iron oxides.

The deposit of needles and microliths of hornblende in the felspars of many rocks — the so-called erratic (*gewanderte*) hornblende — receives fairly full treatment, and there is a series of references.

Quite recently MM. L. Duparc & T. H. Hornung³ have made a most interesting contribution to the literature of this subject. Their paper is entitled "Sur une nouvelle théorie de l'ouralitisation". They describe the alteration noticed in a fine series of rocks collected in the Northern Urals. These rocks are very 'fresh' and are made up of

¹ "The Geological Structure of the North-West Highlands of Scotland": Mem. Geol. Surv. Great Britain, 1907.

² 1893, vol. i, p. 316 et seq.

³ C.R. Acad. Sci. Paris, vol. cxxxix.

basic labradorite, pyroxene, green hornblende, and magnetite. All the forms and stages of uralitization may be seen, and it is possible to separate completely specimens of the almost unaltered pyroxene and the almost fully uralitized mineral. The results of the mean of two concordant analyses of these extreme cases are given.

	Pyroxene, D. 3-358.	Amphibole, D. 3-213.
Si O ₂	50.91	43.34
Al ₂ O ₃	2.64	12.60
Fe ₂ O ₃	—	10.44
Fe O	10.07	7.92
Mn O	Traces	Traces
Ca O	23.33	13.06
Mg O	13.30	12.60
K ₂ O	—	0.02
N ₂ O	—	1.90
Loss on heating	—	0.22
	100.25	102.10

The authors claim that these analyses dispose of the idea of a dimorphous molecule, and that the remarkable freshness of the rocks preclude any idea of hydrochemical processes. The examination of a great number of sections shows that the manner of the uralitization depends upon the permeability of the pyroxene. If the latter are impermeable the change is only peripheral; if, however, there exists in the pyroxenes “une ligne de pénétration ou un accident quelconque dans la structure” the uralitization is internal. This is interpreted as showing that the pyroxenes after crystallization have been acted upon by the still liquid magma. The primordial magma has first of all allowed the crystallization of pyroxene and basic feldspars. Before the complete consolidation of the rock the bath has been modified in composition by the action of mineralizing agents. The bath, thus modified, has reacted upon the pyroxenes, enriching them in alumina and in iron and depriving them of some lime.

It appears probable that the explanation of Duparc & Hornung applies only to certain cases, otherwise one would expect uralitized pyroxenes to be as common in recent rocks as in more ancient igneous rocks, whereas it has over and over again been pointed out that uralitization is rarely found in the more recent basic rocks. The suggestion at once occurs that uralitization is a general term which has been used to describe more than one type of mineral alteration. These types may be tentatively summarized as follows:—

(1) The alteration of diallage to uralite by the action of hot liquids under pressure and at high temperature and containing various dissolved salts, these liquids having penetrated the various planes of discontinuity in the crystals. In this way brown or green more or less compact hornblende may be produced according to the nature of the original pyroxene and the composition of the penetrating fluid.

(2) The alteration of compact secondary hornblende to fibrous actinolite or tremolite, by the gradual leaching out under conditions of moderately high pressure and temperature of more or less of the iron. This process seems to take place in the upper part of the zone of katamorphism, while the former process seems to be characteristic of the lower part of that zone.

These two processes cannot, of course, be sharply separated. There is every possible gradation and combination of the two. The second process may have proceeded to some extent, and then the former may be superimposed, with the result that, in some cases, there has clearly been a passage from pyroxene through fibrous hornblende to compact brown or green hornblende.

(3) There may be magmatic resorption and corrosion of pyroxenes with the result that amphiboles of various kinds, usually aluminous hornblendes, are formed on the periphery, and along and near the planes of penetration, and in the extreme case there may be complete magmatic reconstruction of the pyroxene into hornblende. When this extreme result has been reached it will be clearly impossible to determine the 'secondary' character of the hornblende unless there is a series of partially resorbed crystals to act as a guide. It is, of course, possible to describe such a hornblende as original.

This will probably take place in the zone of anamorphism, and in the upper part of that zone; while the converse change may be looked for in the lower part of that zone, and amphiboles of specific gravity 3 to 3·3 may be converted into pyroxenes of specific gravity 3·2 to 3·5 approximately.

Note I, on Melting-points of Pyroxenes and Amphibole.—The following results have been published by the authors named:—

	<i>Cusack.</i>	<i>Doelter.</i>	<i>Brun.</i>
Augite	1187°	1085°	1230°
	1199°	1200°	
Hornblende	1187°	1065°	1060°
	1200°	1155°	1070°

Cusack: vide *Roy. Ir. Acad.*, vol. iv, pp. 399–413.

Doelter: *Tscherm. Min. Petr. Mitth.*, vols. xx–xxii; *Physikalisch-Chemische Mineralogie*, pp. 99–100.

Brun: *Arch. Sci. phys. et nat.*, Geneva, vol. xiii, pp. 352–75.

Vogt, Day, and others have obtained much higher melting-points for the simple pyroxene diopside, up to 1375°.

Allen, Wright, and Clement (*Amer. Journ. Sci.*, vol. xxii, pp. 385–438) give 1521° as the melting-point of the high temperature stable form of the Mg Si O₃. Instead of simply regarding this simple metasilicate as dimorphous they regard it as tetramorphous, as follows:—

Monoclinic pyroxene; rhombic pyroxene (enstatite);
 Monoclinic amphibole; and rhombic amphibole.

The pyroxenes are stable at high temperatures, the monoclinic form being the most stable; the amphiboles are low temperature minerals, and probably change into stable pyroxenes at high temperatures. Hence we can understand the formation of pyroxene from amphibole as recorded by Lacroix in the lavas of Auvergne. (See also Harker, *The Natural History of Igneous Rocks*, Methuen, 1909, pp. 155–8.)

Note II, the Angle Relations of Augite and Hornblende.—Take the average prism angle of augite as 87½° and that of hornblende as 124½°. Now take half of each of these angles. The following important relation is now evident:—

$$\tan 62\frac{1}{4}^{\circ} \text{ is approximately } 1\cdot90,$$

$$\tan 43\frac{3}{8}^{\circ} \text{ is approximately } \cdot95.$$

That is, the tangent of half the prism angle of hornblende is twice the tangent of half the prism angle of augite.