with respect to that from Long Sleddale. Mr. Harker had informed him (the speaker) that 'giant spherules' occurred with perlitic structure inside; in this case it was difficult to imagine the formation of the spherules subsequent to the consolidation of the rock.

Alluding to Mr. Watts's discovery of a structure resembling perlitic structure in quartz, the speaker deprecated the custom, somewhat rife among geologists, of giving too restricted definitions. If a structure so like perlitic structure as to be practically undistinguishable from it occurred in quartz, it might also occur in other crystalline material.

Dr. J. W. Gregory was, like Mr. Marr, not satisfied that the spherulites in the Long Sleddale rock were later than the perlitic cracks, as such cracks often end off against solid inclusions in the glassy lava. In the Yellowstone Park cases the spherulites are often old ones in a re-fused lava, and the perlites have bent round them. The figure of the Buschbad case is also not conclusive, as some points in the figure suggested that the perlitic cracks might be the earlier.

The Author, in reply, again pointed out what he regarded as the order of sequence of the different structures in the rocks described, and alluded to the sections exhibited by Mr. Watts, in which a structure, seemingly perlitic, traversed crystals of quartz. He doubted whether these cracks were really to be regarded as identical with true perlitic structure. In reply to Mr. Marr, he stated that he had never met with any case in which a perlitic fissure was interrupted and abruptly cut off by a previously-formed spherulite, but cited instances in which such fissures accommodated themselves to the surfaces of comparatively large spherulitic bodies. He also briefly replied to Dr. Gregory's remarks.

3. *The* Basic Eruptive Rocks *of* Gran. (A Preliminary Notice.)

By W. C. Brögger, Ord. Professor in Mineralogy and Geology in the University of Christiania, For. Memb. Geol. Soc. (Read November 22nd, 1893.)

Contents.

I. Introduction.

Ever since the beginning of the present century, when the first pioneers in the geological exploration of Norway (Keilhau, Hausmann, Leopold von Buch, and Naumann) investigated the Christiania region, the igneous rocks of that district have been famous as being of more than common interest, as well from the many unique and remarkable rock-varieties as from the exceptionally instructive development of contact-metamorphism produced by the eruptions, and first brought to notice in this region through the observations of Keilhau, Naumann, and Kjerulf.

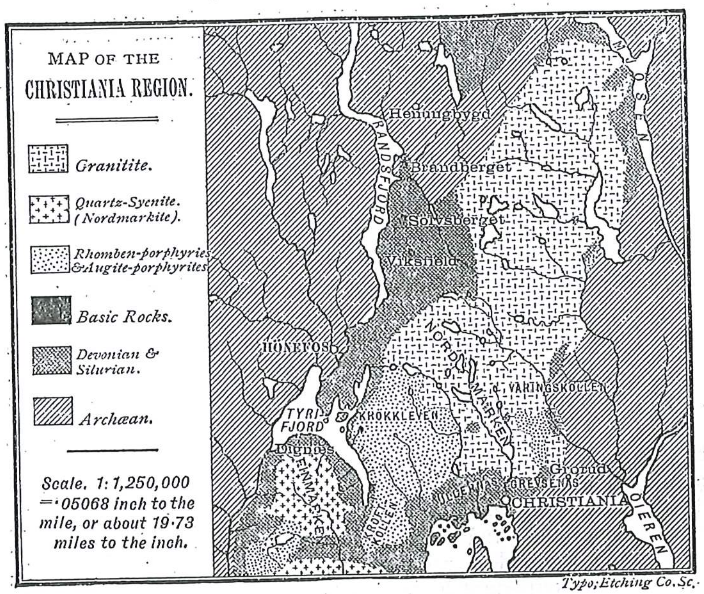
In several preliminary communications[1] on the igneous rocks of the Christiania region I have attempted to prove that all the numerous different masses of eruptive rocks within the sunken district between Lake Mjösen and the Langesundsfjord are genetically connected, and have followed each other in a regular succession; the oldest rocks are the most basic, the youngest (except the unimportant basic dykes of diabase) are the most acid, and between the two extremes I have found a continuous series.

Of late years I have proceeded in a more detailed manner with my investigations of the igneous rocks of the sunken tract of country in the Christiania region. I have not as yet in these studies discovered any facts in contradiction to my previously published observations and the deductions founded thereon. On the contrary, more detailed and minute investigation has only confirmed the correctness of former publications.

[1] 'Ueber die Bildungsgeschichte des Kristianiafjords,' Nyt Mag. for Naturvidenskaberne, vol. xxx. (1886) p. 99. Also, in a detailed address at the meeting of the Association of Scandinavian Naturalists at Christiania, June 1886. A *résumé* was likewise published in my work, 'Die Mineralien der Syenit-Pegmatitgänge der südnorwegischen Augit- und Nephelinsyenite,' Zeitschr. f. Krystallogr. u. Min. vol. xvi. (1890).

I completed in the summer of 1893 a collection of observations for final publication on the oldest basic series of igneous rocks of the Christiania region, and I have now the honour of laying before this learned Society a *résumé* of the most important results of this detailed investigation on the first eruptive series with which the long sequence of volcanic outbursts in the Christiania region commenced in Devonian times.

These oldest eruptions have left a series of interesting plutonic rocks in a number of localities in the parish of Gran, between 50 and 60 kilometres (30 to 35 miles) N.N.W. of Christiania, and near Dignæs, on Lake Tyrifjord, about 35 kilometres (22 miles) W.N.W. of Christiania.

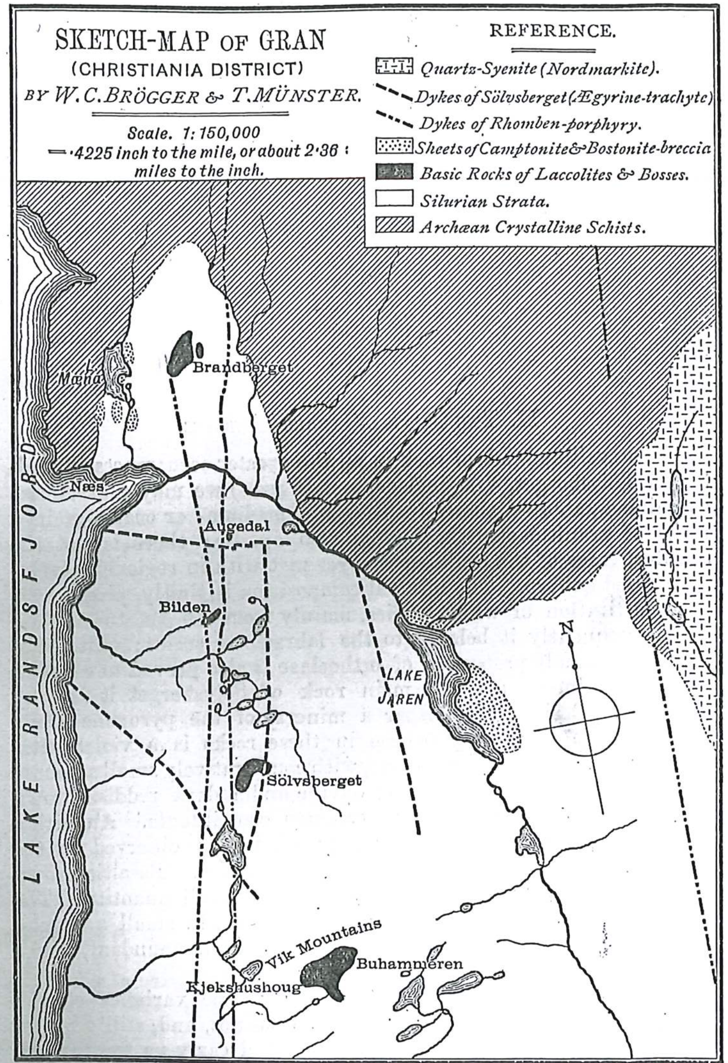


Typo; Etching Co. Sc.

The occurrences in Gran are all situated on a great volcanic fissure-line, in an almost north-and-south direction, parallel with the general direction of the neighbouring Lake Randsfjord, the boundary of the sunken tract in that part of the country. The great fault-lines of Randsfjord cut the Archæan mass of land at Næs in a south-south-west to east-north-east direction. Only a few kilometres east of this fault-line we find the fissure of the basic eruptions indicated by a series of mostly dome-shaped hills. In order, from north to south, they run as follows:—

Brandberget (Brandbokampen), 514 metres (1670 feet) above the sea, an imposing hill.

Subsequently there appear several quite small exposures near Augedal, Solberg, and south of Bilden.



Typo. Etching Co. Sc.

Note.—The numerous dykes of camptonite and bostonite are entirely omitted in the above map, because it would be impossible to represent them satisfactorily on so small a scale.

A more considerable occurrence, Sölvsberget, is there met with (9 kilometres or 5½ miles south of Brandberget), a fine eminence, 484 metres (1575 feet) in height.

Four kilometres (2½ miles) south of Sölvsberget we find the two hills of 'Viksfjeldene' (the Vik mountains), Kjekshushougen and Buhammeren, 537 and 538 metres (1745 & 1749 feet) respectively above the sea-level.

The occurrence at Dignæs, on Lake Tyrifjord, is about 40 kilometres (25 miles) south-west of Buhammeren.

The plutonic rocks in each and all of these localities are closely connected by numerous passage-types, and present a wholly continuous series of basic abyssal rocks. It seems, therefore, impossible to doubt that all these rocks, so closely allied in composition and geological occurrence, have originated from a common source. The limited time at my disposal allows only of a very summary description of the principal varieties.

II. The Olivine-Gabbro-Diabases.

The prevailing kinds of rock in all the greater occurrences (Brandberget, Sölvsberget, Viksfjeldene, and Dignæs) we may characterize as olivine-gabbro-diabases. They are medium- or coarse-grained rocks of granitic structure, often also ophitic; there is not the slightest trace of the ordinary changes met with in regionally metamorphosed gabbro. The mineral composition is, firstly, plagioclase, the constitution of which varies, mainly from Ab_1An_1 to Ab_2An_5, and consequently it belongs to the labradorite series; quite subordinate, a small proportion of orthoclase is also proved to occur in several specimens (in the main rock of Sölvsberget it is very common). Besides the felspar a mineral of the pyroxene group prevails: the common pyroxene in these rocks is a violet, titaniferous, lime-magnesia-pyroxene, with comparatively small amounts of aluminium- and iron-oxides; olivine and a dark reddish-brown biotite (lepidomelane) are both common constituents. An orthorhombic pyroxene (bronzite or hypersthene) is observed in the rock of Sölvsberget, but in very small quantities. Basaltic brown hornblende is rarely present, and then in small quantity. The common iron ores, titanic iron and magnetite, in small amounts, also pyrite, pyrrhotite, and apatite, the last often abundant, make up the rest of the primary components.

A detailed petrographical description of the varieties of the olivine-gabbro-diabase in the different localities, and, still more, a thorough study of all the facies-types, would carry us too far. I shall therefore, on this occasion, confine myself to pointing out the important circumstance that *the prevailing rocks in the different exposures along the fissure clearly change their character in a regular manner from north to south. On the whole, the average basicity of the prevalent rocks can be proved to decrease in that direction.*

In the northernmost locality, Brandberget, the prevailing rock is a very basic olivine-gabbro-diabase, so poor in felspar that it passes into pyroxenite. Jointly with this predominant rock there occur also, to a great extent, typical pyroxenites, often of very coarse grain, besides coarsely radiated hornblendite (with the hornblende-prisms measuring as much as 10 centimetres or 4 inches in length), the latter rather subordinate, and also subordinated hornblende-bearing gabbro-proterobases and other rocks with brown basaltic hornblende. These basic rocks (the pyroxenite, the hornblendite, and the gabbro-proterobase) are traversed by innumerable segregation-veins of a fine-grained augite-diorite or augite-syenite (akerite), which will be further referred to a little later on.

Moreover, in the small exposures of Augedal, Solberg, and Bilden, very basic varieties—pyroxenites combined with camptonites—prevail.

On the top of Sölvsberget a more acid olivine-gabbro-diabase is already the prevalent rock; pyroxenites and other basic rocks are there only observed as rather subordinate contact-facies.

We find the same conditions in the Viksfjeldene, where also more acid segregation-veins of augite-diorite, etc., are widely spread.

The most acid rock is represented in the occurrence at Dignæs; the ultrabasic types are entirely wanting here, the predominant rock being an olivine-gabbro-diabase rich in felspar.

The following analyses (Table I.) serve to illustrate the successive changes in the chemical composition of the prevalent kinds of rock from north to south:—

Table I.

	I.	II.	III.
SiO_2	43·65	47·00	49·25
TiO_2	4·00	2·30	1·41
Al_2O_3	11·48	15·20	16·97
Fe_2O_3	6·32	5·69	15·21 (with FeO)
FeO	8·00	6·59	
MnO	Trace	0·26	Trace
MgO	7·92	8·76	abt. 3·00
CaO	14·00	12·60	7·17
Na_2O	2·28	1·45	4·91
K_2O	1·51	0·66	2·01
H_2O	1·00	0·30	abt. 0·30
P_2O_5	Trace	Trace	0·76
$CaCO_3$	Trace	......	Trace
	100·16	100·81	abt. 100·99

I. Olivine-gabbro-diabase of Brandberget; analysis by L. Schmelck.
II. Do. of Sölvsberget; analysis by Särnström, the alkalies determined by L. Schmelck.
III. Do. of Dignæs; analysis by A. Damm, the alkalies determined by L. Schmelck.

According to an approximate calculation from the above analyses, the mineral composition per cent. may be estimated as follows:—

Table II.

	I. *Brandberget.*	II. *Sölvsberget.*	III. *Dignæs.*
Felspars	about 12	about 46	about 64
Pyroxene	69	26	10
Olivine	5	12½	9
Biotite	3	9½	8½
Iron Ores	7	5	6½
Apatite, serpentine, chlorite, etc.	4	1	2
	100	100	100

The average composition of the three principal varieties of olivine-gabbro-diabase, the iron being calculated as Fe_2O_3 (all analyses calculated free from water, and finally equalized by reducing them to 100 per cent.), is as follows:—

SiO_2	46·48
TiO_2	2·56
Al_2O_3	14·50
Fe_2O_3	14·44
MgO	6·54
CaO	11·23
Na_2O	2·87
K_2O	1·38
	100·00

The olivine-gabbro-diabase of Sölvsberget, as will be thus seen, differs only slightly in composition from the average rock.

The rocks in the northern occurrences of these oldest eruptions in the Christiania region are then, as we have seen, mainly pyroxenic rocks of a basic character, while the southern localities along the same fissure show chiefly felspathic rocks of somewhat greater acidity. Probably the average composition of all the masses of rock in Brandberget differs only slightly from the above-calculated average; on the other hand, it is certain that the average composition of the rocks from Dignæs is more acid than this average. We have, therefore, here a remarkable example of the differentiation of a molten magma in a regular manner *in horizontal direction* along connected fissure-lines. Nor is it the only case of its kind in the Christiania region.

With respect to the geological appearance of these abyssal rocks, I will simply remark that they are only partially of a laccolitic character; as a rule they are enveloped as vertical bosses, the contact-plane often cutting the adjacent Silurian strata.

The small exposure south of Bilden is, on the whole, an inclined laccolitic sheet, the rocks in the same chiefly showing a porphyritic structure and the composition of the camptonite-group, and being only to a slight extent crystallized as pyroxenites. On the Viksfjeldene also the laccolitic character is evident.

As an example of partly laccolitic bosses we will take the case of Sölvsberget.

Sölvsberget is a roof-shaped hill, about 1·5 kilometre (1 mile) in length from north to south, and about 1 kilometre (⅔ mile) in width from west to east; the top is elevated about 250 metres (813 feet) above the surrounding country; the eastern side is very abrupt, the western side more gradually sloping. In its northern and southern parts Sölvsberget is formed of Silurian (Ordovician) strata of étages $4\,a\,\alpha$ and $4\,a\,\beta$ (shales with *Ogygia dilatata*, Brünn, and *Ampyx*-limestone); the main strike is west to east, or west-north-west to east-south-east, the dip generally showing angles varying from 50° to 80°. The central part of the hill is occupied by the eruptive rocks; on the map it will be seen that their surface, in horizontal projection, has a boomerang-like shape; in the south-western part the strata are vertically traversed by the plutonic rock; in the middle of the 'boomerang' the eruptive rock appears to be conformably injected between the shales; but in the eastern part the eruptive surface suddenly sinks to a lower level, and seems there partly to be of a laccolitic character. The whole surface occupied by the plutonic rocks is only 0·3 square kilometre (75 acres).

III. The Effects of Contact-metamorphism by the Olivine-Gabbro-Diabase.

In all occurrences of these plutonic rocks we find a typical abyssal contact-metamorphism, the peripheric extent of which depends on the size of the plutonic masses in the different localities. At Sölvsberget the alteration of the Silurian strata is perceptible at distances of 200 or even 300 metres (220 or 330 yards) from the boundary on the eastern side of the hill, where the strikes of the stratified rocks and of the eruptive boss run in nearly the same direction; in the south-east the observed alterations terminate much nearer to the eruptive rock.

The unaltered rocks of Sölvsberget are the common, black to dark grey, argillaceous shales of étage $4\,a\,\alpha$ (*Ogygia*-shales), with a few interbedded lenticular masses of limestone. By the contact-metamorphism the shales, as usual, are altered into dark violet hornstones, shimmering, as we get closer to the boundary, more and more from innumerable small scales of mica, the diameter of which close to the boundary attains several millimetres. In the next zone of alteration the hornstone is macroscopically crystalline, with a grain of medium size, often possessing a very remarkable porphyritic structure, due to crystals of plagioclase more than 5 millimetres (⅕ inch) long. The limestone-lenses are altered into calcareous hornstone (*kalksilikat-hornfels*).

The contact-metamorphism along the boundary of the olivine-gabbro-diabases of Gran is mainly of interest, because the microscopical observations on the altered rocks make it very probable that the previous supposition, as to the independence of the alteration in regard to the composition of the plutonic rock itself, can be proved to be incorrect. I had myself believed till now that contact-metamorphism in strata of the same nature, by otherwise identical conditions, has generally given rise to the same alteration-products—without regard to the 'chemical quality' of the eruptive rock in question. The development of the contact-metamorphism in Gran seems now to prove that this opinion was erroneous.

The short time at my disposal does not allow of a detailed description of all the observations upon which I found my altered opinion. I shall only mention a single fact.

Along the boundary of the basic plutonic rocks of Gran, all of which are comparatively rich in magnesia and iron oxides, the more highly altered hornstones of the *Ogygia*-shales show an essential percentage of hypersthene. I had previously mistaken the mineral for andalusite; it occurs as innumerable small prismatic crystals, but is easily distinguished by its optical characters. To make assurance doubly sure, I have, with considerable difficulty, isolated a small portion of the hypersthene, and have had it analysed by Herr L. Schmelck. The analysis gave:—

SiO_2	48·10
FeO	22·28
MgO	21·83
CaO	2·20
	94·41

The loss is due to a mishap in the course of determination of the silicic acid; adding 5·56 per cent. SiO_2, the above analysis agrees exactly with the composition of an hypersthene, in which the molecular proportions are

$$FeO : (MgO, CaO) = 1 : 2.$$

Now the very same strata of the *Ogygia*-shales, 7 kilometres ($4\frac{1}{3}$ miles) east of Sölvsberget, are altered into hornstones by the influence of the immense masses of quartz-syenite (nordmarkite) extending over the whole district between Gran and Christiania. I have examined a number of specimens of these hornstones from Rånåsen and other localities. In none of them have I discovered the slightest vestige of hypersthene. As is well known, hypersthene or orthorhombic pyroxene is, upon the whole, never observed to have been produced by contact-metamorphism alongside abyssal rocks.

It seems, therefore, that in this case the basic magma of the olivine-gabbro-diabase, as compared with the acid magma of the quartz-syenite, must have influenced, in a peculiar manner, the argillaceous shales of étage 4 *a α* by altering them into hypersthene-bearing hornstones. Whether this special influence is due to a transfer of magnesia and ferrous oxide from the magma, or not, is a problem which can only be settled by a series of analyses as yet unfinished.

In other respects, too, the contact-metamorphism alongside the above-described basic rocks is of interest; but, as this question is apart from my main subject, I must defer observations in connexion therewith to another occasion.

The small and insignificant basic abyssal masses of Gran are not in themselves of sufficient importance to justify me in occupying the time of this Society by describing them. There are, however, other circumstances, not as yet referred to, which give them great interest. They are accompanied by a great series of dykes and sheets, the study of which throws much light on those processes of differentiation which are just at present being made the object of thorough research by petrologists and geologists.

IV. The Camptonites and Bostonites.

Along both sides of the entire fissure-line on which the abyssal rocks are situated, we find an innumerable multitude of dykes and sheets of camptonite and bostonite, two kinds of rock which have formerly been admitted to be closely associated with masses of nepheline-syenite.

Camptonite (lamprophyric dyke-rock essentially composed of basic plagioclase and brown basaltic hornblende, often porphyritic from phenocrysts of the latter mineral) has been previously described from Campton Falls in New Hampshire[1]; Montreal in Canada[2]; Forest of Dean in Orange Co., N. Y.[3]; Fort Montgomery (Fairhaven, Proctor, etc.) in the Hudson River Highlands[4]; Whitehall in Washington Co., N. Y.[5]; Lake Champlain Valley[6]; nearly allied rocks, though hardly typical camptonites, are described from Val Avisio in the Tyrol[7]; Inchnadampf in the Scottish Highlands[8]; Waldmichelbach and other localities in the Spessart.[9]

The name 'bostonite' was introduced by Rosenbusch and applied to dyke-rocks with trachytic structure, essentially composed of felspars without dark minerals; a more detailed description is given by Kemp. Bostonites are known from Marblehead near Boston,[10] Montreal in Canada,[10] Serra de Tingua in Brazil,[11] and from Lake Champlain Valley.[12] In all previously described occurrences the bostonites are connected with different basic dyke-rocks, and with masses of nepheline-syenite (?) in the vicinity; among the associated basic rocks near Montreal and Lake Champlain there are also camptonites.

1 G. W. Hawes, Am. Journ. Sci. ser. 3, vol. xvii. (1879) p. 147.
2 B. J. Harrington, Geol. Surv. of Canada, Report for 1877–78 G, p. 42.
3 J. F. Kemp, Am. Journ. Sci. ser. 3, vol. xxxv. (1888) p. 331.
4 *Id.* 'Amer. Naturalist' for 1888, p. 691.
5 *Id.* and V. F. Marsters, 'Amer. Geologist,' vol. iv. (1889) p. 97.
6 J. F. Kemp and V. F. Marsters, Trans. N. Y. Acad. Sci. vol. xi. (1891) p. 13.
7 Corn. Dölter, Tschermak's Min. Mitth. (1875) pp. 179, 180, 304; A. Cathrein, Zeitschr. f. Krystallogr. u. Min. vol. viii. (1884) p. 221.
8 J. J. H. Teall, Geol. Mag. for 1886, p. 346.
9 Erw. Goller, Inaug. Diss. (Strassburg, 1889).
10 On literature, see Kemp and Marsters, *op. supra cit.* p. 17.
11 M. Hunter and H. Rosenbusch, Tschermak's Min. u. Petr. Mitth. vol. xi. (1890) p. 445.
12 Kemp and Marsters, *op. supra cit.*

In the parishes of Gran, Hole, Modum, etc., in the Christiania region, these rock-varieties are exceedingly abundant; they appear partly as vertical dykes, generally with a north-and-south or north-north-east and south-south-west strike, parallel to the main strike of the fissures, on which the bosses of olivine-gabbro-diabase and other basic abyssal rocks are situated, along the lines Brandberget-Sölvsberget and Buhammeren-Dignæs. In one part they are also arranged as intrusive sheets introduced between the Silurian strata, chiefly close to the surface of the Archæan schists, especially in étages 1 and 2, also in 3 and 4, and less often in the higher étages.

Although the surface in Gran is somewhat obscured, several hundred occurrences, of dykes as well as sheets of camptonite and bostonite, have been observed. As an example of the frequency of the dykes, I may mention that in one area alone (along the Melbostad and Helgum road) I counted more than 50 dykes in $1\frac{1}{2}$ kilometre (1 mile); the total thickness of these dykes I measured to be 70 metres (227 feet), that is 1 metre of dyke-mass in every 20. The thickness of the dykes is commonly $\frac{1}{2}$ to 2 metres ($1\frac{1}{2}$ to $6\frac{1}{2}$ feet); it seldom attains 5 or 10 metres (16 or 32 feet).

The thickness of the sheets is usually also 1 to 2 metres, less often 10 metres or more; however, a great number of intrusive sheets often follow upon each other, which is the reason why the total thickness in several localities may amount to 20 and even 30 metres ($65\frac{1}{2}$ to about 100 feet).

In the vicinity of Brandberget the magma has in preference been intruded as sheets between the planes of the stratified rocks; in the neighbourhood of Sölvsberget, on the contrary, vertical dykes are more prevalent; perhaps this circumstance can be explained by the fact that at Sölvsberget we find only higher étages (such as étage 4) represented.

The camptonites and the bostonites are very intimately connected with each other, and also with the above-mentioned boss-rocks. These connexions are proved by the following facts:—

Firstly, as regards the relation between the bostonites and the camptonites, we may observe that they everywhere appear together in close companionship. Thus, we find innumerable examples of vertical camptonite-dykes associated with immediately adjacent parallel dykes of bostonite; often the same dyke-fissure contains both bostonite and camptonite, and with equal frequency it happens that both rocks appear together as intrusive sheets.

In many bostonite-sheets and dykes we find phenocrysts of brown hornblende, which is the chief mineral among the phenocrysts of the camptonites. I have moreover observed several examples of dykes or sheets in which the centre is bostonite, the sides camptonite, or *vice versâ*. Finally, I have also, but less frequently, observed intermediate kinds between camptonite and bostonite.

Secondly, as to the relation between the eugranitic boss-rocks, on the one hand, and the dyke- and sheet-rocks on the other, we may remark that in Gran and the surrounding parishes the bostonites and camptonites are represented in many hundred dykes and sheets

in the neighbourhood of the above-mentioned basic boss-rocks, whereas other kinds of dykes appear very seldom. I have observed only a small number of rhomben-porphyries (plagioclase-rhomben-porphyry and common rhomben-porphyry, 7 or 8 great dykes partly followed along a stretch of more than 20 kilometres $=12\frac{1}{2}$ miles), mica-syenite-porphyry and ægyrine-syenite-porphyry (Sölvsberget), 8 to 10 greater dykes; finally, a number of diabase-dykes, etc. On the other hand, the dykes and sheets of bostonite and camptonite outside this tract, in which the basic boss-rocks occur, are very sparsely distributed in the Christiania region, and not in the same typical varieties as in Gran parish.

On Brandberget a hornblende-bearing rock, closely allied to camptonite, locally appears as an unquestionable contact-facies of the olivine-gabbro-diabase.

In the small laccolitic sheet south of Bilden camptonite is the main rock; pyroxenite appears here only subordinate and mostly in the central parts; and all the passage-types between camptonite and pyroxenite are found. At Sölvsberget also I have collected a rock of the camptonite-bostonite series, an intermediate type between both extremes, occurring locally as a contact-facies.

The above observations conclusively prove that the camptonites and the bostonites are nearly connected with, and must be derived from, the same magma as the previously-described boss-rocks.

The mutual relation of age between the camptonites and the bostonites is invariably as follows:—

When dykes of bostonite and camptonite cut each other, the former, without exception, is the younger.

In a bostonite (from Lindberget, on Lake Mæna) I have found rounded enclosures of basic masses partly of camptonite, partly of pyroxenite; these enclosures can only be explained as early crystallizations of basic composition in a magma, from which the distinct magma of the bostonite was not yet separated as a final product of the differentiation.

In seven different localities (chiefly in Næs, south-west of Brandberget) there appear considerable sheets of bostonite-breccia; the main localities of these breccias in Næs are situated on the continuation of the great fault-fissures of Lake Randsfjord, and farther north-north-east continued in the fault-crevice along the bed of the Huns river. The breccias are brimful of angular fragments of Archæan schists and Silurian slates (chiefly alum-shales) and limestones of the lowest étages (1–3), all the fragments being cemented by a bostonite groundmass. In several blocks of this breccia I have observed that every fragment is surrounded by a more basic dark-green mass, partly of camptonitic composition; this basic matter, enveloping the angular fragments, is then itself embedded in the scarce bostonitic groundmass. In a similar breccia from Augedal I found a rounded lenticular mass of camptonitic rock $\frac{1}{3}$ metre (13 inches) in diameter; this mass showed, on chemical analysis, an undoubted camptonitic composition.

V. Their Origin by Differentiation.

The above-mentioned relations prove, in my opinion, that the common magma, from which the basic bosses along the lines Brandberget-Sölvsberget-Viksfjeldene-Dignæs are crystallized as olivine-gabbro-diabases and pyroxenites, etc., must have been the same magma as that from which the innumerable dykes and sheets of camptonite and bostonite are derived; and further, that all these dykes and sheets have arisen as the result of a differentiation in the original magma, in such a manner that first a basic portion, corresponding with the camptonitic magma, has been separated out by diffusion, and, subsequently, the remaining more acid magma has furnished the material for the bostonite-dykes and sheets.

If these views be correct, the chemical analyses of the different kinds of rock should give undoubted proofs of the process of differentiation in the original magma; and, in my opinion, they do so.

The calculated average composition derived from the three analyses of the olivine-gabbro-diabases of Brandberget, Sölvsberget, and Dignæs probably indicates very closely the average composition of the original basic magma, which was pressed up during the oldest magma-eruptions in the Christiania region, along the western boundary of the sunken tract. By differentiation in a magma of this composition the separate magmas of the camptonite-, and the subsequent bostonite-eruptions, must have been formed.

I have now caused a series of chemical analyses to be made of camptonites and bostonites from one and the same locality, from both sides of Brandberget: of camptonite from Lindberget on Lake Mæna, at the western base of Brandberget, and from Egge on the south-eastern side; also of bostonite from the same 'cutting' as the analysed camptonite. These analyses (by L. Schmelck) have yielded the following result:—

Table III.

	IV. *Camptonite, Mæna.*	V. *Camptonite, Egge.*	VI. *Bostonite, Mæna.*
SiO_2	40·60	42·05	56·50
TiO_2	4·20	5·60	0·85
Al_2O_3	12·55	12·30	18·14
Fe_2O_3	5·47	3·81	3·12
FeO	9·52	9·52	2·86
MgO	8·96	4·83	1·22
CaO	10·80	11·55	3 38
Na_2O	2·54	2·18	5·28
K_2O	1·19	1·11	1·60
CO_2	2·68	2·68	5·11
H_2O	2·28	2·88	1·26
	100 79	98·51	99·32

All these rocks are from sheets; they are, on the whole, rich in carbonates. Calculating the substances free from water and carbonic acid at 100 per cent. (the iron as Fe_2O_3), we get:—

Table IV.

	IV a. *Camptonite, Mæna.*	V a. *Camptonite, Egge.*	*Average of* IV a & V a.	*Average of eight Camptonite Analyses.*
SiO_2	41·90	44·73	43·31	43·65
TiO_2	4 34	5·95	5·14	4·63
Al_2O_3	12·94	13·08	13·01	16·29
Fe_2O_3	16·57	15·32	15·94	14·76
MgO	9·25	5·14	7·23	5·96
CaO	11·14	12·29	11·71	10·16
Na_2O	2·62	2·32	2·46	3·05
K_2O	1·24	1·17	1·20	1·50
	100·00	100·00	100·00	100·00

In Table IV., parallel with the average of the camptonite analyses from Mæna and Egge, is placed the calculated average of eight different camptonite analyses (from Campton Falls, Montreal, Fairhaven, Proctor, Fort Montgomery, Mæna, Egge, Hougen); and, as will be seen, the differences are not great.

The following table (V.) shows the bostonite analysis from Mæna, calculated in the same manner; for comparison I have calculated the average of two American bostonite analyses (from Shelburne Point and Champlain Valley) published by J. F. Kemp (*loc. supra cit.*). It will be noticed that the American bostonites are richer in potash than the Norwegian.

Table V.

	VI a. *Bostonite, Mæna.*	*Average of two American Bostonite Analyses.*
SiO_2	60·57	60·73
TiO_2	0·91	......
Al_2O_3	19·45	21·00
Fe_2O_3	6·76	3·83
MgO	1·31	0·79
CaO	3·62	4·44
Na_2O	5·66	4·52
K_2O	1·72	4·69
	100·00	100·00

A simple calculation founded on the above data shows that a mixture of 9 parts of the calculated average of the camptonites from Mæna and Egge, and 2 parts of the bostonite from Mæna, would make a composition differing very little from the above calculated (p. 20) average composition of the olivine-gabbro-diabases from Brandberget, Sölvsberget, and Dignæs.

TABLE VI.

	Average of Analyses of		
	Camptonite & Bostonite.	Olivine-Gabbro-Diabase.	Difference.
SiO_2	46·45	46·48	−0·03
TiO_2	4·37	2·56	+1·81
Al_2O_3	14·18	14·50	−0·32
Fe_2O_3	14·27	14·44	−0·17
MgO	6·15	6·54	−0·39
CaO	10·24	11·23	−0·99
Na_2O	3·04	2·87	+0·17
K_2O	1·30	1·38	−0·08
	100·00	100·00	

I am well aware that every calculation of this kind must agree very accurately with actual fact if any importance is to be attached to it; the calculations of rock-compositions as the results of mixtures of a basaltic and a trachytic magma, according to the law enunciated by Bunsen some forty years ago, are in this connexion warning examples. In our case the accordance is very close in all the components, except the titanic oxide and the lime. With respect to the former, I may remark that its percentage varies between wide limits as well in the camptonites as in the olivine-gabbro-diabases. In the camptonites from Mæna and Egge the percentage of titanic oxide is greater than usual, but in the average of the olivine-gabbro-diabases the small proportion of titanic oxide in the rock from Dignæs (see p. 19) lowers the average percentage somewhat considerably. As to the lime, it must be observed that in the olivine-gabbro-diabases the indicated percentage represents the whole of the lime originally saturated with silica; while, in the average of the camptonites and the bostonites, the lime percentage is calculated in rocks from which, by abundant carbonatizing, a portion of the lime originally present has probably been carried away.

These circumstances being taken into account, I am of opinion that the accordance is sufficient; such an agreement cannot be accidental. I think, therefore, I have sufficiently proved that the camptonites and bostonites in Gran have been produced by differentiation of an original common magma, whose *chemical* composition agreed with the average composition of the olivine-gabbro-diabases on the volcanic fissure-lines between Brandberget and Dignæs.

This differentiation can further be proved to have taken place in a liquid magma, even before crystallization of any importance had begun. This appears evident from the striking difference in the *mineral* composition of the olivine-gabbro-diabases on the one hand, and the camptonites and bostonites on the other. In the former, among the minerals—that is, among the first crystallized constituents—pyroxene, olivine, and dark biotite are prevalent, brown hornblende wanting as a rule, or quite subordinate. In the camptonites, on the contrary, the predominant dark mineral is always brown basaltic hornblende, often amounting to more than

60 per cent. of the rock, while olivine and brown mica are often wanting, and pyroxene is invariably subordinate.

We have consequently in the basic rocks of Gran a remarkable example of the fact that one and the same magma *partly* without essential differentiation has been pressed up to a higher level, and there has crystallized out as large boss-masses (in the form of olivine-gabbro-diabase), *partly* has been differentiated at a deeper-seated level into a basic magma (which by its outburst has formed sheets and dykes with porphyritic structure: camptonites), and into a more acid residuary magma (which in the final eruptions has given rise to sheets and dykes of bostonite). This differentiation (into camptonites and bostonites) has partly also taken place in the dyke and sheet-fissures themselves *after* passing up into a higher level.

In order to explain this fact, that one and the same magma has in part been differentiated, in part not, it seems, in my opinion, necessary to assume that *in the latter case the essential cooling of the magma has first taken place in the bosses themselves; while, in the former case, even before the final pressing-up of the magma, an essential decrease of temperature and pressure along the contact-plane of the magma must have taken place in the magma-reservoir.* In this cooling and diminishing of the pressure the magma must have been subject to conditions necessary for producing a tendency to crystallization of the brown basaltic hornblende, although in all probability actual crystallization did not take place. Along the contact-plane there must then have been concentrated by diffusion a liquid stratum essentially containing the components of the brown hornblende. This may be deduced from the fact that the composition of the camptonite derived from this differentiated magma differs but slightly from the probable composition of the brown hornblende,[1] and from the other fact that brown hornblende is actually the essential mineral of the camptonites. These facts then favour the

[1] The analysis of the brown hornblende in the camptonites of Gran is not yet completed. The difference between that and the composition of the camptonite-hornblende published by Hawes is probably unimportant. I refer, therefore, provisionally to his analysis for comparison with the average camptonite-composition:—

TABLE VII.

	Average of ten Analyses of Basaltic Hornblende.	Camptonite-Hornblende (after Hawes).	Average of eight Analyses of Camptonite.
SiO_2	39·88	40·79	43·65
TiO_2	4·86	(not determined)	4·63
Al_2O_3	14·83	17·36	16·29
Fe_2O_3	12·60	20·85	14·76
MgO	12·27	6·97	5·96
CaO	12·68	10·83	10·16
K_2O, Na_2O	3·39	4·17 (diff.)	4·55
	100·51	100·97	100·00

The average of 10 analyses of basaltic hornblende is calculated from those published by Schneider, Zeitschr. f. Krystallogr. u. Min. vol. xviii. (1891) p. 579.

belief that the differentiation of the original magma has, to an essential degree, been dependent on the laws which govern the sequence of crystallization, an opinion already maintained by the author several years ago (1886), and further sustained, chiefly here in England, by Teall.

The most easily crystallizable compounds (the least soluble) of the magma have in the diffusion first accumulated along the cooling margin. In the liquid magma itself the different compounds were probably dissociated, but the degree of dissociation most probably decreased with diminution of temperature and pressure. Along the cooling margin of the magma a concentration of dissociated compounds to less dissociated groups has thus taken place, a concentration probably governed by the laws of chemical affinity (see the views of J. H. L. Vogt). These compounds (not identical with the '*kerne*' of H. Rosenbusch) concentrated by the diffusion of the less soluble and more easily crystallizable substances, under the stated conditions along the contact-margin of the magma, have then still been liquid or at least been liquid in the main. In the camptonites and the bostonites the consolidation evidently first began after the outburst of the magma into the fissures, which it has filled up.

The opinion that the most easily crystallizable compounds have diffused to the cooler portion of the magma and there have generated a magma-stratum of peculiar composition has been doubted on the grounds that the rock crystallized after the eruption does not show a stoichiometric composition[1]; however, it seems quite probable that this objection is not decisive. That, in the case in question, the camptonite-magma differentiated from the olivine-gabbro-diabase-magma has not exactly the same composition as brown hornblende, finds a natural explanation in the fact that the spaces of crystallization for minerals which *can* crystallize out of a magma of given composition are well known to partly cover and transgress each other. A diffusion of the compounds of the brown hornblende, to the cooler margin of a magma of the composition above supposed, could not therefore have formed a magma of a pure hornblendic mixture, but only such a composition mixed with an addition of other compounds in subordinate quantities. This admixture is, however, in our case not of any great importance. Then we also find—agreeing with the fact that the felspar in the camptonites crystallized as a rule *after* the hornblende—that the residuary bostonite-magma after the differentiation of the camptonite-magma (setting aside the unimportant percentage of magnesia, iron oxides, and titanic oxide) shows an almost felspathic composition of medium acidity.

I think I have proved that the camptonites and bostonites in Gran have been differentiated from a magma of the average composition of the olivine-gabbro-diabases which appear in the same tract. If the above-explained hypothesis be admitted, this fact seems not to be at variance with the observations from other countries,

[1] Iddings, 'On the Origin of Igneous Rocks,' Bull. Phil. Soc. Washington, vol. xii. (1892) pp. 89–214.

that the above-mentioned kinds of rock are otherwise connected with nepheline-syenites. With the '*kern*' hypothesis of Rosenbusch, on the other hand, the above proved connexion does not seem to agree.

[*Note.*—For rock-types, differentiated out of a common magma, I propose the name 'complementary rocks'; camptonites and bostonites are, then, such complementary rocks. Between the dyke-rocks we have also a number of other examples.

Complementary rocks should, therefore, in the classification of rocks be placed in that rock-group which has a chemical composition agreeing with the composition of the original common magma of the complementary rocks; minettes and aplites, for instance, are complementary rocks of the granite-family, and so on.—Dec. 30th, 1893.]

VI. Differentiation in the Bosses.

The differentiation of the olivine-gabbro-diabase magma into camptonites and bostonites is not the only one which has taken place in this magma. In the boss of Brandberget we find that the same or a very closely allied magma has, by differentiation under other conditions, given rise here to other products. It is true that a magma of hornblendic composition (partly crystallized as pure hornblendite, partly as a camptonitic rock) was differentiated out from the original magma; but these masses are here quite unimportant. The conditions here have evidently not permitted to any great extent the crystallization of dark aluminiferous minerals, such as brown hornblende; consequently the differentiation of the magma has not allowed the concentration of liquid compounds of analogous composition along the margins of the boss. On the other hand, it seems clear that the ruling conditions have highly favoured the crystallization of *dark pyroxene*, rich in calcium, magnesium, and iron, and relatively poor in aluminium. Agreeably to this supposition we find that, along the margins of the boss, especially in the west and north, there has been differentiated a basic magma of an almost pure pyroxenic composition, which has often crystallized as very coarse-grained *pyroxenite*, with as much as 95 per cent. pyroxene. An analysis from the laboratory of Herr L. Schmelck gave the following composition for such a very coarse-grained pyroxenite from Brandberget:—

Table VIII.

	Pyroxenite, Brandberget.	*Pyroxene, Limburg.*
SiO_2	45·05	44·65
TiO_2	2·65	2·93
Al_2O_3	6·50	6·62
Fe_2O_3	3·83	5·02
FeO	7·69	3·87
MgO	12·07	14·76
CaO	18·66	20·32
Na_2O	0·94	1·29
K_2O	0·78	0·49
$Ca_3P_2O_8$	0·31	......
H_2O	2·40	.....
	100·88	99·95

For purposes of comparison the analysis by Merian (Neues Jahrb. 1885, Beilage, vol. iii. p. 285) of the pyroxene from Limburg, Kaiserstuhl, Baden, is placed beside that of the Brandberget rock. The agreement between the rock and the mineral is, as will be seen, very close.

The typical pyroxenite of Brandberget consists, practically in its entirety, of dark pyroxene; mingled with this, but quite subordinate, are a little brown hornblende, reddish-brown biotite, traces of plagioclase, etc.; the structure is often miarolitic, with various minerals (splendid crystals of titanite, apatite, etc.) in the open cavities.

This pyroxenite is traversed by innumerable, comparatively acid veins of fine-grained, light-grey augite-diorite, or mica-augite-diorite, invariably rich in yellow titanite, and of a kind passing into the series of augite-syenite, designated formerly by the author as 'akerites.' These veins of augite-diorite are so abundant that the rock on the whole of the western side of Brandberget represents a typical eruptive breccia, containing angular fragments of the dark coarse-grained pyroxenite cemented by the fine-grained, light-grey augite-diorite. This latter then represents the acid residuary magma after the differentiation of the pyroxenite-magma, already consolidated to pyroxenite, when its veins were squeezed up.

The main mass of the magma of Brandberget is not much differentiated, but has crystallized out like the basic olivine-gabbro-diabase mentioned above, differing only slightly from the above calculated average magma of olivine-gabbro-diabase.

All the products of crystallization on Brandberget represent, then, the results of a special differentiation, which has taken place in this boss itself. As we found above (p. 27) that 9 parts of the camptonite composition, and 2 parts of the bostonite composition, gave us the average composition of the olivine-gabbro-diabases of Gran and Modum, in a similar manner it should be possible by the mixture of some parts of pyroxenite, hornblendite, augite-diorite, and olivine-gabbro-diabase (of the analysed composition) to reconstruct an average magma very closely allied to the average composition of the olivine-gabbro-diabases of Gran, or perhaps slightly more basic. To establish this calculation I still need several analyses; a preliminary trial has shown the approximate proportions, and these proportions seem to agree with the observations made in the field as to the extension of the different kinds of rock on the hill-top. When, in a monograph on these basic rocks, I can present, as I hope to do, the exact calculation, founded on a sufficient number of analyses, showing that x parts of the analysed basic olivine-gabbro-diabase of Brandberget mixed with y parts of hornblendite, z parts of pyroxenite, and w parts of augite-diorite (all of analysed varieties from Brandberget) give about the average composition of the olivine-gabbro-diabase above calculated from the analyses of rocks from Brandberget, Sölvsberget, and Dignæs, then I hope to have proved that all the various kinds of rock from Brandberget must be considered as products of differentiation from a

magma only slightly different from the before-mentioned average-magma, which, for the sake of brevity, I will designate as magma O.[1]

If the average composition of the rocks of Brandberget is, possibly, a little more basic than the average composition of the bosses between Brandberget and Dignæs taken altogether—that is, is more basic than magma O—this is certainly not the case with the boss of Sölvsberget. The rocks of Sölvsberget on the whole undoubtedly possess an average composition conforming very closely to that of magma O. Besides, we have found that the bulk of the eruptive rocks on Sölvsberget is represented by an olivine-gabbro-diabase of nearly the average composition. Nevertheless I have also observed on Sölvsberget a series of differentiations of magma O, which are, on many accounts, of much interest.

Moreover, on Sölvsberget I have found the same pyroxenites as on Brandberget, although to a more limited extent, namely on the western and south-western side of the hill, as contact-facies; but I have not observed any hornblendite.

On the eastern end of the boomerang-shaped boss, where the tectonic relations have been quite exceptional, a peculiar differentiation has taken place. By this differentiation along the contact there is separated out a magma which has consolidated as labrador-porphyrite.

The chemical composition of this labrador-porphyrite has not yet been determined by analysis, but it is assuredly not very different from that of the labrador-porphyrite of Huken, north of Christiania, where this rock is spread as an old sunken lava-flow over large areas. An analysis of the Huken rock, made in the laboratory of Herr L. Schmelck, gave:

SiO_2	47·50
TiO_2	3·02
Al_2O_3	17·57
Fe_2O_3	7·24
FeO	5·08
MgO	3·31
CaO	6·19
Na_2O	3·60
K_2O	3·28
H_2O	1·70
$CaCO_3$	0·68
$Ca_3P_2O_8$	1·00
	100·17

The difference between this and magma O, as will be seen, is quite unimportant, because the composition for most compounds lies between magma O and the composition of the olivine-gabbro-diabase from Dignæs. However, a slight differentiation has taken place, the mixture of the labrador-porphyrite being poorer

[1] As above mentioned, the average composition of the rocks of Brandberget seems to be a little more basic than the average of the more southern occurrences.

in magnesia and lime, and richer in alumina and alkalies, than the chief rock of Sölvsberget (see p. 19). As is well known, the conditions of crystallization for pyroxene and labradorite overlap in certain magmas of gabbro and diabase-composition. We find, therefore, that in one case the plagioclase has crystallized essentially before the pyroxene (ophitic structure), in other cases the relation has been the reverse (as in several typical gabbros). A very slight alteration of the physical conditions (temperature and pressure) along the cooling margin on the eastern side of Sölvsberget must have been sufficient here to cause an increased diffusion of the plagioclase-forming compounds in the magma to take place towards the contact; while under the altered conditions the labradorite would have crystallized more easily than the pyroxene. The magma thus separated by a slight differentiation has then, on its subsequent consolidation, been cooled in such a manner that it has assumed a porphyritic structure, and consequently has left a labrador-porphyrite. This—in comparison with the main type on Sölvsberget—more acid rock is undoubtedly a later product of the magma, for we find, at Bjerget for instance, that the labrador-porphyrite is full of angular fragments of the common olivine-gabbro-diabase of Sölvsberget, developed as a characteristic eruptive breccia.

In the close vicinity of Sölvsberget there also occur dykes of augite-porphyrite, with the same mineral composition and structure, as the lava-flows so abundant in the neighbourhood of Holmestrand, etc., which are the oldest effusive rocks of the Christiania region, and undoubtedly an outflow of the same magma as the basic rocks of Gran. These augite-porphyrites show only very slight, if any, difference in their chemical composition from magma O. The above-mentioned dykes are not then chemically differentiated in relation to the main rock-type of Sölvsberget: they merely represent good examples of the influence of differences in pressure and temperature, etc., on the products of crystallization. For the same magma, which by cooling slowly in the boss as an abyssal mass is consolidated to eugranitic olivine-gabbro-diabase, cooling more rapidly in dyke-fissures and on the surface as lava-beds, has left augite-porphyrites, quite different in structure and mineral composition. Examples of this kind are now well known from a multitude of localities; one need only call to mind the Monte Amiata in Tuscany, so well studied by the late F. R. Williams, whose premature decease we all mourn, and the magnificent monograph on the rocks of Electric Peak and Sepulchre Mountain published by J. P. Iddings. In the Christiania region examples of such relations are numerous.

The differentiations in the laccolite of the Viksfjeld show, in the main, similar relations to those just described; more acid quartziferous augite-diorites are here frequent as the latest products of differentiation. Time unfortunately does not allow of a detailed description.

VII. Conclusions.

In the preceding pages I have tried to set forth, in a brief *résumé*, a series of examples illustrating the fact that the compositions of eruptive rocks are sensible functions of the composition of the mother-magma, and of the manner in which this latter has been differentiated during cooling and diminution of pressure.

A magma of a composition closely allied to that above designated as magma O has, so far as I can at present form an opinion, been the oldest product of differentiation from the general magma-reservoir of the sunken tract defined by me as the Christiania region, this magma-reservoir itself having been, perhaps, a product of differentiation, in yet more remote ages, from a universal earth-magma. Magma O was then, if my deductions be correct, the source of all the different basic eruptive rocks in the Christiania region, especially also of the bosses, dykes, and sheets in Gran and the neighbouring parishes, and their equivalents, the effusive basic rocks of the series of augite- and labrador-porphyrites, etc.

In studying these rocks we have found examples of general relations of some importance:—

(1) That we can, with great certainty, connect a series of different dyke-rocks (camptonites and bostonites) with an exactly defined boss-rock of, *per se*, different mineralogical and chemical compositions.

Similar connexions are known from other regions. I need only call to mind the connexion of lamprophyric minettes with granites, often pointed out by our great master in general petrology, Prof. Rosenbusch, and recently so well described by Marr and Harker.[1] But in the present case I think that a connexion of this kind has been more definitely proved than in previously published instances.

(2) That the dyke-rocks in question—the camptonites and the bostonites—have probably been produced by differentiation in an abyssal magma of a certain chemical composition, which we have tried to calculate exactly from sufficient data. A calculation of this kind has not, so far as the writer is aware, been previously published.

(3) That the calculated basic mother-magma, or magma O, has partly consolidated in the bosses in Gran *without* being differentiated, as olivine-gabbro-diabases (type: Sölvsberget), and has partly been differentiated into camptonites and bostonites, but partly also into other kinds of rock: *i. e.* into pyroxenites, hornblendites, and more acid augite-diorites, etc. We have, then, here an example of the remarkable fact that *one and the same magma under different conditions has been differentiated in different ways*, and separated out so as to form different groups of rocks with different chemical compositions in the individual members of each group; we must above all remember that here is a question not only of different mineral-aggregates, but also of different chemical compositions.

It is thereby proved that the differentiation of a magma depends not only on the given chemical composition, but also essentially on

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 266; Geol. Mag. for 1892, p. 199.

the physical conditions under which the differentiation takes place. The '*kern*' hypothesis of Rosenbusch, in the form given by that author, does not fit in with these deductions.

(4) The observations here described probably further show the inverse case, that *the same group of differentiated rocks* (in the present case, camptonites and bostonites) *can be produced by separation from mother-magmas of quite different chemical composition.* In our case these dyke-rocks have been derived from an olivine-gabbro-diabase magma; in other instances we know that the same rocks are connected with nepheline-syenites (augite-syenites?), and have probably in those cases been differentiated out of a nepheline-syenitic (augite-syenitic?) magma. This being so, we have another fact which does not agree with the '*kern*' hypothesis.

(5) I have endeavoured to prove that the inferred *differentiation has been determined by, and is dependent on, the laws of crystallization in a magma* in so far as the compounds, which on given conditions would first crystallize out of the magma, must have diffused to the cooling margin, and in this way have produced, in the contact-stratum, a peculiar chemical composition in the still liquid magma before any crystallization took place.

By the pressing-up in this manner of the differentiated masses to a higher level at lower temperature and pressure, or by continued cooling along the contact-margin with subsequent crystallization, there have then been produced different kinds of rock of peculiar chemical composition, mineralogical constitution, and structure. The sequence of eruptions from a common magma-basin (magma-reservoir) must therefore, to a certain extent, be parallel with the sequence of crystallization in the corresponding kinds of rock. Many years ago, I tried to prove that this opinion is really confirmed by my observations on the rock-succession in the Christiania region, which closely conforms to the sequence of crystallization in the corresponding abyssal rocks in this 'eruptive province.' A series of confirmatory examples is known from the literature of other countries, from the British Islands by the excellent publications of Sir Archibald Geikie, Messrs. Teall, Dakyns, and other authors. The examples are really so numerous that they seem to represent a general law. No doubt in many cases the rock-sequence in different 'eruptive tracts' does not appear to agree with this empirically deduced law. But that does not prove that the law has no existence; it only shows that other conditions besides those above-mentioned are of importance for the determination of the eruptive sequence. A discussion of the great number of different possible cases (for instance, the hypothesis of Iddings as to the eruptive sequence, etc.) would on this occasion lead us too far. Here my intention has been simply to present a series of observations from a single locality, in which the genetic relations between the different kinds of rock seem distinctly to favour the opinion of a conformity between the sequence of crystallization and that of differentiation.

So far, I think, we are on safe ground; I would expressly point out that I have not discussed the primary reason for a differentiation of the above-described nature, whether this is to be sought for in the effect of chemical affinity, or in other causes. Soret's principle, in the effect of chemical affinity, or in other causes. That in many cases also the principle of Guy and Chaperon, the commencement of crystallization and the sinking to the bottom of the crystallized masses, as well as a subsequent re-melting of such early crystallizations, may have performed a part in the processes of magma-differentiation is quite possible. We move here in a maze of hypotheses.

But the differentiation itself is not a hypothesis; it must now be reckoned with as a solid fact of great importance. The same law, which in a narrow dyke-fissure has produced a differentiation along the more rapidly cooling dyke-sides, has, operating on a larger scale in the magma-basins in the earth's crust from which eruptions of a local volcanic centre originate, differentiated out the pressed-up secondary magmas, so that they have succeeded each other in a regular order. Finally, the same law has perhaps determined the particular composition of the magma of each separate magma-basin by differentiating the same out of the *pristine* liquid magma upon which, by the cooling of the earth, the solid crust was deposited.

Discussion.

The President said it was of advantage to the Society to have communications of this kind from distinguished foreign geologists. The paper reminded him of one by Dakyns and Teall, published in Quart. Journ. vol. xlviii. (1892). The basis of this philosophy appeared to lie in the determination of the order of crystallization by the microscope. The theory must be supported by very clear field-evidence, otherwise it would remain a mere speculation.

Prof. Judd said that the Geological Society of London must hail with pleasure the fact that Prof. Brögger had chosen their Journal as the means of communication to the world of a memoir of such value and interest. Prof. Brögger's contributions to all branches of geological and mineralogical science are so large in amount and invaluable in character that his claims on the attention of geologists are unrivalled. The speaker especially referred to the novelty and interest of the Author's views concerning the mode of separation of magmas, and to his suggestion that the nature of contact-metamorphism depends on the character of the erupted rock, as well as on the materials through which it has been ejected.

Gen. McMahon remarked that the Author appeared to hold the view that the differentiation of a magma into a continuous series of rocks, ranging from those of a more basic to those of a more acid type, depended on the laws that determine the sequence of crystal-building—that is to say, that the more basic minerals are those which first crystallize out from a magma, the remaining minerals following in the order of their basicity. Further, the Author held that the more basic rocks were older—that is to say, were erupted before the more acid ones; the latter, as Mr. Teall explained, forming dykes cutting the more basic rocks. If this were so, it would follow that, as the differentiation in the general magma progressed, the basic material would sink to the bottom and the acid portion of the magma would remain at the top. When pressure was exercised on a fluid, or viscid, magma differentiated into layers in the way supposed, and eruptions began to take place, one would have expected the acid top layer to have been the first to have issued from the cauldron. It was a pity that the Author was not present, as he (the speaker) would very much like to learn by what physical process the deeper-seated and more basic portions of the still fluid magma were first erupted.

Prof. J. F. Blake and Mr. W. W. Watts also spoke.

4. *On a* Picrite *and* other Associated Rocks *at* Barnton, *near* Edinburgh. By Horace W. Monckton, Esq., F.L.S., F.G.S. (Read December 6th, 1893.)

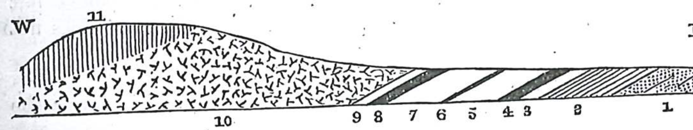
The Barnton Branch of the Caledonian Railway leaves that Company's Edinburgh and Leith line immediately north of Craigleith Station, opposite to Sir James Maitland's great Craigleith Quarry. The Barnton line lies almost entirely on Sir James's property, and I have to thank him for assistance in collecting the facts I now record. On our last visit to the locality we first inspected a trial pit, east of the old railway and close to it, a little north of Craigleith Quarry. The section was as follows:—

1. Surface-bed, with a few large boulders.
2. Thinly-bedded sandstone, about 12 feet.
3. Shaly beds, with an easterly dip of 1 in 4.

The first cutting on the new line is about ¼ mile from the junction at Craigleith. It is 19 feet deep and entirely in Boulder Clay. At from 3 to 4 feet below the top of the cutting there is a remarkably even line of very large boulders, and in one place I noted below them a patch of yellow sand 2 feet thick. The rest of the sides of the cutting is formed of black clay, full of small stones.

More Boulder Clay is shown between House o' Hill and Drylaw, but it is not till we reach Barnton Park that we find a section showing the solid geology. In the first cutting in the park the beds of the Calciferous Sandstone Series are seen dipping westward at an angle of about 30°, and as I began my examination at the eastern end they are here described in ascending order.

Diagram-Section on the Barnton Railway in Barnton Park.



11. Dolerite.
10. Picrite, through which run veins of basalt.
9. Indurated shale.
8. Igneous rock.
7. Indurated shale or 'calm.'
6. Igneous rock, 1 foot (mica-porphyrite).
5. Indurated shale.
4. Igneous rock, 12 feet (mica-porphyrite).
3. Indurated shale.
2. Black shale, with veins of calcite.
1. Thinly-bedded sandstone.

Much of the shale of beds 3, 5, and 7 is of a whitish colour and very hard, of the kind locally termed 'camstone' or 'calm.' A similar rock is, I believe, quarried in Corstorphine Hill.

Associated with this shale are some beds of igneous rock. Microsections have been made from bed No. 4 and from bed No. 6.