PERMIAN ROCKS AND STRUCTURES OF THE OSLO REGION

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Introduction.

The German geologist Leopold v. Buch first described parts of what is now known as the Oslo region as an especially interesting district, in 1810. A first map and regional description of "Das Christiania Übergangsterritorium" was published by B. M. Keilhau in 1838. The correct relationship between the volcanics and the underlying Cambro-Silurian rocks was established by Th. Kjerulf. From his work in the years 1855—1880 may be mentioned several maps and the correct interpretation of the faulting of the region, the cross-cutting nature of the plutonic rocks, the contact metamorphism, etc. But the Oslo region is first of all known from the works of W. C. Brøgger through more than 50 years. Most famous is his monograph of 1890 on the geology and mineralogy of the Langesundsfjord pegmatites, a volum of 900 pages. It also contains the first general account of volcanic, plutonic and dike rocks of the region, described as families of decreasing basicity.

Soon afterwards Brøgger (1894 a) was one of the first to point out that magmatic differentiation is governed by the laws of crystallization. Then followed Brøgger's series: "Die Eruptivgesteine des Kristiania- (Oslo-) gebietes" in 7 volumes. The first one appeared in 1894, the last one in 1933. In this last volume he published 331 rock analyses of igneous rocks, accompanied by general geological comments. Complete references to the publications of Brøgger is found in Barth (1945a) and to the older literature in Holtedahl (1934).

The age of the Oslo rocks was finally determined in 1931 when O. Holtedahl found Permian fossils in sediments just below the lavas.

After the death of Brøgger in 1940 a new series of monographs (in English) was started by O. Holtedahl and T. F. W. Barth. This series has now 16 volumes (1960). Short general surveys on the Oslo region are published by Holtedahl (1934, p. 340—356 and 1943,

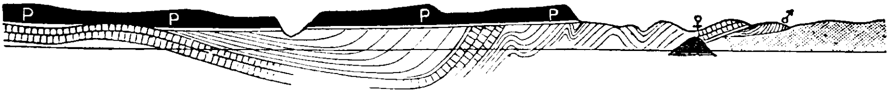

Fig. 99. Section along the western escarpment of the Krokskogen lava plateau. The lavas (P) with their basal Permian sedimentary rocks overlie the folded Cambro-Silurian series. The Drammen granite to the south (right). (After Th. Kjerulf 1865.)

p. 7—24), and he has later presented a comprehensive description of the Permian rock complexes and structures of the Oslo graben (Holtedahl 1953, p. 486—556, in Norwegian).

Together with J. Schetelig, Brøgger edited a number of geologic maps in scale 1 :100 000, covering nearly the whole region.

Unfortunately these maps were never distributed through the regular channels, because they were never given descriptions. A survey map in scale 1 :250 000 was printed in 1923 and was issued 10 years later (Brøgger 1933 a). A map of the surroundings of Oslo (1 :50 000) accompanies the "Guide" by Holtedahl and Dons (1957).

The Oslo region contains irregular areas of Cambro-Silurian sedimentare rocks (Fig. 40), and sedimentary, volcanic, and plutonic rocks of Permian age, see Plate 13. The areal distribution of the more important Permian igneous rocks appears from Table 1. The following description is an attempt to present the most important data from a comprehensive literature. The rocks are grouped in volcanic, plutonic, and dike rocks, and the chapter is concluded with comments on magma formation, faulting, etc.

Permian basal sedimentary rocks.

The Permian supracrustal rocks of the Oslo region consist of a thin series of sedimentary rocks, conformably overlain by a thick series of volcanic rocks. Both of these series have been faulted, but not folded. The sedimentary rocks are lying on a sub-Permian peneplain, cutting various strata of the underlying series of Cambro-Silurian rocks which in the northern half of the Oslo region are folded (Fig. 99) while south of Drammen the folding dies out.

The age of the post-Silurian rocks was not known until 1931 when Holtedahl discovered fossils in the sedimentary series and these fossils were determined to lower Permian age. Fossiliferous strata occur also

Table 1.

Principal igneous rock types of the Oslo region and their areal distribution (from Barth, 1945, p. 17, with some changes).

Magma group	Plutonic rocks	km²	Extrusive rocks	km²
Gabbroic	«Oslo-essexite» (Gabbros, kauaiite, bojite)	15	Basalt and trachy-basalt	220
Monzonitic	Kjelsåsite Larvikite, etc.	201 } 1705 }	Rhomb porphyries Tuff	1160 25
	?		Trachyte, rhyolite, welded tuff, explosion vents	55
Nepheline monzonitic to syenitic	Lardalite to Foyaite	65		
Syenitic	Alkali syenite, Nordmarkite	1400		
Granitic	Ekerite Biotite granite	821 840		
	Sum km²	5047		1460

between the lowermost lava flows at Holmestrand, indicating that also the volcanic activity is of Permian age.

The sedimentary rocks show considerable local variation. They consist of red and grey sandstones, red shales and a quartz conglomerate. This conglomerate is a very characteristic formation within the series. Pyroclastic deposits and sandy tuffitic beds occur in the upper part of the series. The most important section is that of Semsvik, Asker, where the fossils were found, some 19 km WSW of Oslo. The following beds occur, from below: red, sandy shale (not exposed in solid rock); conglomerate with 1—3 cm pebbles of quartz and quartzite (visible thickness 8 m); easily weathered, greenish-grey shale, with sandy layers, fossiliferous (5 m); grey sandstone overlain by red sandy beds, intercalated with conglomeratic beds (10 m). The pebbles of the conglomeratic beds consist of basaltic lavas. Then follows the first basalt lava.

The fossils are plants (Høeg, 1935, 1937 a, b), fresh water molluscs (Dix and Trueman 1935) and fishes (Heintz 1934). The plant fossils belong to the following genera: *Calamites, Lebachia, Walchia, Cordaites, Neuropteris,* and *Callipteris,* the molluscs to *Palæanodonta.*

The fishes are represented by remains of a fresh water shark, *Pleuracanthus,* and of *Megalichtus* and *Amplypterus.* Some fossils indicate clearly a lower Permian age, probably the middle part of lower Permian, while others are related to Carboniferous forms.

Thus the fossils as well as the character of the sedimentary rocks point to a continental deposition in fresh water, with a general relation to the Rotliegendes of Middle Europa.

The thickness of the Permian sedimentary series varies much from north to south. Thus the lavas in the Brumunddal area are lying directly on weathered Silurian rocks, whereas around Oslo the series attains a thickness of 20—30 m. From south of Drammen to Horten only the quartz conglomerate is observed, and even this is lacking in some places. In the Skien district again Permian shales and sandstones are about 50 m in thickness.

The volcanic rocks.

During the volcanic phase a thick series of volcanic rocks were formed over the entire Oslo region. The volcanics consist of trachyandesitic lavas (so-called rhomb porphyries) and basaltic lavas, with a minor amount of acidic volcanics. The area covered by volcanics exceeded that of the present Oslo region (200 km $\times$ 40 km) and may well have been 200 km $\times$ 100 km, possibly 300 km $\times$ 150 km. After erosion had carried off most of the rocks, the present volume is about 300 km^3. The lava series may have had higher members which are now removed and the total volume may have been as much as 6000 km^3 or more (Oftedahl 1952).

The eruptions may be divided into three phases. The first phase of volcanism consisted in the formation of a lava plateau comprising between 10 and 20 single flows of great horizontal extension. These effusives are clearly fissure eruptions, as early pointed out by Brøgger. The second phase is characterized by a number of volcanic centers with large basalt volcanoes with minor amounts of acidic (ignimbritic) rocks and by explosive centers associated with similar acidic rocks. During the third phase the volcanic activity returned to fissure eruption type.

The detailed stratigraphy of the lava flows was first worked out for the Krokskogen lava plateau by Brøgger, Schetelig and collaborators in the period 1910—17. This proved possible because the different trachyandesites exibit different size, shape and packing of their plagioclase phenocrysts. Brøgger applied the old term "rhomb porphyry", originally used by Leopold von Buch in 1810 for a dike rock, to all lavas of this composition, although many of them have not rhomb-shaped phenocrysts.

The observed sequence of the Krokskogen lavas, numbered from the bottom upwards, appears from Table 2. The maps of Brøgger and Schetelig also show a corresponding sequence of lava flows in the other lava areas, but these areas have been later revised (the Nittedal area by Sæther, 1947, the other areas by Oftedahl, 1952). Table 2 shows these revised sequences and some unpublished results. In this table are also included a number of trachytic to rhyolitic flows, — lavas, tuff flows or ignimbrites. These rocks were formerly supposed to be intrusive rocks, but Oftedahl (1957) assumed that all the fine-grained acidic porphyries which are interbedded between lavas are volcanics. Other such porphyries which exhibit a more or less cross-cutting nature are still doubtful (e. g. the Opkuven breccia, and porphyries N of Lommedalen, Bærum).

Petrography.

Basaltic rocks.

At the begin of the last century the basaltic rocks were called *basalts* by Leopold v. Buch, and then assigned as *augite porphyries* by Kjerulf. In Brøgger's short petrographic description in 1890 names such as "Melaphyre, Diabas porphyrit, Labradorporphyrit" were introduced. In later descriptions and maps Brøgger used the designation Essexite lavas. The correcter term basalt was re-introduced by Sæther (1945 b) and the abbreviations B_1, B_2 etc. were introduced by Oftedahl (1952). A detailed description of selected analyzed samples of the lowest lava flows (now called B_1) at Holmestrand was given by Brøgger (1931 a). More recently petrographic descriptions of basaltic rock types belonging to B_3 of the southermost part of the Bærum cauldron have been published by Sæther (1945 b, p. 9—22).

In hand specimens the basaltic rocks show a great variation in appearance. The most basic variety carries abundant augite phenocrysts and pseudomorphs after olivine in a dense groundmass. The most common variety contains abundant phenocrysts of both augite and plagioclase. With few or no augite phenocrysts the rock is more acidic and the composition gradually changes into andesitic. A fourth typical variety is a bluish black non-porphyritic basalt.

Table 2.

Stratigraphy of volcanic rocks, in part preliminary. B_1, etc.-basalts. 1, 2, 3, etc.-rhomb porphyries.
Lava areas: Kr — Krokskogen. Ni — Nittedal. Ve — Vestfold.
Cauldrons: Ø — Øyangen. B — Bærum. A — Alnsjø. D — Drammen. G — Glitrevann. S — Sande.

Kr	Ni	Ø	B	A	D	G	S	Ve
		B_5 17 16 15 14 13	B_4(?)	Lava cgl. Argillite Agglom. of 13 and acid. volc.	14 13	14 13		17 Trach. 16 15 B_4 14 a, b, c 13
B_3	B_3(?)		12 a, b, c Tuffs, aggl. with ignim. B_3 Ignimbrite B_3	Trachyte Tuff Agglom. B_3	B_3 Rhyolitic crystal tuff B_3	Welded agglom. Rhyolitic dome B_3 Rhyolite (ignimbr.) B_3	Agglom. etc.	B_3 Trachytic ignim.
12 11 B_2÷10 9 8 7 6 5 4 a, b 3 a, b 2 a, b 1 B_1	9 8 7 6 5 4 2 1 B_1		11		11 B_2 9 8 7 5÷6 4 2 1 B_1	11 B_2 9 8 7 6 5 4 2 1 B_1	9(?) 7 6 5 4 3(?) 2 1 B_1	12 11 9 8 7 6 a, b 5 a, b 4 a, b, c, d 2 a, b 1 B_1

Microscopic study reveals that true basalts are quite rare. They are found among the rocks rich in augite phenocrysts. Other basaltic rocks carry so much alkali feldspar that they range among the trachybasalts, whereas the plagioclase-rich rocks may be included among the trachyandesites (nomenclature of Rittmann from 1952).

The phenocryst minerals have the following characteristics: The augite is always titaniferous with a violet color and strong dispersion.

The crystals are short prismatic and may be up to 1 cm in length. Pseudomorphs after olivine have a reddish color and consist of dense aggregates of serpentine, quartz, calcite and iron dust. Unaltered olivine is never found in any of the Oslo lavas.

The plagioclase is platy parallel to (010). The plates are usually up to 1 cm in diameter, rarely as large as 2 cm. The thickness is usually a few mm. The plagioclase crystals are often zoned, with a core of composition around 55 An and an outer shell of oligoclase about 20 An.

In the groundmass are seen small crystals of augite and also laths of plagioclase some times zoned with a composition from 50 to 30 An. Iron ore and apatite are among the most important accessory minerals.

By a later hydrothermal alteration the lavas were locally strongly zeolitized (Falkensten at Horten, Barth 1945 b). By contact metamorphism they may be strongly recrystallized, as is the case in part of the Bærum cauldron (Sæther 1945).

Two chemical analyses with modes calculated by Brøgger are presented in Table 3, Nos 1—2, as examples of the petrographic and mineralogical composition of basaltic lavas.

Rhomb porphyries.

As mentioned above the name rhomb porphyry was originally applied to a dike rock. Lather Brøgger used the term for all the effusive rocks of similar composition.

In hand specimen the lavas belonging to the rhomb porphyry sequence show a great variation in appearance, due to the various shapes of the phenocrysts, their size and packing, see Fig. 100. In Rittmann's system they are mostly latites, but the more basic are trachyandesites. Usually they are easy to identify as rhomb porphyries in the field. There are, however, varieties which are transitional into more basic and more acid lava types. Among the trachyandesites occur so-called rectangle porphyries, the name being derived from the strictly rectangular outline of the phenocrysts. This crystal form is due to the faces (001), (010) and ($\bar{2}01$) all of which are nearly vertical to one another. There is little, if any, differences between the uppermost plagioclase-rich basalt of B_3 and the overlying rectangle porphyry (RP_{13}) within the Bærum cauldron. Also some trachytic lavas may at times show appearances similar to the rhomb porphyries.

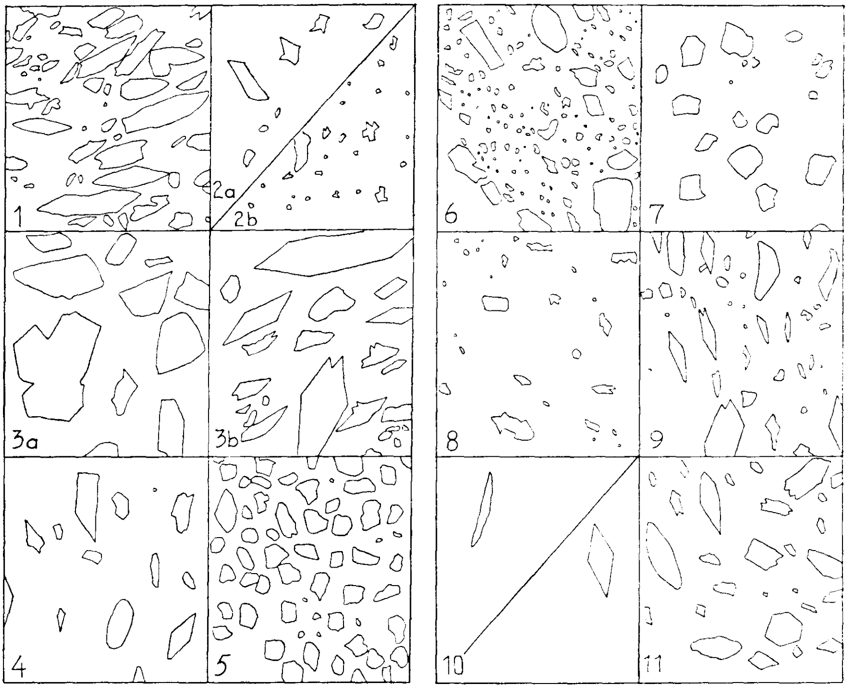

Fig. 100. The rhomb porphyry types RP_{I}—RP_{11} of the Krokskogen lava plateau, ½ ×. (After C. Oftedahl 1952.)

The feldspar phenocrysts of the rhomb porphyries are often cloudy or altered, and their determination is difficult under the microscope. The crystals appear to be monoclinic, and Brøgger (1890) considered them to be alkali feldspars, soda orthoclase.

Later Oftedahl (1946) published descriptions of the rhomb porphyries of the Krokskogen lava plateau. All the phenocrysts consist of oligoclase or andesine. The apparent monocline symmetry of the crystals in random orientation is explained by the presence of very thin albite twin lamellae, seen only when the twin plane is exactly normal to the thin section. Their composition, determined by extinction angles and the immersion method, varies from 35—20 An. Only the rectangle phorphyries have crystals as basic as 40—45 An. These crystals are easily determined as they exhibit broad albite lamellae, and are also much less altered. The optical orientation of the indicatrix is intermediate between that of low temperature optics and typically high temperature optics (Oftedahl 1948).

Twinning is frequent in the phenocrysts. In flows with well developed rhomb-shaped phenocrysts (RP_1, RP_4, RP_{11}, etc.), Carlsbad twinning with (100) as a composition face is so frequent that twinned crystals exceed untwinned crystals in numbers. Complex twinning is abundant, especially in RP_{2a}, where combination twins according to the laws Baveno, Albite, Albite-Carlsbad, Manebach, Ala etc. produce star-like phenocrysts. In one "star" 12 individual crystals have been counted.

Rare augite phenocrysts are up to 5 mm in length (RP_6 at Undrumsdal in Vestfold). This augite has a low axial angle.

The groundmass consists mostly of alkali feldspar which is heavily clouded. The grain size ranges from 0.05—0.3 mm. The grains may be irregular in outline or roughly rectangular. The accessory minerals include quartz, augite, chlorite, calcite, sericite, iron ore, and apatite.

The lowermost member of the rhomb porphyries of the Krokskogen lava plateau (RP_1) is chosen as a typical representative (Table 3). As shown by the tables of analyses by Brøgger (1933 a), where all the types from the Krokskogen plateau have been analysed, the varying macroscopic appearance of the rhomb porphyries can not be related to corresponding changes in chemical composition. Thus a new analysis of RP_{2b}, which has very few and very small phenocrysts, shows exactly the same latitic composition as the average rhomb porphyry. From calculation of the analyses the composition of the groundmass feldspar must be around 40—60 Ab; therefore in addition to this alkali feldspar, rhomb porphyries with very few and small phenocrysts (RP_2 etc.) have 15—20 % plagioclase hidden in the groundmass.

The typical rhomb-shaped crystals have as only crystal faces (110), ($1\bar{1}0$) and ($\bar{2}01$). These faces combined give very flattened crystals which exhibit rhombic cross sections parallel to the *ab* and *ac* planes, but which give an oval outline parallel to the *bc* plane. The faces (001) and (010) may also be developed, in which case the crystals have more regular cross sections. When the (001) and (010) faces predominate, a crystal of the rectangle porphyry type appears.

The origin of the crystal faces which produce the rhombic outline has been much discussed. Such rhomb-shaped crystals occur only in a few igneous provinces in the world, *e. g.* northernmost Sweden, the Kilimandjaro district of Central Africa and Mount Erebus in the Antarctic. Quensel pointed out that features such as a rounded crystal

Fig. 101. Trachytic porphyry ("Lathus porphyry") with flow strcture, phenocrysts and inclusions. Ca. ¾ ×. From the southeastern part of the Bærum cauldron. (After O. Holtedahl 1943.)

outline and a large angle between (110) and ($1\bar{1}0$) suggest an origin by resorption (see Oftedahl 1948, p. 34). This view is also supported by the author's own observations.

Trachytic and rhyolitic lavas and tuffs.

Volcanics with compositions more acidic than the latitic rhomb porphyries are usually recognized by certain features. The groundmass is very finegrained to felsitic, containing small red phenocrysts of rectangular outline, the amount of phenocrysts being usually less than 10 per cent. The typical felsitic porphyries make up a distinct group, in that these porphyries usually show flow structures and contain inclusions.

Thin sections of these rocks reveal little concerning the composition of the rock. Both phenocrysts and particularly the groundmass feldspars are so clouded that an optical determination is usually impossible. Other minerals include quartz and a few accessory minerals (chlorite, calcite, iron ore and dust), but microscopic texture shows a

Table 3.

Chemical analyses and modes of volcanic rocks.

	1	2	3	4	5	6	7	8
SiO_2	44.77	52.47	53.51	57.33	63.56	64.94	63.27	75.44
TiO_2	2.54	2.35	1.25	0.52	1.08	-	0.59	0.07
Al_2O_3	12.19	12.06	18.38	17.96	15.04	-	16.88	12.33
Fe_2O_3	7.26	6.09	7.92	2.79	6.75	-	1.47	0.49
FeO	7.08	7.18	0.97	4.07	0.39	-	2.63	1.00
MnO	0.26	0.19	0.28	0.04	0.13	-	0.03	0.11
MgO	8.08	4.33	1.34	1.55	0.60	-	1.84	0.52
CaO	11.22	7.56	5.07	3.12	0.70	-	2.98	tr.
BaO	0.05	0.06	-	-	-	-	-	-
Na_2O	2.20	2.83	4.68	4.70	3.30	4.66	2.68	2.38
K_2O	1.35	2.34	4.29	4.36	6.73	5.97	6.80	7.13
$H_2O\div$	0.69	-	-	0.05	0.28	-	0.07	-
H_2O+	1.89	1.51	1.15	1.86	1.31	-	0.65	1.26
P_2O_5	0.35	0.36	0.71	0.70	0.22	-	0.31	-
CO_2	0.11	0.20	0.91	0.90	-	-	-	-
Cl	0.03	0.06	0.12	-	-	-	-	-
F	-	-	-	-	-	-	-	-
S	0.03	0.08	-	-	0.13	-	-	-
FeS_2	-	0.03	0.06	-	-	-	-	0.66
	100.19 Cr_2O_3 0.03 V_2O_3 0.06	99.85 ZrO_2 0.12 SrO_2 0.03	100.64	99.95	99.95		100.22	101.73 ZrO_2 0.34

great variation. The ordinary-looking microcrystalline rocks have usually a groundmass consisting of cloudy, subhederal feldspar grains. The felsitic varieties show all kinds of flow and lense structures, mixed with phenocrysts, spherulites, and foreign inclusions. Photomicrographs of a number of varieties are presented by Oftedahl, (1946, p. 32—33).

Chemical analyses are necessary to determine the composition of nearly all these rocks, because even quartz may be difficult to distinguish in the groundmass. In Table 3 five analyses, Nos. 4—8, are given which illustrate the chemical and mineralogical variation within this group. No. 4 has a composition close to the most acidic members of the rhomb porphyries. Among both syenitic and granitic members of the group one feature is worth mentioning. The rocks may have a normal potash: soda ratio or one that is abnormal in that it contains very high percentage of K_2O. Thus the felsitic porphyries of the Bærum cauldron ("Lathus porphyries") may have a normal ratio or contain as much as 6.8 % K_2O (see No. 7). The same relationship was found in a tuffaceous rock from Sørkedal (No. 5) and also in the "quartz

		1	2	3	4	5	6	7	8
		M	M	N	N	N	N	N	N
Phenocrysts	Quartz								15
	Alk.feldsp.					5		5	20
	Plag.	ca. 10		30	25		5		
	(comp.)	(60-20)		(30)	(20)		(20)		
	Oliv. pseudo morphs	8							
	Augite	ca. 15							
Groundmass	Quartz		9	1	4	17	13	11	17
	Alk.f.	11	14	50	49	67	72	61	44
	Plag.	23	34	?					
	(comp.)		(50-20)						
	Augite	ca. 18	27	2	4				
	Chlor. (ol.)		ol:3	5	10	4		4	2
	Iron ore	13	12	8	4	6	10	2	2
	Apatite	1	1	2	2	1			
	Calcite			2	2			2(?)	
	Bas.fragm.							15	
	Color ind.	55	43	17	20	11	10	(6)	4

1. Olivine trachybasalt, Hvitsten, Holmestrand. Brøgger 1931 a, p. 13.
2. Aphyric trachybasalt, Gaasen, Holmestrand. Brøgger 1931 a, p. 23.
3. Rhomb porphyry (RP_1), Kolsås, Bærum. Brøgger 1933 a, p. 68.
4. Porphyritic tuff, Tverelven, Sørkedal. Holtedahl 1943, p. 65.
5. Trachytic tuff, Sloravann, Sørkedal. Holtedahl 1943, p. 64.
6. Trachyte, road intersection at Løn, Vivestad. Anal. B. Bruun, 23/9-1958.
7. Ignimbrite, Lathusåsen, Bærum. Holtedahl 1943, p. 64.
8. Rhyolite crystal tuff, Bragernåsen, Drammen. Brøgger 1933 a, p. 108.

The modes are based on careful microscope determinations where this is possible (M) or on modified norms for more indeterminable rocks (N).

porphyries" of Bragernesåsen, Drammen. An old analysis from Brøgger (No. 8) shows the highest potash content (7.13 %).

The high potash content may be a feature associated with a certain level in the crust. It may have a deep seated magmatic origin, or it may be related to the surface eruption and crystallization, an hypothesis which the author finds more acceptable. Most of the syenitic to granitic volcanics have earlier been considered to be of intrusive origin, but a number of petrographic as well as geologic features suggest that they must be extrusives and Oftedahl (1957) proposed that many of these rocks belong to the group of ignimbritic rocks. Since there is a great deal of confusion in the classification of such rocks, no attempt is made here to distinguish between lavas, more or less welded tuffs, or tuff sheets.

Main geologic features.

The first period of plateau eruption.

The Krokskogen lava plateau is the only large lava field where a great number of flows lying above each other may be traced over distances of more than 10 km, undisturbed be intense faulting. Most of the lava types of the Krokskogen area are also present in other lava areas. These flows may be termed regional flows, whereas those which are restricted to one area may be termed local flows. All the Krokskogen flows are regional flows with the exception of RP_3 and RP_{10}, but in the Vestfold area many local flows are distinguished (RP_{5b}, RP_{5c}, etc.). In the little Brumunddal area at the northern boundary of map, Plate 13, four RP lavas are found, all of which seem to be local flows (Rosendahl 1929).

The earliest regional flows are the most extensive. Thus RP_1 is found over a distance of 170 km from north to south and 40 km from east to west. Therefore Brøgger concluded long ago that these eruptions of the plateau type must be fissure eruptions. A large number of thick rhomb porphyry dikes situated both within and outside the graben area must have served as feeding fissures. Thus the general pictures of the eruptions will be as follows.

From fissures basic magma ascended and flowed out to form a basalt sheet over the whole Oslo region. North of Drammen this basalt (B_1) is relative thin (0—30 m), but south of Drammen it increases in thickness to 120—150 m at Holmestrand and it possibly exceeds 200 m at Skien further to the southwest. The increasing thickness to the south may be caused by an earlier start of the eruptions in the south or by a subsidence during the eruptions. The thinner basalts to the north are mostly non-porphyritic. At Holmestrand an escarpment shows a great number of basalt flows (thickness 4—6 m) with abundant phenocrysts of augite or augite + plagioclase, intercalated with agglomerates and conglomerates of lava material. After a short period of rest similar eruptions from other fissures resulted in the formation of a thick sheet of rhomb porphyry (RP_1) over the whole region. This sheet is generally more than 100 m thick and wedges out only in one small area at Horten. In a similar way successive sheets of rhomb porphyry were emplaced one above the other, see Table 2. Occasionally the rhomb porphyry sequence is interrupted by further basalt flows; thus between RP_9 and RP_{11} basalt B_2 is found with RP_{10} as a bed in it.

The first phase of plateau eruptions in the Krokskogen area ended with the begin of the extrusion of basalt B_3 which overlies RP_{12}.

The intervals between the eruptions must have been relatively short, because above each flow a thin bed of detrital material, with a thickness from a few centimeters to 4 m is developed. These beds may be conglomeratic, with boulders of the underlying lavas. Mostly these deposits contain only lava material and no quartz sand from outside the graben, but the occasional beds of dark reddish clay sand material possibly indicates transport of quartz sand from the surrounding Pre-cambrian district into the graben area.

The first lava flow, B_1, flowed out on dry land. Only in one place a strongly zeolitized variolitic basalt suggests a flöw deposited in a lake (Barth 1945 b). The first eruptions were, however, preceded by fumarolic and solfataric action which in some places altered the Permian sedimentary rocks in various ways. Ash falls of basaltic material also preceded the first lavas in some areas.

The section at the highway north of Holmestrand shows that the basalts consist of many flows, one above the other, but structures indicating the manner of extrusion in the rhomb porphyries are less obvious. Most convincing are the flow structures generally exhibited by the rhomb porphyries carrying boat-shaped or rhombic crystals. Otherwise the rhomb porphyries may be surprisingly compact and structureless, as seen in many road cuts. However, many exposures show some hazy and lumpy structures which may be attributed to the breaking up of solidified lava. Peperitic structures with sedimentary inclusions are not rare; one locality has been described in detail and discussed by Dons (1956). Inclusions at the base of B_1 of the underlying quartz conglomerate are also observed (Oftedahl, 1953, p. 68, see also Brøgger 1933 b, p. 54).

A characteristic feature of the rhomb porphyry flows is that they often form relatively thin plates or sheets. Thus RP_3, obviously a local flow for the Krokskogen area, has a thickness less than 20 m and an extension north to south of 24 km. The areal extension of RP_1 has already been mentioned, similarily RP_2 which also has a thickness of about 100 m is traced from north to south for 100 km. Even if the eruption of one lava type did not come from one main fissure, but from several fissures, the facility with which these lavas must have flowed out and covered a large terrain is surprising.

For this reason an origin as tuff sheets or tuff flows for the rhomb porphyries should not be excluded (oral suggestion by prof. M. Rutten). If the rhomb porphyries were formed as tuff sheets, the top layer of relatively unconsolidated ash must have been eroded and transported away almost at once. This material may indeed be the source of the detritus for the sediments usually found between the flows. A bed of typical agglomerate has been found only in one locality, between RP_{2a} and RP_{2b} just south of Skaret, at Tyrifjord.

The central-eruption period.

The eruptions of the first B_3 basalt lavas indicate the beginning of a period of eruption much more irregular than the first. Besides building up thin basalt sheets, B_3 basalts flowed out in great quantities from a number of foci, where quite large basalt volcanoes were built up. Thus B_3 has a thickness of at least 1000 m in the southern part of the Bærum cauldron (Sæther 1945 b). The great thickness of basalts have only been preserved from erosion in semi-circular subsided areas: cauldrons.

Connected with the B_3 basalts were eruptions of acidic material. These began just before B_3 time continuing in short bursts during the eruptions of B_3 and finishing quite a long time afterwards. The acidic material consists of trachytic lava flows or tuff flows and trachytic to rhyolitic ignimbritic flows. As far as can be judged from rather scant exposures of this higher part of the lava sequence, the acidic effusions were connected either with basalt volcanoes of cauldrons or with explosion centers which only produced acidic material. Six cauldrons and two explosion centers will be briefly described below. The four well developed cauldrons have been the subjects of a monograph by Oftedahl (1953). Of the last two cauldrons only remnants are preserved. One (the Alnsjø area) has been described in detail by Holtedahl (1943), and the other (the Øyangen area) is being described by Sæther. Little has been published on the Hillestad and the Ramnes explosion centers.

The end of the central eruption period is marked by the begin of the effusion of the trachyandesite RP_{13}. This flow which is found in three cauldrons and also in the Vestfold lava area, appears to be a regional flow. In Table 2 the most important formations of the central eruption period are tabulated. More detailed information appears from the description of the cauldrons and the cauldron map of Fig. 102.

The second period of plateau eruptions.

This period is less distinct than the first period of plateau eruptions in that only RP_{13} can be distinguished as a clearly regional flow. Some of the flows RP_{14}—RP_{17} may have been quite extensive, but the evidence supporting this suggestion is faint. Most of the eruptions may have been rhomb porphyries of rather local extension. Some basalts appear also in this period. One of these basalts, B_4, was found in a little exposure in the Bærum cauldron by Sæther, and forms a continuous tuff or lava sheet in Vestfold. In the latter area one or several trachytic lava or tuff flows are interbedded with the rhomb porphyries. Possibly the youngest lava flow of the whole Oslo region is B_5 which is very thick in the Øyangen cauldron.

The cauldrons.

The cauldrons are nearly circular blocks which have subsided along ring faults so that the cauldron rocks of the present surface belong to a much higher part of the stratigraphic sequence than the rocks outside the ring fault. Below are tabulated the size of these subsided blocks, and the amounts of subsidence, deduced from comparison between the stratigraphy within the cauldron block and the rocks outside the ring faults. As a result of later invasion of magma into some of the cauldron blocks, minor intrusions were formed. Finally all the cauldron blocks have been more or less eaten up by the overhead stoping of the large magma chambers. This destruction by stoping has nearly blotted out the Alnsjø cauldron.

Cauldrons	Diameter(s) in km.	Mean vertical subsidence in m.	Volume of subsidence in km³	Intrusion activity in the lavas.	Destruction by plutonic stoping
Bærum	12 × 8.5	1000-1500	80-120	Very faint	Faint (5%)
Drammen	7	ca. 500	ca. 17	None	Ca. 35%
Glitrevann	16 × 10	1500	180	Intermediate	Faint (5%)
Sande	12	500-800	55-80	Faint (?)	Strong (55%)
Alnsjø (remnant)	15 ?	1500-2000	-	?	Very strong (ca. 80%)
Øyangen (remnant)	ca. - 8	3000-4000(?)	-	?	Strong (ca. 60%)

The origin of the cauldrons was first sought in withdrawal of magmatic support by large, underlying magma chambers (Oftedahl 1953). Thus the cauldrons should be connected with the emplacement of the batholithic bodies of nordmarkite and granite. Now it seems probable that the cauldrons are connected with large volcanoes and explosive volcanism, as is the case with the typical volcanic calderas. Anyhow, the subsidence must have taken place over a long time interval. Thus subsidence along the ring fault has brecciated the nordmarkite which cuts a part of the Bærum cauldron.

The *Bærum cauldron* is the most beautiful example of a circular block which has subsided without much disturbances of the block by faulting or marginal upbending. The ring fault has later been intruded by a ring dike of syenite porphyry with a microscrystalline or felsitic groundmass. Within the subsided lava block is preserved a sequence of volcanics (see Table 2) which may yet be elaborated upon by detailed work. In short it consists of basalts (B_3), which have partly flowed on the surface and partly been intruded at levels near to the surface (Sæther 1945 b). Intercalated with these basalts are beds of felsitic porphyries and breccias, considered as ignimbrites ("Lathus porphyry" of Holtedahl 1943). This complex is overlain by porphyritic rocks of latitic to trachytic composition, mixed with rhomb porphyry detritus and felsitic beds. These rocks were all considered as intrusives (Holtedahl 1943, Oftedahl 1946), but they are now interpreted as more or less welded tuffs (Oftedahl 1957). This complex again is overlain by local rhomb porphyry flows and the rectangle porphyry, RP_{13}. Some quartz porphyry dikes were produced by minor intrusive activity, probably contemporaneous with the intrusion of the ring dike.

To the northwest of the cauldron is situated an area of great subsidence bounded on the west by faults against the Krokskogen lava plateau. This area consists of a mixture of acidic effusive rocks (ignimbrites and related rocks) and monzonitic to syenitic intrusive rocks. Further north separated areas of lavas belonging high up in the lava sequence are enclosed in nordmarkite.

The *Drammen cauldron* has recently been re-mapped by Mr. Odd Halsen, so that the old map by Brøgger as well as the description by Oftedahl (1953) are antiquated. The subsidence of the lava block obviously produced a bowl-shaped or saucer-shaped basin with a marginal upbending of the peripheral lavas. Later extensive faulting and invasion by an overhead stoping granitic magma destroyed the eastern part of the cauldron and followed the outside of the western part of the ring fault rather exactly. The western preserved lava field shows a rather extensive lava sequence, characterized by the occurrence of a rhyolitic crystal tuff deposited before most of the basalt lavas B_3 had flowed out. Unusually extensive hydrothermal alteration of the lavas is met with in many small areas. This alteration may be due to solfataric action during the volcanism or to hydrothermal activity of the crystallizing granite magma.

The *Glitrevann cauldron* is shown (Fig. 102) as an example of a large and complexly built cauldron. Much of its area is taken up by a thick unit of the basalt B_3 and younger lavas. At its northern and southwestern margin much of the underlying lava series is exposed by marginal upbending. A number of finegrained rock units which earlier were considered intrusive must now be interpreted as extrusive, belonging to the explosive phase of the central volcanic period (inner quartz porphyry ring dike, felsitic syenite porphyry, syenite breccia and quartz porphyry with breccia). Definite later intrusions of microcrystalline syenite porphyry occur along the ring faults and within the cauldron block. A central massif of felsitic quartz porphyry, transitional into aplite granite, may be interpreted as a magma dome with its chilled contact zone close to the surface. It is uncertain whether this granitic magma belongs to the much later Drammen granite or to the explosive phase of the second volcanic period, when granitic magma was available for extrusion in many foci. Finally the Drammen granite was emplaced by stoping, cutting out a little sector of the cauldron block to the southeast and following the ring fault in the east and northeast.

The *Sande cauldron* consists of a marginal zone of subsided lavas, with the whole interior occupied by a later central intrusion of coarse-grained rocks. The subsidence and later disturbances were so complex that little of the primary lava stratigraphy is retained. The central intrusion is one of the most interesting plutonic bodies of the Oslo region. It is a zoned intrusion with marginal granitic rocks grading into a central core of monzodiorite. Progressive assimilation of basic inclusions towards the roof of the magma chamber by a granitic magma has been suggested as an explanation of this gradual transition (Oftedahl 1953).

The *Alnsjø cauldron* may be regarded as a cauldron only by comparison with the other areas. It is completely "floating" within nord-

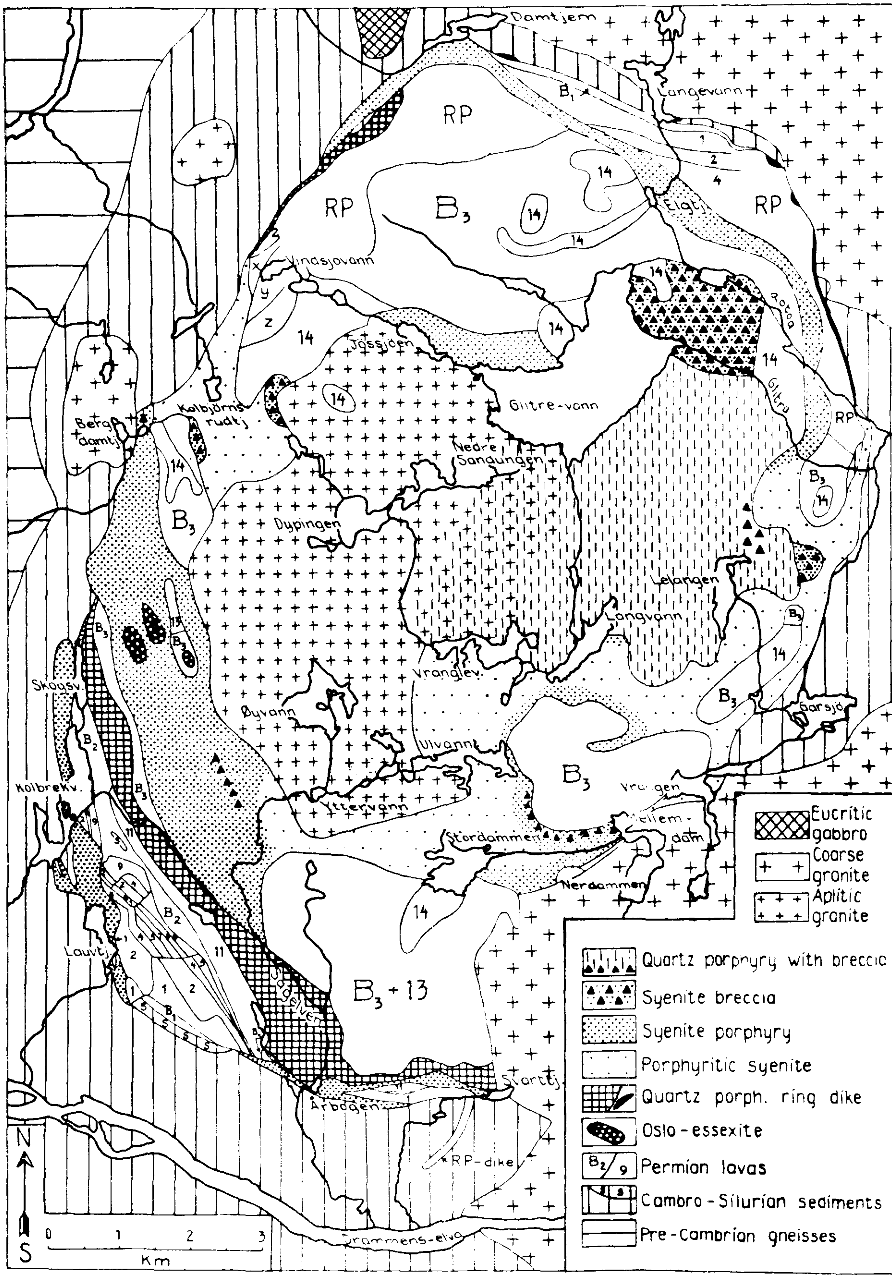

Fig. 102. The Glitrevann cauldron. x, y, z, and RP are un-identified rhomb porphyry types. "The quartz porphyry ring dike" is re-interpreted as a member of the volcanic series. (After C. Oftedahl 1953.)

markitic rocks, and presents an evenly curved southern boundary, which suggests that the area makes up the southernmost fifth of an originally circular cauldron block. Its interesting feature is the fact that the B_3 complex is overlain by argillite of considerable thickness and by a conglomerate. These deposits suggest that the cauldron area was possibly a basin after the formation of B_3, so that rivers could transport both lava material and sandy sediment from outside the graben into the cauldron.

The *Øyangen cauldron* consists as far as is known of lavas which must belong to the uppermost part of the whole lava series (personal communication by Sæther). The western quadrant of its ring fault is now taken up by a marginal intrusion or ring dike, and the eastern half of the cauldron block is removed by stoping of the nordmarkitic magma mass. The most conspicuous feature of this cauldron is its amounts of subsidence, 3—4 km.

Explosion centers.

The *Hillestad explosion center* occurs south of the Sande cauldron, in connection with a little massif of syenitic and granitic rocks (the "Hillestad laccolith" of Brøgger, 1933 a). Felsite porphyries, felsite breccias, and similar rocks occur around lake Hillestadvann, partly as members of the lava series and partly in plug-like bodies. The explosion center may have been north of the lake as the extrusive members are seen to thin out to the south.

The *Ramnes explosion center* is situated 10 km northwest of Tønsberg and is connected with a massif of monzonitic to syenitic rocks. This massif was mapped as kjelsåsite by Brøgger and Schetelig, but Barth (1945 a, p. 76) showed that these rocks are much more syenitic. From Ramnes church in the northwest the basic syenite changes quite gradually into a felsite porphyry at the border. This rock is overlain by welded tuffs, agglomerates and apparent obsidians. A large area with such acidic and finegrained rocks of somewhat doubtful origin, preliminarily labelled as ignimbritic extrusives, suggests the existence of a violent explosion center.

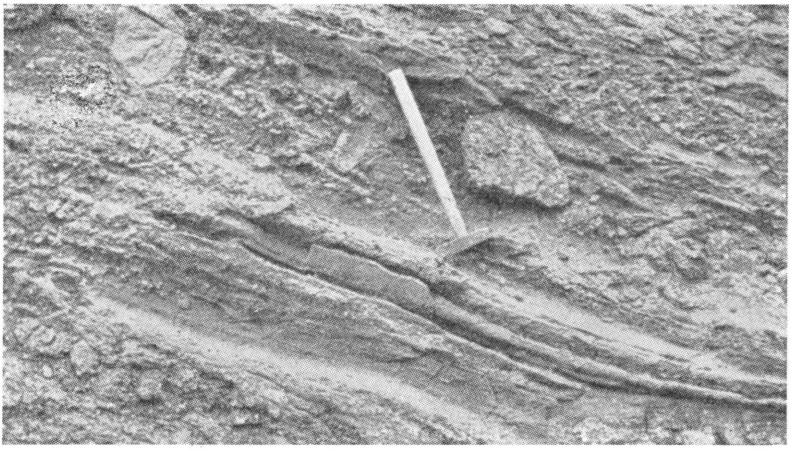

Fig. 103. The rhomb porphyry conglomerate in Rauøy. (After L. Størmer 1935.)

The Brumunddal sandstone and the rhomb porphyry conglomerate.

The Brumunddal sandstone (Rosendahl 1929) overlies the uppermost of the four rhomb porphyries of the Brumunddal area. It is a yellowish or reddish sandstone with a thickness of 4—500 m. It contains up to 30—40 % feldspar grains, derived from rhomb porphyries. With its loose character this sandstone is related to the detrital sediments between the rhomb porphyries and is unlike any other sandstone in Norway.

The rhomb porphyry conglomerate occurs in a number of small islands in the eastern outer Oslofjord, from Revlingen (south of Jeløy) southwards to Søstrene, a distance of 35 km. The conglomerate and its geology have been described by Brøgger and more recently by Størmer (1935). The boulders which may attain 5 m in diameter are rounded or angular and consist almost entirely of rhomb porphyries. Grey and red sandstones partly stratified (Fig. 103) are also observed. The groundmass is made up by gravel and mud of the same lava material. The total thickness of the sediments in Rauøy is about 1000 m. The conglomerate deposit obviously follows the major fault of outer Oslofjord, and Størmer therefore concluded that the conglomerate represents a fanglomeratic deposit of lava material from the eastern, relatively elevated fault block, accumulated after rapid weathering.

The plutonic rocks.

The plutonic rocks of the Oslo region fall into two groups which are different in many respects. The first group comprises the volcanic necks, which consist of gabbros and diorites. The second group embraces all the coarse-grained rocks which make up the large batholiths of the Oslo region. These rocks form a rather continuous series from monzodioritic to granitic composition, and constitute the group of rocks which are most extensively developed within the Oslo graben.

THE VOLCANIC NECKS

The northern volcanic necks were described in some detail by Brøgger in the last century, the rocks being labelled as gabbrodiabase. Later Brøgger applied the term essexite to this family of gabbroic rocks, from the resemblance with the original essexites of Essex county, Mass. In one of his last publications Brøgger (1933 b) summarized the petrographic and geologic facts of the volcanic necks. Later Barth (1945 a, p. 19—70) made a careful systematic study of all the analyzed rocks from the volcanic necks. Although ordinary rocks such as olivine gabbro and gabbro are found, the most frequent rock type is a syenodiorite called kauaiite. Two necks have been studied in great detail: Tofteholmene islands by Brøgger (1931 a) and the Ullernåsen—Husebyåsen group by Dons (1952).

The volcanic necks make up roundish or irregular bodies, with a diameter of 0.5—1 km. A few necks have diameters exceeding 1 km. Thirteen such necks and a few smaller ones are known in the Oslo region. Four necks lie in a row along the western boundary of the Oslo region, and the other nine are situated along an assumed fissure or fissure zone cutting the Oslo region. The five northernmost necks of this central row form a curved line just east of Randsfjord in Cambro-Silurian rocks. Further south this row is cut by the plutonic mass of Nordmarka, but continuing south a new neck complex occurs in the Ullernåsen—Husebyåsen district west of Oslo. This zone seems to continue southwards as a major fault along the Oslofjord, in the middle part of which are situated three necks, the double neck of Hurum, the neck of Vestby on the east side of the fjord, and the Tofteholmene islands.

The western row consists of two necks, situated in Cambro-Silurian rocks and then follows the Snaukollen neck within the Glitre-

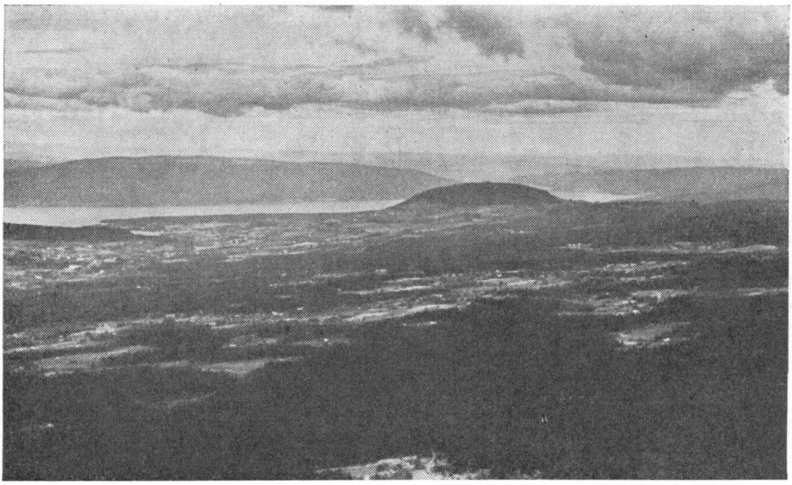

Fig. 104. The Brandbukampen volcanic neck, seen from southeast. Cambro-Silurian rocks around the neck, sub-Cambrian peneplain in the foreground. (After K. Strøm.)

vann cauldron. This neck is important in that it is genetically connected with lavas of B_3 position. The Eiangen neck is situated close to the western tip of the Oslo region and is a large xenolith or a roof pendant in the younger larvikite. In addition to these necks a few smaller ones are known.

The volcanic necks could be feeding pipes for the basalts B_1, B_2, B_3 or later basalts. Now the B_3 time is known as a period of central basalt volcanos, therefore the necks most likely represent B_3 volcanos. Dons (1952) infers a similar age for the Ullernåsen—Husebyåsen necks.

Petrographically gabbro and olivine gabbro are the most common rocks in the five northern necks, whereas kauaiite mostly is the predominating rock type in the southern necks. The latter rock is characterized by zoned plagioclase, alkali feldspar and augite. When barkevikite (a brown basaltic hornblende) occurs as a major dark component, the syenodioritic rock becomes a mafraite. This variety, and the corresponding dioritic rock (bojite) are occasionally met with. Rare differentiates are represented by rocks such as yamaskite, cumberlandite, monzonitic rocks (akerite) and the nepheline-bearing husebyite. Syenitic differentiates are called hurumite (potash-rich) and windsorite. Chemical analyses and modes of the two most typical rocks, olivine gabbro and kauaiite, are tabulated as No. 1 and 2 in Table 4.

THE KJELSÅSITE—GRANITE SERIES

The deep-seated rocks of the batholiths make up a large part of the present Oslo region. A geologic and petrographic survey of these rocks was presented by Brøgger (1890), and Barth (1945 a) later published a short systematic description of the petrography of the rocks using specimens which had been analyzed by Brøgger (1933 a).

Below follows a petrographic survey of each of the main rock types, succeeded by an account of the main geological features of the plutonic bodies and descriptions of the areas occupied by each rock type.

Petrography.

Kjelsåsite, so called from Kjelsås farm in Sørkedal, northwest of Oslo, is typified by a very coarse-grained rock, composed of plagioclase (andesine) and alkali feldspar in the ratio ca. 2 : 1. Thus it is a syenodiorite. In hand specimen the rock is dark and characterized by the rectangular outlines of the feldspar crystals. The dark minerals are diopsidic augite, some biotite, olivine, and accessories (see Table 4). Occasionally a little quartz, hypersthene, and alteration products such as serpentine and chlorite (after olivine) are encountered. Since the kjelsåsite is only slightly more basic than larvikite, the two rocks are mapped together on most of the maps published by Brøgger and Schetelig. From olivine-rich kjelsåsite there is a gradual transition into a rock series called the sørkedalite-apotroctolite series by Barth (1945 a), characterized by olivine as the dominant dark mineral: ol-diorite (sørkedalite) → ol-monzonite (apotroctolite).

The *larvikite* derives its name from the town Larvik and predominates in the whole Larvik district. Laurvikite is an older, now abandoned spelling. Larvikite was termed augite syenite by Brøgger (1890), but Barth (1945 a) finds that the ratio plagioclase: alkali feldspar varies from 40/60 to 60/40. Consequently the larvikites are essentially monzonites.

In hand specimen the typical larvikite is characterized by large feldspar tablets which mostly have a rhombic outline or a more rounded boat shape. Another variety contains clearly rectangular feldspar, but has the same composition, and this rock has in part been called kjelsåsite by Brøgger. In the first-mentioned variety oligoclase makes up the core of the boat-shaped crystals. Alkali feldspar forms mantles around

Table 4.

Chemical analyses and modes of plutonic rocks.

	1	2	3	4	5	6	7	8	9
SiO_2	46.22	46.80	57.44	57.80	54.55	59.63	63.36	76.23	77.17
TiO_2	2.12	2.78	1.42	1.15	1.40	1.03	0.96	0.27	tr.
Al_2O_3	14.70	11.60	17.30	18.82	19.07	18.47	17.00	11.35	12.09
Fe_2O_3	1.34	4.27	3.48	1.60	2.41	1.39	2.26	1.88	1.22
FeO	9.82	9.73	4.61	3.50	3.12	2.92	1.55	0.32	0.07
MnO	0.20	0.22	0.26	0.14	0.17	0.13	0.12	0.20	tr.
MgO	10.04	8.44	1.42	1.48	1.98	1.06	0.77	0.00	0.05
CaO	10.68	10.89	6.20	3.72	3.15	2.35	1.01	0.43	0.65
BaO	0.07	0.04	-	0.17	-	0.16	0.05	-	-
Na_2O	2.41	2.61	4.63	6.48	7.67	5.90	7.00	4.71	3.88
K_2O	1.12	1.30	2.96	3.97	4.84	5.61	5.58	4.57	5.05
$H_2O\div$	0.04	0.09	-	0.02	-	0.07	0.13	0.09	-
H_2O+	0.80	1.01	0.08	0.64	0.72	0.70	0.32	0.30	0.24
P_2O_5	0.28	0.31	0.50	0.55	0.74	0.29	0.19	tr.	tr.
CO_2	0.13	0.20	-	0.10	-	0.20	0.12	-	-
Cl	-	-	0.03	0.05	ca	tr.	-	-	-
F	-	-	0.03	0.04	0.12	0.03	tr.	-	-
S	0.05	0.05	-	0.03	-	-	-	-	-
FeS_2	-	-	0.15	-	-	0.08	-	-	-
	100.02	100.34	100.51	100.39 SrO 0.13	99.94	100.02	100.42	100.35	100.42

	1	2	3	4	5	6	7	8	9
Quartz			7				1	31	33
Alkali feld.		5	25	36	62	84	82	61	66
Plagioclase	48	35	48	43		+			
An in plag.	(57)	(44)	(37)	(23)					
Nepheline				5	13				
Sodalite					2				
Olivine	18	11		2					
Augite	23	39	10	7	8	5	3æg-di		
Hypersthene			2						
Ægirite							5	6	
Hornblende				1			5Na-ho	1Na-ho	
Biotite	8	5	4	5	10	8	1		1
Accessories	4	5	5	3	4	3	2	1	1
Color index	52	59	21	17	22	16	10	8	2

1. Olivine gabbro, Ballangrudkollen. Br. p. 27. B. 15.
2. Kauaiite, Randvikholmen. Br. p. 21. B. 4.
3. Kjelsåsite. Kjelsås in Sørkedal. Br. p. 55. B. 34.
4. Larvikite, opposite Håø, Langesundsfjord. Br. p. 59. B. 38.
5. Lardalite, Løve, Lågendalen. Br. p. 75. B. 45.
6. Nordmarkite (Alkali syenite), Nes, south of Gogsjø at Sandefjord. Br. p. 82. B. 47.
7. Nordmarkite, Kabretta, Sande Cauldron. Br. p. 86. Oftedahl 1953, p. 89.
8. Ekerite, Sanden in Hurdalen. Br. p. 99. B. 57.
9. Granite, quarry at Støa, Drammensfjord. Br. p. 105. B. 63.

(«Br. p. 27» etc. refers to table of analyses in Brøgger 1933 a. «B. 15» etc. refers to numbers of described rocks and modes in Barth, 1945 a).

the crystals and smaller individuals in the groundmass. In the second variety the plagioclase and the alkali feldspar are intergrown forming a coarse microperthite. The x-ray investigation of eight samples by Muir and Smith (1956) suggests that no ordinary plagioclase exists, but this result is criticized by Laves (1956). Thus it is obvious that the larvikite feldspars have a complex thermal history, most likely with compositions filling completely the gap between the oligoclases and the pure alkali feldspars.

The ordinary greyish larvikites have usually a faint schiller or labradorization seen on fresh or polished surfaces. In the Larvik district this schiller may be very strong, especially in dark or nearly black varieties, but strongly schillerising varieties are also found among the light greyish-colored larvikites. These schillerising larvikites have become one of the world's most famous ornamental rocks ("Blue pearl granite" etc.). The schiller has mostly a bluish color, with tinges of violet, yellow or other colors. It comes from the alkali feldspar phase of the larvikites (Oftedahl 1948) and is obviously caused by submicroscopic exsolution of a homogeneous feldspar into orthoclase and albite (cryptoperthite). A schiller effect has also been observed in certain syenitic rocks and in the kjelsåsite north of Sørkedalen.

The other minerals of the larvikite include ordinary augite as the chief mineral, and biotite, which may be the main dark silicate in a variety predominating west of Sandefjord (at Gogsjø). In addition to the normal accessory minerals the larvikites may contain a little quartz or nepheline.

Akerite is named from Aker, the community which formerly surrounded Oslo, but which is now part of Oslo itself. The name was introduced by Brøgger (1890) for syenitic rocks which clearly carry much plagioclase. This term has been used for quite a lot of different rocks of monzonitic composition and the more coarse-grained, deep-seated akerites were reviewed by Oftedahl (1946). On the map, Plate 13, the term akerite is used for both coarse-grained monzonites at various places in Nordmarka and at the southern boundary of the nordmarkite in Aker. Here at the latter locality the akerite is clearly a hybrid rock in most exposures. The term has also been used for medium- to fine-grained rocks of monzonitic to monzosyenitic composition which occur northwest of the Bærum cauldron. Petrographically the rocks are quite normal in carrying two or three of the minerals augite, hornblende, biotite, and chlorite. Hypersthene frequently occurs.

Lardalite was introduced as a special name for the nepheline syenites occurring in a small area north of Larvik. After his first systematic description (Brøgger 1890, with older spelling laurdalite) Brøgger (1898) described the varieties of lardalite in great detail. Unpublished investigations by the author show that four varieties of nepheline-bearing rocks may be distinguished (for map see Oftedahl 1960). In the southern half of the area very coarsegrained to pegmatitic rocks predominate. The feldspar crystals may be up to 3—4 cm in diameter. In one variety, the lardalite proper, the feldspar crystals are more or less rhomb-shaped. This variety carries perhaps more augite than the biotite ("nepheline larvikite"). In the other variety the large feldspar tablets are clearly rectangular bounded by the faces (001), (010), and ($\bar{2}$01). This variety contains biotite as the major dark mineral. A third variety is the nepheline syenite containing microperthite or cryptoperthite, developed as thin plates parallel to (010). Nepheline constitutes 5—30 % of the rock. Minor constituents are ægerite diopside and ægerite. This variety was called foyaite by Brøgger (1898). The fourth variety, the "Lien type" of Brøgger, carries rectangular feldspar tablets 1—2 cm in length, and is intermediate both in grain size and composition between the typical lardalite and the nepheline syenite. As to petrographic classification the Lien type must be regarded as nepheline syenite, whereas the two coarse-grained varieties of lardalite may be nepheline monzonite or nepheline syenite, depending on whether the albite (5—10 An) is classified as plagioclase or alkali feldspar.

Nordmarkite is named from Nordmarka, a district of forested hills north of Oslo, 30 by 20 km in extension. The name was introduced by Brøgger (1890) for red quartz syenite. The dark minerals may be either ægirite and arfvedsonite, or ordinary hornblende with biotite, or even diopside. According to modern nomenclature nordmarkite is thus a "sack name" for several syenitic rocks. This group can be divided in two ways. With some plagioclase the rock is classed as an ordinary syenite; but with only alkali feldspar the rock is an alkali syenite. The degree of alkalinity is also indicated by the dark silicates, which are either ordinary silicates (hornblende and biotite), or alkaline silicates (arfvedsonite or ægirite). This forms three varieties, since plagioclase and ægirite do not occur together. Now the question is which of the three rock varieties should be termed nordmarkite, and various solutions have been suggested (Sæther 1945 a, Barth 1945 a, Oftedahl

1948). It seems natural to reserve the term nordmarkite for the alkali syenite with ægirite and arfvedsonite. So far the three varieties have only been distinguished in the southern half of Nordmarka (Holtedahl and Dons 1957); syenitic rocks are indicated as nordmarkite in the map, Plate 13.

Modern descriptions of nordmarkite varieties are published by Barth (1945 a, p. 86—88) and Oftedahl (1953, p. 85). Usually the nordmarkites carry a little quartz, but the quartz content may increase to between 10 and 15 per cent, so that Brøgger (1933 a) in this table of analyses had to establish an intermediate group, the nordmarkite—ekerite series. These rocks are really granites by most systems of nomenclature, but here they are included in the nordmarkites. A rare variety carries a little nepheline instead of quartz and is thus an umptekite or a pulaskite. Pulaskite as used by Brøgger for an ordinary syenite is now abandoned (Barth 1945 a).

Ekerite derives its name from lake Ekeren (now Eikern). This rock group was distinguished by Brøgger in 1890 as a soda granite. Later the term ekerite was introduced. It carries abundant quartz, a coarse microperthite as the only feldspar, and alkaline dark silicates as the major dark constituents (arfvedsonite and/or ægirite).

Biotite granite, or *Drammen granite* as it has been called from its occurrence around the city of Drammen, contains alkali feldspar and some oligoclase in large tablets in addition to quartz. Biotite is the only important dark silicate. Transitions between this biotite granite and ekerite are reported, but seem to be rare, so that it has been relatively easy to map the granite as a separate rock against ekerite.

Main geologic features.

The large massifs of coarse-grained rocks were considered as laccoliths by Brøgger (1895). When studying the contact of the Drammen granite at Hørtekollen, north of Drammen, Brøgger found that the Ordovician shales form a roof to the granite with an upwards curved contact and an apparent conformity. From this he assumed that the body of granite had a corresponding floor, and that it was in fact a laccolith. Then he extended the use of this concept, so that gradually all deep-seated bodies were called laccoliths (Brøgger 1933 a). Later, attention has been drawn to the many occurrences of steep or vertical contacts of a clearly cross-cutting nature by Schetelig and Holtedahl

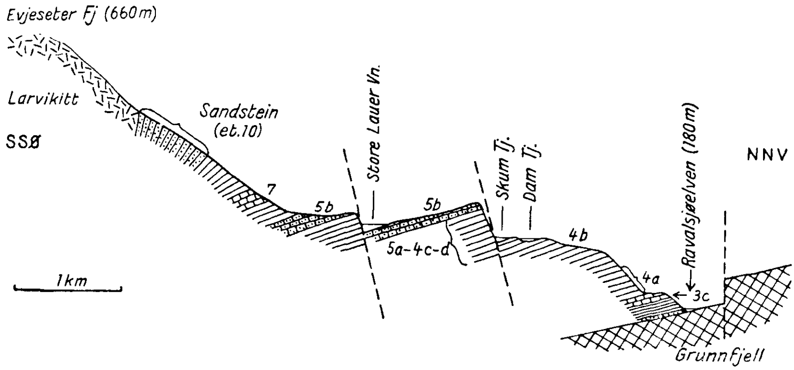

Fig. 105. Section from the larvikite of the northern Skrim Mountains through adjacent Cambro-Silurian series to the Precambrian. By A. Heintz (in Holtedahl 1953).

(1934, p. 350 and 1935, p. 505), who therefore concluded that the bodies must be batholitic.

The mechanism of emplacement of the magmatic bodies was clearly by means of overhead stoping. This is indicated by the abundance of xenoliths in the deep-seated rocks (see especially Holtedahl 1943, p. 26) and by the fact that the sedimentary rocks and lavas at the contacts of the deep-seated bodies always seem to "fall" into the plutons. This feature is observed in a number of localities, for instance Grefsenåsen (Holtedahl 1935, p. 508), Skrimfjell south of Kongsberg (Heintz, Fig. 105), the Skien district (Oftedahl 1952, p. 32), and the Langesundsfjord district (Brøgger 1890). It is therefore clear that the magma stoped its way straight upwards and exchanged place with the country rock. In order to obtain outer surfaces with a minimum size, the magma chambers would get the shape of vertical cylinders. Maybe also the curved outer lines of the magmatic bodies are due to large-scale cauldron subsidences with the cauldron blocks later completely removed by upwards stoping magma (Holtedahl 1943). Doming of the country rocks by ascending magma is observed in some places. Thus the Ordovician at the contact against the Ullernåsen—Husebyåsen volcanic neck has been bent up as much as 100 m (Dons 1952); more extensive uplift is found along the northern contacts of the Drammen granite.

The age relations afford yet another interesting problem. Already in 1890 Brøgger had concluded that the gabbroic group of rocks was the oldest and that increasing acidity was inversely proportional to age. However, he assumed that all gabbroic rocks belong to the oldest period and that all granitic rocks belong to the latest period. This obviously can not be applied to the volcanics, moreover the dike rocks show a very confused pattern of age relations. In spite of this Brøgger's idea is still generally valid for the plutonic rocks. The only reservation is that the different group overlap to a considerable extent, *i. a.* the monzonitic and syenitic rocks (Oftedahl 1951). Such overlapping is indicated by "simultaneous" contacts, as in the contact between larvikite and lardalite described by Brøgger (1898). Here the two rocks share a common boundary surface without any contact relations such as chilled borders, apophyses, or contact metamorphism of the one rock by the other. Brøgger concluded that this indicated that one magma was accomodated just after the crystallization of the other magma, but while the latter was still very hot. Such contacts have later been found between other rocks, such as larvikite/basic nordmarkite in Lågendalen, and akerite/nordmarkite at Bogstad, Oslo.

The *pegmatites* of the Oslo region have become well known, especially the nepheline syenite pegmatites of the Langesundsfjord area. These pegmatites will be mentioned together with their associated rocks.

The *contact metamorphism* is developed in classical exposures around the plutonic bodies of the Oslo region, especially in the Cambro-Silurian shales and limestones adjacent to such bodies. Interesting mineral development occurs within a contact zone of 1—2 km width. Kjerulf showed as early as 1853 that the metamorphism is a re-crystallization process due to the heat given off by the crystallizing magmas. Brøgger gave further details of this contact metamorphism, but it became well known from the famous monograph by V. M. Goldschmidt (1911). He succeeded in showing that the mineral paragenesis in the metamorphosed rocks is a result of the original composition of the rock. Goldschmidt divided the mineral associations of the series from metamorphosed shales to limestones ("hornfelses") in ten classes, later to be known as the hornfels mineral facies of metamorphic rocks. Sæther (1946) has studied the metamorphism of the outer contact zones in the Nittedal district, where he mapped the areas of the hornfels facies, amphibolite facies, and the peripheral actinolite greenstone facies and epidote amphibolite facies.

Areal description.

In the following a description of the regional geology of the main rock types is presented. In cases where different rock types occur together in minor areas within one massif, the features are described under the most abundant rock type.

Kjelsåsite is shown only in a few smaller areas within the 1:100 000 rectangle maps published by Brøgger and Schetelig. In other areas it is grouped together with larvikite as "kjelsåsite—larvikite". East of Kjelsås in Sørkedal the Brøgger map "Kristiania" of 1917 shows an area marked as coarse-grained kjelsåsite. This is the type locality of kjelsåsite, but the rocks of this area are included in the group "kjelsåsite and larvikite" on the geological map of Oslo and surroundings (Holtedahl and Dons 1957). This area contains what probably should be called kjelsåsite. Around the farm Kjelsås Brøgger mapped a little area of what he called basic kjelsåsite, but which on the latter map has been designated sørkedalite. From available descriptions (Barth 1945 a, Oftedahl 1960) it is obvious that this little area contains a lot of unusual rocks ("sørkedalite—apotroctolite series") which in part are coarse-grained to pegmatitic in appearance. The rock types vary from place to place. Consequently this small area must have had special mode of origin. Various geologists have suggested that the rocks represent part of a volcanic neck which has been "drowned" by a younger magma, resulting in assimilation and recrystallisation. Another area of kjelsåsite ("larvikite—kjelsåsite" on Plate 13) is distinguished in the Brøgger maps around Ramnes, northwest of Tønsberg. Petrographic observations by Barth (1945 a, p. 75) and field observations by the author seem to indicate that this area may be occupied instead by basic syenite. Kjelsåsite is also marked in the Skrim Mountains (700 m) south of Kongsberg. Within this area hybrids are abundant, and at one place near the top large xenoliths mostly of basalt are seen. Thus the "kjelsåsite" is here only a larvikite, modified by assimilation of basalt.

Larvikite and what has been mapped as kjelsåsite—larvikite is found in a number of massifs, the largest of which occur between outer Oslofjord and Langesundsfjord. This area measures 50 × 25 km and constitutes the largest plutonic massif of any rock type within the Oslo region. The larvikite with long rhombic or boat-shaped feldspars is most typically developed in the coastal area between Tønsberg and

Langesundsfjord. Within large parts of this area the larvikite is surprisingly homogeneous. A number of varieties occur within the northern parts of the massif. Around the city of Tønsberg the larvikite shows a continuous transition from a dark grey to a brick red rock which has been termed tønsbergite. Another type is found at Hedrum between Gogsjø and Lågendalen, northwest of Sandefjord. This variety was described as *an augite-bearing mica syenite* by Brøgger (1890, p. 31), and was later termed hedrumite. There appears to be a gradual transition into regular larvikite, but the rocks within most of the outcrops are rather syenitic, therefore it is shown as nordmarkite on Plate 13.

The next largest area of larvikite occurs in the western "nose" of the Oslo region. Quite a number of varieties are met with according to field investigations by the author. A regular larvikite with boat-shaped feldspar crystals is one important type, but equally important is the variety showing more rectangular feldspars. Porphyritic varieties of different appearance occur, for instance with scattered rhomb-shaped phenocrysts in a finegrained groundmass. Hybrids with a varying degree of assimilation of fragments are also relatively frequent, especially in the Skrim Mountains. The larvikite is cut by ekerite and the Drammen granite and is thus clearly older than these rocks. The boundary against the nordmarkite to the south is found in one place (road cuts at Fjellvann) where there is a gradual transition over a distance of a few hundred meters.

Of special interest are the larvikite varieties in the district Andebu—Kodal, 10—20 km west of Tønsberg. Brøgger (1890) found a gradual transition from larvikite to rhomb porphyry and concluded that these may indicate areal eruptions of the larvikite magma. In places the semi-porphyritic larvikites even resemble definite RP type (Oftedahl 1952).

The border zone of the larvikite massif in the Langesundsfjord district has a number of peculiar features which have become well-known from the carefully illustrated descriptions by Brøgger (1890) in connection with his treatise of the nepheline syenite pegmatites occurring in this zone. These features are partly due to the invasion of the nepheline-bearing pegmatite dikes; they will be described under the nepheline-bearing rocks (lardalites).

The *pegmatites of the larvikite* are also described by Brøgger (1890) and classified as syenite pegmatites. They occur around Stavern and eastwards and carry a micro- to cryptoperthite as the only feldspar. In the dikes of southernmost Tjømø and at Ula the cryptoperthite is a moonstone with a strong and beautiful deep blue schiller. The dark minerals are barkevikite and lepidomelane and a few rare minerals (zirkon, polymignite, titanite, etc.).

The *lardalite* occurs within one small area north of Larvik, between Lake Farris and Lågendalen. From the border relations Brøgger concluded that the lardalite magma had invaded larvikite just after it had crystallized far enough so as to behave as a solid, but while it still was very hot (*e. g.* at the roadside between Rydningen and Ono). In the Ono bay and Bjørnøya in Lake Farris the contact is made up by a layer of nepheline, 10—15 cm in thickness. Up to one meter from the nepheline the larvikite is hybridized.

The four varieties of lardalite all show gradual transitions, and two varieties may occur together as alternating veins with sharp boundaries. A preliminary map of the distribution of the four varieties has been attempted (Oftedahl 1960).

Pegmatites are rare within the lardalite area. Only along the western boundary do occur pegmatites in intimate association with all the four types of lardalites over distances of a few meters. This pegmatitic or hybrid border zone runs along the western boundary (from Liurvann northwards). In addition nepheline syenite pegmatites occur in the Langesundsfjord district. They were thought to be genetically associated with the lardalite and are accordingly described below.

The *nepheline syenite pegmatites of the Langesundsfjord district* are famous from the detailed description by Brøgger (1890). More than 40 rare minerals occur in the dikes and 20 of these minerals were first found there. The dikes occur in a very irregular way on the islands of the Langesundsfjord and on the main land to the east as far as Tveidalen. One of the largest dikes covers nearly all of Låven, a small island about 120 meters in length. It was discovered around 1830, and already in 1839 leucophane and mosandrite were known from this locality. The important minerals are: a white feldspar (a microperthite), a reddish or brownish, partly altered nepheline, grey sodalite, ægirite, lepidomelane, and magnetite. Here and there the following rare minerals occur in considerable quantity and size: apatite, mosandrite, låvenite, wöhlerite, pyrochlore, zircon, orangite, etc. etc.[1]

[1] A more complete list is given by I. Oftedal in Guide to Congress excursions A_{12}—C_8 (1960).

All the nepheline syenite pegmatite dikes lie within the border zone of the larvikite massif, and many peculiar rocks and structures occur within this border zone. They were desribed in detail by Brøgger (1890). Best known are the relations on the island Store Arø. The originally flatlying Silurian sedimentary rocks seem to "fall" into the larvikite, and the uppermost formation, the Ringerike sandstone, stands nearly vertical. Within the adjacent larvikite, fragments of the basalt B_1 and rhomb porphyry RP_1 are locally abundant. The fragments are either angular or due to mobilization drawn out to long lenses. Then follows a series of gneissic rocks; the gneissification gradually decreases with increasing distance from the contact. In short the gneissic zone contains: 1. Schlieren with gneissic larvikite and nepheline syenite, mostly with gradual transitions, connected with nepheline syenite pegmatite. 2. A gneiss of more or less nepheline syenitic composition with lenses of undeformed larvikite. 3. Strongly drawn-out fragments of rhomb porphyries in 1. and 2. or in undeformed larvikite. These features may be explained by the two successive processes:

The first process concerns the stoping of the larvikite magma. Close to the boundary of the ascending magma the whole series of supracrustal rocks slid down into the magma; in some places the rocks of the lowest part of the lava series became squeezed out by the movement. Fragments of these squeezed-out rocks were later distributed trough the larvikite. Where the magma was hot enough, fragments of basalt and rhomb porphyry were mobilized and drawn out. After crystallization of the larvikite, but while it still was quite hot, the second process followed. This is connected with a cauldron-like subsidence of the crystallized roof zone of larvikite. The still hot larvikite was protoclastically broken up in a border zone, in which solutions or gases from a crystallizing nepheline syenite ascended. The ascending fluids contained an excess of soda and rare elements. The soda excess produced a "fenitization" of the larvikite so that it became a gneissic nepheline syenite. This metasomatism occurred chiefly in deformation zones, partly including lenses of undeformed larvikite. In connection with these movements pegmatite also crystallized together with the gneisses. After these movements had ceased nepheline syenite pegmatites formed in irregular and cross-cutting fissures. Although most beautifully developed in the islands of outer Langesundsfjord these border relations of the larvikite can be followed from the northernmost part of Eidangerfjord to Nevlunghavn.

Nordmarkite occurs as the dominating rock in the northern composite batholith between Oslo and Mjøsa, and in a number of smaller areas. Brøgger tried to distinguish between a basic variety (pulaskite) and a more acidic variety (nordmarkite) in his 1917 Hønefoss map sheet. Otherwise he never attempted any areal distinction between the nordmarkite varieties. Sæther succeeded (as shown in the Oslo map, Holtedahl and Dons 1957) in distinguishing between five nordmarkitic rock types. Of the three mentioned petrographic varieties (p. 324) the ordinary syenite was divided into a coarse-grained and a porphyritic type, and it was necessary to characterize a type as alternation of ægirite-bearing and ægirite-free nordmarkitic rocks. The contacts between all these varieties may be sharp or transitional. In many parts of the northern batholith the rocks are quite homogeneous, in other parts it is hybridic or contains recognizable inclusions.

Of special interest are the semi-circular or half-moon shaped areas in Nordmarka where the nordmarkite by gradual transition changes into rather well defined zones of various types of intermediate rocks (basic syenite, larvikite, and kjelsåsite). Little is known about the origin of these structures, but one may think of more or less completely assimilated cauldrons (Holtedahl 1943).

In the southwestern part of the Oslo region an area of nordmarkite is situated between the northern and southern larvikite massifs. This rock shows a gradual transition against the larvikite in the north (Fjellvann), and a sharp and "simultaneous" contact in Lågendalen against typical larvikite. Thus this basic syenite has obviously crystallized soon after the larvikites.

A smaller mass of typical ægirite-bearing nordmarkite is known as "The Hillestad laccolith" from Brøgger (1933 a). Other areas of syenitic rocks perhaps more closely allied with nordmarkite than larvikite occur in Ramnes and in Hedrum.

Ekerite occurs with its largest massif around Lake Eikern. It has clearly cross-cutting relations against the larvikite, and it surrounds the Sande cauldron. Within the central intrusion of this cauldron ekerite forms a ring-shaped body, and the rock changes towards the interior, becoming syenitic and finally basic monzonitic. This change is quite gradual and takes place simultaneously with the occurrence of a large number of more or less assimilated fragments of lavas, chiefly basalt. The ekerite "ring" makes up the outer lowest part of the hills, the tops of which are situated in the center of the ring. Thus the change to more basic rocks is accompanied by increasing elevation. This gradual change in basicity is explained due to the increasing assimilation of basalt fragments towards the roof of the magma chamber of the ekerite.

A large body of ekerite is found from north of Nittedal to the west side of Hurdalssjø. A number of smaller bodies of ekerite occur within the nordmarkite of the northern batholith, and no doubt many of these massifs are transitional into the related nordmarkite. Such transitions are so frequent that Brøgger in some maps distinguished an "ekerite poor in quartz".

The largest pluton of the *biotite granite* (the Drammen granite) lies between Tyrifjord and central Oslofjord. The magma of the Drammen granite gradually ascended by overhead stoping, until the magma became so viscous that fragments could no longer sink. In some places the magma then pushed the roof rocks upwards, causing doming of the roof, *e. g.* the northernmost part (Finnemarka) and in the Sande valley. By its stoping the granite magma destroyed much of the Drammen cauldron. It also cut out a little sector of the Glitrevann cauldron. In the field the Drammen granite is the most homogeneous plutonic rock in the Oslo region. It contains nearly no pegmatite veins or nests, and inclusions are rare. Only hydrothermal quartz veins and cross-cutting aplite dikes may be found.

Besides normal aplitic and quartz porphyry border zones, an abnormal border is found along the northern boundary at Tyrifjord. Here the granite gradually changes outwards into syenite and then monzonite. On Plate 13 this border zone is shown as larvikite. It is quite often hybridic with partially assimilated fragments. Locally sharp contacts between these rock varieties are observed. There can be little doubt that this basified border zone is a result of peripheral assimilation of shales and limestones by the granite magma.

A number of granite bodies are situated along the eastern border of the northern batholith. One mass is entirely situated within Pre-cambrian rocks as is also the case with a small granite area just west of the southern composite batholith. Thus it seems that the ascent of the granite magma was almost independent of the fissures of the Oslo graben proper.

Dike rocks.

Igneous dikes occur in great numbers in the Oslo region. They are abundant in some of the Cambro-Silurian, and less abundant within the lavas or deep-seated rocks. Brøgger devoted three of his seven volumes in the Oslo region series to these rocks (Brøgger 1894, 1898, and 1930). Also in the new publication series the dikes have received considerable attention (Sæther 1947, Dons 1952, and Oftedahl 1957 a). In the last century Brøgger published a map of the dikes of the islands in innermost Oslofjord, and Werenskiold (1911) mapped the Fornebo penninsula just west of Oslo. This investigation was continued by Sæther (1947) who mapped nearly the whole of Bærum lowland, finding 521 dikes. In the vicinity of the Ullernåsen—Husebyåsen volcanic neck Dons (1952) mapped 365 dikes. Below the petrography, mode of occurrences, and age relations of the dike rocks (sills also included) are described.

Petrographically the dike rocks are highly varied in composition and texture, and Brøgger distinguished between a great number of varieties, many of which were given new names. However, many of these names have not been used internationally, and in the following only those rocks which are important or the names of which have been used outside Norway are mentioned.

Among the rocks of basic composition, the ordinary pyroxene-bearing *diabase* as well as the *proterobase* (with barkevikite as major dark constituent) and *camptonite* are abundant. The latter rock is rich in barkevikite and carries either augite and/or barkevikite as phenocrysts. Less frequent is *kersantite* with biotite as the chief dark silicate. The most frequent basic dike is the altered diabase, in which the dark silicates are chloritised and the plagioclase altered to albite.

Among the monzonitic dikes the *rhomb porphyry* dikes are the most important. Usually they carry large and rhomb-shaped crystals in a fine-grained macro-crystalline groundmass. Monzonitic dikes with rectangular plagioclase phenocrysts have been termed *akerite porphyry dikes*.

In the syenitic group occur a number of varieties. The most important one is *nordmarkite porphyry*, the dike equivalent of the normal syenite. It carries alkali feldspar and some oligoclase, with hornblende and biotite as subsidiary minerals. The other important variety is called *mænaite* from Lake Mæna in Hadeland. It is felsitic with a light grey color, the color index is always low (at least below 20). The rock is trachytoidal, with oligoclase as the chief mineral, and less than 30 per cent orthoclase. With more orthoclase the dike is called *bostonite*. Its granitic equivalent was termed *lindøite*. Among the dikes of nepheline syenitic composition may be mentioned *foyaite,* which is trachytoidal and carries augite or ægirite-augite as the important dark silicate. With ægirite as the major dark silicate the rock is called *tinguaite*. This rock forms a continuous series with the syenitic equivalent *sølvsbergite* and the granitic equivalent *grorudite*. Other dikes of granitic composition are *quartz porphyries,* carrying mostly biotite as the dark mineral.

Geologically the mænaite is conspicuous in forming large sills at the base of the Cambro-Silurian series, mostly in flatlying Cambrian shales. This is ascribed to the fact that when the mænaite magma was intruded the Precambrian basement was fractured, but fissures could not form in the overlying Cambro-Silurian rocks (Holtedahl 1953, p. 502). One sill is especially worth mentioning: it runs close to the base of the Cambrian along the southwestern branch of Tyrifjord and southwards for 20 km.

Most of the other dike rocks occur either as cross cutting dikes trending NNW—SSE (Fig. 41) or NNE—SSW (parallel to the strike) as "sills" which occasionally cut the bedding (Dons 1952). In the Ullernåsen—Husebyåsen area Dons found that the dikes take up 17 % of the total area.

The *age relations of the dikes* are very interesting. Brøgger originally thought that they followed the general rule of differentiation, with basic dikes being the oldest, the acidic dikes being the youngest. Later he found that the youngest group of diabases are cutting the biotite granite (Brøgger 1933 a). Sæther (1947) concluded that the semi-concordant intrusions of diabase, mænaite, with bostonite and lindøite make up an early group while diabase and in part mænaite continue as "Durchläufer" through the period of ordinary, syenitic dikes. The results of Dons (1952) shows a similar arrangement. In his area mænaite and related rocks make up an early group, representing nearly half of all the dikes (by number). Then follow dikes such as rhomb porphyry, akerite porphyry, syenite porphyry and nordmarkite porphyry, ending up with quartz aplite. Diabase and quartz porphyry are "Durchläufer". Thus it is obvious that the igneous dikes do not represent samples from the magmas of the plutonic masses.

Some of them do, but much more complicated processes than a regular fractional crystallization has been operative in producing many of the dikes. Particularly dubious is the origin of composite dikes of diabase with quartz porphyry margins or syenitic dikes with more basic margins (Dons 1952). It has been suggested (Oftedahl 1957) that assimilation of the roof rock by magma intruded in chambers close to the surface, is responsible for the extraordinary dikes.

A few dikes have been marked on the map Plate 13. Within Oslo the Tyveholmen rhomb porphyry dike runs from the fjord northwards until it ends in the akerite. A similar rhomb porphyry dike runs from the fault south of Oslo, southwards east of the Bunnefjord. The longest known rhomb porphyry dike is the one which runs from west of Tyrifjord and northwards for 87 km. Outside the Oslo region a number of Permian dike rocks are known. A great number of diabase dikes are found in the coastal areas southwest of the Oslo region and a rhomb porphyry dike also occurs here. Similar dikes also occur along the Swedish coast southeast of the Oslo region. These dikes witness that Permian magmatic activity has occurred also outside the Oslo graben. The long rhomb porphyry dikes with a thickness of up to 30 m may be assumed to be feeders for rhomb porphyry flows.

Within the area studied by Dons (1952) a few per cent of the dikes carry xenoliths of the bedrock (Cambro-Ordovician sedimentary rocks and Precambrian crystalline rocks), always testifying of an upwards movement of the xenoliths.

Finally a peculiar mænaite sill at Byrud, southern end of Lake Mjøsa, deserves mentioning. This sill shows a transition into pegmatite and carries a beryl so pure that the rock was mined for emerald around 1880.

Volcanic vent breccias.

A number of bodies of cross-cutting igneous breccias connected with explosive volcanic action are described from or just outside the Oslo region.

Just northwest of Oslo are situated three explosion vents in Ordovician shales. The Holmen—Dagali breccia has a nearly circular outline and a larger diameter of 1.5 km. It is described by Holtedahl (1943, p. 50, according to field work by Dons). Some parts of the breccia is a solid and hard rock with distinct fragments, in other parts the breccia is looser and showing agglomerate-like character with more rounded fragments. Nearly all fragments seem to be some kind of finegrained syenitic rocks just as the groundmass. Further southwest two smaller breccias are described by Werenskiold (1920), the Øraker and the Jar breccias, each a few hundred meters across. Both carry large fragments of Precambrian, Cambro-Silurian rocks and Permian lavas, essentially rhomb porphyries.

In connection with the Ullernåsen—Husebyåsen volcanic neck a few small areas of breccia, probably explosion breccias, have been mentioned by Dons (1952), another breccia is known at Tyrifjord (marked on Pl. 13).

At Lindum, some 5 km southwest of Drammen, the Drammen granite has been cut by an explosion pipe which may be a few hundred meters in diameter. The author has only found one good exposure of the breccia. It contains small fragments of basaltic lavas and of fine-grained syenitic rocks which also make up the groundmass.

The Sevaldrud breccia is situated in the Precambrian just west of Randsfjord. It has been described in great detail by Brøgger (1931 b). The breccia is about 1200 m long and has a width varying from 100—200 m. Precambrian gneisses are abundant as fragments close to the contact, elsewhere the fragments are mostly made up of shales, limestones and sandstone from the Cambro-Silurian series and different types of rhomb porphyries from the Permian volcanic sequence. The fragments are rarely larger than 10 cm. The groundmass has a dark, rather earthy appearance and is called lava detritus by Brøgger. This groundmass contains some fragments and droplets of a basalt which still has a glassy groundmass. Thus the explosion seems to have occurred when liquid basaltic magma was available. Therefore it seems reasonable to assume that the explosion is connected with the eruption period of central volcanism which also was explosive. Interesting is the fact that the Sevaldrud breccia proves that a quite thick lava series existed west of Randsfjord.

The Oppkuven breccia has been shortly mentioned by Sæther (1945 a). It has a roundish outline and a diameter of ca. 5 km. The breccia consists of felsite porphyries with a marked flow structure and with inclusions of kjelsåsite which also surrounds it along most of its outline. The felsite porphyry has a clearly cross-cutting nature against the adjacent kjelsåsite. Sæther considers that the breccia forms an intrusive body, the overlying rhomb porphyries in a northwestern portion of the breccia being roof pendants. Another possibility is the deposition of the breccia in an explosion funnel, an explosion so violent that material was cleared away to the surface. Then the explosion funnel was filled with the exploding magma of syenitic compositions and inclusions of the deep-seated bedrock. Thus the overlying rhomb porphyries have to be younger.

The Gardnos breccia (Broch 1945) is situated in the Precambrian 90 km northwest of Tyrifjord. It is about 4 km in diameter and consists of angular fragments of size from dust to 50 m in a black matrix. The fragments are essentially derived from adjacent Precambrian rocks. One large fragment of phyllite must originate from the once overlying phyllite of Cambro-Ordovician age. Thus a minimum age for the breccia is given. No volcanic rocks have been observed, and Broch concludes that the breccia was formed by a gas explosion, most likely of Permian age.

Ore deposits.

A great number of small ore deposits have been found in the Oslo region. Their mode of occurrence is very characteristic: they all occur at the very contact of the plutonic bodies or a little outside the contact in the adjacent Cambro-Silurian rocks. A number of these deposits were mined in the last centuries, but they are all too small (even if rich) to be mined in the present days. A description of many of these old occurrences was published by J. H. L. Vogt (1884), and Goldschmidt (1911) described all the most important deposits, some of which were in operation at that time.

The deposits contain a number of different ore minerals. The most important ones are magnetite, hematite, pyrite, chalcopyrite, galena, sphalerite, molybdenite, and more rarely minerals of bismuth and manganese. Different ore minerals predominate in the different areas. Thus iron ores predominate in the northernmost part at Mjøsa (Skreia, Mistberget) and in part of the Konnerudkollen area at Drammen. Copper minerals predominate in the Grorud—Alnsjø area etc. Zinc and lead are the dominating minerals in Konnerudkollen, Grua and parts of the Hakadal—Nittedal area.

All these ore deposits occur in connection with the magmatic rocks, and Goldschmidt (1911) concluded that all deposits are contact-pneumatolytic, formed by the interaction of magmatic gases with the bedrock, mostly limestones, rarely shales.

Fissure fillings of a loose swampy hematite and fluorite in rhomb porphyries and other rocks (around Bærums Verk, etc.) represent direct precipitation of the magmatic gases.

Genetic relations and origin of magmas.

The plutonic rocks indicate that there are two clearly different magma series, the series made up by the volcanic necks (essentially gabbroic) and the rather continuous series from basic kjelsåsite to ekerite and biotite granite. This dualism is also reflected by the lavas, in that there are several sharp changes between effusions of basalts and rhomb porphyries. Thus a principal feature of the magmatism within the Oslo region is that two types of magmas were available both at the surface and within the crust, viz. the basaltic (in part olivine basaltic) magmas which may be derived from the upper part of the mantel, and the intermediate to acid magmas which must have formed in some other way. Oftedahl (1952) suggests that all the latter magmas were formed by mobilization of the lower part of the continental crust, and Barth (1954) shows that only small chemical changes are necessary to produce mildly alkaline Oslo magmas out of the basic granodiorites of the subcrust. The necessary heat for the mobilization was supposed to be derived essentially by gasseous transfer from the mantel. Such a simple twofold division, however, does not explain the acidic explosion products which seem to be genetically related to the basalts of B_3 age. These acidic magmas could be either differentiates of the basaltic magma or formed by interaction between the basaltic magma and the crustal bedrocks. However, the possibility that the acidic magmas mentioned could be derived from the nordmarkite magmas etc. cannot be excluded.

Considered as an igneous rock series, the Oslo rocks are mildly alkaline according to Peacock's alkali:lime index. Mineralogically they are clearly alkaline both by containing alkali pyroxene and hornblende in acidic rocks and by containing the series olivine — titaniferous augite — ægirite augite in basic rocks.

Faulting and subsidence of the graben area.

The faulting is so well developed in the Oslo region that it early attracted the interest of the geologists. Thus Kjerulf found and described many fault lines of the region, especially in the vicinity of Oslo. Also Brøgger devoted much of his interest to faulting in early papers of 1883 and 1886. Later the faulting has been studied by Cloos (1928), Størmer (1935), Gleditsch (1944), Dons (1952) and Oftedahl (1952).

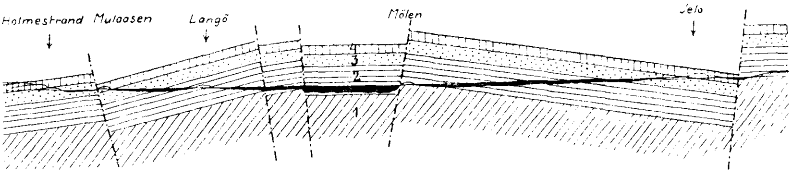

Fig. 106. Schematic section across the Oslofjord through Jeløy and Holmestrand. 1 — Precambrian, 2 — Marine Cambro-Silurian, 3 — Sandstone, 4 — Lavas. (After W. C. Brøgger 1886.)

Already at the begin of this century most of the more or less straight-lined faults were known, as well as their displacements. All faults seem to be normal faults. Their dip slip may be more than 1000 m on large, single faults. Thus the most conspicuous fault of eastern outer Oslofjord has a dip slip of about 2000 m (at Jeløya), increasing southwards to perhaps 3000 m. Frequently the faults occur in parallel groups, either as irregular faults (*e. g.* the Krokskogen lava plateau) or as antithetic step faults (*e. g.* the Vestfold lava area, the Langesundsfjord area). In these cases the dip slips are usually less than 50 m, in some cases up to 200 m or more.

The faults are not only dip slip faults; thus the fault west of Nesodden has a strike slip of several hundred meters (Cloos 1928). One of the necks of the Ullern—Husebyåsen area is cut by a fault which has a strike slip of 200 m and a dip slip of 50 m (Dons 1952).

Both the survey map (Pl. 13) and detail maps (e. g. Holtedahl and Dons 1957) show that along some of the faults the displacement is not translatory, but rotational. This fault type has been studied by Gleditsch (1944) in the Røyken area of Inner Oslofjord.

The net effect of all the faulting is that the area of the Oslo graben has been subjected to an irregular block faulting which has resulted in a subsidence of between 2000 and 3000 m for the south central part of the graben, but much less for the other parts.

Important Permian faulting occurs also outside the Oslo region. At Lake Øyeren a small area of Cambrian rocks is faulted down (Holtedahl 1953, p. 551). Also the faults in more northern districts of Rendalen and Engerdalen, as well as the faults cutting the Cambro-Silurian of the Vänern—Vättern district of Sweden has been supposed to be of Permian age.

Since the faults are cutting even the youngest lavas, the main period of faulting is no doubt later than the formation of the volcanic series. But the faulting may have occurred soon after the volcanic period, because no major faults are known within the plutonic bodies. Anyhow, the fault lines have repeatedly been exposed to fault movements; thus some of the Permian fault breccias are accompanied by older, Precambrian breccias, and in the present days the Oslofjord area is one of the areas of strong seismic activity in Norway.

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