CONTRIBUTION TO THE GEOLOGY OF THE SOUTHERN PART OF THE OSLOFJORD

THE RHOMB-PORPHYRY CONGLOMERATE WITH REMARKS ON YOUNGER TECTONICS

WITH 12 TEXT-FIGURES, 5 PLATES AND 1 MAP

BY

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Introduction.

In his classical work: "Über die Bildungsgeschichte des Kristiania-fjords" (= Oslofjord), Brøgger (1886) was able to demonstrate and explain in their main features, the peculiar geologic structures which led to the formation of the Oslofjord and influenced the topography also of the adjacent parts of the Oslo Region. The origin of the fjord is chiefly due to considerable subsidences along mainly N—S fault-lines probably of Permian age. The greatest fault runs along the east side of the fjord and borders the Oslo Region with its Paleozoic sediments and igneous rocks, from the Precambrian area to the east.

The present paper deals primarily with the so-called rhomb-porphyry conglomerate which forms one of the youngest sedimentary series of the Oslo Region and which occurs on a number of islands situated along the east side of the fjord. The term rhomb-porphyry conglomerate was introduced by Brøgger (1900) to signify a thick series chiefly of breccias and conglomerates consisting almost exclusively of fragments of various types of Permian rhomb-porphyry lavas. The sediments exhibit several peculiar characteristics which are described and tentatively interpreted in the present paper. The consolidated sediments have in post-Permian time been subject to considerable tectonic disturbances. A study of the structures has led the author to the conception of a connection with the late Mesozoic and Tertiary orogenetic movements of northern Europe. In order to elucidate the structural lines of the fjord, maps indicating the submarine topography have been worked out.

Grants from the Fridtjof Nansen Fund has rendered it possible for me to spend parts of the summers 1933 and 1934 on the rhomb-porphyry islands. Most of the research was carried out on Rauøy which is the largest of the islands. From here chiefly, the about twenty other islands and skerries were visted by boat. I wish to express my gratitude to Mr. A. Mathiesen and Captain A. Kvissgaard for their readiness in giving me valuable assistance during my stay on Rauøy.

In connection with my geological investigations of the island, I also had the opportunity of taking several air-photographs (Leica camera) which have proved very helpful in the study of the tectonic structures.

Through the courtesy of the military authorities special maps (1 : 25000) were borrowed for the preparation of the geological sketch-maps. The submarine contour lines on the maps of the present paper have been drawn according to the soundings indicated on the mentioned special maps and on the ordinary charts published by Norges Geografiske Opmåling.

During the preparation of the present paper I have received valuable assistance from Professor J. Schetelig who has very kindly expressed his views on several of the collected rock specimens and permitted me to use for comparison the original collections in the Geological Museum at Oslo. He also placed at my disposal some Oslofjord charts on which submarine contour lines had been drawn. I am especially indebted to Professor O. Holtedahl for helpful advise and valuable critisism during the present work. Acknowledgements are also due to the curators of the Geological Museum, Messrs. H. Rosendahl and H. Bjørlykke, who have kindly assisted me on various occasions. Dr. K. Münster Strøm permitted me to use a bathymetric map of the southern Oslofjord which he had drawn from the soundings stated on the ordinary chart.

Valuable technical assistance has been obtained from Miss Lily Monsen during the preparation of the illustrations.

Previous Research and Conceptions of the Rhomb-porphyry Conglomerate.

Keilhau (1838, p. 85) had already noticed some peculiar brecciated rocks on the island Revlingen near Moss. He points out that the breccia contains angular and rounded pebbles of the various porphyries occurring in the district and classifies the rocks together with other coarse sediments, such as those of Holmestrand and Alnsjø, formed in connection with the Oslo-eruptions. In the second part of the last century, little or no attention was paid to the breccia which was marked on the maps with the same colour as the rhomb-porphyry.

The rhomb-porphyry conglomerate was actually discovered by Brøgger (1900) who has given a detailed description and discussion of these interesting sediments. Brøgger was able to show that although the rock consisted of more than 90 % Rhomb-porphyry, it was not an effusive, but a true sediment with a thickness of the series probably exceeding 750 m. The almost unstratified sediment showed a constant variation of finer and coarser beds, the latter having angular and rounded boulders of a size up to 5×3×3 m. Among the pebbles in conglomerate or breccia, was also noticed specimens of the Downtonian sandstone underlying the lavas in the district. With regard to the age of the deposits, Brøgger points out the absence of acid lava-pebbles in the rhomb-porphyry conglomerate, a fact which he explains as an indication of the sediments being formed before the later (Nordmarkite-Ekerite-Granitite) eruptions of the Oslo region. In his discussion on the formation of the breccias, Brøgger arrives at the conclusion that they were formed by rapid washes into shallow, subsiding lakes also extending east of the great fault-line along the east side of the fjord.

The rhomb-porphyry conglomerate is mentioned by Øyen (1914) as an agglomerate.

With regard to the formation of the sediments, Brøgger (1914) suggests that the sediments were deposited in an extended basin and were deposited partly by mud-flows like those we find nowadays in desert regions.

Stille (1925) points out that the breccias were laid down in a kind of continental geosyncline with its eastern border corresponding to the eastern boundary of the Oslo Region.

Holtedahl has gone even further, in pointing out in his ordinary geological lectures at the university and in two smaller papers (1931 a and 1932) the possibility of the rhomb-porphyry conglomerates being formed in intimate connection with the large eastern fault. The sediments are regarded as detritus-material washed down at a marked slope from the highland east of the fault-line.

Description of Localities.

As seen on the general map pl. VI, the islands consisting of rhombporphyry conglomerate occur on a narrow, more or less continuous, submarine platform bordered on the west by the fjord depth and on the east by the channel marking the course of the large Permian fault-line. In order to give a more detailed map of the different islands, it has become necessary to figure each island, or group of islands, separately. Text-figs. 2 and 4 gives the sketch-maps, starting with Revlingen farthest north and ending with S. Søster in the south. The various islands are described below in succession.

On account of the constant variation from bed to bed, in the coarseness of the rhomb-porphyry conglomerate, it has been very difficult to give a fairly correct impression of the characters of the sediments in the respective localities. In determining the relative degree of coarseness, one has to take the average of a series of succeeding beds. In the sketch-maps (text-figs. 2 and 4), I have tried to illustrate, according to my notes, the distribution on a larger scale, of the finer and coarser types of the rhomb-porphyry sediments. Although the method, indicated above, is left to the subjective judgment of the worker in the field and therefore is apt to be less accurate, it might be useful and it seems possible to draw some conclusions from the observations.

Revlingen.

(Pl. I, fig. 2; text-figs. 1 and 2).

The small island and the adjacent skerry "Kalven", are situated about 2 km south of the large Jeløy island which consists of Downtonian Sandstone and Permian lavas dipping slightly towards east. Pl. I, fig. 2 shows how the island Revlingen to a large extent is covered by glacial material leaving only the central higher part of the island exposed.

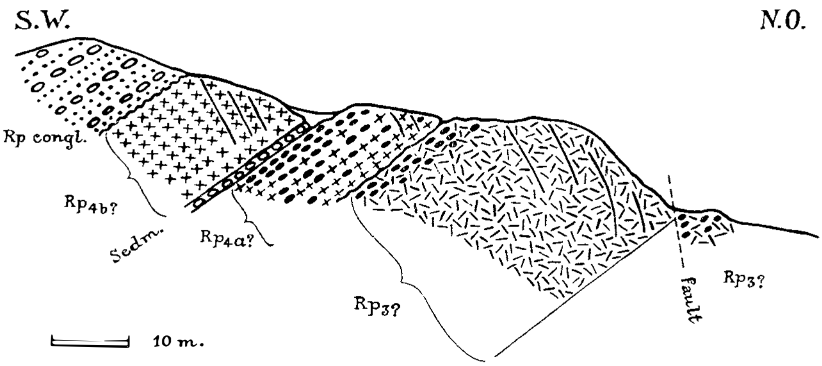

Fig. 1. Section from the NE part of Revlingen. Rhomb-porphyries (Rp) and the basal beds of the rhomb-porphyry conglomerate (Rp congl).

Revlingen deserves special interest because this is the only locality where the contact between the rhomb-porphyry conglomerate and the underlying rhomb-porphyry lavas is exposed. The lavas occur only on the northern part of the island and the lack of sections along the shore line has made it rather difficult to interprete the geological structures.

The rhomb-porphyries. The basal part of the section (text-fig. 1) consists of a red vesicular lava with rather large regular phenocrysts of felspar. The rock resembles that of the top of the following lava flow from which it is separated by a fault striking N 45° W and dipping 80° to NE.

In the continuous section exposed on the hill, the lowest 28 m (measured perpendicular to the surface of the lavas) represent one distinct lava flow. The rhomb-porphyry has well-developed phenocrysts with regular outline of the ordinary type characteristic of Rp_1, Rp_3 and others. Vesicles (black bodies in fig.) occur in the upper 5 m, but are especially abundant near the surface of the flow.

Above the vesicular bed, one finds a distinct contact against an upper flow which is nearly barren on vesicles in the lowest part. The felspar phenocrysts of this lava differ distinctly from those in the one below. The felspars generally appear as rather complicated crystal aggregates like the type figured by Rosendahl (in Holtedahl 1934, p. 380) for Rp_8 of the Krokskogen district near Oslo.

This flow has a thickness of 10 m, and is a typical vesicular lava with the bladders present also near the bottom. In the most complete section NW of the NE fault mentioned below, the top of the lava is not exposed on account of the presence of loose material as indicated in text-fig. 1. On the SE side of the fault-line, however, one finds a good section showing the transition between the two lava flows. Above the highly vesicular flow comes a coarse agglomerate of variable thickness (average 0.5 m) which is again succeeded by a younger rhomb-porphyry with a very distinct lower boundary and which is almost barren of bladders. The phenocrysts are similar to those in the underlying lava-flow and the thickness of this upper porphyry is about 14 m.

Identification of the rhomb-porphyries. Text-fig. 1 illustrates clearly the three different lava-flows described above. In order to attempt a possible identification of the rhomb-porphyries mentioned, I have, with the kind permission of Professor J. Schetelig, compared the collected rock-specimens with the rhomb-porphyry types in the Geological Museum. Professor W. C. Brøgger and Professor J. Schetelig have distinguished and indicated on the geological maps in 1 : 100 000, a number of different rhomb-porphyries which represent separate succeeding flows. Professor Schetelig has kindly drawn my attention to the difference in the development of the rhomb-porphyries in the Krokskogen district near Oslo, and in the Vestfold district (Holmestrand—Tønsberg) (pl. VI). Certain characteristic types are not developed in both areas and the numbers given to the respective types of the porphyries for that reason do not necessarily mean that they are identical flows.

The rhomb-porphyries of the Vestfold district are of special interest on account of their position very near to the rhomb-porphyry conglomerates. Most of the rhomb-porphyries of this region are of the Rp_1 and Rp_2 types, a few, however, have special characteristics and might permit a closer identification. In the section of Revlingen the two upper porphyries, with their phenocrysts forming crystal aggregates, resemble rather closely the rhomb-porphyry of the Korsegaard type. According to the geological maps of "Moss" and "Tønsberg" issued by Brøgger and Schetelig, this lava represents four different flows which have been termed $Rp_{4\,a,\,b,\,c,\,d}$. The basal porphyry in the Revlingen section corresponds well to samples of Rp_8 of the Vestfold district (not the characteristic Rp_8 of the Krokskogen district).

The comparison has shown that in the Revlingen section the basal rhomb-porphyry is probably identical with Rp_8 and the two upper ones with Rp_4, perhaps $Rp_{4\,a-b}$, of the Vestfold district. Professor Schetelig has very kindly looked through the types examined and regards the above-given correlations as probable.

The basal contact of the rhomb-porphyry conglomerate. The contact is at first sight not easy to locate. After some search, however, it is possible to follow the contact-line very distinctly. It is evidently very straight and seems to correspond fairly well to the bedding planes of the lavas and the conglomerate above. The upper part of the uppermost lava seems to have been weathered to a considerable extent, but I have not noticed any pronounced primary jointing of the surface of the porphyry. The surface is neither smooth nor polished, such as might be expected if it had been ground by a glacier.

The rhomb-porphyry conglomerate. The sediment above the lava has from the very beginning the normal character which is found in all the beds above. No transition zone is noticeable, and very close to the contact a boulder measuring 20 cm was found. The continuous series of sediment forming the main part of the island, consists of alternating coarser and finer beds. Although one finds large boulders in several beds, the comparatively finer layers are rather typical for the island. The most common type of sediments is rather coarse gravel. Really fine sediments seem to be rare.

The dip and strike. Text-fig. 2 shows how these characters vary to a considerable extent. The strike turns in a short distance as much as 90°. The average dip is about 35—40°. In accordance with the alteration of the strike, the largest dip is found on the east side.

The faults and joints. Text-fig. 1 shows the already-mentioned fault with a strike to NW. The sketch-map of Revlingen (text-fig. 2) indicates a more prominent fault with a fault-plane striking to N 40° E and dipping 70—80° SE. The fault which is visible on the air-photograph illustrated on pl. I, fig. 2 has a throw of 10 m. The presence of this fault across the contact-line has complicated the structures to some extent. Within the sediments it has very seldom been possible to distinguish real faults. Jointing is a very common feature. The jointing is often accompanied by the formation of crevices such as the one across the middle of the island. The prominent direction of the joints seems to be to NW. Joints with this direction are also seen in the rhomb-porphyries (text-fig. 1).

Kollen.

(Pl. I, fig. 1; text-figs. 2 and 12).

In spite of its small size, this island attains a height of 49 m, and is thus higher than any of the others. It is also wooded, contrary to most of the other naked islands. Exposures are only found along the east coast.

The rocks. Along the SE side of the island one has the opportunity of studying a peculiar brecciated rock which differs considerably from the normal sediments found on all the other islands. The geological structures are difficult to work out on account of the bad preservation of the deposits. Large parts of the exposures seem to consist of solid rhomb-porphyry, among others a type with small phenocrysts resembling closely a special variety (the "Sollerød"-type) of Rp_2 of the Vestfold district. At other places the rock has more the characteristics of a breccia in situ, a breccia where the different rock-pieces are difficult to distinguish from each other. The same porphyries seem to constitute the large and smaller fragments and also the coarse matrix.

Farther north more normal rhomb-porphyry conglomerate occurs. The character of the sediments, however, is also here difficult to study on account of the bad preservation probably caused by tectonic disturbances. The sediments show the usual alternation in coarser and finer beds.

The strike and dip have been difficult to measure, but seem to be rather constant N 35° W, 40° E.

The faults and joints have not been studied in detail. Typical for the Kollen island is, as above mentioned, the presence of a considerable alteration of the rocks. The rocks seem to have been crushed by tectonic pressure, an assumption which might be seen in connection with the position of the island very close to the large fault-line. That the bad preservation of the sediments is due to some kind of a friction-breccia in connection with the large Permian fault, is not much likely since slickensides and prominent quartz-veins have not been noticed.

Eløy.

(Pl. I, fig. 1; text-figs. 2, 7 and 12).

The chief part of this island is covered by glacial deposits. The large amount of glacial material also forms the bottom of the shallow sound between Eløy and Kollen.

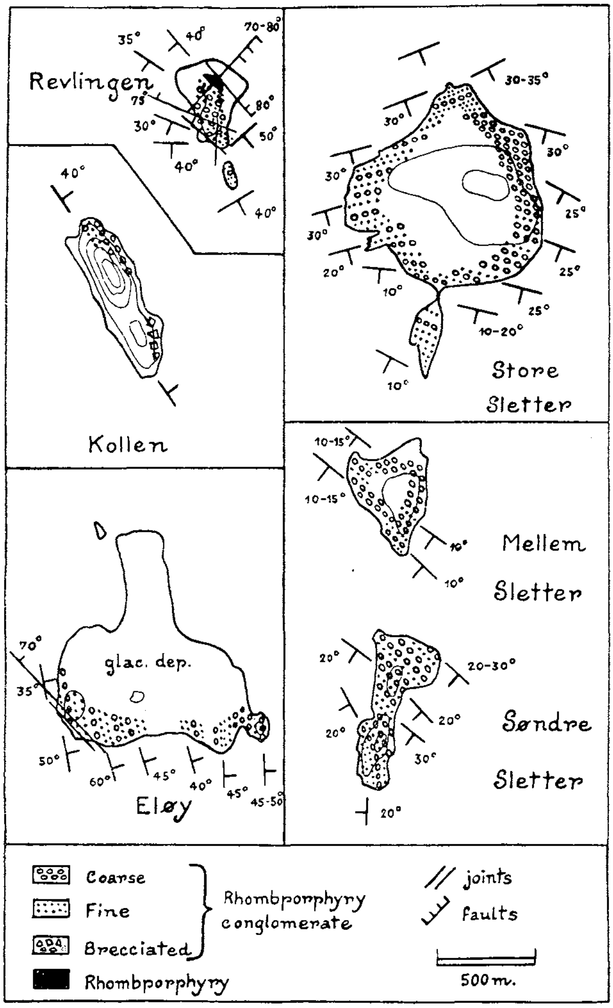

Fig. 2. Geologic sketch-maps of the northern islands. Contour lines with 10 m equidistance.

The southern coast of Eløy gives a rather complete section, only interrupted by a few smaller sandy-beaches which hardly hide any considerable faults. Text-fig. 7 indicates the section which represents a thickness of about 800 m, if we assume a continuous section not interrupted by faults.

The rocks. The sediments have generally the character of coarse gravel with a few larger boulders intermingled. It is of special interest to notice that the oldest layers in the west contain a piece of red sandstone which evidently is derived from the Permian or Downtonian sediments below the lavas. In the western part of the island, the boulders and pebbles seem to be more angular and sharp-edged than further east. In the SW a smaller case of cross-bedding with the distance between the nearest parallel beds amounting only to 30 cm, was observed.

The strike and dip. The strike is rather constant N 0°—10° W, and differs therefore somewhat from the strike of Kollen. The difference might be due to the existence of two separate tectonic blocks. A hypothetical fault-line is indicated on the general map (pl. VI) on account of the change in the direction of the strike and the presence of a submarine escarpment NW of Kollen.

The dip varies from 35°—60° E. A maximum value of 60°, or perhaps 65° is the strongest dip measured on any of the islands and exceeds the earlier measurements by Brøgger (1900, p. 44—45) of 45°.

The faults and joints. A few joints with a NW-direction were measured on the SW-part of the island as indicated on the sketch-map.

The Sletter Islands.

Store Sletter, Mellem Sletter and Søndre Sletter.

(Pl. I, fig. 1; Pl. III, fig. 2; text-figs. 2, 3 and 12).

The three separate islands seem to represent one geological unit, and are therefore treated together below. Morphologically, the rather flat, partly grass-covered islands have a very characteristic appearance as seen on the air-photographs reproduced in pl. I, fig. 1, and text-fig. 3. Glacial material, to a large extent washed out during post-glacial time, covers considerable parts of the Sletters. Raised beaches might be seen on Nordre Sletter. Text-fig. 3 shows the presence of one at a height of about 10 m above sea-level. Ragged pillars and bastions are also formed by the erosion.

The three Sletter islands are separated from each other only by very shallow water with a maximum depth according to the soundings, of not more than 10 m. Between the shoals "Hellene" and the island Eløy, the maps (text-fig. 12) indicate a submarine channel with a minimum depth of 20 m. The southern slope of this

Fig. 3. Store Sletter. Bolærne in the background. A raised beach at a height of about 10 m above sea-level is indicated. Air-photograf towards SSW. (Aut. phot.)

channel continues to WSW on the prominent escarpment along the main fjord depth. Søndre Søster is bordered to the SE by a more than 20 m deep channel which here has a NOE—NE direction.

The rocks. On Store Sletter the rhomb-porphyry conglomerate is well-preserved and exhibits a large variation from rather fine to very coarse types. The NE-part of the island has very coarse and unsorted beds with large boulders, among others one measuring 3×2.40 m was observed. The gravel-beds prevail along the southern, western and northern coasts. The gravel-beds also contain to a certain extent larger boulders. Along the east coast the boulder-beds are much more common. Some very coarse unsorted layers are almost unstratified and have a tillit-like appearance.

On Store Sletter it is possible to get an impression of the lateral variation in the coarseness of the sediments. As indicated on the sketch-map, the rocks are coarser on the east side of the island than on the west. On account of the W—E direction of the strike we have here the opportunity of studying the lateral variation in this direction.

Mellem Sletter which is considerably smaller than the preceding island, has very beautiful exposures of the conglomerates. Especially the rocks along the east coast exhibit very well the extremely coarse and tillit-like deposits characteristic of this island. From a locality in the SE, Brøgger (1900, p. 35, and pl. II) described and figured the largest boulder which has been observed in the rhomb-porphyry conglomerate, and which measures 5×3×3 m. Pl. III, fig. 2 gives an idea of the sediments of this locality. The rather unsorted boulder-beds alternate with well-stratified finer layers. A number of samples of the various rock-types found in the pebbles of the conglomerate, was collected in this locality. The different types of rhomb-porphyry is by far the most common, but it is not unusual to find boulders of essexite-lava, Downtonian and Permian sandstone, and of the beautiful and characteristic Permian conglomerate.

Søndre Sletter resembles in regard to the character of the rocks, the preceding island, but the coarseness of the sediments is not so pronounced. The boulders occurring in the finer gravel have often rather sharp angles. A block with a rectangular cross-section, measuring 0.39×1.10×1.20 m, has some distinct grooves on the under side. The grooves do not resemble glacial striae.

The strike and dip. On account of the pronounced coarseness of the sediments in many localities of the Sletter islands, it has often been difficult to establish the correct values of the strike and dip. As a general rule the conglomerate-beds exhibit a small inclination and partly for this reason the strike is rather variable. The sketch-map (text-fig. 2) illustrates how the strike turns gradually from ENE to ESE on Store Sletter, and, further, to SE on Mellem Sletter, and even to SSE and S on Søndre Sletter. The strike thus turns around about 120° indicating the northern and eastern borders of a trough.

The dip varies from 10° to 30°, or perhaps 35°. On Store Sletter the strike converges towards west. If the sediments had the same thickness on both sides of the island, one would under such conditions expect to find the beds on the west side dipping at a larger angle than those on the east side (such as on Revlingen). This has not been found, a fact which suggests that the sediments on the east side of the island attained a greater thickness than those on the west side. This assumption corresponds very well to the observation of an increase in the coarseness of the sediments from west to east.

The gradual change in the direction of the strike, as well as the absence of intersecting submarine channels, make it probable that the Sletter islands belong to one continuous tectonic block as suggested by Brøgger (1900, p. 48). A separation from the Eløy block is expressed in the discontinuation of strike and dip, and is also indicated by the W—E submarine channel mentioned above. The NW and W border of the great Sletter block evidently correspond to the marked SE and E slopes of the main fjord depth (pl. VI and text-fig. 12). On account of the great difference in the strike and dip of Søndre Sletter and Svarteboene farther south, the southern border of the block occurs somewhere between those islands. An indentation in the submarine escarpment along the fjord depth, and the presence of a small submarine channel SE of Søndre Sletter, as above mentioned, suggest a NE fault-line as the border as indicated on the general map (pl. VI).

The great Sletter block has a central trough-shaped depression with depth about 115 m (max. 124 m) and its largest extension parallel to the main fjord depth. The Sletter islands form together one side of syncline and it seems possible that the central depression of the tectonic block might represent the central area of the same trough of which the Sletter islands constitute the east side.

Faults and joints. The larger tectonic lines have been discussed above. The jointing has not been studied in detail, but does not seems to be strongly developed.

Svarteboene.

(Text-fig. 4)

The largest of the small skerries measures only about 30 m in length. The rocks, having a strike N 65° W and a dip about 30 N, consist of ordinary rhomb-porphyry conglomerate with gravel-beds and scattered boulders.

Rauøy.

(Pl. II, figs. 2—3; pl. III, fig. 1; pl. IV; pl. V, figs. 1—5 and 7. Text-figs. 4, 7 and 8).

The island is one of the largest in the Oslofjord. Its length amounts to not less than 4.4 km or 4.6 km, if we include the small Veslekalven, only separated from the main island by a narrow, shallow sound. The largest width of Rauøy does not exceed 1.1 km. The whole islands consists of rhomb-porphyry conglomerate which gives to it the characteristic red colour expressed in the name (Rau=red, øy=island).

Rauøy might be divided, morphologically, into three different parts. In the north, the characteristic Rauøykalven ascends to a height of 43 m. The wooded northern slope shows a moderate inclination, while the southern side of "Kalven" exhibits a very steep escarpment (well illustrated by Øyen 1914) partly covered by huge blocks of rhomb-porphyry conglomerate forming the rock-waste at the foot of the cliff. A narrow isthmus composed of water-warn gravels, connects Rauøykalven with the main part of the island. The latter part is to a large extent covered with wood and forms a gentle elevation with a maximum height of 45 m. The rocks crop out many places in the central wooded region, but this has not been studied in detail and is therefore not treated on the sketch-map (text-fig. 4). Meadows also constitute a considerable part of the land east of Møkkalassodden and east of Svarteberget. West of the bay Bauen, the bed-rock is partly covered by water-worn pebbles indicating raised beaches. The up to 30 m high land of Rauøytangen, forming the third and southern part of Rauøy, is deeply dissected along the shores by the action of the waves and the shore-ice which have cut out deep chasms and coves in the exposed rocks.

The action of the waves and the shore-ice can be traced almost everywhere along the west coast of Rauøy. The action of the erosion has not been studied specially, but I find it appropriate in this place to draw attention to certain more or less distinct abrasion levels indicating beaches formed at sea-levels different from the present.

The coast of Rauøy is fringed by a rather broad zone of shallow water outlined on the ordinary charts by a dotted line. This shelf on a small scale, seems to have about 8 m as a common depth along SW coasts. North of Svarteberget, the platform is less distinct, and according to the soundings, we find here a more gently shelving level descending from the shore-line and down to a depth of about 6 m where the steeper slope begins. Similar levels are very common round most of the conglomerate islands. With regard to the distribution, they are a little more common along the western exposed coasts of the islands than on the more sheltered eastern coasts. It seems to be a question whether these platforms were formed at present sea-level only, or had been worked out partly at a lower water-level. The platform with the apparantly rather even

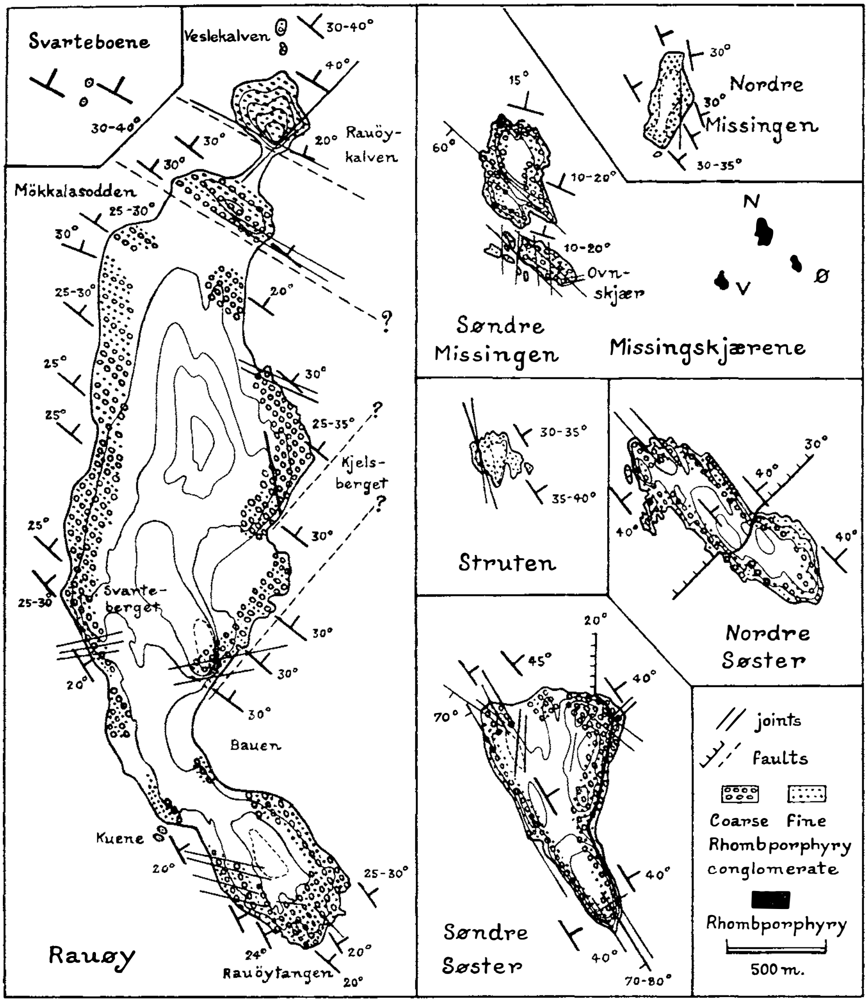

Fig. 4. Geologic sketch-map of the southern islands.
Contour lines with 10 m equidistance.

depth of 8 m along the SW coast of Rauøy seems to ascend rather abruptly to the beach platform with its surface about present sea-level. It seems difficult to explain the lower platform as due to abrasion during the present sea-level.

As pointed out and illustrated by Øyen (1914 p. 8—9, pl. II—III), the erosion has cut out at sea-level, a very distinct platform in the solid rock. On the west coast of Rauøy the rock-bench thus formed is very conspicuous below the steep cliffs as shown on pl. II, figs. 2 and 3. The platform is cut out from the bed rock which crops out ewerywhere between the covering rock debris. The width of the level is in most places very considerable and this suggests a longer stay at the present height of the water-level as pointed out by Øyen (1914 p. 9). The rock-bench described corresponds to the shore-ledges described by Nansen (1922 p. 36—38) from the inner Oslo-fjord and referred by him chiefly to frost erosion. The rock-bench from Rauøy, mentioned above, is much wider on the exposed western side of the island than on the more sheltered east side where Øyen figures platforms only a couple of metres wide. (I have noticed similar narrow benches on the SW-side of Revlingen).

From his studies of the different gravel bars along the shore south of Rauøykalven, Øyen was inclined to distinguish five different beach-horizons distributed at levels between 0 and 10 meter. I have not studied the traces of raised beaches, but on several occasions I have noticed a certain line at a height of about 5 m above sea-level. Here we find very good examples of the peculiar erosion phenomena similar to the "Raukar" of Gotland and so characteristic of the conglomerate in many places. Pl. II, fig. 3 shows a beautiful example of a single pillar modelled out by the force of the erosion. Similar formations are also formed at lower levels as shown in the photograph. The broad pillars resting on the flat rock platform at the shore-line, has been given the name Kuene (= cows), a rather characteristic name for these formations. The foundation of the pillars and bastions seems to be rather commonly at a height about 5 m, therefore indicating a raised shore-line around this level.

A more distinct raised beach is marked at a height about 10 m. Large beach bars with water-warn flakes and pebbles are found at this level along the west coast of Rauøy. This raised shore-line is also distinct on the east side of Store Sletter and on the more central part of Søndre Søster.

The rocks. The large island offers very good opportunities for a closer study of the rhomb-porphyry conglomerate. The rather continuous section along the shore is at some places interrupted by small sand-beaches, but largely the exposures are as complete as indicated on the sketch-map text-fig. 4.

In the SW at Kuene the lowest beds of the Rauøy-section occur. Gravel beds are the most common rocks, but they alternate all the time with layers containing larger boulders, of which one was measured at 2.10×2.20 m. The boulders are frequently found in finer gravel. Among the loose beach-stones it is not unusual to find fine-grained flakes of arkose which show *mud-cracks* and *raindrop-markings* (pl. V, fig. 4).

A beautiful section is exposed in the western cliff of Svarteberget. The cliff which is illustrated on pl. III, fig. 1, has a rather distinct stratification. The specific characters of the conglomerate is discussed in detail in a later chapter and in this place therefore only the local development is touched upon. Unsorted beds of a thickness of about 1 m are rather common among the finer strata.

Farther north, along the west coast, we find the same regular alternation between coarser and finer beds, the latter being apparently the most prevailing. South of Møkkalassodden the fine-grained sediments are intermingled with layers containing boulders of 1—2 m in diameter. At Møkkalassodden the finest sediments of the rhomb-porphyry conglomerate have been noticed in certain layers. Farther east, the section is interrupted by a rather broad covered belt without exposures. A coarse type of conglomerate constitutes the bedrock in the marked ridge forming a distinct southern cliff. From here on one passes on the north the narrow isthmus built up by loose gravel. The section of Rauøykalven is very imposing, and as pointed out by Brøgger, the rock is somewhat different from the type found farther south. It consists of well-stratified gravel beds, the very coarse beds, so common in other localities, being more or less absent although separate boulders occur here and there.

In the sections along the east side of Rauøy the sediments are generally very coarse. This is especially the case with the rocks of Kjelsberget. The sediments have very nearly the character of a tillite with its very unsorted material representing all sizes of fragments from fine grains to large boulders measuring up to 2.50 m or more in diameter. The stratification is almost absent, but yet it is possible to find finer films among these coarse beds. In one of the exposures on the north side of Kjelsberget, I noticed signs of mud-cracks in one of these films or thin zones of finer arkose. Samples of a considerable number of various boulders were collected in the section of Kjelsberget. The pebbles of the conglomerate consist almost exclusively of rhomb-porphyry, of which a type with red-violet phenocrysts (in weathered state) seems to be most common, a type which resembles the Rp_8 of the Vestfold district. Various Rp_2 types are also characteristic. Only very few specimens of essexite-lava and Downtonian or Permian sandstone were noticed.

The prominent coarseness of the sediments is a little less pronounced farther south near the bay of Bauen. From a locality north of the bay I collected from some large weathered blocks of the rhomb-porphyry conglomerate, boulders which exhibit the original surface. Three of these blocks have been depicted on pl. V, figs. 1—3. As a general rule, the boulders of the conglomerate of Rauøy are decidedly more rounded than those of the Sletter islands.

The section of Rauøytangen shows the ordinary alternation of gravel and boulder-beds. At the SW-point, where the gravel-beds seem to be most common, samples of the boulders were collected. Among the different types of rhomb-porphyry, I noticed a characteristic one with large thick phenocrysts mixed with quite small ones. Pieces of calcareous sandstone and coarse crystalline calcite, the latter evidently representing filled cavities in the lavas, were also collected. In the finer beds of the sediments, mud-cracks were found.

As indicated in the preceding pages, there exists a certain vertical and horizontal variation in the distribution of the rhomb-porphyry conglomerate of Rauøy. With regard to the vertical distribution, one finds, as pointed out by Brøgger (1900 p. 50), an indication of a comparatively finer lower series, a very coarse middle, and a decidedly finer, upper series. A horizontal variation in the direction of the trend is also perceptible. On the central part of Rauøy the coarsest sediments are found on the east side of the island.

The strike and dip. In spite of the large size of the Rauøy island, the measured strikes and dips are remarkably constant. The strike varies from N 72° W to N 20° W, with a common average of N 50° W. The directions of the strikes converge towards NW and in spite of this, the angle of dip seems to be slightly larger on the east, than on the west coast. This supports the establishment of the occurrence of coarser beds and greater thickness of sediments on the east coast.

On account of the coarseness of the sediments in many places it has been difficult to give distinct values of the strike and dip. The dip varies from 20°—40°. The average dip is not less than 25°—30°, an inclination which indicates a remarkable thickness of the sediments if the section is not repeated by faults.

The thickness of the sedimentary deposits are indicated in the general sections shown in text-fig. 7 b and e. The first section is drawn along one straight line on the map. This line which corresponds more or less to the section along the coast north of Bauen, does not exhibit a quite continuous exposure, but considerable faults in the direction of the strike do not seem very likely. A continuous series would represent a thickness of about 550 m. The other section is not drawn along one line, but gives a composite section where the different sections from Kuene — Svarteberget in the south to Svarteboene in the north, are projected on a line perpendicular to the strike. It seems probable that the section of the central part of Rauøy, from Kuene to Møkkalassodden, is rather continuous. If this is the case, we have a thickness of 1000 m. Although the ridge north of Møkkalassodden, and the prominent Rauøykalven, have the same strike and dip as the series farther south, they can hardly be regarded as a direct continuation of the section. The section seems here to be interrupted by two NNW faults. In spite of this possibility, it is very difficult to find, in the coarse series of central Rauøy, groups of sediments corresponding to the finer gravel series of Rauøykalven.

The faults and joints. At a locality near Kuene I have noticed a fault which cuts through a boulder measuring 40 cm across. Only one half of the block is visible so it is not possible to determine the size of the throw. As already mentioned, the general topography suggests the presence of two WNW faults in the northern part of Rauøy. These lines are also pointed out in the submarine relief. A detailed map shows a distinct submarine channel with a WNW direction, and with a steep northern slope forming the continuation of the cliff of Rauøykalven. The fault-escarpment seems to be slightly curved as indicated on the general map pl. V. Svarteboene, Veslekalven and Rauøykalven might belong largely to one tectonic block. Along the east coast of Rauøy two distinct parallel cliffs with NE directions evidently represent tectonic lines.

The main part of Rauøy seems to belong to one tectonic block. It seems very probable that the western border of this block is largely identical with the conspicuous submarine escarpment along the main fjord depth which in this place has a marked NW—NNW direction. The escarpment has, judging from the course of the contour lines, a smaller indentation south of Rauøytangen, an indentation which might possibly indicate a NE fault. Farther south, the greater Rauøy-block might have its southern border at the most narrow part of the submarine platform north of Nordre Missingen, or between this island and Søndre Missingen.

The rocks of Rauøy has been subject to considerable jointing. Several of these, which appear as prominent open crevasses, have been depicted on the sketch-map text-fig. 4. Some of the joints are nearly parallel to the strike, while others form a distinct angle to it. A western trend is rather characteristic.

The Missingen Islands.

(Text-figs. 4, 5 and 7).

The islands of the Missingen-group have a rather isolated position about 3.2 km south of Rauøy and 5.6 km north of Struten. The group includes Nordre Missingen, Søndre Missingen with Ovnskjær, and Missingskjærne. The naked islands, as well as the bottom of the surrounding shallow waters exhibit a very uneven surface dissected by jointing and erosion.

The rocks. On Nordre Missingen the gravel-beds are even more pronounced than on Revlingen and Rauøykalven. Mud-cracks and raindrop-markings were found in beds on the southern point of the island. Along the NE coast the rock is badly preserved on account of tectonic pressure. Quartz veins with a northern trend are also present in this part.

Søndre Missingen is built up of coarser sediments. The central part of the island exhibits particularly many coarse layers with larger, rather angular boulders. The lower part of the series to which Ovnskjær belongs, seems to be somewhat finer.

The three low skerries which constitute the Missingskjærne, are not easily accessible on account of their exposed position. When the sea was favourably calm I managed to pay short visits to the islands. *The rocks consist of solid rhomb-porphyry* which has not previously been described from this part of the Oslofjord. On the western skerry the rhomb-porphyry is very compact with rather large and regular phenocrysts in a matrix with a few vesicles resembling the type identified as Rp_8? of Revlingen. The eastern skerry has evidently the same porphyry. The presence of the same rock on these well-separated localities makes it probable that the porphyries were

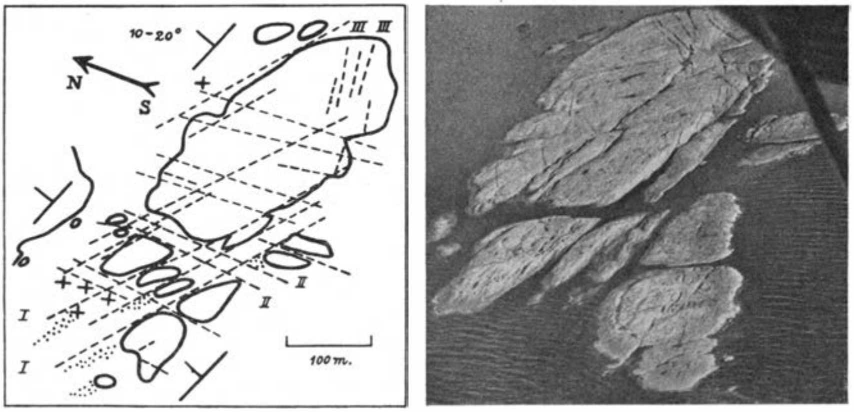

Fig. 5. Ovnskjær of Søndre Missingen. Joint-lines visible on the air-photograph (taken at an oblique angle) have been drawn on the topographic map. (Aut. phot.)

lavas and not dykes such as described from Bohuslen by Ljungner (1930 p. 45). The rhomb-porphyry of the northern skerry is of another type which can hardly be identified.

The strike and dip. Nordre Missingen has a strike varying from N 40° W to N 10° W and converging towards SSE. The dip is rather constant 30°. Another strike and dip are found on Søndre Missingen and the adjacent skerries, where the beds show a low inclination of 10°—20°, and a strike NNW.

The faults and joints. Quartz-veins of a northern trend indicate a certain older jointing on Nordre Missingen. Søndre Missingen is almost cleaved by a marked fissure crossing the island in a NW direction and with a dip of 60° to SW. The jointing was not studied in details in the field. Some of the air-photographs which I have taken, have, however, proved very helpful in distinguishing a large number of distinct joints. Text-fig. 5 shows the magnified map of Ovnskjær and one of the air-photographs of the same region. The main group of joints (I) have a NW direction, but the N direction (II) is also prominent. An E—W set of joints (III) is also indicated.

The Missingen islands are situated on a submarine platform which is connected with the Rauøy-Storegrunden platform by a comparatively narrow ridge separating the central fjord-depth from the deep channel along the large eastern fault-line. The ridge does not go below 62—68 m according to the chart. The very prominent submarine escarpment west of Rauøy changes its marked NW direction into N—NNE farther south on the Missingen islands. West of Søndre Missingen, the slope is very steep. According to the chart the bottom descends to a depth of 227 m with an average slope of not less than 39°. This western escarpment evidently has a tectonic origin corresponding to faults or joints (glacial erosion was also very active at this turn in the fjord channel). A depth of 189 m west of Søndre Missingen shows that the slope is not as regular as west of Rauøy. This might be due to the difference in direction of escarpment and direction of strike of sediments. It is interesting to substantiate the correspondence in the direction of the submarine slope and the N trend of one of the chief sets of joints (II) of Ovnskjær. The correspondence suggests strongly that the direction of the fjord depth is due to faulting and jointing along N—S lines. NNE—NE lines are also expressed in the submarine relief. Among the Missingen islands the submarine platform is intersected by certain narrow and deep submarine channels which separate Nordre Missingen, Søndre Missingen with Ovnskjær, and Missingskjærne. The lines are indicated on the map (pl. VI) and in text-fig. 7 c.

South of the Missingen islands the submarine platform descends to a depth of about 100 m, allowing a communication at this depth, of the main fjord-depth and the eastern fault-channel.

Struten.

(Text-fig. 4).

The small island with the lighthouse is not easily accessible on account of its exposed position.

The rocks are very similar to those of Nordre Missingen and consist almost exclusively of gravel-beds, often rather coarse gravel or shingles. Among the gravel-beds I also noticed more distinct stone-beds with angular stones of 10—20 cm predominating. Only rhomb-porphyry was noticed in the pebbles of the Struten-series.

The strike and dip were N 30°—35° W and 30°—40° E.

The faults and joints. Struten is situated close to the western escarpment, on a submarine platform of rather uneven depth. As shown on pl. VI, a NE channel indicates a certain separation of the platforms of Struten and Søstrene. The Struten island is intersected by two distinct fissures shown in text-fig. 4.

Nordre Søster.

(Pl. I, fig. 3; text-fig. 4).

Like the Missingen islands and Struten this rather large and naked island has been subject to considerable erosion on account of its exposed position. The ragged western coast with its numerous, smaller chasms and coves due to the erosions is very difficult to traverse.

The rocks. Gravel-beds, often of a rather coarse type, are characteristic of the series. Stone-beds and separate boulders were also observed in several beds. The pebbles of the conglomerate seem to consist almost only of rhomb-porhyry. A piece of a probably Downtonian red sandstone has been collected.

The strike and dip are constant N 40° W and 40° NE.

The faults and joints. As indicated on the sketch-map (text-fig. 4), the island is pierced by a distinct fault. The fault-plane is marked by well-defined slickensides and the presence of numerous quartz veins or sheets, parallel to the fault-plane which has a NE strike and a dip of 30° to NW. The origin of the fault is discussed in a later chapter. Near the fault on the east side of the island, some other quartz veins were noticed which were parallel to the strike, but dipping steeply to SW opposite to the sediments. The jointing was not studied in detail, but a general jointing parallel to the strike and with a dip more or less perpendicular to the dip of the sediments, was observed. A jointing with a N direction is also shown on the photographs.

Søndre Søster.

(Pl. I, fig. 3; pl. II, fig. 1, 4; pl. III, fig. 3; pl. V, fig. 6; text-fig. 4, 6 and 7).

This, the most southern of the rhomb-porphyry conglomerate islands, is rather large and imposing with its high cliffs of which those bordering the 40 m high southern point of the island (pl. II, fig. 1) are the most conspicuous.

The south-eastern abrasion cliff with the rocky shoals marking the platform in front, is well demonstrated on the air-photograph, pl. I, fig. 3. A similar, but less typical cliff, is developed on the east side. Also here the cliff is fringed by a shallow platform.

The central part of the island is to a large degree covered by water-worn rock-material. Raised beaches have not been studied, but their presence, at least at a level somewhere round 10 m above sea-level, is evident. The highest level forms to a large extent the central part of the island. A more thorough study of the raised beaches of Søndre Søster might perhaps be able to trace recent orogenetic displacements which possibly might have occurred in this place rather close to the "Hvaler depth" and the epicentre of the earthquake in 1904.

The rocks. The many beautiful exposures are often very steep and inaccessible. The west coast is parallel to the strike and is therefore able to show the horizontal variation of the sediments over a distance of 1.3 km. I did not find any typical difference in the development of the conglomerate. Gravel-beds with more separate boulders are typical for the series. Pl. II, fig. 1 gives a good impression of the well-stratified gravel-beds so well exposed in the southern cliff of the island. The northern coast exhibits a rather complete section through a thickness of about 475 m (text-fig. 7). A very interesting section is demonstrated in a smaller exposure on the northern coast between two beaches. Pl. III, fig. 3 and text-fig. 6 show the unusual combination of very large boulders in comparatively fine gravel. The characters of this profile are described and discussed in a later chapter. These rocks, and the rocks of the NE part of the island, are very coarse, in many places reminding one of the coarse beds from the east coast of Rauøy. The boulders seem to consist almost only of various rhomb-porphyries. A piece of calcite of a length of 10 cm probably represents a filled cavity in the lavas.

The strike and dip are rather constant N 30°—45° W, and 40°—45° NE respectively. On account of considerable tectonic crushing of the rock in the NE part of the islands, the measured values were not very accurate.

The faults and joints. The Søstrene islands are situated on a submarine platform with uneven surface. Between the two islands the level is intersected by a narrow cove with a depth down to 62 m. The western border of the submarine platform is not marked by a greater depth such as was the case, farther north, but a certain depression continues SSE and suggests a tectonic line as shown on the map pl. VI. The map also has a parallel line farther west which is also indicated by a certain longitudinal depression in the submarine relief. South of Søndre Søster a NE line parallel to the one between Struten and Nordre Søster, is suggested. South of these lines, shoals such as Seierkrakken, make it probable that the rhomb-porphyry conglomerate was also present so far south.

As shown on the air-photograph (pl. I, fig. 3) it is possible to distinguish a remarkable fault along the east coast of the island. The fault-plane, which to some extent has the characteristics of a thrust-plane, is shown on pl. II, fig. 4. The fault-plane having an average strike N and a dip of 20° W, has been followed along the east coast southwards to the steep eastern cliff. The fault-plane shows slickensides and is accompanied by a set of parallel quartz veins. The quartz veins are visible on pl. II, fig. 4. Each vein has a thickness of generally less than 5 cm. In several cases sharp-edged pieces of rhomb-porphyry conglomerate form a friction-breccia in the quartz veins. The rock above and below the fault-plane, is so strongly intersected by the quartz veins that a secondary shistosity parallel to the fault-plane is attained, especially in the couple of metres nearest to it. The pronounced shistosity, which forms an angle of about 120° to the bedding-plane of the sediments, has evidently caused a considerable rock-slip which occurred on the east coast several years ago. The origin of the fault is discussed in a later chapter.

Quartz veins were also observed on the NW point of the island where they have a N 50° W direction nearly parallel to the strike.

The air-photograph (pl. I, fig. 3) shows plainly the considerable jointing which has taken place in the rocks of Søndre Søster. The main directions of the observed joints are indicated on the sketch-map (text-fig. 4). Especially characteristic, is a trend parallel to the strike. The dip of the joint-planes is about 70° to SE, and hence different to the dip of the sediments. A certain NE—ENE direction (opposite the main direction) is indicated on the southern part of the island. Pl. I, fig. 3 indicates also a N direction exhibited in certain crevasses on the NW part of the island.

Remarks on the Area south and west of the Rhomb-porphyry Islands.

As indicated above, the southern limit in the distribution of the rhomb-porphyry conglomerate, is expressed in the presence of the peculiar and characteristic "Hvaler depth" about 5 km south of Søndre Søster. I have used this name for the submarine "trough" extending from the Hvaler islands towards SW (pl. VI), and then to SSW along the Torbjørnskjær-platform till it becomes nearly obsolete at a point SW of Torbjørnskjær. The about 2 km wide, submarine depression has rather steep slopes; the number of soundings is rather small, but they have been sufficient to demonstrate that the bottom of the u-shaped "valley" is very level with a nearly constant depth of about 450 m and a maximum of 465 m.

According to Brøgger (1886 p. 198) the small islands Torbjørnskjær and Kollen on the shallow platform south of the Hvaler depth, consist of Precambrian rocks. The Precambrian block mark the presence of a considerable fault along the submarine "valley". The important fault-line actually forms the SE border of the Oslo region as indicated on maps by Brøgger and others.

Another fault-line is suggested along the inside of the mentioned Torbjørnskjær-block. The submarine channel leading ESE to the distinct Koster-channel (cf. Ljungner 1930, pl. I) indicates the course of the tectonic line.

A considerable earthquake on October 23, 1904 had its epicentre, according to Kolderup (1905, 1913), at the mouth of the Oslofjord, probably in the area occupied by the Hvaler depth.

The submarine channel marking the course of the large eastern fault-line, has been mentioned on several occasions above. On the general map (pl. VI) the straight and distinct channel with its constant NNW direction, is clearly traceable. The soundings on the detailed charts show also very plainly how the depression occurs also in the more shallow area east of the Sletter-Eløy islands. North of Kollen the main fault turns in a more northern direction as also indicated by the contour lines. From Larkollen and southwards, the depth of the fault-channel increases as far as to the Missingen islands. East of the Søster islands, the contour lines as shown on pl. VI have a very irregular course, and in spite of the comparatively small number of soundings, the presence of certain more or les complete ridges crossing the channel, are indicated. It is interesting to find, on the most narrow point between Søndre Søster and the Nordreboene west of Vesterøy, a bridge damming up the channel to a depth of about 110 m. A tectonic origin of the threshold is not excluded since a NE line is indicated in the relief as suggested on the general map. The pool, about 220 m deep, south of the mentioned ridge, is also dammed by a transverse ridge of 152 m.

The Precambrian region east of the large fault-line, consists, as shown on the map, of gneis in the northern part and granite farther south. The jointing of the granite has particular interest in connection with the tectonic movements of the region. The jointing of the gneis is of minor importance since it is dependent upon the primary strike of the rock. The considerable jointing of the granite was not studied in the field, but from the general topographic maps it is possible to distinguish certain well-marked, probably tectonic, lines. Among the few lines indicated on the map, pl. VI, the long and narrow Ellingaardskilen is very typical.

Brøgger (1900 p. 61) points out the lack of younger dykes intersecting the rhomb-porphyry conglomerate. In this connection I made a brief survey of the granite coast east of the conglomerate islands. Dykes seem to be very rare. A diabase dyke with a thickness of 1 m and a strike N 50° E and dip 70°—80° SE, occurs at Steinsholmene east of Nordre Missingen. Nearly 1 km north of the southern point of Smaustangen, east of Rauøy, I noticed a diabase dyke with a thickness of 35 cm and a strike and dip of N 55° E and 80 NW. This dyke points in a direction of about Bauen bay on Rauøy.

Erratic boulders of the rhomb-porphyry conglomerate are rather common in the glacial deposits in Denmark and have proved useful in determining the direction of glacial transport (cf. Milthers 1932).

A peculiar occurrence of a large erratic boulder in the granite district east of Rauøy was pointed out to me by a young boy of the neighbourhood. I was puzzled to find that a small rock or shoal marked on the ordinary chart as a small point between two skerries east of Risholmen and north of Bratholmen, actually consists of rhomb-porphyry conglomerate. By wading and removing some of the adhering seaweeds, I was able to establish the presence of a glaciated granite surface below the conglomerate. The boulder seems to occupy a space of not less than about 5×6 m. The glacial striae on the granite surface have a NE direction suggesting a transport from out of Ellingaardskilen, a direction of transport which does not harmonize with our present knowledge of the distribution of the conglomerate. Perhaps the large boulder was transported by drifting icebergs.

General Description and Discussion of the Rhomb-porphyry Conglomerate.

General Character of the Sediments.

The previous chapter deals with the various occurrences of the conglomerate. The general character of the sediments has been described and discussed by Brøgger in his paper of 1900. The following description is to a certain extent a repetition of his results, but several new features have also been contributed.

The basement rock of the sediments. From exposures on the island Revlingen it has been possible to demonstrate that the sediment series rests on rhomb-porphyry lavas, evidently Rp_4 according to the terminology introduced by Brøgger and Schetelig for the Vestfold effusives. The contact between the lava and the overlying conglomerate has been followed over a certain distance. Any traceable unconformity has not been observed. The surface of the effusive does not bear the signs of being primarily crevassed to any large degree, but the surface seems to have been subject to weathering. A polished surface has not been found.

The rhomb-porphyry conglomerate. Just above the contact, the sediment is very typically developed. It is rather peculiar to notice the marked uniformity of the rhomb-porphyry conglomerate through the large thickness and on the many localities distributed over an extended area. Everywhere one finds the same constant change of coarser and finer, badly sorted, detritus sediments built up almost exclusively of rather fresh rhomb-porphyry material.

The stratification of the sediment is not very distinct. The photographs reproduced on pls. 2—4 illustrate rather well the stratification in the different types of sediments. In spite of the coarsness and unsorted character of the conglomerate, it is almost always possible to distinguish a certain bedding. The 30—40 m high wall of Søndre Søster (pl. II, fig. 1) illustrates very well the stratification. The finer beds are more resistent against the erosion than the coarser ones and therefore stand out as separate beds. This feature is noticeable in the section in the escarpment on the west side of Rauøy (pl. III, fig. 1) and in the erosion pillar, shown on pl. II, fig. 3, in which the top consists of a finer arkose bed. The coarser beds of the same section are almost barren of any stratification and appear as quite unsorted boulder beds. Similar unsorted zones are also seen on pl. III, fig. 3 (to the left) and on pl. IV, fig. 1 (in the middle).

The zones of very coarse and unsorted material is always intercalated by stratified zones of finer material and it is therefore always possible to determine the strike and dip even in series where the coarser beds prevail strongly. Pl. III, fig. 2 and 3 and pl. IV, fig .1 illustrate how the coarser unsorted beds are interrupted by finer sediments distinctly bedded.

During my survey of the numerous good exposures of the rhomb-porphyry conglomerate, I tried to find examples of distinct cross-bedding which would naturally be expected in such thick and coarse sedimentary series of rocks. I was surprised to find an *almost complete lack of cross-bedding in the rhomb-porphyry conglomerate.* The pronounced parallel bedding is well illustrated in the large section of Søndre Søster (pl. II, fig. 1). Although I have particularly looked for traces of cross-bedding, I have only in a few cases in the finer beds observed diverging bedding planes with a distance between the nearest parallel beds of not more than 30 cm. Small filled channels or furrows have also been noticed in some cases.

The thinning out of the separate zones is illustrated on pl. IV, fig. 2. Usually, the finer beds gradually become coarser and coarser in lateral direction without any marked transition line (left side of the photograph), less commonly the finer beds wedge out with indication of cross-bedding (right side of the photograph).

As pointed out above, it is possible to distinguish finer and coarser zones of the rhomb-porphyry conglomerate. I have not found it necessary to carry out a more detailed classification of the sediments according to the size of the grains. In the sketch-maps only finer and coarser beds are stated, but in the following description also the term gravel beds are applied for the coarser types of the finer beds.

The finer beds consist of red (and in a few local cases yellow) arkoses. The fine-grained sediments are only found in thin layers often between very coarse beds. They are well exposed along the west coast of Rauøy. Pl. IV, fig. 1—2, illustrates in detail the alternation of finer and coarser strata.

Typical mudstones have not been found. Certain beds, however, are very fine-grained with a diameter of the grains less than 0.1 mm.

In these finest sediments, occur in several cases, distinct *raindrop markings* and *mud-cracks*. A beautiful specimen was described by Holtedahl (1931) and is also depicted on pl. V, fig. 4. An orientated thin section across a mud-crack from Nordre Missingen shows a very fine-grained sediment on each side of the filled fissure. The grains have a size below 0.025 mm and a number of tiny blades of mica orientated parallel to the bedding plain are intermingled with the grains of felspar and quartz. In the mud-crack the size of the grains amounts to 0.5 mm and slightly more.

The mud-cracks and more or less distinct raindrop markings have been found in several localities and at various horizons. On the east side of Rauøy they have been noticed even in the series where the very coarse beds prevail. Their presence signifies the casual draining of the basin into which the rock material was transported and deposited.

The thin section depicted on pl. V, fig. 6, illustrates the angular, slightly rounded felspar grains from the arkose beds marked gr. on pl. III, fig. 3 from Nordre Søster. The stratification is distinct and the size of the grains is rather constant about 0.5—1 mm, and this suggests that the material was rather well sorted. (As pointed out below, these finer beds change very rapidly into exceedingly coarse and unsorted beds with boulders of several meters in diameter).

Among the grains of felspar one notices also frequently fragments of the matrix of the porphyries. The finest beds also contain a considerable amount of quartz grains. The section pl. V, fig. 7 shows the angular, generally sharp-edged grains with a size usually below 0.5 mm. The grains occur in a red ferro-bearing calcite matrix. In a local yellow bed from Rauøy the average size of the quartz grains was about 0.1 mm.

The large amount of felspar and the sharp-edged character of the grains show that the material was rapidly deposited and had not been subject to any lengthy exposure to wave action. The sediments closely resemble those occurring between the different lava-flows of the rhomb-porphyries. These have been described from the Brumunddal district by Rosendahl (1929). The younger Brumunddal sandstone described by the same author, differs decidedly in being a typical sandstone with well-rounded partly eolian quartz grains.

The gravel beds are perhaps the most characteristic sediments of the conglomerate series. They consist, as shown on pl. V, fig. 3, of angular to fairly rounded pebbles. Generally, the beds are rather well sorted, consisting of pebbles of nearly the same size. In these shingle beds one often notices with the naked eye the white calcite cementing the pebbles together. The gravel beds might be more or less coarse and unsorted. Pl. III illustrates typical gravel beds gradually changing into coarser ones. The beds shown on pl. IV, fig. 2, are more unsorted and unstratified. As mentioned under the description of the localities, the typical gravel beds are especially abundant on Revlingen, Rauøykalven. Nordre Missingen and Struten.

The coarse beds are illustrated on plates II—IV where most of the photographs illustrate the peculiar very coarse and unsorted breccias or conglomerates so characteristic of the rhomb-porphyry conglomerate. There exists a gradual transition between the typical gravel beds and these formations. The gravel beds are decidedly more stratified and sorted even when they accomplish the appearance of typical stone beds with an enrichment of stones measuring up to 10—20 cm in diameter.

A special local type of the coarse sediments is found at the SE side of the island Kollen (p. 50). The sections and the preservation of the rock are not very good. There occur very large angular pieces of rhomb-porphyry which seem to lie more or less in situ in a cemented detritus which is difficult to distinguish from the larger blocks. The nature of these deposits has not been cleared up, but they might represent piedmont formations, or perhaps rather, smaller submarine landslips, an explanation which is also corroborated by their presence very close to the large eastern fault-line.

They typical coarse beds occur practically on all the conglomerate islands, but are especially well-developed on the east coast of Store Sletter, Mellem Sletter and Rauøy and on the north-east coast of Søndre Søster. Pl. III, fig. 2 and particularily fig. 3, show the prominent size of the boulders in the conglomerate. Brøgger (1900 p. 39) describes the huge boulder from Mellem Sletter measuring $5 \times 3 \times 3$ m. I have not found any larger, but in several cases, noticed blocks with diameters of 2—3 m.

The shape of the boulders is rather variable. Brøgger points out that the smaller boulders (10—20 cm) are scarcely rounded while the larger ones have worn angles or are rounded. A local variation is also observable. On Mellem and Søndre Sletter the boulders (pl. III, fig. 2) seem to be less rounded than on Rauøy (pl. IV, fig. 1). Also the small pebbles and boulders have worn angles and bear the signs of having been transported or moved to a certain extent in water. The largest boulders (pl. III, fig. 3) are generally rather well-rounded and are surprisingly like the erratic boulders in the glacial moraines. Generally, it is very difficult to remove the boulders from the matrix. In a few cases I have had the opportunity of splitting larger weathered conglomerate blocks and remove boulders as those illustrated on pl. V, fig. 1—3 from Rauøy.

The medium-sized boulder in fig. 1 is unusually well-rounded. The surface is not very well preserved. The fine-grained matrix is also shown along the under side. The block on fig. 2 is not quite complete, but it has been figured to show the partly faceted surface of the boulder which resembles those occurring in glacial deposits. The angular boulder depicted on fig. 3 has a rather peculiar shape with its strongly developed facets and one of the sides is even slightly concave. The boulder has a certain appearance of a dreikanter.

The surface of the boulders is generally not well preserved on account of the coarseness of the rhomb-porphyries. Only the Rp_2-type with a small amount of phenocrysts exhibits a comparatively smooth surface. A number of boulders have been carefully investigated in order to trace glacial stria or other surface-markings. The angular boulder on pl. V, fig. 3 has the indication of certain parallel furrows on one of the sides, but they are not very distinct and cannot be taken as a signification of glacial striae. A larger ($1.20 \times 1.10 \times 0.40$ m) angular boulder on Søndre Sletter has on its under side a number of furrows which, however, are not very similar to typical glacial striae and probably were formed when the boulder originally was loosened from the rock.

The occurrence of the boulders in the matrix is very characteristic. I have already pointed out how the typical coarse beds are very little sorted. It is rather peculiar to find even large boulders embedded in a finer matrix. This feature is shown on several of the reproduced photographs. On one locality on Store Sletter a large boulder measuring 3×2.40 was noticed in a fine-grained matrix where most of the grains had a size below 0.5—1 mm.

An extreme combination of large boulders and finer sediments was examined on Søndre Søster. Pl. III, fig. 3 illustrates the presence of several large (more than 2 m in length) rounded boulders of rhomb-porphyry situated in coarser gravel just above a 1.10 m thick zone with finer gravel. The Rp-boulder in the background seems to occur in the same zone as the finer gravel in the middle. Text-fig. 6 indicates the section. It is interesting to ascertain that there does not exist any distinct boundary between the finer and coarser beds.

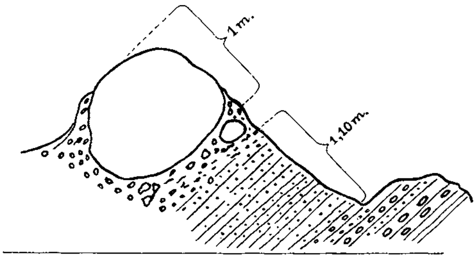

Fig. 6. Section from Søndre Søster illustrated on pl. 3 fig. 3. Rapid alternation between finer and very coarse beds of rhomb-porphyry conglomerate. Great boulders in comparatively finer matrix.

The peculiar combination of very large boulders in a comparatively fine matrix in stratified sediments almost without any traces of cross-bedding suggest a rather special formation of the rhomb-porphyry conglomerate.

Pl. IV, fig. 1 shows an about one meter thick coarse bed bordered below and above by finer beds. In the coarse unsorted zone all sizes of boulders are present. I have noticed in several cases the presence of similar zones of about the same thickness. On pl. III, fig. 3 one notices in the middle of the section two boulder beds of this type with a thickness of about one meter. It is important that these beds do not show a distinct border towards the neighbouring finer strata.

Brøgger (1900 p. 41) pointed out very strongly the casual orientation of the blocks in the matrix. Angular blocks found in a labiale position do not indicate a lengthy exposure to wave action. In the upper boulder bed on pl. III, fig. 1 one might notice near the right side of the photograph a narrow block apparently balancing on its sharpest edge. The unstable position of the blocks is found in the very unsortered and unstratified beds. In beds with more distinct stratification such as on pl. III, fig. 2, the boulders have a more stabile position resting on their largest levels. A special current arrangement of boulders has been observed in one case (p. 80).

The Rocks of the Boulders in the Rhomb-porphyry Conglomerate.

The conglomerate or breccia is really a rhomb-porphyry sediment. Probably not less than 95 per cent of the rock-material consists of various types of this characteristic effusive rock. A large number of different types is always found in one locality, although one type might be more common than the others. In order to identify some of the rocks I have compared the boulders with the rhomb-porphyry samples of the Vestfold district determined by Brøgger and Schetelig and preserved in the Geological Museum of Oslo. The Rp_1 and Rp_8-type is very common. According to verbal information from Professor J. Schetelig several of the younger porphyries are also of this type. A species of Rp_8? with the felspars weathering with a characteristic red-violet colour, seems to be very common. Rp_2 with its usually small number of phenocrysts is also very abundant and a very characteristic type of it with numerous small phenocrysts, which has been called the "Sollerød type" Rp_{2a} by Brøgger, has been frequently met with not only in the ordinary conglomerate, but also in the special development on Kollen. A characteristic Rp_2 with quartz-filled vesicles which occurs on the shore at Vallø in Vestfold, seems to be identical with the rock of a boulder found on the NW side of Rauøy (old collection). Rp_4 and perhaps also Rp_5 (Kongsteigstypen) has been noticed.

The essexite-lavas being the oldest effusives of the series, and occurring below the rhomb-porphyries, are not well represented in the boulders. More fine-grained types are found in most places, but the coarser porphyritic types such as occur at Holmestrand, have not been recorded.

Certain syenitic rocks with an intrusive appearance were suggested by Schetelig to represent dykes in the rhomb-porphyry lavas and do not need to be much younger than these.

Pebbles of calcite up to a size of 10 cm and chalcedony or jasper-like nodules probably originated from filled cavities in the lavas.

A piece of a typical pegmatite found at the SW point of Eløy, might have come from a boulder in the Permian conglomerate.

Sedimentary rocks have been collected from a number of localities although they are rather rare. The beautiful and characteristic Permian conglomerate is easily traced among the boulders.

Several different sandstones have been found as boulders in the rhomb-porphyry conglomerate. A red, fine-grained and cross-bedded sandstone from the SE side of Nordre Søster has fairly well-rounded quartz grains. A coarser red type from the basal beds of Eløy has sub-angular grains. Lighter and darker grey sandststones, often containing a certain amount of mica are known from various localities.

With regard to the age of the sandstones, it is possible that certain types with slightly rounded grains might belong to the local sedimentary series occurring between the different lava flows. It seems probable that the Permian sediments older than the lavas constitute a certain part of the sandstone boulders. The presence of such sediments is likely although they are not preserved between the Downtonian sandstone and the overlying lava at Jeløy. Probably a large part of the sandstone boulders is derived from the Downtonian sandstone which forms a thick series of sediments below the Permian.

Silurian or older blocks have not been found.

Vertical Variation and Thickness of Series.

From the local descriptions given in an earlier chapter, it becomes apparent that several of the larger islands present good sections through considerable series of succeeding beds. Text-fig. 7 shows several of the more complete sections.

In spite of the considerable thickness of the series, it has not been possible to find certain characteristic zones which might have been identified on different islands. In addition to the constant change in the coarseness of the sediments there seems to exists a variation also on a larger scale. Brøgger (1900 p. 55) assumed a division of the rhomb-porphyry conglomerate in a finer basal series, a coarse middle, and a higher, chiefly finer, series. The basal beds of Revlingen are rather fine. The fairly complete (?) section of Rauøy (text-fig. 7 e), shows a very coarse middle series, a somewhat finer basal and a decidedly finer upper series (Rauøykalven). It is not, however, certain that the upper series form a direct continuation of the probably rather complete section of the rest of the island, but yet it seems largely possible to maintain this rough division. To apply this division to the other islands is probably impossible on account of the horizontal variation which evidently occurrs.

The distribution of the different boulders has not offered possibilites as to a correlation of beds from different islands. Brøgger (l. c.) pointed out that while the basal (Revlingen) part of the section only carries rhomb-porphyries as boulders, the middle and upper series have boulders of older rocks suggesting a gradual denudation of the porphyry plateau down to the older rocks below. This "inverted" vertical distribution of the boulders is not well demonstrated in the sections. The presence of sandstone pebbles in the basal beds of the thick series of Eløy and Rauøy, shows that the rocks below the lavas were reached at an early stage in the sedimentation.

The thickness of the rhomb-porphyry conglomerate has to be determined from the singular sections. On account of its uniform character, it has been very difficult to trace faults interrupting the observed sequences. Not only for this reason has one to be care ful not to obtain too great values for the thickness. In a marginal deposit, the material transported is chiefly laid down on the subaquatic slope in front of the alluvial cone. A measurement of the thickness of a large number of succeeding "slope-beds" would give a far too great value for the thickness of the delta itself. Under such delta-conditions, however, one is apt to get disconformities and cross-bedding at the place where later stream-washes pass over the uppermost part of the older buried distal slopes. Disconformities of this type have not been observed in connection with the rhomb-porphyry conglomerate and the values found probably give a rather true impression of the thickness of the deposits.

As shown in text-fig. 7 and mentioned under the local description, the section of the middle part of Rauøy seems to be fairly complete and unbroken. Judging from the figures obtained the thickness of the strata amounts to not less than 1000 m in this place. The finer series of Rauøykalven might belong to the lower part of the section mentioned, but it seems more probable that it represents a younger series and thus adds a couple of hundred meters to the 1000 m already measured.

It seems, therefore, reasonable to assume that *the thickness of the rhomb-porphyry conglomerate amounts to about 1000 m or possibly more.* The thickness of the sediments exposed in the different sections is shown in text-fig. 7.

Horizontal Variation and Determination of Direction of Transport.

It has already been pointed out that coarse beds horizontally grade into finer ones. In addition to this variation, however, it has become possible to determine a certain distribution on a larger scale, a distribution of the finer and coarser beds which must be due to a difference in the length of transport of the deposited material.

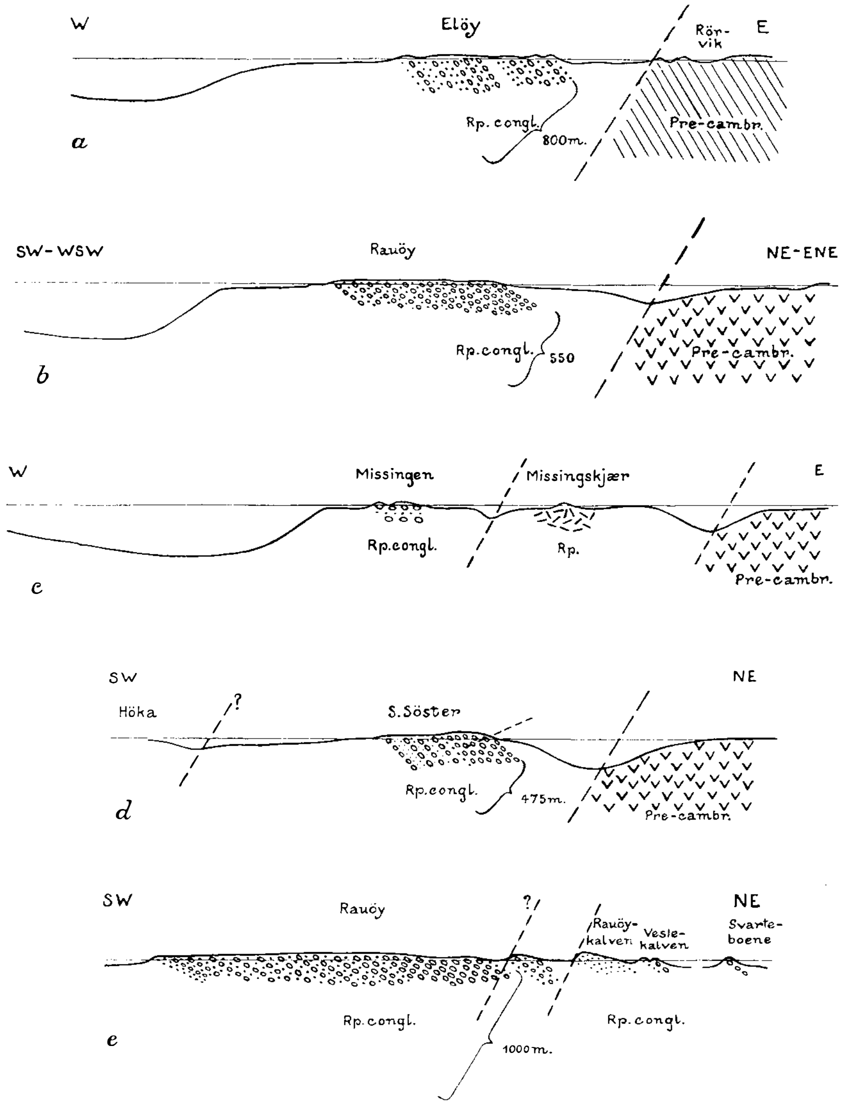

Fig. 7. Sections of several rhomb-porphyry conglomerate islands. The tilting and thickness of the sediments are demonstrated. Rhomb-porphyry (Rp) is exposed on Missingskjær. *e* = composite section., Heights and depth not exaggerated.

On the larger islands such as Store Sletter, Rauøy and Søndre Søster the same beds might be followed over greater distances and it is therefore possible to study the horizontal variation. As pointed out in the description of the localities, the beds on the east side of Store Sletter are, as a general rule, coarser than those on the west coast. The measurements of strike and dip also indicate a larger thickness of the series along the east coast. On Rauøy where the strike is not W—E, but NW—SE the coarsests beds are also found in the eastern exposures and the dips suggest a larger thickness of these beds too. On Søndre Søster with its NNW—SSE strike, and where the same beds are exposed along the west coast over a distance of about 1300 m, there does not seem to occur any distinct variation in the coarseness.

By these observations we should be able to a certain extent to determine the direction of the transport of the material deposited. On the first mentioned islands, the strike forms a distinct angle to the direction of the Permian fault-line, on the last it is nearly parallel to it. The decrease in the coarseness and thickness of the sediments as we move westwards from the fault-line suggests strongly that the material was transported from a higher land east of the fault-line, in a western direction.

In order to obtain further information as to the direction from which the rock material had been transported, I have tried to trace any special arrangement of the boulders in the conglomerate. Pl. IV fig. 3 and text-fig. 8 illustrate a beautiful case of current-arrangement of the blocks observed on the west coast of Rauøy to the north of Svarteberget. On the text-fig. 8 I have outlined the blocks according to the details visible in the magnified potograph. As it appears from the drawing, the stratification is indicated by two thinner beds of finer material. Between those two layers (in the lower half of the picture) occurs a typical about 0,5 m thick boulder-bed with a great variation in the size of the blocks. As against the lack of grading in regard to the size, one notices a very distinct arrangement of the larger blocks. On account of weathering, several of the boulders stand out from the surrounding matrix. The blocks, which on the photograph appear to have a narrow oblong outline, have a flat lower and upper surface strongly suggesting that the boulders were flat with their largest diameter perhaps perpendicular to the plane of the paper. This assumption is corroborated by the presence, a little to the left, of a quite similar block orientated in the same way and having its largest diameter nearly perpendicular to the plane of the paper.

As shown in the illustrations, the various flat blocks show very nearly the same dip. Fortunately, on account of the blocks weathering out, it became possible to measure not only the dip, but also the strike of the lower and upper flat surfaces of the the two blocks marked 1 and 2 in text-fig. 8, and of the mentioned block a little to the left of the section illustrated on the photograph. The two first-mentioned blocks have a strike N 20° W and the last N 30° W. The dip of the sediments in this place is about 25°. If we eliminate this secondary inclination of the sediment and reckon with a fairly level original position of the sediments, the strikes measured accomplish the values N 5° W and N 15° W which correspond to the direction of the large eastern fault-line.

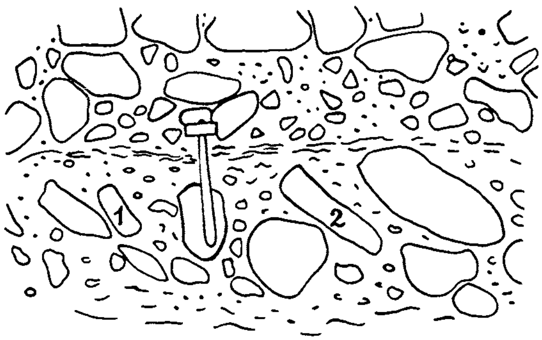

Fig. 8. Current arrangement indicating E-W transport of the boulders in the conglomerate. Boulders outlined after photograph on pl. 4 fig. 3.

With regard to the orientation of the boulders illustrated in text-fig. 8 there can hardly remain any doubt as to their arrangement being due to current action. The "imbricated" structure might be explained by the assumption of a current running from the right to the left (cf. Andersen 1931 p. 177). One notices also how a number of smaller sized blocks are enriched on the left, the lee-side, of the larger boulders. It seems safe to conclude that the current came from the east and had a direction practically perpendicular to the strike of the flat blocks. Since we hardly can expect a meandric course of the flood or river (?) depositing these coarse sediments, we arrive at the conclusion that the rock material in this place was transported from east to west at a direction perpendicular to the great Permian fault-line.

The results obtained from a study of the horizontal variation, and the current arrangement of the boulders of the coarse sediments, have shown with considerable evidence that *the direction of transport of the rock material of the rhomb-porphyry conglomerate was from east to west.*

The rhomb-porphyry conglomerate with its uniform character, occurs on a narrow, but more than 35 km long, area situated immediately west of the Permian fault-line. *The present results corroborate strongly the assumption of Holtedahl of a formation of the rhomb-porphyry conglomerate in intimate connection with the great Permian fault along the east side of the Oslofjord.* The rock material was transported from the high plateau land down on to the subsided area to the west of the fault-line.

The Mode of Formation of the Rhomb-porphyry Conglomerate.

Before we attempt a stratigraphical correlation with similar deposits of other regions, it is necessary to try to find out the conditions under which these peculiar rocks were deposited. First of all we must bear in mind that the so called rhomb-porphyry conglomerate is not a typical conglomerate in the usual sense of the word, but has more the characteristics of a sedimentary *breccia.* A classification of the many different types of sedimentary breccias has been given by Norton (1917) and discussed by Woodford (1925), and others. In conecction with the origin of the rhomb-porphyry conglomerate, Brøgger discussed several different possibilities.

Agglomerate (volcanic breccia and volcanic conglomerate). In its typical development, the rhomb-porphyry conglomerate might exhibit a close resemblance to pyroclastic rocks. The high percentage (perhaps 95) of rhomb-porphyry, especially offer this impression. Brøgger pointed out, however, that several facts strongly contradict such an assumption. The constant variation of porphyries (and older sediments) and the complete lack of lava sheets through the thick series of sediments were his objection to such an explanation.

According to the more recent studies of agglomerates, however, it appears that pyroclastic rocks might accomplish very different characters and are often very difficult to distinguish from normal sedimentary rocks. A very useful discussion on the origin of various pyroclastic rocks has been given recently by Andersen (1933) in connection with his description of the Tuscan formation in California.

The absence of lapilli, bread-crust bombs and boulders, and probably also of volcanic glass fragments, excludes the rhomb-porphyry conglomerate from one type of pyroclastic rocks. In connection with explosive eruptions, however, the mentioned characteristic features might be quite absent. Large volcanic breccias containing a mixture of different rocks have been formed in connection with Peléan and ultra-volcanic eruptions. The breccias extend over very long distances and are not restricted to the surroundings of singular volcanic vents. Anderson (l. c.) divides the pyroclastic rocks into those transported in dry condition and those transported in connection with water. With regard to the rhomb-porphyry conglomerate, only the latter is applicable. During Peléan eruptions (Lassen Peak in California) considerable amount of ejected pyroclastic material is often mixed with water from the immediately melting snow accumulations on the hill sides. The water highly facilitates the transport of the volcanic breccia which soon attains the character of a mud flow and in this condition might be transported over incredibly long distances. Larger volcanic breccias accumulated near their source, might, by occasional cloud-bursts, be swept down the hill sides forming the same kind of mud flows as those formed during the eruption. These last-mentioned pyroclastic rocks are naturally very difficult, if not impossible, to distinguish from the fanglomerates below described which only differ by virtue of transporting rock-material formed by regular weathering and not by volcanic eruptions.

With regard to the agglomerate nature of the rhomb-porphyry conglomerate, professor Schetelig has pointed out to me the small probability of this explanation on account of the very small amount of agglomerate accompanying the rhomb-porphyry lava series so well known from the area west of Oslo. In spite of the small amount of agglomerates in the extrusive series, there occurred certain considerable explosive eruptions such as the one producing the Sevaldrud breccia described by Brøgger (1931), which probably took place at a time just before the extrusion of the last flows of rhomb-porphyry. It seems rather unlikely that limited explosive eruptions of this type might have been able to produce the perhaps 1000 m thick series of rhomb-porphyry sediments which also differ petrologically from the rocks of the explosive vents mentioned. With the assumption of a E—W transport of the material in the sediments, one would expect the vents to occur either east of the fault-line or along the fault-line which is now below water. No explosive vents have, however, been traced in the eastern area, and the occurence of larger explosions along the fault-line very close to the conglomerate islands would probably have caused a considerable local variation in the characters of the sediments.

For these reasons the agglomerate origin of the rhomb-porphyry conglomerate seems rather unlikely.

Submarine landslips. Along prominent tectonic lines one often gets large subaquos rock-slips which in several cases seem to have played an important part in forming thick series of unsorted sediments. The conglomerate or breccia along the "Logan Line" in Canada seems to be of this type according to Bailey, Collet and Field (1928). During the great earthquake of Tokio in 1923 a 230 m deep submarine channel seems to have been filled by landslips of this type.

It is hardly possible to explain the Oslofjord sediments in this way on account of their generally rather distinct stratification and the presence of mud-cracks and raindrop-markings in a number of layers. (Possibly the local rock formations on Kollen might be due to submarine rockslips on a smaller scale.)

Glacial deposits. On account of its stratification, the rhomb-porphyry conglomerate differs from ordinary moraine deposits, but might be compared with glaci-fluvial deposits. In fact the sediments, as clearly shown on many of the reproduced photographs, bear a very close resemblance to such deposits, Brøgger (1900 p. 42) strongly pointed out this resemblance and drew a comparison with the late-glacial Svelvik moraine in the Oslofjord. This type of marginal glacial deposits is often barren of boulders with glacial striae, and one finds, as shown on the section given by Brøgger (1900—01 p. 136), a fairly parallel bedding (especially in the lower part which has not been rewashed later) with larger, often rather angular boulders in a finer matrix. After having studied the section in the same submarine moraine at Drøbak, I was at first almost convinced of a glacial origin of the rhomb-porphyry sediments. Andersen (1931) has given a detailed discussion of the structure of the glaci-fluvial deposits and it appears from his account that although the horizontal strata are the primary melt-water deposits, these strata are often interrupted by incline-bedded strata forming a marked angle to the horizontal beds. In the case of broader marginal deposits, a section through the delta would reveal inclined (once distal) beds at deeper levels in contradistinction to the more horizontal layers near the surface.

The many thorough investigations of the Late-Paleozoic tillites and Dwyka conglomerates (stratified glacial deposits), have presented many details characteristic of the glacial deposits. The faceted, and at the same time striated, pebbles probably furnish the best evidence for a glacial origin. Striated pebbles might be very rare or even practically absent in glacial deposits and their possible occurrence in rock-flows formed without any influence of ice, make them less conclusive. Woodworth (1912 p. 76) regards "the pebble with the blunted and snubbed ends with or without striae" as typical of the old and recent moraines. Sayles (1914 p. 143) also regards the concave fractures as "as positive a mark of glaciation as striae". The boulder figured on pl. 5 fig. 3, shows a very distinct concave surface which is probably due to fracture and not to wind erosion. This single case can hardly be taken as an indication of glacial origin. The boulder on pl. 5 fig. 2, has a rather glacial appearance with its faintly faceted surface.

The drift-conglomerates, formed by the dropping of larger boulders from drifting icebergs down into finer sediments, are rather common in the Late-Paleozoic glacial deposits. In these deposits one often finds a characteristic mixture of larger boulders in a decidedly finer matrix, but, generally, the separate boulders occur scattered in the finer mudstones and the sediments attains a character rather different from the coarse beds of the rhomb-porphyry conglomerate.

Although the rhomb-porphyry sediments in many respects bear a close resemblance to a glacial deposit, there are certain features which are very difficult to explain in connection with such an explanation. In spite of the fact that the sediments are derived from the red-weathering rhomb-porphyries, the intensive red colour of the quartz-bearing, finest deposits, suggests warmer conditions. The presence of mud-cracks and raindrop-markings point also in this direction. The occurrence of these in several different zones denies the possibility of a continuous submarine deposit. A casual draining along an ice-front would probably have caused several river-channels which might have been traced in the stratification. As pointed out by Brøgger, glacial deposits of this size evidently would have shown a greater horizontal and vertical variation. One would naturally expect to find beds of mudstones representing the clay-deposits so typical of recent and old marginal glacial deposits. Finally, the knowledge of the climatic condition in Permian-Triassic time of northern Europe speaks strongly against a considerable glaciation of the Oslofjord area during this time.

Fanglomerate. Lawson (1913) introduced this name for the coarser alluvial fan deposits formed under special arid conditions. He found these deposits very characteristic of the recent condition in the arid parts of the United States and Mexico, but was surprised of the scarcity of these formations in the rocks of the past. Later studies, however, have pointed out very strongly the importance of the fanglomerates among the sediments from earlier geological times.

Descriptions and characteristics of the fanglomerates have been given by Norton (1917), Woodford (1925), Kaiser (1927) and Blackwelder (1928) among others. In normal or extreme arid regions with little vegetation the seasonal or very rare rainfalls cause large flows which sweep down the rock-waste accumulated along the slopes of the mountains. These floods which, at the beginning, have the character of very rapid washes, very soon absorb a large quantity of the dry sand and dust met with on their way down to the flat basins below the mountains, and from having the appearance of a very rapid stream, the flood soon assumes the character of a real mud-flow moving more and more slowly untill it at lost stops on account of the great viscosity. As pointed out by Woodford (1925 p. 234) and Blackwelder (1928 p. 480), the floods have a surprising capability of carrying even huge boulders over large, gently-sloping areas. During a very considerable flood in Utah in 1923, thousands of boulders weighing several tons were carried down a slope with an inclination of only four to eight degrees. Smaller angles have often been observed.

Woodford draws attention to the experimental works of Sudry and shows that according to his formula a medium composed of 25 per cent clay and 75 per cent water will transport blocks nine times as large as those carried by clear water. In a river, the larger boulders are transported rolling along the bottom and therefore soon get well-rounded. In a mud-flow, on the other hand, the boulders are carried floating among the finer material and are therefore more protected and may largerly maintain their original angular shape.

The characteristic features of a fanglomerate are: The unsorted till-like character with often larger boulders in a finer matrix, the sub-angular pebbles and grains, the freshness of the rock-material, the stratification (which may be obliterated in the typical mud-flow-beds), the lack of cross-bedding and the vertical alternation of finer and coarser sediments (arkoses and fanglomerates).

Returning now to the rhomb-porphyry conglomerate, it becomes apparent that the characteristics of the fanglomerate appeal very well to this sediment. The type of stratification and the general character of the sediment are the same, and as mentioned under the description of the coarse beds, one might distinguish certain unsorted beds (pl. III fig. 1 and pl. IV fig. 1) which might very well be explained as separate mud-flows similar in parts to those described by Kaiser (1927) from tertiary beds in Spain. The red colour of the sediments and the presence of mud-cracks and raindrop-markings conform to the assumption of a formation in a warmer arid climate.

The Miocen San Onofre Breccia of California, which is regarded by Woodford (1925 pl. XXV) as a fanglomerate formed in front of a large escarp, shows, according to the published photographs, a close resemblance to the Oslofjord deposits. Especially a photograph published by Blackwelder (1928 fig. 7) of a section through successive recent mud-flows in California, reveals conditions very similar to those exhibited in the rhomb-porphyry conglomerate. The coarse, rather unsorted, beds representing the mud-flows, alternate with finer sediments from the intervals between the floods.

The close correspondence makes it very probable that *the rhomb-porphyry conglomerate represents a series of alternating arkoses and fanglomerates deposited by sudden washes and mud-flows during an arid climate.*

This explanation conforms very well with the assumption set forth by Brøgger (1914).

Correlation with similar Deposits outside the Oslofjord District.

Norway. The Brumunddal Sandstone described in detail by Rosendahl (1929) also rests on sheets of rhomb-porphyry lava. The red and yellow sandstone was formed during periodical floods and drainings in a continental climate. Although the typical sandstone with well-rounded (also æolian) quartz-grains (1. c., p. 436) differs considerably from the arkoses of the Oslofjord series, both might probably have been deposited about the same time.

Goldschmidt (1913 p. 22) points out the resemblance between the rhomb-porphyry conglomerate (which previously was regarded to be of Devonian age) and the thick series of Devonian sediments from Røragen near Røros. Devonian plants have determined the age of the lower part of the series consisting of grey sandstones and conglomerates of a normal alluvial type. The upper part of the series, however, includes a red sandstone and a peculiar serpentine conglomerate which bears a close outer resemblance to the rhomb-porphyry conglomerate. The red colour of the sediments and the occurrence of 1—3 m thick beds of unsorted schale-breccias alternating with sandstones (1. c., p. 16) suggest strongly the presence of a fanglomerate. As pointed out by Goldschmidt, this change in the lithological characters shows an alternation of the outer (climatic) condition. In spite of this marked change and the demonstration of a certain overlapping of the younger series over the older, it seems unlikely that the red beds are much younger and that they belong to the Permian.

England. Holtedahl (1931 b footnote) has drawn attention to the great similarity which exists between the Permian Pennine-Craven faults with their adjacent breccias or "brockrams" and the Permian fault with the rhomb-porphyry conglomerate of the Oslofjord. A general review of the studies of the sediments formed in connection with these faults in NW England has been given by Wills (1929 p. 88). The brockrams are roughly stratified and contain both coarser and finer angular fragments. The sediments are regarded as delta fan deposits formed under semi-arid conditions from local scree-material swept down from the great fault scarps formed by the Pennine-Craven fault system. Eastwood, Dixon, Hollingworth and Smith (1931 p. 207) describing the brockrams of the Whitehaven district, point out their present day equivalents in the fanglomerates. On account of the apparent absence of distinct mud-flow-beds and the presence of current bedding in certain layers, the brockrams might have been deposited in a semi-arid, rather than a normal, or extreme arid, climate characteristic of the typical fanglomerates according to Kaiser.

In the Vale of Eden which is the classical occurrence of the brockrams, they form a lower and upper division of the thick Penrith Sandstone. Dr. Hollingworth pointed out to me the close resemblance of the mentioned sandstone to samples of the (also in parts æolian) Brumunddal Sandstone of Norway.

With regard to the stratigraphy, the Penrith Sandstone probably represents the Upper Rotliegende (Versey 1929 p. 310) and the characteristic overlying Magnesian Limestone, parts of the Zechstein. According to the results obtained from studies in the Whitehaven district, Dixon, Eastwood, Hollingworth and Smith (1931) found that the brockrams were deposited during a long period of time. Inland (near the source of the material) a brockram with a thickness up to 400 feet seems to correspond to: a basement brockram, the Magnesian Limestone, the St. Bees Shale and part of the St. Bees Sandstone in the coast-line section. Since the St. Bees Sandstone is regarded as belonging to the lower Trias, the deposition of the brockrams might have lasted from early Permian to early Trias in this part of England.

On account of the great resemblance in origin (in connection with probably Permian faults) and character of the English and Norwegian sediments it seems probable to regard them as fairly simultaneous formations.

Sweden. Holtedahl (1932) has drawn attention to the close resemblance between the rhomb-porphyry conglomerate and the Keuper or Kaagerød-deposits in Scania. In both cases we have coarse sediments evidently deposited along fault-lines of the Late Paleozoic.

The Keuper or Kaagerød sediments have been described in detail by Hadding (1927, 1929) who regards them as partly fluviatile and partly lacustrine (possibly also to a small extent marine) formations. The deposits consist of alternating beds of conglomerate, sandstone and mudstones. The stratification is not always distinct and both parallel bedding and cross bedding are common. As shown in the section given by Hadding (1929 p. 197), the finer beds between the more thick and coarse ones, show incline-bedded banks of a type typical of alluvial sediments (cf. schematic drawing of Andersen 1931 fig. 38). According to the photographs given by Hadding of the coarse beds of the Kaagerød sediments, they resemble closely those of the rhomb-porphyry conglomerate. They seem to be similar deposits, although those of the Oslo Region were probably formed under more arid conditions. The Swedish deposits have more well-rounded rock fragments.

The connection between the Kaagerød sediments and the late Paleozoic tectonic disturbances has been argued by Troedsson (1932). On account of the presence of continental Permian sediments in the Oslo Region, he considers it probable that the Kaagerød sediments belong to the Permian, rather than the Trias (Keuper), to which it was generally attributed on account of the apparently gradual transition into the overlying Rhæt-Lias-series. It seems natural to correlate the Scanian deposits with the Permian and possibly early trissic brockrams of NW England and with the rhomb-porphyry conglomerate of the Oslo Region.

According to the description of Hadding (1927 p. 58), a peculiar conglomerate occurring on the islands Jungfrun and Fjuk in the lake Vettern might resemble the Oslofjord deposits. The age of the coarse beds which look like a gravel-moraine is not known and it might perhaps be possible that they represent fairly young "brockrams" formed in connection with faults along the lake of Vettern.

East Greenland. The Eotriassic series of the area round Nathorst fjord have been described by Noe-Nygaard (1934). Arkoses and coarse conglomerates build up parts of the series. Conglomerates carrying a large amount of red porphyries (of the Cape Fletcher series which, curiously enough, have been compared with the igneous series of the Oslo Region) suggest a resemblance to the rhomb-porphyry conglomerate. The Greenland series have not been connected with special Late Paleozoic faults.

Brøgger (1900), in discussing the age of the rhomb-porphyry conglomerate, points out the importance of the lack in the sediments, of acid rocks corresponding to the acid intrusives forming a later phase of the major eruptions of the Oslo Region. For this reason the conglomerate was regarded as younger than the larvikite-rhomb-porphyry series, but older than the nordmarkite series.

The present studies have shown that the rhomb-porphyry conglomerate on Revlingen evidently rests on the rhomb-porphyry Rp_4. Judging from the condition in Vestfold on the west side of the fjord, several younger flows of rhomb-porphyry were probably present above No. 4, also on the east side of the fjord. The lack of the younger series might signify a certain interval of erosion between the formation of the extrusives and the sediments above. Taking into consideration the considerable jointing which took place previous to and during the deposition of the conglomerate, the observed break in the succession might be due to strong local erosion and does not need to represent a long space of time.

On account of the close connection between the lower extrusives and the underlying fossiliferous beds of the Rotliegende, it is reasonable to regard the rhomb-porphyries also as belonging to the lower Permian. (Holtedahl 1931 b p. 333).

For these reasons and from a correlation with English conditions, it seems probable that the rhomb-porphyry conglomerate was deposited during *middle and upper Permian and possible early Trias.* A closer determination is not possible.

The mutual relation of age between the conglomerate and the younger larger intrusives of the Oslo Region can hardly be solved from the fact of a lack of acid extrusives as boulders in the sediment. The large batholitic masses might not necessarily have been associated with extrusives and the absence of such rocks among the boulders is not a proof of the greater age of the conglomerate. As pointed out by Brøgger, the rhomb-porphyry conglomerate is not intersected by dykes. Although the younger diabases of the coast east of the fault-line are rather scarce, one was noticed pointing across the southern part of Rauøy. It might, however, have died out somewhere between the island and the coast and does not present a strong significance of a greater age of the dykes.

Summary on the Origin and Formation of the Rhomb-porphyry Conglomerate.

In the lower Permian, the Oslo Region and a large part of its neighbourhood, were covered by enormous sheets of essexite and rhomb-porphyry extrusives. (The presence of Rotliegende fossils in beds with boulders of the oldest lavas indicates the age.) Probably in Permian time the level lava-land was subject to a very considerable jointing chiefly along N-S lines. The large fault along the east side of the Oslofjord was formed, at least in part, at this time. During its formation, the area west to it was subject to considerable subsidence while a certain upheaval evidently took place in the block to the east of the line. The escarpment thus formed, was soon intersected by stream gullies through which great quantities of detritus material were transported down on to the subsided plains below. During an arid climate, the plateau land was gradually worn down and the plains west of the fault-line covered by huge alluvial fans. During sudden and rare rainfalls considerable amounts of accumulated rock-waste were washed down on to the lowland. Often the floods attained the character of mud-flows which possessed the possibility of carrying very coarse material long distances even when the sloping angle was very small.

The perhaps more than 1000 m thickness of sediment indicates a fairly long time of sedimentation. The material building up the conglomerate or breccia consists almost only of rhomb-porphyry from the lavas above the Paleozoic sediments. The considerable denudation of the plateau land was, therefore, restricted to the upper part of the series. Since Brøgger assumes a thickness of all the lavas of 800 m, and the throw of the fault (to-day) amounts to perhaps 2500 m or more, it becomes evident that the accumulation area was subject to a gradual subsidence during the deposition of the material transported from the eastern plateau. The surface of the alluvial cones did not at any time lie much below the surface of the Paleozoic sediments underneath the lavas. The plateau land was eroded backwards, but yet the mud-flows were able to transport the coarse material which is found through the whole series.

The formation of thick, coarse series of sediments in connection with considerable faults, seems to be a characteristic feature of the partly desert landscapes of northern Europe during Permian (and early Triassic?) time. The conditions might have resembled those of western North America of to-day.

The local English term "brockram" might perhaps be used as a more general name for fanglomerates deposited in connection with considerable faults.

The rhomb-porphyry conglomerate, with its great thickness and coarseness, seems to be one of the most outstanding examples of a brockram, or arid fault deposit.

Tectonics.

The Great Permian Fault.

Brøgger (1886) demonstrated the presence of the large N—S faults of the Oslofjord area. His section from Holmestrand to Jeløy (l. c., text-fig. 19) illustrates very well the large scale faults of which the most prominent ones are indicated on the general map pl. VI. The by far most imposing fault is the one following the east side of the main part of the Oslofjord. (It is not possible to decide whether it also occurs in the Precambrian area of the Drøbak sound.) In the southern part of the fjord a distinct submarine channel (pl. VI) indicates the course of the great fault. Brøgger (1886) assumed the presence of two sets of friction-breccias along the fault in the northern part of the fjord. This led Bugge (in Holtedahl 1934 p. 3 footnote) to the assumption of the fault-line being established already in the Precambrian.

In the southern part of the Oslofjord the minimum downthrow of the fault at Jeløy where we have the earliest rhomb-porphyry preserved at the top, might amount to nearly 2000 m or more. Farther south the downthrow is much more considerable. Following Kiær and Brøgger (1933 p. 46) in their assumption of a 1700 m thick series of lower Paleozoic sediments and a 800 m thick series of extrusives above, one arrives at the assumption of a downthrow of at least 2500 m. On account of a secondary tilting of the series the accurate values are difficult to establish.

As pointed out above, the block west of the fault gradually subsided also during the deposition of the sediments. This subsidence (and eventual uplift of the eastern plateau) might to certain extent have been due to isostacy. The thicknes of the rhomb-porphyry conglomerate, however, was not the same on the east and west sides of the tectonic blocks. The proximal eastern parts carried a larger load of sediments than the western distal parts where the finer material was deposited. The blocks for these reason were probably subject to a certain tilting with the beds dipping towards the fault-line. The tilting would also be facilitated by an eventual upheaval of the denuded western part (cf. section of Brøgger). As indicated on the general map pl. VI, the large island Jeløy together with Mølen and Tofteholmene seem to constitute one large tectonic block. Judging from the presence of Precambrian rocks on Mølen and gently sloping sandstones and lavas (which evidently, before the erosion, was covered by rhomb-porphyry conglomerate), the large block seems to be tilted against the great eastern fault-line as would be expected from the above mentioned grounds. (Brøgger 1886 fig. 18 suggested a division of the Jeløy block into several smaller ones, but this seems to be of minor importance and is not expressed in the contour lines of the more recent bathymetrical charts.)

The tectonic blocks farther south are also tilted, but generally to a much stronger degree and with dips and strikes different from those which would be expected from an uneven loading.

Tilting and Folding of the Sediments.

In the chapter on the local descriptions, the variation of dip and strike is described. The dip of the rhomb-porphyry conglomerate varies to a considerable degree. The average value of inclination seems to be not less than 25°—35° and these values are by far the most common. As shown on text-fig. 2 the angle of declination might be rather great such as on Eløy where angles up to 60° have been measured.

The dip and strike are generally rather constant on the respective islands. Typical folding has not been observed, but on Revlingen and the Sletter islands a distinct and continuous change in the dip and strike is noticeable. On Revlingen, the strike turns 90 degrees and the beds seem to form part of a dome. The three Sletter islands form together one side of an oblique trough as seen on the sketch-maps text-fig. 2. On each of the other islands the strike and dip are surprisingly constant suggesting that the islands form exposed parts of strongly-tilted tectonic blocks.

With regard to the direction of the dip and strike almost all directions are represented. Dips pointing in directions between W and N 10° E are not observed. In spite of the fact that so many strike directions are found, it seems possible to distinguish one direction which is much more common than the others. Text-fig. 9 presents a rough attempt to illustrate the distribution of the various directions of the strike. Since only the outcrops along the coasts have been investigated, I have only measured roughly the extension of the outcrops and used these values instead of the area, as a measure of the length of the vectors. Although this method is very incomplete, the illustration gives an impression of the strike variation.

It is remarkable that *the NW direction of the strike is decidedly more common than the other directions.* Strikes in the N—E quadrant are practically absent. On text-fig. 9 the angles between the dotted lines signify the variation in direction (in N and S parts of the area) of the large Permian fault-line. The strikes of Eløy and N. Missingen fall within the sectors, but all the others outside.

If the dip of the sediments were only due to a tilting towards the fault-plane, one would expect to find most of the strikes parallel to the fault-line and if deviations from this direction occurred, they should have been equally distributed on each side of the faultdirection. This is not found, however, but a marked prevalence of the NW direction.

The NW direction is also expressed outside the rhomb-porphyry islands. In the Holmestrand area (pl. VI) the larger Permian faults mainly have a N—S direction, but the tilting of the Paleozoic rocks on the islands and the main land has occurred along NW to NNW fault-lines marking the borders of extended tectonic blocks.

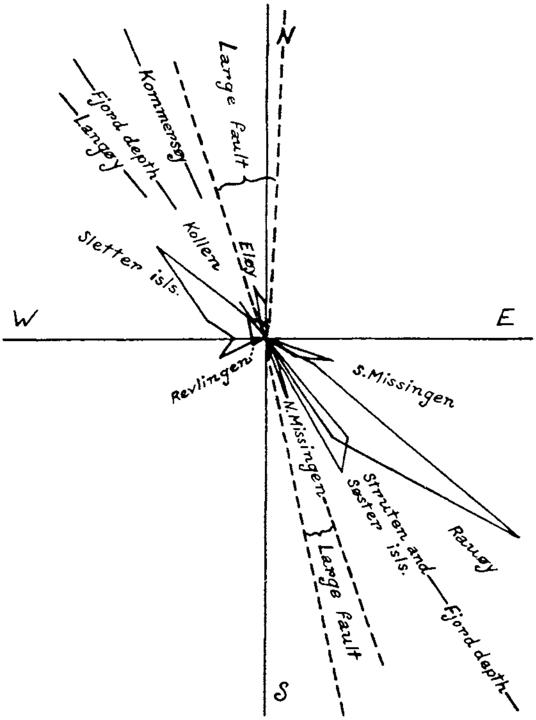

Fig. 9. Tectonic directions.

The NW direction is also indicated in the directions of the disturbances noticed during the Oslofjord earthquake in 1904. Kolderup (1905 pl. II) indicates lines which correspond to those described above. Also on the map showing the distribution of the greatest intensity (strength 8) a certain NW or WNW direction is suggested (Kolderup 1913).

Also in the submarine topography this direction is pointed out. East of Langøy in the Holmestrand area, the fjord-channel with a NW direction might be distinguished. The channel might be traced more or less continuously (interrupted by the inner Ra-moraine ridge) to the area east of Bastøy. The submarine channel is very conspicous in the southern part of the fjord. The general map pl. VI shows its angular, "bayonet-shaped" course. *An intimate connection exists between the course of the submarine fjord-channel and the tectonic features of the rhomb-porphyry islands.* The NW to NNW direction is particularily significant, but also the different characteristic directions of Eløy and Nordre Sletter are indicated in the submarine topography. Only the strike of Søndre Missingen deviates distinctly from the direction of the neighbouring submarine escarpment, but in this case a study of the joints has suggested strongly that this is due to a pronounced cross-jointing as shown on text-fig. 5.

A geological and morphological study of the southern part of the Oslofjord has thus pointed out the existence of a marked NW tectonic direction which might be distinguished from the N—S directions characteristic of the major Permian fault-lines. The rhomb-porphyry conglomerate, deposited during and after the formation of the Permian fault, was, after it became consolidated, strongly tilted along lines apparently independent of the typical Permian N—S direction. The tectonic blocks are not only strongly tilted, but in some cases a slight folding is indicated. The structures found suggest that the tectonic blocks had been subject to compression caused by a pressure perpendicular to the strike. A tension might also have produced a tilting and flexure, but hardly to the same degree.

This type of tectonic disturbances seems, according to the terminology suggested by Stille (1924 p. 222), to correspond to the so-called "*Bruchfaltung*" by which a considerable jointing takes place simultaneously with a slight folding. The Saxonic orogeny in Germany is characteristic of this type. Before we attempt to offer an explanation of the tectonic disturbances, it is necessary to mention the faults and joints.

Faults and Joints.

On account of the great uniformity of the rhomb-porphyry conglomerate, it has been very difficult to establish the presence of faults. Not only the lack of distinguishable zones, but also the fact that the fault-planes generally run outside the boulders in the conglomerate, make it difficult to determine the throw.

One of the most typical morphological features of the conglomerate islands, is the intersection of the rocks by distinct fissures or joints which often appear as open clefts (in Norwegian: "klover"). Brøgger (1883) has described and figured the same type of fissures from the Skien-Langesund district and here they are generally connected with determinable faults.

The different types of faults and joints are described below — the local descriptions are found in an earlier chapter.

Permian (?) faults. Two very prominent fault-planes have been found on Nordre and Søndre Søster. The fault-planes might be seen on pl. I fig. 3 and pl. II fig. 4, and their position is indicated on the sketch-maps text-fig. 4. In both localities well developed slickensides associate the fault-planes. The most characteristic feature, however, is the presence of numerous, about 5 cm thick, quartz veins running parallel to the fault-plane and distributed over a thickness of several meters as shown in the photograph pl. II fig. 3. The quartz veins often contain sharp-edged pieces of the surrounding rock and, therefore, partly have the character of a friction breccia.

The dip of the fault-planes varies slightly, but the average values are not more than 30 and 20 degrees for the northern and southern island. On account of this small declination the term thrust, instead of fault, would at first sight, seem more appropriate for these tectonic disturbances. With regard to the quartz veins, however, they can hardly be explained otherwise than as filled, premarily open fissures. It is very difficult to understand how such fissures could remain open during an over-thrust of considerable quantities of rock which by their mere weight certainly would have closed any open fissure parallel to a 20—30 degrees thrust-plane.

For these reasons I found it worth while to investigate the possibility of a secondary tilting of the thrust or fault-planes. On combined plastiline and cardboard models the mutual position of the fault-planes and the bedding planes of the sediments, which at both places dip 40°, were demonstrated. If we assume that the thrust-planes are older than the tilting of the sediment series, this would mean that in the models we have to turn the bedding planes down to a nearly level position.

This gives a surprising result. Not only do the thrust-planes at both places attain a dip of nearly 60°, which is a very common angle of declination in the usual gravity faults, but also the strikes of the fault-planes change and accomplish nearly the same strikes N (Nordre Søster) and N 15° W (Søndre Søster). The found values of the dip and strike of the fault-planes correspond very closely to those of the typical Permian faults, particularly the main Permian fault a little farther east.

For these reasons it seems highly probable that *the "over-thrusts" on the Søster islands are nothing but ordinary faults* *of the N—S Permian type formed during a late stage, or shortly after, the deposition of the rhomb-porphyry conglomerate, and before the tilting and other tectonic disturbances of the conglomerates took place.*

Younger faults. These have steeper fault-planes without associating quartz veins. Only on Revlingen, where the different lavas form distinguishable zones, has it been possible to determine the throw (10 m). In spite of the difficulty in tracing true faults in the sediments, it has been possible, as pointed out in the chapter on the local occurrences, to locate several larger tectonic lines or faults. On Rauøy certain prominent escarpments (text-fig. 4) probably might be explained as indicating fault-lines althoug similar formations on a smaller scale might occur along joints on the lee-side of "roche moutonné".

As mentioned above, it has been possible to demonstrate an intimate connection between the submarine morphological lines and the main tectonic lines, particularily the strike directions. The jointing of Søndre Missingen and adjacent skerries (see below) have shown that the submarine morphological lines are also strongly dependent on the jointing.

From a study of the discontinuity in the strikes and dips, and of the course of more prominent submarine morphological lines, it has become evident that *the whole area occupied by the rhomb-porphyry conglomerate has been devided in a number of larger tectonic blocks as suggested by Brøgger.* The general map pl. VI indicates the probable fault-lines which chiefly have a NE direction.

The jointing. A more detailed study and mapping of the joint has not been carried out, but the more prominent sets of joints have been noticed and illustrated on the sketch-maps text-figs. 2, 4. Several of the air-photographs (pl. I fig. 3 and text-fig. 5) demonstrate very well the presence of different sets of joints. The joints are not equally distributed on all the islands. Comparatively few have been observed on the Sletter islands. The joints generally have a dip-angle of 60—80 degrees.

Although almost all strike directions are represented by the joint-planes, it is possible to distinguish certain main directions more common than the others. *A NW trend of joints is very common.* This direction corresponds to the prominent strike of the sediments.

On the Søster islands, where the strike of the joints and the strata is the same, the joint and bedding-planes dip in opposite directions forming an angle of about 60—70 degrees. It is important to notice that the NW direction is persistent also on Eløy and Søndre Missingen which have a somewhat different strike of the beds.

In addition to the NW direction, a N direction and the opposite W (or WSW) are rather characteristic. The air-photograph of Ovnskjær (text fig. 5) demonstrates very well the three sets of joints. The course of the submarine channel of the fjord exhibits just the NW and N (NNE) direction which is characteristic of the two main sets of joints. It is very reasonable to assume that the formation of the submarine relief of the fjord was dependent not only on the strike of the rocks, but also on the jointing which aided and guided the erosion.

Crushing of the rocks. The sediments are not equally well preserved at the different localities. The rocks of Kollen and of the NE parts of Nordre Missingen and Søndre Søster, are strongly crushed and the original strike and dip are almost obliterated. On account of the presence of the crushed rocks close to the great fault-line, it seems probable that they are due to tectonic disturbances along this line.

An Attempt at an Interpretation of the Structure.

Brøgger (1900 p. 48) pointed out the correspondance in the fault-directions of the rhomb-porphyry conglomerate and the course of the NE border of the great larvikite intrusive mass to S W. The present studies have shown that the NW direction in the structures is not a local feature, but might be traced over a large area.

In the southern part of the Oslofjord the main tectonic units are: 1) the large circular (?) larvikite intrusive in SW, 2) the tilted Paleozoic sediments and lavas in the fjord, and 3) the large Precambrian massive to the E and ENE. On account of the difference in the tectonic competence of these units, it is evident that the structure to a large extent is dependent on the local distribution of the different types of rock.

The study of the rocks and the submarine topography indicates that the sediments and lavas west of the large Permian fault-line have been subject to a certain horizontal compression producing a tilting and folding with a chiefly NW trend of the axis. The force producing this compression had a SW—NE direction. A folding, however, might be due to either direct or indirect folding. While the direct folding is due to normal pressure only, the indirect folding, according to Willis and Willis (1934 p. 101) is produced by a rotational or shearing stress. A shearing stress acting in the horizontal plane brings forth an indirect folding where the axis of the folds forms an angle of 45° or less to the direction of the shearing couple. This has been shown experimentally by Mead (1920).

In more rigid masses, less apt to be folded, the shearing stress produces high-angle shear planes at angles (in the horizontal plane) of about 45° to the direction of the forces.

In the Oslofjord structures, a mixture of folding and faulting has taken place. The direction of the tilting axis seems to be rather different from the course of the border of the Precambrian shield. They are not due to a normal pressure perpendicular to the border. The tilting and folding are associated by joint-systems of which a NW set is most conspicuous. The joints may be conciderably younger than the tilting. The joints are high-angle shear planes and, therefore, resemble those produced by rotational stress rather than the generally more low-angled shear planes produced by mere compression. For these reasons it seems reasonable to assume that the tectonic structures of the rhomb-porphyry conglomerate to a large extent is due to indirect folding produced by rotational stress. A force couple pointing southwards (or SSW) in the eastern area and northwards (or NNE) in the western, might produce such a structure. In text-fig. 10 the arrows p_1 and p_2 indicate the possible force couple.

Horizontal displacements due to forces creating a rotational stress, are associated with certain characteristic structures which have been studied by Cloos (1928), Ljungner (1930 p. 122), Riedel (1929 p. 354) and others. Riedel has experimentally and theoretically created and discussed the typical tension joints ("Fiederspalten" of Cloos) which occurs in such displacements and which form an acute angle about 45° opening against the direction of the forces. In addition to the tension joints one gets a set of closed joints parallel to the direction of the forces. Along these closed joints or fault-planes the horizontal displacements take place.

Cloos (1928 p. 297) has tried to explain the prominent N and NNW tectonic lines of the Oslo Region as true tension joints ("Fiederspalten") produced by a slight displacement towards SSW of the large Precambrian massive west of the Oslo Region.

With regard to the younger geologic structure of the southern part of the Oslofjord, it seems possible to locate joints of the type characteristic of horizontal displacements. If we assume, as above mentioned, a force couple of a N—S direction (p_1, p_2 on text-fig. 10) it would result in a southward movement of the eastern block, and a relative northward movement of the western. Accordingly we might expect to find tension joints at angles of about 45° opening northwards in the eastern area and the opposite in the western, and fault-planes for horizontal displacements striking N parallel to the forces.

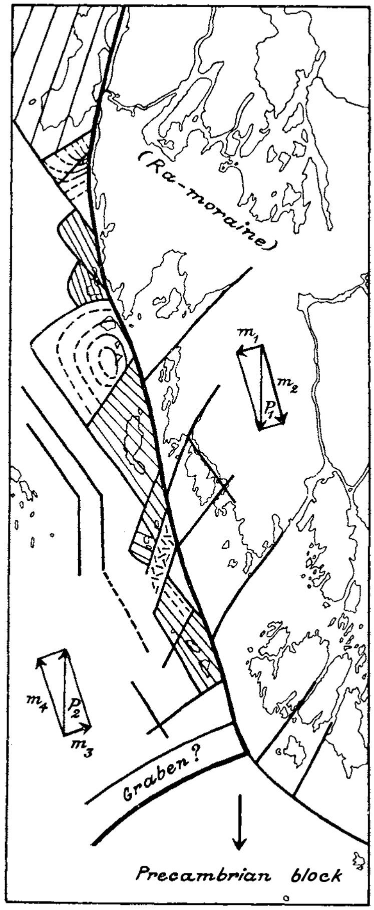

Fig. 10. Sketch-map indicating the tectonic blocks along the Permian fault-line.

As shown on the general map pl. VI, and indicated on the diagrammatic sketch-map text-fig. 10, we might trace with a certain amount of evidence, several tectonic lines which correspond to eventual tension joints. The NE and NNE lines occur not only in the area occupied by the sediments and lavas, but they are also very conspicuously expressed in the direction of the many narrow sounds (and a few dykes) intersecting the gneis and the granite (without primary strike) area to the east. *The tectonic NE lines on both sides of the Permian fault-line might represent tension joints produced by a relative southward movement of the eastern area.* (The NW direction of the Hankø sound might perhaps belong to the indirect folding.)

With regard to the presence of N—S fault-planes for the horizontal displacement, the structure is complicated, not only on account of the local difference of the rocks, but also by the presence of the older active Permian fault-line. During a horizontal displacement the old fault-plane was therefore naturally applied.

Now the Permian fault-line as shown on the maps, has a slightly shifting direction. From being NNE directed in the Moss district, it turns N and NNW farther south and from the east corner of the Hvaler depth one branch seems to continue towards the Swedish border along a NW to WNW line. If we assume a southward drift of the eastern block (or an opposite movement of the western) the areas where the fault-line has the NNW, and especially where it has the NW—WNW direction, would be subject to a certain compression. This might be illustrated by decomposing the force into two components, one parallel (m_1) and one perpendicular (m_2) to the fault-line as is indicated on text-fig. 10. It seems possible that the crushing of the rocks on several of the islands situated near the fault-line is due to this compression. The syncline of the broad Sletter block might also to some extent have been formed by this compression.

The origin of the Hvalerdepth might be explained in accordance with the above presented views. During a southward displacement of the Precambrian block, the NW—NNW line south of Hvaler islands formed a too large angle to the direction of the movement to serve as a fault plane along which a horizontal displacement might occur. The Precambrian block west to it, the Torbjørnskjær block, took part in the southward movement and the area N and NW to it was therefore subject to considerable tension. It seems reasonable to regard *the Hvalerdepth as a true graben due to a tension acting perpendiculary to the main axis of the depression.* Recent orogenetic movements in this area are indicated by the above mentioned earthquake in 1904.

Correlation with similar Disturbances outside the Oslo Region.

In Sweden, Ljungner (1930) has studied in details the geological structures of the Skagerrak coast. He found a distinct NW jointing both in the Permian rhomb-porphyry dykes and in the Precambrian rocks. In spite of the occurence of the joints in both places, he regards the NW joints in the granite as being older (l. c., p. 162) than the rhomb-porphyry dykes which, according to his investigations, possess their own joint-systems younger than those of the surrounding rock.

Scania exhibits several geological features suggesting a connection with the conditions of the southern part of the Oslofjord. As already mentioned, the Kaagerød or Keuper sediments resemble the rhomb-porphyry conglomerate and were probably formed in connection with large late-Paleozoic faults. In Scania it has been possible to trace also younger, post-liassic disturbances. The younger faults have the same NW direction as the older (Permian) ones and must be regarded as a renewal of the older tectonic lines.

Voigt (1929 p. 53) shows that not only vertical, but also horizontal displacements took place along these lines bordering the prominent horsts of Scania. The horsts were partly over-thrusted ("Kippschollenbau") over the area SW to the main fault-lines. Troedsson (1932 p. 223) and Hadding (1933 p. 22) also point out that the youngest (Jurassic) sediments are folded due to a compression perpendicular to the NW axis of the folds. Bubnoff (1935 p. 146) mentions recent studies by Weverinck according to which a SE to SSE displacement of the tectonic blocks of Scania has been established.

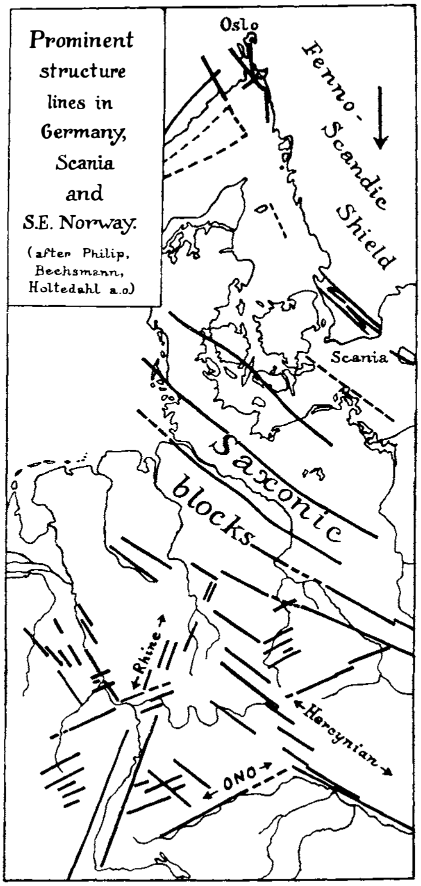

Fig. 11.

Farther east on Bornholm, the geological features are similar to those in Scania. The tectonic lines have a more western trend. According to Stehman (1934) the synclines, which might be post-Liassic of age must be explained as due to a N—S compression.

Bubnoff (l. c.) points out that the southern border of Scandinavia is marked by the NW directions of Scania and the WNW directions of Bornholm. From the results of recent studies he arrives at the conclusion that northern Europe has been subject to a southward movement. The disturbances along the border of the Fennoscandic shield are produced by this southward drift.

Voigt (1929) drew a comparison between the geological structures of Scania and those of Hartz in Germany and considered a very close resemblance had been found. The Saxonic orogenetic movement exhibit the characteristics of a typical "Bruchfaltung" (Stille 1924 p. 222): Simultaneously with the folding, the rigid crust breakes up into long tectonic blocks parallel to the fold axis. The sketch-map (text-fig. 11) mainly based on one presented by Phillip (1931. Fig. 15), indicates the most typical younger tectonic lines of western and southern Germany. The "Herzynian" direction striking NW and WNW is the oldest, with strong orogenetic movements already at the transition from Jurassic to Cretaceous. The "Rhine" direction is typical of the Tertiary and the ENE direction is the youngest, being active up to recent time.

The older Saxonic movements of Germany resemble both in structure ("Kippschollenbau") and direction those in Scania and Bornholm and must be regarded as related and probably contemporaneous formations. According to Becksmann (1934) and Ødum (1935), Herzynian tectonic lines are expressed in the basement complex of northern Germany and southern Denmark (text-fig. 11) which therefore seems to form a transition to the condition in Scania and Bornholm.

Hadding (1933 p. 21) assumes that the earlier Scania orogenetic movements commenced during late Jurassic (late Kimmeric movements) and the later disturbances took place during upper Cretaceous and Tertiary (Sub-Herzynian, Laramid and Tertiary movements).

Returning to the Post-Permian geological structures of the southern part of the Oslofjord, there appears to exists a strong resemblance to the above mentioned Late Mesozoic or Tertiary structures of Scania, Bornholm and Germany. 1. The combination of folding and faulting ("Bruchfaltung", "Kippschollenbau") is characteristic of all the districts. 2. The disturbances of the Oslofjord, Scania and Bornholm have occured along the SW and S border of the Fennoscandic Shield and the tectonic lines form more or less a continuous curve from NNW—NW (Oslo) to WNW (Bornholm). De Geer (1910 p. 858) and Holtedahl (1934 p. 11) assume the presence of post-Permian sediments in Skagerrak and Kattegat which, therefore, geologically rather belong to Denmark than to Norway and Sweden. 3. It seems possible to explain the younger Oslofjord structures by the assumption of a southward drift of the Fennoscandic Shield, a drift which also explains the disturbances farther south along the border.

The geological structures of the rhomb-porphyry conglomerate bear a considerable resemblance to those of Scania, Bornholm and Germany, and indicate strongly the presence of Late Mesozoic or Tertiary orogenetic movements in the southern part of the Oslo Region. The disturbances might have been due to a southward movement (Bubnoff) of northern Europe towards middle Europe of which the southern part of the Oslo Region forms a northernmost wedge-like extension.

Remarks on Glacial Features in the Southern Part of the Oslofjord.

In the preceding pages I have pointed out the distinct connection which exists between the present submarine relief of the fjord and the ancient tectonic lines exhibited in the geological structures of the islands and the neighbouring mainland. As pointed out by Brøgger (1886 p. 129) the present fjord-topography to a large extent is also due to glacial activity. The glacial erosion had been directed by the more prominent tectonic lines such as the large faults which had formerly caused the subsidence of the present fjord area.

During the gradual retreat of the ice-sheet of the last glaciation, several very conspiciuous terminal moraines were laid down in the Oslofjord district. Most typical are the large "Ra"-moraines which form continuous ridges on each side of the fjord (pl. I fig. 1). The "Ra's" which were submarine deposits, have been correlated with the large Mid-Swedish moraines and the Salpausselkä of Finland. In the Oslofjord area there is an eastern and a western main row of the moraine. The western "Ra" has a NE-direction and leaves the mainland at Horten. The eastern branch has a NW-direction, leaves the mainland at Moss, crosses Jeløy island and probably meets the western branche somewhere in the fjord.

Øyen (1911) and others have drawn attention to another set of terminal moraines which have a more southern position. This outer row of Ra-moraines runs parallel to the main, or inner, row and, according to the map of Øyen (1911 p. 17), consists of a western branch crossing Nøtterøy, leaving the coast at Slagenstangen and an eastern branch extending from Larkollen towards Halden (Fredrikshald) and on into Sweden.

Schetelig (1920, and in a lecture given in Geologisk Forening in Oslo in 1919) has drawn attention to a still older "Ra" which he called the "Tjøme-Ra" after its occurrence on Tjøme island. He also intended to trace the moraine across the mouth of the Oslofjord on account of the statements of "sandy bottom" on the charts.

The bathymetric maps drawn from the special and ordinary charts have been able to indicate not only the more important tectonic lines, but also the main glacial features of the southern part of the Oslofjord.

The inner Ra-moraine. As shown on the map pl. VI, and mentioned in a preceeding chapter, a NW—NNW-direction is distinctly pointed out in the depth of the fjord from the outlet of the Drammensfjord to the area east of Bastøy. The chart has rather few soundings of the fjord north of Bastøy, but yet it seems possible to distinguish a certain submarine bridge crossing the main fjord depth a little to the north of the narrow part between Horten and Jeløy, as shown on pl. VI. The ridge, having its surface about 150 m below sea level, is apparantly very level and slopes gradually down to a depth of 200 m east of Horten. In its position the ridge forms a continuation of the western branch of the inner Ra-moraine. Whether the ridge represent a treshold of solid rock or a submarine transverse moraine (or a mixture of both) is not possible to decide with our present knowledge of the submarine topography of this place. Since more recent conceptions as to the formation of the Ra-moraines are apt to consider the Ra's as being formed during a subsidence of the land up to the highest marine limit (Antevs 1922), it is possible that the ice-front exhibited a considerable indentation above the deeper parts to which even the more shallow ridge must be reconed.

The outer Ra-moraine. The southern part of the fjord depth east of the island Bastøy, ist shown in details on textfig. 12 with contour lines for every 20 m. The u-shaped cross-section indicate glacial erosion. East of Mefjordboen the deeper (300 m) submarine channel of the fjord is interrupted by a marked transverse ridge with a surface 170—200 m below sea level. South of the ridge

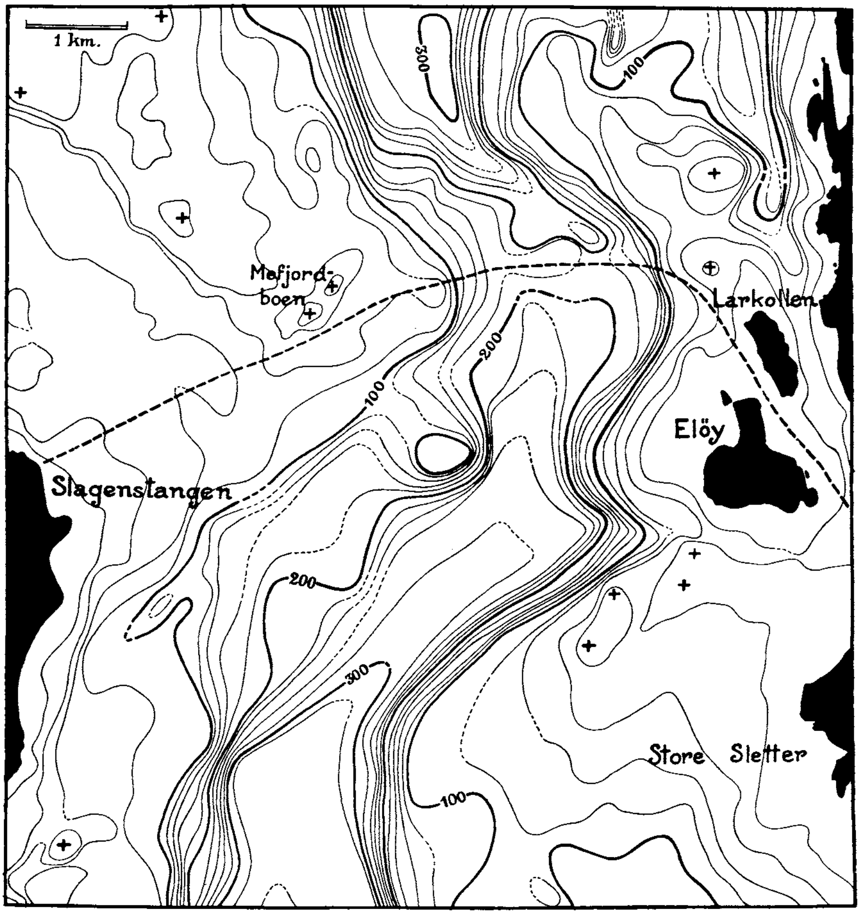

Fig. 12. Bathymetric map accross the Oslofjord at Larkollen. The angular deeper channel and the ridge crossing it (at dotted line) are demonstrated.

the bottom slopes more gently down to the deeper level bottom of the fjord.

The position of the described ridge correspond to a continuation of the western and eastern branch of the outer Ra-moraine according to the sketch-map presented by Øyen (1911 p. 17). The western branch of the Ra leaves the coast north of Slagenstangen and probably continues farther to Mefjordboen as suggested by the dotted line on textfig. 12. The contour lines suggest that loose materials accumulated over the area between Slagenstangen and Mefjordboen. The slope following the 100 m-contour line south of Mefjordboen might either represent a tectonic line parallel to the escarpment west of Store Sletter, or it migt mark the SE border of a submarine Ra, filling up a "hanging" valley with a bottom of 180—200 m and joining the main glacial trough at a right angle. Future echo-sounding series might perhaps solve the question.

The ridge accross the fjord channel east of Mefjordboen, situated a little to the north of the narrow point between Slagenstangen and Eløy, probably, on account of its low position (surface abot 320 m below highest marine limit), represent a treshold of chiefly solid rock rather than a submarine moraine ridge damming up to the fjord channel.

The outer "Ra"-moraine is easily traced along the east side of the fjord. In an earlier chapter I have pointed out the large quantities of glacial material deposited on the islands Eløy and Store Sletter. The sound between Eløy and Kollen is nearly filled up by similar deposits. The coast east of Store Sletter is also covered by moraine material. The local names "Sandyhook" and "Danmark" are rather characteristic. The small island called Danmark, is built up by coarse moraine material with large boulders. From here onwards the outer "Ra" continues across the Krogstadfjord in a SE—ESE-direction towards Onsøy and on to Halden, as indicated on earlier maps.

As shown above it seems possible to locate two submarine ridges crossing the main fjord channel and having positions corresponding to a submarine continuation of the inner and outer Ra-ridges on both sides of the fjord. Their low positions make it less probable that they represent moraine ridges. Probably they chiefly form rock tresholds formed during the glacial excavation of the fjord and separating deeper parts of the glacial "valley". In both cases the tresholds are situated slightly north of narrow passages in the fjord. Sauramo and others have pointed that ice-fronts are inclined to stagnate at narrow passages and where tresholds are present in the underground. Although the tresholds during the considerable late-Glacial subsidence evidently were not touched upon by the ice, they might have been an important factor in determining the position of the Ra-moraines.

South of the outer "Ra"-moraine just described, the submarine fjord-channel takes a peculiar angular turn, evidently due to the primary tectonic lines. At the curve the western slope of the channel is very steep. A section across the channel in this place would show the most typical u-shape with its steep walls descending on either side from a depth of 90 m down to the flat bottom of about 330 m. A little farther south the western slope has the indication of a narrow rock-terrace at a depth of 160—200 m.

The long and straight fjord depth between Bolærne and Rauøy has been subject to considerable glacial erosion. The bottom is apparantly comparatively level with a few shallow undulating pools characteristic of the glacial bottoms. While the NE slope is very steep, the western exhibits a less pronounced and variable inclination. The asymetric section might probably be due to the presence of harder plutonic (?) rocks (larvikite) along the SW-side in contrast to the less solid sedimentary (?) rocks on the other side.

The narrow submarine channel marking the geological eastern border of the Oslo Region, is not so distinct in the Larkollen district where to a large extent it is filled by moraine material from the outer "Ra". The depth of the channel increases gradually southwards. At several places it widens and forms evidently glacial pools with a flatter bottom. Typical pools with round outlines are developed east of the Søster islands.

The submarine barrier at the mouth of the fjord. The general map pl. VI shows how the deep channel in the central part of the fjord is barried by a submarine treshold crossing the fjord between Bolærne and the Søster islands. The broad barrier has a comparatively level surface (about 50 m below sea level) which slopes very gently towards the distal slope descending more rapidly from 60—100 m. The proximal slope is steeper with the deeply eroded fjord depth close to it.

The barrier is intersected by a few narrow passages which, however, do not exhibit any great depth. The soundings indicate that the passage between the shoals Høka and Lille Høka is the deepest with depth evidently about 130 m. Outlets of the Oslofjord deeper than 100 m seem to occur only in this place and perhaps also across the submarine platform south of Missingen, a passage leading to the eastern fault channel which has its outlet in the Hvaler depth.

In order to obtain an impression of the morphological features of the barrier, a detailed bathymetric map with contour lines for every 20 m (in parts also every 10 m) was worked out from the soundings given on the ordinary and special charts. The map shows several peculiar features. In the proximal part of the barrier the contour lines indicate rather level plains interrupted by shoals. The middle part exhibits several apparantly round and toungue-shaped depressions without outlets and in the distal part submarine channels and indentations of the border of the barrier are indicated.

The illustration of the submarine relief as presented on the map, is in many respects suggestive of morphological features characteristic of marginal glacial deposits. From the contour lines on the map, however, it is difficult to have any idea of the amount of glacial material deposited on the treshold of solid rock.

Through the kindness of Captain O. Bull and Mr. Bjørnstad first mate on S/S "Bergensfjord" of Den Norske Amerikalinje, I have obtained an echo-sounding section accross the barrier. The section has proved to be of considerable interest since it shows that the proximal parts of the barrier is not in details so even and level as might be expected from the figures presented on the maps. Future dredgings might help to determine to some extent the distribution of glacial material on the chiefly rocky treshold across the mouth of the fjord.

Since these investigations have not yet been brought to an end, I have in this connection only briefly mentioned the submarine morphological features of the barrier and not reproduced the mentioned map.

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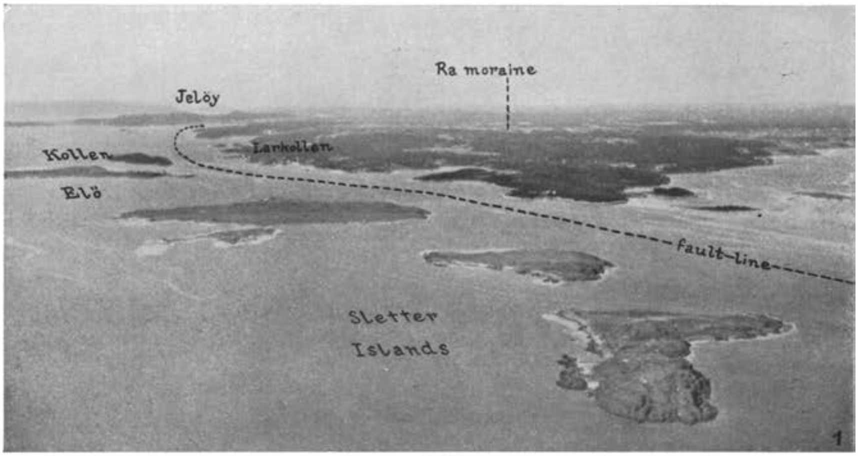
Plate I.

Fig. 1. The great Permian fault-line (dotted) with the Precambrian area to the east and the rhomb-porphyry conglomerate islands to the west. The cultivated fields in the background indicate the position of the inner Ra-moraine. Air-photograph looking north.

» 2. Revlingen. Glacial drift (gl) fringes the rock exposures. The contact between the rhomb-porphyry (Rp) and the overlying sediment (Rp-congl) is indicated by dotted line. The NE fault-line is possible to trace in the air-photograph.

» 3. The Søster islands. The two Permian (?) fault-planes are pointed out. The jointing parallel to strike is well exposed in the beautiful abrasion cliff along the SW coast of Søndre Søster. The rocks below indicate the abrasion platform.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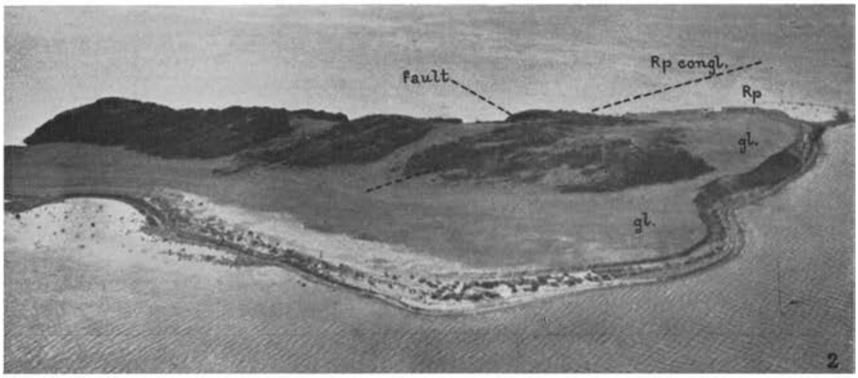
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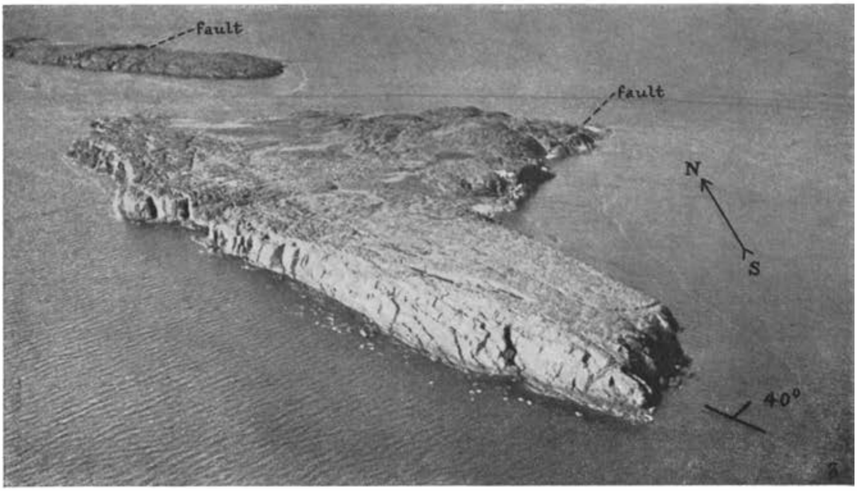
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Plate II.

Fig. 1. The about 35 m high southern escarpment of Søndre Søster. Parallel bedding of gravel beds in the rhomb-porphyry conglomerate series.

» 2. Typical rhomb-porphyry conglomerate from the west coast of Rauøy. A rock bench is formed at sea-level below the cliff.

» 3. Erosion pillars ("raukar") on the west coast of Rauøy. In the background the Søster and Struten islands are visible between Nordre and Søndre Missingen.

» 4. Fault-plane and associating quartz-veins on Søndre Søster. The hammer near the bottom indicates the size.

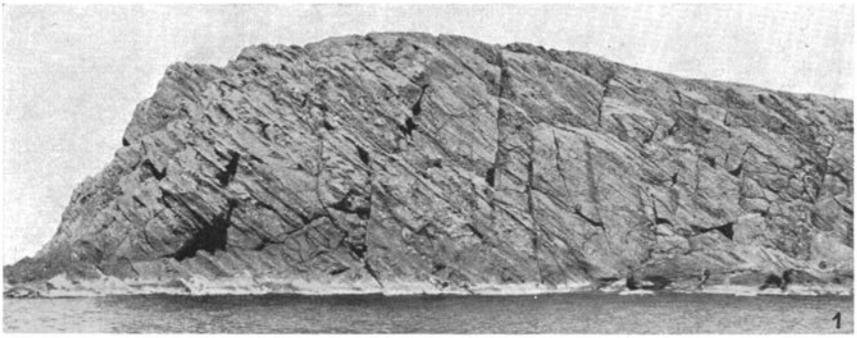

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Plate III.

Fig. 1. Rhomb-porphyry conglomerate in the cliff of Svarteberget on the west coast of Rauøy. Gravel beds alternate with coarser and more unsorted layers of which two, with a thickness of about 1 m, is shown in the middle of the section. To the right at the top of the upper coarse bed one might notise a narrow triangular boulder resting apparantly in labile position.

» 2. Rhomb-porphyry conglomerate form the SE coast of Mellem Sletter. The stratification is distinct in the arkose beds. Larger boulders occur in rather fine gravel.

» 3. Rhomb-porphyry conglomerate from the north coast of Søndre Søster. The exposure demonstrates the sudden and very considerable changes in the coarseness of the sediments. Just above the finer gravel beds (gr) one finds great boulders of rhomb-porphyry (Rp) measuring more than two meters, in coarser gravel (congl). The section is indicated on text-fig. 6. On the photograph the erratic boulder (gl b) does not belong to the section.

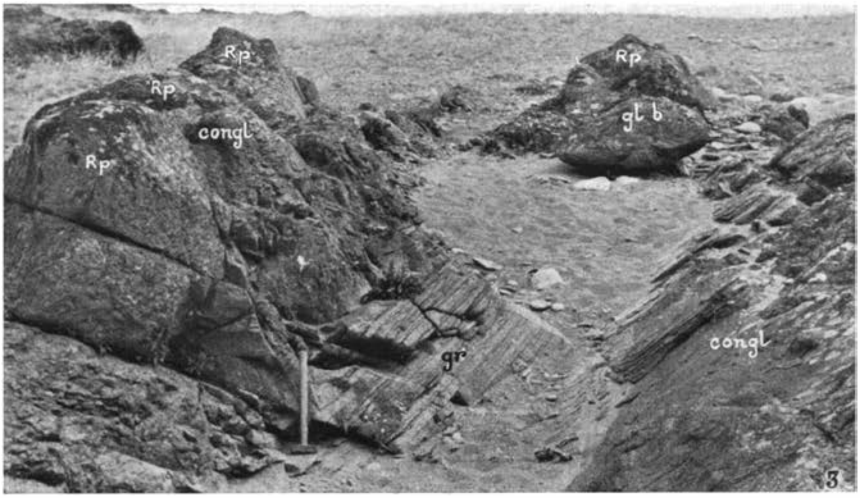

Rp
Rp
congl
Rp
Rp
gl b
gr
congl

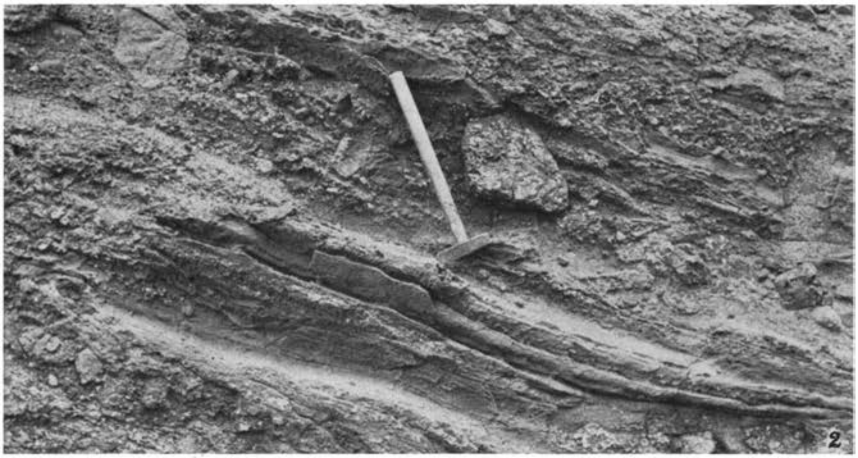
Plate IV.

Fig. 1. Rhomb-porphyry conglomerate from Svarteberget on the west coast of Rauøy. Coarse and unsorted boulder bed between layers of finer arkose.

» 2. Beds from about the same locality. The horizontal and vertical variation is demonstrated.

» 3. Current arrangement of the boulders in the conglomerate a little to the north of the above mentioned localities. The different boulders are outlined on text-fig. 8.


1


2

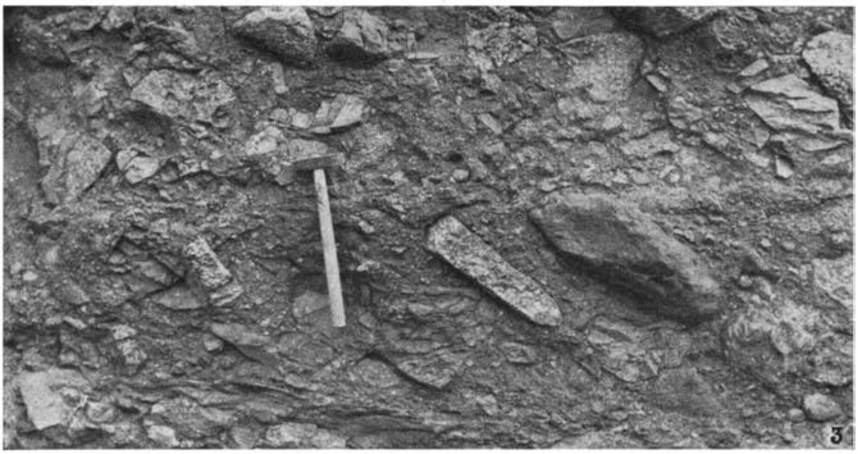

3

Plate V.

Fig. 1. Well rounded boulder in fine-grained matrix. Rhomb-porphyry conglomerate from section north of Bauen, Rauøy.

» 2. Boulder with glacial appearance. From the same locality.

» 3. Angular "faceted" boulder. From the same locality.

» 4. Mud-cracks and raindrop markings in fine-grained arkose from the west coast of Rauøy. Collected, described and figured by Holtedahl (1931 a). 0,8 ×.

» 5. Typical gravel (shingle) of the rhomb-porphyry conglomerate. Wheatered specimen from the section north of Bauen Rauøy. 0,8 ×.

» 6. Thin secton perpendicular to bedding plane of arkose from Søndre Søster. The sample was taken from the gravel beds (gr) on pl. III fig. 3. Magnification the same as for the following.

» 7. Thin section of quartz-bearing arkose from the west coast of Rauøy. Magnification indicated by the scale.

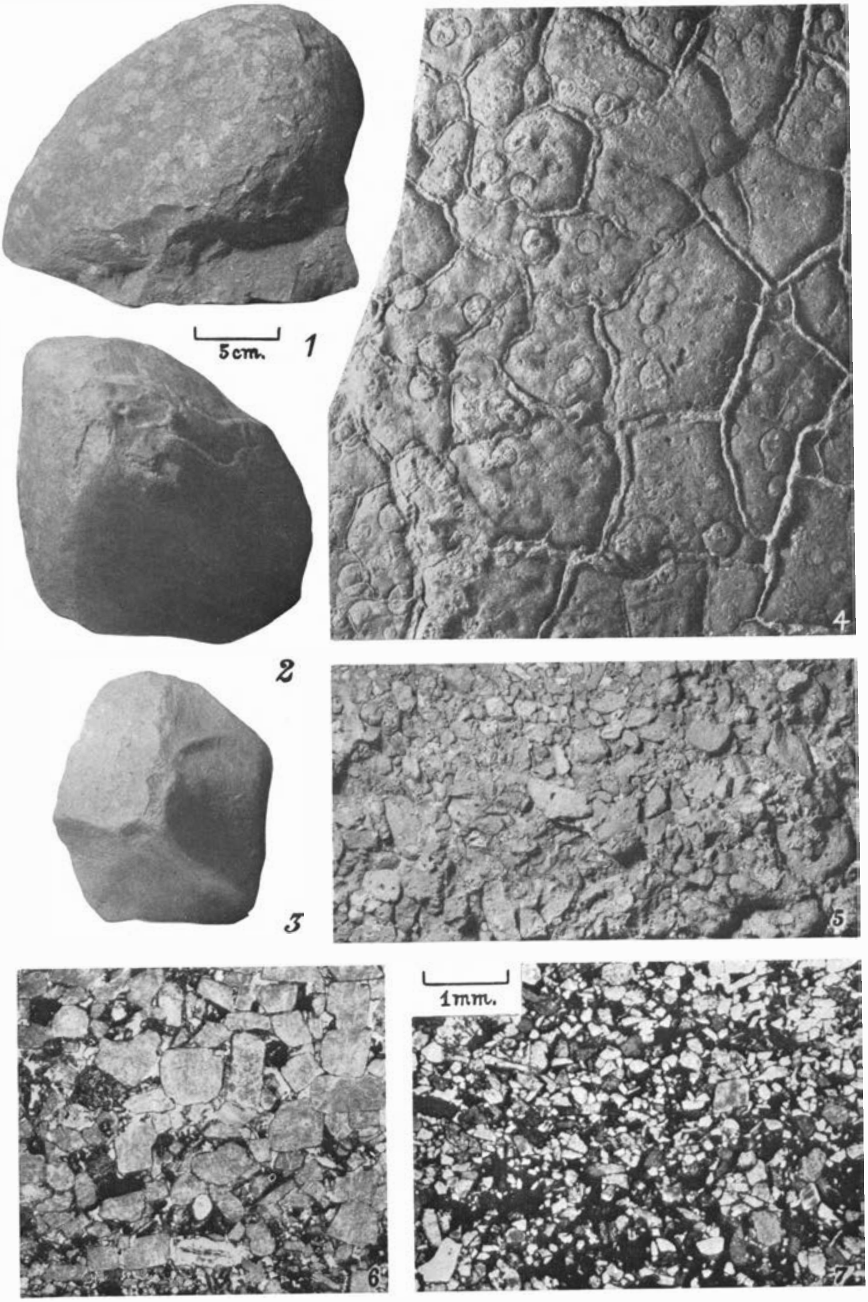
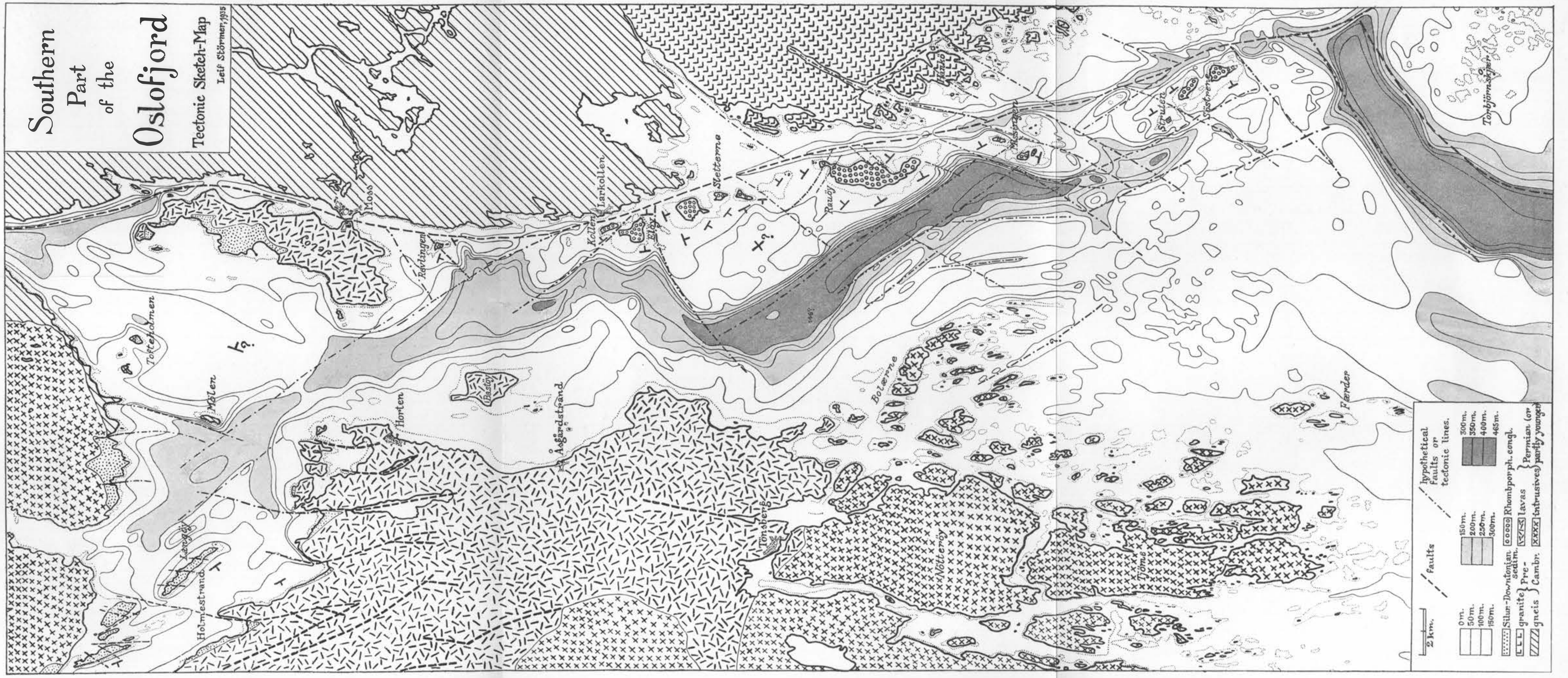

5 cm.
1
2
3
4
5
1 mm.
6
7

Plate VI.

General map of the southern part of the Oslofjord.


Southern Part of the Oslofjord
Tectonic Sketch-Map
Leif Störmer 1935
Moss
Horten
Tönsberg
Nötteröy
Tjöme
Færder
Bolærne
Bastöy
Rauöy
Stetterne
Tofteholmen
Hölen
Larkollen
Kollen
Rævlingen
Åsgårdstrand
Lengöy
Holmestrand
Torbjörnskjær
2 km.
faults
hypothetical faults or tectonic lines.
0 m.
50 m.
100 m.
150 m.
200 m.
250 m.
300 m.
350 m.
400 m.
465 m.
Silur-Downtonian sedim.
Rhombporph. congl.
lavas
Permian (or partly younger)
intrusives
granite
Pre-Cambr.
gneis