Excursion 3

Central Part of the Oslofjord*

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The central part of the Oslofjord area is of particular interest because it includes several geological features of structural and petrological significance which can be better demonstrated here than at other localities within the graben. In fact, the extensive rhomb porphyry (RP) conglomerate, which is a key indicator of the major subsidence that took place along the Oslofjord fault zone, can only be examined on the islands along the ancient fault-scarp on the east side of the fjord (Figs. 1 & 2). Other points of interest are the small gabbroic necks (the subvolcanic 'Oslo-essexites') which are beautifully exposed on some of the small islands and skerries. There is no better place in the Oslo Region to study igneous layering and minor structural details than on the island of Ramvikholmen south of Tofte (Ramvikholmen = Ran(d)vikholmen). The western shores of Jeløya offer excellent opportunities to study volcanologic and structural details of the early stages of the Oslo Graben history. Here one can see the Lower Paleozoic substratum on which the earliest Permian sediments rest. These are then overlain by B_1 basalt, pyroclastic rocks and rhomb porphyry lava flows.

Morphological and bathymetric features (Fig. 2) reveal that, apart from the major graben subsidence, the fjord area was intensely deformed by faults in several different directions. This faulting led to the subdivision of the graben 'floor' into a system of small-scale basin-and-range-like structures, tilted fault-blocks, etc. This is why Precambrian rocks generally found to the east of the Oslofjord master fault, also outcrop occasionally within the fjord area (island of Mølen) (Fig. 3).

The vertical displacement of 2–3 km(?) and an overall 60°W dip of the master fault considered with data from the numerous normal faults in the Vestfold area (Oftedahl 1952) and the fjord area, suggest a crustal extension within the eastern half of the graben of about 2.5 km. An earlier estimate for the entire

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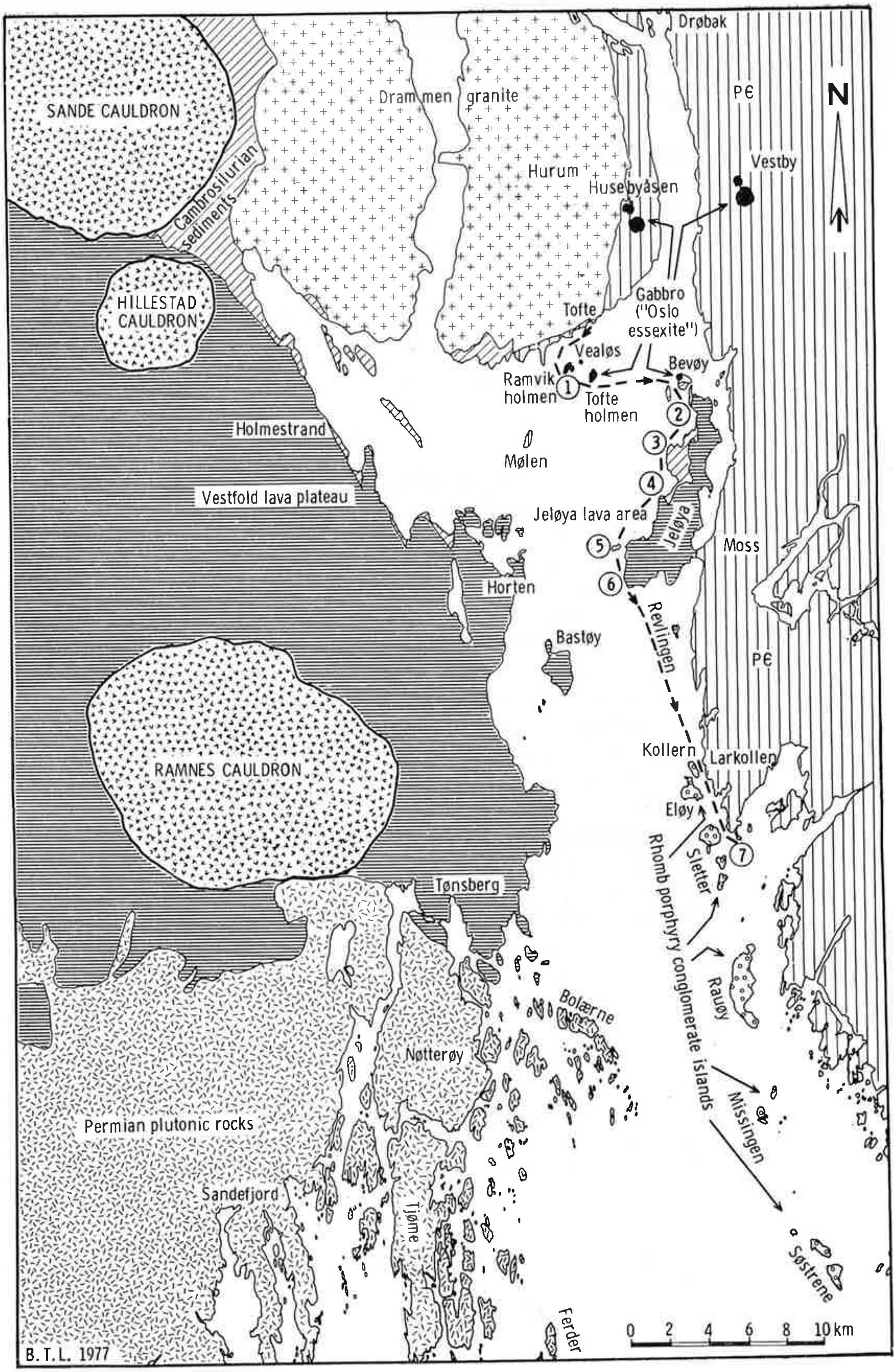
* Of the present review, the Jeløya part has been prepared by ESJ who has carried out detailed investigations in that area for a number of years. For the remaining areas to be visited, studies are in progress, but the presentation here (BTL & IBR) is based on brief field visits, previous reports (e.g. Brøgger 1886, 1900, 1931, 1933, Størmer 1935) and experience from other parts of the graben area.


SANDE CAULDRON
Cambrosilurian sediments
Drammen granite
Drøbak
PЄ
N
Hurum
Vestby
Husebyåsen
HILLESTAD CAULDRON
Tofte
Gabbro ("Oslo essexite")
Vealøs
Bevøy
Ramvik holmen
①
Tofte holmen
②
③
④
Holmestrand
Mølen
Vestfold lava plateau
Jeløya lava area
Jeløya
⑤
Moss
⑥
Horten
Revlingen
Bastøy
PЄ
Kollern
Larkollen
RAMNES CAULDRON
Eløy
Sletter
⑦
Rhomb porphyry conglomerate islands
Tønsberg
Rauøy
Bolærne
Nøtterøy
Missingen
Permian plutonic rocks
Sandefjord
Tjøme
Søstrene
Ferder
0 2 4 6 8 10 km
B.T.L. 1977

→
Fig. 2. Bathymetric chart of outer Oslofjord, N.E. Skagerrak and the northern part of the Swedish west coast.

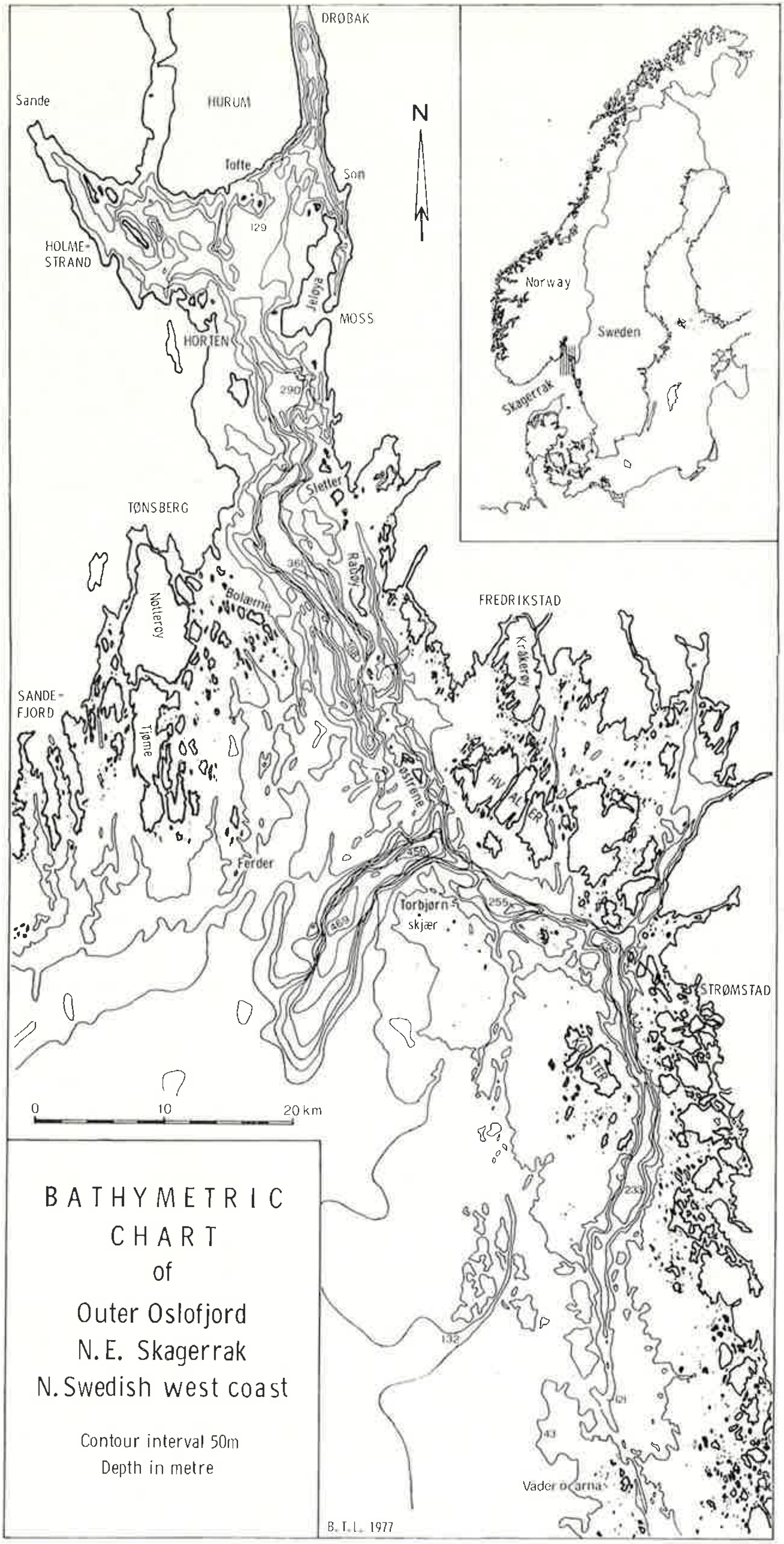


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Fig. 1. Geological sketch map of the Oslofjord area with excursion route. Locality 3, Tangen, is at the northern end of Jeløya.

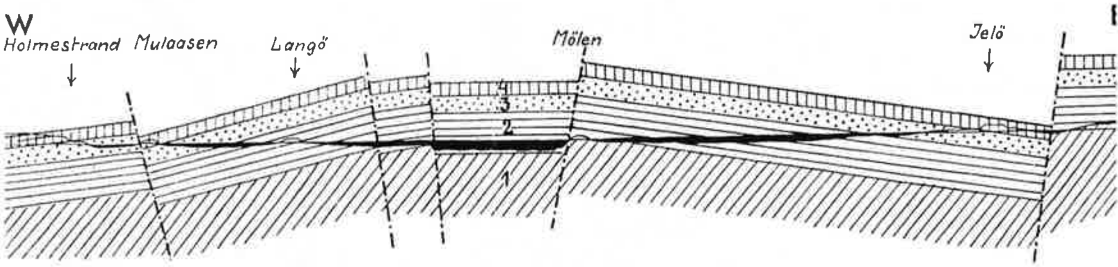


Fig. 3. Section E–W across the middle part of the Oslofjord between Holmestrand and Moss. From Brøgger (1896. 1 – Precambrian, 2 – Marine Cambro–Silurian sediments. 3 – Continental Upper Silurian sandstone (Ringerike Formation), 4 – Permian volcanics.

(central part of the) graben was about 4 km (Ramberg 1976). Since most of the graben area elsewhere is occupied by the largely late-formed intrusive masses, the fjord area in general represents the most favourable area for studying details of the early crustal break-up.

Gabbroic necks ('Oslo-essexites')

The volcanic necks of the Oslo Region are situated along two major tectonic lines. One of these lines trends N–S, following the *Oslofjord master fault* and its northward extension, the *Randsfjorden–Hundselv master fault.* The other line trends NNE–SSW, following the monoclinal flexure in the west (see Plate 2 and Ramberg & Larsen, this volume, Fig. 5, p. 66). About 13 major necks (0.5–1 km in diameter) and at least 5–6 smaller ones (dikes or minor necks) are hitherto recorded; six of these are double or multiple necks. (A general survey is presented in Ramberg 1976).

The emplacement of the necks preceded that of the main plutonic series; hence most necks occur in border regions of the graben, outside the major batholiths. One of the larger necks (at Eiangen) and several smaller ones (e.g. at Mylla, Øyangen, etc.) are regarded as inclusions within the younger intrusives. A large, layered, plate-like intrusion within the basal part of the Cambro–Silurian sedimentary sequence at Jarenvann (Ramberg 1976, p. 95), may be connected with a string of volcanic necks, the nearest one situated some 5 km to the west. Another possibly related intrusive is found in the Precambrian about 2 km south of the composite neck at Vestby. Here, an orbicular lamprophyre dike (Bryhni & Dons 1975) exhibits a mineralogy closely similar to that of the gabbroic necks.

The volcanic necks, which demonstrate a great petrographic variability and complexity, are predominantly composed of gabbroic to syeno–dioritic rocks of alkaline affinities (Brøgger 1931, Barth 1945, Dons 1952, Oftedahl 1960, Ramberg 1976). Several necks have melanocratic central parts which grade into more leucocratic composition towards the rims (e.g. Vestby). Inversed zoning is also known, for instance at Husebyåsen in Hurum where coarse-grained

Fig. 4. Trough-like structure in the steep-dipping rhythmic layered gabbro. SW Ramvikholmen.

pyroxenites characteristically occur along the margin, encompassing a less melanocratic core.

The various necks are of different overall composition, varying from silica-undersaturated (basanitic) as for example at Ullernåsen to silica-oversaturated (quartz tholeiitic) at Sølsberget. In the double neck at Vestby one neck is alkaline, the other quartz–tholeiitic (Ramberg 1970, see Neumann, this volume Table 1, p. 28). Preliminary investigations of the augites of gabbros from various necks reveal great differences (of up to 7%) in the Al content, indicating contrasting genetic conditions for the individual necks (E.-R. Neumann, pers. comm. 1977).

Igneous layering occurs in the majority of the necks, and is more frequent and diverse than previously recognized. Rhythmic layering on various scales, with troughing, slumping and 'current bedding' structures, etc., is present together with internal breccias (Figs. 4, 5a, b, 6). The layers can be enriched in plagioclase (anorthosite), olivine–clinopyroxene (pyroxenite) or even Fe–Ti oxides (cumberlandite). The generally steeply dipping layers vary in thickness from a few centimetres to several metres. One of the three bodies forming the Ullernåsen mafic intrusion shows mineral orientation of platy plagioclase which describes a funnel or inverted cone (Dons 1952).

Cumulus textures are common; major cumulus minerals are plagioclase, augite and olivine, plus magnetite and apatite in lesser amounts. The three major minerals are found as orthocumulates with or without a certain adcumulus growth. This is especially true for plagioclase. The plagioclase is often zoned in an irregular manner (Barth 1945). Fig. 7 illustrates how the An content varies within one single plagioclase crystal from An_{15} to An_{60}. This

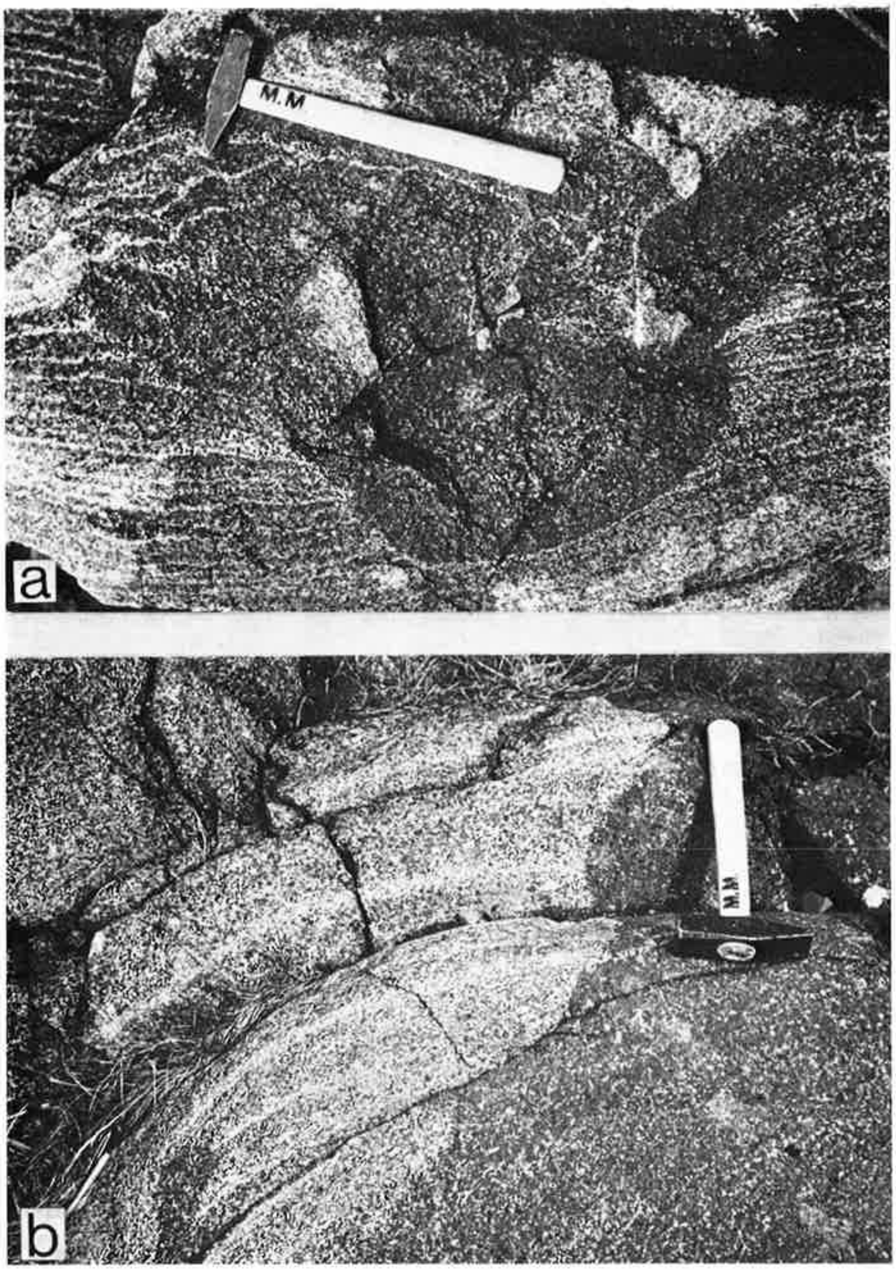
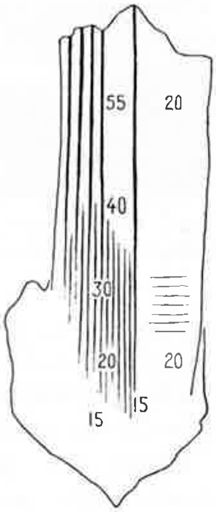


Fig. 5. (a) Pyroxenite xenolith in rhythmic layered gabbro.
(b) Contact between layered gabbro and pyroxenite. Both from SW Ramvikholmen.

particular feature could tentatively be interpreted as a zoned orthocumulate with unzoned adcumulate growth of An$_{15-20}$. Heteradcumulate plagioclase is also found. Oscillatory zoned augites (orthocumulate?) up to a few centimetres in length are common in some necks.

Fig. 6. Rheomorphic breccia containing fragments of different gabbro types, pyroxenite and and Cambro–Silurian sediment, eastern Ramvikholmen.

Fig. 7. Plagioclase lath in gabbro (kauaiite): after Barth (1944): Right half of the plagioclase lath rather homogeneous oligoclase, An_{20}. Left half strongly zoned from An_{55} to An_{15}. Length of lath about 2 mm. Left side could represent an orthocumulate phase and right side an adcumulus growth.



Other minerals found are Fe–Ti oxides, biotite, amphibole (kaersutite), potash feldspar, orthopyroxene, nepheline, apatite and melanite. Most of these crystallized in the intercumulus liquid. In some rocks, large (up to 10 cm) amphibole crystals occurring especially along the borders may possibly represent a cresscumulus mineral (Wager et al. 1960, Wager & Brown 1968).

The various structures described often exhibit cross-cutting relations, indicating a sequence of magmatic events. With regard to the absolute or relative age of the necks as a whole, there is still some uncertainty. Although it seems that the volcanic necks generally preceded the emplacement of the main inter-

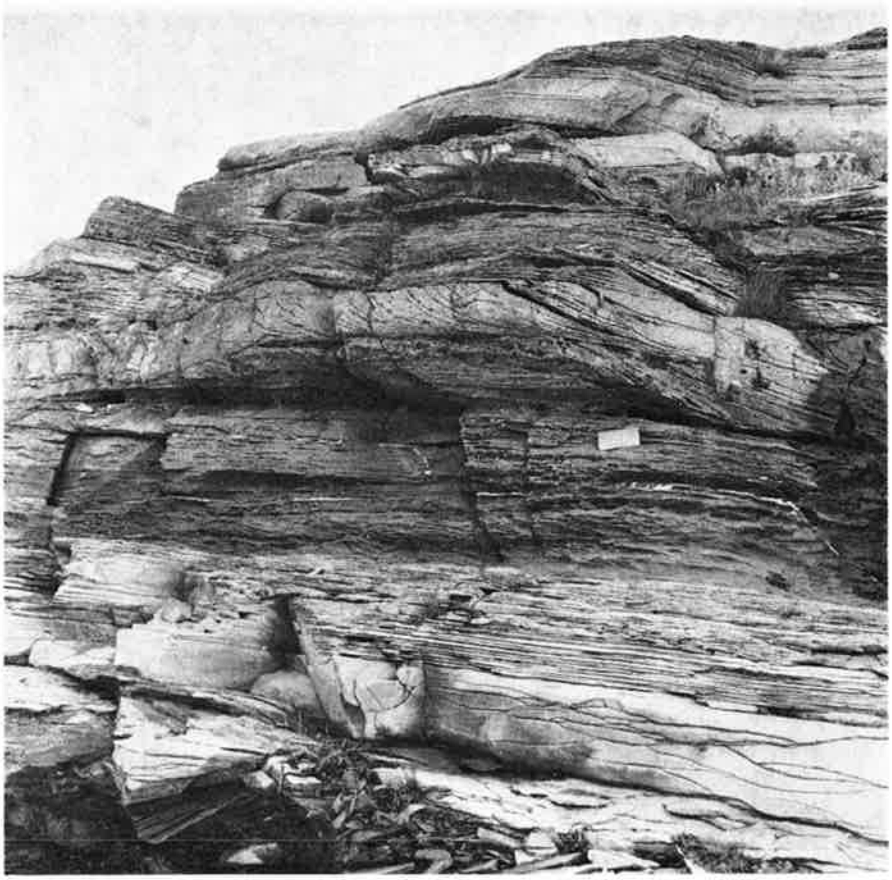


Fig. 8. Grey to reddish Ringerike Sandstone with large-scale trough cross-bedding. Bileholmen, NW of Jeløya. See also Plate 5.

mediate to felsic plutonic series, it is not certain whether the formation of the necks corresponds to a single episode or stage. If one stage has to be chosen, the major central volcano stage has been suggested as the most likely time of origin for the necks (e.g. Dons 1952, Ramberg & Larsen, this volume).

Gravity investigations of the volcanic necks (Ramberg 1976) demonstrate that the necks are remarkably shallow, ranging in 'thickness' from about 0.25 km to perhaps 1.5 km. Below depths not greater than the diameter of the individual necks, no traceable density contrast exists. Thus the necks seem to represent floored magma chambers within which the rising basaltic magma was stored and further differentiated before extrusion. This model is in good agreement with the layering and cumulus minerals observed. The similarity between the Oslo Region necks and for instance the Monteregian intrusions of Canada is striking with regard to petrographic, structural and geophysical features (Philpotts 1968, 1970, 1974, Bhattacharji 1966, Bhattacharji & Nehru 1972, Kumarapeli 1970, Kumarapeli & Saull 1966, Kumarapeli et al. 1968).

In the Monteregian intrusions evidence of liquid immiscibility has been

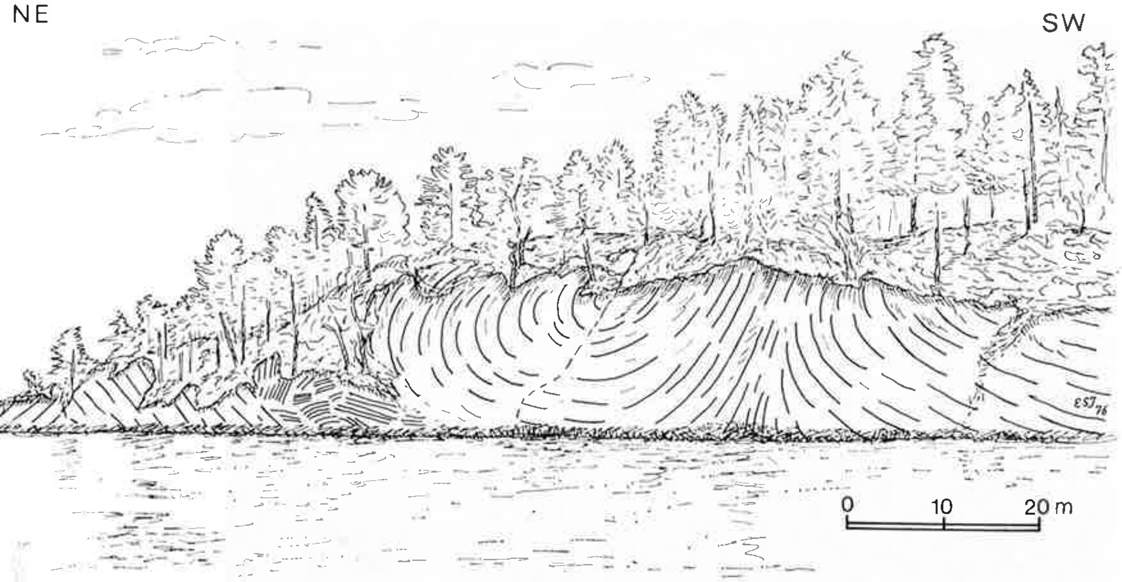


Fig. 9. Brecciated and folded Ringerike Sandstone deposited as fragments in a Permian debris flow from the ENE. Tangen, northern Jeløya.

found (Philpotts 1971, 1972), but no indications of such have been found in the Oslo mafic intrusions. Bhattacharji (1970) suggested flow differentiation as a possible mechanism operating during the formation of the Canadian necks.

In addition to the various mafic dikes which can be shown to be directly associated with the gabbroic necks, dikes in general are very frequent in the neighbouring areas. Thus, Dons (1952) calculated a dike frequency of about 17% of the total area surrounding the Ullernåsen necks. A wide range of dike types occur, varying from most basic to acidic. About half of the dikes of the region are, however, of a felsic rock-type commonly termed *mænaite.* This is a dike rock almost exclusively composed of feldspar (plagioclase, $An_{10\text{-}25}$) often with a trachytoid texture.

Jeløya

Jeløya is the largest of the many islands of the Oslofjord. It is situated close to the eastern border of the Oslo graben (Fig. 1). The Jeløya fault-block has sunk at least 2–3000 m relative to the Precambrian basement to the east (Plate 5).

The island is built up of Downtonian sandstone (Fig. 8), overlain by several Permian debris flows that were deposited during the initial phase of the volcanic period (Fig. 9). The volcanic rocks, dominated by tuffs and volcanic breccias in the northern part of the island (Fig. 10), have deformed the unconsolidated surface of the debris flow deposits and, in connection with the development of mega-load-cast structures, have pressed sandstone dikes high

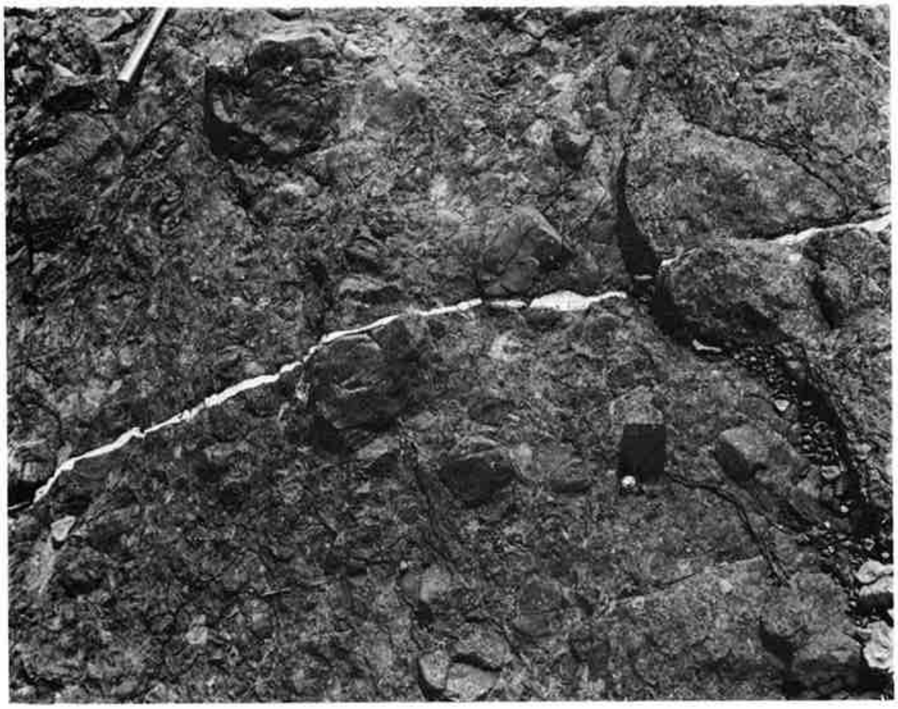


Fig. 10. Volcanic breccia at Nebbeåsen, Jeløya.

up into the overlying tuffs and breccias. The lava flows (e.g. Fig. 11), which are prevalent in the central and southern part of Jeløya, are together with the tuffs and volcanic breccias in the north referred to the lower basalt (B_I) series. In the southernmost part of Jeløya the B_I series is followed by several rhomb porphyry lava flows that are intercalated with rather thick volcanic breccias and agglomerates of RP composition. The Jeløya basalts are alkaline and commonly of mugearite type (see Fig. 2, Ramberg & Larsen, this volume, p. 61). They thus differ from the Holmestrand basalts on the other side of the fjord, which are of alkali olivine basaltic to hawaiittic composition (Weigand 1975). All the volcanic deposits on Jeløya show evidence of a rather close proximity to a volcanic vent.

On the little island Revlingen south of Jeløya the RP lava flows are overlain by rhomb porphyry conglomerate, a fanglomerate deposit formed along the eastern escarpment of the Oslo graben.

Fig. 11. Augite porphyry pahoehoe toe in red volcanic sand. Gullholmen, W of Jeløya.

Rhomb porphyry conglomerate

Together with Jeløya, the RP conglomerate islands along the eastern side of the fjord constitute a separate volcanic province. At Jeløya agglomerates and other pyroclastic rocks represent a substantial part of the Permian deposits, and on the islands to the south of Jeløya and Revlingen (Figs. 1 & 2) fanglomerates completely dominate the sequence. This is in sharp contrast to the lower part of the Vestfold lava series which contains only negligible amounts of sedimentary and pyroclastic material. The difference is believed mainly to reflect the proximity of the eastern province to the Oslofjord master fault.

The rhomb porphyry conglomerate (Brøgger 1900, Størmer 1935) is found on a number of islands from Revlingen in the north (where it rests on $RP_{4(?)}$) to the islands Søstrene in the south, i.e. over a distance of about 38 km. Everywhere it consists of alternating finer and coarser strata of badly sorted clastic material almost exclusively composed of rhomb porphyry fragments of

Fig. 12. Rhomb porphyry conglomerate (fanglomerate). Mellom Sletter island, eastern coast. Coarsening-upward sequence with relatively flat top, typical for aggradation and progradation of alluvial fans. The hammer shaft measures about 1 m. Most fragments consist of RP-lavas. A large basalt block is seen near the head of the hammer.

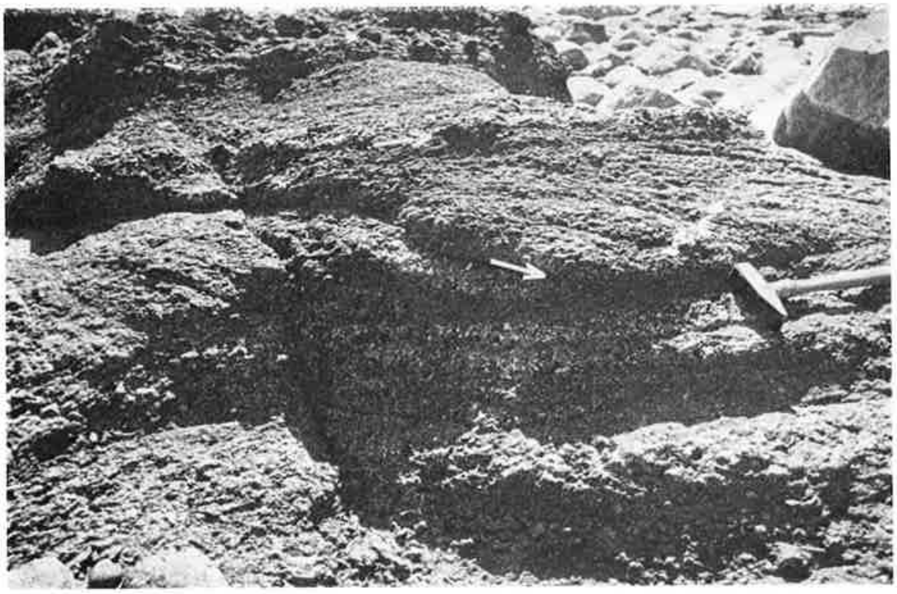


Fig. 13. Finer rhomb porphyry conglomerate with low-angle cross-bedding. Mellom Sletter island, western side. Cross-bedding (lower arrow) dipping roughly to the west. Head of hammer measures about 10 cm.

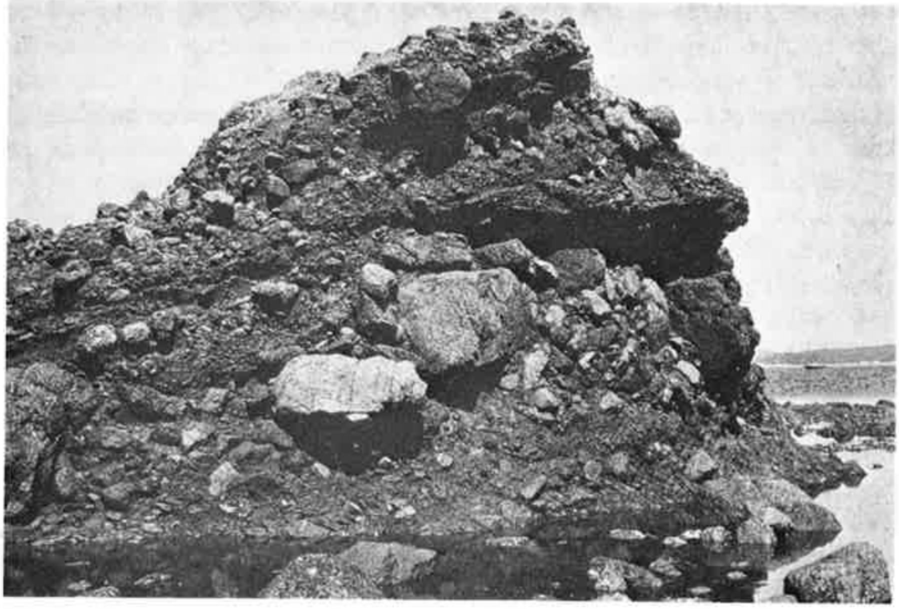


Fig. 14. Coarse rhomb porphyry conglomerate. Mellom Sletter island, eastern side. The biggest blocks are about 1.5 m in size.

different RP types (Fig. 12). Other rock-types constitute less than 10% and include various basalts, Permian quartz conglomerate (Tanum Formation) and Upper Silurian sandstone. Precambrian rocks have never been found.

Stratification is marked (Figs. 12 & 13). The change from finer to coarser beds and vice versa is commonly rather abrupt, typically a coarsening-upward sequence (Fig. 12) although general reduction in size upwards has also been observed. The individual beds, which typically form long, lense-shaped bodies, range in composition from mudstone to beds with chaotically arranged blocks measuring up to 3–5 m in diameter (Fig. 14). Low-angle, cross-bedding is apparent in some of the gravel beds (Fig. 13) but is in general rather uncommon. Channel-like syn-depositional features have been observed in a few cases.

Transport directions appear to be generally from the east but partly also from the north. The presence of mudcracks and raindrop markings in the finer beds as well as pockets of caliche indicate periods of subaerial exposure of these beds. The sedimentary milieu, the huge stratigraphical thickness of alternating fine to very coarse beds, the nearly monomict composition of the material and the characteristic extension of the deposits along the eroded graben escarpment imply together a fanglomeratic origin. Repeated debris flows, initiated by sudden rainstorms, gradually built up huge alluvial fans of mainly volcanic material from the elevated graben shoulder to the east. The occurrence of extremely coarse, breccia-like and lense-shaped bodies, especially in the easternmost parts, and a generally westward reduction in grain-size of the material (as observed for instance on the Sletter islands) is evidence in support of this hypothesis. The same conclusion may be drawn from the occurrence of scattered, very large blocks (of the order of metres) which are surrounded by relatively fine-grained stratified sediments (Størmer 1935, fig. 6). This type of occurrence is typical for many modern debris flow deposits, building up huge fan wedges, here about 1 km in 'diameter'. Rapid subsidence of the graben (rift valley) floor followed by aggradation and progradation of the alluvial fans is suggested by the flat tops and the coarsening-upwards motifs shown by the conglomerate wedges (Fig. 12). Considering the generally arid climate that prevailed during the Lower Permian, it seems likely that the finer beds, which measure down to a few centimetres in thickness, may have graded into playa deposits further west in the more central parts of the graben.

The individual alluvial fans probably attained considerable thicknesses as judged from the apparent thickness presently observed. On the Søstrene islands (Figs. 1 & 2), the deposits show evidence of having been distinctly more consolidated through compaction and diagenesis than on the other islands. Post-depositional rotational block-faulting (Størmer 1935) has here led to the exposure of previously deeply buried strata.

The Oslofjord master fault was evidently active for a relatively long period from perhaps before RP_4 time and upwards, simultaneous with the eruption of lavas, giving rise to the extensive RP fanglomeratic deposits. Subsequent to the deposition of the presently observed conglomerates, the deposits were further deformed by subdivision into individual blocks, tilting of the blocks, minor faulting and jointing, indicating a prolonged period of extensional tectonic activity.

Road log (Excursion 3)

1. Ramvikholmen (Fig. 15)

Landing at the southwestern point of the island (if weather permits). Foot traverse along the southwestern tip, possibly crossing over to the southeastern shore of the island. The rocks are mainly gabbros, often with near-vertical igneous layering, and pyroxenite.

The small island complex, Tofteholmen, Ramvikholmen, Vealøs and some minor skerries, is situated in the middle part of the Oslofjord, 3 km SSW of the small community Tofte at Hurum. The islands have a rounded topography and are mainly built up of mafic intrusives ('Oslo-essexites').

Because of their location and special rock-types the islands show a rather unusual fauna and flora with a varied population of both seabirds and landbirds and many rare flowers and trees (e.g. Viscum album; misteltein). The island Tofteholmen next to Ramvikholmen was one of the first places in Norway to be protected by law (1919) on account of its general public and scientific significance.

The different types of mafic intrusives at Ramvikholmen show great petrographic variety (Fig. 15). Different layering structures and cumulate rocks are well preserved. Excellent exposures along the southwestern shore exhibit

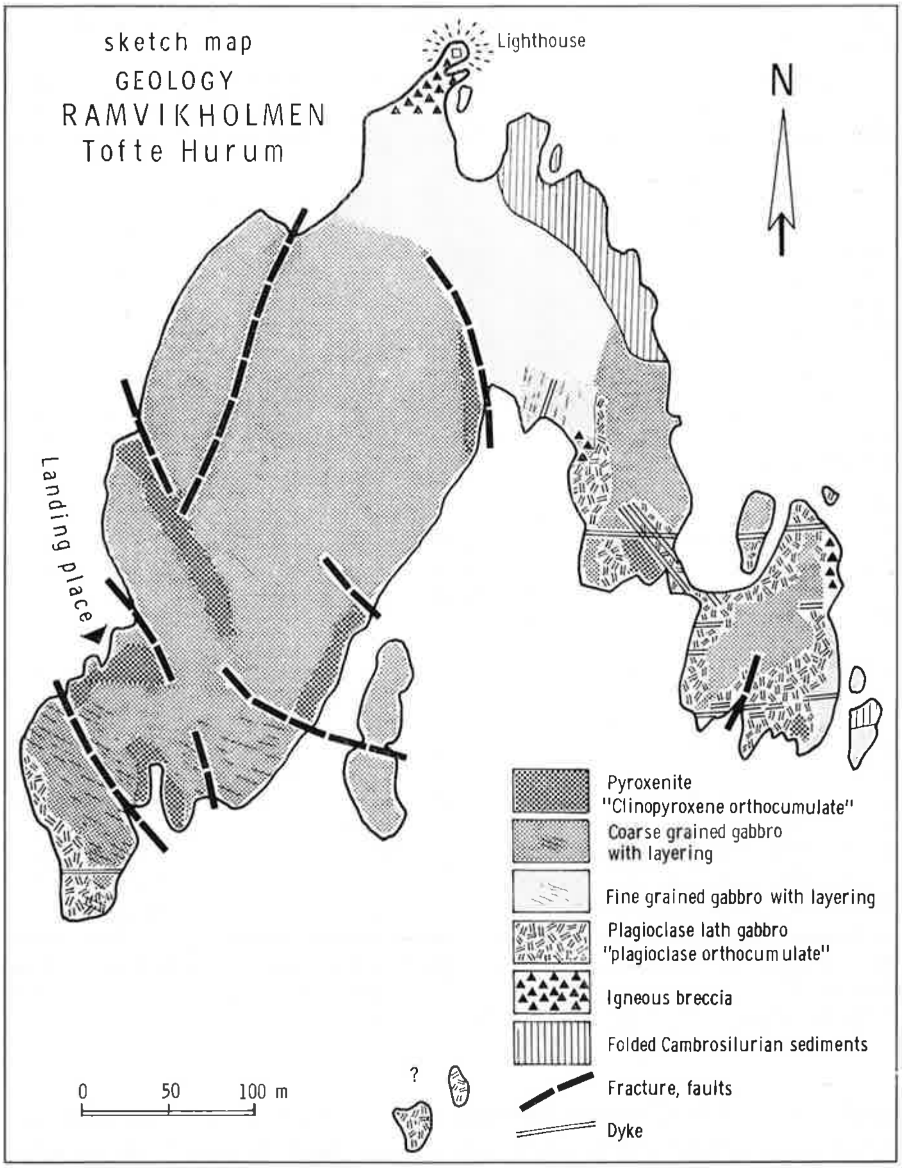


Fig. 15. Geology of Ramvikholmen; partly after Brøgger (1931).

many structural features and contact relations. A small segment in the north consists of contact-metamorphosed, folded Silurian sediments.

The mafic igneous rocks of the island can be roughly divided into four types: Medium-grained (1–2 mm) gabbroic rocks, coarse-grained (3–6 mm) gabbroic rocks (both leuco-gabbros), pyroxenite (often containing 10mm-long cpx crystals) and plagioclase gabbro with (often >10 mm) platy plagioclase laths. The two first, which predominate (Figs. 4, 5a, b), commonly show a pronounced, steep rhythmic layering. The pyroxenite and the plagioclase-

Table 1. Chemical analyses and katanorm calculations of Ramvikholmen/Tofteholmen mafic intrusion area (From Brøgger 1933). Calculated on CO_2- and H_2O-free basis

	RA 1	RA 2	RA 3	RA 4	RA 5	RA 6	RA 7	VE 1	TO 1	TO 2	TO 3	TO 4	TO 5
SiO_2	46.80	49.60	50.00	48.54	50.07	46.00	16.50	59.85	47.90	48.37	51.95	56.97	42.72
TiO_2	2.78	3.00	2.88	2.02	1.92	2.20	11.86	1.61	1.91	3.11	2.30	1.19	5.37
Al_2O_3	11.60	12.95	13.50	12.94	18.47	5.83	3.41	15.88	16.55	15.45	15.00	18.40	7.82
Fe_2O_3	4.27	3.48	3.00	3.35	3.33	3.70	28.82	0.19	3.41	4.25	3.42	0.55	5.49
FeO	9.73	9.80	9.47	11.64	5.58	9.93	22.06	5.94	9.53	7.90	7.68	3.82	10.96
MnO	0.22	0.17	0.14	0.16	0.35	0.40	0.25	0.09	0.60	0.23	0.18	0.11	11.64
MgO	8.44	5.10	5.15	5.75	3.08	12.65	12.85	2.15	4.44	4.55	4.18	2.97	12.58
CaO	10.89	9.32	8.83	9.22	8.65	16.35	0.99	4.46	9.35	9.55	6.98	8.68	1.63
Na_2O	2.61	3.25	3.05	3.62	4.03	1.80	0.09	2.87	3.23	3.31	4.17	3.20	0.39
K_2O	1.30	2.25	2.37	1.74	2.77	0.50	0.01	5.95	2.08	1.67	2.68	3.79	0.21
P_2O_5	0.31	0.01	0.01	0.45	2.20	0.01	0.01	0.04	0.32	0.73	0.51	0.28	0.00
	98.95	98.93	98.40	99.43	100.45	99.37	96.85	99.03	99.32	99.12	99.05	99.96	98.81
KATANORM													
Q	–	–	–	–	–	–	–	5.56	–	–	–	5.81	4.44
C	–	–	–	–	–	–	1.93	–	–	–	–	–	4.67
OR	7.87	13.69	14.17	10.49	16.39	3.00	0.07	35.76	12.55	10.14	16.10	23.62	1.33
AB	22.71	28.64	28.31	27.55	36.24	3.34	0.97	26.22	24.79	30.53	38.09	30.31	3.76
AN	16.51	14.53	16.70	14.22	24.18	6.45	5.80	13.11	25.06	22.99	14.55	11.62	8.67
NE	0.79	0.85	–	3.38	–	7.83	–	–	2.90	–	–	–	–
HY	–	–	4.05	–	3.25	–	18.44	9.48	–	6.38	3.21	0.17	62.94
DI	29.44	26.41	22.81	23.58	3.52	60.60	–	7.31	16.15	16.63	13.82	25.50	–
OL	13.47	7.80	6.25	13.37	5.41	11.73	18.38	–	11.51	2.75	6.25	–	–
MT	4.57	3.75	3.24	3.57	3.49	3.92	31.69	0.20	3.64	4.56	3.64	0.61	6.15
HM	–	–	–	–	–	–	2.91	–	–	–	–	–	–
IL	3.97	4.31	4.15	2.87	2.68	3.11	19.78	2.28	2.72	4.45	3.26	1.75	8.03
AP	0.66	0.02	0.02	0.96	4.61	0.02	0.03	0.09	0.68	1.57	1.08	0.62	–
D.I.	31.37	43.18	42.78	41.42	52.63	14.17	1.04	67.54	40.24	40.67	54.19	59.74	9.53

Petrographic name/Brøgger's name: RA–1 gabbro/essexite gabbro. RA–2 gabbro/essexite gabbro, fine-grained. RA–3 gabbro/essexite gabbro, fine-grained. RA–4 gabbro/essexite gabbro. RA–5 gabbro/essexite, plagioclase laths. RA–6 pyroxenite/olivine yamaskite, coarse-grained. RA–7 cumberlandite/cumberlandite. VE–1 syenodiorite/hurumite, K-rich essexite. TO–1 gabbro/essexite gabbro. TO–2 gabbro/essexite gabbro (bronzite). TO–3 gabbro/essexite. TO–4 monzonite/akerite. TO–5 pyroxenite/maderite.

gabbro can be looked upon as orthocumulates of clinopyroxene and plagioclase, respectively. Trough and slumping structures can be recognized in the rhythmic layered parts (Fig. 4).

At Ramvikholmen a number of observations can be made concerning the relative age of the four types (Figs. 5a, b & 6). These indicate the following sequence:

Time ↑

Leuco-gabbro, medium-grained
Pyroxenite
Leuco-gabbro, coarse-grained
Plagiocase gabbro

Transitional types between the three 'youngest' rock-types can be found. The tentative scheme may further represent an oversimplification, since various observations seem to infer repeated intrusive cycles. In the breccia (Fig. 6), the medium-grained gabbro always forms the matrix, and the three other major rock-types are found as fragments, together with xenoliths of the medium-grained gabbro itself.

Chemical analyses (after Brøgger 1933) of the mafic rocks at Ramvikholmen, Tofteholmen and Vealøs are shown in Table 1. Most of the rocks are mildly alkaline in character except the Vealøs sample which is tholeiitic. This may represent a parallel to the Vestby gabbroic intrusions, with one tholeiitic and one alkaline neck (Ramberg 1970).

Gravity studies of the gabbroic necks (Ramberg 1976) indicate that most necks are rather shallow features with depths of the order of 1 km, probably representing subvolcanic magma chambers. The Ramvikholmen–Tofteholmen anomaly is highly uncertain since the gravity profile had to be based on only a few measurements made on the islands. The best estimate infers a possible depth of 1–2 km (in harmony with the geometry of the petrographically rather similar occurrences at Vestby).

The gabbroic rocks of the Ramvikholmen and neighbouring islands (centre of 'Der grosse Hurumvulkan' of Brøgger 1931, 1933) have commonly been associated with the first basalt (B_1) phase in the Oslo Region. This relation now seems more questionable. Investigations still in progress will hopefully help to solve this problem.

2. *Bileholmen – Nes, Jeløya*

Ringerike Sandstone (Fig. 8). Medium- to fine-grained, grey to reddish sandstone with fluviatile sedimentary structures: large-scale trough cross-bedding (channels, scour-and-fill), ripple marks, parting lineation, convolute bedding; palaeocurrent from NNW. Intraformational conglomerates with shale-flakes and rounded sandstone pellets are frequent. Extraformational conglomerates with scattered quartzite pebbles occur. The sandstone is cut by several basaltic dykes and sills. The surface of the sandstone often shows good examples of ice-erosion features.

3. *Tangen, northern Jeløya*

Disturbed sandstone (Fig. 9). Megabreccia often with huge fragments of sandstone (Ringerike type). Matrix consists of grey to reddish, fine-to medium-grained, relatively soft sandstone often with distinct flow structures around the fragments, several of which show plastic deformation. The fragments are normally imbricated or arranged in fold structures. The breccia formation can be followed from Bevøya in the north along the escarpment of Bjørneåsen and Rambergåsen to the farm 'Ramberg', where the sandstone and breccias are down-faulted below sea level. The formation lies with a slight discordance on undisturbed Ringerike Sandstone and is overlain by Permian basaltic tuffs, agglomerates and lava with a highly undulating lower contact, so that the thickness of the breccia formation varies from 1 to 40 m. The breccia carries, in addition to sandstone fragments, scattered fragments of a quartzite conglomerate (Kolsås type) in contact with or together with fragments of basaltic lava which can be referred to the lower part of the B_1 series on Jeløya.

Beds of tuff with volcanic bombs are seen to be undisturbed within the breccia with no sign of erosion on the upper contact. The breccia formation is therefore interpreted as representing a series of Permian debris flows deposited during the initial phase of volcanism. The undulating upper contact of the breccia is due partly to load, partly to palaeotopography.

4. Nebbeåsen, S of Ramberg bukta

The profile on the steep cliffs of Nebbeåsen shows a 300 m-thick sequence of volcanic breccias (Fig. 10) and agglomerates with two horizons of lava flows, 60 m and 20 m thick, respectively. The breccia sequence is built up of several, up to 5 m-thick beds, which in part could represent volcanic mudflows. The lava flows, hawaiitic in composition, often show pahoehoe toes 20 cm in diameter. The sequence represents the lowermost, explosive, part of the more than 1200 m-thick B_1 formation on Jeløya. The lower contact to the sandstone and megabreccia is below sea level. Over the breccia-agglomerate sequence follows another 300 m of hawaiitic lava, here again with pahoehoe toes well developed. The sequence dips 60° towards SE.

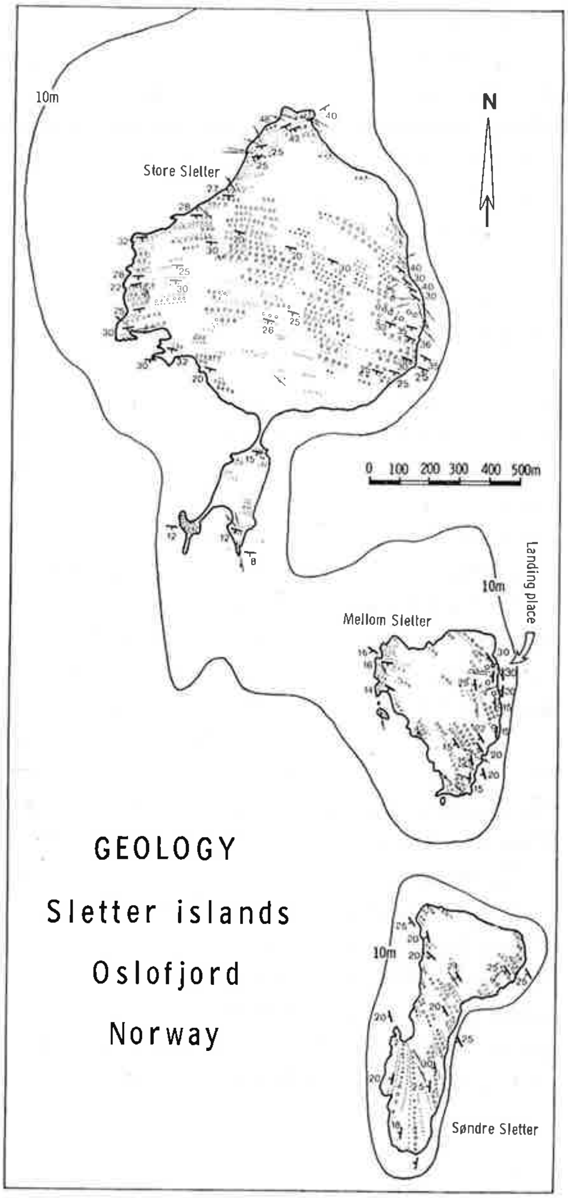
5. Gullholmen

Representative B_1 section starting with an agglomerate composed of hawaiitic augite porphyry bombs (up to 30 cm across) in a red sandy matrix. Over this agglomerate follows a spectacular plagioclase porphyry with a lower contact which shows signs of pillow structure and autobrecciation, indicating that the lava poured out over the sandy agglomerate while it was still wet. The thickness of the plagioclase porphyry flow (a mugearite in composition) is about 10 m and it is overlain by a 2–3 m-thick ignimbritic layer. This ignimbrite of trachytic composition, constitutes together with the plagioclase porphyry below an excellent marker horizon in the B_1 stratigraphy on Jeløya, where these two layers can be followed across the island almost to the east coast. Over the ignimbrite follows a typically hawaiitic B_1 lava series; some of the flows are up to 25 m in thickness and often show spectacular ropy pahoehoe surfaces (Fig. 11). Between the lava flows there is red sandstone, probably of aeolian origin and often containing volcanic bombs. The B_1 sequence of Gullholmen dips 30° towards SSW.

6. Rødåsen – Stalsberget

Contact between the B_1 and the RP series. The uppermost B_1, a basaltic augite-porphyry, is overlain by 0.5 m agglomerate with up to 5 cm augite-porphyry bombs in a red sandy matrix. The RP series on the southern part of Jeløya consists of several flows from 2 to 25 m thick. The flows are separated by agglomerates of about the same size as the flows and are composed of up to 25 cm RP bombs, in the lower part of the series developed as spatter and cow-dung bombs. The RP flows can be separated into two main types, a

Fig. 16. Sketch map of the geology of the Sletter islands. Partly after Størmer (1935). Possibly three separate alluvial fan wedges can be recognized. Fining of the conglomerate towards west. Landing on Mellom Sletter. Strike and dip of bedding plane and strike of joints marked. Also indicated 10 m depth contour.



phenocryst-rich (RP_1 type) and a type with rather scattered phenocrysts (RP_2 type). The latter type dominates in the upper part of the RP sequence on Jeløya but can also be seen in the lower part. Some of the RP flows show a tendency to tumulus structures on the pahoehoe surface. The RP sequence on southern Jeløya generally dips 30° towards SSW.

7. Mellom Sletter (Fig. 16)

Foot traverse along the east shore and across the island to the west shore. Rock-types: rhomb porphyry (RP) conglomerate (Figs. 12, 13 & 14).

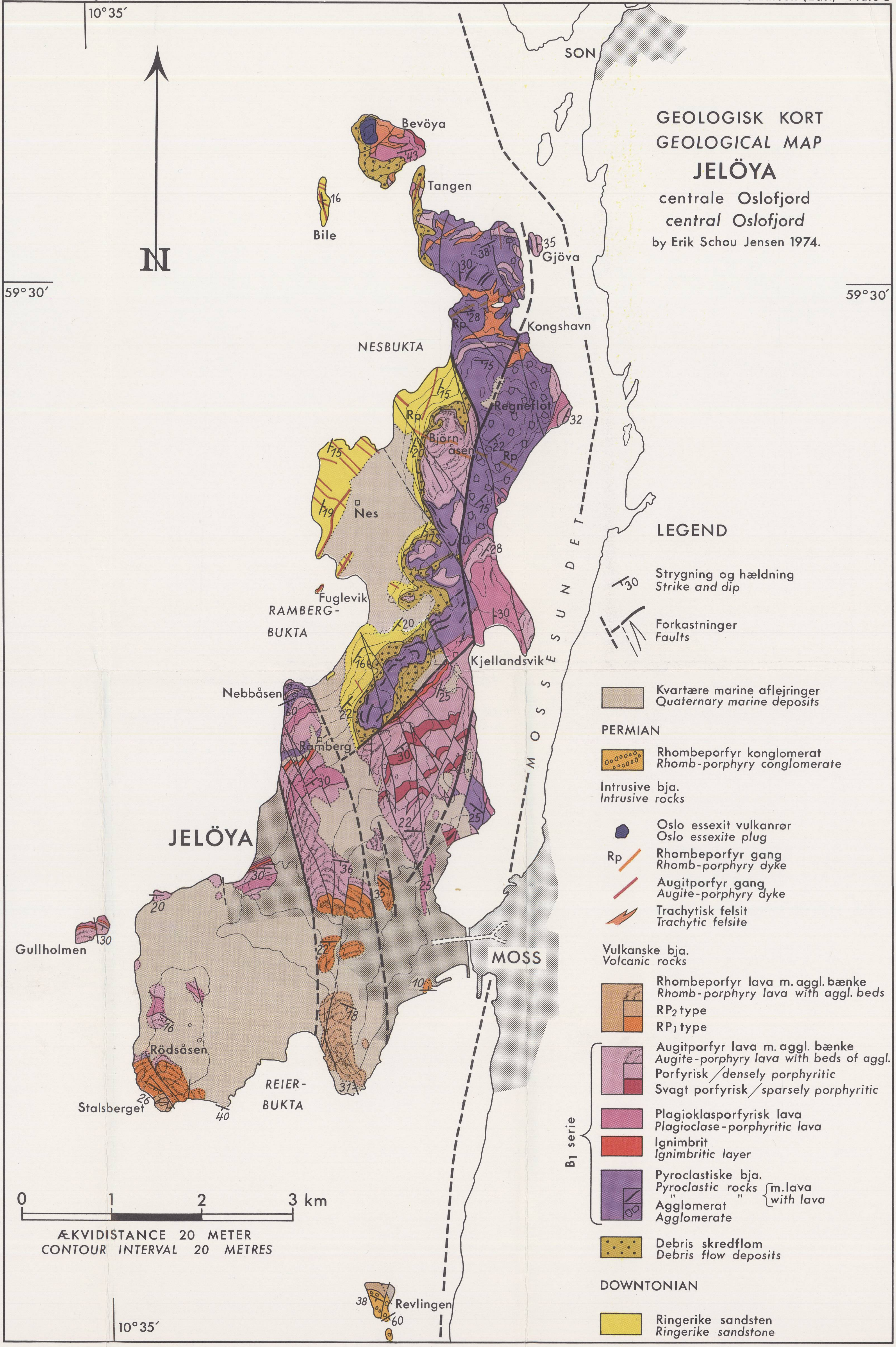
The characteristically flat Sletter islands are bush- and grass-covered with a rich, strand-type flora. The only permanent inhabitants are rabbits, but the islands (especially the southern tip of Store Sletter) serve as a nesting place for a large number of seabirds, for instance the eider duck; occasionally also a casting place for the endangered, small population of seal (Phoca vitulina) mostly living in the outer parts of the fjord. Several burial mounds are known on Store Sletter.

The three Sletter islands (Fig. 16) belong to a single tectonic block separated from similar units to the north and south by inferred NE-trending faults (Brøgger 1900, Størmer 1935). Within the 'Sletter block' the strike turns gradually from N–S on Søndre Sletter to WSW–ENE on the west side of Store Sletter. This is likely to represent a primary, depositional feature. Combined with an apparent strike convergence towards the west (and north) and observed dip values as read from Fig. 16, this phenomenon suggests an original thickening of the fanglomerate towards the east (and south). This assumption corresponds well with the marked decrease in coarseness of the conglomeratic beds from east to west as observed both on Store and Mellom Sletter.

The eastern shore of Mellom Sletter demonstrates well the sometimes extremely coarse and breccia-like deposits characteristic for these easternmost parts. Blocks up to 5 m across have been recorded. Quite unsorted beds with large boulders alternate with well-stratified finer beds, but no sandy or muddy layers occur on this side of the island. Various rhomb porphyry types predominate among the boulders and pebbles. However, a number of other rock-types such as basalts (several distinct types), Downtonian and Permian sandstone and Permian quartz conglomerate can be found at this locality.

The short trip (ca. 150 m) to the west shore of the island reveals that a distinct fining of the beds has taken place over this relatively short distance.

Post-depositional calcite-filled joints and minor faults are present all over the islands. Directions appear to be rather irregular, but NNW–SSE to W–E trends prevail. Where boulders are cut in two, the displacement (if any) along the common NW–SE trending faults, suggests an oblique faulting generally with a right-lateral strike-slip movement.



GEOLOGISK KORT
GEOLOGICAL MAP
JELÖYA

centrale Oslofjord
central Oslofjord
by Erik Schou Jensen 1974.

LEGEND

30 Strygning og hældning
Strike and dip

Forkastninger
Faults

Kvartære marine aflejringer
Quaternary marine deposits

PERMIAN

Rhombeporfyr konglomerat
Rhomb-porphyry conglomerate

Intrusive bja.
Intrusive rocks

Oslo essexit vulkanrør
Oslo essexite plug

Rp Rhombeporfyr gang
Rhomb-porphyry dyke

Augitporfyr gang
Augite-porphyry dyke

Trachytisk felsit
Trachytic felsite

Vulkanske bja.
Volcanic rocks

Rhombeporfyr lava m. aggl. bænke
Rhomb-porphyry lava with aggl. beds
RP$_2$ type
RP$_1$ type

B$_1$ serie

Augitporfyr lava m. aggl. bænke
Augite-porphyry lava with beds of aggl.
Porfyrisk / *densely porphyritic*
Svagt porfyrisk / *sparsely porphyritic*

Plagioklasporfyrisk lava
Plagioclase-porphyritic lava

Ignimbrit
Ignimbritic layer

Pyroclastiske bja.
Pyroclastic rocks { m. lava
" " { *with lava*
Agglomerat
Agglomerate

Debris skredflom
Debris flow deposits

DOWNTONIAN

Ringerike sandsten
Ringerike sandstone

ÆKVIDISTANCE 20 METER
CONTOUR INTERVAL 20 METRES