Echo-soundings in the Skagerrak.

With remarks on the geomorphology.

By

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With 1 plate and 7 text-figures.

Introduction.

In a paper of 1956, published in "Geotektonisches Symposium zu Ehren von Hans Stille", the writer has briefly (pp. 59–60) mentioned Norwegian echo-sounding work carried out during the years 1953–55 and also reproduced two bottom-profiles across the Norwegian Channel from the Norwegian coast towards northern Jutland (cf. also Geology of Norway, N.G.U. 208, p. 354, 1960). In the said paper attention was drawn to the investigations by the Deutsches Hydrographisches Institut 1950–52 and especially to the very important paper of 1952 "Zur Geologie der norwegischen Rinne" by the late Dr. Otto Pratje, an authority on submarine geology.

In the present publication a more general account of the Norwegian work, with reproduction of a considerable number of sounding profiles will be given. The work was started[1] in order to provide supplementary data concerning the submarine relief of the area shown in No. VII (the most southern one) of the series of coloured bathymetrical maps of the writer's publication of 1940, "The submarine relief off the Norwegian coast». To begin with the work was concentrated in the northernmost part of the Skagerrak area where amongst others, we have the interesting trenches outside the Langesundsfjord and the Hvaler Islands. Soundings were carried out here in 1953 by M/S "Gunnar Knudsen", research vessel of Institutt for marin biologi, section A, of the University of Oslo, director Prof. J. T. Ruud. The Captain was the late H. Høium while

[1] The writer was at that time not aware of the German investigations mentioned.

O. Dragesund (now fishery biologist at Fiskeridirektoratets forskningsinstitutt, Bergen) assisted with the soundings and worked out the data for the present publication. A few extra profiles were also taken outside Jomfruland, an island built up of the "Ra"-moraine.

During the following years 1954–56 soundings, mainly along NW–SE lines, were carried out over a quite large area of the Skagerrak by M/S "G. M. Dannevig", research vessel of Statens biologiske stasjon, Flødevigen, near Arendal, director the late Dr. Alf Dannevig, and from 1957 Dr. Gunnar Dannevig. Some supplementary sections were taken 1960. In charge of the soundings was Captain, G. Terjesen, who also has been helpful with later work. Positions, when far from land, were determined with a Decca-outfit and based on the Danish Decca lattice chart "Skagerrak".

Some Scandinavian passenger ships have, on request, in 1956, kindly provided echograms from the area here dealt with. In the western part of pl. 1 there is shown a profile, parallel to the Norwegian coast, based on an echogram taken by M/S "Blenheim", Fred. Olsen & Co., Oslo, and in fig. 5 a profile drawn after material from M/S "Bretagne" of the same Company, is reproduced. In the eastern Skagerrak area we see in pl. 1 two profiles drawn from echograms taken by ships belonging to Det Forenede Dampskibs-Selskab, Copenhagen, the western profile by M/S "Vistula", (Oslo–Frederikshavn), the eastern one by M/S "Kronprins Olav", (Oslo–Copenhagen). Fig. 7 is taken from an echogram provided 1958 by the same Company's "Prinsesse Margrethe".

A number of persons have assisted in the preparation of the illustrations, especially Mrs. Kari Utheim Riis (main map of pl. 1), Mrs. Nussa Bø, and Mrs. Kirsten Gran.

Economic support to the soundings as well as to the later work has been given by Norges Almenvitenskapelige Forskningsråd.

To all institutions and persons the writer's thanks are due.

Notes on the sounding profiles.

Starting from the southwest we distinguish in profile 10 (pl. 1 and fig. 1–2) the three main units: 1. a relatively steep slope, leading from the rugged Precambrian coastal area of Norway down to about 500 m; 2. the central, deep part of the Norwegian Channel with a smooth and even bottom showing a slight inclination towards the Norwegian side; 3. the slope on the Danish side with a distinctly convex curve, flattening towards the shallow sea off Jutland, the even bottom here telling of unconsolidated sediments. A slight depression (at about 390 m) separates units 2 and 3 and a very slight break in the curve of the southeastern side occurs at about 330 m.

Profiles 9–8 are rather similar to 10, yet with some differing features. The Norwegian "land-slope" is steeper, with maximum declivity about 6°. The central deep has a slight elevation (represented by the oblong area off the Kristiansand district in the contour line map of pl. 1). In 9 the transition from the central deep to the south-eastern slope starts at about 410 m, with a more marked break in the curve at about 350 m. In 8 there is a quite marked depression, with maximum depth at 495 m, between units 2 and 3 and then several breaks in the convexity of the curve (at about 370 and 320). A rather striking feature is the series of marked incisions in the distinctly convex part of the curve at higher levels.

In profiles 7–5 and northwards, cf. also profiles I–VI of fig. 3, a new topographic element comes in on the Norwegian side. It is well marked in the 1940 coloured map, and in the contour map of pl. 1, and will be termed the "foreland block". It is, especially in the southwestern part, more or less distinctly separated from the Norwegian coastal slope element by a depression, and has (for a considerable distance SW–NE) a remarkable flatness, with a depth of about 400 m, as already pointed out by Pratje. In detail the surface is rather uneven. A steep slope, in profiles 7–6 about 250 m high and striking SW–NE, leads down to the central depth.

As to the more south-eastern part of profile 7 (cf. also SE part of VI) it resembles number 10 very strongly, although the north-western end of the convex part of the curve is more marked and situated at greater depth (470 m, not very different from the depth of the main, lower break of profile 8). In profile 6 conditions are somewhat different, the central deepest part is more irregular, and there is a marked concace bend bordering the rising southeastern part. Furthermore we have, higher up, a slight concavity in the curve. Still higher there is again a marked convexity and here we have (as in 8) a series of well marked incisions (cf. also Pratje's section III). The greatest depths of these incisions are of the order 10–20 m.

Profile 6 leads over to morphological features which become more and more accentuated as we pass northwards: first, as in profiles 5 and I, a steplike rise southeast of the greatest depth, and then, profile 4, a quite steep and high slope (150–160 m) with above a nearly flat curve which

Fig. 1. Positions of profiles seen in fig. 2 (full drawn lines), in fig. 3–4 (–·– 1955–56, – – –1960), and fig. 5 (. . . . and –· · ·–). Cf. also main map, pl. 1.

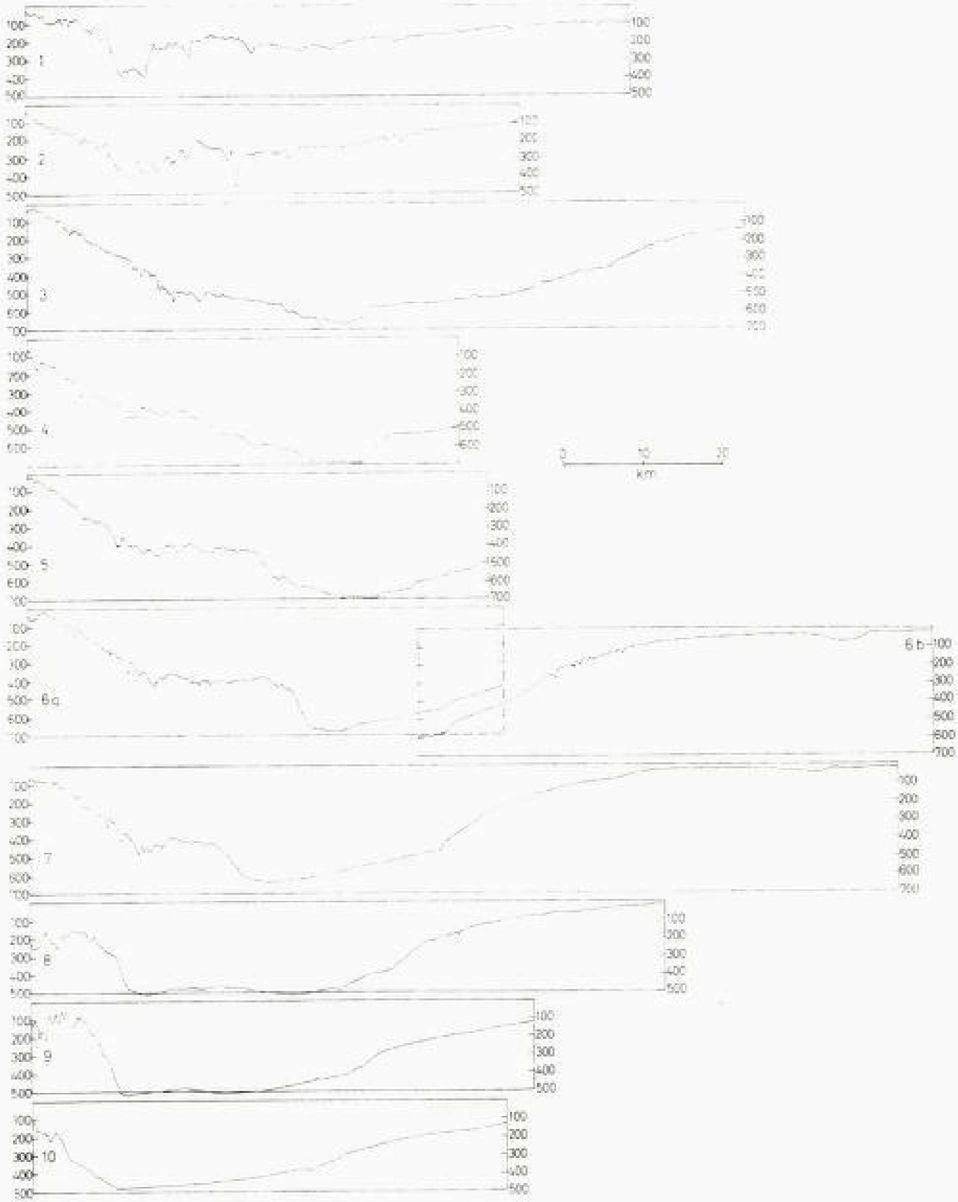


Fig. 2. Profiles based on echograms (with Hughes sounder) taken by "G. M. Dannevig" 1954.

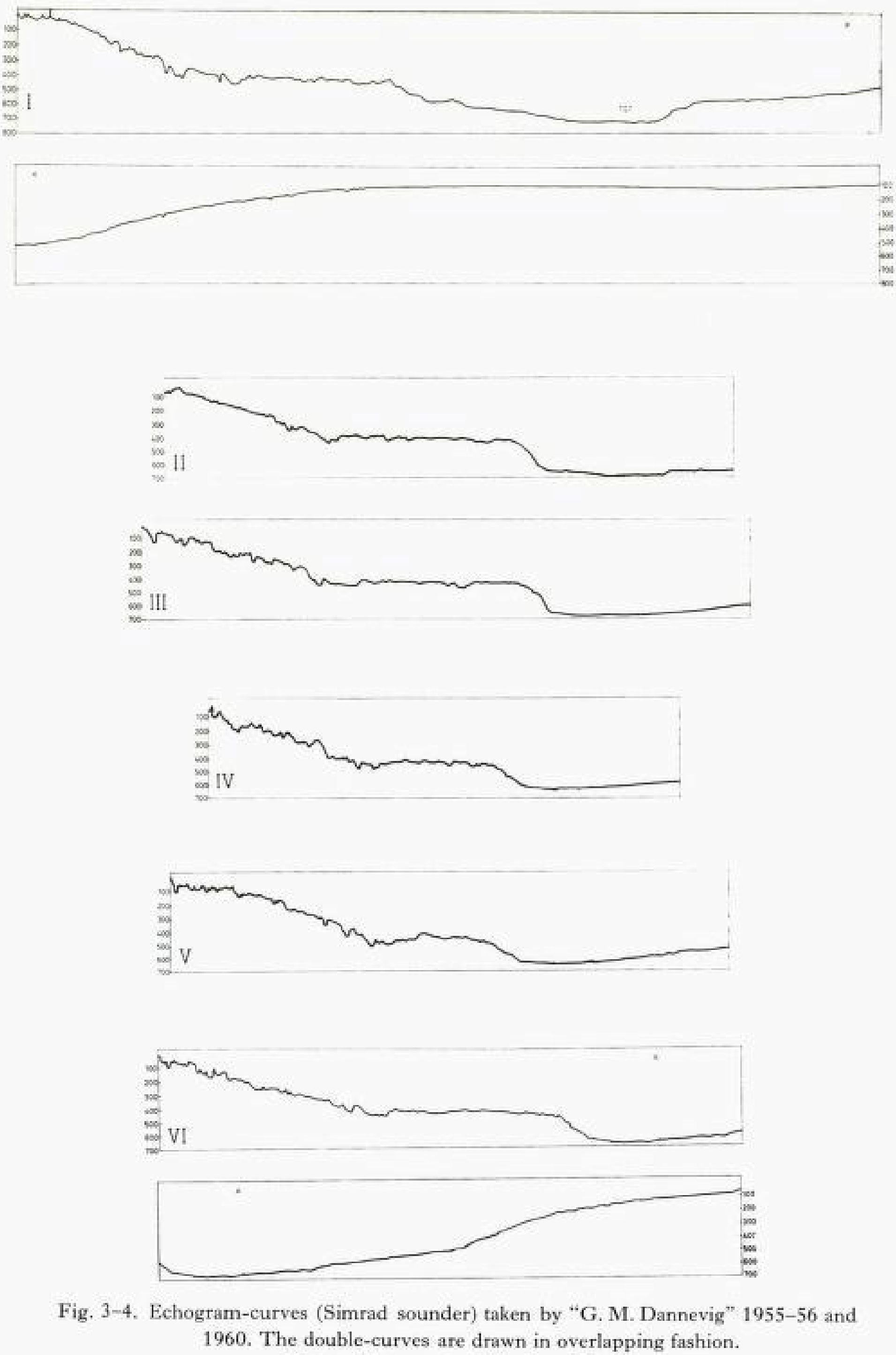
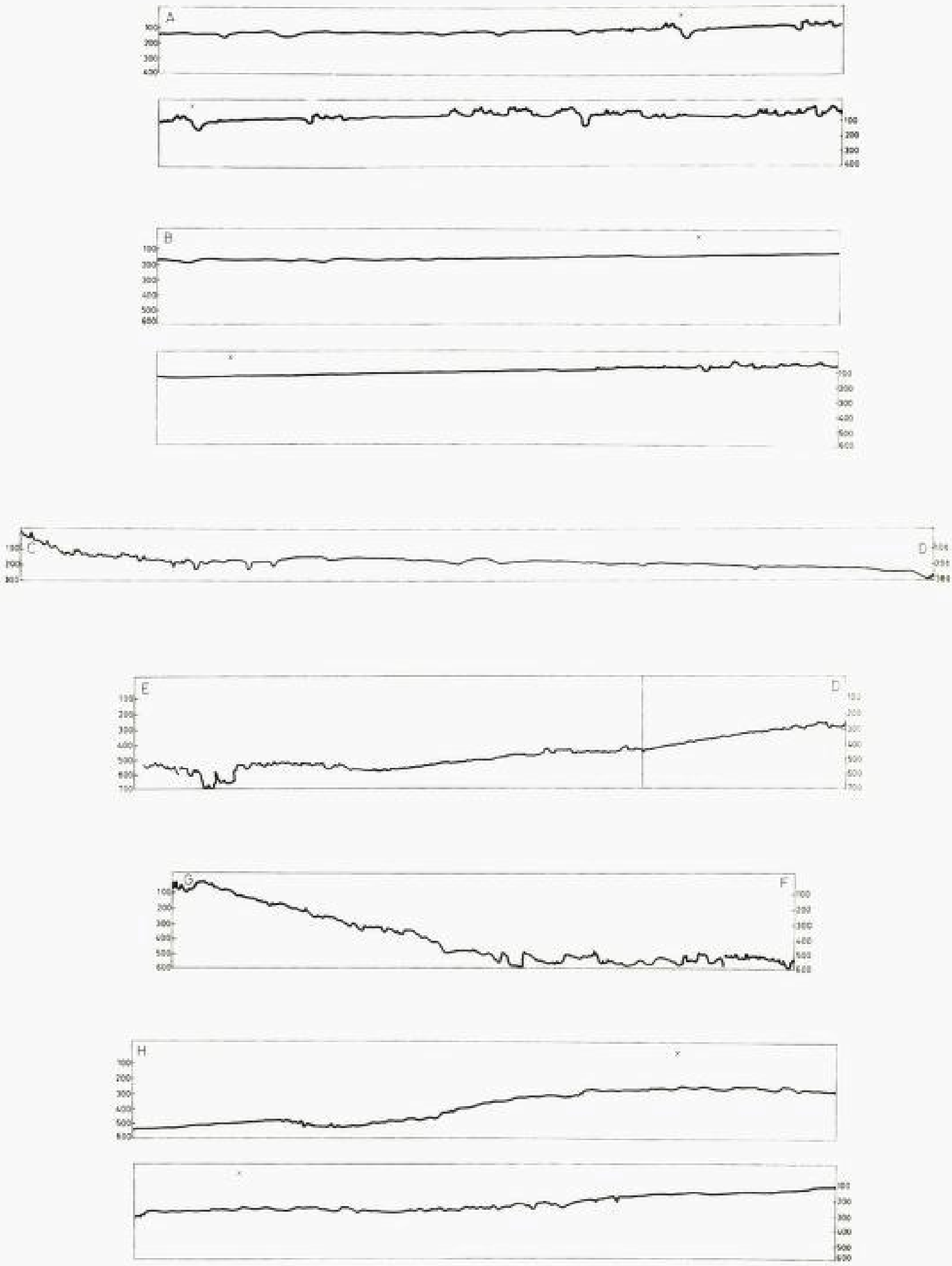


Fig. 3–4. Echogram-curves (Simrad sounder) taken by "G. M. Dannevig" 1955–56 and 1960. The double-curves are drawn in overlapping fashion. For positions see text-fig. 1 and pl. 1.


A
B
C
D
E
D
G
F
H

after a very gentle concave rise passes into a convex one (cp profile I).

Another change, started already in 5, is this that the "foreland-block" has no longer such a steep south-eastern declivity as further south. In profile 4 we see an irregular slope. A quite distinct depression occurs in a position corresponding to the boundary "land-slope" – "foreland block" of more southern sections.

In profile 3 we have also a very marked southeastern margin of the central depth, which in its western part shows a narrow depression with bottom at 690 m. In the eastern part the curve has much the same character as in profile I. It should be mentioned that at about 360 m there is in profile 3 a quite distinct, shelf-like break in the general trend of the curve.

Profile H is the first one that crosses the northeastern, «Swedish", slope of the main Norwegian Channel depression and it is seen to be largely characterized by much small-scale unevenness except especially near to land where no doubt the bottom is made up of loose deposits. Of interest is that the surface in some places (the central part of the upper curve in fig. 4) seems to drop stepwise towards deeper water (cf. x–y profile of fig. 5). The convexity to the extreme left corresponds to the slight elevation (cf. contour map) which stretches northwards in the eastern part of the main depression (in direction south from Larvik).

In the right hand part of profile E–D we have another section of a part of the eastern slope of the main basin, showing a rather even grade, yet with a good deal of small irregularities. The remaining part of profile E–D gives together with profile G–F a more northerly section of the central part of the main depression, rather different from that of profile 3. In E–D we see to the left a very rugged surface at a level of about 500 m, and cut sharply by two narrow incisions, the deeper one with a bottom at 680 m. In profile G–F we see the same very irregular type of surface with, in the right-hand part of it, small elevations rising to about 500 m. To the left we find, as was to be expected, features reminiscent of those seen in profile 3.

From the still more northerly part of our area there exist some profiles which are only to be seen in pl. 1. There are two curves between those last mentioned (G–F, E–D) and profile 2. They are characterized by having a very rugged character in the middle and western part. It is furthermore typical that we now have indications of a somewhat elevated area, bordered to the west by a rather broad depression, to the east by more sharply cut incisions. The echograms here are not quite complete for the eastern incision. The depth for the southern profile exceeds 610 m, for the northern one 500 (in the Norwegian charts the figure 550 is marked in a corresponding position).

In the very interesting profile 2 conditions appear very accentuated; in the western part there is a deep and broad depression, with a very irregular bottom section; further east a section of a relatively very deep and narrow submarine trench (well marked in the 1940 map) is situated, about south of Larvik and east of the Risør–Lyngør coast. The said echogram shows the bottom at about 460 m while the depths on both sides are about 250. The depth of the trench itself thus is about 200 m, the width at the top being about 1,5 km. Under the assumption that both sides are of equal steepness the gradients will be about 15°.

The profile of pl. 1 a little further north shows a section of a more proximal (northern) part of the same submarine trench. The depth is here 365 m, the adjoining seabottom at 250 m.

Profile 1 is dominated by the composite depression in the western part, with the maximum depth below sea-level about 400 m and 2–300 m below the adjacent sea-bottom. We notice (see above) how the depression under consideration becomes less marked southwards although it increases in depth. It seems to disappear more or less at about 450 m while to the north it continues, with an angular trend to the Langesundsfjord. Very interesting is the unsymmetrical cross sections seen in some of the sections in pl. 1.

East of the *Langesund Channel*, as it might be termed, we have the elevated area mentioned before (the southern part of it bounded to the east by the narrow submarine trench of profile 2 in pl. 1). Also further north an eastern border is well marked in the W–E profile, by a shallow channel with a somewhat curved trend, which evidently leads into the Larviksfjord incision. In profile 1 we cut this border channel rather far to the south (the most eastern one of the two smaller depressions of that section). Regarding the district further north, corresponding features are seen in profiles a and b in fig. 5.

We now turn to the more northeasterly part of our area. A very important profile is represented by the x–y curve, fig. 5, the greater part of it shown also in pl. 1. We notice how the bottom profile gradually bends down south-westwards with two quite distinct breaks, represented firstly by two very distinct depressions and secondly by what looks like relative displacements of rather regularly inclined parts of the curve, with drops to the southwest.

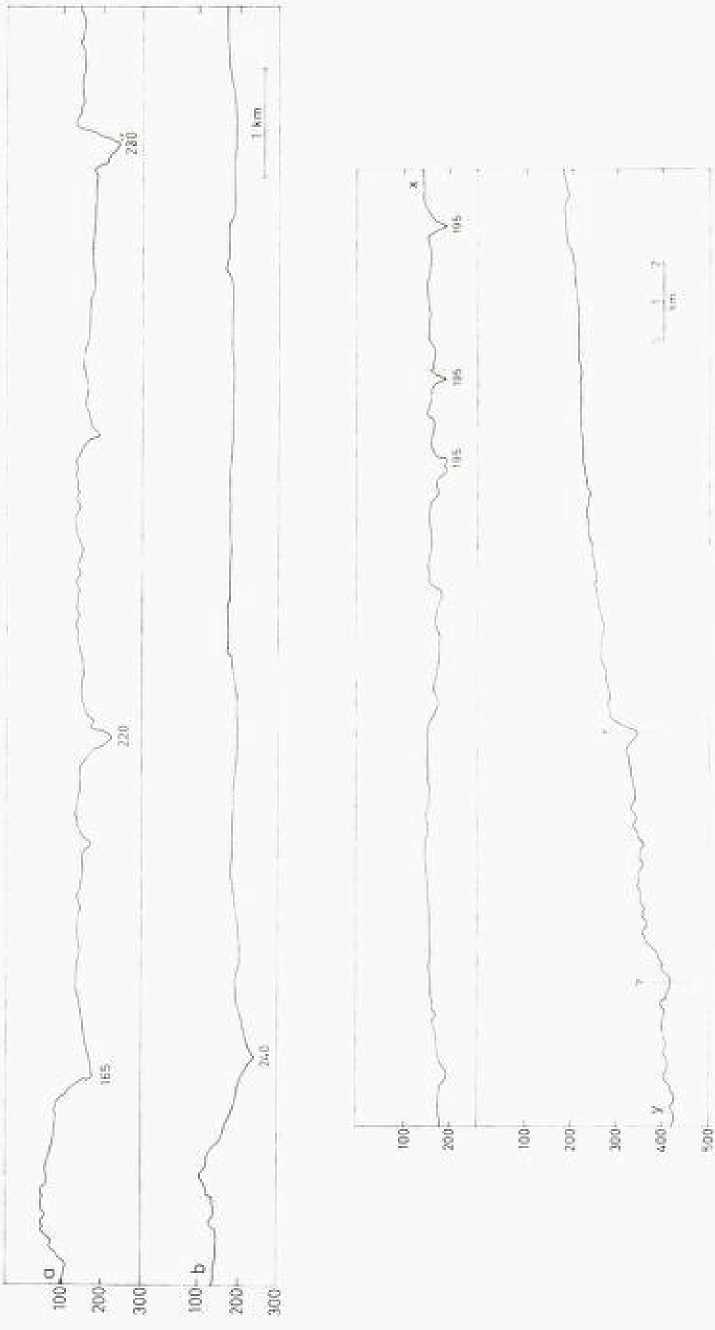


Fig. 5. Above, fragments of two curves ("G.M.D.", Simrad sounder, 1955), below profile based on (Hughes sounder) echogram taken by "Bretagne" 1956. Cf. fig. 1 and pl. 1.

The most marked submarine geomorphological feature in the extreme northeast of the Skagerrak area is the *Hvaler deep* (the term Ferder deep is also in use) stretching southwest and southwards from the Hvaler Islands, see contour map, pl. 1. The northern part of this depression is shown in pl. VI of a paper by L. Størmer (1935). A series of echograms (pl. I of the present paper), shows a deep and narrow shape in the northern part, a broader one in a more southerly one. The depression then decreases gradually in dimensions southwards and has, as shown also by longitudinal sections, a typical trough form. The profile starting at Ferder lighthouse and the next one, farther south, show sections also of the much smaller trough-like depression, marked in the 1940 map, running more a less parallel to the main channel and joining it further south.

As to the profiles from the farthest west and east of the area, the curve parallel to the Norwegian coast shows, as was to be expected, a very uneven character, especially in the more shallow parts, with no indication, however, of marked channels in NW–SE direction. Concerning the two long eastern curves, one point of interest in the western one (Ferder–Skagen) is the rather uneven character of the curve in the deeper part of it, possibly indicating locally exposed bed rock. We are here in the lower outer part of the Swedish Skagerrak slope (cf. parts of profile H in fig. 4). In a more northern district the curve under consideration has a more or less even character pointing to a cover of unconsolidated sediments. Outside the very shallow areas near land we evidently have such a cover over wide areas in the northeastern part of Skagerrak (cf. e.g. profiles A and B, fig. 4).

From one district only, near the Swedish Kattegat coast, echograms at hand have shown the bed rock surface *below the cover* (fig. 6). This probably indicates that the Quaternary deposits here are of an especially loose character.

In pl. 1 there is a particular map showing the result of soundings off the southeastern side of the *"Ra" island of Jomfruland,* taken because the charts seemed to indicate a low submarine ridge here, possibly representing an older end moraine; some of the profiles show a ridge-form quite well.

The local soundings in the *Kristiansand district* (pl. 1) does not show any very marked channel passing out to deep sea from the fjord basin in which quite big rivers come down. A feature of some interest is the nearly flat and very even longitudinal section of the fjord bottom, telling of a quite important accumulation of loose material here since the fjord became

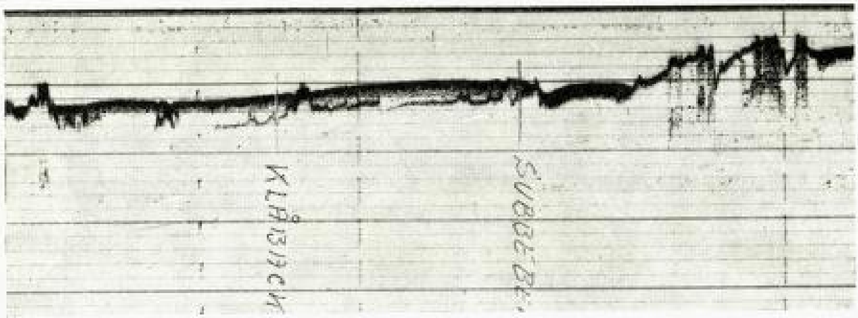


Fig. 6. Fragment of (Atlas) echogram showing especially in central part bed rock below loose cover, taken 1958 by "Prinsesse Margrethe" in the Kattegat near the Swedish coast, from Morups Tånge (spit) to the right (M. T. in pl. 1, map upper left corner), and northwards. Between the thick lines: 40 m.

ice-free. (Also in the *Frierfjord* basin inside Langesund (and Brevik) the central part seems, according to the charts, to have a relatively flat (sediment) bottom, here with depths of about 90 m.)

Some general remarks on the geomorphology.

Before geophysical and geological research work have provided data concerning the thickness and character of the unconsolidated deposits and the nature of the rock masses below them, the many problems regarding the geological structure and history of the Skagerrak submarine area cannot be definitely solved.

One main point, however, cannot be doubted, viz. that the deep – *Norwegian Channel* – part of the area represents a depression primarily of tectonic origin, and of a rather young age. That the Norwegian Channel has been originally formed through a subsidence of the crust has for over half a century been maintained by a number of scientists (cf. O. Holtedahl 1950, p. 494) though some writers (Shepard 1931, p. 352, and Kuenen 1950, p. 484–85), have classified it as just a glacial trough. The tectonic concept has now been strongly supported by O. Pratje in his previously mentioned paper of 1952, based on the German sounding sections, "Aus den Schnitten geht deutlich hervor, dass die Norwegische Rinne tektonischen Ursprungs ist, und dass sie kaum glazial ausgeräumt sein kann" (pp. 85, 87).

In the present writer's general (small scale) map of the 1940 paper, fault lines ("Inferred fault lines of Cainozoic age") have been indicated or suggested both on the Norwegian, Swedish and Danish side of the Norwegian Channel deep. We shall first deal with the Norwegian side. Here one line has (in the said map) been drawn along the steep coastal slope of the Mandal–Kristiansand–Lillesand area with suggested continuation towards the SW–NE trending part of the Langesund channel. Further out at sea a fault line was indicated on the outer margin of what has in the description above been termed the "foreland block", the SW–NE direction of this line pointing towards the deep and narrow trench in the slope south of the Larvik district.

From the profiles one gets the impression that the "foreland block" is made up of the same hard material as the land slope passing into the ice-scoured Precambrian crystalline territory of "Sørlandet", even if its surface in some places show a less rugged character. In pl. 1 (the main map) a simplified and somewhat generalized section of the land surface from Tromøya and northwestwards has been shown and it is seen that is even more broken than the slope sections below the sea. Here, as in the flat rocky area further out, sedimentation may to some extent have filled out the depressions. The general grade of the surface on land (as based on the summit heights) is distinctly smaller than that out at sea in the same district.[1]

As regards the "foreland block" with its remarkable flatness over a large area, Pratje has explained it as the remains of a "Rinnenboden", a channel bottom, of once greater extension (see later). Another possibility which is based on the existence of longitudinal depressions between the land slope and the "block" (with continuation in the Langesund channel), is that we have before us a subsided peripheral Precambrian mass with a peneplane character still largely preserved (in horizontal position) and separated from the land block inside it by a fault.

As to the central, deepest part of the southern parts of the map area the smooth and practically horizontal surface (if drawn in correct horizontal–vertical relation) indicates a filling up with loose sediments. Concerning the slope on the Danish side, the geomorphology is here totally different from that met with to the northwest, and very difficult to explain. The markedly convex surface, seen in cross section, is one puzzling feature. In the paper of 1956 (p. 60) the writer suggested as a

[1] From the region from Tromøya westwards, 100 m-contour lines showing the general, very moderate, slope of the land surface towards the coast, are drawn in pl. 2 of B. G. Andersen's paper "Sørlandet" (1960).

possibility "eine flexurartige Verbiegung". However, bearing in mind that the thickness of the Quaternary deposits at Skagen (Gregersen and Sorgenfrei 1951, plate) is found to be about 220 m (here resting on lower Cretaceous rocks), and that great thicknesses of loose deposits probably exist also in the submarine district off the Jutland coast further to the SW, it may not seem very probable that the present submarine surface has been shaped mainly through tectonic causes. On the other hand it is not easy to explain the geomorphology just on the basis of exogenic processes: accumulation or/and erosion. The way in which the convex surface, with increasing steepness, borders the practically flat bottom of the greatest depth, with in several cases a little depression in between, is a rather striking feature.

There are as mentioned above, p. 145, in the southern profiles (7–10) some small breaks in the surface especially at levels of between 300 and 400 m, and one might suggest the idea of abrasion having cut into the slope during a much lower relative level of the sea. However, in profile 7 the convex curve goes down to about 475 m and in profile 6 (a–b) the border zone between the fairly flat central part and the marked slope to the southeast is situated at about 560–570 m.

Rather surprising features to be taken up by future detailed studies are the incisions seen in several profiles just in the most strongly curved parts of the curve. They cannot well be explained as due to slides, and still less to river erosion.

As described in more detail above, the character of the surface changes quite rapidly further northwards, a main feature being a more or less steep and high slope bordering the deep central depression on its southeast side. At the same time we have now at higher level (about 550 m), a broad area of relatively flat sea-bottom, especially on the east side (cp. e.g. profile 3). Pratje (p. 85) assumes here a second, inner, zone of tectonic subsidence. "Diesen Teil der Rinne möchte ich als Schachtelgraben bezeichnen, wo ähnlich wie beim Roten Meer im grossen hier im kleinen in einer Grabenzone eine zweite eingeschaltet ist". Pratje regards the said flat area on the east side with depth about 550 m, as a part of an older channel bottom which seems a rather natural conclusion. That we have here a parallel to the distinctly higher, flat surface of the "foreland block" on the Norwegian side may be less probable.

The "inner depression" now mentioned leads northwards, through an area of very irregular, broken topography (formed by selective ice erosion in more or less hard rocks?), to the relatively deep and narrow trench seen especially well in profile 2. This trench has probably been cut by erosion along a fracture line connected with fault lines in more southwesterly districts.

There may not be any quite clear connection between the said narrow trench and the much more open and shallow one further north (fig. 5, a and b) which here borders, to the east, the elevated area stretching as a submarine projection southwards from the peninsula between Larviksfjord and Langesundsfjord. However, it seems as we here too are dealing with a structural line, responsible also for the incision of the Larviksfjord. The gradient of this shallow trench is very small and to the east of it we have a fairly flat area with depths between 200 and 300 m (cf. eastern part of profile b), a sort of submarine platform, in the southern part of which the deep narrow trench starts rather abruptly. We observe how in profile a there are two depressions (cross sections of trenches ?) which cut down to 220–230 m and which are not represented in profile b.

A most interesting profile is x–y, showing the northeastern slope of the main basin somewhat east of the deep trench. We might imagine an even land (peneplane) surface bent and tilted southwestwards, with two marked breaks, each indicating a relative sinking on the seaward side.

Concerning the *general outline of the northernmost Skagerrak deep* it should be mentioned that the old rock structures may to some extent have had a guiding influence on the direction of the more recent crustal deformations. The slopes bordering on the main Norwegian Channel depression have a SW–NE, respectively a NNW–SSE, trend and these are also dominating directions for the Precambrian rocks on the adjacent land (cp. contour line map of pl. 1). Upper Paleozoic dykes (of rhomb porphyry and/or diabase) with corresponding trend are known from various parts of the coastal districts here under consideration.[1]

In addition, an interesting feature in this connection is the big SW–NE fault on Norwegian side (cp. small map in the upper left corner of pl. 1), active both in Precambrian and Permian time, with subsidence on the southeast side. In the Porsgrunn area the post-Silurian vertical displacement must be at least 500 m. Recently interesting gravimetrical data from the outer Sørland area pointing in the same direction have been provided by S. B. Smithson (1963).

A NW structural trend is, as is well known, represented in various

[1] The relation between dyke-fissures of the Swedish coastal district of Bohuslän and the assumed subsidence of the Skagerrak deep has been discussed by the late Swedish geologist E. Ljungner (1927, p. 249–50).

ways in the geology of southernmost Sweden, in Scania (cp. pl. 1), with faulting in this direction affecting rocks of *inter alia,* Cretaceous age. In Jutland the nearly flat-lying Mesozoic-Tertiary formations are arranged in belts with similar direction (thus here at right angles to the trend of the Danish Skagerrak slope).

The *Hvaler depth* must have been eroded along a SW-NE fault (or fault zones, Størmer 1935) separating the Oslo region of subsidence from the crystalline Precambrian to the south (Torbjørnskjær etc.). Landwards the depression joins at right angles the fault line trench of the east side of the Oslofjord and its southern continuation on Swedish side, but abuts to the northeast against the Hvaler islands. As previously pointed out by the writer, we have here a system of depressions, which in a small scale resembles the system: (large) transverse shelf channels – "marginal channels" in parts of northern Norway. A suggestion also put forward on previous occasions is that the Hvaler depth, where erosion must have been at work probably at an early date along the old Permian fault line, may mark the position of a peripheral part of a former larger Glomma river system, the original connection broken by a relative uplift of the land area to the east.

The Hvaler depth has a typical trough character and must once, probably together with the far less deep tributary trough to the west, have been occupied by ice. The markedly unsymmetrical character of especially a part of the trough fits well with the idea of glacial erosion, working with a broad base and especially strongly on the northwestern (outer) side of the curved depression. During the time of the last ice-retreat an (isolated) ice-tongue cannot well have existed in this depression since this would imply that the relative stand of the sea had been lower and not, as was the case, higher than at present. Possibly a particular glacier may have been active here during an early phase of last glaciation, the whole area being later covered by the inland ice.

Somewhat west of the southern part of the Hvaler glacial trough complex there is, according to the charts (cp. also 1940 map) a broad and shallow depression (depth mostly 170–180 m) with a southwestern trend, and broadening into the previously (p. 153) mentioned fairly flat area, with depths exceeding 200 m.

The northern part of the x–y profile (fig. 5) shows some particular bottom features in this general area. The problem is if the depressions seen (with depth 195 m) represent subaerially formed trenches, and if so, *when* they were formed. The same problems meet us in other profiles from the northeastern part of the Skagerrak area.

We now return to the *Langesund channel* which with increasing width goes down to well below 400 m (p. 147). Here again we find an unsymmetrical cross section, now in the opposite way, indicating a stronger erosion on the (outer) eastern side of the curved channel than on the other one. The longitudinal profile seems to be of an undulating character (see also 1940 map), and glacial erosion, along structural lines of weakness, would seem to be the natural explanation. The very uneven cross section of the bottom, as seen especially in profile 2, may be due to the existence of rocks of very different hardness striking parallel to the SW–NE trend of the outer part of the channel, in accordance with conditions on land.

It seems as if (glacial) erosion has been very powerful outside the Langesund–Kragerø coast. This may be due to various causes. We must assume that already at an early period erosion had dug deeply along the zone of eastward-tilted Cambro–Silurian sedimentary rocks situated between the hard Precambrian complex to the west and the still harder area of Oslo plutonics to the east (pl. 1). Furthermore there is a large upland drainage area with high, mountainous country not very far inland. The grade of the glacier bed has been relatively steep and the power of erosion correspondingly great.

Now, if glacial work has been of such importance in this submarine area one might have expected the ice masses from northeast, from the large Oslofjord–Glomma drainage district, to have cut farther into the sloping ground on the northeast side of the Norwegian Channel depression than seems to have been the case. One reason may be the main topographic difference that in the eastern district the high ground is situated very far away.

Pratje has assumed the Skagerrak dislocations to have started in early Tertiary time. As to the "inner" central depression, as seen e.g. in profiles 3–4, he regards it as an "overdeepening" possibly in connection with the uplift of the Scandinavian land mass in late Quaternary time ("Aufsteigen Skandinaviens seit der Eiszeit", p. 87). The fact that the depression has not been filled with sediments is, according to this writer, a proof of its young age. However, these structures, with SW–NE strike, cannot in any case have close relation to the isostatic uplift of Fennoscandia after the last glaciation. The isobases of this uplift have, as well known, a NW–SE direction in the adjacent parts of southern Scandinavia. As to sedimentation from relatively recent time, the uneven bottom of e.g. the Langesund Channel shows that even near the outlet of such a large drainage area the quantity of outwash material has not been very large.

The Norwegian Channel, passing for a length of about 900 km outside the south Norwegian land mass, has of course, been a topographic feature of the greatest importance for the distribution and direction of movement of the Quaternary ice masses. What has been well known for a long time is that especially in the lowland of Jæren in the far southwest of southern Norway (cf. lower left corner map of pl. 1), there occur huge quantities of moraine material characterized largely by rock material of eastern or southeastern origin: chert, chalk, Oslo and even central Swedish and Baltic rocks. This material (in the "Skagerrak moraine") is generally supposed to have been transported during the glaciation preceding the last one[1] (or possibly during an early phase of the last glaciation) by ice masses following more or less the Norwegian Channel depression. Off the Jæren lowland there is a marked shallowing up of the channel, with depths much less than 300 m.[2] The bottom then increases gradually in depth northwards till it exceeds 400 m near the continental slope. We get the impression of a very thick accumulation of unconsolidated material. This is a point of interest for a discussion of the nature of especially the *deep NNE-running trench* at the margin of the main depression south of the Larviksfjord, a trench distinctly marked down to 500 m. If we are here dealing with an incision cut *subaerially* (along a line of structural weakness), it must be of very considerable age.

Just north of northernmost Jutland there is a submarine trench, with direction WSW–ENE. It starts very gradually and shows a regular increase of depth eastwards till it joins the broad depression reaching southwards from the main Norwegian Channel. Some sections of this trench are shown in fig. 7. In the 1940 general map the writer tentatively indicated a structural line here. Now, as before stated, we know that the unconsolidated Quaternary deposits have a very great thickness in the Skagen area, and possible tectonic influences are scarcely visible in the present topographic picture. The most probable explanation would then be that we have here the result of submarine erosion caused by "longshore current" running eastwards.

Now it seems strange that the trench in its western part is situated

[1] A C-14 dating of shell from the moraine has given as a result: > 36000 years (cf. Geology of Norway. N.G.U. 208, p. 364, 1960).

[2] In the German "Fischereikarte der Nordsee, Nordblatt", published by Deutsches Hydrographisches Institut, Hamburg, there is marked an area of "Steiniger Grund" at depths of about 300 m in the central and western part of the Norwegian Channel off Southern Jæren, an interesting feature.

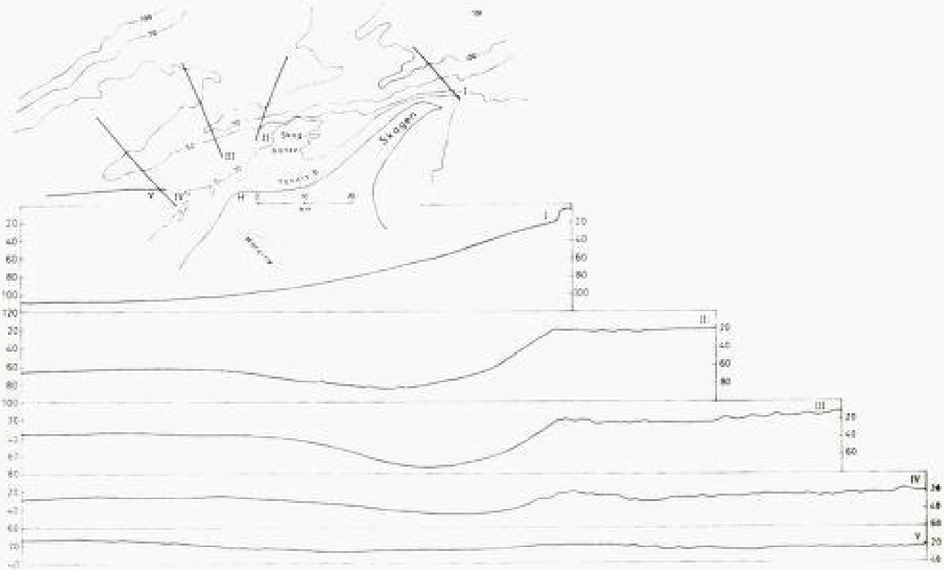


Fig. 7. Profiles (fragments of "G.M.D." profiles) off northernmost Jutland (H-Hirtshals) with submarine contour lines after Danish chart Skagerrak.

quite a distance from land while at Skagen it comes near to it. However, looking at the Danish charts we may find a reasonable explanation in the fact that between Hirtshals and Skagen there is a submarine elevation, the Skagbank, projecting towards the northeast. The shallow sea in these districts has evidently largely a moraine bottom. During my visit with "G. M. Dannevig" at Hirtshals in 1954 I observed "boulder fishing" going on: big boulders from the shallow bottom being hoisted up into small barges, for use on land. Now there is (V. Milthers, 1936) just inside Hirtshals a well marked moraine zone stretching southwards and representing a particular stage during the general retreat of the south Scandinavian inland ice of last glaciation (at a time when the shallow Kattegat basin was still ice-filled). We notice a northeasterly trend also for the land moraine in its most northern part, and there seems, perhaps, reason to believe that the Skagbanke-elevation is a continuation of the moraine on land and not just a sand bank laid up outside Tannis Bay? Such a projecting moraine would eventually to some degree resist the attack of waves and of current sweeping along the coast.

It seems at any rate possible that some of the submarine moraine material in the Hirtshals district has been transported from the east and not from the north. The suggestion by Pratje (1951, map p. 113) that the Norwegian Channel was ice-filled during the East Jutland stage of ice retreat is rather improbable.[1]

Concerning the *Norwegian Channel as a whole* it should be emphasized that this deep and narrow zone of depression cutting very far into the northwest-European land block, represents a very striking feature in the "face of the earth". Pratje in his discussion of the Channel depths has referred to features known from the Red-Sea, a sea-way of fault origin which also cuts through a continental block. One main point of difference is of course that the last mentioned depression (of quite other dimensions) represents but a part of a huge system of straight-lined fault zones. Typical of the Norwegian Channel is its curved character and the fact that it forms the border between a low and flat area on the outer side and a relatively high land, made up of older rocks, on the inner (Norwegian) one. We shall cite Pratje's words at the end of his publication of 1952: "Kurzum die Norwegische Rinne ist ein Randgraben im Schelf am aufsteigenden Skandinavien", yet make the reservation that the uplift under consideration probably has no close relation to the gravimetrical changes caused by the Quaternary ice masses.

As to the character at the subsidence, faults seem to have been characteristic of the inner (Norwegian) side of the depression, while flexures or tilting with, possibly, minor faults may have been dominating features of the outer one, including the slope at the upper end, off the Swedish coast.

Sammendrag.

Denne avhandling gir, først og fremst på plansjen og andre figurer, resultatet av ekko-lodninger som på foranledning av forfatteren, i tidsrommet 1953–60, er blitt utført i Skagerrak-området av en rekke fartøyer (se s. 139–140) til belysning av den submarine geomorfologi og i tilknytning til fremstillingen på blad VII av den i 1940 utgitte dybdekartserie. Tidligere, i årene 1950–52, hadde fartøyer fra Deutsches Hydrographisches Institut i Hamburg, foretatt systematiske ekko-lodninger i den sydlige og midtre del av området og en liten men viktig avhandling "Zur Geologie der norwegischen Rinne" var offentliggjort av den nå avdøde marin-geolog

[1] We shall not here enter into the problems connected with the occurrence of Norwegian (Oslo) rock material in northern Jutland but only refer to the important paper by K. Milthers (1942).

professor O. Pratje. Nærværende fremstilling supplerer og støtter i hovedsaken hans resultater.

En vesentlig del av Skagerrak opptas av den innerste del av *Den norske renne* der som en 900 km lang undersjøisk fordypning strekker seg fra kontinentalskråningen nordvest for Stad til ut for Kragerø. Man kan si at ekko-lodningene gir ytterligere støtte for den stort sett alminnelige antagelse at denne dyprenne representerer en innsynkningssone, av forholdsvis ung, rimeligvis tertiær alder. Mens, innen det her behandlede område, den undersjøiske topografi synes å angi markerte forkastninger utenfor norskekysten, er forholdene på Jylland-siden vanskelige å tolke og sikre data kan bare skaffes ved geofysiske undersøkelser over de løse massers tykkelse og den underliggende fjellgrunns karakter.

Lenger nordover smalner den sentrale dyprenne inn og vi får en steil østside (sannsynligvis forkastning), mens vestsiden blir jevnere. I fortsettelsen av den sentrale fordypning forekommer, etter et parti med sterkt uregelmessig relieff, en forholdsvis *smal og dyp renne* (bl. a. profil 2 på fig. 2) som må antas å være utgravd langs en bruddlinje. Avgrenset fra denne renne ved et ryggformet parti har vi lenger vest den brede forsenkning (*Langesundsrennen*) som, noenlunde parallelt kysten, fører nordover – sannsynligvis langs en sprekkesone, til den svinger inn mot Langesundsfjorden. I det sistnevnte strøk må sikkerlig erosjonen tidlig ha funnet vei ut mot havsenkningen idet vi her har hatt en NV-SØ-gående stripe med (løsere) kambro-silurbergarter mellom grunnfjellsbergarter i vest og Oslo-dyperuptiver i øst. Langesundsrennens form tyder på at her har foregått en sterk iserosjon.

Den skråning som avslutter Skagerraks hoveddyp mot nordøst er sannsynligvis oppstått ved en fleksur-bevegelse av landplaten, kanskje i forbindelse med mindre forkastninger, sml. profil x–y på fig. 5. I det forholdsvis grunne område langt i nordøst har vi *Hvaler-dypet* som iallfall i sin innerste del følger den NØ-strykende forkastning som skiller Oslofeltet fra grunnfjellsområdet utenfor Strømstadkysten lenger syd. Her har, rimeligvis etter en tidligere periode med elveerosjon, ismasser etterlatt seg en trau-formet fordypning.

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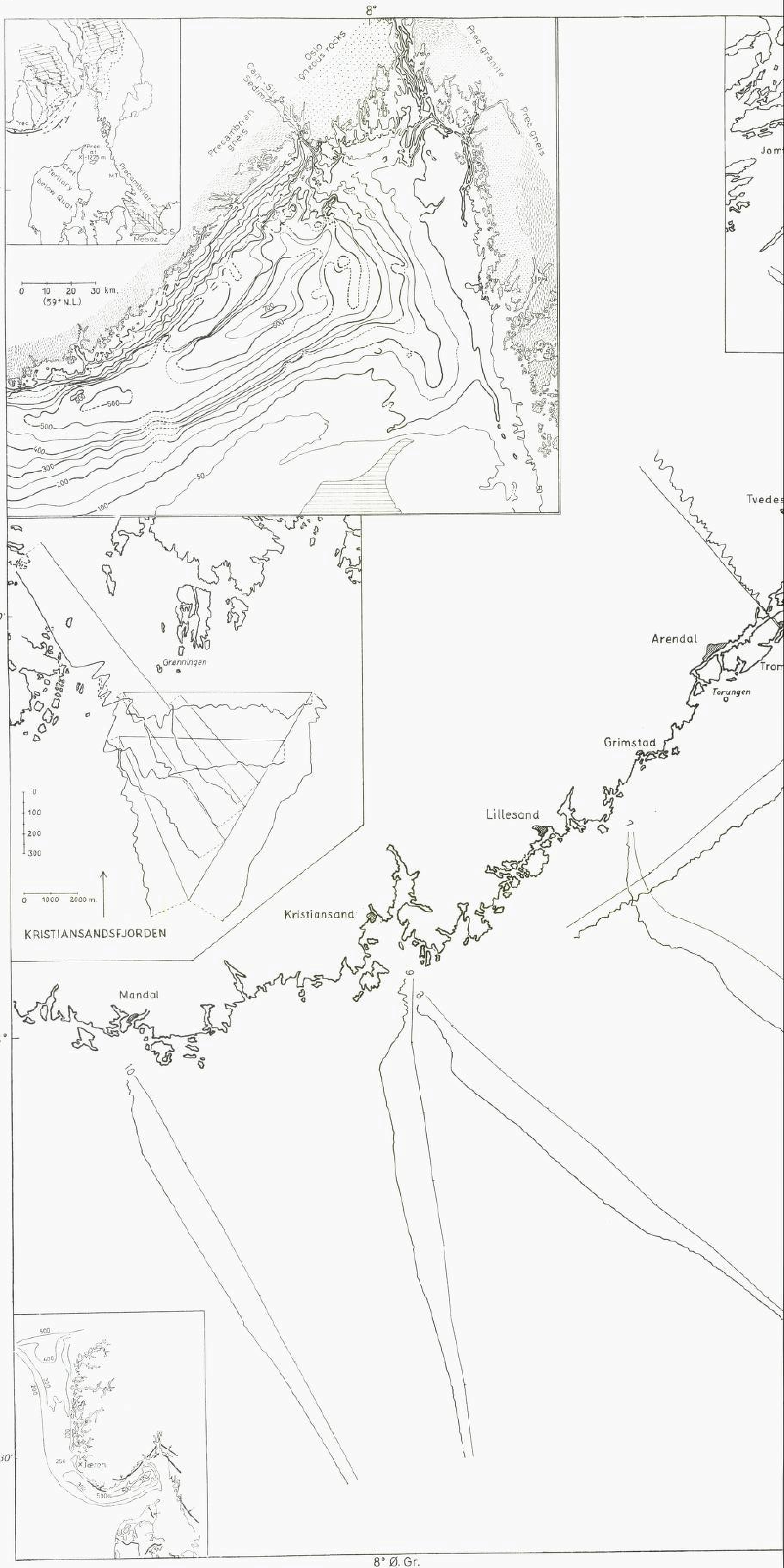
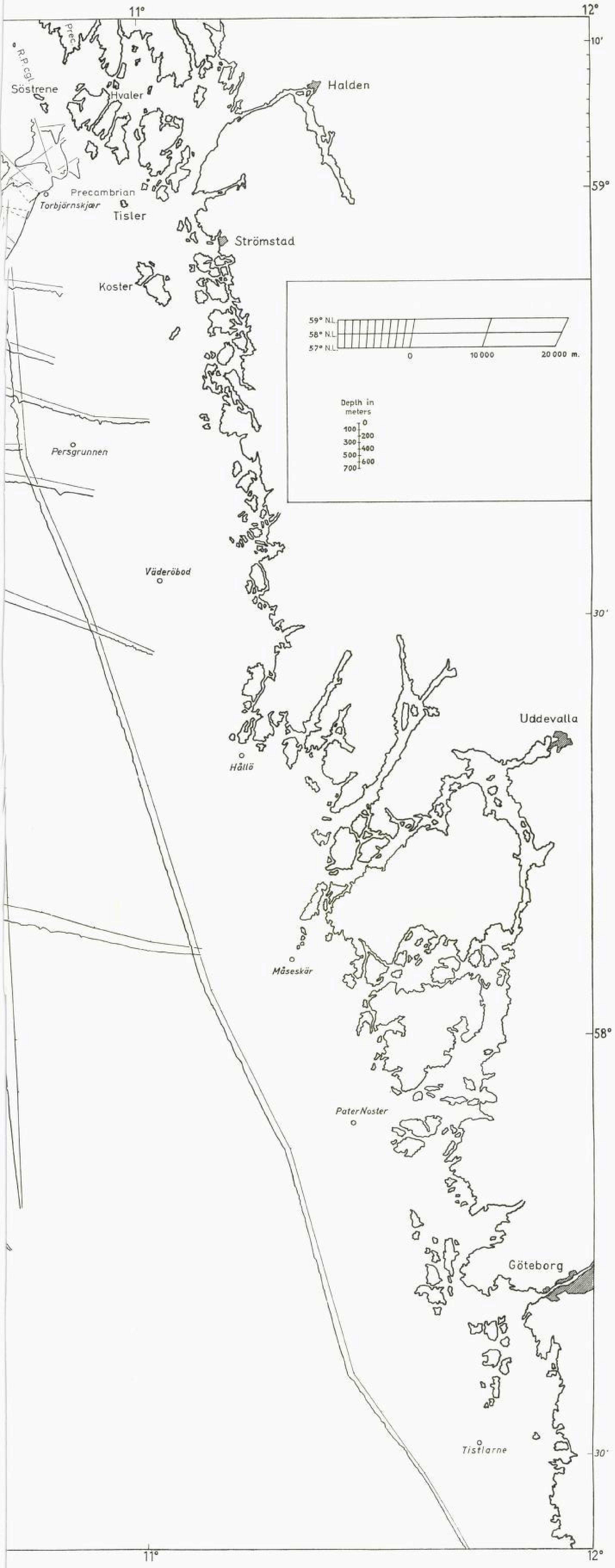
Pl. 1. The *main map* shows echo-sounding profiles based on material provided by the following vessels (cf. Introduction) "Gunnar Knudsen" (1953), "G. M. Dannevig" 1954–56, "Blenheim", "Bretagne", "Vistula", "Kronprins Olav", all 1956. Furthermore there is introduced a somewhat generalized land-surface profile, from the northern part of Tromøy towards the north-west. R. P.cgl. : rhomb porphyry conglomerate (of the Oslo region rock complex) occurring in a row of islands near the east side of outer Oslofjord. *Larger map, upper left:* submarine contour lines, from bathymetrical map VII in O. Holtedahl (1940). Some geological data along the Norwegian and Swedish coastal zones are also given. *Smaller map, upper left corner:* full-drawn and dashed lines show some supposed fault lines in submarine area. Dotted lines show 1. a principal fault inside the Norwegian Skagerrak coast, 2. faults (Upper Paleozoic and(?) younger) bordering the Oslo region at mouth of the Oslofjord, with supposed continuation outside Hvaler and along the Swedish coast (Koster trench). Also some geological data from Jutland and southernmost Sweden are introduced. Ruled: drainage areas of Telemark (west) and Glomma river systems. M.T. cf. fig. 6. *Map, lower left corner:* The Norwegian Channel and some end moraines of last glaciation. *Special maps:* sounding-profiles in the Kristiansandsfjord area and outside the (Ra) island of Jomfruland.


8°
59°
58°
30'
8° Ø. Gr.
Precambrian gneis
Cam.-Sil. Sedim.
Oslo igneous rocks
Prec granite
Prec gneis
Prec
Cret
Tertiary below Quat
Precambrian
Mesoz
0 10 20 30 km.
(59° N.L.)
500
400
300
200
100
50
KRISTIANSANDSFJORDEN
0 1000 2000 m.
Grønningen
Mandal
Kristiansand
Lillesand
Grimstad
Arendal
Torungen
Tvedes
Trom
Jom
10
6
8
Jæren


9°
10°
Porsgrunn
Sandefjord
Frierfjord
Tjöme
Larvik
Langesund
Ferder
Svenner
Kragerö
0
100
200
0 1000 2000 m.
Jomfruland
Risör
Lyngör
Mökkalasset
Hirtshals
Skagen
Frederikshavn



11°
12°
10'
Prec.
R.P. cgl
Söstrene
Hvaler
Halden
59°
Precambrian
Torbjörnskjær
Tisler
Strömstad
Koster
59° N.L.
58° N.L.
57° N.L.
0
10 000
20 000 m.
Depth in meters
0
100
200
300
400
500
600
700
Persgrunnen
Väderöbod
30'
Uddevalla
Hållö
Måseskär
58°
Pater Noster
Göteborg
Tistlarne
30'
11°
12°