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Tectonic lineaments in the Baltic from Gävle to Simrishamn

Tom Flodén

Stockholms Universitet 1977-12-15

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TECTONIC LINEAMENTS IN THE BALTIC FROM GÄVLE TO SIMRISHAMN

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TECTONIC LINEAMENTS OF THE BALTIC FROM GÄVLE TO SIMRISHAMN

by

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INTRODUCTION

The present report deals with the tectonic pattern within the offshore area of middle and SE Sweden. The study is restricted to the large scale pattern that can be detected by seismic reflection profiling. Neotectonic events are discussed in connection with the special study of echosounding and seismic records from the Baltic Sea.

This report is mainly based on investigations performed during the period 1966-1976 by means of continuous seismic reflection profiling. The investigations were mainly concentrated to areas with a sedimentary rock cover and thus, there is a large discrepance in the amount of available information between different parts of the Baltic.

In the coastal zone, only those tectonic lineaments that are of importance for the understanding of the offshore conditions are included in the present maps. References to other known lineaments are made in the text. The geologic time scale is reproduced in Table I.

SONIC METHODS

The tectonic lineaments in the Baltic, that are presented in this report, have been determinated from continuous seismic reflection profiling. The seismic profiler is an instrument that works on the same basic principles as the ordinary echo-sounder. The results are in both cases presented in a similar way on graphic recorders.

Equipment

The main difference between the echo-sounder and the seismic profiler is the transmitter frequency. In echo-sounding the typical frequency range is 30-200 kHz. In the low range, around 30 kHz, the signal will penetrate soft sediments in the sea floor as well as the water. The echo-sonder has a discrete frequency transducer which is pre-set for each equipment. In the present case a 30 kHz echo-sounder was used as a complement to the seismic profiling.

The frequency range of the seismic profiler is significantly lower than that of the echo-sounder, typically 50-2 000 Hz. At these frequencies the signal will penetrate the sediment cover and proceed into the bedrock. Low frequencies will result in good penetration but poor resolution in the records. The use of higher frequencies will result in better resolution but less penetration.

A seismic profiler is usually built to fulfill specific requirements regarding penetration, resolution etc. In the present case a BOLT 600 air gun was used. This transmitter works on compressed air at 80-160 at. and it has a useful frequency range of 50-2 500 Hz. A frequency range of 100-200 Hz was found to fulfill the requirements for the study of sedimentary rock strata in the Baltic. In addition, the signal frequency range of 50-2 000 Hz was recorded on tape for future needs. The apparatus and technology used are presented in works by FLODÉN (1975) and AXBERG (1976).

INTERPRETATION OF LINEAMENTS

The present sonic methods, seismic reflection profiling and echo-sounding, are undoubtedly powerful tools for the evaluation of submarine tectonic lineaments. The fractures are mostly distinct in the records, but their direction may sometimes not be determined due to the distance between the successive profiles. In tha Baltic Sea, the present profiles are only occasionally spaced closer than 3 km. Taking into account that many of the profiles cut the tectonic lineaments at small angles, it is obvious that at present only the most persistent lineaments can be fully evaluated.

The tectonic lineaments have different appearances in the profiling records depending on the nature of the bedrock as well as on the nature of the fracture. Below is presented a number of records that exhibit cracks, joints and faults, typical for different parts of the present area.

The first record, Fig 1A, shows the fracture valley topography typical of the crystalline bedrock area outside the Swedish coast between Stockholm and Oskarshamn. In this area, only a very limited number of the fractures can be correlated between successive profiles. The fracture valley marked A in the figure is one in the set of fractures that intersect closely SW of the Landsort Trench (Fig 5). The depth of the valley is about 100 m. It is traceable for a distance of about 70 km southwards from the Landsort Trench. The deep valley at B is the S part of the Landsort Trench. This glacially eroded trench marks the important fault line that separates the crystalline bedrock in the W from downfaulted Jotnian sandstones in the E. The vertical displacement is estimated to

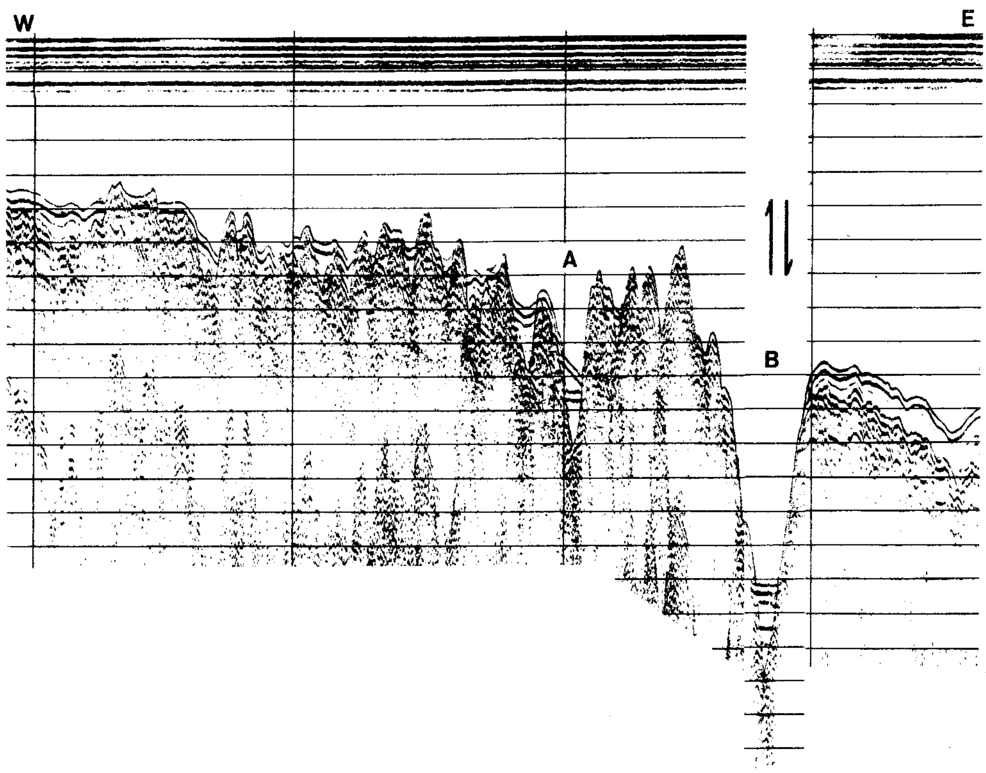

Fig 1A. Seismic profile across the S part of the Landsort Trench. A - fracture valley in crystalline rocks, B - the Landsort Trench with crystalline rocks on the left (W) side and Jotnian sandstones on the right (E) side. Depth between horizontal lines is 18 m at water velocity and the distance between vertical lines is about 4.5 km. The scales are the same in Figs 1B-1E.

be more than 750 m in this section.

In the Landsort area, the boundary between the crystalline rocks and the Jotnian sandstones is easily distinguished as shown in Fig 1A. In the Åland Sea and in the S part of the Bothnian Sea, on the other hand, the corresponding boundaries are less evident as demonstrated in Fig 1B. The boundary

A in this figure separates between Jotnian sandstones in the N and crystalline bedrock in the S. The sandstone is here downfaulted several hundred metres, but the exact amount is not known at present.

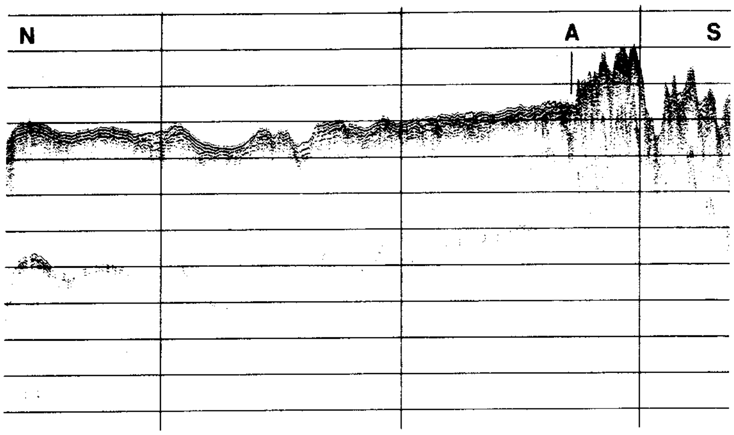

Fig 1B. Seismic profile from the S part of the Åland Sea. The bedrock in the left (N) part of the profile consists of Jotnian sandstone downfaulted in respect to the crystalline bedrock in the right (S) part of the profile. The fault runs approximatly at A. Scales are given in Fig 1A.

Within the Paleozoic areas of the Bothnian Sea and the Baltic Sea, the fractures exhibit only limited amounts of displacement. A minor fault (A) with a displacement of only a few metres is shown in Fig 1C. This record is representative for the conditions within the large area of Ordovician limestone in the Central Baltic. Differences in erosion on two sides of a crack or a small fault in the hard limestone often gives a misleading impression of a larger displacement than is actually present. Structures

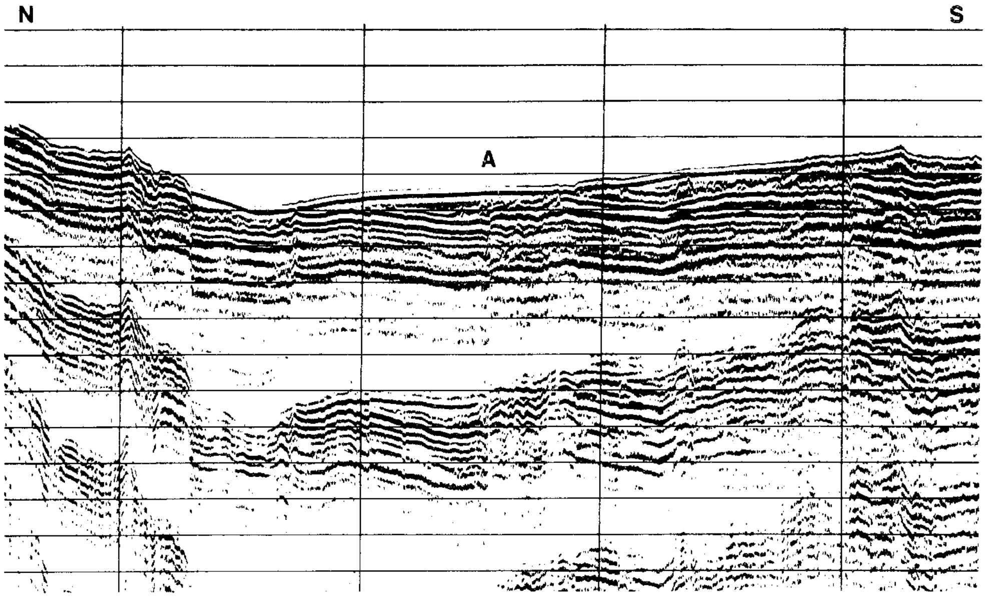

Fig 1C. Seismic profile from the area E of Gotska Sandön. The bedrock surface consists of Ordovician limestone some 20-30 m thick. A - minor fault

of this kind are shown in the left (N) part of the Fig 1C.

In the Silurian E and S of Gotland the fractures are usually very distinct and they can generally be recognized in several successive profiles. The Fig 1D from the area closely SE of Gotland shows a fault (A) with a vertical displacement of about 45 m, which is the largest amount measured in that area. Further S in the profile a minor fracture is shown (B) with a very small vertical displacement.

The Paleozoic of the Bothnian Sea is to a large extent subdivided in blocks that are displaced and tilted in respect to each other. This may also be partially true for the lower part of the sequence in the Central Baltic, while in the upper Silurian and Devonian parts the net value of the displacements is usually almost negligible as shown in Fig 1E.

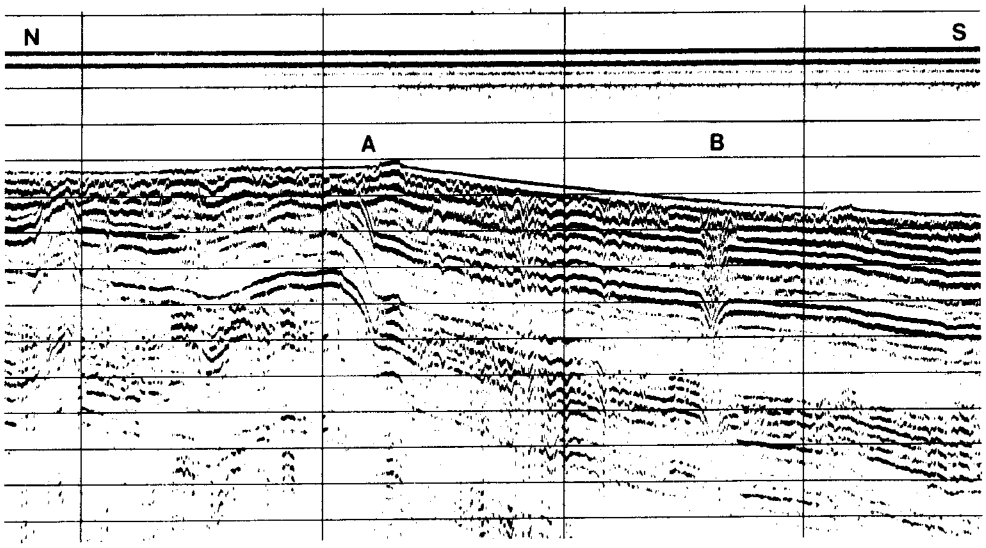

Fig 1D. Seismic profile from the area closely SE of Gotland. A - fault with a displacement of about 45 m, B - minor fracture.

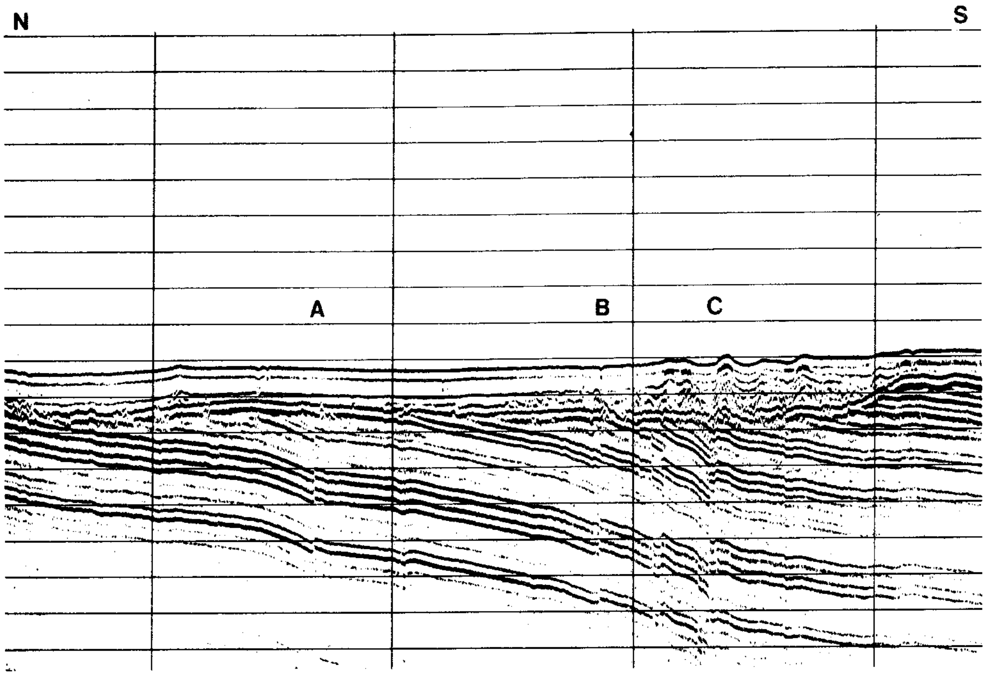

Fig 1E. Seismic profile from the area SE of Gotland. A, B and C denote minor displacements in the bedrock, The fracture system between B and C is typical of the "Neman Zone" that extends from S Gotland in the NW to Klaipeda on the Lithuanian coast in the SE. The bedrock is of Upper Silurian (Downtonian) age. Note that the fracture (A) is not recorded in the upper sediments of the sea bed, while the fracture (B) is followed by a slight suture that may be associated with neotectonic movements.

GEOLOGY AND TECTONIC LINEAMENTS

The Baltic forms a major zone of subsidence in the East European Platform. In the Bothnian Sea and in the Åland Sea the main tectonic lineaments roughly coincide with the Swedish coast line. These lineaments are characterized by large vertical displacements that also separate bedrock units of different ages. An examination of the sedimentary rock strata in the offshore area reveals the high age of these lineaments and also their repeated regeneration.

In the Baltic Sea the Swedish coast is not followed by any prominent lineaments comparable to those further N. Two main lineaments trending NW-SE occur; the Landsort-Kappelshamn line with the adherent Jotnian fault basin and the Västervik-S Gotland-Kaliningrad line (the Neman Zone). Apart from these, subordinate, but still important lineaments occur mainly parallell to the strike of the sedimentary rocks.

The SW border of the East European Platform extends through the S part of the Baltic Sea from SW Scania to NW Poland. The marginal parts of the platform have been subject to intensive faulting and the horst system of Scania has been proved to continue in the Baltic Sea from the Bornholm Gat in the NW to the coast of Poland in the SE.

The Bothnian Sea

The bottom of the Bothnian Sea consists of sedimentary rocks to a much larger extent than in the surrounding coastal areas, Fig 2. This difference is mainly due to the repeated subsidence of the area. This subsidence has given the sedimentary rocks a

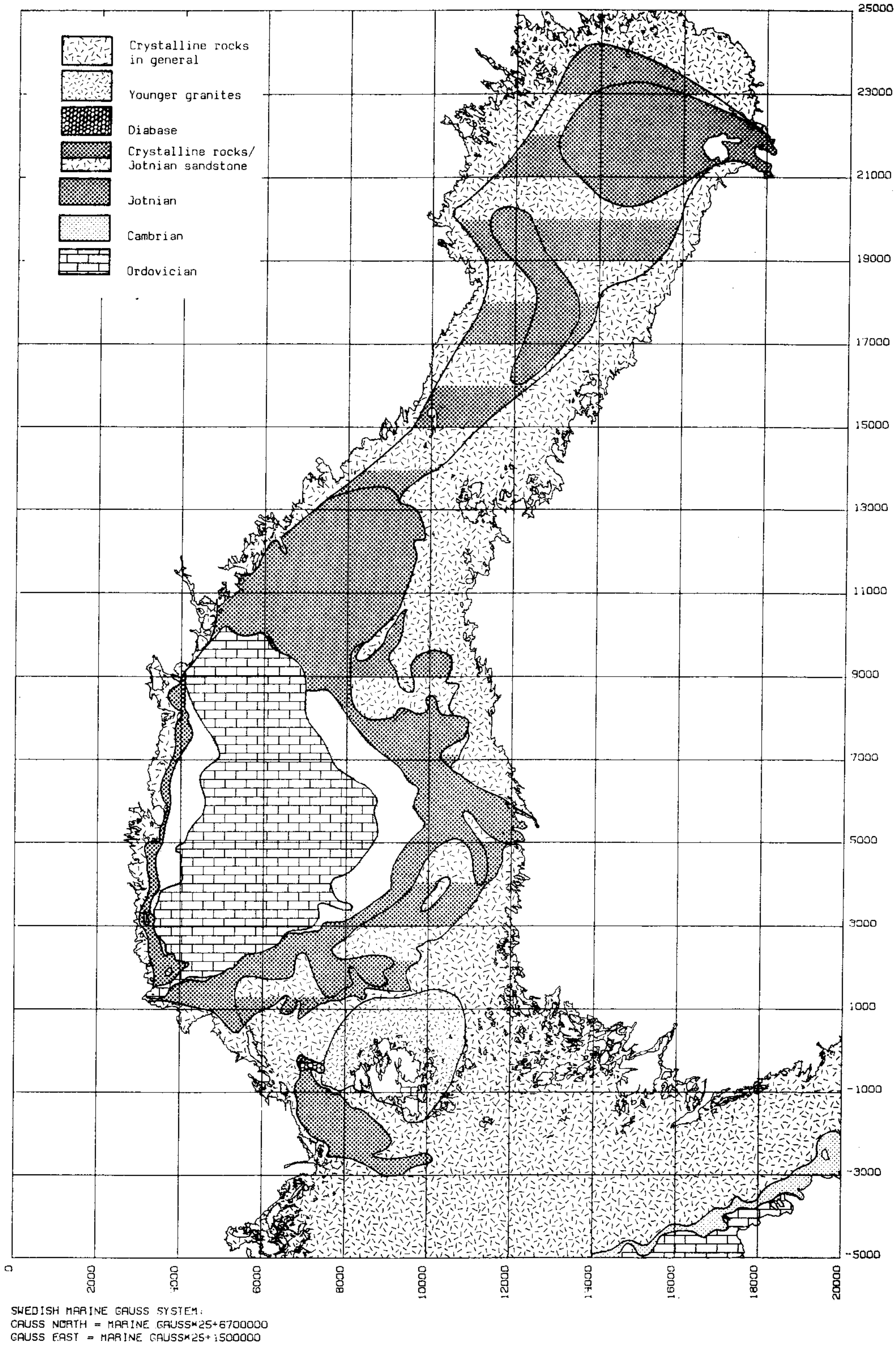

Fig 2. The bedrock in the Gulf of Bothnia (from AXBERG and FLODÉN, 1977). Scale 1:4 milj. The sedimentary rocks in the Bothnian Bay and in the northernmost part of the Bothnian Sea may be younger than Jotnian as stated in this map. Current research indicates a possible late Riphean age (WINTERHALTER, pers comm).

protected position against erosion. The age of the strata range from late Proterozoic (Jotnian) to early Paleozoic (Cambrian and Ordovician), see Table I.

The Swedish coastline northwards from Gävle forms one of the main tectonic lineaments of the area; the Bothnian Zone (see STEPHANSSON and CARLSSON, 1976, Fig 31). Along this lineament evidence is found of a deep fracture in the earths crust, such as e.g. the presence of Cambrian carbonatites on Alnön near Sundswall (KRESTEN et al., 1977) and the possibly Tertiary andesites in lake Dellen W of Hudiksvall.

Tectonic lineaments of the NW-SE direction that are commonly found in the surrounding land areas of Sweden and Finland, are also frequent in the Bothnian Sea. A third system of fractures in this area has a direction parallell to the Bönan fault, NE-SW.

Jotnian

Jotnian sedimentary rocks have been described from many locations in Sweden and in Finland. Their age is stated to be 900-1100 M.Y. and they mainly consist of reddish sandstones preserved by downfaulting.

The largest ocurrence of Jotnian sandstone is found in the Bothnian Sea. The sandstones rest on a surface, eroded in the crystalline basement. This surface is often referred to as the sub-Jotnian peneplain (see e.g. von ECKERMANN, 1937) but at least in the Bothnian Sea it is not from a geomorphological point of view comparable to the very even sub-Cambrian peneplain. Refraction measurements in the S Bothnian Sea indicate that the relief of the sub-

Jotnian peneplain exceeds 100 m. This is an important factor in the discussion of the sandstone boundary in the S part of the Gävle Bay.

Within the SE and E marginal parts of the sandstone area in the Bothnian Sea, the strata are thin and they only partially cover the crystalline basement. In the area NW of Åland (see the map Fig 2) sandstones and crystalline rocks have an almost equal distribution, while in the Gävle Bay from Örskär to Gävle the boundary is more distinct. Possibly, the boundary in the Gävle Bay is at least in its W part a tectonic boundary, but the investigations performed so far have not been focused on this problem.

Jotnian sandstones cover the crystalline basement in the larger part of the Gävle Bay and they are assumed to be present below the Paleozoic rocks also in the central part of the Bothnian Sea. An exception is the Finngrunden shoals, where borings have revealed crystalline rocks below the Paleozoic (THORSLUND, 1970). The shoal areas have recently been studied in detail by AXBERG (1977), who found them to coincide with two monadnocks in the crystalline basement. AXBERG (op. cit.) also found evidence that the Paleozoic sequence is locally reduced in thickness within the shoal areas.

In the close vicinity of Gävle, the NE-SW Bönan fault forms the boundary between crystalline rocks on land and sedimentary rocks in the harbour inlet, Fig 3. With a few interruptions this lineament has been traced as far as half way across the Bothnian Sea (WINTERHALTER, 1972). The lineament is partially followed by faulting. The NE prolongation of the Bönan fault may coincide with the NW limit of the Finngrunden monadnocks. The SE limits of the monadnocks coincide with another NE-SW lineament that roughly conforms with the present day boundary of

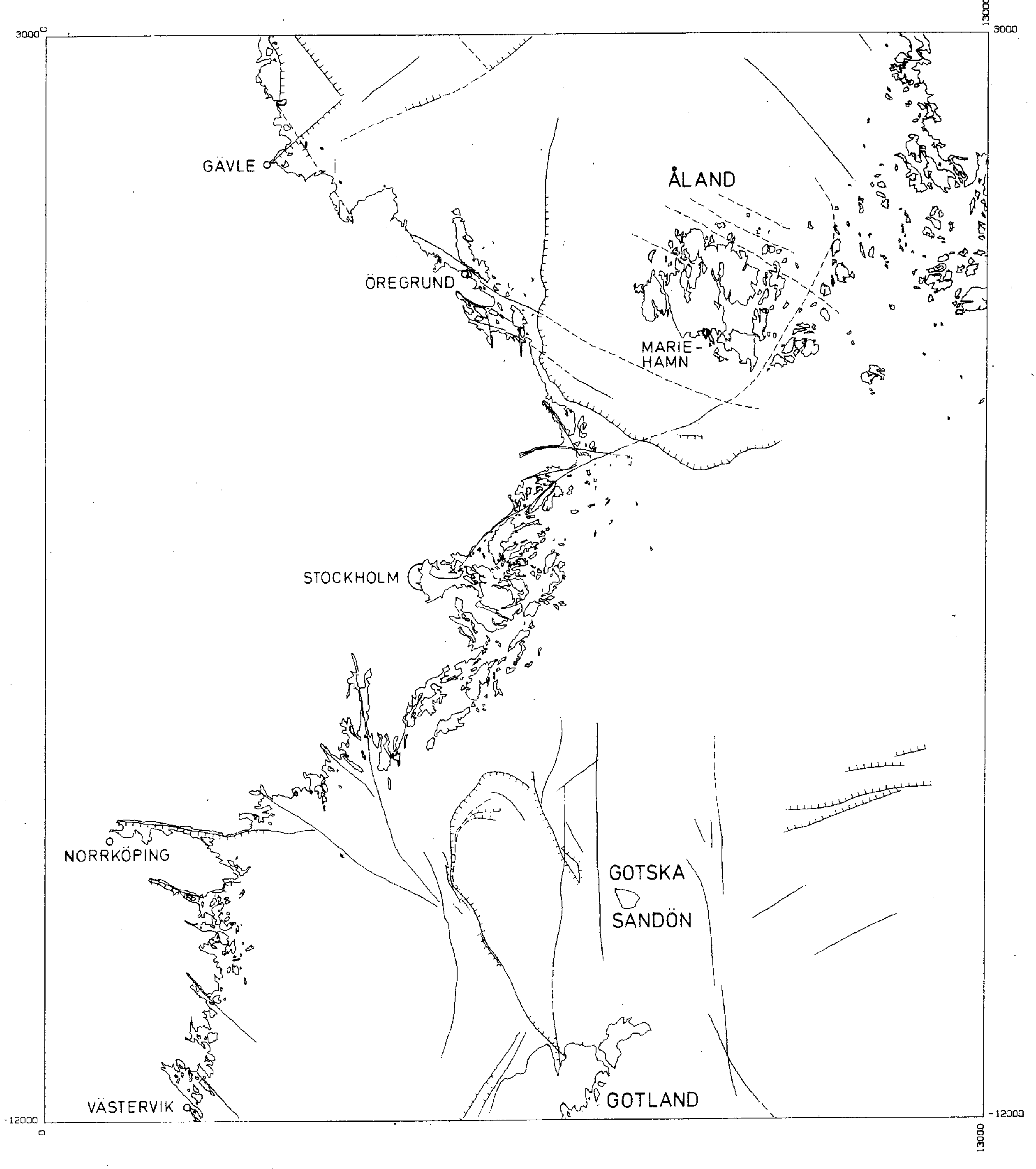

Fig 3. Tectonic lineaments in the Baltic from Gävle to Västervik

the Paleozoic. Towards the SW the lineaments continue on land where they delineate parts of the Gävle sandstone area (see e.g. LUNDEGÅRD, 1967).

Along the coast, northwards from Gävle, the Jotnian sandstone is distinctly downfaulted. The faulting has taken place in the main direction of the coast, but the close examination performed by AXBERG (1977) has shown that the main N-S lineament is composed from a series of faults of NW-SE and NE-SW directions (Fig 3). The magnitude of displacement along the coast has a general increase towards the N, but no exact figures are yet available.

Cambrian and Ordovician

The Paleozoic strata in the Gävle Bay consist of about 40 m Cambrian clays with subordinate layers of sandstone followed by 50-60 m of Ordovician limestone. The Cambrian as well as the Ordovician sequences exhibit a general increase in thickness towards the N and NE in the Bothnian Sea. The strata are also assumed to be more complete in this direction.

The Paleozoic rocks rest on a very even surface, the sub-Cambrian peneplain. This peneplain is partially eroded in crystalline rocks and partly in Jotnian sandstone. The presence of the peneplain proves that the Jotnian sequence was downfaulted well before the onset of the Cambrian, possibly even before the sedimentation was fully concluded.

The downfaulting of the Paleozoic rocks is generally stated to be post-Ordovician in age, but the large difference in thickness of the Cambrian sequence between the Gävle Bay in the S (approximatly 40 m) and the area SE of Härnösand in the N (more than 150 m) may partly be due to subsidence already in the Lower Cambrian. In any case, the traces of post-Ordovician tectonism is undisputable. The entire limestone area in the Bothnian Sea is fractured in smaller or larger blocks that are slightly tilted in regard to each other. The present day boundaries of the limestone area are also eroded along fractures of the main NW-SE and NE-SW directions. The S boundary of the Paleozoic in the Gävle Bay is even partly downfaulted as much as 50-60 m, see Fig 3.

In the Tertiary, the Caledonides were raised to their present position. During this major event in the evolution of Fennoscandia the Swedish coast line served as a hinge-line. Today the remnants of the sub-Cambrian peneplain W of the Bothnian Sea and also close to the coast in the Bothnian Sea (AXBERG, 1977) has a general dip towards E, while the peneplain in the corresponding coastal parts of Finland and in the main part of the Bothnian Sea has a general dip towards W. The amount of vertical displacement that took place during the Tertiary is not known, but it is not unlikely that the erosional upper surface of the Ordovician limestone in the Bothnian Sea was in level with the crystalline basement in the Bothnian coast prior to the Tertiary. In this case, the Tertiary downfaulting of the Paleozoic outside the Swedish Bothnian coast would be in the region of 50 m. Indications of late, possibly Tertiary, tectonic events are also found in the Åland Sea and in the Gotland area as will be discussed below.

The Åland Sea

The crystalline bedrock of the Åland Sea and the adjacent coastal areas is mainly of Svecofennian age. The crystalline rocks of the Åland mainland and the adjacent archipelago towards the north and east consist of the sub-Jotnian Rapakivi granites. An outer string of islands between the Åland mainland and the Åland Sea are of Svecofennian age. In the main part of the Åland Sea, the Svecofennian rocks are overlain by sandstones of Jotnian age, Fig 4. A Late Jotnian oliviniferous diabase occurs on some small islets in the Märket and Halsaren areas of the northernmost Åland Sea. Remnants of the Lower Cambrian are found as fissure fillings in Uppland and on Åland. Bay Lumparen on Åland forms an isolated occurrence of Ordovician limestone that rests on Lower Cambrian clays.

According to HAUSEN (1964), the Rapakivi granite on Åland was intruded as a lakkolite below a thin cover of older rocks. The cap rocks have later been completely abraded. The vertical feeding channel of the granite coincides with the eastern limit of the Rapakivi massif. The boundary runs first in a NNE direction from the Åland Sea, past Föglö and Kumlinge and later in a due N direction into the Bothnian Sea. The vertical feeding channel is stated by HAUSEN (1964) to coincide with a prominent fracture zone. The investigations in the Åland Sea indicate that it extends across the sea N of Lågskär and forms the SE coast of the Uppland mainland.

The intrusion of the sub-Jotnian Rapakivi granites and the deposition of the Jotnian sandstone were separated by a period of intensive erosion leading to the formation of the sub-Jotnian peneplain. Remnants of the sub-Jotnian peneplain are found closely off the western coast of Åland where the crystalline bedrock exhibits a comparatively smooth relief with a regular dip towards the Jotnian sandstone area in the SW. In this area immediately outside the Åland coast the Jotnian sandstone is assumed to have

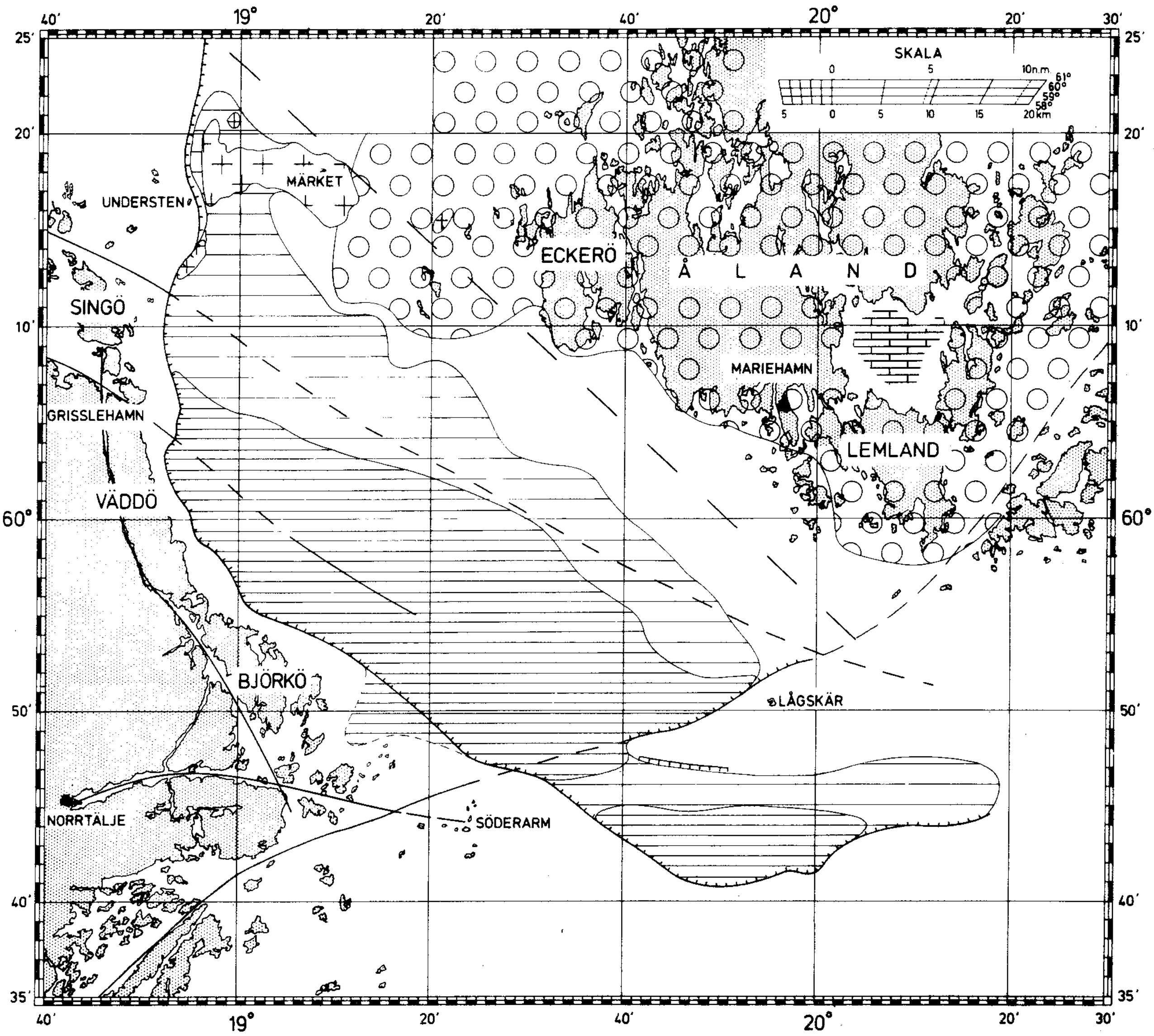

Fig 4. The bedrock and the tectonic lineaments of the Åland Sea. Open circles - Rapakivi granites, horisontally striated - Jotnian sandstone (the sub-Cambrian peneplain preserved in the closely striated areas), crossed area - - Jotnian diabase, brick - the Ordovician limestone in the bay Lumparen. (From FLODÉN, 1977A)

been eroded away as late as during the Pleistocene, leading to the formation of the present day deep trench along the Åland coast.

W of Mariehamn on Åland, the sub-Jotnian peneplain has a dip of about 2.5° towards the SW. The dip and strike of the separate layers in the sandstone sequence are estimated to be equal to those of the peneplain. This implies that the northwestern limit of the Jotnian sandstone in the Åland Sea basin is erosional and also that Jotnian sandstone once covered the Åland islands. The presence of an almost horizontal sub-Cambrian peneplain formed in the Jotnian sandstone and the presence of Cambrian sandstone dykes on Åland (ASKLUND, 1926 and MARTINSSON, 1956) and in the region of Uppsala (WIMAN, 1918) show that the Jotnian sandstone was limited to the present day Åland Sea already in the beginning of the Cambrian. The sandstone in the basin SW of Mariehamn (the Åland Sea Basin) has a general dip towards the SW, while the corresponding strata in the basin S of Lågskär (the Lågskär Basin) has a general dip towards the south. Both sandstone areas are cut by the almost horizontal sub-Cambrian peneplain at roughly the same level. These general conditions in the Åland Sea area show that major tectonic activity has taken place after the depostion of the sandstone but previously to the final formation of the sub-Cambrian peneplain. During this tectonic period the sandstone was downfaulted and tilted to more or less the angle it has today. The remnants of the sub-Cambrian peneplain in the Åland Sea forms an even, almost horizontal, surface situated about 90 m below the present sea level. It must therefore be anticipated that younger, possibly Tertiary, movements have occurred along the old tectonic lineaments in the Åland Sea. The conditions are the same on land in the Gävle area where the top of the Gävle sandstone is found about 15 m lower than the surrounding crystalline bedrock (GORBATSCHEV, 1967).

The thickness of the Jotnian sandstone in the Åland Sea Basin has not yet been calculated, but an estimate based upon the general dip and strike indicates that the thickness exceeds 1 000 m in the central and western parts of the Åland Sea Basin and somewhat less in the Lågskär Basin. These figures should be compared with the estimates of the thickness of the Gävle sandstone, 800-900 m, given by GORBATSCHEV (1967, p.8).

The Åland Sea area of subsidence is governed by at least four major lineaments. The fractures in the Åland Sea are essentially submarine extensions of those within the bordering coastal areas and within the Bothnian Sea. They commonly extend far inland. A general description of the fracture systems in the eastern part of Uppland is given by SVEDMARK (1887) and in the Åland area by HAUSEN (1919). A recent evaluation of the lineaments is given by STEPHANSSON and CARLSSON (1976).

Of fundamental importance for the understanding of the two basins in the Åland Sea is the NW-SE fracture system. This fracture system is dominant in the coastal area from the Gävle bay to the Åland Sea, in which area it coincides with the general direction of the coast line. Two major fractures are present on land, one entering the Åland Sea south of Singö at Grisslehamn (the Forsmark-Granfjärden line according to SVEDMARK, 1887) and one entering the Åland Sea north of Singö (the Öregrund-Singö line according to the same author). On the basis of morphological features these fractures have been extended into the Åland Sea. The southern fracture is recognized as a minor erosional valley in the Jotnian sandstone as far towards the SE as outside Simpnäs. The southeastward extension of the northern fracture, on the contrary, is a prominent feature in the Jotnian landscape. This fracture divides the Åland Sea Basin in two morphologically different parts, a southwestern part of comparatively small relief and a heavily eroded northeastern part. The smooth topography of the southwestern block constitutes the remnants of the sub-Cambrian peneplain, see Fig 4.

NW-SE fractures are, apart from the areas previously mentioned, also present on Åland where they form the northeastern boundary of the Åland island. In the Åland area, the fracture system exhibits three fractures (Fig 3) that are traceable on the sea charts through the entire Rapakivi massif of the northeastern Åland archipelago and that continue into the area between Åland and the Finnish mainland (c.f. HAUSEN, 1964).

Towards the SW, the Åland mainland is bordered by an equally important, but less obvious tectonic line of the same NW-SE trend, Fig 4. No major faulting or erosional valley has been discerned in this line that seems to form a hinge-like flexure separating the almost horizontal sub-Cambrian peneplain of the Åland islands from the southwesterly dipping peneplain in the Åland Sea Basin. The dip, 2.6° towards the SW, is representative of the entire distance along the hinge line from its intersection with the N-S fracture SE of the Grundkallen shoal and southeastwards, past Åland, to NE of Lågskär. An even further extension of this lineament is suggested by a marked fracture valley in the SE prolongation of the hinge outside the Jotnian sandstone area. The hinge line is broken in an area west of Eckerö, where the Åland archipelago extends westwards across the lineament. The archipelago is here limited towards the Åland Sea by local faults and therefore on the whole the dip of the basement is maintained also in this area. The Märket and Sankan shoals are formed by a Jotnian olivine diabase, which most probably was intruded as a sill in the Jotnian sandstone (HAUSEN, 1964, Fig 2). It is therefore possible that the crystalline basement also in this area has a southwesterly dip.

The Åland Sea Basin is restricted towards the SE by the Lågskär fault. This is located in the continuation of the NE-SW lineament that forms the boundary between the mainland of Uppland and the north Stockholm archipelago. This lineament has been traced as far towards the SW as Trälhavet near Stockholm (SVEDMARK, 1887, p. 192 and map Tafl. 6). E of the Åland Sea, the lineament trends towards the NNE and later due N through the entire Åland archipelago and where it coincides with the E limit of the Rapakivi granite massif (c.f. Fig 2).

The crystalline bedrock south of the Lågskär Fault forms a tilted block with a general southerly dip of 2.5^{o}. The northernmost part of this block forms the gneissic Lågskär islets while towards the south, in the Lågskär Basin, the basement is overlain by Jotnian sandstone as previously described. The Åland Sea Basin and the Lågskär Basin are both boundered towards the SW and the S, respectively, by the same system of faults, Fig 4. From Björkö and northwards along the eastern coast of Väddö, past Halsaren and Understen islets the fault system is parallell to the N-S fracture system of Uppland and Åland, e.g. Ortalaviken which separates the northern part of Väddö from the mainland and Marsund which separates Eckerö from the Åland mainland. The vertical displacement seems to diminish towards the north from Understen and turn into a prominent northward fracture valley, traceable on the sea charts as far as 50 km into the Bothnian Sea (c.f. WINTERHALTER, 1972, Fig 38). In resemblance to the Ortalaviken-Björköfjärden fracture which separates Väddö from the mainland, this fault system turns toward the SE off Björkö, thus parallelling the previously described NW-SE fracture system of Uppland and Åland. East of Söderarm it turns towards the E, encircles the Lågskär basin and ends up in a northerly direction. The part of the fault system E of Söderarm may constitute a direct continuation of the E-W lineament through Norrtälje. This lineament has been traced on sea charts as far E as Söderarm. It is, however, equally possible that an eastern prolongation of the Norrtälje fracture runs somewhat further towards the N. It may follow the E-W boundary between the S part of the Lågskär Basin where the sub-Cambrian peneplain is preserved and the N part where the sandstone is deeply eroded (se Fig 4). For this reason no attempt has been made to draw the extension of the Norrtälje lineament outside the Swedish archipelago.

The Baltic Sea

The main part of the Baltic Sea belongs to the East European Platform. The Fennoscandian Border Zone that forms the SW margin of the Platform extends from central Jutland in the NW, past Scania and Bornholm to Poland. The continuation of this lineament has been traced as far towards the SE as the Black Sea. The southeastern part of the Baltic Sea, NE of the Border Zone, forms a subsided part of the Platform; the Baltic Syneclise. The thickness of the sedimentary rocks reaches 2 000 m SE of Gotland, Fig 5, and more than 3 000 m in the southeasternmost

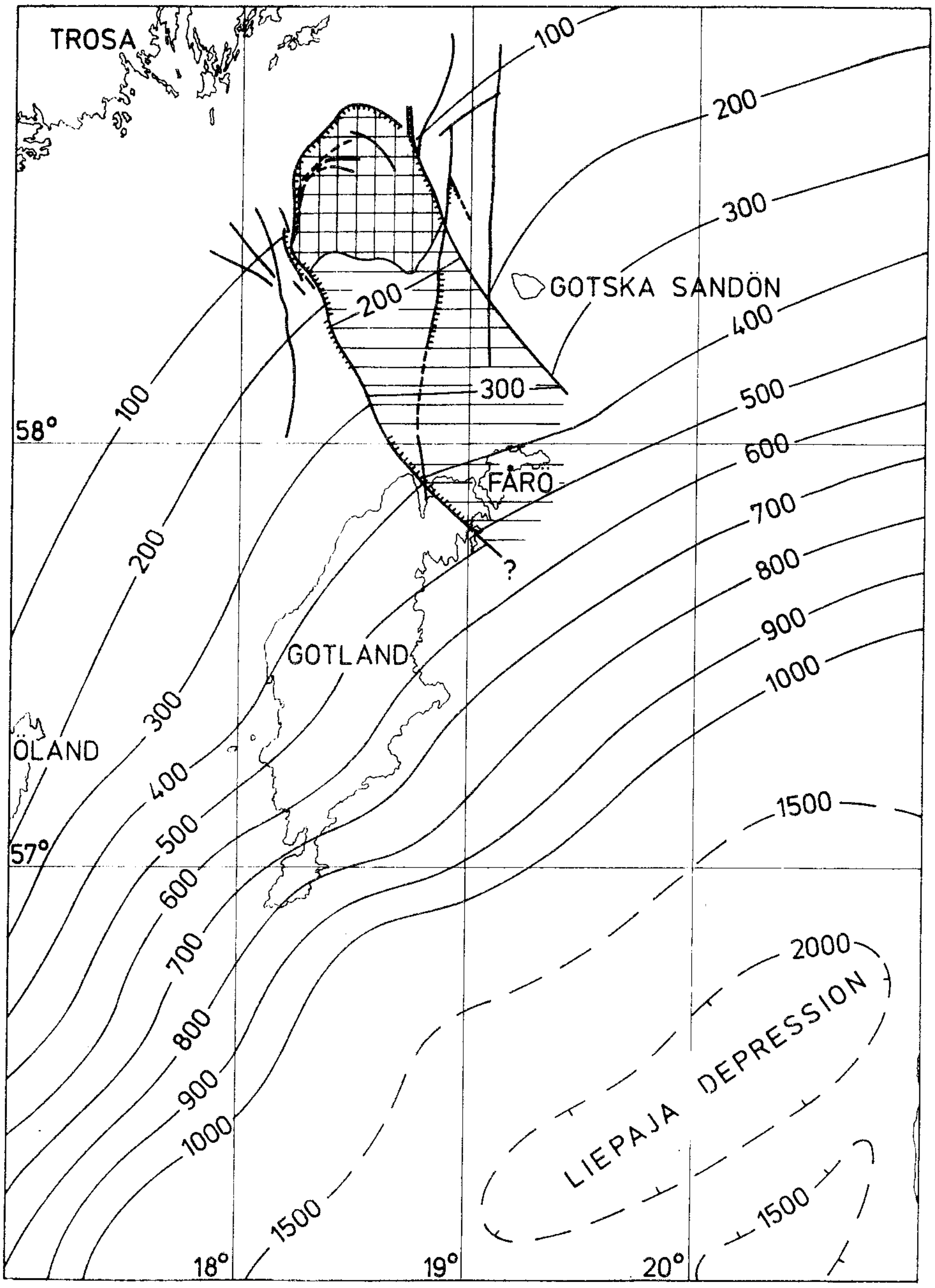

Fig 5. The sub-Cambrian peneplain in the Gotland area. The mainly SE dip of the peneplain is rather regular down to a maximum depth of more than 2 000 m below sea level in the Liepaja depression. The regular dip of the peneplain is locally broken within the Jotnian fault basin. Horizontally striated area: the Jotnian fault basin. Horizontally and vertically striated area: northwestern part of the Jotnian fault basin where the sub-Cambrian peneplain is downfaulted and tilted to an almost horizontal position. (From FLODÉN, 1975)

part of the Baltic Sea (see e.g. VOLKOLAKOV, et al., 1977). SW of the Fennoscandian Border Zone the crystalline basement is found at depths of 5 000-7 000 m (ANDERSEN, et al., 1975).

The basement

The crystalline basement outside the Swedish coast, from Blekinge in the S to Norrköping in the N, has a regular dip towards the ESE. In contrast to the Bothnian Sea, the position of the Swedish coast does not coincide with any tectonic lineament, but the geomorphology of the coast area is highly influenced by fracture valleys of the main NW-SE, but also of the E-W, directions. Towards the E the crystalline basement is covered by an increasing thickness of sedimentary rocks, Fig 6.

In the main part of the Hanö Bay, the Mesozoic sedimentary rocks rest directly on the crystalline basement. The basement outside the Blekinge coast has an even dip towards the S. The maximum thickness of the Mesozoic in the Hanö Bay sedimentary basin is about 1 000 m closely N of the Christiansö Horst. Tectonic lineaments have not been observed in the direction of the Blekinge coast.

A. The area E and SE of Stockholm. Due to the absence of sedimentary rocks, the area E and SE of Stockholm archipelago has not been included in the current survey of the Baltic. The geomorphology of the area has previously been studied by FROMM (1943). FROMM (op. cit.) presented the fracture valley topography in a bathymetric map and also the main topographical features over a larger area, Fig 7. He also pointed out that the outer chain of islands SE of Stockholm are the peaks of long, tilted blocks, the western margin of which are lifted up.

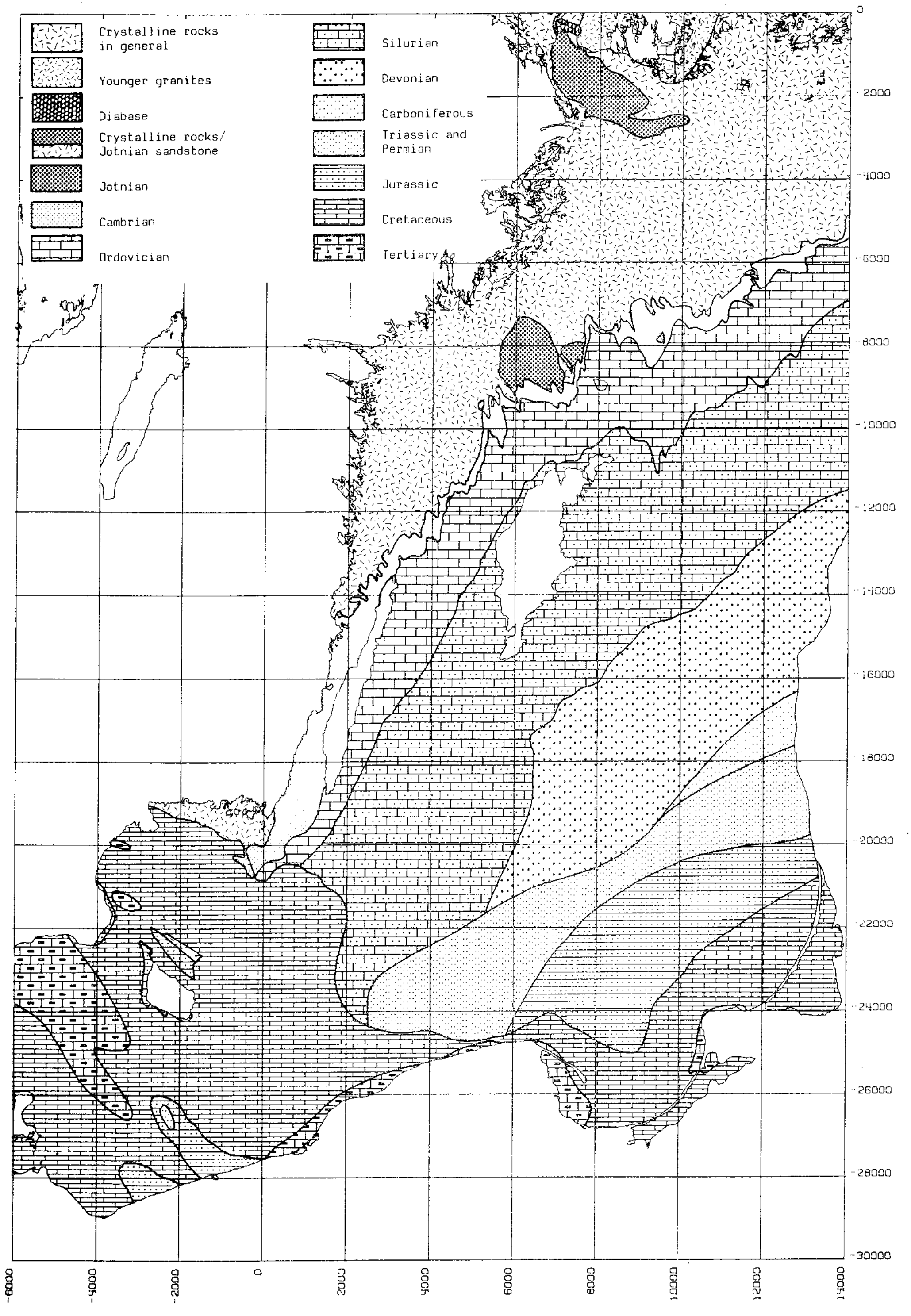

Fig 6. The bedrock in the Baltic Sea (from FLODÉN, 1977B). Scale 1:4 milj.

Fig 7. Main topographical features in the Stockholm-Landsort area. (From FROMM, 1943).

This is a common feature in the NW Baltic. The blocks are tilted in the general direction of the Baltic Syneclise.

B. The area outside the coast from Norrköping to Öland. The area N of Öland is characterized by its very even sub-Cambrian peneplain. The fracture valley topography on land (NORDENSKJÖLD, 1944) continues on the sea floor, but the influence of Quaternary erosion rapidly diminishes towards the Paleozoic boundary in the E, Fig 8.

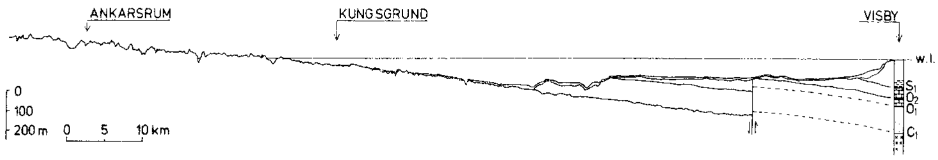

Fig 8. Geological section Ankarsrum-Visby. Kungsgrund is located closely SE of Västervik. Note that the small fault W of Visby is only local and not included in the map Fig 9. (From FLODÉN, 1977C).

Only three NW-SE lineaments within the Västervik area are included in the present map, Fig 9. Other fractures of different directions occur in the area, but these seem mainly to be associated with the local tectonic blocks and have no larger horizontal endurance.

C. The area outside Blekinge. The preliminary evaluation of the seismic records from this area reveals no striking tectonic features. The two lineaments in the Hanö area (Fig 9) are adopted from BERGSTRÖM (et al., 1973).

The Neman Zone.

A prominent feature in the basement of the Baltic Sea is the NW-SE trend of magnetic and gravimetric anomalies that extend from Västervik in the NW, across S Gotland, to Klaipeda on the Lithuanian coast. This lineament, the "Neman Zone", was first recognized by EFENDIYEVA (1967) and interpreted by him as a fracture zone. More details, within the area SE of Gotland, are later added by KUCHMAZOV et al. (1970). A possible NW prolongation of this lineament from S Gotland in the SE, to the Norwegian Sea in the NW is described by STRÖMBERG (1976). Along the "Neman Zone" in the area SE of Gotland the Silurian and Devonian sequences are fractured in the main NW-SE direction, Fig 8. The vertical displacement is generally small as demonstrated in Fig 1E. The fractures are probably of a late Paleozoic age, no older than the Devonian. An interesting feature is that some of the fractures in the "Neman Zone" display the results of selective glacial erosion, Fig 9, while other fractures of the same main direction are unaffected, Fig 1E. This difference may indicate that only some of the fractures have been reactivated and thus, have been subjected to a decrease in erosional resistance. The formation of other trenches in the Baltic area, such as e.g. the Landsort Trench, may be explained in a similar way. Efforts have been made to distinguish the prolongation of the "Neman Zone" W of Gotland, but the present information is insufficient. Undoubtedly, fractures of short horizontal duration occur in the direction of the Zone at least in the Karlsö area but possibly also in the region of Knolls Grund.

The Jotnian

The area SE of the Landsort Trench forms a large fault basin of mainly Jotnian sedimentary rocks. The basin is limited towards the SW by the main tectonic lineament of this area, the Landsort-Kappelshamn fault, that extend from the S part of the Landsort Trench in the NW to Kappelshamnsviken on Gotland in the SE. From here the lineament most probably extends further across Gotland. Towards the NE the basin is limited by the Utö-Fårö fault that extends from the N part of the Landsort Trench in the NW and projects towards NE Fårö. The extension towards the SE of the fault basin is at present unknown.

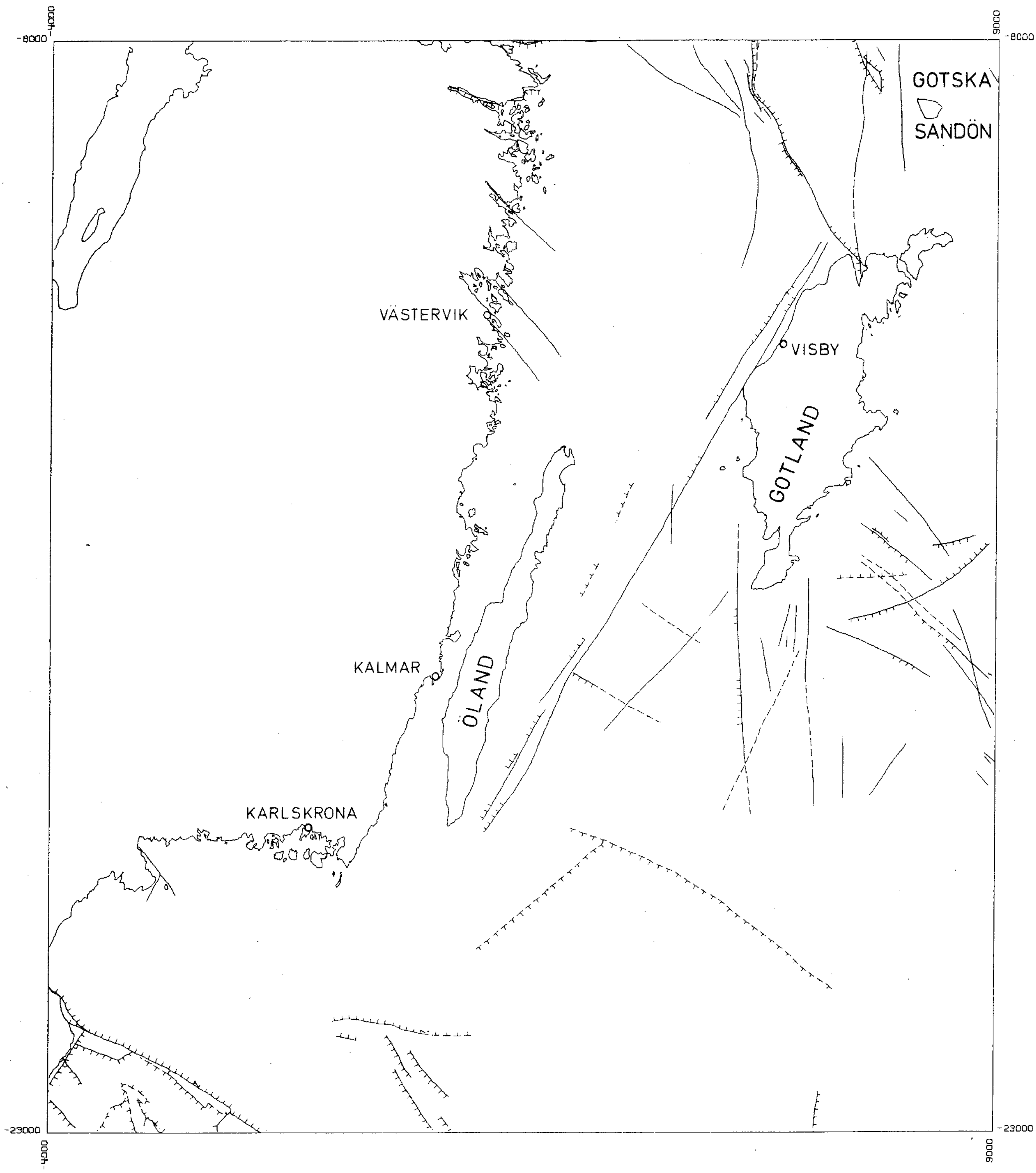

Fig 9. Tectonic lineaments in the Baltic from Norrköping to Simrishamn.

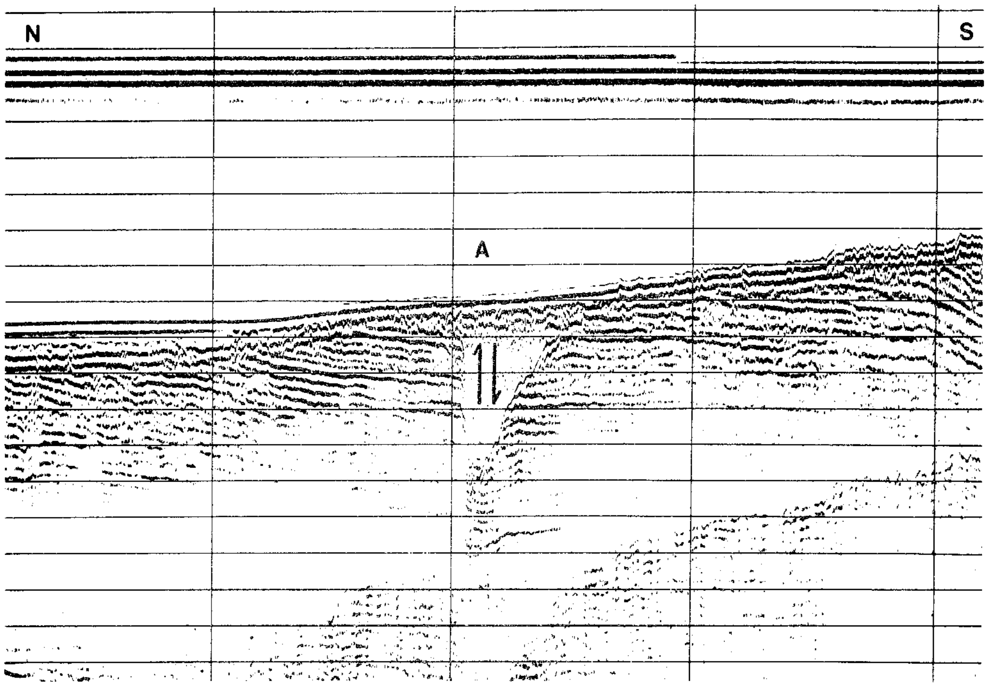

Fig 10. Seismic profile from the area SE of Gotland. The profile shows the selective glacial erosion of a fracture within the "Neman Zone (A). Scales: see Fig 1A.

As already discussed the sea bottom along the Swedish coast from Öland and northwards is formed by the even sub-Cambrian peneplain. The morpholgy resembles closely the adjacent land area. Towards the N, within the area between Landsort and Fårö, the fracture valley morphology gradually becomes more accentuated towards the boundary of the Jotnian fault basin. Northeast of Gotska Sandön the fracture valleys become less accentuated and the even peneplain is resumed.

A. The Landsort-Kappelshamn fault. The largest displacement has occurred along the Landsort-Kappelshamn fault. Seismic refraction work indicates that the Jotnian NE of the fault may be downfaulted as much as 900 m. The faulting is assumed to have occurred during, or soon after, the deposition of the Jotnian sedimentary rocks. No difference in the thickness of the Cambrian sequence NW of Gotland has been detected between the two sides of the fault. This implies that no displacement was present between the two sides of the fault at the onset of the Cambrian. Later, minor displacements have again occurred. The age of these movements is uncertain, but a Tertiary age is suggested. During this reactivation of the lineament, the Cambro-Silurian was fractured along the entire length of the old fault from the Landsort Trench to Kappelshamnsviken. Along the NW part of the Landsort-Kappelshamn fault from the Landsort Trench to Hall Banks, the SW side is down-faulted, while from Hall Banks to the inlet of Kappelshamnsviken the NE side is downfaulted. The largest displacement, about 20 m, has been measured N of Kappelshamnsviken. The displacement decreases towards Hall Banks, where only fracturing is descerned. From Hall Banks the amount of displacement again increases to about 15 m in the S part of the Landsort Trench.

B. The Utö-Fårö fault. The vertical displacement along the Utö-Fårö fault is considerably less than along the Landsort-Kappelshamn fault. Along the Utö-Fårö fault the crystalline basement descends stepwise towards the SE, a total of about 200 m. From this depth the basement attains a fairly even SW dip towards the Landsort-Kappelshamn fault.

The tectonic history of the Utö-Fårö fault is similar to that of the Landsort-Kappelshamn fault and no vertical displacement was present between the two sides of the fault line at the onset of the Cambrian. In resemblance with the Landsort-Kappelshamn fault younger tectonic events have also occurred along the Utö-Fårö fault. The present day vertical displacement within the Cambro-Ordovician area is however quite small, and consequently this tectonic line is soon lost towards the SE.

C. The Landsort Trench. The Landsort Trench has been formed along fault lines of the N-S and NE-SW directions. The NE-SW fault line of the northern part of the Landsort Trench has a direct NE-continuation in a minor fracture valley that extends some 20 km outside the fault area. Towards the SW, no obvious continuation exists (cf. FROMM, 1943). The conditions are similar along the N-S fault line of the southern part of the Trench. Towards the N this fault line turns into a minor fracture valley, traceable about 15 km outside the fault area, while towards the S the fault line is lost in the much dissected area S of the Trench. Further towards the S a deeply eroded fracture valley of the same trend is present in the Paleozoic area.

In resemblance to the Utö-Fårö and the Landsort-Kappelshamn faults at least two periods of faulting are discerned along the Landsort Trench. During the first, late Jotnian (?), tectonic period the Jotnian sandstone was downfaulted and at the same time tilted towards the SW. It is probable that the vertical displacement along the Landsort Trench was about 200 m in the northernmost part and about 900 m in the southernmost part at the end of this tectonic period. The fault has probably been reactivated a number of times since the end of the Silurian. A Tertiary age is suggested for the final movements. The reactivation of the fault has led to a further subsidence of the Jotnian sandstone. At present the sub-Cambrian peneplain forms an almost horizontal surface at a depth of 200 m SE of the Landsort Trench, Figs 5 and 11. The horizontal part of the sub-Cambrian peneplain is restricted to the area NW of the Paleozoic boundary, Fig 5, while the Jotnian sandstone has a general SE to S dip below the Paleozoic. The horizontal sandstone block in the NW is separated from the SE part of the Jotnian sandstone basin by an E-W hinge-line, located W of Gotska Sandön, Fig 5. The seismic recordings reveal that an extensive fracturing of the sandstone has occurred in a 5 km wide zone along the Landsort Trench. The Landsort Trench itself has mainly been formed by repeated actions of selective glacial erosion during the Quaternary glaciations. The remarkably deep erosion supports the general concept of comparably late tectonic movements in the area. It must be anticipated that the fractures in the sandstone were to a large extent still open and unaffected by secondary cementation.

D. The Huvudskär-Kappelshamn and the Almagrundet--Fårö lineaments. Two lineaments of the N-S direction cross the Jotnian fault basin W of Gotska Sandön, Figs 5 and 9. The eastern of these, the Almagrundet - Fårö lineament, is represented by a partly deep fracture valley traceable from the region of Almagrundet in the N to half way between Gotska Sandön and Fårö in the S. A fracture of the same trend is found in the lowermost part of the Silurian sequence closely NW of Fårö. No vertical displacement has been discerned in the Silurian close to Fårö but it is not improbable that faulting has occurred in the Jotnian along this line, see Fig 11.

For a distance of more than 30 km between Gotska Sandön and Kopparstenarna the Almagrundet-Fårö line runs closely W of the Ordovician clint. Similar conditions occur along several other lineaments in the

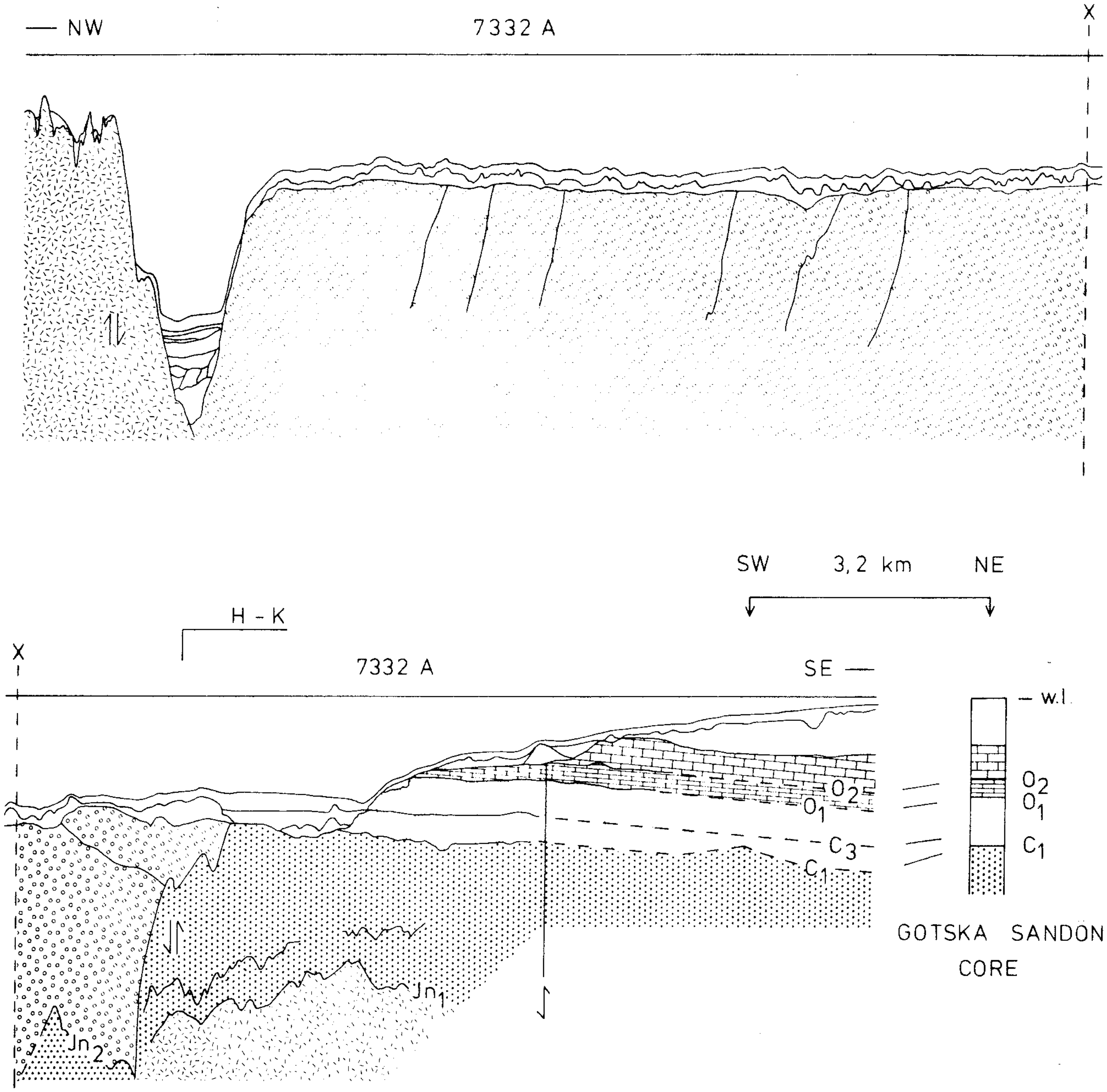

Fig 11. Geological section across the Jotnian fault basin from the Landsort Trench in the NW to S of Gotska Sandön in the SE. The horizontal scale is 1:250 000 and the vertical scale 1:10 000.

UPPER SECTION: The Landsort Trench is 5 km wide in the present section and the maximum depth to bedrock 580 m. The basic difference in geomorphology between areas of crystalline basement (NW of the Trench) and sedimentary rocks (SE of the Trench) is clearly demon-

Fig 11. ...

strated in the section. Six reflectors dipping about 10^{o} towards the NW are seen in the Jotnian sandstone unit SE of the Trench. These are interpreted as volcanic dykes.

LOWER SECTION: Jn_1 - bottom of the lower, possibly sub-Jotnian, rock unit, Jn_2 - bottom of the Jotnian sandstone unit, C_1 - Precambrian/Cambrian boundary, the sub-Cambrian peneplain, O_1 - Cambrian/Ordovician boundary, O_2 - approximate level of the Middle/Upper Ordovician boundary, H-K - location of the Huvudskär-Kappelshamn lineament. (From FLODÉN, 1977C).

Gotland area, e.g. the fracture that extends southwards from the S part of the Landsort Trench. It is evident that fractures in the Paleozoic rocks have governed the erosional pattern of the entire area to a large degree.

The western of the two lineaments, the Huvudskär-Kappelshamn fracture, has been traced most of the way from about 20 km E of Huvudskär to Kappelshamnsviken. North of the Jotnian fault basin the lineament is partly developed as a fracture valley. Within the Jotnian basin, faulting has occurred in this lineament, Fig 11. Two different periods of faulting are suggested, one Jotnian and one possibly Tertiary. During the first period of faulting, the sedimentary rocks W of the tectonic lineament were downfaulted. The vertical displacement increases towards the S within the fault basin.

The younger period of faulting only affected the N part of the lineament within the Jotnian fault basin.

Here the Jotnian sedimentary rocks were downfaulted W of the line in connection with the formation of the horizontal plain previously mentioned. Like the Almagrundet-Fårö lineament, the Huvudskär-Kappelshamn lineament is lost in the seismic profiles within the area NW of Fårö. The lineament is resumed further towards the S and is followed into Kappelshamnsviken. It can be assumed that this tectonic line extends across Gotland and possibly even further towards the S along the E coast of the island.

The Paleozoic (Cambrian and Ordovician)

The elongated area of Cambrian and Ordovician rocks that extends from S Öland past Gotland and Gotska Sandön to N Estonia, Fig 6, forms a marginal zone of the Baltic Syneclise. This zone is characterized by two different very even and persistant dips of the sub-Cambrian peneplain, Fig 8. The Jotnian fault basin divides the zone in two large blocks, a NW Baltic block with the main ESE dip and a NE Baltic block that dips in the SSE direction. Within the Jotnian fault basin itself the dip ranges from SE to S, Fig 5. E of Gotland the basement dip gradually increases towards the Liepaja depression in the northern part of the Baltic Syneclise. This main subdivision of the marginal Paleozoic area in the Baltic stresses the importance of the lineaments in the Landsort-N Gotland area. The tectonic block W of Gotland is part of the SE Swedish block that will be further discussed below.

The marginal Paleozoic area in the Baltic Sea is dominated by lineaments parallell to the strike of the basement. Thus, their direction is mainly ENE-WSW in the area E of Gotska Sandön, Fig 3, and NNE-SSW in the area W of Gotland, Fig 9. The vertical displacements are generally small, hardly anywhere exceeding 10 m. The downfaulted side is always directed away from the syneclise. The most persistant lineament parallells the Ordovician-Silurian boundary the entire way from S Öland to NW Gotland (Fig 9).

As mentioned previously, lineaments have been found that closely parallell the Cambrian-Ordovician boundary W of Gotska Sandön and also S of the Landsort Trench. These lineaments have evidently governed the erosional pattern in those areas. It is therefore not unreasonable to assume that e.g. Kalmarsund is also eroded along a tectonic lineament.

The presence of a lineament in Kalmarsund has been suggested by EHRENBORG (1977). Efforts have been made to distinguish a southward extension of this assumed lineament in the present seismic profiles, but the result was negative. It may, however, be worth mentioning that the SE coast of Bornholm as well as the SE limit of the Christiansö Horst (ANDERSEN, LARSEN and PLATOU, 1975, WANNÄS, 1977) roughly coincide with the extension of the Kalmarsund lineament as it is outlined by EHRENBORG (op. cit.).

In the area between Gotska Sandön and N Estonia only lineaments within the Paleozoic are included in the map, Fig 3. The Paleozoic boundary N of Estonia may indicate the presence of a tectonic lineament in the main Mälardalen-Gulf of Finland direction.

The Paleozoic (Silurian and Devonian)

Lineaments of different directions seem to be more abundent within the area of exposed Silurian and Devonian beds in the Gotland region than within the Cambro-Ordovician area, Fig 9. Probably this is only partially true as fractures of all kinds are more easily distinguished in the soft Silurian and Devonian strata than in the hard Ordovician limestone (for a comparison see Figs 1C and 1E). In resemblance to the Ordovician area, the vertical displacements are generally small, rarely exceeding some 20-30 m. The main directions of lineaments in the area around Gotland are N-S, NE-SW and NW-SE. Joints of the NE-SW and the NW-SE directions have been distinguished on Gotland (KAUFMANN, 1931), while the N-S direction is missing.

Lineaments of the N-S direction are found in two areas, NE of Gotland and S of Gotland. The N-S lineament 25 km E of Fårö has been subject to intensive erosion of the Paleozoic rocks, see Fig 6. The lineament is traced from the Paleozoic boundary NE of Gotska Sandön to the Silurian reef area E of Gotland. A lineament of approximatly the same trend has been proposed from magnetometric data by LEVCZENKO and MARTINOWA (1965) and later by e.g. BERZINA, KLAVINS and OZOLINA (1973).

In the area S of Gotland, several of the lineaments have a larger extension than shown in the present map. Towards the S, they commonly reach the limit of the investigated area while towards the N they are lost in the shallow water area close to Gotland. The western of the two N-S lineaments in this area probably extends along the Gotland coast as far N as Högklint. It may even form a direct continuation of the lineament that extends southwards from the Landsort Trench. The distinctly different trends in the Gotland coastline coincide to a large degree with the lineaments found at sea. Undoubtedly, the details of the coastline result from a close relationship between tectonic lineaments and geomorphology.

The lineament map of EHRENBORG (1977) contains SW-SE lineaments. One of those extends from the area S of lake Vättern in the NW to the Borgholm area on Öland in the SE (see also RÖSHOFF and LAGERLUND, 1977, Fig 3). This line may have a continuation E of Öland where a lineament of the same trend has been found in the lower Silurian.

In the present map, Fig 9, two fault lines are suggested in the area SE of Öland (dashed lines). These lineaments are adopted from DADLEZ (1974). The mainly NW-SE of these inferred lineaments conforms approximatly with lineaments in EHRENBORG's map.

The tectonic block of SE Sweden

The tectonic block in the area W of Gotland forms a continuation of the large block in SE Sweden. The large scale tectonic pattern on land has recently been discussed by STEPHANSSON and CARLSSON (1976) and RÖSHOFF and LAGERLUND (1977).

The W limit of the SE Swedish block extends from the northern part of lake Vättern to the margin of the East European Platform in the S. The N limit is formed by the Motala-Söderköping lineament in the Motala area and by the Norrköping fault further towards the Baltic coast. Outside the coast the Norrköping fault is the southernmost of the four lineaments that merge into the Landsort-Kappelshamn line at the S end of the Landsort Trench, Fig 3.

The S limit of the block is more difficult to distinguish. Investigations in the Hanö Bay (KUMPAS, 1977) show that the present day erosional boundary of the Paleozoic rocks S of Öland was mainly established already at the beginning of the Mesozoic. The crystalline basement in the Hanö Bay together with the Paleozoic area further E seem to have been a part of a sub-Mesozoic peneplain at that time. The dip and strike of the Paleozoic sequence in the area S of Öland is approximatly the same as further N. During the Mesozoic, the Hanö Bay was subjected to subsidence in connection with the formation of the horsts in the Fennoscandian Border Zone. Southwards from the Blekinge coast to the Långagrund-Christiansö horst, the basement today exhibits a general increase in dip towards the S.

With the present method of investigation, no detectable lineaments or hinge lines separate the Hanö Bay basin from the SE Swedish tectonic block. However, from irregularities in shore level diagrams on land, MÖRNER (1977A, Fig 21 and 1977B, Fig 3) suggests the presence of an E-W hinge line in the Bergkvara area S of Kalmar. The location of this line is supposed by him to coincide with the boundary between Gothian granites in the N and the Blekinge gneisses and granites in the S. The presence of a hinge line in this area is in good agreement with the general arrangement of the Blekinge-Hanö Bay area. Thus, the Blekinge area should probably be excluded from the SE Swedish tectonic block.

The E limit of the block is also indistinct. As previously mentioned, the dip of the sub-Cambrian peneplain is very constant in the area W of Gotland, while E of the island the dip increases irregularily (Fig 5). The NNE-SSW lineament that runs from the area SE of Öland to the NW coast of Gotland, Fig 9, should possibly be regarded as the E limit of the block. On the other hand it must be pointed out that at present there is no evidence that this lineament marks any important zone in the basement below the Paleozoic.

The evolution of the Baltic Syneclise is important for the discussion of the Paleozoic tectonic events in SE Sweden. The pre-Paleozoic events are comparably well recorded. In the Landsort area the Jotnian sandstone was downfaulted prior to the formation of the sub-Cambrian peneplain and in the Vättern area the Riphean deposits were most probably downfaulted prior to the same event.

The Paleozoic events are also comparably well established in time. The initial stage in the development of the Baltic Syneclise took place during the early Cambrian. The next stage is ascribed to the early Silurian, while the main stage took place in the late Silurian-early Devonian. The late Silurian-early Devonian stage was followed by faulting in the area SE of Gotland (e.g. VOLKOLAKOV, 1977), while the late Paleozoic evidently was a tectonically stable period in the central Baltic area.

The majority of the fractures in the Paleozoic of the Gotland area may have originated already during the late Silurian-early Devonian tectonic stage. SE of Gotland, fractures in the "Neman Zone" extend through the Devonian strata. These fractures may be comparably young, possibly Tertiary.

The "Neman Zone" SE of Gotland (EFENDIYEVA, 1967) and its extension in SE Sweden, the Värmland-Västervik Zone (STRÖMBERG, 1976), extends through the SE Swedish block. As previously discussed, the zone has not with certainty been identified within the Paleozoic W of Gotland. MÖRNER (1977A, Fig 21) demonstrates a shore-line bend in the Värmland-Västervik zone - or more specific in the Ukna-Loftahammar fault. The existance of the zone should therefore not be doubted, while its importance for the discussion of the SE Swedish block seems to be small.

The Mesozoic and Paleozoic of the Hanö Bay

As previously mentioned, the Paleozoic rocks are restricted to the easternmost part of the Hanö Bay. Their western, erosional, boundary follows roughly the S prolongation of Kalmarsund (KUMPAS, 1977). In the area closely S of Öland the Paleozoic rocks attain about the same dip and strike as in the Öland region and in resemblance to that area only minor fractures occur. Further towards the S, the Paleozoic rocks have been subject to intensive faulting along E-W and NW-SE lineaments, Fig 9. This fault area is characterized by strongly tilted blocks that prohibits an identification of the different Paleozoic units from this area and southwards. As shown in Fig 9, the lineaments are restricted to the Paleozoic area and none of them have been traced into the central parts of the Hanö Bay. Their eastern extension in the present map coincides with the boundary of the investigated area.

KUMPAS (1977) has shown that the upper surface of the Paleozoic rocks forms part of a sub-Mesozoic peneplain as well inside as outside the fault area. The lineaments are thus of a late Paleozoic age, not older than the late Silurian-early Devonian period. The lineaments have been reactivated during later tectonic periods.

The Mesozoic sediments form a wedge-shaped deposit in the Hanö Bay. The largest thickness, about 1000 m, is found along the Långagrund-Christiansö Horst system (ANDERSEN, LARSEN and PLATOU, 1975 and WANNÄS, 1977). The Mesozoic in the central parts of the Hanö Bay is according to KUMPAS (1977) mainly free of fractures. The basement is rather even and no obvious pre-Mesozoic lineaments have yet been found. The direction of the downfaulting, indicated in Fig 9, for the previously described lineaments in the easternmost part of the Hanö Bay refers to the reactivation of the lineaments. The faulting probably occurred during the Tertiary (DADLEZ, 1974 and KUMPAS, 1977).

The NW-SE system of horsts in the Fennoscandian Border Zone form the SW border of the Hanö Bay sedimentary basin. In the Bornholm Gat the Border Zone is crossed by a major NE-SW tectonic structure (WANNÄS, 1977). In the Christiansö Horst N of Bornholm, the crystalline basement forms the sea bed in an elongated area trending NW-SE, see Fig 6. The vertical offset along the NE limit of the Christiansö Horst is close to 1000 m. The horst is strongly tilted towards the SW. Between Christiansö and Bornholm is found an area of faulted Mesozoic sediments dipping in the same, SW, direction. These sediments are assumed to range from the Triassic to early Cretaceous. The Långagrund Horst in the Bornholm Gat is formed along the same lineaments as the Christiansö Horst, but according to the investigation performed by WANNÄS (op. cit.) it is a deep lying structure, that only rises some 200 m above the basement in the SW part of the Hanö Bay. Similar conditions have been found in the Hammervand Horst area. The SE coast of Scania is followed by a complicated NE-SW fault. A detailed investigation of this lineament and its structural connection to the

NW-SE lineaments in Scania is still missing.

NEOTECTONIC FEATURES

The present investigations in the Baltic area are concentrated on the sedimentary rock sequence. The seismic equipment is intended to penetrate the sedimentary rocks to depths of several hundred metres. This means that the resolution in the uppermost layers is comparably poor in comparison to those instruments that are only intended to penetrate the Quaternary sediments. An echosounder, with a comparably low operating frequency of 30 kHz was used in addition to the present seismic profiling equipment. This echosounder only penetrates clayey sediments to a maximum depth of 30 m below the sea bed.

The purpose of the present inspection of recordings from the Baltic Sea was to ascertain whether or not neotectonic events can be identified in the present seismic and echosounding records. For this reason, about 5 000 km of echosounding records have been evaluated. The records were chosen from three different areas namely; within the Landsort Trench area, within the "Neman Zone" SE of Gotland and within the fault area in the easternmost part of the Hanö Bay. Only a very limited number of structures were found in the two areas SE of Gotland and in the Hanö Bay S of Öland. No structures were found in the Landsort Trench area. It is doubtful whether all of these structures have resulted from neotectonic movements or if some of them have a different explanation.

Two structures are presented from the area SE of Gotland. The Fig 12A shows an irregularity in the

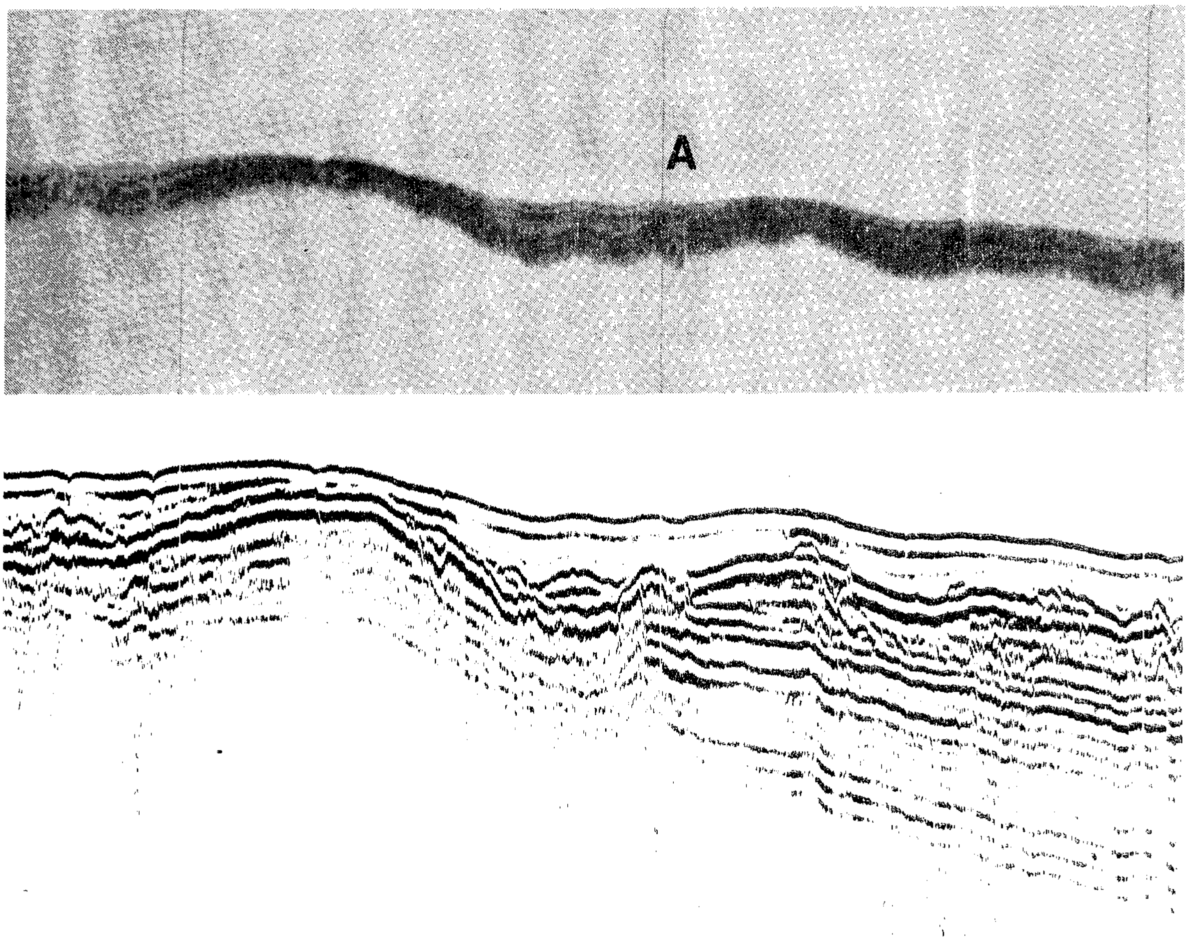

Fig 12A. Echosounding section (upper) and seismic section (lower) from the area SE of Gotland. The structure at (A) in the upper record may originate from neotectonic activity.

glacial clay (A, upper section). This irregularity corresponds to an almost negligible structure in the sedimentary rock sequence (lower section) that may be interpreted as a minor crack. A more promising structure in the glacial clay is given in Fig 12B (A in the upper section). The bedrock below exhibits structures that may be interpreted as minor cracks. It is however obvious that the very distinct structure in the clay sediment has another main explanation.

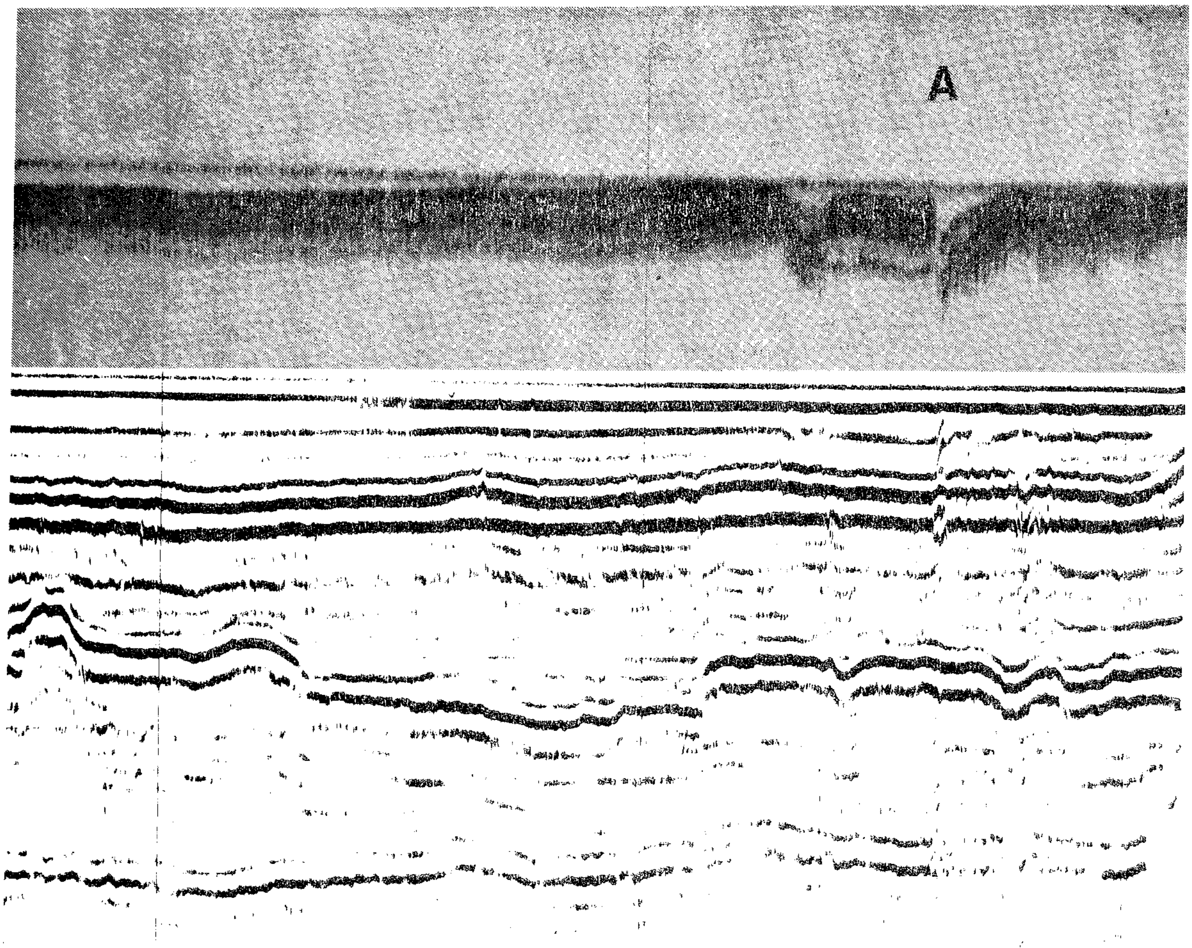

Fig 12B. Irregularity in the Quaternary sediments (A).

The lineaments within the fault area S of Öland may usually be followed in the seismic records as well as in the echosounding records, A in Figs 12C and 12D. In the Fig 12C, it seems obvious that movements have occurred in the glacial and post-glacial sediments, while this is not the case in Fig 12D. However, the lineaments in this area are usually eroded as shown in the seismic records. In Fig 12C, the maximum thickness of the Quaternary sediments is about 90 m within the erosional trench as compared to 20-25 m on the two sides. It must therefore be anticipated that the structure A in

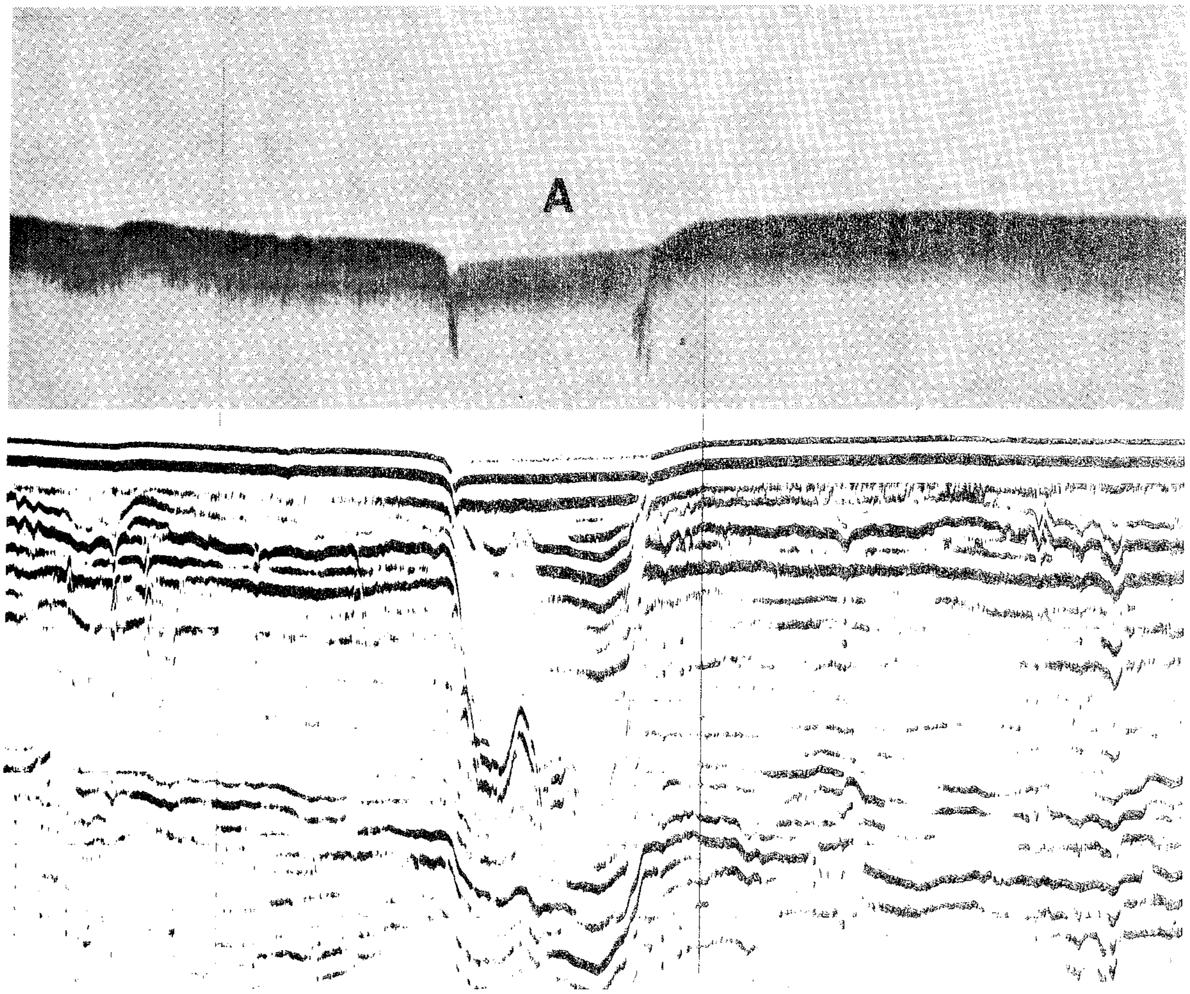

Fig 12C. Tectonic lineament in the area S of Öland. The structure in the echosounding record is probably mainly a result of compaction in the sediment.

Fig 12C primarily results from compaction of the sediments in the erosional trench. Neotectonic movements may well have occurred, but the records offer no positive evidence in this respect. The structure marked B in the echosounding record, Fig 12D, coincides with a fracture in the sedimentary rock sequence and thus, it may be of tectonic origin. The structure marked C in the same record indicates a recent fault with an offset of about 1 m. Similar structures were found in three other separate profiles from the same area S of Öland. Note that the

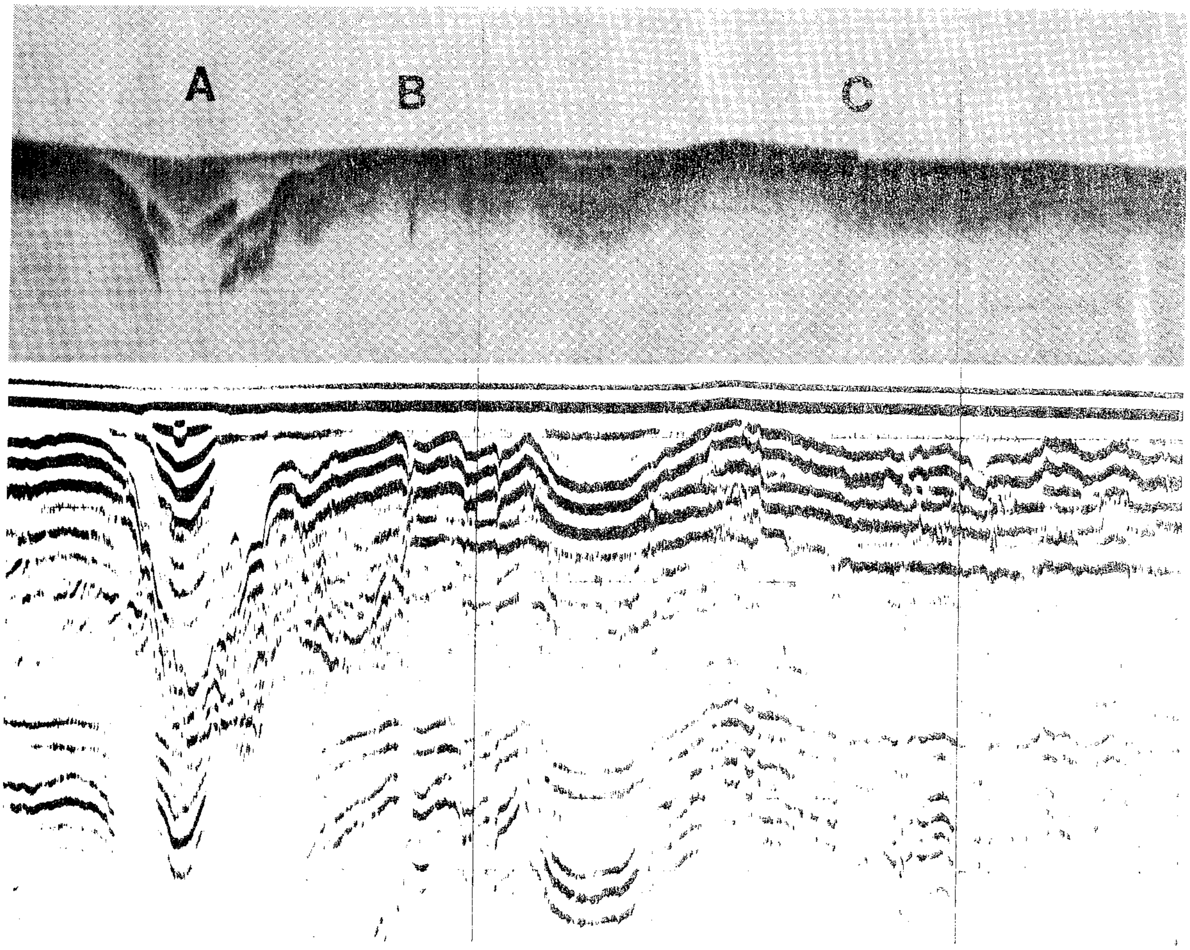

Fig 12D. Tectonic lineament in the area S of Öland.
A - lineament in the sedimentary rock,
B - and C - structures in the Quaternary that may be associated with neotectonic events.

offset (C in Fig 12D) is too small to be recorded in the sea bed of the seismic section and that the corresponding fracture in the sedimentary rock sequence is hardly visible.

The present inspection of echosounding records from the Baltic Sea has given only a very limited number of structures that are interpreted as resulting from neotectonic activity. The comparison between corresponding echosounding and seismic records has shown that distinct structures in the clay often have other explanations than tectonism and thus, that merely echosounding is insufficient for the identification of neotectonic structures.

LAGERBÄCK and HENKEL (1977) demonstrate a number of neotectonic structures in N Sweden. This neotectonic activity seems mainly to have occurred in connection with the final withdrawal of the ice sheet and the events are recorded in the till (LAGERBÄCK and HENKEL, op. cit., Fig 4). Structures of this kind are unlikely to be identified in the present records due to the limited penetration of the echosounder and to the poor resolution of the seismic profiler. A certain improvement in this respect may possibly be achieved by a further signal processing of the present seismic data. Despite these technical imperfections, structures that can be associated with neotectonic activity seem to be extremely rare within the areas so far examined. The following tentative conclusions are drawn:

- Neotectonic lineaments occur in the Baltic Sea.

- Only occasional neotectonic movements have occurred since the deglaciation period.

- The majority of the pre-Quaternary fractures in the Baltic Sea show no evidence of Neotectonic activity.

Table I. Geological time table. (According to VAN EYSINGA, 1975).

Era	Period	Geological time (M.Y.)
Cainozoic	Quaternary	
		1.8
	Tertiary	
		65
Mesozoic	Cretaceous	
		141
	Jurassic	
		195
	Triassic	
		230
Paleozoic	Permian	
		280
	Carboniferous	
		345
	Devonian	
		395
	Silurian	
		435
	Ordovician	
		500
	Cambrian	
		570
Proterozoic	Vendian	
		650
	Riphean x)	
		1600

x) The Visingsö Beds in lake Vättern are of a late Riphean age (750-800 M.Y.), while the Jotnian sandstone is of a middle Riphean age (900-1100 M.Y.).

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