GEOLOGINEN TUTKIMUSLAITOS

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ON THE PRE-QUATERNARY GEOLOGY OF THE BOTTOM OF THE BOTHNIAN SEA

BY

VALTO VELTHEIM

WITH 30 FIGURES IN TEXT AND ONE PLATE

ACADEMICAL DISSERTATION

HELSINKI 1962

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ERRATA

Page	18,	line 23;	for glaci-fluvial read glacio-fluvial.
»	25,	» 7;	for Quarternary read Quaternary.
»	34,	table, Vaasa, Granite;	for 61 % read 51 %.
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»	41,	Fig. text;	for lowed read lowered.
»	42,	line 16;	for proof read piece.
»	44,	lines 36 and 40;	for 1906 read 1908.
»	45,	line 15;	for another read other.
»	46,	» 15;	for sedimentogeneous read sedimentogenic.
»	48,	» 18;	for 1,170 read decimals in smaller print.
»	51,	Sample V 5;	for granitedi read granite.
»	70,	» L 69;	for hade read had.
»	77,	» L 89;	for limetsone read limestone.
»	77,	» L 91;	for garned read garnet.
»	90,	» L 119;	for fellows read follows.
»	90,	» L 119;	for rondedness read roundedness.
»	113,	» H 10;	for deeper read greater.
»	120,	Fig. 19, L 160, fraction 8—16 mm;	line points to 32 % instead of 23 %.
»	151,	» 29, Sample L 72;	for 1.1 read 0.91.
»	151,	» 29, Sample L 77;	for 0.98 read 0.48.
»	156,	Fig. text;	for rests read remnants.
»	162,	Gylling;	for Finland read Finnlands.
»	163,	Kanerva;	for Rapakivigebietet read Rapakivigebiet.
»	165,	Stollry;	for Natuw. read Naturw.
»	165,	Tanner;	for fossilienführenden read fossilienführendem.
»	165,	» ;	for Kirshspiel read Kirchspiel.

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Helsinki, February 1962.

Valto Veltheim

ABSTRACT

The present experimental study is based on evidence obtained on land showing that in areas covered by ancient continental ice the drift is to a large extent of local origin so that the quality of the rock ground is determinable from the composition of the drift with a great degree of probability. A geological map based on the bottom samples has accordingly been sketched of the Bothnian Sea area.

Echo sounding has been made use of in determining the quality of the bottom at the sample points as well as for the interpretation of the morphological picture of the sea bottom.

In order to obtain a uniform interpretation basis as well as a statistically adequate amount of stone grains from each sample, 2—16 mm has been chosen as the grain size for the pebble counts.

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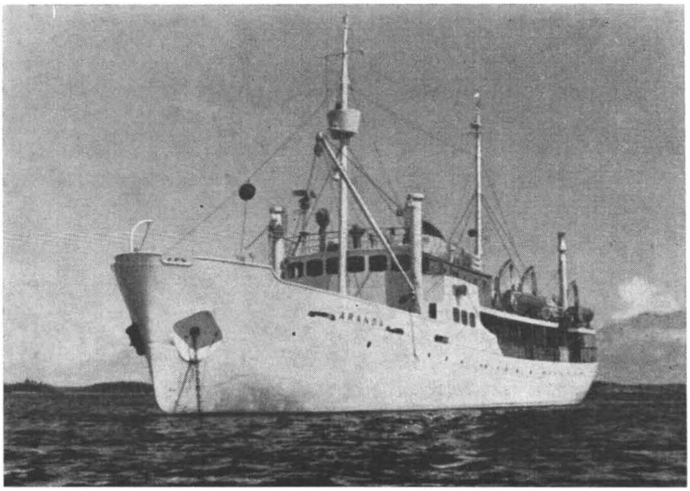

Fig. 1. The Finnish research vessel M/s Aranda.

INTRODUCTION

On the geological map of Fenno-Scandia, which is one of the geologically best known parts of the world as the classic region for Archean bedrock investigations, the Baltic Sea and its bays still form a »blank region». This fact is all the more remarkable since it is known that important geological boundaries are situated in the area of the Baltic basin. The northern coast of the Gulf of Finland consists entirely of Archean bedrock, the southern side, the coast of Estonia, on the other hand, contains Paleozoic sediments. The boundary line between the two runs within the marine area. A similar state of affairs exists also in the central Baltic, between the east coast of Sweden and the Baltic States, Gotland and Öland.

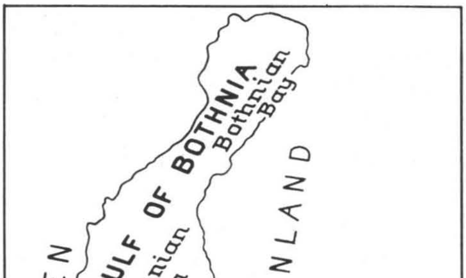

Fig. 2. The Baltic Sea.

Archean bedrock is the dominant rock type on each side of the Gulf of Bothnia. It is believed that certain large scale geological features extend along the sea bottom connecting both sides of the Gulf. Judging in particular by the boulder findings made along the coastal areas of the Bothnian Sea, it has long since been possible to deduce that rock types that are rare or totally non-existent in the surrounding coastal regions exist or have existed on the sea bottom.

Since the interpretation of the quality of the covered bedrock on the basis of drift investigations has yielded positive results on the mainland, and considering, on the other hand, the high technical level of the general marine research today, it could be expected that advanced interpretation possibilities concerning the sub-marine bedrock, would appear when based on material received from the marine area itself.

The present investigation is to a very large extent pioneering work. The author is well aware of the fact that inadequacies, and very possibly also erroneous interpretations, may be found in his conclusions. The disproportion between the small number of observation points and the extensiveness of the area under study is obvious. It is all the more satisfactory that in many respects it has nevertheless been found that the various investigations have resulted in a logical total composition.

The author's interest in the research on the bedrock of the sea bottom derives from the Bothnian Bay area, where he started collecting stones as early as in 1953, originally without any specific purpose in mind. This varying collection consisted of stones likely to have their origin in the bottom of the sea (Veltheim, 1958). Since some of the collected boulders contained a relatively high percentage of ore (sandstone impregnated by sphalerite and galena) the author's interest in the possibility of explaining the origin of the boulders with the help of bottom samples taken from the outer marine area was aroused.

The preparatory trial research work was, however, carried out in the Bothnian Sea. The reason for this lay in the fact that in the western part of this area, in the region of the Finngrunden shoal, the existence of a Paleozoic limestone formation distinguishable from its surroundings could be assumed on the basis of investigations made by Gripenberg in 1934 and of echo soundings made by Ignatius (Ignatius and Veltheim, 1959) in the early part of the summer 1958. Experimental research carried out in this region could thus be assumed to give positive interpretation possibilities in the comparison of the bottom samples and the bedrock.

The first bottom samples (the V samples) were taken on the Finngrunden shoal in July 1958. In view of the positive results obtained, samples were taken during the same summer also from the sub-marine ridge north of Finngrunden (the K samples), in front of the Finnish coast (samples P 1—6)

Ceratopyge limestone
Ceratopyge shale and »Stinkkalk»
Obolus sandstone
Olenellus sandstone
Algonkian sandstone

It is worth noting that the Cambrian system is represented only by the lower Cambrian Olenellus sandstone. From the Olenellus sandstone onwards the whole series belongs to the Ordovician period *.

Solid rock discoveries of the following components of this series have been made: Algonkian sandstone on the mainland and on the islands of the Gävle Bay, Olenellus sandstone at Wattholm which is situated approximately 18 kilometers north of Uppsala, Ceratopyge limestone on the Limö island, and Planilimbata and Limbata limestone on the islands of the Gävle Bay.

There is a remarkable consistency in the appearance of the erratic boulders. On the south coast of the Gävle Bay are found mainly representatives of the more ancient sediments, Olenellus sandstone (Limö, Biludd), Ceratopyge shale (Biludd) and Limbata limestone. Along the eastern part of the Uppland coast, between Öregrund and Norrtelje, there is, on the other hand, an abundance of younger Orthoceras limestone and Chasmops limestone boulders and, especially on the north part of the coast, boulders of Baltic limestone. A stone count that was made south of Öregrund, at Mälby, gave a result of 63 % of Silurian limestone, chiefly including the above mentioned types of stone. It should be noted that considerable amounts of Obolus sandstone have only been found on the Fanton island, which is situated south of Öregrund.

Only occasional boulders of the following limestone types have been found: Ceratopyge limestone (6—8 boulders), Macrourus limestone (»einige wenige Geschiebe»), Leptaena limestone (4 boulders) and Gigas limestone (1 boulder).

The author has taken the liberty of quoting Wiman's own words on the main points of the part of Wiman's valuable research which deals with the occurrence of Paleozoic formations on the bottom of the sea (Wiman, 1905, p. 36): »Dass sich das Vorkommen der kambrisch-silurischen Schichten im Meerbusen von Gefle nicht besonders weit ausserhalb Eggegrund» ... »streckt, halte ich für wahrscheinlich» ... »Innerhalb dieses Gebietes finden sich hauptsächlich ältere Schichten, Olenellussandstein — Limbatakalk. Ein anderes, weit grösseres Gebiet, vorzugsweise die jüngeren Schichten,

* Both Wiman and some later experts on this region include the Ordovician system into the Silurian one, thus following a classification no longer in use. In referring to the writings in question the author has not wanted to make any change in this respect.

Limbatakalk — Ostseekalk umfassend, dehnt sich zwischen einerseits dem südlichsten Teil von Gräsö, Singö und dem Väddöland und anderseits Åland aus.»

In addition, Wiman's assumption that the Ceratopyge shale in the Gävle Bay had become deposited directly upon the Cambrian Olenellus sandstone is worthy of note. Wiman has further pointed out the general shortage of shale among the sediments.

Concerning the appearance of the shale boulders on the northern coast of Uppland, there is, however, later information available. From Hessland's (1949) description it is apparent that Cambrian alum shale and Ceratopyge shale boulders may in some places be rather common — even in such a degree that a solid Cambrian alum shale formation is supposed to exist quite close to the coast (in front of Biludd).

At a comparatively early stage loose boulders had been found at Åland, the parent rock of which was assumed to lie outside the island. As early as in 1878 Wiik stated that he had discovered fossiliferous limestone boulders. Later at least the following scholars have given similar information: De Geer (1881), Schmidt (1881), Wiik (1881), Holm (1886 and 1893), Moberg (1891), Wiman (1894), Stolley (1897), Schmidt (1898), Hausen (1911), Metzger (1922 and 1927).

The limestone boulders that were discovered on Åland mainly consist of Orthoceras limestone, Chasmops limestone and Baltic limestone. But findings of Olenellus sandstone have also been made there. In connection with his stone counts Hausen (1911) proved that the proportion of Silurian limestone in the till does not as a rule amount to more than two or three percent. Only at the western part of the island, at Eckerö, does it rise to 12 %. Considering the fact that limestone boulders are quite frequently found on the shores of the Åland islands the result is surprising. Hausen, however, assumes that the limestone in the till has been pulverized and the assumption is strengthened by the high lime content of the till.

The Jotnian sandstones show comparatively high percentages in all Hausen's stone counts in the whole of Åland. Their average proportion amounts to 20 % and might in some cases rise to 40 %. Hausen also makes observations on the porphyry and rapakivi boulders in his stone counts. The amounts of the former seem to vary up to some percent. Kattby in Hammarland is an exception. There the proportion of porphyries (Hausen's »post archean eruptives») amounts to 21 %. It is self-evident that the amount of rapakivi is also very high throughout the region, although, unexpectedly, the amount is largest on the northern part of the main Åland island (Geta, 55.9 %).

The lime content in the Åland till has later been investigated by Eklund (1935). On the basis of the investigations Eklund assumed that there is a

Paleozoic limestone formation in the southern part of the Bothnian Sea, north of Åland.

References to post-Archean sediment boulders found in the southwestern part of Finland and in the nearby archipelago also appear. Holm (1893), among others, mentions a fossiliferous Cambrian sandstone boulder which was found by Sederholm in the Turku archipelago. Metzger (1927) states that there is plenty of Baltic limestone in the Turku archipelago. Likewise Hellaakoski (1930) reports the finding of a boulder of Paleozoic limestone in the Laitila region.

Hausen (1912 a) studied the origin of the porphyry boulders found in the western and southwestern parts of Finland and came to the conclusion that their parent rock, probably a rather extensive formation, is located at the bottom of the sea, to be more exact in the northern part of the Bothnian Sea south of Merenkurkku (Norra Kvarken).

Eskola (1928) has given an account of the origin of the rapakivi boulders that appear along the coastal region of the Bothnian Sea right up to Vaasa in the north. According to Eskola, the rapakivi boulders have their origin at the bottom of the Bothnian Sea. He notices the fact that findings of rapakivi boulders are made in the same region where the above mentioned porphyry boulders had been found, this applies also when these rocks appear in solid rock. It is worth mentioning that Eskola is the first to give a summary of the observations that had been made about the bedrock of the Bothnian Sea up to that time.

On the Finnish coast of the Bothnian Sea the abundance of Jotnian sandstone in the drift has been the subject of observations for a considerable time. Besides appearing on the shores, sandstone is also found comparatively far inland. In his explanations to the Tampere map sheet Sauramo (1924) expressed the belief that these stones come from »the depths of the Gulf of Bothnia».

The solid formation of sandstone stretching down to the coast of Satakunta is of importance to the research of the sea bottom. Laitakari (1925) presumed that the formation extended westwards and that it covered quite a large part of the Bothnian Sea.

In the stone counts that are presented in connection with the explanations to the Vaasa map sheet (Mölder and Salmi, 1955), a Jotnian sandstone component appears continuously and its proportion, especially to the south of Vaasa, is remarkably large. The authors support the idea expressed by Laitakari (1942) that the parent rock of these sandstone boulders is to be found on the sea bottom outside Vaasa.

Both Laitakari (1925) and Hellaakoski (1930) have noticed the fairly regular appearance of a more fine-grained pale sandstone in addition to the Jotnian sandstone. On the basis of fossils the sandstone proved to be Cambrian. Since the parent rock of this formation was in all probability not to be found on the mainland this was a case of boulders that had drifted from their sub-marine parent rock.

Taking the general movement direction of the continental ice sheet into consideration, it becomes clear that one cannot expect to find stone material that has drifted from the sea on the western coast of the Bothnian Sea, at least not to the same extent as on the eastern coast. Nevertheless, boulders presumably originating from the sea have been found also on the Swedish coast.

In this respect the investigations made by Schön (1911) regarding the appearance of »Silurian» boulders on the Brämö island, which is situated southeast of the town of Sundsvall, are very remarkable. The same applies to the discovery of similar boulders on the small Gran island 20 kilometers south of Brämö. In both places plenty of limestone boulders have been found, while such boulders appear very occasionally in the corresponding regions on the mainland. Schön presumes that the parent rock is situated on the sea bottom outside the coast of Medelpad. Most of these boulders are of red Orthoceras limestone. Baltic limestone has been discovered in small amounts only on the east coast of the Brämö island. Lime-sandstone boulders, in which Schön has found shells of Obolus fossil, appear on the aforementioned island among the limestone boulders.

On the basis of the investigated boulders Schön has constructed the following sediment series:

Baltic limestone
Orthoceras limestone
  Platyurus limestone
  Asaphus limestone
  Limbata limestone
  Planilimbata limestone
Obolus sandstone

As this series to some extent corresponds to the series that has been discovered in the Uppland area (Wiman, op. cit.), Schön has assumed that a continuous formation formerly probably extended as far north as Sundsvall.

There are, however, more recent observations about limestone boulders that have been found farther north. Hörnsten (1959) has come across numerous Limbata limestone boulders belonging to the red Orthoceras limestone group, among other places on the south coast of the Härnö island, near Härnösand. The direction of the continental ice sheet movement there has been proved to have been N36°W. Since there have been no findings of limestone boulders on the western side of the island or on the mainland, which is facing the arrival direction of the ice, Hörnsten assumes that the boulders were probably carried with an earlier glacier which came from the east or from a northeasterly direction.

In this connection a certain earlier reference (Lindström, 1888), to the appearance of red limestone on two small islands south of Härnö is worth noting. These findings might, as far as their origin is concerned, be placed in the same category as the above mentioned boulders. Lindström does, however, mention that he has found sporadic limestone boulders »dark grey Silurian limestone containing Orthoceratites» in the Tuna esker which is situated approximately 20 kilometers west of the coast. He has also made similar findings in the region of Torphammar, which lies at a distance of approximately 65 kilometers from the coast. Lindström presumes that the limestone material in both these cases originates in the Paleozoic formations of the Scandinavian mountain chain.

The assumption made by Gripenberg (1934) that a solid »Silurian» limestone formation is to be found in the region of Finngrunden must be considered a very significant milestone in the research of the bedrock of the Bothnian Sea. Gripenberg came to this conclusion because of the limestone grains that had been discovered among the soft sediments of the sea bottom and because of the high lime content of the sediments. Likewise, Gripenberg assumed that the sub-marine ridge situated north of Finngrunden, the sediments of which were also found to have a very high lime content, in all probability indicated a limestone sediment located at the bottom of the sea.

Inspired by Gripenberg's research results, Lundqvist (1935b) drew a map of the Cambro-Silurian formation on the bottom of the Bothnian Sea. On the map the formation covers a fairly large part of the western marine area, i.e. from Gävle up to north of Härnösand. The formation extends from the coast to approximately Long. 19°E in the east. Another smaller formation, based upon observations made by Hessle (which the author regrets he has been unable to obtain) is situated farther east, outside Pori.

A geological map of a more general character, dealing with the southern part of the Bothnian Sea, was produced a little later by Backlund (1937). Besides the Cambro-Silurian formations, Backlund has sketched a region containing Jotnian sandstone, areas of different rapakivi types and sediments of the Noppi series.

ON THE GENERAL CONDITIONS OF SUB-MARINE BEDROCK RESEARCH WITH SPECIAL REGARD TO THE BOTHNIAN SEA

GLACIAL DRIFT IN RELATION TO SOLID BEDROCK

The absolute distance travelled by the glacial drift from its source and the qualitative correlation between the bedrock and the drift have for long presented a problem of interest to Nordic Quaternary geologists. Lundqvist (1935 a) presented the historical development of this branch, the different methods used in the research work and — principally on Swedish territory — the results achieved. Kivekäs (1946) published a summary of the work carried out on the Finnish side, together with extensive investigations of his own. Among later investigations carried out in Finland should be mentioned those by Okko (1945, 1949), Mölder (1948), Saksela (1949), Aurola (1955), Kauranne (Simonen and Kouvo, 1955), Repo (1957), Virkkala (1958), Hyvärinen (1958) and Matisto (1961). Lundqvist (1951) has also done some extensive and varied research work in the matter in the region of central Sweden.

The investigations have produced relatively uniform results establishing that drift generally derives from a fairly close-lying source. The relation between bedrock and drift is, however, dependent on various factors which may vary a great deal according to circumstances, and which should be known for purposes of interpretation.

In areas once overlaid by a continental ice sheet the present rock surface is mostly covered by drift removed by the ice from the bedrock. Ice, or glaci-fluvial streams in the ice, have transported the drift varying distances from its original site and it has been deposited on its present site not later than at the end of the deglaciation phase. Drift that has been transported only with the ice is called till. The till is chiefly unsorted and includes also the material within the finest grade sizes. The stones and grains in the till are generally rather poorly rounded. From the drift that has, at some stage, been transported by the water currents, the water has washed away the finest material and the stone grains have become rounded in the course of their journey. It is generally believed that this, i.e. the sorted drift, has travelled a somewhat longer distance than the till.

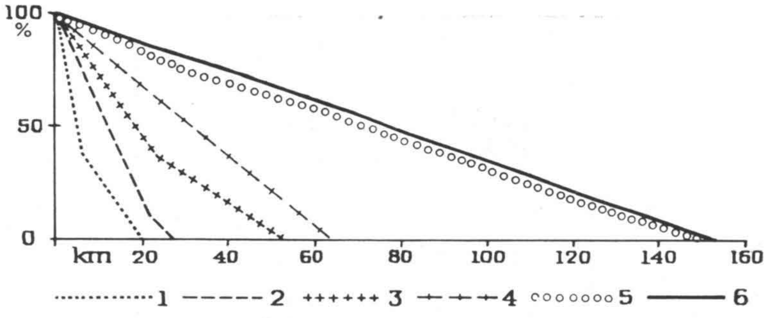

Fig. 3. The relative obliteration speed of different rock types according to experiments as compiled by Lundqvist (1935 a). 1 Rhaetic sandstone, 2 shale, 3 pre-Cambrian limestone, 4 Orthoceras limestone, 5 Jotnian sandstone, 6 granite.

Since glacial drift has in all instances been transported from its original site, it is obvious that it has been subjected to wear during this stage. The degree of wear does, presumably, depend on the absolute resistance of the rock in question, as well as on the mutual relative resistance of the different rock types. It seems evident that less resistant rocks are ground to pieces and obliterated from the stone material faster than are resistant rocks. Lundqvist and Virkkala investigated the relative speed of obliteration of different rocks. The question was graphically illustrated by Lundqvist's (1935 a) experiment, Fig. 3, which shows the relative wearing speeds of different rock types.

Within the glacial transport it is, presumably, thus possible to speak of a »reduced transport distance», which would indicate a transport distance reduced owing to the lack of resistance in the rock, the distance being shorter — often quite considerably so — than the more or less theoretical distance which the material could have travelled owing to the transport potential of the continental ice.

On the basis of the distance transported, the material is divided into local and long distance transported material. Lundqvist (1957) holds the opinion that the former consists of material which has its source in the vicinity and which has been transported not more than some score kilometers (»högst någon mil», mil = 10 km). The long distance transported material, on the other hand, has, according to Lundqvist, been transported by the ice at least 50 kilometers (»åtminstone 5 mil»).

It hardly seems possible to determine a maximum distance for the transported boulders. It is common knowledge that boulders found in central Europe have been proved to have their origin in Fenno-Scandia. It should be noted, however, that these boulders are so rare that they are

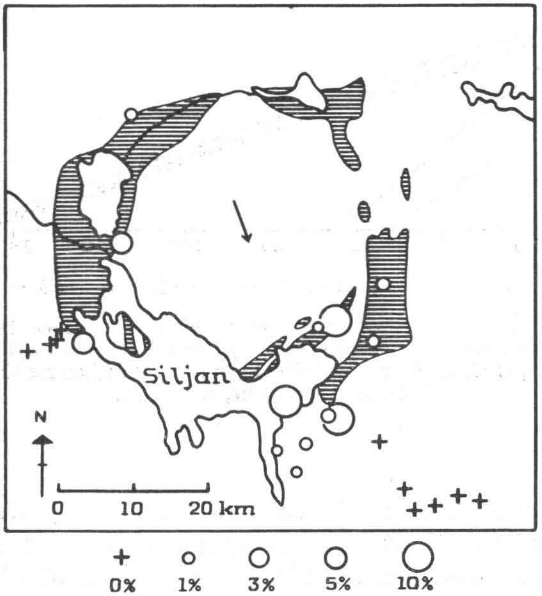

Fig. 4. The distribution of limestone boulders from a Silurian formation in central Sweden. Lundqvist, 1951.

hardly definable as a group of their own in the ordinary stone counts. Material that has been transported from afar, even if it is small in quantity, may nevertheless be of significance in the interpretation of the extent of a solid formation. A direct logical relation presumably exists between the size of the formation and the frequency of boulders.

On the distal side of a solid formation, however, a culmination point in the boulder frequency may be found, which can be considered as dividing the material into two parts also from the point of view of transportation distance. In normal cases the boulder frequency in a boulder fan declines primarily rather steeply (to 5—10 %), subsequently the frequency decline generally decreases, however, and stone percentages amounting to only a few percent no longer seem to have a correlation capable of interpretation as to quantity and the length of the transportation distance.

In amounts over 10 %, on the other hand, it is possible to observe rather considerable correlation between the amount and the transport distance. Since the relation depends on many factors the question should be discussed in the light of different examples.

Lundqvist's investigations (1951) in the province of Kopparberg, in central Sweden, include a Paleozoic (Silurian) limestone formation, Fig. 4.

THE DEVELOPMENT OF THE PRE-QUATERNARY MAP OF THE BOTHNIAN SEA

The oldest geological observations of the bedrock of the Bothnian Sea are related to the findings of erratic boulders on the shores of Uppland. Wiman (1905) has given a detailed history of these findings and of further investigations of the material. According to this survey fossiliferous limestone boulders are mentioned for the first time during the 18th century (1715, Roberg). Not, however, until the next century did anyone put forth the assumption (Hisinger, 1828, and Erdman, 1859) that the discovered boulders actually originated from the bottom of the sea, from the Gävle Bay and from the sea bottom close by the coast of Uppland. At the end of the 19th century Cambro-Silurian formations were discovered as solid rock also, to start with on the islands of the Gävle Bay (Wahlquist, 1869), later on the mainland (Högbom, 1891).

Wiman (1905 and 1908) published a continuous and extremely detailed report regarding the findings of limestone boulders and the deposits of limestone in the bedrock. Since these discoveries are important to the research on hand, it is in this connection necessary to give some of the main points of the results of Wiman's investigations.

Wiman composed the following sedimentary series in which the boulders as well as the observations of the bedrock are taken into consideration:

- Baltic limestone (incl. Leptaena limestone)
- Chasmops limestone (incl. Macrourus limestone)
- Orthoceras limestone
    - Chiron limestone
    - Platyurus limestone
    - Gigas limestone
    - Asaphus limestone
    - Limbata limestone
    - Planilimbata limestone
- Ceratopyge sediment
    - Clay, including lime ellipses and Glauconite shale

and from the Bothnian Bay area (samples P 7—33). On these results the author wrote a report dealing chiefly with the methods of research (Veltheim, 1959). The report will probably remain unpublished since an opportunity to continue with the bottom investigations arose already the same summer, 1959, and a research expedition of approximately three weeks was arranged, during which a considerable number of bottom samples were taken from the Bothnian Bay area (samples L 1—46) and the Bothnian Sea area (L 47—164).

It seemed appropriate to divide the treatment of the rather extensive research material into two parts, one part dealing with the Bothnian Sea area and the other with the Bothnian Bay region, the research at hand being limited to the first mentioned area.

Once the research material from the Bothnian Sea area had been treated and the outlines of the results began to be apparent, certain of the worst regional deficiencies became evident. It appeared, for example, that it was not possible to formulate satisfactory explanations regarding the area to the north of Åland, where the existence of geologically important facts could nevertheless be assumed. The gravimetric map also showed a large positive anomaly area in the middle of the Bothnian Sea. The anomaly could possibly be interpreted as being an indication of a rock type heavier than its surroundings. As there were no bottom samples from these areas two more sample series were taken in the summer 1961, one between Rauma and Mariehamn (samples H 1—16) and the other from the central and northern parts of the marine area (H 17—22). The first samples elucidated the construction of the area north of Åland, whereas, owing to the large amount of clay in the bottom, it was unfortunately not possible to obtain suitable samples from the central sea area.

The distribution of the boulders deriving from this formation is »insignificant». Boulders of a more considerable size are found only some 100 to 200 meters from the source. It is notable that even on the site of the formation the proportion of boulders may be only as small as 10 %.*

Boulder observations made on the Cambrian shale formation in the Lugnåsberg region in southern Sweden (Lundqvist, 1935 a) show the relatively small transport resistance of this rock as well. A stone count performed on the formation showed the proportion of shale as being 100 %. However, as near as half a kilometer away, on the distal side of the formation, the percentage of shale is only 20 % and at a distance of some 4 kilometers the stone count no longer shows evidence of it.

Lundqvist (1935 a) also investigated the distribution of Cambrian sandstone in the above region. The proportion of sandstone on the formation is almost 80 %. Well over one kilometer away from the distal contact the amount is still 60 %, at a distance of 3 kilometers there is some 38 % of sandstone, and at a distance of 5 kilometers the figure is 20 %. Some 3 kilometers farther away, the proportion of sandstone has fallen to a few percent. It should be noted, however, that an observation made at a distance of 13 kilometers still shows a small (1 %?) amount of sandstone.

The next object consists of a sandstone formation in the parish of Isojoki in Finland. Sederholm (1913) and Simonen (Simonen and Kouvo, 1955) have assumed, the former, however, with reservations, that the sandstone is Cambrian. In its resistance this type of stone, however, differs relatively much from the typical early-Paleozoic sandstone, in fact in this respect it may best be compared to Jotnian sandstone. The figure No. 5, left, by Kauranne (Simonen and Kouvo, 1955) depicts the distribution of boulders. It shows that the frequency curves registering larger amounts of sandstone are situated relatively near the formation. The curve of 10 %, on the other hand, already shows a more extensive area of distribution. Within the limits of the studied area it has not been possible to determine a distribution of less than 10 % in the direction of the ice movement.

Lundqvist (1951) studied the boulder distribution of Jotnian sandstone in the region of Dalarna in central Sweden. This example serves to throw light on the significance of the extent of the formation as compared to the distribution of the boulders. The diameter of the formation in the direction NNW—SSE, i.e. the direction of the ice movement, is some 150 kilometers. In conformity with its location it has been named the Dala sandstone formation. On the formation, in particular in its southern part, the sandstone content in the drift is throughout more than 50 %, in many places probably

* Stone counts made by Lundqvist in central Sweden, some of which are presented in the present work, are based on one hundred stones 2.5—10 cm in diameter. Since Lundqvist presented the results graphically, the percentages in this article should be regarded as approximate.

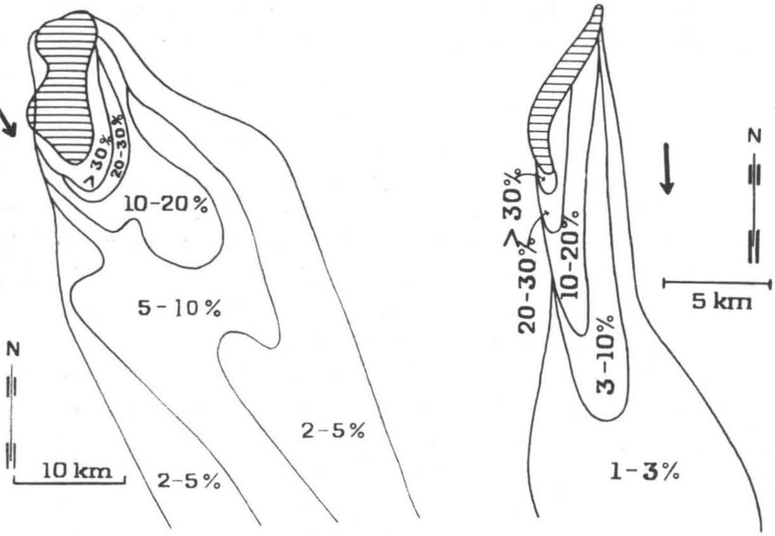

Fig. 5. The distribution of boulders from the solid formation. Left, sandstone at Isojoki, Finland (Kauranne—Simonen and Kouvo, 1955); right, mica-schist at Ställberg, Sweden (Lundqvist, 1935 a).

as much as 100 %. Rather large percentages are found also outside the distal contact. In this way it is possible to note in a stone count at a distance of well over 20 kilometers a proportion of 50 % sandstone, and even as far as 40 kilometers away, stone count observations show a proportion of sandstone amounting to 30 %. The farthest points of observation for percentages amounting to 20 % and 10 % lie some 70 and 90 kilometers respectively from the distal contact. Lundqvist's statement that the distance observations made between the distribution of boulders and the formation are somewhat unreliable owing to the fact that the boundaries of the Dala sandstone formation are not exactly defined, and that smaller separate formations may well exist outside the actual large formation, should be noted. The Dala sandstone is, at all events, according to Lundqvist, one of the stones with the largest distribution in the drift of the region, and amounts of a few percent are found relatively regularly even at distances well over one hundred kilometers from the assumed formation.

Magnusson's (Lundqvist, 1935 a) investigations at Ställberg, central Sweden, present an example of blocks deriving from an Archean mica-schist formation, Fig. 5.

Hellaakoski (1930) studied the correlation of esker drift, till and bedrock in the rapakivi district of Laitila in southwest Finland. His observations were made from an esker which, in the ice movement direction, crosses

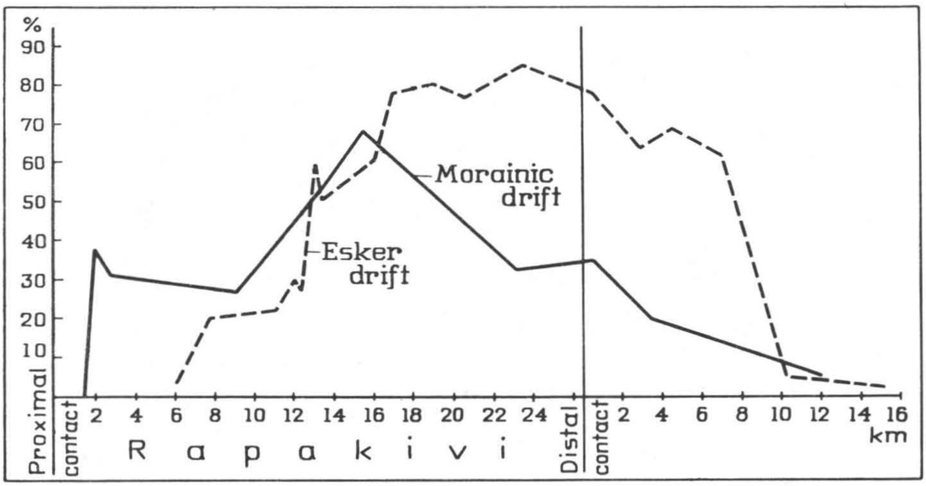

Fig. 6. The relation between the rapakivi formation and the proportions of the same rock in drift, Laitila, Finland. Hellaakoski, 1931.

the rapakivi formation and continues to the distal side. The till observations came from the sides of the esker. In the attached graphic picture presented by Hellaakoski the proportion of rapakivi in both glacial materials can be observed. The stone counts are based on 200 stones 2—6 centimeters in diameter.

It can be seen that on the proximal side of the formation the rapakivi »emerges» in the till already at a distance of some 1.5 kilometers from the proximal contact, while the corresponding distance for esker drift is some 6 kilometers. On the distal side it is found that the decline of the rapakivi material to less than 10 % takes place practically simultaneously in both glacial materials, some 9—10 kilometers from the distal contact. The different character of the curves before this distance should, however, be noted.

In his investigations Hellaakoski came to the conclusion that the esker drift was in fact till which had been retransported at a later stage and had been carried by the water current a relatively short distance, some 4 kilometers. During this journey the till had acquired the special characteristics of sorted drift.

Okko (1941) has made an extensive comparison between the correlation of glacial drift and bedrock. The investigation was carried out in the region covered by the two map sheets, Ylitornio and Rovaniemi, in north Finland. By comparing the stone count results to the bedrock map it has been pos-

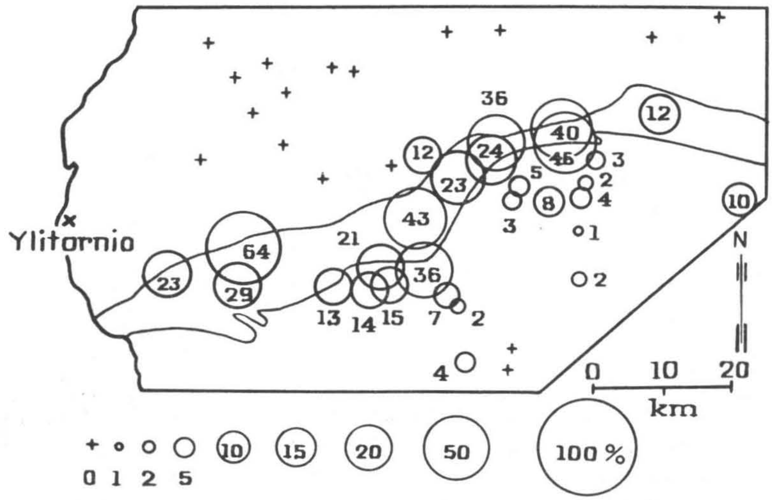

Fig. 7. The proportions of mica-schist in the drift as related to an extensive solid formation, northern Finland. Okko, 1941.

sible to establish that in the till each type of rock is concentrated in the regions where it forms the bedrock. A typical example can be seen in the adjoining Fig. No. 7, where the correlation covers mica-schist. Okko stressed the point, however, that in order to emerge in the till the formations have to be sufficiently large — smaller formations might not appear at all in the »till picture».

In the Kopparbergslän province, in central Sweden, Lundqvist (1951) made a corresponding regional study. Certain examples quoted above as to the distribution of drift are already included in this regional investigation. From the total result of Lundqvist's investigations it is obvious, moreover, that the bedrock can with a rather large degree of probability be interpreted from the qualitative composition of the drift.

ON THE MOVEMENTS OF THE CONTINENTAL ICE SHEET IN THE BOTHNIAN SEA AREA

The logical relation between the direction of the ice movement and the transportation of drift within the framework of separate boulder fans has become apparent in the previous chapter. In view of the nature of the present work the question requires further attention, however.

Since observations regarding the movement directions of ice are not available from the sea area itself, attempts must be made to interpret these

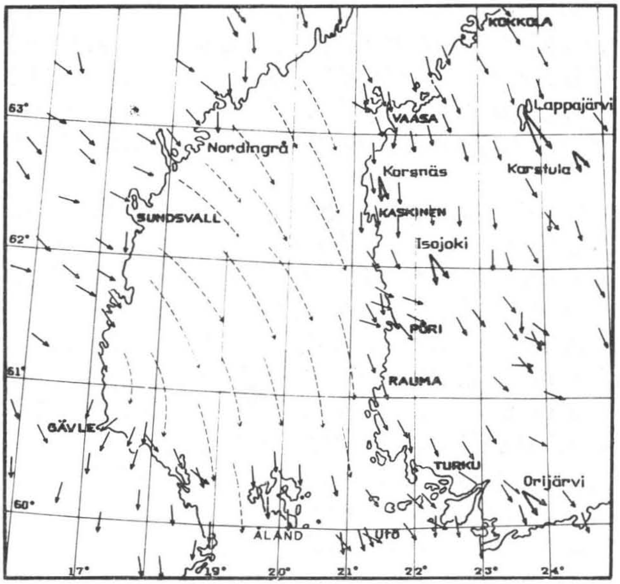

Fig. 8. Continental ice movement observations on both sides of the Bothnian Sea and the supposed main transportation directions in the sea area. Small arrows = striae directions, double-arrows = boulder fans, dashed arrows = supposed directions.

directions on the basis of observations made on the surrounding coastal areas. In addition, an attempt must be made to determine which of the often several and different movement directions of the continental ice sheet, is, or should be regarded as dominant from the point of view of transportation.

The determination of the movement direction of the continental ice sheet is very largely based on striae direction observations. These observations are incorporated in the reports and studies on the Quarternary geology of the area. The dominant striae directions observed at different points of the coast are marked on the adjoining map, Fig. 8. In accordance with the Nordic custom, the movement directions in the written text are given as arrival directions.

In the region of the map sheet of Vaasa (Mölder and Salmi, 1955) two main movement directions differing in age have been established. Variations in their simultaneous appearances can be detected in different parts of the map. In the northeastern part of the map sheet, both directions are simultaneously apparent, while near the coast, in the western and southwestern parts of the region, only the more northerly direction, which has also been found to be the more recent one, can by now be detected. The direction of

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the older ice movement varies between N 66—42°W. In the younger movement direction regular variations have been observed in so far that in the eastern part of the map the direction is N36—6°W, while in the western part of it, it is N14°W—N6°E. At Kaustinen, in the north, it is N36—48°W, further south, at Lappajärvi, N18—30°W, and at Seinäjoki N0—12°W (Mölder, 1948).

In the coast region near Kaskinen and Kristiinankaupunki, the prevailing striae direction follows an almost north-south direction.

Further south at Siipyy the ice movement direction is from the north-northwest. Between Merikarvia and Rauma the map shows west-northwest as the dominant direction. This direction is found to be relatively strong at this level also further inland, as far as Tampere, where Helaakoski (1940) has noted as many as five directions, W, N66°W, N36°W, N6°W and N32°E, two of the directions, N66°W (west-northwest) and N36°W are, however, clearly more marked than the others. In age the western directions are older, the northern ones more recent.

South of Rauma, at Uusikaupunki, the dominant striae direction keeps between northwest and north-northwest (Gylling, 1891). The same feature can be noted also in the archipelagos outside Uusikaupunki and Turku. The directions of the crossing striae measured on the island of Utö run from N10°W and N35°W (Moberg, 1891).

At Åland the prevailing striae direction is from north to south (Moberg, 1891; Frosterus and Sederholm, 1892; Frosterus, 1892; Jaatinen, 1960).

In the region of Uppland, on the Swedish side, the north-south direction is also found to be the most general one, although there are also other directions, such as the directions running from the northwest near the coast and the direction from the northeast in the bay of Gävle. Farther north, on the western coast of the Bothnian Sea, greater variation is again found. Further away from the coast the northwest to southeast direction is the dominant one. Near the coast signs of a north-south direction are found in addition. At Nordingrå most of the striae observations point to a direction from northwest.

According to the total picture obtained on the Finnish side, the earliest discernible movement direction of the continental ice sheet has been west-northwest to east-southeast. Later signs of movement point to a more northerly direction. This ice movement in particular, which can be reproduced as a more coherent picture on the basis of available observations, points, on the coast of the northern part of the Bothnian Sea, very nearly in a northwest to southeast direction. Farther south, the direction veeres southwards and in the Åland region it is practically a north to south one. A corresponding change in the direction is observable on the western coast of the Bothnian Sea, with the reservation, however, that in the northern part of the coastal region the movement direction of the ice, as compared to the eastern coast, is rather more westerly.

The movement directions of continental ice can be studied also with the help of boulders and boulder fans. In addition to the direction, it is thus possible to make direct observations on the transportation of drift. A study of this kind presupposes a distinctly limited formation composed of a certain type of rock, and familiarity with the boulders and/or boulder fan deriving from it.

The small dacite formation at Lappajärvi lies some 70 kilometers east of Vaasa. The boulder fan follows rather closely the later movement direction of continental ice observable in this area, the direction being in Saksela's (1949) map N27°W. Saksela points out, however, that the boulders which have been found in small quantities east of Lappajärvi, at Kyyjärvi, must have been transported during the older, more westerly movement. Saksela has also proved the causal connection between the spread of the boulders and the topography of the terrain in so far that the fan is relatively narrow as long as it is on the flat region of Ostrobothnia, while, on arrival in central Finland, which is characterized by a relatively heavy topography, the sides of the fan start drawing apart to an increasing extent.

At Karstula, some 60 kilometers southeast of Lappajärvi, Sauramo (1916) has found and mapped a group of sandstone boulders, which in all probability seems to have its origin in the bottom of the nearby Vahankajärvi lake. Sauramo's map shows the boulder fan as running in the direction N30°W, which is also the direction of the more recent striae found in the area.

Hyvärinen (1958) has studied the boulder fan which has its provenance in the lead ore formation at Korsnäs, some 35 kilometers south of Vaasa. He shows that the lead ore boulders have been transported in the directions N8—18°W, which also corresponds to the most recent movement direction observed in this area.

Kauranne (Simonen and Kouvo, 1955) depicts in his map a boulder fan (cf. p. 22) deriving from the Lauhavuori sandstone formation in the parish of Isojoki, some 50 kilometers east-southeast of Kristiinankaupunki. The direction of the fan is N28°W. This direction is also rather close to the striae direction found in the area and established as the more northern one.

The boulder fan deriving from Granaattinokka at Orijärvi follows the direction N35°W (Sauramo, 1924). Sauramo (1940) has marked the same transportation direction also for drift from the Laitila rapakivi area and from the olivine-diabase and sandstone formations in Satakunta.

On the basis of continental observations it must thus be assumed that drift covering the base rock derives chiefly from the direction that has been taken as being the latest movement direction of the continental ice sheet. On the basis of the above direction observation the assumption that the movement of this ice forms an enormous arch in the Bothnian Sea area seems justifield. The arch, running from west-northwest on the western and northwestern side of the sea area, curves in a southerly direction in the region of the basin so that in the southern part of the Bothnian Sea, close to Åland, its relatively exact direction is from north to south.

In the present work the transportation of the drift in the sea area has been interpreted in accordance with this assumption.

ON THE GEOLOGY OF THE COAST OF THE BOTHNIAN SEA

The research work on the bottom of the Bothnian Sea can be aided considerably by a knowledge of the geological composition of the surrounding coastal region. This has been previously to some extent dealt with in the chapter describing the development of the map of the Bothnian Sea. The interpretation of the bottom samples at hand, however, demands a somewhat more detailed description of the geology of the coastal zone. Since it is appropriate to restrict the survey of the coastal region to a description within the frame of the sector that will be studied on the basis of the bottom samples, it is not expedient to attempt more than a mere definition of the different rock type areas.

The enclosed geological map of the coastal area is, on the Finnish side, based upon the general geological map of Finland, sheets Vaasa, Tampere and Turku. On the Swedish side the source has been the geological map of Sweden prepared by Magnusson and others (1960). In addition to the above mentioned map sheets and their explanations, a number of more detailed investigations of this area have been made use of in the accounts given of the various types of rock.

On the northernmost part of the Finnish coast there is a relatively large intrusive formation, the so called Vaasa granite. On Saksela's map the area has been named the »syn-orogenic eruptive region».

In its typical state the Vaasa granite is unoriented, grey porphyritic granite. The chief mineral components are plagioclase (more often oligoclase), quartz, biotite and microcline. At some places garnets may appear in the granite and, especially on the marginal zones of granite, pyroxenes may occur. (Saksela, 1935).

South of the Vaasa granite there is a broadish supracrustal zone, the so called Bothnian schist zone of Ostrobothnia. On Saksela's map this region has been marked as »migmatitic biotite-plagioclase-gneiss». The gneiss is considered as originating partly from weathering, partly from volcanic sediments, (Laitakari, 1942; Nykänen, 1960). The main minerals of this rock are quartz, plagioclase (An 10—30) and biotite. In many places the gneiss is of

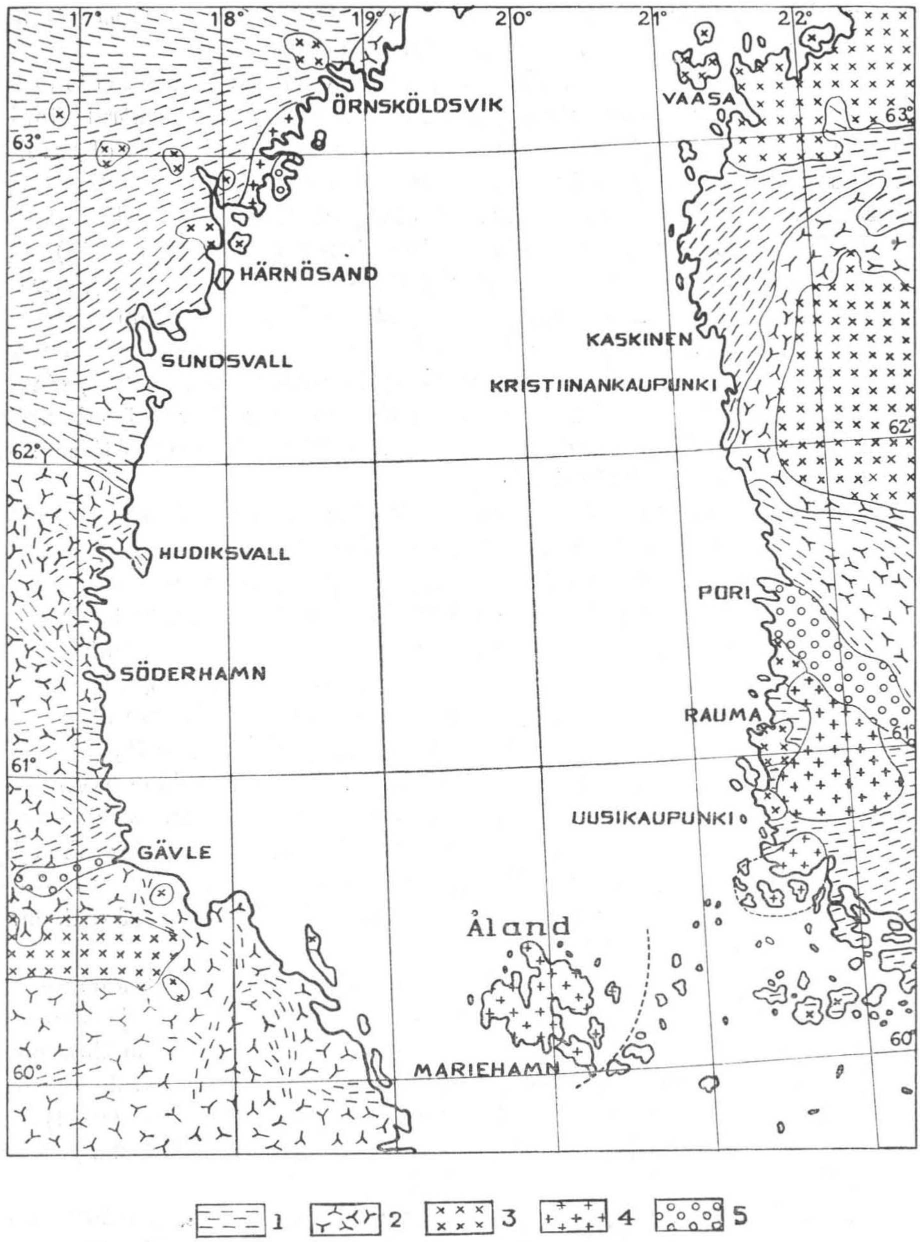

Fig. 9. The geology of the coastal area of the Bothnian Sea. 1 mainly sedimentary rocks, 2 and 3 mainly intrusive rocks, 4 rapakivi, 5 Jotnian sandstone.

the veined gneiss type, when one may also find microcline, muscovite and sillimanite in addition to the above mentioned minerals.

The area of intrusive rock, which is situated on the southeast side of the supracrustal zone, is the western part of the large so called central-Finnish granite area. According to Saksela the region is mainly composed of granites and granodiorites belonging to the »late-orogenic eruptive rocks». The same rock area, which extends to the Tampere map sheet, has there been called »post-Bothnian younger granite of the inland type». (Sederholm, 1913).

The intrusive rocks belonging to the late-orogenic series are generally unoriented. The series includes a gradually alternating series from granite to peridotite. As to their proportion the rocks of granodioritic composition are predominant. The main minerals composing the rock are microcline, plagioclase, quartz, biotite and hornblende. In the acid members of this series both porphyritic and even-grained types appear. The colouring of these rock types is usually red. (Laitakari, 1942).

Between the granite region of central Finland and the Bothnian schist zone there is a continuous zone which, on Saksela's map, has been marked as gneiss-granite belonging to the syn-orogenic group of igneous rocks. The same zone extends, though in a somewhat disconnected state, to the area of the Tampere map sheet where it has been described as »pre-Bothnian older granite (gneiss-granite)», (Sederholm, 1913). Also basic rocks, diorites, as well as peridotites and gabbros, are included in the gneiss-granite series, although the acid members are predominant in regard to quantity.

On the north side of Pori the map shows a broad zone which extends in a northwest-southeast direction and which is composed of alternating gneiss-granitic and supracrustal types of rock. The latter have been described by Sederholm on the map as »pre-Bothnian mica-gneiss». In the areas which have been marked as being composed of mica-gneiss the type of rock may often be more metamorphic mica-schist.

The possible underwater connection of the above mentioned zone and of the schist zone of Ostrobothnia referred to above, has been subject to different interpretations. The two likely alternatives are to assume that both zones join so that the supracrustal zone forms a sub-marine arch, or that both zones extend westward into the marine region. Väyrynen (1954) has found the latter alternative more probable on the grounds that the general trend of the schist on the Swedish side is from east to west.

In the vicinity of Pori there appears a sandstone formation, extensive in Finnish circumstances, which runs in a northwest-southeast direction, and which, on the basis of the mainland observations, has been presumed to continue right up to the marine region. The length of the continental formation is approximately 80 kilometers and the average width amounts to 15 kilometers. On the basis of a deep drilling made by the Geological Survey of

Finland in 1960 it has been established that the thickness of the sediment bed exceeds 591 meters at a point which is situated approximately 6 kilometers south of the town of Pori.

Sandstone has been considered to belong to the Algonkian era in regard to its age, and in accordance with the old Fenno-Scandian custom it has been called Jotnian. This sandstone formation has been named the Jotnian sandstone area of Satakunta, and has been described in detail by Laitakari (1925).

In its most typical form the Jotnian sandstone of Satakunta is a red or reddish, medium coarse, arkose sandstone. The coarseness degree may however, alternate from being coarse grained, conglomeratic, to shale. A clear stratification can often be seen in the rock and ripple marks may be found in individual boulders. Enclosed in the rock, soft clay inclusions, with a diameter of some centimeters, have often been discovered.

In surveying the geological composition of the coast south of Pori, it is important to consider two rapakivi areas of which the larger one is situated farther north and is called the Laitila rapakivi formation. The more southern area is called the Vehmaa rapakivi formation. The term rapakivi (Finnish; rapa = crumble, kivi = rock) is used about a special kind of porphyritic potash granite in which scattered ovoid potash-feldspar crystals are surrounded by a thin mantle composed of plagioclase (oligoclase). The base consists of quartz, potash-feldspar, plagioclase and dark mica. Even-grained rapakivi-granites also belong to the same group. In addition, basic types of stone are included in the rapakivi-series. Besides the above mentioned structural characteristics, certain other more detailed features are typical of rapakivi and rapakivi-like granite. The potash-feldspar component of this rock chiefly consists of orthoclase. The quartz may simultaneously appear both as pseudomorphic and idiomorphic grains — the latter can be seen on the rock surface as roundish grain figures. The idiomorphic quartz is mostly of a dark smoke-grey colouring. The micropegmatitic intergrowth of feldspar and quartz is characteristic of some rapakivis. The typical accessories to rapakivi are: apatite, zircon and fluorspar. Topazes may also sporadically appear in rapakivi (Laitakari, 1925). The rapakivi rocks are usually red.

The Laitila and Vehmaa rapakivi formations differ from each other in regard to the petrographic structure of the rock. The Vehmaa formation consists of almost even-grained rapakivi-granite (Kanerva, 1928), whereas the ovoid type is common at Laitila.

The Laitila rapakivi formation is bounded by Jotnian sandstone in the north. With the exception of a certain small bay the formation does not extend to the coast in the west. The intervening narrow strip is depicted as including supracrustal rocks of sedimentary origin and intrusive rocks belonging to the class of granodiorite.

A more continuous kinzigitic mica-gneiss zone stretches in between the rapakivi formations in the direction of the marine area.

The rapakivi formation at Vehmaa extends to the coast and includes a part of the archipelago which is situated outside the coastal area. According to Sederholm (1934) the rapakivi of these islands is partly of the porphyritic type.

The outer islands have been described by Sederholm as consisting of »migmatite of pre-Bothnian schist and post-Bothnian granite.»

The boundary between the above mentioned migmatite and the rapakivi formation of Åland has been determined as lying west of the fairly large Kumlinge island.

Sederholm has estimated that the total area of the Åland rapakivi formation amounts to at least ten thousand square kilometers. According to this estimate the sub-marine part of the formation is more than 80 % of the total area. The massive includes types of rapakivi which vary to a great extent.

Because of its uniqueness the solid Ordovician limestone formation, which is situated on the Lumparen inland sea, should be mentioned. The limestone is visible only in one small protruding crag, the diameter of which is some meters. A larger formation is, however, assumed to lie at the bottom of the sea. The limestone at the outcrop is of the Baltic limestone type (Kulling, 1926).

The fault cracks filled by sandstone, which have been found both on the main Åland island and on the small islands, are of great significance. On the basis of discovered fossils, the sandstone has been determined as Cambrian (Tanner, 1911).

On the small island of Röko, situated in the above mentioned Lumparen inland sea, Asklund (1926) has described a Jotnian basal breccia resting as a thin sheet on the rapakivi.

The Swedish coastal area (Uppland) opposite Åland has, on Magnusson's map, been described as consisting of older (Svionian) granites. These synkinematic granites were put in the same category as the Finnish gneiss-granites and the latter term was used by the Swedish geologists in the investigation of the above mentioned area (Lundegårdh, 1946). Changes in the structure and composition of the gneiss-granites have also been observed in the Swedish area. In the region of Uppland a grey oligoclase granite has been given a type name of its own, i.e. »the Uppsala granite».

The granite area of Uppsala includes, to a small extent, supracrustal rocks, leptites of which the majority are considered to be of volcanic origin. Especially on the northern coast of Uppland, granites »which have a more and more independent and intrusive appearance» (Magnusson, 1960) are found among the gneiss-granites. These »independent granites» have in

Sweden been included in a group of granites which has been called »the Fellingsbro-Stockholm granites» and they are regarded as late-orogenic granites. They are comparatively homogeneous in regard to their composition, rich in quartz and microcline, red or grey in colour, porphyritic (Fellingsbro granites) or even-grained (Stockholm granites).

The Uppland gneiss-granite area in the north extends as far north as Gävle. The Paleozoic sediment formations situated in the Gävle region have been mentioned previously (p. 13). In the vicinity of Gävle there is a zone of Algonkian rock which is approximately 35 kilometers long and has an average width of somewhat under 10 kilometers. This zone has been observed to extend in a west-southwest direction and consists mainly of Jotnian sandstone with the exception of a small granite formation which has been established near the coast.

The coastal area of the Bothnian Sea north of Gävle belongs to a region which was called by Magnusson »the great Norrlandic bulk of veined gneiss», which description gives quite a good picture of the rock facies which predominates in this area. When a more detailed classification of the rock types is made, the area of veined gneiss is, however, divided into two parts by a boundary line running on the northern side of Hudiksvall.

The part which lies farther south, i.e. the coastal area between Gävle and Hudiksvall, is highly complicated in its geological structure. The predominant general rock type is the gneiss-granite (»the svionian, most ancient granite»).

However, fairly frequent entries on the map (Magnusson, 1960), indicate that there are also metamorphosed supracrustal types of rock. On the north side of Gävle, at Hamrånge, the supracrustal rocks appear in a less metamorphic state. In the more northern part the granites dominate over the other rocks. The granites in question have been called red and grey »Ljusne granites». They are often augen granites.

At a point on the north side of the boundary, near Hudiksvall, the coastal area chiefly includes rock types which on Magnusson's map have been called »metamorphosed veined gneiss». These rocks mostly derive from sediments and are best preserved along the coast between the towns Härnösand and Örnsköldsvik. In this region the sediments often have a well preserved bedding and clastic grains are clearly visible. Towards the north the supracrustal rocks have been more and more attacked by granitization and pass into granitic rock rich in dark micaceous »schlieren» which must be considered as being remnants of sediments. Successively these transition rocks turn into typical granites (»Revsund granites»). These granites are characterized by usually 2—5 cm large phenocrysts of microcline in a groundmass of microcline, oligoclase, quartz and biotite, sometimes also hornblende and garnet (Magnusson, 1960).

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Location and Latitude	Quartzite, sandstone, leptite	Schist, phyllite	Gneiss	Granite
Valassaari 63°15'N	9 %	3 %	24 %	64 %
Vaasa, 8 km SSE 63°02'N	31 %	8 %	10 %	61 %
Petolahti 62°55'N	32 %	2 %	28 %	38 %
Korsnäs 62°45'N	17 %		52 %	31 %
Bultan 62°34'N	3 %		70 %	27 %
Närpiö 62°28'N	34 %		33 %	33 %
Kaskinen 62°23'N	2 %		79 %	19 %

On the narrow frontage between Härnösand and Örnsköldsvik there is one more formation of Algonkian rock. The basis is composed of a rapakivi series which cuts through the Archean bedrock of the surrounding area, and which has been differentiated and consists both of granite and basic variations. On the base, considered as sub-Jotnian peneplain, lies a horizontal Jotnian sandstone formation, the so called Nordingå sandstone, measuring about 60 meters in thickness. The sandstone again is overlaid by a bed of olivine-dolerite likewise in a nearly horizontal position.

Observations made in the coastal zone on boulders have been partly dealt with in connection with the development of the geological knowledge over the bottom of the Bothnian Sea. The results of the stone counts carried out on the coast should, however, also be taken into account when the pebble counts of the sea area are being considered. The following observations are, however, limited to those made on the Finnish side only.

From the area covered by the Vaasa map sheet of superficial deposits a number of results of stone counts made near the shore are available in the explanation to the sheet (Mölder and Salmi, 1955). Stones 2—10 cm in diameter have been used in these counts. The stones numbered one hundred (oral information). The classification of the rock types is unfortunately not the best possible from the point of view of the present work. Quartzites, sandstone and leptites have, for example, been grouped together. The proportion of sandstone, which would be of interest for sea bottom investigation, does not, consequently, appear from the stone counts. Nor have the groups »gneiss» and »granite» been subjected to a more detailed sub-classification or explanation. The proportion of paragneiss thus remains undefined in the former group while the latter does not indicate the possible amount of rapakivi-like granite.

Location and Latitude	Sandstone	Mica-schist	Gneiss-granite	Granite	Others
Siikainen 61°53′N	2 %	5 %	10 %	81 %	2 %
Siikainen 61°50′N	8 %	4 %		84 %	4 %
Pomarkku 61°45′N	6 %	21 %	21 %	50 %	2 %
Toukari 61°34′N	7 %	26 %	46 %	20 %	
Friitala 61°27′N	72 %	12 %	2 %	14 %	
Irjanne 61°15′N	4 %	17 %	10 %	63 %	6 %
Eurajoki 61°12′N	12 %	10 %	8 %	64 %	6 %

The stone counts in question are, nevertheless, indicative in the interpretation of the bedrock in the sea bottom (as well as on land). The table on page 34 presents the results of stone counts made near the shore.

It appears that south of Vaasa there exists a considerable quartzite-sandstone-leptite group. According to oral information supplied by Dr. Mölder, the proportion of red Jotnian sandstone in the drift is considerable in particular in the Maalahti-Petolahti region. In regard to bedrock geology, it should be noted that the three northernmost stone counts have been made in the Vaasa granite region, a fact which is also reflected in their relatively high amounts of granite. The stone counts on the southern side are, again, from the Bothnian schist zone. No further details are available on the rock material of the stone count made in Närpiö which contains 34 % quartzite, sandstone and leptite.

Published stone count results from the coastal area between Kaskinen and Rauma are not available. Dr. K. Virkkala who has been investigating this area has, however, kindly allowed the present author to make use of the stone counts that so far exist only as diary notes. The stone counts have been performed on 50—100 approximately fist-size stones. The table above presents the results of the stone counts made by Dr. Virkkala close to the sea shore.

The very high proportion of sandstone at Friitala should be noted in the above stone counts. According to Virkkala's notes the sandstone is very largely of the red Jotnian type. Jotnian sandstone is to be found in the bedrock at the sample point.

Stone counts compiled by Hellaakoski (1930) are available from the area between Rauma and Uusikaupunki. The counts are based on some 200 stones 2—6 cm in diameter and are taken from the till.

Location and Latitude	Cambrian sandstone	Jotnian sandstone	Rapakivi	Archean rocks	Others
Poltti 60°58′N	1.5 %	8 %	1 %	87 %	2.5 %
Lahniojärvi 60°55′N	1.2 %	9.2 %	28.3 %	57.5 %	3.8 %
Vidilä 60°51′N	1 %	2.5 %	67 %	26 %	3.5 %
Viikainen 60°48′N	2 %	12.5 %	31 %	52 %	2.5 %

The above stone count sites are in the Laitila rapakivi area; the first mentioned is situated some 1.5 kilometers southeast of the proximal contact of the formation. The relatively large amount of Jotnian sandstone in the southernmost sample, as well as the small amounts of Cambrian sandstone in all stone counts, should be noted. The Cambrian sandstone has been identified on the basis of the fossils found.

The following table and the map (Fig. 10) present the stone count results obtained by Hausen (1911) at Åland. »Nearly all» the stone counts have been made on till, and for each count »a couple of hundred fist-size stones» have been collected.

No. (on the map) and Location	Silurian limestone	Cambrian sandstone	Red sandstone	Rapakivi	Foreign granites	Gneiss, gneiss-granite	Others
1 Hammarland	2.4 %		29.1 %	35 %	27.6 %	5.9 %	
2 Eckerö	12.0 %		19.0 %	25 %	39.4 %	4.6 %	
3 Östanträsk			40.6 %	28.4 %	28.4 %	2.6 %	
4 Jomala			31.3 %	41.6 %	19.0 %		8.1 %
5 Finström	1.0 %	4.9 %	24.1 %	38.6 %	27.5 %	1.0 %	3.9 %
6 Geta			17.9 %	55.9 %	21.8 %		4.4 %
7 Saltvik		1.5 %	21.3 %	48.6 %	25.5 %		3.1 %

In the stone counts attention is primarily focused on the large amounts of rapakivi and red (Algonkian) sandstone. The column headed »Foreign granites» chiefly indicates grey biotite-granite of medium grain size. Within the column headed »Others» the author has incorporated rarer rock types, such as quartz-keratophyrs, quartz-porphyries, felsites, diabases and olivine-diabases, which Hausen had originally classified into different groups. The definition Cambrian sandstone is based on the petropgraphic appearance of the stone. In regard to »Silurian» limestone Hausen has not defined the different limestone types.

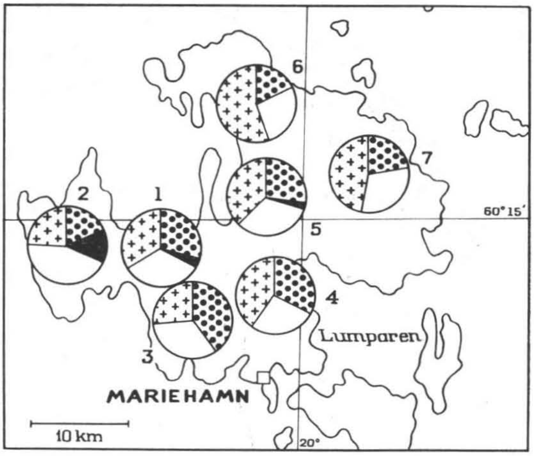

Fig. 10. The distribution of the main rock types in the drift at Åland. According to Hausen, 1911. Black = Paleozoic limestone, dotted = sandstone, crossed = rapakivi, blank = Archean rock.

GENERAL MORPHOLOGICAL FEATURES OF THE BOTHNIAN SEA

The significant morphological diversity between the western and eastern coastal region of the Bothnian Sea is evident in the scenic picture of the mainland as well as in the depth ratios of the sub-marine coastal zones.

Typical of the western region, the Swedish side, is a rather heavy topography of the terrain, characterized by rather steeply rising coastal banks and fjordlike bays. In the sea there is great depth variation quite close to the shore. An isobate of 50 or even 100 meters runs in many places relatively near the coastal line.

The eastern region, on the other hand, is characterized by flatness. On the mainland this feature produces a broad, flat coastal region, which has for long been underlined in the country's morphological general picture. In the sea area the isobates are found at lengthy regular distances from each other following the line of the coast. The average distance of the 100 meters isobate from the shore is 50 kilometers.

The shallow water zone outside the coast curves west in the southern sea area, i.e. on the northern side of Åland.

The most notable of the shoals is Finngrunden situated some 80 kilometers northeast of Gävle. The 20-meters isobate encircles a roundish area of some 18 kilometers in diameter in the region. The lowest depth reading in the chart is 1.5 meters. Proceeding eastwards from the shoal one finds

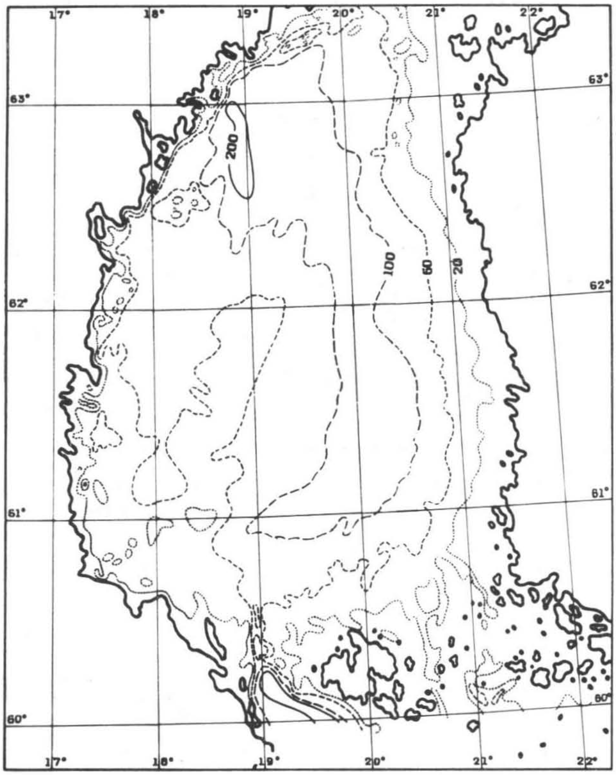

Fig. 11. The general depth conditions in the Bothnian Sea area.

that the depth increases at a relatively rapid rate and some 25 kilometers from the centre of the shallows it is already over 100 meters. South of the shallows there is a rather extensive flat bottom area where the average depth is about 60 meters. The shallower water zone extends from Finngrunden in the west-southwesterly direction close to the Swedish coast. In the zone there are a number of separate banks registering less than 20 meters in depth.

A zone of shallower water can also be observed north of Finngrunden extending somewhat beyond the 62nd Latitude. In the present work this shallow zone has been called the sub-marine ridge of the Bothnian Sea. The ridge is some 100 kilometers long and has an average width of 25 kilometers. It rises in a relatively gentle slope from its surroundings. The depth of the sea at its shallowest points is well over 30 meters.

Two more notable depth areas belong to the sphere of the Bothnian Sea. In the northwestern part of the sea, outside Härnösand, a 200-meters isobate indicates a depression 50 kilometers in length and some 15 kilometers

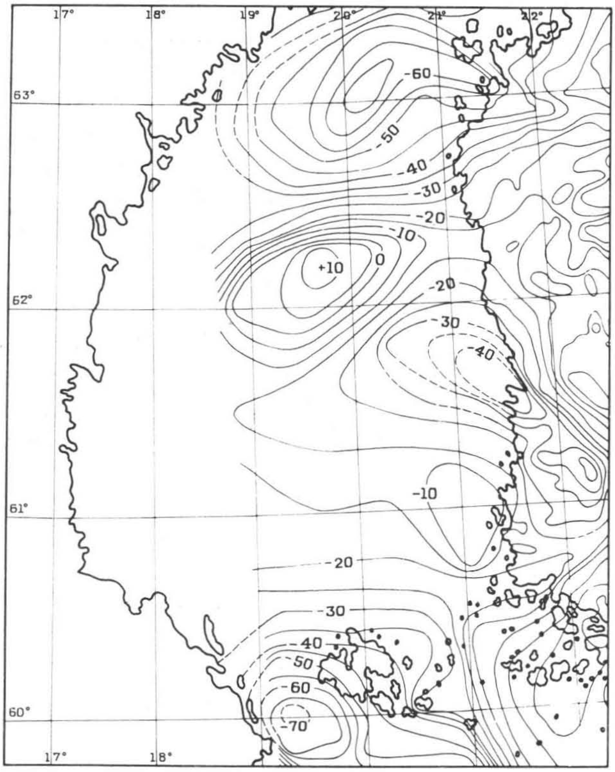

Fig. 12. The gravity anomalies in the Bothnian Sea area. Finnish Geodetic Institute, Honkasalo, 1959.

in width running from north to south. The highest depth reading figure in the chart shows a depth of 294 meters. West of Åland there is a depression running northwest to southeast, the so called Åland graben depression. The walls of the depression rise in places rather steeply, sometimes as much as 100 meters, Fig. 20. Starting in the northwestern end of the depression and running in a northerly direction, there is a narrow canyon like valley which divides the rather shallow coastal regions of Sweden and Åland.

GRAVIMETRIC SURVEYS IN THE BOTHNIAN SEA

For the present study the author has made use of the gravimetric map over Finland published by Honkasalo (1959) since the map covers also the major part of the Bothnian Sea area, Fig. 12.

The geological and the gravimetric pictures show a considerable degree of correlation on the mainland. The rapakivi areas as well as the established large grabens in Satakunta and at Muhos (not visible in the map) are thus fairly easily discernible on the gravimetric map. Whenever rapakivi and Jotnian sandstone join, as in Satakunta, the gravimetric picture may not allow a differentiation between them, however. As the sandstone formation in Satakunta, running in a southeast-northwest direction, continues from the mainland into the sea area, it affords an excellent subject for an interpretation of the geology on the basis of the gravimetric map of the sub-marine area. (Cf. the accompanying gravimetric map and the geological map over the coast area.)

In addition to the negative anomaly area in front of Satakunta, two other areas of the kind are found in the Bothnian Sea area: close to Åland and in the northernmost part of the sea area. The former indicates the well known Åland rapakivi massive, which in all likelihood connects up with a Jotnian sandstone formation. Judging by the bottom samples it seems highly likely that both the above mentioned rock types are represented also in the northern area.

A comparatively large positive anomaly area is to be found south of the negative anomaly area in the north. It may be assumed that this reflects a formation composed of rock heavier than its surroundings. Owing to the clay composition of the bottom, suitable bottom samples are unfortunately not available from this area.

INVESTIGATIONS IN 1958—1961

THE TAKING OF BOTTOM SAMPLES AND THEIR TREATMENT

The up-to-date condition of the ship and the instruments made smooth and effective work possible during the taking of the bottom samples. The preliminary interpretation of the quality of the sea bottom was carried out with an echo-sounder, which phase of the investigations is described later in this context (p. 121).

While the bottom samples were being taken the motors of the ship were at a standstill and the ship was turned crosswise against the wind. She was not anchored. The samples were taken on the windward side of the ship by using a marine-grab of the *van Veen* type, Fig. No. 13. In order to obtain good samples several grabs of the bottom material generally had to be made, depending upon the amount of material obtained in each lifting and upon the quality of the sea bottom. The greatest difficulty in

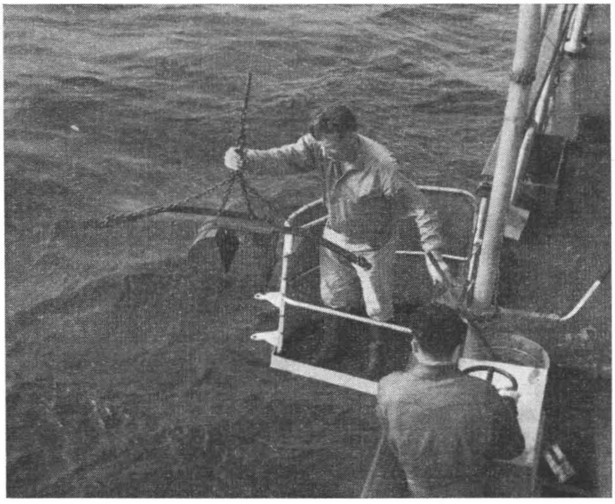

Fig. 13. The *van Veen* marine-grab ready to be lowed down.

obtaining suitable material for the pebble count was caused by the clayey condition of the bottom, which could not always be ascertained by the curve derived from the echo-sounder. Quite frequently only one or a few bigger stones were caught in the marine-grab. In some cases no samples could be taken despite lengthy and frequent attempts.

Since the ship was drifting, the quality of the bottom could change during the taking of a sample. It became apparent that when the ship was drifting from shallow to deeper waters the bottom material became finer in grain size each time a lifting was made. In many cases this observation was applied in order to obtain a suitable sample.

The preliminary treatment of the samples took place on board. If the quality of the large sized samples proved to be suitable as such, a part-sample of some kilograms was put aside for further research. From samples that included clay and/or fine sand these ingredients were removed by sifting with the help of a powerful sprayer. Moreover, larger stones were thrown back into the sea after a small proof had been detached.

Before a description of the further treatment of the samples, some facts that are important from the point of view of the practical application of boulder research should be stated. It is also necessary to stress the limitations of the bottom samples. Regarding the individual stone counts and the adaptation of the results derived from them to regional research, it is vital to note the following facts:

— The number of stones or stone grains must be large enough to be of statistical use.
— The size of the grains must be sufficiently large so that their quality can be identified.
— For regional research it is necessary that the investigation of all samples is based upon grains uniform in size.

In this respect the material that was obtained from the sea bottom necessitated somewhat exceptional treatment. The greatest disproportion appeared between the size and the number of the grains. In this case it was completely impossible to determine the counts upon »fist-size» stones or grains of »some centimeters», as has been the custom when working in mainland conditions.

To obtain a sufficient amount of grains and in order to make the bottom samples from the entire marine area analogous, stone material with a diameter of 2—16 mm was adopted as a basis for the investigations. This method was chosen after it had become clear that more coarse grained material was very sparsely to be found, and also because it was found that the three main rock facies, Paleozoic limestone, sandstone and Archean (crystalline) rocks, could easily be determined correctly to the lower limit mentioned above. A binocular magnifying glass was used in the manipulation. There was generally enough stone material of the 2—16 mm size available. The different rock types included in the main rock facies classification could, however, not be determined in all of the material 2—16 mm in diameter. Their proportions had to be determined from more coarse-grained parts of the material, viz. on the basis of fraction 8—16 mm, or when this material was unobtainable, which happened quite frequently, from the 4—8 mm fraction.

The further treatment of the bottom samples, i.e. of the samples brought from the ship, took place as follows: by a 16—8—4—2 mm sieve series the sample was divided into corresponding fractions. Stones that exceeded 16 mm or were below 2 mm were not taken into account in the analyses with some few exceptions that were used for experimental and comparison purposes. The coarsest stone material, however, often offered the most profitable material for more detailed research of the rock quality. The division of the above preliminary pebble count into the three main rock facies was thus made according to the three fractions, 8—16 mm, 4—8 mm and 2—4 mm. In the pebble count at least 500 grains from each fraction were used if sufficient material was available. The surplus material of each fraction was divided on the basis of the proportions obtained.

The proportions were determined by weighing. In some few cases when the amounts of material were so small that individual larger or smaller grains were likely to give a misleading picture if weighing was employed, the proportions were determined on the number of the grains. Some trial estimates showed that when the number of grains was suitably large the final result was identical between the weight and the number of grains. The following ratios were found between the numbers and the weights of the grains:

2— 4 mm	100 grains	weight	approx.	6 gr
4— 8 »	100 »	»	»	28 »
8—16 »	100 »	»	»	116 »

The results of the pebble counts are given in even percentages. Amounts below 0.5 % are marked plus (+). The total result, i.e. the division of the material 2—16 mm in size into the above three main rock facies, is shown on map, (Plate 1). On an average, the proportions obtained are based on results from the treatment of more than 1 000 grains.

The division of the main stone facies into different sub-facies, which are called rock types in the present study, was made on the basis of a pebble count of the 8—16 mm or 4—8 mm fractions. It should be pointed out at once that the division into rock types is not, from a statistical point of view, as reliable as the main classification. The result of the former was based upon an average of 100—200 grains. In many cases one had to be satisfied with an even smaller number of grains. Since the limitations of the available sample material had previously been taken into consideration, no difficulties arose in the identification of rock types in the coarser fraction. The identification of the rock types was not, however, always indisputable in the 4—8 mm fraction, particularly in regard to Archean grains. It is perhaps worth noting that the division of the material in all cases has had to be undertaken on the basis of a macroscopic investigation, as the total material manipulated amounts to a couple of hundred thousand grains. The colour was consequently also taken into consideration in making the division, although colour may not generally be regarded as a certain proof in identification. In some cases grains representing a certain rock type were, however, subjected to a microscopic investigation. In doubtful cases an acid test for limestone was made.

From the Paleozoic limestone Baltic limestone and red Orthoceras limestone were separated.

Baltic limestone is an old name for a special type of limestone which appears fairly frequently as boulders on the coasts surrounding the Baltic Sea and on the Åland islands. The word appears in writing for the first time in 1885 (Swedmark). This limestone is easily distinguished from other types of limestone by its petrographic characteristics. Wiman (1893) distinguished between several variants of Baltic limestone. The most common variants are, according to Wiman's classification, the types A and B, which Wiman later (1908) called »graue Ostseekalk» and »rotflammige Ostseekalk». In both cases the main characteristics of the limestone are similar. The rock is of a light grey colour, very tough and hard. The shape of the break fracture is »shell-like» (»muscheliger Bruch»). The latter type is distinguished by a faint reddish colouring and stronger streaks of red. Baltic limestone is generally poor in fossils. Stratigraphically Baltic limestone belongs to the Upper Ordovician epoch (Tretaspis stage; Thorslund, 1960).

The red Orthoceras limestone forms another clearly distinguishable type of limestone which has also been treated as a separate group by continental boulder research (cf. e.g. Schön, 1911). In its most typical form this limestone type is brownish-red. The tone of the color may, however, change. The surface of the grains is usually dull and rough. In his investigations Wiman (1906) discovered the following red Orthoceras limestone types in the Uppland area: Platyurus limestone, Asaphus limestone, Limbata limestone and Planilimbata limestone. It is, in addition, worth noting that a brownish red Ceratopyge limestone sediment bed, 0.43 meters thick, has been found in the bedrock of the Limö island in the Gävle Bay (Wiman, 1906).

The third limestone group is composed of grains which it has not been possible to classify on macroscopic investigation. It is natural that this group

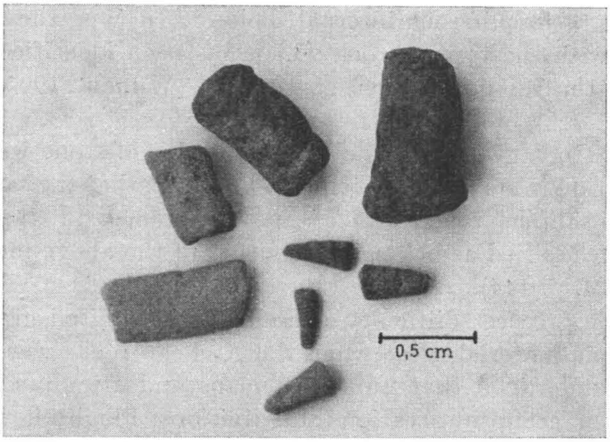

Fig. 14. Cones and cylindres composed of sandstone of the Cambrian type.

may also form the predominant part of the limestone. In general the majority of grains in the unclassified group of limestone consists of grains of a greenish colouring.

In the division of the sandstone facies into sandstone types, a distinction has been made between Jotnian sandstone and Cambrian sandstone. These two types generally differ from each other so clearly that the type division could be made quite easily also in the 4—8 mm fraction.

The Algonkian sandstone, which appeared in abundance as boulders and also in the bedrock of the coastal regions of the Bothnian Sea (Pori, Gävle, the Nordengrå area), has in the Nordic countries been called Jotnian sandstone. The main characteristics of Jotnian sandstone are its red or reddish colour and a considerable resistance. Generally the rock is medium or coarse grained, although a range of variation can be observed as far as the size of the grains is concerned (cf. p. 31.).

In studying the sandstone of the bottom samples, the another type of sandstone may be clearly distinguished. This type is grey in colour though sometimes it may show shades of green and brown. It is even and fine grained. In contrast to the Jotnian sandstone grains the shape of these grains is often flat. The stone is comparatively brittle. On the surface of some larger flat grains one can observe certain minor figures which greatly resemble trails of worms and which are characteristic of Paleozoic sandstone. Likewise in the samples where the amount of sandstone is remarkably large, cones a couple of millimeters in diameter and composed of the same sandstone may be found in the sample, see Fig. 14. The cones are to a very great extent similar to fossiliferous internal molds *. In type the sandstone can be compared with the type of rock which has been identified as Cambrian sandstone by the inland boulder researchers (Wiman, 1905, Hellaakoski, 1930).

In the sandstone group no »unclassified» grains of stone were discovered. In this connection it must be pointed out, however, that the sandstone which appears in the samples taken west of Åland (L 138, L 139, and L 140) cannot clearly be classified as belonging to either of the above mentioned types of sandstone (cf. p. 144).

Perhaps the greatest difficulty caused by the limited grain size of the available sample material arose when the Archean rocks were investigated. It should be underlined that numerous plans and attempts were made to divide this stone group into various sub-divisions. Finally it was considered advisable to make a general division into two rock groups only. This division comprised the sedimentogeneous and the intrusive rocks. In addition, a third group of »unclassified» rocks had to be included.

The grains whose sedimentary origin could be established on the basis of a macroscopic examination, were included in the sedimentary group. The main part of the stones belonging to this group is fine grained mica-schist. To some extent these may be phyllites. This group also included coarser grained mica-schists as well as fine grained mica-gneiss. Likewise this group contained stones of more purely arenaceous origin, although such stones generally appeared in very small amounts. The group included, unintentionally as well as by design, fine grained sediments of volcanic origin.

The group of intrusive stones included those medium and coarse grained granitoid stones which, on the basis of a macroscopic examination, could be assumed to belong to the following rock series: granite-granodiorite-diorite.

The structure of the granitoid rock could be either massive or slightly schistose. Because of reasons stated below it was considered advisable to divide the group into two sub-groups so that the first sub-group included the »grey granites», the granodiorites and the diorites, while the other subgroup covered the »red granite» types.

The rapakivi-like granite grains were separated from the red granite group on the basis of the characteristics of this rock type (see p. 31). The amount of rapakivi obtained in this manner is given as a proportion of the Archean rock facies and also as a proportion of the whole sample. The latter is given in brackets.

It is obvious that the group of red granite represents to a considerable degree potash-granite, whereas the aforementioned group of »grey granite» mainly includes plagioclase-granites.

* Discussing the significance of the cones Prof. Hessland thought it highly probable that they could be considered *Volborthella*.

The rocks representing the most basic members of the intrusive series were not included in the groups mentioned above, since it was considered doubtful whether they really belonged to intrusives, instead of, for example, to semisuperficial or effusive rocks. Thus they were included in the unclassified group.

Taking into consideration the defined limitations of both the sedimentary and the intrusive rocks, it is remarkable that the unclassified group is, as a rule, so small. The main part of this group is composed of various gneiss-like rocks which could not be placed in any of the above groups. The most common types of the accidental stone grains included in this group are the diabases and the porphyrites.

In some special cases it has, however, been regarded necessary to give the percentages of certain rock types.

The medium grained biotite-plagioclase-gneiss appears as a very distinct component of the bottom samples taken in the eastern part of the Bothnian Sea outside the coastline from Pori to Vaasa. In some samples this rock is even found to be predominant. In the general division the biotite-plagioclase-gneiss has been included in the sedimentary group (cf. Laitakari, 1942; Nykänen, 1960. See also p. 28).

In certain bottom samples it has been possible to separate the pegmatitic granite into a group of its own.

In sample L 72, which was taken outside Härnösand, a distinct, ultrabasic intrusive rock group is to be found.

BOTTOM SAMPLES

Sample V 1 Location 60°57′15″N 18°40′30″E Depth 61 meters

For some unknown reason no bottom sample was obtained.

Sample V 2 Location 60°59′00″N 18°40′30″E Depth 40 meters

The bottom sample was composed of gravel. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 817 gr	4—8 mm 388 gr	2—4 mm 94 gr	2—16 mm = 1.290 kg
Paleozoic limestone	45 %	36 %	24 %	41 %
Sandstone	1 %	+	+	1 %
Archean rock	54 %	64 %	76 %	58 %

The Paleozoic limestone divided in the 8—16 mm fraction as follows:

Baltic limestone	8 %
Red Orthoceras limestone	65 %
Unclassified	27 %

With the exception of some Cambrian grains the sandstone was of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		32 %	
Intrusive rocks			
Grey granite — diorite	43 %	51 %	
Red granite	8 %		
Rapakivi		1 %	(1 %)
Unclassified		16 %	

As stated in connection with the treatment of the samples, the percentages given in brackets for rapakivi as well as for the sandstone types, indicate the amounts of these rocks in the total sample material in the 2—16 mm grain size.

As there was a sufficient amount of material in a larger grain size, the rock facies classification was also made in the 16—32 mm fraction. The fraction weighed 1.170 kg and divided as follows:

Paleozoic limestone	59 %
Sandstone	2 %
Archean rock	39 %

In addition, the classification was made in the 1—2 mm fraction. This work was done with the binocular microscope and no difficulties were encountered in the identification of the rock grains. For the classification, an amount of 11 grams, corresponding to about one thousand grains, was used. The result was as follows:

Paleozoic limestone	15.2 %
Archean rock	84.8 %

No sandstone grains could be found.

In order to compare the results obtained by ocular classification with those obtained by dissolving the limestone by acid, a test series was done. This series included also two more fine grained fractions viz. those of 0.5—1 mm and 0.25—0.5 mm.

The two series indicating the determination of the limestone in the different fractions are as follows:

	16—32	8—16	4—8	2—4	1—2	0.5—1	0.25—0.5 mm
Ocular determination	59 %	45 %	36.4 %	24.2 %	15.2 %		
Loss of weight by acid dissolving			36.5 %	24.2 %	16.0 %	7.2 %	3.3 %

The sample contained relatively few fossils. Most of them were ring-shaped stalk pieces of crinoids, fragments of bryozoa and brachiopods. In addition there were a couple of corals and one piece of a trilobite.

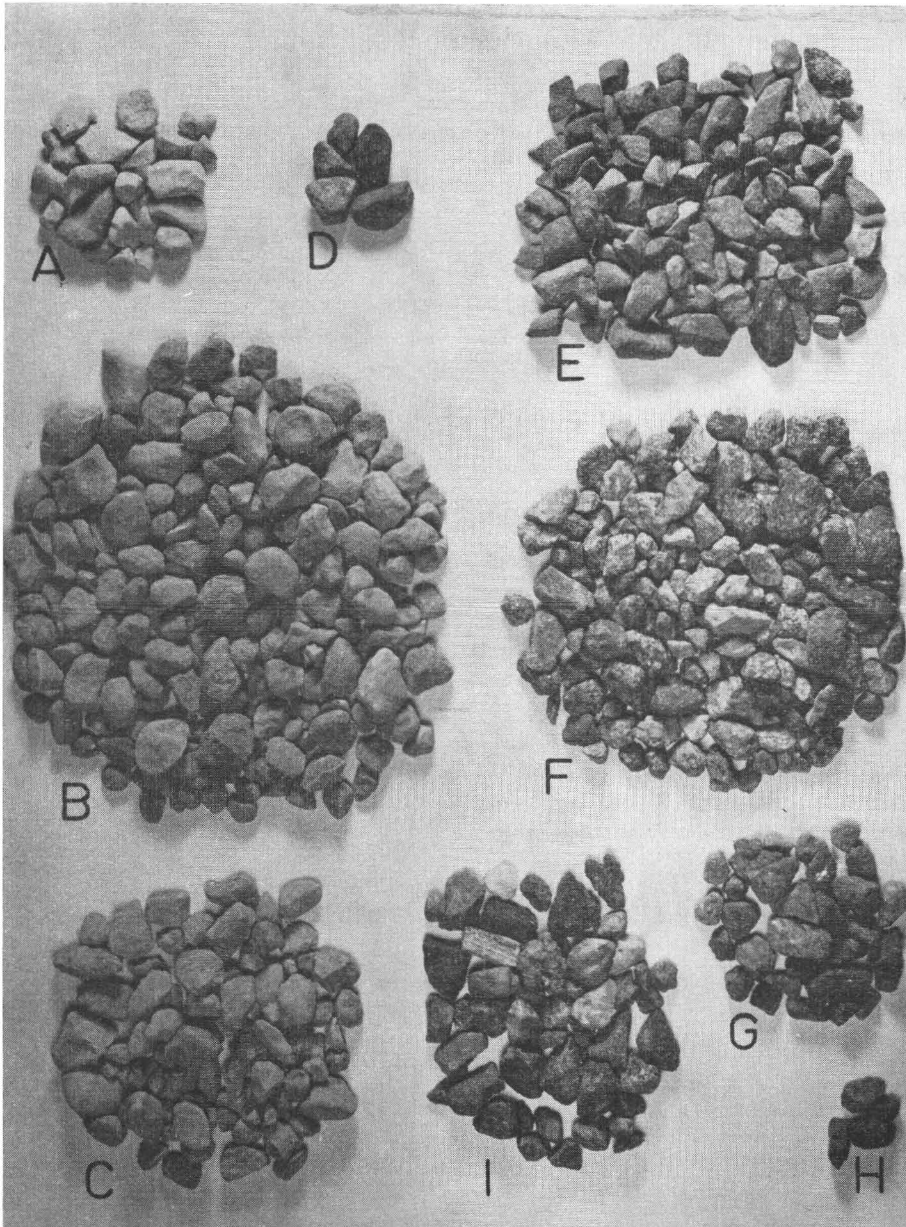

Fig. 15. Classified stone material in 8—16 mm grain size, bottom sample V 2. A Baltic limestone, B red Orthoceras limestone, C unclassified limestone, D sandstone, E Archean sedimentary rocks, F grey granite — diorite, G red granite, H rapakivi-like granite, I unclassified Archean rocks.

Sample V 3 Location 61°00′10″N 18°40′30″E Depth 35 meters

The bottom sample consisted of clayey sand and gravel as well as bigger stones. The material in the 2—16 mm grain size separated by sieving divided as follows:

	8—16 mm 552 gr	4—8 mm 153 gr	2—4 mm 93 gr	2—16 mm = 798 gr
Paleozoic limestone	35 %	28 %	26 %	33 %
Sandstone	+	1 %	+	+
Archean rock	65 %	71 %	74 %	67 %

In the 8—16 mm fraction the Paleozoic limestone divided:

Baltic limestone	13 %
Red Orthoceras limestone	52 %
Unclassified	35 %

Most of the sandstone grains were of the Jotnian type.

The Archean rocks divided in the 8—16 mm fraction as follows:

Sedimentary rocks		28 %	
Intrusive rocks			
Grey granite — diorite	62 %	70 %	
Red granite	8 %		
Rapakivi		1 %	(1 %)
Unclassified		1 %	

The sample contained rather few fossils: about thirty pieces of crinoids, half a dozen fragments of bryozoa, and some pieces of coral and brachiopods. A sandy internal mold of a gastropod was found.

Sample V 4 Location 61°01′45″N 18°40′30″E Depth 37 meters

The bottom sample consisted of rather coarse stone material, gravel and a small amount of sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 288 gr	4—8 mm 62 gr	2—4 mm 33 gr	2—16 mm = 383 gr
Paleozoic limestone	40 %	33 %	25 %	39 %
Sandstone	2 %	+	+	1 %
Archean rock	58 %	67 %	75 %	60 %

In the 8—16 mm fraction the Paleozoic limestone divided as follows:

Baltic limestone	11 %
Red Orthoceras limestone	64 %
Unclassified	25 %

The few sandstone grains were of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		18 %	
Intrusive rocks			
Grey granite — diorite	58 %	63 %	
Red granite	5 %		
Rapakivi		6 %	(4 %)
Unclassified		13 %	

The amount of fossils in the sample was rather meagre; they consisted mostly of small fragments of crinoids, bryozoa and brachiopods. In addition one piece of coral and a piece of a trilobite were found.

Sample V 5 Location 61°04′40″N 18°40′30″E Depth 44 meters

The bottom sample consisted of clay, clayey sand and gravel and some bigger stones. The material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 94 gr	4—8 mm 41 gr	2—4 mm 36 gr	2—16 mm = 171 gr
Paleozoic limestone	22 %	12 %	6 %	16 %
Sandstone	+	1 %	+	+
Archean rock	78 %	87 %	94 %	84 %

16 grains of Paleozoic limestone in the 8—16 mm fraction divided as follows:

Baltic limestone	9 = 56 %
Red Orthoceras limestone	1 = 6 %
Unclassified	6 = 38 %

The limestone grains were considerably weathered.

There were a few Jotnian sandstone grains.

The Archean rocks divided in the 8—16 mm fraction as follows:

Sedimentary rocks		20 %
Intrusive rocks		
Grey granitedi — diorite	39 %	58 %
Red granite	19 %	
Unclassified		22 %

The degree of roundedness of the Archean grains was greater than usual.

In the sample were found some fragments of crinoids and bryozoa as well as a couple of silicified corals.

Sample V 6 Location 61°04′30″N 18°35′00″E Depth 39 meters

The bottom sample consisted of fine sand and some coarser stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 82 gr	4—8 mm 38 gr	2—4 mm 33 gr	2—16 mm = 153 gr
Paleozoic limestone	10 %	7 %	4 %	8 %
Sandstone	3 %	2 %	1 %	3 %
Archean rock	87 %	91 %	95 %	89 %

Owing to the high degree of weathering of the limestone grains no classification could be carried out. Judging by visual estimates the Baltic limestone was predominant.

With the exception of some Cambrian grains the sandstone was of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		33 %	
Intrusive rocks			
Grey granite — diorite	49 %	54 %	
Red granite	5 %		
Rapakivi		2 %	(2 %)
Unclassified		11 %	

With the aid of a binocular microscope the main classification was carried out also in the 1—2 mm grain size. The division of 59 gr of material was as follows:

Paleozoic limestone	2.4 %
Sandstone	+
Archean rock	97.6 %

The roundedness of the coarse Archean stone material was greater than usual.

Some small silicified fragments of crinoids and corals were found in the sample.

Sample V 7 Location 61°04′30″N 18°30′30″E Depth 30 meters

The bottom sample consisted of clayey sand and gravel and bigger stones. Material in the 2—16 mm grain size separated by sieving divided as follows:

	8—16 mm 509 gr	4—8 mm 311 gr	2—4 mm 243 gr	2—16 mm = 1.063 kg
Paleozoic limestone	69 %	66 %	63 %	67 %
Sandstone	+	+	1 %	+
Archean rock	31 %	34 %	36 %	33 %

In the 8—16 mm fraction the Paleozoic limestone divided as follows:

Baltic limestone	28 %
Unclassified	72 %

Most of the Baltic limestone grains belonged to the »rotflammiges» type (Wiman, 1908). The main part of the unclassified limestone group was distinctly green.

Among the sandstone grains both Jotnian and Cambrian grains were found.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		16 %
Intrusive rocks		
Grey granite — diorite	51 %	67 %
Red granite	16 %	
Unclassified		17 %

The amount of fossils, especially of bryozoa was large. Fragments less than a millimeter to one and a half centimetres long could be collected by the hundred. Occasionally individual grains with delicate ramifications were found. Also the surface designs were well preserved in many cases. A considerable number of fragments of crinoids, brachiopods and trilobites was found. Corals and gastropods were represented by a few poorly preserved pieces.

Sample V 8 Location 61°01′45″N 18°30′00″E Depth 23 meters

The bottom sample consisted of coarse stone material with comparatively little gravel and sand. Material in the 2—16 mm grain size separated by sieving divided as follows:

	8—16 mm 436 gr	4—8 mm 164 gr	2—4 mm 120 gr	2—16 mm = 720 gr
Paleozoic limestone	45 %	35 %	29 %	40 %
Sandstone	+	1 %	1 %	+
Archean rock	55 %	64 %	70 %	60 %

In the 8—16 mm fraction the limestone consisted of:

Baltic limestone	47 %
Red Orthoceras limestone	2 %
Unclassified	51 %

The limestone is comparable to that of the preceding sample.
The Archean rocks divided in the 8—16 mm fraction as follows:

Sedimentary rocks		20 %	
Intrusive rocks			
Grey granite — diorite	57 %	65 %	
Red granite	8 %		
Rapakivi		1 %	(1 %)
Unclassified		14 %	

The fossils present resembled those in the previous sample both in quantity and character.

Sample V 9 Location 61°00′10″N 18°30′30″E Depth 17 meters

The bottom sample contained bigger stones, gravel and sand. Material 2—16 mm in grain size analysed as follows:

	8—16 mm 1.073 kg	2—8 mm 614 gr	2—4 mm 518 gr	2—16 mm = 2.205 kg
Paleozoic limestone	67 %	63 %	59 %	61 %
Sandstone		+		+
Archean rock	33 %	37 %	41 %	39 %

In the 8—16 mm fraction the Paleozoic limestone consisted of:

Baltic limestone	43 %
Red Orthoceras limestone	7 %
Unclassified	50 %

The Archean rocks divided in the 8—16 mm fraction as follows:

Sedimentary rocks		22 %	
Intrusive rocks			
Grey granite — diorite	57 %	66 %	
Red granite	9 %		
Rapakivi		1 %	(+)
Unclassified		11 %	

The main classification was also made in the 1—2 mm fraction. The result was: Paleozoic limestone 45 %, Archean rock 55 %.

In the sample there was an abundance of fossils, particularly bryozoa. Crinoids and brachiopods were also numerous. Among the latter some well preserved *Orthis* like specimens were found. See Fig. 16.

Sample V 10 Location 60°56′45″N 18°32′00″E Depth 18 meters

The bottom sample contained bigger stones, gravel and sand being present in a smaller quantity. Material in the 2—16 mm grain size separated by sieving divided as follows:

	8—16 mm 297 gr	4—8 mm 124 gr	2—4 mm 90 gr	2—16 mm = 511 gr
Paleozoic limestone	64 %	55 %	49 %	59 %
Sandstone		+		+
Archean rock	36 %	45 %	51 %	41 %

In the 8—16 mm fraction the Paleozoic limestone consisted of:

Baltic limestone	46 %
Red Orthoceras limestone	13 %
Unclassified	41 %

The Archean rocks divided in the 8—16 mm fraction as follows:

Sedimentary rocks		22 %	
Intrusive rocks			
Grey granite — diorite	65 %	68 %	
Red granite	3 %		
Rapakivi		1 %	(+)
Unclassified		9 %	

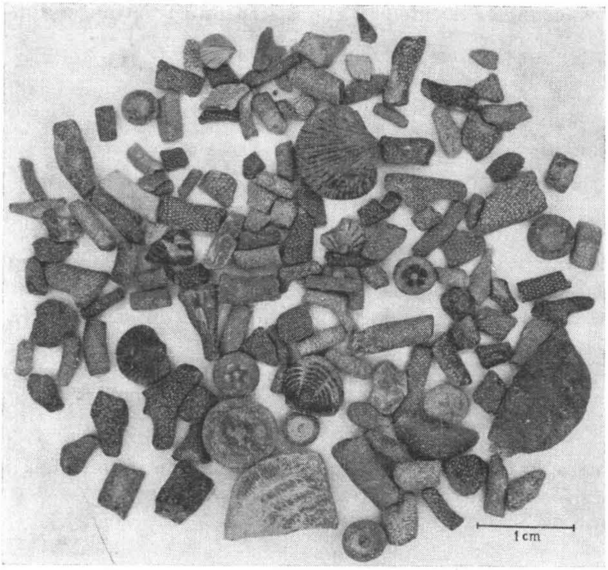

Fig. 16. Fossils found in the sample V 9.

Fossils were abundant, their relative amounts and character were similar to those in the previous sample.

Sample V 11 Location 60°54'30"N 18°32'00"E Depth 50—52 meters

The bottom sample consisted of soft clay without any stone material.

Sample V 12 Location 60°49'30"N 18°31'30"E Depth 53 meters

The bottom sample consisted mainly of clay and limonite concretions, it also included stone material in a moderate quantity. Stone material in the 2—16 mm grain size separated by sieving fell into the following divisions:

	8—16 mm 313 gr	4—8 mm 324 gr	2—4 mm 109 gr	2—16 mm = 742 gr
Paleozoic limestone	26 %	15 %	9 %	19 %
Sandstone	6 %	9 %	6 %	7 %
Archean rock	68 %	76 %	85 %	74 %

The limestone grains were weathered to such a degree that no classification in percentages could be carried out. At a rough estimate, the Baltic limestone was considered to be the dominant limestone type, the red Orthoceras type was represented by only a few grains.

The sandstone was solely of the grey fine grained type considered Cambrian.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		25 %	
Intrusive rocks			
Grey granite — diorite	64 %	67 %	
Red granite	3 %		
Rapakivi		3 %	(2 %)
Unclassified		5 %	

In the sample only some twenty fossils could be found consisting of fragments of bryozoa, crinoids and brachiopods. In addition, two cones a couple of millimeters in size, composed of grey fine grained Cambrian type sandstone, were found.

Sample K 1a Location 61°14′45″N 18°26′30″E Depth 27 meters

The bottom sample consisted mainly of coarse stone material. The fraction in the 2—16 mm grain size fell into the following groups:

	8—16 mm 109 gr	4—8 mm 24 gr	2—4 mm 8 gr	2—16 mm = 141 gr
Paleozoic limestone	85 %	79 %	71 %	84 %
Sandstone		+	+	+
Archean rock	15 %	21 %	29 %	16 %

The Paleozoic limestone was almost solely of the »unclassified», green limestone type, the type being rather homogeneous as such. In addition, some few grains of Baltic limestone and one red Orthoceras limestone grain were found. The stone material coarser than 16 mm in diameter was solely composed of the green limestone type.

The amount of fossils found in the sample was relatively large, they consisted mostly of fragments of bryozoa, crinoids and brachiopods, with smaller amounts of trilobites, corals and gastropods.

Sample K 1b Location 61°17′00″N 18°53′00″E Depth 60 meters

The bottom sample consisted of clay and limonite, mixed with some stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 181 gr	4—8 mm 133 gr	2—4 mm 137 gr	2—16 mm = 451 gr
Paleozoic limestone	7 %	6 %	4 %	8 %
Sandstone	13 %	6 %	4 %	6 %
Archean rock	80 %	88 %	92 %	86 %

The relatively small amount of limestone was composed chiefly of the green limestone type, considered as »unclassified», although red Orthoceras limestone and Baltic limestone grains were also found.

Of the sandstone in the 8—16 mm fraction two thirds was of the red Jotnian type, the rest being of the grey or greenish-grey Cambrian type. These amounts correspond to 4 % and 2 %, respectively, of the whole sample.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		29 %	
Intrusive rocks			
Grey granite — diorite	48 %	53 %	
Red granite	5 %		
Rapakivi		7 %	(6 %)
Unclassified		11 %	

The amount of fossils in the sample was small, the fragments being small and worn. The main part was composed of silicified fossil fragments, which were mostly corals and crinoids. In addition, one globular gastropod a couple of mm in diameter was found.

Sample K 1c   Location 61°09′00″N 18°48′00″E   Depth 60 meters

The bottom sample consisted of clayey sand and gravel as well as single stones varying in size. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 481 gr	4—8 mm 356 gr	2—4 mm 176 gr	2—16 mm = 1.013 kg
Paleozoic limestone	39 %	33 %	26 %	34 %
Sandstone	3 %	2 %	2 %	3 %
Archean rock	58 %	65 %	72 %	63 %

The limestone grains were to a large extent weathered which made their proportional classification difficult. At a rough estimate the green »unclassified» limestone type was found to be predominant. There was a certain amount of Baltic limestone, while only a few grains of red Orthoceras limestone were found.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		23 %	
Intrusive rocks			
Grey granite — diorite	55 %	61 %	
Red granite	6 %		
Rapakivi		4 %	(3 %)
Unclassified		12 %	

Rather few fossils were found despite the relatively large amount of limestone. These consisted mainly of silicified coral fragments, some ring-shaped stalk pieces of crinoids and a small fragment of brachiopod. Three worn brachiopods still in a carbonatic stage were also found.

Sample K 2   Location 61°22′40″N 18°45′00″E   Depth 55 meters

For some unknown reason it was difficult to obtain this bottom sample. The entire sample weighed only a couple of kilograms, and consisted of a mixture of stones, gravel and sand mixed with clay and peppercorn shaped limonite. Material in the 2—16 mm grain size separated by sieving, and from which the limonite had been removed by picking, gave the following division:

	8—16 mm 195 gr	4—8 mm 121 gr	2—4 mm 119 gr	2—16 mm = 435 gr
Paleozoic limestone	40 %	29 %	20 %	32 %
Sandstone	6 %	6 %	3 %	5 %
Archean rock	54 %	65 %	77 %	63 %

The limestone grains were to a large extent weathered. At a rough estimate the greenish type of limestone was predominant, there was a certain amount of Baltic limestone, while the red Orthoceras limestone appeared only as single grains.

With the exception of a few grains, the sandstone was entirely of the red Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		27 %	
Intrusive rocks			
Grey granite — diorite	50 %	61 %	
Red granite	11 %		
Rapakivi		2 %	(1 %)
Unclassified		10 %	

The amount of fossils was very small, consisting of a few silicified coral and crinoid fragments, two fragments of bryozoa and one crinoid still in a carbonatic state.

Sample K 3 Location 61°29′30″N 19°00′30″E Depth 47 meters

The bottom sample was composed of clay without any stone material.

Sample K 3a Location 61°31′15″N 18°48′00″E Depth 47 meters

The bottom sample consisted of a mixture of fine clayey sand, sand, gravel and stones. There was a moderate amount of limonite.

Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 466 gr	4—8 mm 176 gr	2—4 mm 105 gr	2—16 mm = 747 gr
Paleozoic limestone	7 %	5 %	4 %	6 %
Sandstone	3 %	2 %	+	2 %
Archean rock	90 %	93 %	96 %	92 %

In the 4—8 mm fraction the limestone fell in the following divisions:

Baltic limestone	33 %
Red Orthoceras limestone	14 %
Unclassified	53 %

With the exception of a couple of grains, the sandstone was entirely of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		44 %	
Intrusive rocks			
Grey granite — diorite	43 %	46 %	
Red granite	3 %		
Rapakivi		1 %	(1 %)
Unclassified		9 %	

The fossils found in the sample amounted to about a dozen fragments, 1—2 mm in size, of silicified corals and bryozoa.

Sample K 4 Location 61°32′00″N 18°42′00″E Depth 40—46 meters

The bottom sample was composed of clay without any stone material.

Sample K 5 Location 61°35′00″N 18°18′00″E Depth 60 meters

The bottom sample was composed of clay without any stone material.

Sample K 6 Location 61°43′30″N 18°56′00″E Depth 31 meters

The bottom sample consisted of well-washed gravel including some stone material of a larger grain size.

Material in the 2—16 mm grain size sieved from a part sample gave the following division:

	8—16 mm 572 gr	4—8 mm 427 gr	2—4 mm 481 gr	2—16 mm = 1.480 kg
Paleozoic limestone	+	+	+	+
Sandstone	2 %	2 %	1 %	2 %
Archean rock	98 %	98 %	99 %	98 %

The occasional limestone grains found were of the Baltic limestone type.

The sandstone was throughout of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		35 %	
Intrusive rocks			
Grey granite — diorite	37 %	61 %	
Red granite	24 %		
Rapakivi		2 %	(2 %)
Unclassified		3 %	

Among the sample gravel half a dozen silicified fossil fragments were found.

Sample K 7 Location 61°53′15″N 18°58′30″E Depth 37 meters

The bottom sample was composed chiefly of fine sand among which there was coarser sand, gravel and stone material.

Material in the 2—16 mm grain size sieved from a part sample gave the following division:

	8—16 mm 675 gr	4—8 mm 965 gr	2—4 mm 104 gr	2—16 mm = 1.744 kg
Paleozoic limestone	11 %	4 %	3 %	7 %
Sandstone	36 %	28 %	22 %	30 %
Archean rock	53 %	68 %	75 %	63 %

In the 8—16 mm fraction the limestone fell into the following divisions:

Baltic limestone	61 %
Red Orthoceras limestone	3 %
Unclassified	36 %

The 4—8 mm fraction made for the sake of comparison gave the following division:

Baltic limestone	56 %
Red Orthoceras limestone	10 %
Unclassified	34 %

The limestone grains were to a great extent worn and weathered. In addition, about 1—2 % of the limestone grains were silicified.

In the 8—16 mm fraction the sandstone gave the following division:

Jotnian sandstone	96 %	(29 %)
Cambrian sandstone	4 %	(1 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		32 %	
Intrusive rocks			
Grey granite — diorite	45 %	50 %	
Red granite	5 %		
Rapakivi		10 %	(6 %)
Unclassified		8 %	

The degree of roundedness of the stone pebbles was unusually great.

Sample K 7a Location 61°59′00″N 19°00′00″E Depth 38 meters

The bottom sample consisted of a mixture of stones, gravel and sand. Material in the 2—16 mm grain size sieved from a part sample gave the following division:

	8—16 mm 529 gr	4—8 mm 195 gr	2—4 mm 143 gr	2—16 mm = 867 gr
Paleozoic limestone	7 %	6 %	4 %	7 %
Sandstone	22 %	16 %	14 %	19 %
Archean rock	71 %	78 %	82 %	74 %

In the 4—8 mm fraction the limestone fell into the following division:

Baltic limestone	45 %
Red Orthoceras limestone	26 %
Unclassified	29 %

The limestone grains were to some extent weathered. Some grains were silicified. In the 8—16 mm fraction the sandstone gave the following division:

Jotnian sandstone	97 %	(18 %)
Cambrian sandstone	3 %	(1 %)

As the amount of grains in the above division was rather small, a control division was made in the 4—8 mm fraction. This gave the following result:

Jotnian sandstone	99 %
Cambrian sandstone	1 %

The Archean rock divided in the 8—16 mm fraction as follows:

Sedimentary rocks		40 %	
Intrusive rocks			
Grey granite — diorite	37 %	43 %	
Red granite	6 %		
Rapakivi		7 %	(5 %)
Unclassified		10 %	

The rapakivi grains included in the sample were semi-angular or angular in shape.

Owing to a sufficient amount of coarser grained material in the sample, the main classification was carried out also in the grain size 16—32 mm in diameter. This fraction weighed 1.625 kilograms and gave the following division:

Paleozoic limestone	12 %
Sandstone	22 %
Archean rock	66 %

The fossils found in the sample were almost solely silicified consisting mainly of ring-shaped stalk pieces of crinoids, fragments of corals as well as some fragments of gastropods and brachiopods. The fossil in a carbonatic state was a small bryozoan fragment.

Sample K 8 Location 62°01′30″N 19°01′00″E Depth 60 meters

The bottom sample was composed of clay and limonite, among which a minute amount of stone material could be found. This divided as follows:

	8—16 mm 103 gr	4—8 mm 60 gr	2—4 mm 40 gr	2—16 mm = 203 gr
Paleozoic limestone	7 %	7 %	6 %	6 %
Sandstone	15 %	17 %	12 %	15 %
Archean rock	79 %	76 %	82 %	79 %

In the 4—8 mm fraction the limestone fell into the following division:

Baltic limestone	10 %
Red Orthoceras limestone	68 %
Unclassified	22 %

The limestone grains were to some extent weathered, which often appeared as a thin decalcified crust around the grains.

In the 4—8 mm fraction the sandstone gave the following division:

Jotnian sandstone	85 %	(13 %)
Cambrian sandstone	15 %	(2 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		35 %	
Intrusive rocks			
Grey granite — diorite	51 %	54 %	
Red granite	3 %		
Rapakivi		3 %	(2 %)
Unclassified		8 %	

Sample K 9 Location 62°21′15″N 19°07′00″E Depth 84 meters

The bottom sample was composed of clay and limonite, among which a minute amount of stone material could be found. This divided as follows:

	8—16 mm 83 gr	4—8 mm 70 gr	2—4 mm 74 gr	2—16 mm = 227 gr
Sandstone	+	1 %	+	+
Archean rock	100 %	99 %	100 %	100 %

The few sandstone grains were of the red Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		36 %
Intrusive rocks		
Grey granite — diorite	45 %	49 %
Red granite	4 %	
Unclassified		15 %

The roundedness degree of the stone pebbles was greater than usual. In addition, many of the pebbles were weathered.

Sample P 1 Location 61°45′00″N 21°05′30″E Depth 20 meters

The bottom sample was composed mainly of clay which included some stone material of sand and gravel grain size. In addition, there appeared some bigger stones. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 92 gr	4—8 mm 57 gr	2—4 mm 47 gr	2—16 mm = 196 gr
Sandstone	13 %	4 %	4 %	8 %
Archean rock	87 %	96 %	96 %	92 %

In the 8—16 mm fraction the sandstone gave the following division:

Jotnian sandstone	87 %	(7 %)
Cambrian sandstone	13 %	(1 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		47 %	
Intrusive rocks			
Grey granite — diorite	39 %	45 %	
Red granite	6 %		
Rapakivi		2 %	(2 %)
Unclassified		6 %	

Well over half of the sedimentary rock pebbles were biotite-plagioclase-gneiss. The proportion of this rock group was 26 %.

Sample P 2 Location 61°53′45″N 20°55′00″E Depth 38—46 meters

The bottom sample was composed of clay. In the sample one Archean stone was found.

Sample P 3 Location 62°11′00″N 20°31′00″E Depth 15 meters

The bottom sample consisted of a mixture of stones, gravel, and sand mixed with clay.

The material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 325 gr	4—8 mm 211 gr	2—4 mm 130 gr	2—16 mm = 666 gr
Sandstone	5 %	4 %	2 %	4 %
Archean rock	95 %	96 %	98 %	96 %

The sandstone was solely of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		69 %	
Intrusive rocks			
Grey granite — diorite	20 %	24 %	
Red granite	4 %		
Rapakivi		1 %	(1 %)
Unclassified		6 %	

The sedimentary rock pebbles consisted mainly of biotite-plagioclase-gneiss. The proportion of this rock group was 55 %.

Sample P 4 Location 62°28′45″N 20°11′30″E Depth 15 meters

The bottom sample was composed of limonite, among which a minute amount of stone material could be found. This divided as follows:

	8—16 mm 19 gr	4—8 mm 13 gr	2—4 mm 10 gr	2—16 mm = 42 gr
Sandstone	13 %	7 %	4 %	5 %
Archean rock	87 %	93 %	96 %	95 %

The sandstone grains were of the red Jotnian type.

The Archean rock facies divided in the 4—8 mm fraction as follows:

Sedimentary		21 %
Intrusive rocks		
Grey granite — diorite	58 %	68 %
Red granite	10 %	
Unclassified		11 %

Because of the small amount, the classification was based on grain number.

Sample P 5 Location 62°40′00″N 20°39′00″E Depth 12 meters

The bottom sample was composed of stones, gravel and sand mixed with clay.

The material in the 2—16 mm grain size separated from a part sample gave the following division:

	8—16 mm 452 gr	4—8 mm 387 gr	2—4 mm 245 gr	2—16 mm = 1.084 kg
Sandstone	3 %	2 %	+	2 %
Archean rock	97 %	98 %	100 %	98 %

The sandstone was of the red Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		56 %	
Intrusive rocks			
Grey granite — diorite	23 %	37 %	
Red granite	14 %		
Rapakivi		+	(+)
Unclassified		7 %	

The major part (38 %) of the sedimentary rock group was composed of biotite-plagioclase-gneiss. The red granite contained mainly rather coarse pegmatitic grains.

Sample P 6 Location 62°48′30″N 20°36′00″E Depth 21 meters

The bottom sample consisted of a mixture of stones, gravel, sand and fine clayey sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 189 gr	4—8 mm 125 gr	2—4 mm 128 gr	2—16 mm = 442 gr
Sandstone	2 %	1 %	+	1 %
Archean rock	98 %	99 %	100 %	99 %

The sandstone grains were of the red Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		28 %
Intrusive rocks		
Grey granite — diorite	20 %	62 %
Red granite	42 %	
Unclassified		10 %

The sedimentary rock group was chiefly composed of biotite-plagioclase-gneiss. The proportion of this rock group amounted to 27 %.

The red granite was of a uniform rock type. A microscopic investigation showed the rock to be microcline-granite. See further p. 145.

Sample L 47 Location 63°28′30″N 21°13′30″N Depth 25 meters

The bottom sample was composed of soft clay, among which a minute amount of stone material could be found. This was analysed as follows:

	8—16 mm 42 gr	4—8 mm 69 gr	2—4 mm 51 gr	2—16 mm = 162 gr
Archean rock	100 %	100 %	100 %	100 %

The stone grains had a rust-like colour which greatly hampered the identification of the rock quality. For this reason the classification had to be made in the 8—16 mm fraction despite the small amount in this fraction:

Sedimentary rocks		10 %
Intrusive rocks		
Grey granite — diorite	71 %	81 %
Red granite	10 %	
Unclassified		9 %

Sample L 48 Location 63°15′50″N 21°29′00″E Depth 17 meters

The bottom sample was composed of clay. No stone material could be obtained.

Sample L 49 Location 63°14′30″N 20°54′10″E Depth 21 meters

The bottom sample was composed of limonite. In the sample one Archean stone about 15 cm in diameter was found.

Sample L 50 Location 63°20′10″N 20°32′00″E Depth 63—64 meters

The bottom sample was composed of clay. No stone material could be obtained.

Sample L 51 Location 63°19′30″N 20°35′00″E Depth 37 meters

The bottom sample was composed of clay mixed with gravel. Stone material in the 2—16 mm grain size separated by sieving gave the following analysis:

	8—16 mm 305 gr	4—8 mm 136 gr	2—4 mm 63 gr	2—16 mm = 504 gr
Archean rock	100 %	100 %	100 %	100 %

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		30 %
Intrusive rocks		
Grey granite — diorite	58 %	61 %
Red granite	3 %	
Unclassified		9 %

Sample L 52 Location 63°23′00″N 20°14′10″E Depth 28—60 meters

A sample taken from shallower depth consisted of bigger stones only. When the ship had drifted into deeper water the material became successively more finely grained, being first gravel, then sand and finally clay. Material in the 2—16 mm grain size separated by sieving from a part sample divided as follows:

	8—16 mm 231 gr	4—8 mm 83 gr	2—4 mm 59 gr	2—16 mm = 373 gr
Sandstone	+	+	+	+
Archean rock	100 %	100 %	100 %	100 %

The few sandstone grains were of the Jotnian type.

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		32 %
Intrusive rocks		
Grey granite-diorite	55 %	62 %
Red granite	7 %	
Unclassified		6 %

Sample L 53 Location 63°14′00″N 20°23′00″E Depth 79 meters

The bottom sample was composed of clay without any stone material.

Number L 54 was reserved for samples taken on the trips by motorboat to the islands outside Vaasa. See p. 141.

Sample L 55 Location 63°00′00″N 20°36′00″E Depth 32—44 meters

The bottom sample was composed of clay and clayey sand and gravel. The stone material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 233 gr	4—8 mm 184 gr	2—4 mm 143 gr	2—16 mm = 560 gr
Sandstone	1 %	1 %	+	1 %
Archean rock	99 %	99 %	100 %	99 %

The sandstone grains were of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks	24 %	
Intrusive rocks		
Grey granite	29 %	
Rapakivi	38 %	(38 %)
Unclassified	9 %	

Sample L 56 Location 63°00′00″N 20°23′00″E Depth 52—55 meters

The bottom sample was composed of limonite. The small amount of stone material which could be picked out from the sample divided as follows:

	8—16 mm 101 gr	4—8 mm 75 gr	2—4 mm 34 gr	2—16 mm = 210 gr
Sandstone	1 %	+	+	1 %
Archean rock	99 %	100 %	100 %	99 %

The few sandstone grains were of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		34 %	
Intrusive rocks			
Grey granite — diorite	47 %	55 %	
Red granite	8 %		
Rapakivi		9 %	(9 %)
Unclassified		2 %	

Sample L 57 Location 63°00′00″N 20°14′00″E Depth 90 meters

The bottom sample was composed of clay. No stone material could be found.

Sample L 58 Location 63°00′00″N 19°52′30″E Depth 89 meters

The bottom sample was composed of clay and limonite, among which some stone material could be found. This divided as follows:

	8—16 mm 109 gr	4—8 mm 45 gr	2—4 mm 30 gr	2—16 mm = 184 gr
Sandstone	72 %	60 %	57 %	67 %
Archean rock	28 %	40 %	43 %	33 %

The sandstone was of a uniform, carmine red, medium grained Jotnian type. The shape of the sandstone grains was angular to an unusual degree.

The Archean rock facies divided in the 4—8 mm fraction as follows:

Sedimentary rocks		25 %
Intrusive rocks		
Grey granite — diorite	59 %	64 %
Red granite	5 %	
Unclassified		11 %

Sample L 59 Location 63°00′00″N 19°29′00″E Depth 135 meters

The bottom sample was composed of clay. No stone material could be obtained.

Sample L 60 Location 63°00′00″N 19°09′00″E Depth 120—140 meters

The bottom sample was composed mainly of clay which included limonite and some stone material. The latter was separated by picking and it divided as follows:

	8—16 mm 149 gr	4—8 mm 72 gr	2—4 mm 7 gr	2—16 mm = 228 gr
Sandstone	5 %	4 %	3 %	4 %
Archean rock	95 %	96 %	97 %	96 %

The sandstone was of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		29 %	
Intrusive rocks			
Grey granite — diorite	59 %	64 %	
Red granite	5 %		
Rapakivi		2 %	(2 %)
Unclassified		5 %	

Sample L 61 Location 63°00′00″N 18°45′00″E Depth 120 meters

The bottom sample was composed of clay. No stone material could be found.

Sample L 62 Location 62°55′30″N 19°00′00″E Depth 155 meters

The bottom sample was composed of clay. No stone material could be obtained.

Sample L 63 Location 62°49′20″N 19°18′00″E Depth 148—151 meters

The bottom sample was composed of clay. No stone material was found.

Sample L 64 Location 62°44′00″N 19°36′00″E Depth 122 meters

At the sample point the sea bottom consisted of clay and limonite. From the large amount of sieved material it was possible to pick some thirty grains, all of them of Archean rock composed of grey granite, mica-schist, some quartz, quartzite and red granite grains.

Sample L 65 Location 62°42′00″N 19°43′00″N Depth 95 meters

At the sample point the sea bottom consisted of clay and limonite. From a large amount of sample material some ten Archean grains were separated by picking.

Sample L 66 Location 62°38′00″N 19°57′00″E Depth 130 meters

The sea bottom at the sample point consisted of a thick stratum of clay.

Sample L 67 Location 62°34′00″N 20°10′00″E Depth 80—86 meters

At the sample point the sea bottom consisted of clay rich in limonite. From the large amount of sample material it was possible to pick 12 grains all of which were of the Archean rock type.

Sample L 68 Location 62°31′00″N 20°18′00″E Depth 65 meters

The bottom sample was composed of sand which included material of coarser grain size. Stone material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 136 gr	4—8 mm 191 gr	2—4 mm 193 gr	2—16 mm = 520 gr
Sandstone	10 %	8 %	7 %	8 %
Archean rock	90 %	92 %	93 %	92 %

The sandstone was of the Jotnian type, about half of the grains were, however, rather coarse grained, pale red in colour, representing a somewhat unusual Jotnian sandstone type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		21 %	
Intrusive rocks			
Grey granite — diorite	40 %	52 %	
Red granite	12 %		
Rapakivi		3 %	(3 %)
Unclassified		5 %	

The major part, 19 %, of the sedimentary rock group was biotite-plagioclase-gneiss.

Sample L 69 Location 62°33′30″N 19°35′00″E Depth 119 meters

The bottom sample was composed of clay and limonite, among which a minute quantity of stone material could be found. After the clay hade been separated by sieving the stone grains were picked out and these divided as follows:

	8—16 mm 58 gr	4—8 mm 18 gr	2—4 mm 2 gr	2—16 mm = 78 gr
Sandstone	41 %	24 %	44 %	37 %
Archean rock	59 %	76 %	56 %	63 %

The sandstone was of the red Jotnian type.

The Archean rock facies divided in the 4—8 mm fraction gave the following division:

Sedimentary rocks		37 %	
Intrusive rocks			
Grey granite — diorite	55 %	61 %	
Red granite	6 %		
Rapakivi		1 %	(1 %)
Unclassified		1 %	

Sample L 70 Location 62°34′30″N 19°17′00″E Depth 125 meters

The bottom sample was composed of clay and limonite. No stone material could be obtained.

Sample L 71 Location 62°36′30″N 18°43′00″E Depth 98 meters

The sea bottom at the sample point consisted of clay rich in limonite. From some 11 kilograms of sample material it was possible to separate by sieving and picking about fifty stone grains varying in size, all of them of the Archean rock type. Mica-schist, grey granite and granodiorite were the principal components of the grains. Some rapakivi grains were also found.

Sample L 72 Location 62°36′30″N 18°28′30″E Depth 23 meters

The bottom sample was composed of rather coarse grained stone material. When sieved, a sufficient amount of material for classification was obtained only in the 8—16 mm fraction. This fraction, which weighed 154 grams, was, with the exception of one Jotnian sandstone grain, composed of Archean rock, which divided as follows:

Sedimentary rocks		41 %
Intrusive rocks		
Grey granite — diorite	33 %	45 %
Gabbro	8 %	
Red granite	4 %	
Rapakivi		1 %
Unclassified		13 %

In this single case only was the gabbro classified as an independent rock group and included in the intrusive rocks.

Sample L 73 Location 62°38′00″N 18°13′00″E Depth 95—101 meters

The bottom sample was composed of clay and limonite. No stone material could be obtained.

Sample L 74 Location 62°33′00″N 18°10′00″E Depth 37 meters

The bottom sample was composed of sand among which there was some coarser stone material. Material in the 2—16 mm grain size sieved from a part sample gave the following division:

	8—16 mm 263 gr	4—8 mm 208 gr	2—4 mm 235 gr	2—16 mm = 706 gr
Paleozoic limestone	4 %	2 %	+	2 %
Sandstone	1 %	+	+	+
Archean rock	95 %	98 %	100 %	98 %

The Paleozoic limestone was solely composed of red Orthoceras limestone grains.

The sandstone was in the 8—16 mm fraction throughout of the Jotnian type. In the 4—8 mm fraction there appeared, however, some grains of the Cambrian sandstone type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		39 %
Intrusive rocks		
Grey granite — diorite	37 %	52 %
Red granite	4 %	
Pegmatite granite	11 %	
Rapakivi		+
Unclassified		9 %

Sample L 75 Location 62°32′00″N 18°16′30″E Depth 30 meters

The bottom sample was composed of fine sand among which there was some coarser grained material. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 148 gr	4—8 mm 169 gr	2—4 mm 251 gr	2—16 mm = 568 gr
Paleozoic limestone	1 %			+
Sandstone	3 %	2 %	+	1 %
Archean rock	96 %	98 %	100 %	99 %

The few limestone grains were of the Baltic limestone type.

In the 8—16 mm fraction two thirds of the sandstone grains were of the Jotnian type, the rest being Cambrian. In the 4—8 mm fraction, however, the majority, about three fourths, was of the Cambrian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		39 %
Intrusive rocks		
Grey granite — diorite	51 %	55 %
Red granite	4 %	
Unclassified		6 %

S a m p l e L 7 6. This sample, which was taken after the ship had drifted a short distance from the sampling point L 75, was later combined with sample L 75.

S a m p l e L 7 7 Location 62°29′00″N 18°07′20″E Depth 32—40 meters

The bottom sample was composed of a mixture of stones, gravel and clay. Material in the 2—16 mm grain size separated by sieving divided as follows:

	8—16 mm 141 gr	4—8 mm 219 gr	2—4 mm 265 gr	2—16 mm = 625 gr
Paleozoic limestone	1 %		+	+
Sandstone		+	+	+
Archean rock	99 %	100 %	100 %	100 %

The few limestone grains were of the red Orthoceras limestone type.

The sandstone was of the hard, rather coarse grained, greyish type considered as Jotnian.

Divided in the 8—16 mm fraction the Archean rock facies gave the following division:

Sedimentary rocks		29 %	
Intrusive rocks			
Grey granite — diorite	36 %	60 %	
Red granite	5 %		
Pegmatite granite	19 %		
Rapakivi		4 %	(4 %)
Unclassified		7 %	

S a m p l e L 7 8 Location 62°17′00″N 17°57′30″E Depth 41—57 meters

The bottom sample was composed of a mixture of stones, gravel and clay. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 701 gr	4—8 mm 481 gr	2—4 mm 347 gr	2—16 mm = 1.527 kg
Paleozoic limestone	+	+		+
Sandstone	1 %	1 %	1 %	1 %
Archean rock	99 %	99 %	99 %	99 %

The sandstone was of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		19 %
Intrusive rocks		
Grey granite — diorite	55 %	81 %
Red granite	15 %	
Pegmatite granite	11 %	
Rapakivi		+

S a m p l e L 7 9 Location 62°12′10″N 17°54′00″E Depth 34—52 meters

In the obtaining of this bottom sample the circumstances were unusual in so far that between two liftings the sample material changed in a very great degree: the first samples taken with the marine grab were chiefly composed of Archean rock material. When further samples were taken the material, however, changed between two liftings so that it came to consist almost throughout of whitish-grey limestone sand and gravel. In between the two liftings the ship had drifted approximately 50 meters. Cf. further p. 134.

From the sample rich in Archean rock material the 2—16 mm fraction was separated by sieving. This gave the following division:

	8—16 mm 457 gr	4—8 mm 200 gr	2—4 mm 203 gr	2—16 mm = 860 gr
Paleozoic limestone	10 %	6 %	5 %	8 %
Sandstone	4 %	2 %	+	2 %
Archean rock	86 %	92 %	95 %	90 %

The limestone in the 8—16 mm fraction was throughout of the Baltic limestone type. In the 4—8 mm fraction, however, 8 % was of the red Orthoceras limestone type.

The sandstone was of the red Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		28 %	
Intrusive rocks			
Grey granite — diorite	59 %	60 %	
Red granite	1 %		
Rapakivi		6 %	(5 %)
Unclassified		6 %	

In the unclassified group were included some greenish-brown syenite-like rock grains. These might be derived from the Alnö formation.

The part sample rich in limestone gave the following division:

	8—16 mm 124 gr	4—8 mm 102 gr	2—4 mm 101 gr	2—16 mm = 327 gr
Paleozoic limestone	100 %	96 %	96 %	97 %
Archean rock		4 %	4 %	3 %

The limestone in the 8—16 mm fraction was throughout of the Baltic limestone type. In the 4—8 mm fraction, however, a small amount, about 1 %, of the red Orthoceras limestone type could be found.

No loose fossils could be found, which is rather surprising in view of the large amount of limestone.

Sample L 80 Location 62°05′40″N 17°49′10″E Depth 29—55 meters

The bottom sample was composed of sand and gravel. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 326 gr	4—8 mm 176 gr	2—4 mm 125 gr	2—16 mm = 627 gr
Sandstone	+	+	+	+
Archean rock	100 %	100 %	100 %	100 %

Among the few sandstone grains there were both Jotnian and Cambrian grains.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		19 %
Intrusive rocks		
Grey granite — diorite	71 %	74 %
Red granite	3 %	
Rapakivi		1 %
Unclassified		6 %

Sample L 81 Location 62°03′00″N 17°44′00″E Depth 35—45 meters

The bottom sample was composed of sand among which there was coarser stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 247 gr	4—8 mm 96 gr	2—4 mm 75 gr	2—16 mm = 428 gr
Sandstone	4 %	1 %	+	2 %
Archean rock	96 %	99 %	100 %	98 %

The sandstone was of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		8 %
Intrusive rocks		
Grey granite — diorite	83 %	89 %
Red granite	6 %	
Unclassified		3 %

The grey granite-diorite group formed a relatively uniform rock group chiefly composed of grains of massive granite poor in dark mineral components.

Sample L 82 Location 62°01′30″N 17°41′30″E Depth 25—45 meters

The first liftings contained big Archean stones, subsequent liftings brought up fine sand. No stone material suitable for pebble count could be obtained.

Sample L 83 Location 62°00′00″N 17°51′00″E Depth 67 meters

The bottom sample consisted of clay among which there was a minute amount of stone material. This divided as follows:

	8—16 mm 92 gr	4—8 mm 65 gr	2—4 mm 76 gr	2—16 mm = 233 gr
Sandstone	2 %	+	+	1 %
Archean rock	98 %	100 %	100 %	99 %

The sandstone was of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		31 %
Intrusive rocks		
Grey granite — diorite	54 %	59 %
Red granite	5 %	
Unclassified		10 %

In the unclassified group there were some syenite-like grains. These might derive from the known Alnö alkaline rock formation situated in the nearby coast region.

Sample L 84 Location 62°00′00″N 18°12′00″E Depth 81—92 meters

At the sample point the sea bottom consisted of clay rich in limonite. From the large amount in the original sample (about 30 kg) some twenty grains were separated by sieving and picking. All of them were Archean consisting of schist, grey granite, some grains of quartz and one red granite grain.

Sample L 85 Location 62°00′00″N 18°33′00″E Depth 85 meters

The bottom sample was composed of clay and limonite. No stone material could be obtained.

Sample L 86 Location 62°00′00″N 18°43′30″E Depth 48—51 meters

The bottom sample was composed of a mixture of bigger stones, gravel and sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 152 gr	4—8 mm 100 gr	2—4 mm 68 gr	2—16 mm = 320 gr
Paleozoic limestone	2 %	2 %	+	2 %
Sandstone	20 %	11 %	5 %	14 %
Archean rock	78 %	87 %	95 %	84 %

The limestone grains divided in the 4—8 mm fraction as follows:

Baltic limestone	14 grains
Red Orthoceras limestone	2 »
Unclassified	4 »

The sandstone was throughout of the Jotnian type.
The Archean rock facies gave the following division:

Sedimentary rocks		33 %	
Intrusive rocks			
Grey granite — diorite	38 %	54 %	
Red granite	7 %		
Pegmatite granite	9 %		
Rapakivi		5 %	(4 %)
Unclassified		8 %	

In the sample one silicified coral fragment was found.

Sample L 87 Location 62°00′00″N 18°55′00″E Depth 50 meters

The bottom sample consisted of sand, clay and stones. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 322 gr	4—8 mm 179 gr	2—4 mm 130 gr	2—16 mm = 631 gr
Paleozoic limestone	13 %	15 %	18 %	14 %
Sandstone	27 %	30 %	20 %	26 %
Archean rock	60 %	55 %	62 %	60 %

In the 4—8 mm fraction the limestone fell into the following division:

Baltic limestone	32 %
Red Orthoceras limestone	42 %
Unclassified	26 %

With the exception of one single grain considered as Cambrian, the sandstone was throughout of the red Jotnian type. The rock type showed, however, variation in colour and grain size. In general, the colour was pale brick red, several grains were, however, dark, carmine red in colour.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		52 %	
Intrusive rocks			
Grey granite — diorite	28 %	33 %	
Red granite	5 %		
Rapakivi		11 %	(7 %)
Unclassified		4 %	

In the sample half a dozen very poor silicified fossil fragments were found.

Sample L 88 Location 62°00′00″N 19°04′30″E Depth 87 meters

The bottom was composed of clay. No stone material could be obtained.

Sample L 89 Location 62°00′00″N 19°20′15″E Depth 60—62 meters

The bottom sample was composed of a mixture of bigger stones, gravel and clayey sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 123 gr	4—8 mm 123 gr	2—4 mm 115 gr	2—16 mm = 361 gr
Paleozoic limetsone			+	+
Sandstone	9 %	10 %	9 %	9 %
Archean rock	91 %	90 %	91 %	91 %

The only limestone grain found in the 2—4 mm fraction was of the red Orthoceras limestone type.

In the 8—16 mm fraction the sandstone divided as follows:

Jotnian sandstone	94 %	(8 %)
Cambrian sandstone	6 %	(1 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		15 %	
Intrusive rocks			
Grey granite — diorite	55 %	65 %	
Red granite	10 %		
Rapakivi		3 %	(3 %)
Unclassified		17 %	

Sample L 90 Location 62°00′00″N 19°40′00″E Depth 80 meters

The bottom sample was composed of soft clay without any stone material.

Sample L 91 Location 62°00′00″N 20°08′30″E Depth 135 meters

The sea bottom at the sample point consisted of clay rich in limonite. From a large amount of sieved material some twenty grains were separated by picking, all of them Archean with the exception of one red sandstone grain. The Archean grains mostly contained plagioclase-biotite-gneiss and mica-schist. One largish, 3 cm, angular garned-muscovite-schist stone was found.

Sample L 92 Location 62°00′00″N 20°34′00″E Depth 85 meters

The bottom sample was composed of clay and limonite. No stone material was obtained.

Sample L 93 Location 62°00′00″N 20°54′30″E Depth 38 meters

The bottom sample was composed of bigger stones, gravel, sand and clay. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 573 gr	4—8 mm 224 gr	2—4 mm 276 gr	2—16 mm = 1.074 kg
Sandstone	3 %	2 %	1 %	2 %
Archean rock	97 %	98 %	99 %	98 %

The sandstone was of the red Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		76 %
Intrusive rocks		
Grey granite — diorite	11 %	18 %
Red granite	7 %	
Unclassified		6 %

The sedimentary rock group was composed mainly of biotite-plagioclase-gneiss. The proportion of this rock was 66 %.

Sample L 94 Location 62°00′00″N 21°03′00″E Depth 40 meters

The bottom sample was composed of clay and limonite among which there was a minute amount of stone material. Material in the 2—16 mm grain size separated by sieving and picking divided as follows:

	8—16 mm 99 gr	4—8 mm 58 gr	2—4 mm 41 gr	2—16 mm = 198 gr
Sandstone	+	+	+	+
Archean rock	100 %	100 %	100 %	100 %

The few sandstone grains were of the red Jotnian type.

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		50 %
Intrusive rocks		
Grey granite — diorite	28 %	43 %
Red granite	15 %	
Unclassified		7 %

The main part of the sedimentary rock group was of medium grained biotite-plagioclase-gneiss. The percentage of this group was 40 %.

Sample L 95 Location 61°53′30″N 21°03′30″E Depth 44 meters

The bottom sample was composed of clay among which a small amount of stone material could be found. Material in the 2—16 mm grain size gave the following division:

	8—16 mm 124 gr	4—8 mm 74 gr	2—4 mm 68 gr	2—16 mm = 266 gr
Sandstone	4 %	4 %	+	4 %
Archean rock	96 %	96 %	100 %	96 %

With the exception of a couple of Cambrian grains the sandstone was of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		36 %
Intrusive rocks		
Grey granite — diorite	43 %	49 %
Red granite	6 %	
Unclassified		15 %

The majority of the sedimentary rock group was composed of biotite-plagioclase-gneiss. The proportion of this group in the Archean rock facies was 27 %. Since the rock grains considered as grey granite were in this sample schistose, the difference between this and the biotite-plagioclase-gneiss was not quite clear.

Sample L 96 Location 61°47′40″N 21°03′30″E Depth 35 meters

The bottom sample was composed of clayey gravel. The stone material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 406 gr	4—8 mm 225 gr	2—4 mm 144 gr	2—16 mm = 774 gr
Sandstone	10 %	6 %	6 %	8 %
Archean rock	90 %	94 %	94 %	92 %

The sandstone in the 8—16 mm fraction was throughout of the Jotnian type. In the 4—8 mm fraction some Cambrian grains could be found, however.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		66 %
Intrusive rocks		
Grey granite — diorite	17 %	27 %
Red granite	10 %	
Unclassified		7 %

The major part of the sedimentary rock group consisted of biotite-plagioclase-gneiss. The proportion of this group in the Archean rock facies was 42 %.

Sample L 97 Location 61°41′30″N 21°03′30″E Depth 55 meters

The bottom sample was composed of clay. No stone material could be obtained.

Sample L 98 Location 61°40′10″N 21°07′30″E Depth 37 meters

The bottom sample was composed of clay among which there was a small amount of stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 200 gr	4—8 mm 164 gr	2—4 mm 148 gr	2—16 mm = 512 gr
Paleozoic limestone	+			+
Sandstone	26 %	22 %	15 %	22 %
Archean rock	74 %	78 %	85 %	78 %

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	80 %	(18 %)
Cambrian sandstone	20 %	(4 %)

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		27 %	
Intrusive rocks			
Grey granite — diorite	53 %	62 %	
Red granite	9 %		
Rapakivi		4 %	(3 %)
Unclassified		6 %	

Almost one half of the sedimentary rock group was composed of biotite-plagio-clase-gneiss.

For the sake of comparison the main classification was made also in the 1—2 mm fraction. A binocular microscope was used and no difficulties in determining the rock quality were encountered. The size of the fraction was 23.5 grams, corresponding to about two thousand grains. The following result was obtained:

Sandstone	10.6 %
Archean rock	89.4 %

No limestone grains were found.

Sample L 99 Location 61°36′00″N 20°18′00″E Depth 128 meters

The bottom sample was composed of clay. No stone material could be obtained.

Sample L 100 Location 61°36′00″N 19°58′30″E Depth 110 meters

At the sample point the sea bottom consisted of clay from which 15 small stone grains were separated by sieving. One of the grains consisted of red sandstone.

Sample L 101 Location 61°36′00″N 19°36′00″E Depth 79 meters

The bottom sample was composed of clay from which a minute amount of stone material could be separated. This divided as follows:

	8—16 mm 14 gr	4—8 mm 21 gr	2—4 mm 23 gr	2—16 mm = 58 gr
Sandstone	6 %	14 %	10 %	11 %
Archean rock	94 %	86 %	90 %	89 %

Owing to the small amount the classification was based on the number of grains.

The sandstone was of the Jotnian type.

The Archean rock facies was divided in the 4—8 mm fraction as follows:

Sedimentary rocks		22 %	
Intrusive rocks			
Grey granite — diorite	56 %	63 %	
Red granite	7 %		
Rapakivi		6 %	(5 %)
Unclassified		9 %	

Sample L 102 Location 61°36′00″N 19°10′00″E Depth 81 meters

The bottom sample was composed of clayey sand among which coarser stone material could be found. The material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 108 gr	4—8 mm 198 gr	2—4 mm 153 gr	2—16 mm = 459 gr
Paleozoic limestone	3 %	2 %	+	2 %
Sandstone	14 %	7 %	3 %	7 %
Archean rock	83 %	91 %	97 %	91 %

All limestone grains were of the Baltic limestone type.

The sandstone was of the red Jotnian type.

The Archean rock facies was divided in the 8—16 mm fraction as follows:

Sedimentary rocks		36 %	
Intrusive rocks			
Grey granite — diorite	45 %	46 %	
Red granite	1 %		
Rapakivi		11 %	(10 %)
Unclassified		7 %	

Some mica-schist grains of the sedimentary rock group were garnet-bearing.

In the sample some silicified fragments of corals and crinoids were found.

Sample L 103 Location 61°36′00″N 19°05′00″E Depth 53 meters

The bottom sample was composed of clay and clayey gravel. The material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 168 gr	4—8 mm 97 gr	2—4 mm 81 gr	2—16 mm = 346 gr
Paleozoic limestone	16 %	13 %	11 %	14 %
Sandstone	8 %	4 %	3 %	6 %
Archean rock	76 %	83 %	86 %	80 %

The small limestone amount in the 4—8 mm fraction was divided as follows:

Baltic limestone	67 %
Red Orthoceras limestone	1 %
Unclassified	32 %

All the sandstone grains in the 8—16 mm fraction were of the Jotnian type. In the 4—8 fraction, however, some Cambrian grains could be found.

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		20 %	
Intrusive rocks			
Grey granite — diorite	50 %	61 %	
Red granite	11 %		
Rapakivi		7 %	(6 %)
Unclassified		12 %	

In the sample some half a dozen poor fragments of crinoids were found.

Sample L 104 Location 61°36′00″N 18°54′20″E Depth 58 meters

The bottom sample was composed of clay among which a minute amount of stone material could be found. Material in the 2—16 mm grain size separated by sieving divided as follows:

	8—16 mm 66 gr	4—8 mm 41 gr	2—4 mm 55 gr	2—16 mm = 162 gr
Paleozoic limestone	41 %	15 %	6 %	22 %
Sandstone	1 %	+	+	+
Archean rock	58 %	85 %	94 %	78 %

The small limestone amount in the 4—8 mm fraction gave the following division:

Baltic limestone	59 %
Red Orthoceras limestone	10 %
Unclassified	31 %

Of the two sandstone grains included in the 8—16 mm fraction, one was of the Jotnian the other of the Cambrian type.

The small amount of Archean rocks in the 8—16 mm fraction divided as follows:

Sedimentary rocks		22 %
Intrusive rocks		
Grey granite — diorite	59 %	69 %
Red granite	10 %	
Unclassified		9 %

One grain included in the red granite group was of rapakivi-like granite.

Sample L 105 Location 61°36′00″N 18°45′30″E Depth 49 meters

The bottom sample was composed of fine sand among which there was a small amount of coarser grained stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 76 gr	4—8 mm 58 gr	2—4 mm 75 gr	2—16 mm = 209 gr
Paleozoic limestone	3 %	2 %	+	2 %
Sandstone	20 %	10 %	7 %	12 %
Archean rock	77 %	88 %	93 %	86 %

Most of the limestone grains were of the Baltic limestone type.

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	6 %	(1 %)
Cambrian sandstone	94 %	(11 %)

For the sake of comparison the sandstone was divided also in the 4—8 mm fraction. This gave the following result:

Jotnian sandstone	5 %
Cambrian sandstone	95 %

The small amount of Archean rock pebbles in the 8—16 mm fraction divided as follows:

Sedimentary rocks		28 %
Intrusive rocks		
Grey granite — diorite	39 %	57 %
Red granite	18 %	
Unclassified		15 %

In the sample one bryozoan fragment was found.

Sample L 106 Location 61°36′00″N 18°35′30″E Depth 63 meters

The bottom sample was composed of clay and limonite among which a very minute amount of stone material could be picked out. This divided as follows:

	8—16 mm	4—8 mm 15 gr	2—4 mm 9 gr	2—16 mm = 24 gr
Sandstone		3 %	4 %	3 %
Archean rock		97 %	96 %	97 %

Owing to the small amount of material the classification was based on the grain number.

The sandstone was of the red Jotnian type.

The Archean rock facies divided in the 4—8 mm fraction as follows:

Sedimentary rocks		22 %
Intrusive rocks		
Grey granite — diorite	48 %	57 %
Red granite	9 %	
Unclassified		21 %

Among the red granite group a couple of pebbles might possibly be defined as rapakivi-like granite.

Sample L 107 Location 61°36′00″N 18°24′30″E Depth 49 meters

The bottom sample was composed of a mixture of gravel, sand and clay. Material in the 2—16 mm grain size separated by sieving from a part sample was divided as follows:

	8—16 mm 173 gr	4—8 mm 169 gr	2—4 mm 135 gr	2—16 mm = 477 gr
Paleozoic limestone	2 %	2 %	+	2 %
Sandstone	2 %	1 %	1 %	1 %
Archean rock	96 %	97 %	99 %	97 %

The limestone grains were of the Baltic limestone or of the greenish type ranked as »unclassified».

The sandstone was of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		23 %	
Intrusive rocks			
Grey granite — diorite	35 %	61 %	
Red granite	14 %		
Pegmatite granite	12 %		
Rapakivi		3 %	(3 %)
Unclassified		13 %	

Sample L 108. At the sampling point the sea bottom was composed of clay and limonite. The ship was allowed to drift a short distance and the sample then taken was numbered L 109.

Sample L 109 Location 61°36′00″N 18°05′00″E Depth 58—77 meters

The bottom sample was composed of clay among which a minute amount of stone material could be found. In addition, however, some half a dozen stones 5—10 cm in diameter were caught by the marine-grab. Most of these were Baltic limestone. The material in the 2—16 mm grain size separated by sieving divided as follows:

	8—16 mm 19 gr	4—8 mm 11 gr	2—4 mm 5 gr	2—16 mm = 35 gr
Paleozoic limestone	75 %	89 %	79 %	81 %
Archean rock	25 %	11 %	21 %	19 %

The classification was based on the grain number.

The limestone was almost throughout of the Baltic limestone type. In the whole sample only two grains of red Orthoceras limestone were found.

Because of the small amount of material no classification in the Archean rock facies could be carried out.

Sample L 110 Location 61°36′00″N 17°42′45″E Depth 55 meters

The bottom sample was composed of clayey gravel and sand. The material in the 2—16 mm grain size separated by sieving from a part sample divided as follows:

	8—16 mm 251 gr	4—8 mm 149 gr	2—4 mm 91 gr	2—16 mm = 491 gr
Paleozoic limestone	57 %	32 %	25 %	44 %
Sandstone	1 %	+	+	+
Archean rock	42 %	68 %	75 %	56 %

All the limestone was of the Baltic type with the exception of one red Orthoceras limestone grain found in the 8—16 mm fraction.

The few sandstone grains were of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		31 %	
Intrusive rocks			
Grey granite — diorite	36 %	54 %	
Red granite	18 %		
Rapakivi		1 %	(1 %)
Unclassified		14 %	

In the sample some fragments of crinoids were found.

Sample L 111 Location 61°30′00″N 17°46′30″E Depth 15—38 meters

The bottom sample taken from the shallower depth consisted of stones bigger than fist size. The material from the deeper depth was composed of sand including some coarser grained material. The material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 82 gr	4—8 mm 188 gr	2—4 mm 399 gr	2—16 mm = 669 gr
Paleozoic limestone	6 %	+	+	1 %
Sandstone	2 %	2 %	+	1 %
Archean rock	92 %	98 %	100 %	98 %

The few limestone grains were of the Baltic limestone type.

The sandstone was of the red Jotnian type.

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		15 %	
Intrusive rocks			
Grey granite — diorite	40 %	64 %	
Red granite	24 %		
Rapakivi		5 %	(5 %)
Unclassified		16 %	

In the sample were found about a hundred small silicified fossil fragments. Several of these showed very delicate structural features.

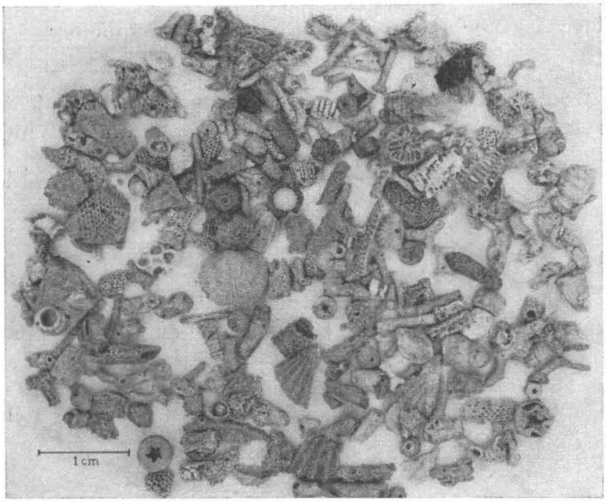

Fig. 17. Silicified fossils found in the sample L 111.

The majority of the stones obtained at the early stage of the taking was limestone. This point should be noted since the limestone content in the material for the pebble count is very small, especially in the two finer grained fractions.

Sample L 112 Location 61°24′40″N 17°47′00″E Depth 67 meters

The bottom sample was composed of a mixture of stones, gravel, sand and clay. The material in the 2—16 mm grain size separated by sieving from a part sample divided as follows:

	8—16 mm 333 gr	4—8 mm 124 gr	2—4 mm 81 gr	2—16 mm = 538 gr
Paleozoic limestone	4 %	3 %	+	3 %
Sandstone	4 %	2 %	2 %	3 %
Archean rock	92 %	95 %	98 %	94 %

The limestone grains were, with the exception of one red limestone grain, of the Baltic limestone type.

All sandstone grains in the 8—16 fraction were of the Jotnian type. In the 4—8 mm fraction, however, some Cambrian grains could be noted.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		10 %	
Intrusive rocks			
Grey granite — diorite	54 %	78 %	
Red granite	24 %		
Rapakivi		2 %	(2 %)
Unclassified		10 %	

Sample L 113 Location 61°19′30″N 17°47′00″E Depth 46 meters

The bottom sample was composed of sand among which there was coarser grained stone material, which in the 2—16 mm grain size, separated by sieving from a part sample, gave the following division:

	8—16 mm 58 gr	4—8 mm 96 gr	2—4 mm 199 gr	2—16 mm = 354 gr
Paleozoic limestone	5 %	5 %	1 %	3 %
Sandstone	+	1 %	+	+
Archean rock	95 %	94 %	99 %	97 %

Except for two red Orthoceras limestone grains the limestone was of the Baltic type.

The few sandstone grains were of the red Jotnian type.

The Archean rock facies in the 8—16 mm fraction fell into the following division:

Sedimentary rocks		7 %
Intrusive rocks		
Grey granite — diorite	63 %	88 %
Red granite	25 %	
Unclassified		5 %

In the sample were found some poor fossil fragments.

Sample L 114 Location 61°14′30″N 17°47′00″E Depth 50 meters

The bottom sample was composed of clayey sand and gravel as well as stones of bigger size. The material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 300 gr	4—8 mm 258 gr	2—4 mm 296 gr	2—16 mm = 854 gr
Paleozoic limestone	25 %	33 %	25 %	27 %
Sandstone		+	+	+
Archean rock	75 %	67 %	75 %	73 %

The limestone divided in the 8—16 mm fraction as follows:

Baltic limestone	66 %
Unclassified	34 %

The few sandstone grains were of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		6 %
Intrusive rocks		
Grey granite — diorite	74 %	81 %
Red granite	7 %	
Unclassified		13 %

Sample L 115 Location 61°09′00″N 17°47′00°E Depth 58 meters

The bottom sample was composed of a mixture of sand, clay, gravel and stones of bigger size. The material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 145 gr	4—8 mm 169 gr	2—4 mm 165 gr	2—16 mm = 479 gr
Paleozoic limestone	2 %	1 %	+	1 %
Sandstone	6 %	6 %	3 %	5 %
Archean rock	92 %	93 %	97 %	94 %

The limestone grains were weathered to a great degree. At a rough estimate the main part of them was of the greenish type.

The sandstone was throughout of the red Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		23 %	
Intrusive rocks			
Grey granite — diorite	36 %	52 %	
Red granite	16 %		
Rapakivi		1 %	(1 %)
Unclassified		24 %	

In the sample a couple of poor ring shaped crinoid fragments were found.

Sample L 116 Location 60°58′20″N 17°45′30″E Depth 50 meters

The bottom sample was composed of clay, clayey gravel, sand and stones of bigger size. Material in the 2—16 mm grain size separated by sieving from a part sample divided as follows:

	8—16 mm 345 gr	4—8 mm 116 gr	2—4 mm 93 gr	2—16 mm = 554 gr
Paleozoic limestone	36 %	36 %	35 %	36 %
Sandstone	+	1 %		+
Archean rock	64 %	63 %	65 %	64 %

The limestone gave in the 4—8 mm fraction the following division:

Baltic limestone	67 %
Red Orthoceras limestone	7 %
Unclassified	26 %

The sandstone included both Jotnian and Cambrian sandstone types.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		24 %	
Intrusive rocks			
Grey granite — diorite	51 %	58 %	
Red granite	7 %		
Rapakivi		3 %	(2 %)
Unclassified		15 %	

In the sample a score of grains composed of rather soft shale-like matter were found. These grains could probably be considered as representing Paleozoic shale.

Sample L 117 Location 60°54′15″N 17°47′00″E Depth 14 meters

The bottom sample was composed of sand among which there was coarser grained stone material. Material in the 2—16 mm grain size separated by sieving from a part sample divided as follows:

	8—16 mm 184 gr	4—8 mm 188 gr	2—4 mm 703 gr	2—16 mm = 1.075 kg
Paleozoic limestone	21 %	7 %	2 %	5 %
Sandstone	1 %	+	+	+
Archean rock	78 %	93 %	98 %	95 %

The limestone was mainly red Orthoceras limestone. One fifth of the grains could be defined as being of the Baltic limestone type.

The few sandstone grains were of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		5 %
Intrusive rocks		
Grey granite — diorite	70 %	85 %
Red granite	15 %	
Unclassified		10 %

The sedimentary rock group consisted mainly of quartzite pebbles. Only some few grains were mica-schist.

Sample L 118 Location 60°53′30″N 17°57′30″E Depth 14 meters

The bottom sample was for the most part composed of bigger than fist size stones. From the finer grained material obtained, material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 232 gr	4—8 mm 45 gr	2—4 mm 19 gr	2—16 mm = 296 gr
Paleozoic limestone	12 %	7 %	3 %	10 %
Sandstone			+	+
Archean rock	88 %	93 %	97 %	90 %

Except for one limestone grain the limestone was of the grey Baltic limestone type.

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks	12 %
Intrusive rocks	
Grey granite — diorite	80 %
Unclassified	8 %

The degree of roundedness of the stone grains was noticeably greater than usual.

Sample L 119 Location 60°58′15″N 18°05′30″E Depth 21 meters

The bottom sample was composed of sand and gravel. Stone material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 376 gr	4—8 mm 322 gr	2—4 mm 275 gr	2—16 mm = 972 gr
Paleozoic limestone	14 %	4 %	3 %	8 %
Sandstone	+	+	+	+
Archean rock	86 %	96 %	97 %	92 %

The limestone was mainly of the Baltic type. Some red and green grains were found.

Among the sandstone grains both Jotnian and Cambrian types could be found.

The Archean rock facies divided in the 8—16 mm fraction as fellows:

Sedimentary rocks		9 %	
Intrusive rocks			
Grey granite — diorite	75 %	87 %	
Red granite	12 %		
Rapakivi		1 %	(1 %)
Unclassified		3 %	

The rondedness degree of the grains was greater than usual.

Sample L 120. At the sampling point the sea bottom was composed of fine sand. The ship was allowed to drift a short distance and the sample then taken was numbered L 121.

Sample L 121 Location 60°54′30″N 18°28′00″E Depth 28 meters

The bottom sample was composed of gravel. The material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 679 gr	4—8 mm 423 gr	2—4 mm 130 gr	2—16 mm = 1.272 kg
Paleozoic limestone	25 %	22 %	18 %	23 %
Sandstone	1 %	+	+	+
Archean rock	74 %	78 %	82 %	76 %

The limestone divided in the 8—16 mm fraction as follows:

Baltic limestone	39 %
Red Orthoceras limestone	14 %
Unclassified	47 %

The few sandstone grains were of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		12 %	
Intrusive rocks			
Grey granite — diorite	67 %	77 %	
Red granite	10 %		
Rapakivi		2 %	(2 %)
Unclassified		9 %	

In the sample were found some fifty fossil fragments mainly crinoids and bryozoa.

Sample L 122 Location 61°00′15″N 18°29′30″E Depth 16 meters

The bottom sample was composed of a mixture of bigger stones, gravel and sand. The material in the 2—18 mm grain size separated by sieving from a part sample divided as follows:

	8—16 mm 227 gr	4—8 mm 106 gr	2—4 mm 81 gr	2—16 mm = 414 gr
Paleozoic limestone	67 %	55 %	53 %	62 %
Archean rock	33 %	45 %	47 %	38 %

The limestone gave in the 8—16 mm fraction the following division:

Baltic limestone	44 %
Red Orthoceras limestone	9 %
Unclassified	47 %

The unclassified group consisted mainly of the greenish limestone type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		10 %
Intrusive rocks		
Grey granite — diorite	49 %	74 %
Red granite	25 %	
Unclassified		16 %

The sample contained a few rather well preserved fossils. These were inter alia one Orthis (?) brachiopod, one piece of trilobite, fragments of bryozoa and crinoids.

Sample L 123 Location 61°02′50″N 18°29′15″E Depth 30 meters

The bottom sample was composed of about twenty fist size stones and a small amount of sand and gravel. The material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 97 gr	4—8 mm 92 gr	2—4 mm 89 gr	2—16 mm = 278 gr
Paleozoic limestone	31 %	14 %	4 %	17 %
Archean rock	69 %	86 %	96 %	83 %

The limestone gave in the 8—16 mm fraction the following division:

Baltic limestone	25 %
Unclassified	75 %

The unclassified limestone group was mainly of the greenish limestone type. The regular diminution of the limestone should be noted.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		8 %
Intrusive rocks		
Grey granite — diorite	63 %	84 %
Red granite	21 %	
Unclassified		8 %

In the sample small grains composed of rather soft shale-like matter were found. These could probably be Paleozoic shale grains.

In the sample a dozen of fragments of bryozoa and crinoids was found.

Sample L 124 Location 61°02′50″N 18°22′00″E Depth 39 meters

The bottom sample was composed of gravel and sand. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 294 gr	4—8 mm 103 gr	2—4 mm 80 gr	2—16 mm = 477 gr
Paleozoic limestone	2 %	+	+	1 %
Sandstone	1 %	1 %	+	1 %
Archean rock	97 %	99 %	100 %	98 %

The limestone grains were of the Baltic limestone type.

The sandstone grains were of the Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		12 %
Intrusive rocks		
Grey granite — diorite	70 %	79 %
Red granite	9 %	
Unclassified		9 %

The degree of roundedness of the stone pebbles was somewhat greater than usual.

Sample L 125 Location 61°02′50″N 18°15′00″E Depth 48 meters

The bottom sample consisted of fist size or bigger stones which were composed both of Archean and Paleozoic limestone. Suitable material for a pebble count was scanty and divided as follows:

	8—16 mm 91 gr	4—8 mm 46 gr	2—4 mm 34 gr	2—16 mm = 171 gr
Paleozoic limestone		1 %	+	+
Sandstone	1 %	+		1 %
Archean rock	99 %	99 %	100 %	99 %

Among the sandstone both Jotnian and Cambrian sandstone grains could be noted.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		4 %
Intrusive rocks		
Grey granite — diorite	75 %	88 %
Red granite	13 %	
Unclassified		8 %

The degree of roundedness of the pebbles was somewhat greater than usual.

Sample L 126 Location 60°57′40″N 18°15′00″E Depth 35—38 meters

The bottom sample which weighed about 10 kilograms consisted almost throughout of fist size stones composed of red Orthoceras limestone. Only a small amount of material for a pebble count was obtained and it divided as follows:

	8—16 mm 52 gr	4—8 mm 30 gr	2—4 mm 11 gr	2—16 mm = 93 gr
Paleozoic limestone	46 %	47 %	36 %	45 %
Archean rock	54 %	53 %	64 %	55 %

The limestone was throughout of the red Orthoceras limestone type.

The Archean rock pebbles divided in the 4—8 mm fraction as follows:

Sedimentary rocks		21 %
Intrusive rocks		
Grey granite — diorite	60 %	69 %
Red granite	9 %	
Unclassified		10 %

Some of the red granite grains had the appearance of rapakivi-like granite.

Sample L 127 Location 60°53′30″N 18°15′00″E Depth 52 meters

The sea bottom at the sample point consisted of fine sand in which some limonite was to be found.

After the original sample of some 4 kilograms had been sieved, 14 grains 2—16 mm in diameter remained, dividing as follows:

Paleozoic limestone	4 grains	= 29 %
Sandstone	1 »	» 7 %
Archean rock	9 »	» 64 %

Sample L 128 Location 60°48′30″N 18°23′30″E Depth 55 meters

The bottom sample was composed of clayey sand and gravel. Material in the 2—16 mm grain size separated by sieving divided as follows:

	8—16 mm 160 gr	4—8 mm 152 gr	2—4 mm 109 gr	2—16 mm = 421 gr
Paleozoic limestone	31 %	24 %	22 %	26 %
Sandstone	4 %	4 %	3 %	4 %
Archean rock	65 %	72 %	75 %	70 %

The limestone divided in the 4—8 mm fraction as follows:

Baltic limestone	34 %
Red Orthoceras limestone	44 %
Unclassified	22 %

The sandstone gave in the 4—8 mm fraction the following division:

Jotnian sandstone	56 %	(2 %)
Cambrian sandstone	44 %	(2 %)

The Archean rock facies was divided in the 8—16 mm fraction as follows:

Sedimentary rocks		16 %	
Intrusive rocks			
Grey granite — diorite	56 %	66 %	
Red granite	10 %		
Rapakivi		6 %	(4 %)
Unclassified		12 %	

In the sample a score of fossils was found consisting of fragments of crinoids, bryozoa and brachiopods.

Sample L 129 Location 60°44′00″N 18°31′00″E Depth 52 meters

The bottom sample was composed of clayey gravel and sand. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 479 gr	4—8 mm 286 gr	2—4 mm 249 gr	2—16 mm = 1.014 kg
Paleozoic limestone	19 %	12 %	9 %	15 %
Sandstone	13 %	12 %	11 %	12 %
Archean rock	68 %	76 %	80 %	73 %

The limestone divided in the 8—16 mm fraction as follows:

Baltic limestone	32 %
Red Orthoceras limestone	38 %
Unclassified	30 %

Except for one Jotnian grain the sandstone in the 8—16 mm fraction was throughout of the Cambrian type.

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		23 %	
Intrusive rocks			
Grey granite — diorite	41 %	63 %	
Diorite	22 %		
Rapakivi		3 %	(2 %)
Unclassified		11 %	

In the sample about ten fossils were found consisting of fragments of corals, bryozoa and crinoids. In addition, three cone shaped pieces, about 3 mm in diameter and composed of sandstone of the Cambrian sandstone type, were found. Regarding the possible significance of the cones see p. 45.

Sample L 130 Location 60°40′00″N 18°38′00″E Depth 45 meters

The bottom sample was composed of sand and clayey sand among which there was some coarser stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 92 gr	4—8 mm 225 gr	2—4 mm 239 gr	2—16 mm = 556 gr
Paleozoic limestone	4 %	2 %	+	2 %
Sandstone	10 %	8 %	5 %	7 %
Archean rock	86 %	90 %	95 %	91 %

In the limestone group there were Baltic and red Orthoceras as well as »unclassified» type grains to be found.

The sandstone divided in the 4—8 mm fraction as follows:

Jotnian sandstone	7 %	(1 %)
Cambrian sandstone	93 %	(6 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		22 %	
Intrusive rocks			
Grey granite — diorite	34 %	63 %	
Red granite	29 %		
Rapakivi		6 %	(5 %)
Unclassified		9 %	

In the sample half a dozen poor fossil fragments were found.

Sample L 131 Location 60°32′00″N 18°51′30″E Depth 31—41 meters

The bottom sample was composed of sand and gravel. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 402 gr	4—8 mm 171 gr	2—4 mm 109 gr	2—16 mm = 682 gr
Paleozoic limestone	+	+		+
Sandstone	1 %	2 %	1 %	1 %
Archean rock	99 %	98 %	99 %	99 %

The sandstone was of the Cambrian sandstone type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		20 %	
Intrusive rocks			
Grey granite — diorite	24 %	55 %	
Red granite	18 %		
Pegmatite granite	13 %		
Rapakivi		19 %	(19 %)
Unclassified		6 %	

Sample L 132 Location 60°22′40″N 18°57′00″E Depth 130 meters

The bottom sample was composed of clay from which, by sieving, only a minute amount of stone material could be separated. This divided as follows:

	8—16 mm —	4—8 mm 9 gr	2—4 mm 6 gr	2—16 mm = 15 gr
Paleozoic limestone		+		+
Sandstone		4 %	4 %	4 %
Archean rock		96 %	96 %	96 %

The classification was based on grain number. Among the few sandstone grains there were both Jotnian and Cambrian ones.

Sample L 133 Location 60°16′20″N 19°00′50″E Depth 179 meters

The bottom sample was composed of soft mud and clay. No stone material was obtained.

Samples L 134—L 136 were taken in the Lumparen inland sea in Åland. These are not included in the present work.

Sample L 137 Location 60°10′30″N 19°10′30″E Depth 270 meters

The bottom sample was composed of clay and limonite from which a minute amount of stone material could be picked out. This divided as follows:

	8—16 mm 14 gr	4—8 mm 15 gr	2—4 mm 8 gr	2—16 mm = 37 gr
Sandstone		+	+	+
Archean rock	100 %	100 %	100 %	100 %

The few sandstone grains were of the red Jotnian type.

The Archean rock pebbles divided in the 4—8 mm fraction as follows:

Sedimentary rocks		29 %	
Intrusive rocks			
Grey granite — diorite	33 %	40 %	
Red granite	7 %		
Rapakivi		27 %	(27 %)
Unclassified		4 %	

Sample L 138 Location 60°14′00″N 19°07′00″E Depth 115 meters

The bottom sample was composed of clayey gravel and sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 360 gr	4—8 mm 114 gr	2—4 mm 130 gr	2—16 mm = 604 gr
Sandstone	18 %	14 %	3 %	14 %
Archean rock	82 %	86 %	97 %	86 %

Except for some typical red Jotnian sandstone grains, the sandstone in the sample was of a rather coarse grained, pink, on the grain surface somewhat porous type, not distinctly belonging to either of the sandstone types. See further p. 144.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		37 %	
Intrusive rocks			
Grey granite — diorite	13 %	22 %	
Red granite	9 %		
Rapakivi		28 %	(24 %)
Unclassified		13 %	

Sample L 139 Location 60°17′40″N 19°02′30″E Depth 100—110 meters

The bottom sample was composed of clayey gravel and sand as well as of stones of bigger size. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 735 gr	4—8 mm 518 gr	2—4 mm 212 gr	2—16 mm = 1.465 kg
Sandstone	23 %	18 %	13 %	20 %
Archean rock	77 %	82 %	87 %	80 %

The majority of the sandstone was of the type found in the previous sample. In addition, some individual grains of the typical Jotnian and Cambrian sandstone types were found.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		48 %	
Intrusive rocks			
Grey granite — diorite	21 %	37 %	
Red granite	16 %		
Rapakivi		5 %	(4 %)
Unclassified		10 %	

The sedimentary rock group consisted for the most part of fine grained, nearly phyllite-like schist grains.

Sample L 140 Location 60°18′30″N 19°01′30″E Depth 26—46 meters

The sample was composed of coarse gravel and stones of bigger size. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 370 gr	4—8 mm 37 gr	2—4 mm 11 gr	2—16 mm = 418 gr
Sandstone	25 %	19 %	9 %	24 %
Archean rock	75 %	81 %	91 %	76 %

The sandstone was of the same unusual type as in the two previous samples.
The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		31 %	
Intrusive rocks			
Grey granite — diorite	43 %	54 %	
Red granite	11 %		
Rapakivi		4 %	(3 %)
Unclassified		11 %	

Sample L 141 Location 60°21′00″N 18°59′30″E Depth 176—197 meters

The bottom sample was composed of dark clay. No stone material could be obtained.

Sample L 142 Location 60°26′35″N 18°59′30″E Depth 50 meters

The entire sample consisted of some twenty grains of different types of Archean rock.

Sample L 143 Location 60°30′30″N 18°59′30″E Depth 50—75 meters

The bottom sample was composed of fist size or bigger stones and of clayey gravel and sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 335 gr	4—8 mm 277 gr	2—4 mm 169 gr	2—16 mm = 781 gr
Paleozoic limestone	6 %	6 %	4 %	5 %
Sandstone	5 %	6 %	4 %	5 %
Archean rock	89 %	88 %	92 %	90 %

About half of the limestone grains were of the red Orthoceras limestone type, the rest consisted of Baltic limestone and the greenish unclassified type.

The sandstone was throughout of the Cambrian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		17 %	
Intrusive rocks			
Grey granite — diorite	39 %	43 %	
Red granite	4 %		
Rapakivi		35 %	(32 %)
Unclassified		5 %	

In the sample a couple of poor fragments of corals and crinoids were found.

Sample L 144 Location 60°36′15″N 18°57′60″E Depth 45—55 meters

The bottom sample was composed of gravel and sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 279 gr	4—8 mm 346 gr	2—4 mm 178 gr	2—16 mm = 803 gr
Sandstone	4 %	3 %	2 %	3 %
Archean rock	96 %	97 %	98 %	97 %

The sandstone was throughout of the Cambrian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		8 %	
Intrusive rocks			
Grey granite — diorite	37 %	67 %	
Red granite	30 %		
Rapakivi		17 %	(16 %)
Unclassified		8 %	

Sample L 145 Location 60°42′30″N 18°53′15″E Depth 57 meters

The bottom sample was composed of clay among which there was stone material mainly of the gravel coarseness class. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 322 gr	4—8 mm 240 gr	2—4 mm 220 gr	2—16 mm = 784 gr
Paleozoic limestone	2 %	3 %	1 %	2 %
Sandstone	17 %	18 %	20 %	18 %
Archean rock	81 %	79 %	79 %	80 %

About half of the limestone grains were of the red Orthoceras type. The rest consisted of Baltic limestone as well as of the greenish, undeterminable type.

The sandstone gave in the 8—16 mm fraction the following division:

Jotnian sandstone	8 %	(1 %)
Cambrian sandstone	92 %	(17 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		20 %	
Intrusive rocks			
Grey granite — diorite	30 %	66 %	
Red granite	36 %		
Rapakivi		5 %	(4 %)
Unclassified		9 %	

The red granite group was for the main part composed of rather coarse grained granite poor in dark minerals.

About half a dozen silicified fossil fragments could be found in the sample.

Sample L 146 Location 60°45′30″N 18°51′30″E Depth 55 meters

The bottom sample was composed of clay mixed with gravel and sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 220 gr	4—8 mm 239 gr	2—4 mm 248 gr	2—16 mm = 707 gr
Paleozoic limestone	5 %	5 %	1 %	4 %
Sandstone	30 %	20 %	15 %	25 %
Archean rock	65 %	75 %	84 %	71 %

The Baltic limestone type was dominant in the limestone group. The red Orthoceras and the greenish limestone types were, however, also to be found.

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	15 %	(4 %)
Cambrian sandstone	85 %	(21 %)

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		28 %
Intrusive rocks		
Grey granite — diorite	51 %	64 %
Red granite	13 %	
Rapakivi		+
Unclassified		8 %

In the sample some poor fossil fragments could be found. In addition, one cone composed of Cambrian sandstone-like matter was found.

Sample L 147 Location 60°49′00″N 18°49′00″E Depth 69 meters

The bottom sample was composed of clay. No stone material could be obtained.

Sample L 148 Location 60°56′00″N 18°45′00″E

No sample with the marine-grab was obtained at the sampling point.

Sample L 149 Location 61°00′00″N 18°43′00″E Depth 62 meters

The bottom sample was composed of sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 33 gr	4—8 mm 20 gr	2—4 mm 15 gr	2—16 mm = 68 gr
Paleozoic limestone		1 %	+	+
Sandstone	6 %	5 %	+	4 %
Archean rock	94 %	94 %	100 %	96 %

The sandstone grains were of the red or greyish-red Jotnian type.
The Archean rock grains divided in the 4—8 mm fraction as follows:

Sedimentary rocks		41 %
Intrusive rocks		
Grey granite — diorite	49 %	51 %
Red granite	2 %	
Unclassified		8 %

Sample L 150 Location 61°03′30″N 18°41′30″E Depth 40 meters

The bottom sample consisted of gravel, sand and clay. Material in the 2—16 mm grain size sieved from a part sample gave the following division:

	8—16 mm 516 gr	4—8 mm 307 gr	2—4 mm 333 gr	2—16 mm = 1.156 kg
Paleozoic limestone	36 %	29 %	20 %	30 %
Sandstone	1 %	+	+	+
Archean rock	63 %	71 %	80 %	70 %

The limestone divided in the 8—16 mm fraction as follows:

Baltic limestone	71 %
Red Orthoceras limestone	21 %
Unclassified	8 %

The sandstone grains were of the red Jotnian type.
The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		35 %
Intrusive rocks		
Grey granite — diorite	45 %	59 %
Red granite	14 %	
Unclassified		6 %

In the sample about thirty poor fossil fragments consisting of corals, crinoids and brachiopods were found.

Sample L 151 Location 61°04′50″N 18°41′30″E Depth 45 meters

The bottom sample consisted of sand and gravel. Material in the 2—16 mm grain size separated from a part sample gave the following division:

	8—16 mm 236 gr	4—8 mm 147 gr	2—4 mm 145 gr	2—16 mm = 528 gr
Paleozoic limestone	8 %	9 %	5 %	7 %
Sandstone	1 %	2 %	2 %	2 %
Archean rock	91 %	89 %	93 %	91 %

Baltic limestone was dominant in the limestone group. Some grains of red Orthoceras limestone were found. The rest was of the greenish limestone type.

Except for some few Cambrian grains, the sandstone was of the red Jotnian type.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		19 %
Intrusive rocks		
Grey granite — diorite	35 %	72 %
Red granite	37 %	
Unclassified		9 %

In the sample about twenty poor fossils consisting of crinoids, brachiopods and corals were found.

Sample L 152 Location 61°04′00″N 19°01′00″E Depth 70 meters

The bottom sample was composed of clay from which a relatively small amount of stone material could be separated by sieving. Material in the 2—16 mm grain size divided as follows:

	8—16 mm 210 gr	4—8 mm 156 gr	2—4 mm 160 gr	2—16 mm = 526 gr
Paleozoic limestone	19 %	20 %	15 %	18 %
Sandstone	+	+	+	+
Archean rock	81 %	80 %	85 %	82 %

Except for some red Orthoceras and greenish limestone grains the limestone was of the Baltic limestone type.

Among the sandstone grains both the Jotnian and the Cambrian types were represented.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		33 %
Intrusive rocks		
Grey granite — diorite	38 %	47 %
Red granite	9 %	
Unclassified		20 %

Sample L 153 Location 61°04′00″N 19°28′00″E Depth 120 meters

The bottom sample was composed of clay and limonite. The relatively small amount of stone material which could be separated by sieving gave the following division:

	8—16 mm 135 gr	4—8 mm 89 gr	2—4 mm 78 gr	2—16 mm = 302 gr
Paleozoic limestone	25 %	17 %	12 %	19 %
Sandstone	7 %	2 %	1 %	4 %
Archean rock	68 %	81 %	87 %	77 %

The limestone divided in the 8—16 mm fraction as follows:

Baltic limestone	93 %
Unclassified	7 %

The few sandstone grains in the 8—16 mm fraction gave the ratio 3: 1 between the Jotnian and Cambrian types.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks	22 %	
Intrusive rocks		
Grey granite — diorite	57 %	
Rapakivi	4 %	(3 %)
Unclassified	17 %	

Sample L 154 Location 61°04′00″N 19°56′30″E Depth 102 meters

The bottom sample was composed of stone material of average gravel coarseness mixed with abundant clay. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 304 gr	4—8 mm 290 gr	2—4 mm 269 gr	2—16 mm = 864 gr
Paleozoic limestone	71 %	63 %	63 %	66 %
Sandstone	4 %	5 %	3 %	4 %
Archean rock	25 %	32 %	34 %	30 %

The limestone divided in the 8—16 mm fraction as follows:

Baltic limestone	59 %
Red Orthoceras limestone	12 %
Unclassified	29 %

The unclassified group consisted mainly of grains of a greenish colouring.

The ratio between the Jotnian and Cambrian sandstone in the 8—16 mm fraction was 2: 1.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		35 %	
Intrusive rocks			
Grey granite — diorite	43 %	50 %	
Red granite	7 %		
Rapakivi		9 %	(3 %)
Unclassified		6 %	

In the sample about twenty poor fossil fragments consisting for the most part of crinoids and brachiopods could be found.

Sample L 155 Location 61°04′00″N 20°12′45″E Depth 100 meters

The bottom sample was composed of clay and limonite. The small amount of stone material which could be separated gave the following division:

	8—16 mm 59 gr	4—8 mm 43 gr	2—4 mm 30 gr	2—16 mm = 132 gr
Paleozoic limestone	17 %	14 %	7 %	14 %
Sandstone	3 %	5 %	1 %	3 %
Archean rock	80 %	81 %	92 %	83 %

The limestone grains were weathered to such a degree that a classification could not be carried out.

The sandstone grains fell into the ratio 2: 1 between the Jotnian and the Cambrian sandstone types.

The Archean rock pebbles gave in the 8—16 mm fraction the following division:

Sedimentary rocks	19 %	
Intrusive rocks		
Grey granite — diorite	60 %	
Rapakivi	2 %	(2 %)
Unclassified	19 %	

Sample L 156 Location 61°04′00″N 20°21′00″E Depth 92 meters

The bottom sample was composed of clay and limonite from which a minute amount of stone material could be separated. This divided as follows:

	8—16 mm 47 gr	4—8 mm 42 gr	2—4 mm 35 gr	2—16 mm = 124 gr
Paleozoic limestone	30 %	14 %	14 %	20 %
Sandstone	13 %	7 %	3 %	8 %
Archean rock	57 %	79 %	83 %	72 %

The limestone grains fell in the 4—8 mm fraction into the following division:

Baltic limestone	41 %
Red Orthoceras limestone	23 %
Unclassified	36 %

The sandstone grains divided in the 4—8 mm fraction as follows:

Jotnian sandstone	70 %	(6 %)
Cambrian sandstone	30 %	(2 %)

The Archean rock facies gave in the 4—8 mm fraction the following division:

Sedimentary rocks		19 %
Intrusive rocks		
Grey granite — diorite	64 %	78 %
Red granite	14 %	
Unclassified		3 %

Sample L 157 Location 61°04′00″N 20°35′00″E Depth 75 meters

The bottom sample was composed of clay among which there was stone material of gravel and sand coarseness. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 142 gr	4—8 mm 139 gr	2—4 mm 155 gr	2—16 mm =436 gr
Paleozoic limestone	17 %	12 %	9 %	12 %
Sandstone	16 %	18 %	13 %	15 %
Archean rock	67 %	70 %	78 %	73 %

In the limestone group the Baltic limestone type was dominant. Some red limestone grains could be found in addition.

The sandstone gave in the 8—16 mm fraction the following division:

Jotnian sandstone	79 %	(12 %)
Cambrian sandstone	21 %	(3 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		34 %	
Intrusive rocks			
Grey granite — diorite	47 %	59 %	
Red granite	12 %		
Rapakivi		4 %	(3 %)
Unclassified		3 %	

In the sample were some fragments of crinoids, corals and bryozoa.

Sample L 158 Location 61°04′00″N 20°51′30″E Depth 50 meters

The bottom sample was composed of clay among which stone material of gravel and sand coarseness was found. Material in the 2—16 mm grain size separated by sieving from a part sample divided as follows:

	8—16 mm 159 gr	4—8 mm 164 gr	2—4 mm 175 gr	2—16 mm = 498 gr
Sandstone	17 %	16 %	14 %	15 %
Archean rock	83 %	84 %	86 %	85 %

The sandstone gave in the 8—16 mm fraction the following division:

Jotnian sandstone	69 %	(10 %)
Cambrian sandstone	31 %	(5 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		14 %	
Intrusive rocks			
Grey granite — diorite	40 %	70 %	
Red granite	30 %		
Rapakivi		2 %	(2 %)
Unclassified		14 %	

The rather large red granite group was for the most part composed of grains of pegmatitic granite.

Sample L 159 Location 61°04′00″N 21°03′30″E Depth 30 meters

The whole sample weighed 2.5 kilograms and consisted of 10 stones varying in size from 0.5 to 15 centimeters in diameter. Two of the stones were of red Jotnian sandstone.

Sample L 160 Location 61°10′30″N 21°03′30″E Depth 42 meters

The bottom sample was composed of gravel. Stone material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 316 gr	4—8 mm 399 gr	2—4 mm 368 gr	2—16 mm = 1.083 kg
Sandstone	23 %	13 %	10 %	15 %
Archean rock	77 %	87 %	90 %	85 %

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	79 %	(12 %)
Cambrian sandstone	21 %	(3 %)

The Archean rock facies fell in the 8—16 mm fraction into the following division:

Sedimentary rocks		14 %	
Intrusive rocks			
Grey granite — diorite	39 %	74 %	
Red granite	35 %		
Rapakivi		5 %	(4 %)
Unclassified		7 %	

The red granite group was composed mainly of rather coarse grained pegmatitic granite.

Sample L 161 Location 61°16′50″N 21°03′30″E Depth 45 meters

The bottom sample was composed of clay from which a minute amount of material for pebble count could be separated. This divided as follows:

	8—16 mm 94 gr	4—8 mm 60 gr	2—4 mm 43 gr	2—16 mm = 197 gr
Paleozoic limestone	1 %	+	+	+
Sandstone	15 %	33 %	14 %	17 %
Archean rock	84 %	77 %	86 %	83 %

Among the few limestone grains both the Baltic and the red as well as the greenish limestone types were represented.

The sandstone gave in the 8—16 mm fraction the following division:

Jotnian sandstone	59 %	(10 %)
Cambrian sandstone	41 %	(7 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		20 %	
Intrusive rocks			
Grey granite — diorite	61 %	71 %	
Red granite	10 %		
Rapakivi		3 %	(2 %)
Unclassified		6 %	

The sample included a roundish pyrite concretion about 1 centimeter in diameter.

Sample L 162 Location 61°23′30″N 21°03′30″E Depth 48 meters

The bottom sample was composed of sand among which there was some coarser grained stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 125 gr	4—8 mm 124 gr	2—4 mm 109 gr	2—16 mm = 358 gr
Paleozoic limestone	2 %	+		+
Sandstone	18 %	11 %	11 %	14 %
Archean rock	80 %	89 %	89 %	86 %

The limestone was represented by Baltic as well as red Orthoceras limestone grains.

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	78 %	(11 %)
Cambrian sandstone	22 %	(3 %)

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		26 %
Intrusive rocks		
Grey granite — diorite	63 %	70 %
Red granite	7 %	
Unclassified		4 %

S a m p l e L 1 6 3 Location 61°29′30″N 21°03′30″E Depth 41—43 meters

The bottom sample was composed of sand from which a small amount of stone material suitable for pebble count could be separated by sieving. This divided as follows:

	8—16 mm 36 gr	4—8 mm 44 gr	2—4 mm 35 gr	2—16 mm = 115 gr
Sandstone	28 %	26 %	6 %	21 %
Archean rock	72 %	74 %	94 %	79 %

The sandstone gave in the 4—8 mm fraction the following division:

Jotnian sandstone	86 %	(18 %)
Cambrian sandstone	14 %	(3 %)

The Archean rock facies divided in the 4—8 mm fraction as follows:

Sedimentary rocks		22 %	
Intrusive rocks			
Grey granite — diorite	59 %	67 %	
Red granite	8 %		
Rapakivi		2 %	(2 %)
Unclassified		9 %	

S a m p l e H 1 Location 61°00′30″N 20°55′00″E Depth 37 meters

The bottom sample was composed of clay and fine sand from which a small amount of stone material for pebble count could be separated by sieving. This divided as follows:

	8—16 mm 76 gr	4—8 mm 52 gr	2—4 mm 48 gr	2—16 mm = 176 gr
Sandstone	27 %	19 %	14 %	21 %
Archean rock	73 %	81 %	86 %	79 %

The sandstone gave in the 8—16 mm fraction the following division:

Jotnian sandstone	87 %	(18 %)
Cambrian sandstone	13 %	(3 %)

The Archean rock pebbles divided in the 4—8 mm fraction as follows:

Sedimentary rocks		21 %	
Intrusive rocks			
Grey granite — diorite	40 %	56 %	
Red granite	16 %		
Rapakivi		7 %	(6 %)
Unclassified		16 %	

Sample H 2 Location 60°56′30″N 20°50′00″E Depth 31—38 meters

The bottom sample was composed of stones, gravel, sand and clay. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 519 gr	4—8 mm 225 gr	2—4 mm 141 gr	2—16 mm = 885 gr
Paleozoic limestone		+	+	+
Sandstone	14 %	11 %	9 %	12 %
Archean rock	86 %	89 %	91 %	88 %

Among the few limestone grains both Baltic and red Orthoceras limestone was represented.

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	86 %	(10 %)
Cambrian sandstone	14 %	(2 %)

For comparison the division was carried out also in the 4—8 mm fraction. This gave the following result: Jotnian sandstone 92 %, Cambrian sandstone 8 %.

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		20 %	
Intrusive rocks			
Grey granite — diorite	33 %	72 %	
Red granite	39 %		
Rapakivi		1 %	(1 %)
Unclassified		7 %	

The red granite group was composed mainly of rather coarse grained pegmatitic granite.

Sample H 3 Location 60°50′30″N 20°42′00″E Depth 35—41 meters

The bottom sample was composed of fist size or bigger stones, coarse gravel and a comparatively small amount of sand. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 296 gr	4—8 mm 62 gr	2—4 mm 30 gr	2—16 mm = 388 gr
Paleozoic limestone		+	+	+
Sandstone	16 %	9 %	12 %	14 %
Archean rock	84 %	91 %	88 %	86 %

Most of the few limestone grains found were of the Baltic limestone type.

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	78 %	(11 %)
Cambrian sandstone	22 %	(3 %)

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		35 %	
Intrusive rocks			
Grey granite — diorite	32 %	44 %	
Red granite	12 %		
Rapakivi		3 %	(3 %)
Unclassified		18 %	

About half of the red granite was of the rather coarse grained pegmatitic type.

Sample H 4 Location 60°46′00″N 20°29′00″E Depth 46—56 meters

The bottom sample was composed of fist size or bigger stones, gravel, sand, and, from the greater depth, of clay. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 485 gr	4—8 mm 282 gr	2—4 mm 259 gr	2—16 mm = 1.026 kg
Paleozoic limestone	9 %	6 %	5 %	7 %
Sandstone	19 %	17 %	13 %	17 %
Archean rock	72 %	77 %	82 %	76 %

The limestone fell in the 8—16 mm fraction into the following division:

Baltic limestone	14 %
Red Orthoceras limestone	31 %
Unclassified	55 %

The unclassified group was mainly of the greenish limestone type.
The sandstone gave in the 8—16 mm fraction the following division:

Jotnian sandstone	90 %	(15 %)
Cambrian sandstone	10 %	(2 %)

The Archean rock facies divided in the 8—16 mm fraction as follows:

Sedimentary rocks		33 %	
Intrusive rocks			
Grey granite — diorite	27 %	37 %	
Red granite	10 %		
Rapakivi		11 %	(8 %)
Unclassified		19 %	

In the sample a roundish pyrite concretion about 2 cm in diameter was found.

Sample H 5 Location 60°42′30″N 20°20′00″E Depth 45—56 meters

The bottom sample was composed of clay from which a minute amount of stone material suitable for pebble count could be separated by sieving. This divided as follows:

	8—16 mm 24 gr	4—8 mm 14 gr	2—4 mm 7 gr	2—16 mm = 45 gr
Paleozoic limestone	16 %	2 %	2 %	10 %
Sandstone	29 %	26 %	15 %	26 %
Archean rock	55 %	72 %	83 %	64 %

Among the limestone grains both the Baltic and the red Orthoceras limestone types were represented.

The sandstone divided in the 4—8 mm fraction as follows:

Jotnian sandstone	88 %	(23 %)
Cambrian sandstone	12 %	(3 %)

The Archean rock pebbles fell in the 4—8 mm fraction into the following division:

Sedimentary rocks		27 %	
Intrusive rocks			
Grey granite — diorite	29 %	46 %	
Red granite	17 %		
Rapakivi		10 %	(6 %)
Unclassified		17 %	

Sample H 6 Location 60°41′00″N 20°15′30″E Depth 51—52 meters

The bottom sample was composed of clay among which there was some stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 75 gr	4—8 mm 65 gr	2—4 mm 85 gr	2—16 mm = 225 gr
Paleozoic limestone	14 %	2 %	1 %	6 %
Sandstone	14 %	11 %	10 %	11 %
Archean rock	72 %	87 %	89 %	83 %

Note should be taken of the relatively great amount of limestone in the 8—16 mm fraction compared to the amount appearing in the finer grained fractions. The same feature is to be seen also in the previous sample. In the sample at hand both the Baltic and the red Orthoceras limestone types were present.

The sandstone gave in the 8—16 mm fraction the following division:

Jotnian sandstone	77 %	(9 %)
Cambrian sandstone	23 %	(2 %)

The Archean rock facies divided in the 4—8 mm fraction as follows:

Sedimentary rocks		27 %	
Intrusive rocks			
Grey granite — diorite	29 %	43 %	
Red granite	14 %		
Rapakivi		16 %	(13 %)
Unclassified		14 %	

Sample H 7 Location 60°39′30″N 20°10′00″E Depth 43 meters

The bottom sample was composed of clay from which a minute amount of stone material suitable for pebble count could be separated by sieving. This divided as follows:

	8—16 mm 22 gr	4—8 mm 17 gr	2—4 mm 10 gr	2—16 mm = 49 gr
Paleozoic limestone	4 %	3 %	5 %	4 %
Sandstone	19 %	7 %	6 %	12 %
Archean rock	77 %	90 %	89 %	84 %

Most of the limestone grains were of the Baltic limestone type. Some red grains could be found in addition.

The sandstone fell into the ratio 5: 1 in regard to Jotnian and Cambrian sandstone.

The Archean rock pebbles divided in the 4—8 mm fraction as follows:

Sedimentary rocks		31 %	
Intrusive rocks			
Grey granite — diorite	28 %	33 %	
Red granite	5 %		
Rapakivi		18 %	(15 %)
Unclassified		18 %	

Sample H 8 Location 60°36′30″N 20°00′00″E Depth 32—42 meters

The bottom sample was composed of fine sand and clay mixed with sand. Material suitable for pebble count separated by sieving gave the following division:

	8—16 mm 35 gr	4—8 mm 66 gr	2—4 mm 246 gr	2—16 mm = 347 gr
Paleozoic limestone	2 %			+
Sandstone	43 %	23 %	15 %	19 %
Archean rock	55 %	77 %	85 %	81 %

The only limestone grain found in the 8—16 mm fraction was of the Baltic limestone type.

The sandstone divided in the 4—8 mm fraction gave the following division:

Jotnian sandstone	55 %	(10 %)
Cambrian sandstone	45 %	(9 %)

The Archean rock pebbles fell in the 4—8 mm fraction into the following division:

Sedimentary rocks		21 %	
Intrusive rocks			
Grey granite — diorite	30 %	38 %	
Red granite	8 %		
Rapakivi		29 %	(23 %)
Unclassified		12 %	

Sample H 9 Location 60°35′00″N 19°55′30″E Depth 20—52 meters

During the taking of the sample the depth increased rapidly. The material obtained from the bottom consisted, at the beginning, of fist sized or bigger stones, gravel, sand and, finally, of clay. Material in the 2—16 mm grain size separated from a part sample gave the following division:

	8—16 mm 240 gr	4—8 mm 221 gr	2—4 mm 151 gr	2—16 mm = 612 gr
Paleozoic limestone		+	+	+
Sandstone	23 %	18 %	13 %	19 %
Archean rock	77 %	82 %	87 %	81 %

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	71 %	(13 %)
Cambrian sandstone	29 %	(6 %)

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		17 %	
Intrusive rocks			
Grey granite — diorite	31 %	40 %	
Red granite	9 %		
Rapakivi		34 %	(28 %)
Unclassified		9 %	

Sample H 10 Location 60°38′40″N 19°52′30″E Depth 27—53 meters

No sample was obtained from the shallower depth. Only when the depth had increased to about 40 meters was bottom material composed of coarse gravel obtained. At a still deeper depth the sample consisted of sand. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 379 gr	4—8 mm 126 gr	2—4 mm 69 gr	2—16 mm = 574 gr
Paleozoic limestone	1 %	+	+	1 %
Sandstone	25 %	15 %	16 %	22 %
Archean rock	74 %	85 %	84 %	77 %

Of the four limestone grains included in the 8—16 mm fraction two were of the Baltic type, one of the red Orthoceras limestone type.

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	93 %	(20 %)
Cambrian sandstone	7 %	(2 %)

The Archean rock facies fell in the 8—16 mm fraction into the following division:

Sedimentary rocks		28 %	
Intrusive rocks			
Grey granite — diorite	34 %	38 %	
Red granite	4 %		
Rapakivi		18 %	(14 %)
Unclassified		16 %	

Sample H 11 Location 61°05′00″N 19°56′00″E Depth 108 meters

The bottom sample was composed of clay and limonite from which a minute amount of stone material could be separated by sieving and picking. This divided as follows:

	8—16 mm 80 gr	4—8 mm 56 gr	2—4 mm 40 gr	2—16 mm = 176 gr
Paleozoic limestone	10 %	20 %	15 %	14 %
Sandstone	16 %	12 %	5 %	12 %
Archean rock	74 %	68 %	80 %	74 %

The limestone grains were weathered. In some better preserved grains it was possible, however, to determine the presence of both the Baltic and the red Orthoceras limestone types.

All the sandstone grains were of the Jotnian type.

The Archean rock pebbles divided in the 8—16 mm fraction as follows:

Sedimentary rocks		29 %	
Intrusive rocks			
Grey granite — diorite	41 %	49 %	
Red granite	8 %		
Rapakivi		3 %	(2 %)
Unclassified		19 %	

The sample included one fragment of a brachiopod and one of a gastropod.

Sample H 12 Location 60°38′00″N 19°41′00″E Depth 46 meters

The bottom sample was composed of clay. In the sample one Archean stone was found.

Sample H 13 Location 60°33′20″N 19°30′30″E Depth 62—64 meters

The bottom sample was composed of gravel and sand. Material in the 2—16 mm grain size separated by sieving from a part sample gave the following division:

	8—16 mm 252 gr	4—8 mm 346 gr	2—4 mm 336 gr	2—16 mm = 934 gr
Paleozoic limestone	+			+
Sandstone	16 %	14 %	11 %	14 %
Archean rock	84 %	86 %	89 %	86 %

The sandstone divided in the 8—16 mm fraction as follows:

Jotnian sandstone	64 %	(9 %)
Cambrian sandstone	36 %	(5 %)

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		16 %	
Intrusive rocks			
Grey granite — diorite	26 %	46 %	
Red granite	20 %		
Rapakivi		28 %	(24 %)
Unclassified		10 %	

Sample H 14 Location 60°34′00″N 19°23′30″E Depth 54 meters

The bottom sample was composed of clay. No stone material was obtained.

Sample H 15 Location 60°34′00″N 19°10′00″E Depth 69 meters

The bottom sample was composed of clay and limonite without any stone material.

Sample H 16 Location 60°34′00″N 19°07′00″E Depth 51 meters

The bottom sample was composed of a mixture of gravel, sand and clay. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 123 gr	4—8 mm 113 gr	2—4 mm 183 gr	2—16 mm = 419 gr
Paleozoic limestone	1 %	1 %	+	+
Sandstone	4 %	7 %	8 %	7 %
Archean rock	95 %	92 %	92 %	93 %

Among the few limestone grains both the Baltic and the red Orthoceras limestone types were represented.

The sandstone divided in the 4—8 mm fraction as follows:

Jotnian sandstone	4 %	(+)
Cambrian sandstone	96 %	(7 %)

The Archean rock facies gave in the 8—16 mm fraction the following division:

Sedimentary rocks		14 %	
Intrusive rocks			
Grey granite — diorite	30 %	52 %	
Red granite	22 %		
Rapakivi		15 %	(14 %)
Unclassified		19 %	

Sample H 17 Location 61°58′00″N 19°44′00″E Depth 82 meters

The bottom sample was composed of clay and limonite. The minute amount of stone material which could be separated by sieving and picking divided as follows:

	8—16 mm 26 gr	4—8 mm 15 gr	2—4 mm 12 gr	2—16 mm = 53 gr
Sandstone	6 %	4 %	4 %	5 %
Archean rock	94 %	96 %	96 %	95 %

The sandstone was of the red Jotnian type.

The Archean rock grains divided in the 4—8 mm fraction as follows:

Sedimentary rocks		24 %
Intrusive rocks		
Grey granite — diorite	45 %	55 %
Red granite	10 %	
Unclassified		21 %

Sample H 18 Location 62°04′00″N 19°49′00″E Depth 109 meters

The bottom sample was composed of soft clay and limonite. No stone material could be obtained.

Sample H 19 Location 62°08′00″N 19°45′30″E Depth 113 meters

The bottom sample was composed of soft clay and limonite. By sieving and picking a score of stone grains could be separated all of which were of Archean rock composition.

Sample H 20 Location 62°13′00″N 19°40′00″E Depth 115 meters

The bottom sample was composed of soft clay. No stone material could be obtained.

Sample H 21 Location 63°10′10″N 19°59′00″E Depth 62—65 meters

The bottom sample was composed of sand among which there was a little coarser grained stone material. Material in the 2—16 mm grain size separated by sieving gave the following division:

	8—16 mm 127 gr	4—8 mm 92 gr	2—4 mm 77 gr	2—16 mm = 296 gr
Sandstone	15 %	10 %	6 %	11 %
Archean rock	85 %	90 %	94 %	89 %

The sandstone was throughout of the Jotnian type.

The Archean rock facies divided in the 4—8 mm fraction as follows:

Sedimentary rocks		27 %	
Intrusive rocks			
Grey granite — diorite	42 %	52 %	
Red granite	10 %		
Rapakivi		3 %	(3 %)
Unclassified		18 %	

S a m p l e H 2 2 Location 63°14′00″N 19°38′00″E Depth 72—80 meters

The bottom sample was composed of clay from which a small amount of stone material suitable for pebble count could be separated by sieving. This divided as follows:

	8—16 mm 138 gr	4—8 mm 53 gr	2—4 mm 30 gr	2—16 mm = 221 gr
Sandstone	3 %	2 %	2 %	3 %
Archean rock	97 %	98 %	98 %	97 %

The sandstone was of the Jotnian type.

The Archean rock pebbles divided in the 4—8 mm fraction as follows:

Sedimentary rocks		24 %
Intrusive rocks		
Grey granite — diorite	23 %	58 %
Red granite	35 %	
Unclassified		18 %

GENERAL OBSERVATIONS MADE IN CONNECTION WITH PEBBLE COUNTS

Prior to the interpretation of the underlying rock crust on the basis of stone counts, certain general observations that have come to light in connection with the treatment of the samples should be examined.

The main question is which glacigenic drift, unsorted (till) or sorted (esker) drift the material obtained from the sea bottom should be regarded as belonging to. This point is of importance in so far that, in general, the latter is regarded as having been transported a somewhat longer distance (cf. Hellaakoski, 1930). Admittedly, the relatively slight difference in transportation distances, even if not taken into account, is hardly likely to give rise to noticeable differences in interpretation, in view of the large scale nature of the present work.

A determination of the glacigenic type of the bottom drift may be achieved by considering the picture of the bottom structure given by the echo and by the bottom sample itself.

According to the echo picture, the samples largely derive from the sea bottom drift, which covers the rock crust in an evenly distributed thin layer, being therefore, presumably, till. To a great extent, however, it has not been possible to carry out even this interpretation of the bottom. On the basis of the echo curve it has been possible to establish features pointing to the potentiality of esker drift in the sub-marine ridge of the Bothnian Sea only.

In the last resort the interpretation of the quality of the bottom drift must therefore be based on the sample material itself, particularly on the grade of wear and the degree of roundedness of the grains in it. It has not been possible to use assortedness, in particular the content of clay or the lack of it, as a criterion, since one must assume a continuous wash on the one hand, and sedimentation of the clay material on the other, as taking place in the surface layer of the sea bottom.

As regards the degree of roundedness of the stone grains, the bottom samples of the sea area resemble each other to a considerable degree, and notable regularity exists in that respect also between the grain size fractions of single samples. As a regular feature the degree of roundedness decreases from coarser to finer grain size. It can also be observed that the degree of roundedness is dependent on the type of stone. It is thus possible to draw the general conclusion that mica-schist and fine grade mica-gneiss grains 8—16 mm in diameter are, as a rule, more rounded than granite grains, which are semi-rounded or angular. In the following 4—8 mm grain size, the degree of roundedness is clearly smaller so that granite grains are angular almost throughout. It should be mentioned that single grains with an exceptionally high degree of roundedness are found fairly regularly in the sample material. As a rule sandstone and limestone grains become rounded more easily than do Archean stones.

There are, however, some exceptions to be found to the general observations. Thus one can see, for example, that the stone material along the northern border of the Finngrunden shoal shows an unusually high degree of roundedness. The same feature is partly apparent also in the bottom samples taken from the sub-marine ridge. The observations regarding the roundedness of the grains have been stated in the sample reports only in these exceptional cases.

In many samples the limestone grains have proved to be greatly weathered. It has not been possible to observe an obvious correlation between the degree of weatheredness and the distance of transportation, however. In fact, the weathering of the limestone grains is, presumably, dependent on many other factors, such as the pH value of the water, the strength of the current, the quality of the bottom material, and the relative amount of limestone in it.

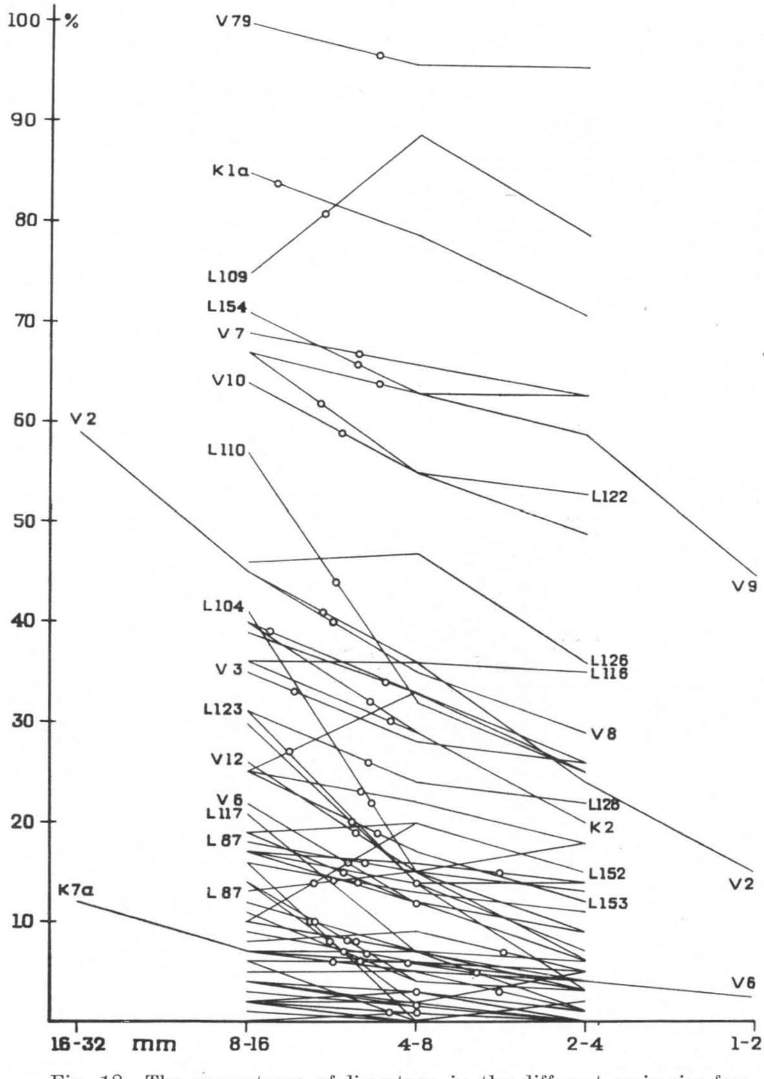

Fig. 18. The percentages of limestone in the different grain size fractions of the bottom samples.

Apart from the aforementioned exceptions, which will be considered in their respective connections, the stone material obtained from the sea area has been regarded as being till, and its transportation has been interpreted on the basis of observations made on till.

The variation in the quantity of limestone and sandstone in different fractions follows a remarkable regularity. This is evident from the adjoining

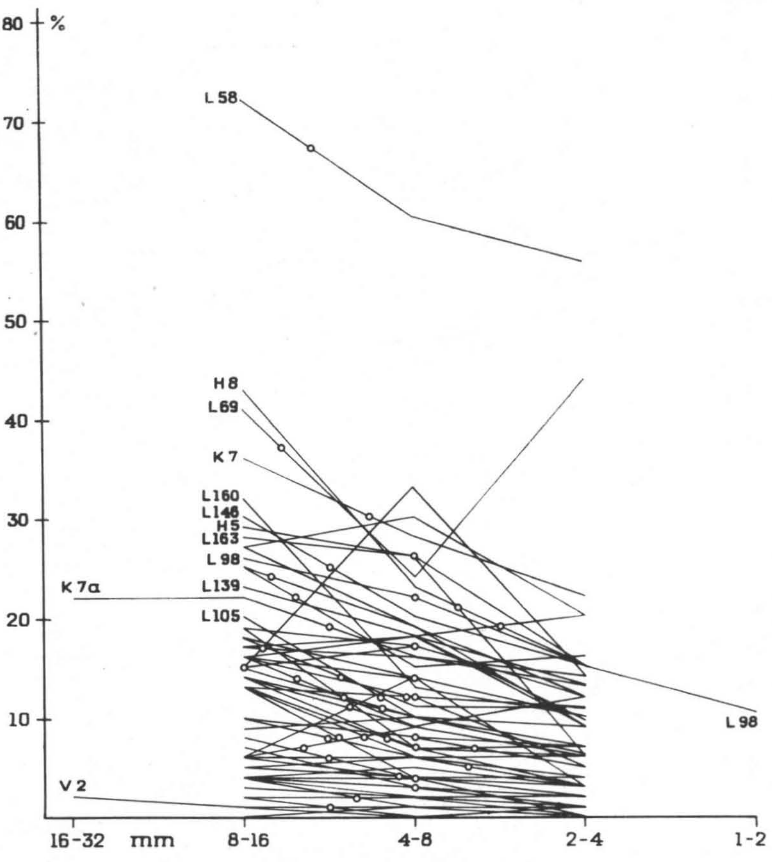

Fig. 19. The percentages of sandstone in the different grain size fractions of the bottom samples.

graphic tables in which the amounts of the said rock types have been marked in different fractions for each bottom sample.

A feature that stands out clearly is the fact that the proportion of both rock types decreases with a diminution in the grain size.

Between the 2—4 mm and the 4—8 mm fractions in limestone, only few exceptions to the general rule are to be found. Between fractions 4—8 mm and 8—16 mm some more exceptions are to be found. In some cases one can assume that the deviation from the regular rule is accounted for by the small quantity of the material used in the pebble count. Thus e.g. in sample L 109, see Fig. 18, the amount of limestone in the 8—16 mm fraction is based on material that consists of only 16 grains.

In the three samples, V 2, V 6 and V 9, in which the amount of limestone has been calculated also in the 1—2 mm fraction, a regular decrease is found to have taken place also between the fractions 2—4 mm and 1—2 mm. Similarly it is found that the amount of limestone has increased in proportion in the 16—32 mm fraction in the two samples, K 7a and V 2, in which it has been possible to perform a stone count. According to the dissolving experiment by acid, performed in sample V 2, a steady decrease of limestone is observed as continuing at least to grain size ¼ mm in diameter.

In regard to sandstone, most of the exceptions are also found between the fractions 4—8 mm and 8—16 mm. It is found that in the two samples in which it has been possible to perform the stone counts also in the 16—32 mm fraction, the proportion of sandstone has risen by 2 % in one sample, while in the other it has remained the same as in the 8—16 mm fraction.

It must be assumed that the explanation, primarily, lies in the smaller resistance degree of both rock types in comparison with the other rock types of the sample, and in the obvious fact that the break-up rate increases with the decrease of grain size. Another important factor with regard to limestone must be assumed to be its solubility, which shows a considerable increase following a decrease in the size of the grain.

The diagram of each sample has been marked with a point showing the percentage of the said rock type in the total sample, i.e. material with a 2—16 mm fraction. It appears that the points fall rather regularly in the space between 4—8 mm and 8—16 mm.

In conclusion it is possible to register the important fact that with respect to limestone and sandstone, pebble counts performed on fine grade stone material yield smaller values than do results obtainable from coarser material. At a rough estimate it can be assumed that the amount of limestone in the 2—16 mm stone material is approximately 10 percent smaller than in material of the 16—32 mm fraction. With regard to sandstone the difference is probably smaller. Stone material 16—32 mm in diameter is in fact in the same class with regard to size as the material used in continental stone counts.

ECHO SOUNDING

In addition to the usual echo sounder used in navigation, the vessel was equipped with an ATLAS echo sounder, specially constructed for bottom investigation, which could simultaneously direct to the sea bottom two separate impulses registering frequencies of 15 kHz and 80 kHz. As the 15 kHz impulse penetrated in part the softer strata of mud and clay and was reflected from the harder stratum below these, it was possible to interpret the quality of the bottom from the echo picture to a great extent. Interpretation of the harder stratum, based on the degree of sharpness of the echo curve and the small scale topography of the sea bottom, was primarily intended to register the sand and gravel strata at the bottom. On the basis of the echo picture it has not been possible to interpret with certainty possible rock outcrops.

In the adjoining figure No. 20 echo profile A depicts variation in the sea bottom quality. On the right can be seen an elevation (a) which contains fairly thick amounts of relatively hard bottom matter that has been interpreted as glacial clay. On both sides of the elevation there is a softer layer of mud (b) on top of the hard clay. Proceeding leftwards it is found that the harder clay layer ends in a steeply rising terrain point (c), after which the character of the curve also shows an essential change. This »saw edged» sea bottom (d), with its relatively uneven relief, reflects a rather characteristic pre-Cambrian rock base, which is covered by a thin layer of loose soil containing smaller or larger quantities of stone matter. The sharpest points may even be rock outcrops. The bottom sample (L 98) taken from the point marked consisted of a mixture of clay and gravel.

Along both edges of profile B can again be observed typical pre-Cambrian base rock covered by a harder thin layer of loose soil and a relatively thick layer of mud (the impulse fed is considerably much weaker than the preceding one). In the centre of the picture there is a level plain rising somewhat from the base level. In this the harder stratum is somewhat thicker, it is, however, again mostly covered by a soft layer of mud. Along the right edge of the plain there is, however, a small mud-free elevation. Bottom sample L 154 from this spot consisted of gravel mixed with clay. The remarkable point is, however, that the stone matter in the sample contained 66 % Paleozoic limestone. The large proportion of this rock quality entitles one to assume that at this point limestone forms the bedrock of the sea bottom. From this it has further been deduced that the level area apparent in the profile might be a relic of a Paleozoic sediment bed resting on a pre-Cambrian base.

The short profile C depicts the small Sylen shoal that lies some 25 kilometers north of Finngrunden. The shoal rises relatively steeply from its surrounding depth level of some 60 meters up to a depth of 9 meters according to the marine chart. Bottom sample (K 1 a) taken at a depth of 27 meters, contained 84 % Paleozoic limestone. The shoal of Sylen has also been interpreted as being a small remnant of a Paleozoic sediment formation. As appears from the profile, the walls of the shoal are so steep in places that the echo impulse has in part been reflected sidewards.

Profile D shows the echo curve from the Finngrunden shoal. The entire area is characterized by the evenness of the bottom. The bottom material

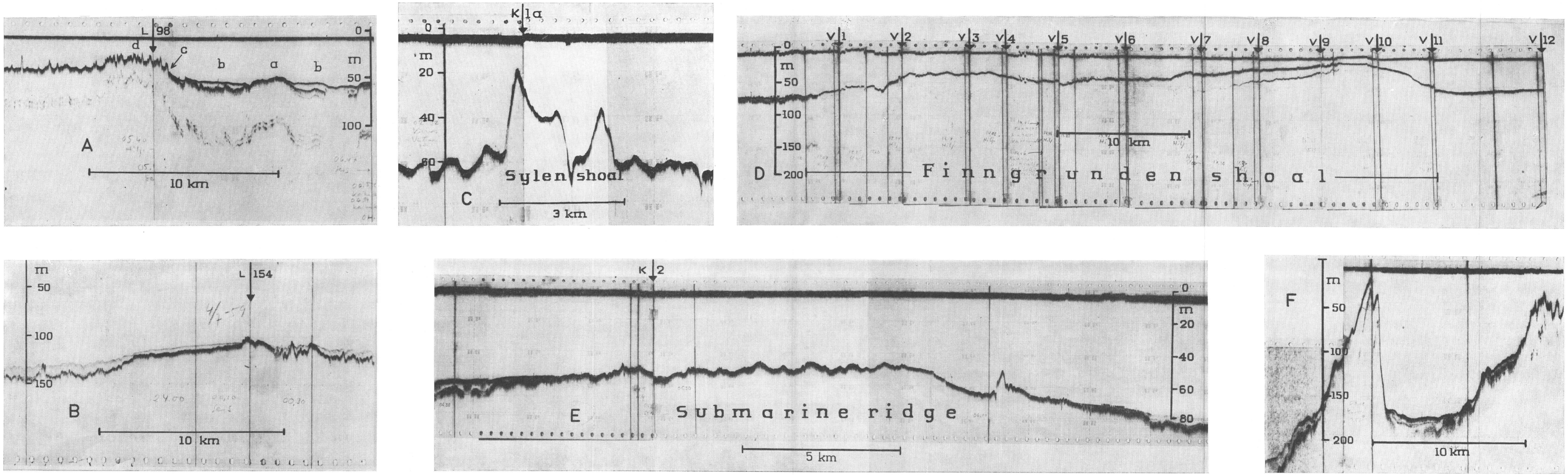
L 98
d
c
b
a
b
0
m
50
100
A
10 km
K 1a
0
m
20
40
60
Sylen shoal
C
3 km
V 1
V 2
V 3
V 4
V 5
V 6
V 7
V 8
V 9
V 10
V 11
V 12
0
m
50
100
150
200
D
10 km
Finngrunden shoal
m
50
100
150
L 154
B
10 km
K 2
0
m
20
40
60
80
E
Submarine ridge
5 km
m
50
100
150
200
F
10 km

Fig. 20.

of the samples consists chiefly of rough gravel with a rather large proportion of limestone. The Finngrunden shoal has been interpreted as a large Paleozoic sediment formation.

Profile E shows a cross section of a sub-marine ridge in the Bothnian Sea. As can be seen in the echo curve, the ridge differs in its surface relief from the areas interpreted as Paleozoic rock as well as the areas with a typical Archean rock base.

Profile F shows a typical section of the graben depression area at Åland.

ADDITIONAL FEATURES TO THE MORPHOLOGY OF THE BOTTOM OF THE BOTHNIAN SEA

Echo sounding that has been performed continuously in connection with the sea bottom investigation described here, has disclosed features, which, together with bottom samples, must be taken into account when defining the morphological picture of the bottom of the Bothnian Sea.

The level bottom zone, sloping gently westwards in front of the Finnish coast, has already been referred to (p. 37). This zone also appears in the west-east depth profiles of the marine area. Figure No. 21 shows two echo profiles considerably reduced in the horizontal direction. Profile A divides the Bothnian Sea along the 62nd latitude. Profile B is a division in the corresponding direction between Finngrunden and Rauma (Lat. 61°04′).

In profile A in particular, it can be seen that from the coast (on the right) onwards the depth shows a relatively regular increase and the variation in small scale relief is slight. The flat area extends some 8 kilometers west of sample point L 92. At this point the depth is 120 meters and the distance from the Finnish coast some 48 kilometers. The gradient of the sea bottom is consequently 1: 400.

In profile B the depth is also found to be increasing rather evenly, although the slope is in this case somewhat less steep and the sea bottom is more uneven in small scale relief. The even area can be considered as extending to the middle of samples L 154 and L 155, a point which lies some 65 kilometers from the Finnish coast and where the depth is about 130 meters. The gradient is thus 1: 500.

The coastal zone on the Finnish side has of old been considered an old peneplain (Sauramo, 1916). A direct proof of this is afforded by the Lauhavuori sandstone formation at Isojoki, some 50 kilometers east of the coast. The Lauhavuori hill rises rather steeply from its surrounding altitude of about 125 meters above sea level up to a height of 223 meters. The base

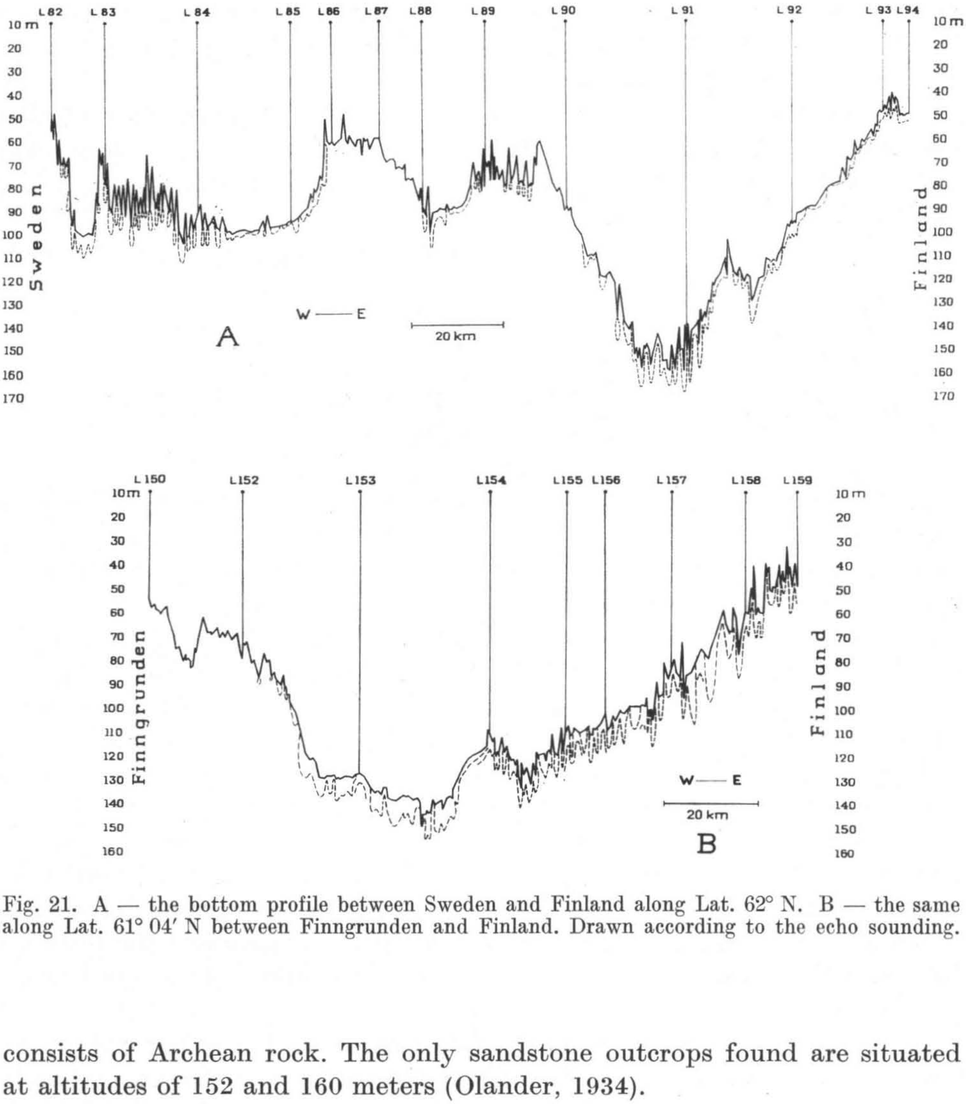

Fig. 21. A — the bottom profile between Sweden and Finland along Lat. 62° N. B — the same along Lat. 61° 04′ N between Finngrunden and Finland. Drawn according to the echo sounding.

consists of Archean rock. The only sandstone outcrops found are situated at altitudes of 152 and 160 meters (Olander, 1934).

In the Finnish coastal zone the altitude curves follow the line of the coast. At Kaskinen the 50-meters isohypsis is found some 20 kilometers from the coast. At Pori the distance is about 25 kilometers. This distance increases, however, southwards and is about 40 kilometers at Uusikaupunki. The gradient of the coastal zone in the more northern area is thus 1: 400—500, and in the southern area 1: 800.

In their entirety the above mentioned zones on each side of the coast line form a uniform level area and thus it may be assumed that the submarine part could be a continuation of the peneplain of the continental part.

[As has been described elsewhere in greater detail (p. 122), profile B exhibits an elevation in the sea bottom directly west of the plain. This has been interpreted as a Paleozoic sediment bed resting on a pre-Cambrian base. In view of this the peneplain extending from the coast can be considered as continuing some 10 kilometers farther westward. A similar elevation is also found in profile A, this, too, could be composed of younger sediments. Without evidence this possibility must, however, be regarded as not proven.]

The fact that a zone of approximately the same width and showing a regular slight increase in depth continues right on to the northern side of Åland lends support to the assumption that this zone might be a continuation of the degradation zone referred to above. The fault cracks filled with Cambrian sandstone occurring on Åland show, as pointed out by Tanner (1911), that the present degradation level of these islands cannot greatly differ from the sub-Cambrian sedimentation level.

The culmination line in the depth of the sea area lies, on an average, some 85 kilometers from the Finnish coast. From here the depth gradually diminishes in the direction of the sub-marine ridge. In profile A it is found that the surface of the slope rising gradually westward is relatively even. Judging by the bottom sample (L 90), the evenness must, however, be regarded as being primarily caused by a thick post-glacial clay layer. It should be mentioned that the obtaining of suitable samples in this central area has been chiefly hampered by the high clay content of the bottom.

The western end of profile A affords a picture of the uneven structure of the sea bottom in front of the Swedish coast.

Echo sounding shows that south of the Finngrunden shoal there lies a relatively even area, which extends some 50 kilometers from the shoal in the direction of the measuring line (SSE). Echo profile, however, shows that in the southern part of the area variations in depth can be found in small scale relief, while the northern side, nearer to the Finngrunden shoal, is characterized by an exceptional evenness of the sea bottom.

From a morphological point of view one is inclined primarily to assume that the level area represents an old degradation level which is connected with a corresponding level assumed to exist north of Åland. The question will be dealt with again in connection with Cambrian sandstone.

In the chapter dealing with the interpretation of echo sounding, a profile picture of the Finngrunden shoal is incorporated. Morphologically it should be noted that the shoal forms a flat somewhat terraced elevation and that its surface in small scale relief is extremely flat.

A cross section outlined by the echo over the sub-marine ridge of the Bothnian Sea is also presented. It should be noted that owing to its more varied surface relief this ridge differs from the Finngrunden shoal.

PALEOZOIC LIMESTONE

The chapter dealing with the treatment of the samples presents the general facts concerning the appearance of limestone. In the same connection the two types of limestone that it has been possible to separate from the limestone bulk on the basis of macroscopic examination have been described, i.e. Baltic limestone and red Orthoceras limestone.

On the enclosed map (Fig. 22) the amount of limestone in each bottom sample has been marked. The fact that the appearance of limestone is limited to the southwestern side of the NW—SE diameter of the Bothnian Sea can be established as a general observation. There, again, the Finngrunden shoal can be discerned as a central marine area, rich in limestone.

If some samples which showed a poor amount of limestone and which were taken from the northern border zone of the shoal are excluded, the average limestone content of the samples of the Finngrunden shoal amounts to 43 %. Sample V 7 is richest in limestone, 67 %. On the enclosed figure No. 23 the total amount of limestone in the bottom samples as well as the distribution of different types of limestone expressed in percentages have been graphically presented. In addition the depth curves of the area have been drawn. This has been done on the basis of the depth figures on the nautical charts and on the observations made on board with the help of an echo sounder.

Regarding the distribution of the various types of limestone, samples V 2, V 3 and V 4, which were taken from the east part of the Finngrunden shoal, form a separate group in that the amount of red Orthoceras limestone is predominant in them. The proportions of this type of limestone in the above mentioned samples amount to 65 %, 52 % and 64 %, respectively. The average amount of Baltic limestone in the samples is 10 %. The depth of the sea at the sample points is: V 2—40 meters, V 3—35 meters and V 4—37 meters.

The distribution of the types of limestone is the opposite in samples V 10, V 9 and L 122 taken 8 kilometers farther in the west-southwesterly direction. In all these samples the proportion of Baltic limestone is very large, 46 %, 43 % and 44 %, while the amount of red Orthoceras limestone is small, V 10—13 %, V 9—7 % and L 122—9 %. The depth of the sea at the sample points varies between 16 and 18 meters.

South of the above mentioned samples, approximately 6 kilometers southwest of sample V 10, is the site of bottom sample L 121. Here the depth of the sea shows an increase amounting to 26 meters. From the point of view of the distribution of the different types of limestone, this sample, however, still belongs to the same category as the former samples. The Baltic limestone in this sample amounts to 39 %, the red Orthoceras limestone to 14 %.

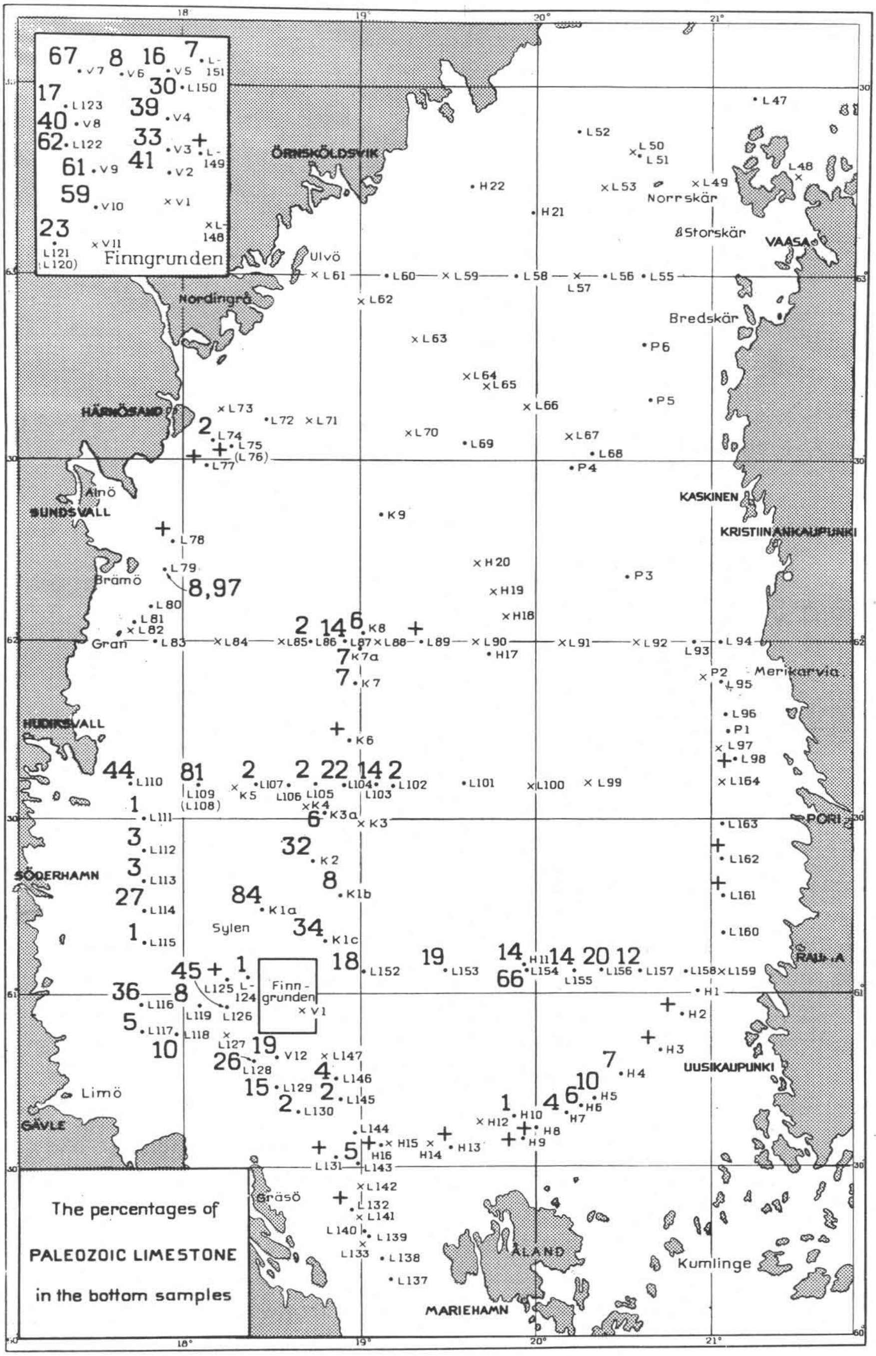
18°
19°
20°
21°
63
62
61
60
30
Finngrunden
ÖRNSKÖLDSVIK
Ulvö
Nordingrå
HÄRNÖSAND
Alnö
SUNDSVALL
Brämö
Gran
HUDIKSVALL
SÖDERHAMN
Sylen
Finn-grunden
Limö
GÄVLE
Gräsö
ÅLAND
MARIEHAMN
Kumlinge
VAASA
Norrskär
Storskär
Bredskär
KASKINEN
KRISTIINANKAUPUNKI
Merikarvia
PORI
RAUMA
UUSIKAUPUNKI
The percentages of
PALEOZOIC LIMESTONE
in the bottom samples

Fig. 22.

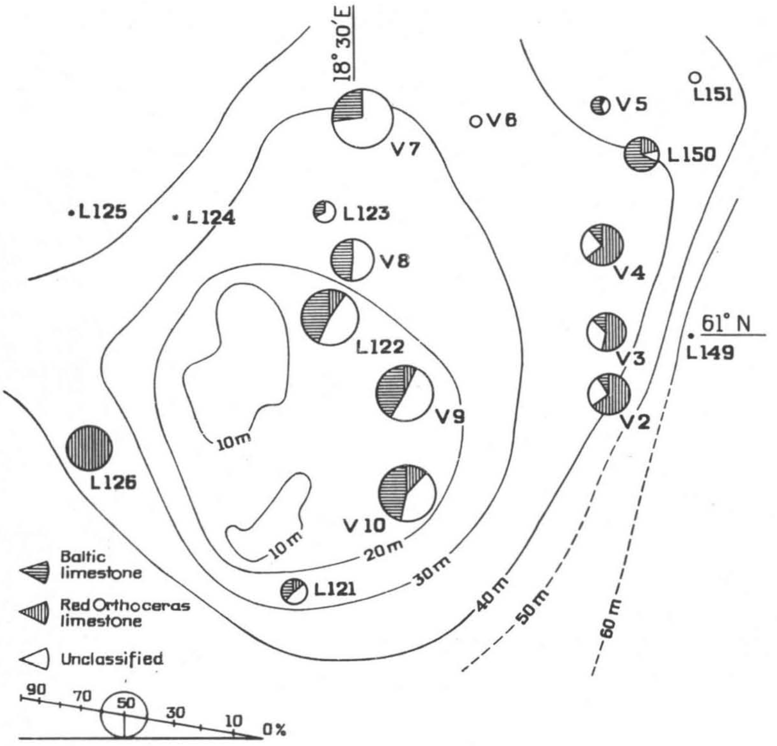

Fig. 23. The relative amounts (size of the rings) of Paleozoic limestone in the bottom samples at the Finngrunden shoal, the division of the limestone into the two determinable types in the samples and their relation to the depth.

North of the central region of the shoal three bottom samples were obtained, counting from the south: V 8, L 123 and V 7. The depth of the sea is in the corresponding places 23 meters, 30 meters and 30 meters. The amount of »unclassified» limestone in them is dominant. The samples contain the following amounts of Baltic limestone: V 8—47 %, L 123—25 %, and V 7—28 %. Red Orthoceras limestone is almost non-existent.

Sample L 126 was taken from the west side of the shoal at a depth of 37 meters. Every single grain of limestone in this sample is of the red Orthoceras limestone type.

A considerable consistency thus exists in the distribution of the limestone types of the above mentioned samples so that in samples taken at a greater depth (35—40 meters) the red Orthoceras limestone is predominant, whereas the amount of Baltic limestone is very large in the samples from shallower points (16—26 meters) in the central region of the shoal. The »unclassified group» is predominant in the intermediate samples which were taken at a depth of approximately 30 meters. It has been mentioned before that a green colour tone is characteristic of the main part of the limestone grains in this group.

Bottom samples L 150, L 151, V 5 and V 6 were taken in the north-eastern border zone of the Finngrunden shoal. Except for the first sample, the amount of limestone in these samples is relatively small varying from 7 % to 16 %, and as the material is very weathered a classification of the limestone into different types has become difficult. On the basis of a rough estimate Baltic limestone seems, however, to be predominant. The samples were taken at depths of 39—45 meters. Likewise, on the northwest side of the shoal two samples were taken, L 124 (depth 39 meters) and L 125 (depth 48 meters), the limestone amounts of which were very small, i.e. plus and 1 %.

Sample L 150 forms a notable exception regarding the relation between the depth of the sea and the predominant type of limestone: although the sample was taken at a depth of 40 meters it contains 71 % of Baltic limestone, while the percentage of red Orthoceras limestone only amounts to 21 %. The fact that this and the five other samples referred to were taken on the northern side of the marginal zone of the shoal might explain their divergence from all other samples.

The assumption presented by Gripenberg in 1934 that a »Silurian» formation was to be found in the Finngrunden marine area is strongly confirmed by the present results. Unless it is taken for granted that such a formation really exists, it is difficult to explain the large amount of limestone that appears in the samples from the Finngrunden area, as well as the logical distribution of the limestone types at the depth levels so that they follow the stratigraphy of the Ordovician series.

It is important to keep in mind that Wiman (see p. 13) proved that the limestone boulders on the coast of Öregrund (directly south of Finngrunden) mainly consist of red Orthoceras limestone, Chasmops limestone, and Baltic limestone, which types of limestone are also predominant on the Åland islands.

If, in addition to this, one takes into consideration the depth features of the Finngrunden area made on the basis of echo-sounding (p. 122), it becomes evident that the shoal is likely to be composed of a Paleozoic sediment bed which lies on a pre-Cambrian rock base.

The bottom samples do not in all cases provide sufficient evidence for a more exact definition of the limestone formation. But if the indications of the bottom level of the sediment bed are assumed to be at a depth of approximately 60 meters, the size of the formation can be determined to some extent.

The eastern limit of the formation is probably the easiest one to define. The depth of the sea on the east side of samples V 2—4 increases quite rapidly so that it exceeds 60 meters only a few kilometers farther east. In addition, sample L 149 (depth 62 meters) which is situated about 3 kilometers east of sample V 3 contains less than 1 % of limestone.

As will be seen in the following chapter, the underlying Cambrian sandstone formation probably extends farther south than the limestone (p. 136). The »emergence» of sandstone in the samples taken on the distal side of the shoal thus suggests an extension of the limestone. Samples V 12, L 128, and L 129, in which the amounts of sandstone are 7 %, 2 %, and 12 %, respectively, are important and must be regarded as »border cases». On the other hand, the limestone content of these samples is »still» considerable amounting to 15 %—26 %. The samples were taken at depths of 52—55 meters. The southern boundary of the limestone bed thus obviously runs a small distance to the north of the samples L 128 and V 12.

A wide zone of shallow water stretches from the shoal in a west-southwesterly direction reaching Sweden at the coast of Gävle. Some banks in this zone come very near to the surface. The amount of limestone in the rather few samples taken from the shallow zone is, however, fairly small. On the other hand, Paleozoic limestone has been found in the solid rock on certain outer islands outside Gävle (p. 13).

From the Finngrunden shoal a shallow water zone also extends in the north-northeasterly direction joining with the so called sub-marine ridge of the Bothnian Sea. The next point where we are dealing with the appearance of limestone is the northern part of this shallow region.

The bottom samples K 7, K 7a, K 8, and L 87 were taken in this area, the centre of which is Lat. 62°N, Long. 18°E. The amounts of limestone in these samples are fairly small, 6 %—14 %, so that a determination of the existence of a possible solid formation of limestone on the basis of the amount of limestone would not be justified. There is, however, a different angle to this question, which becomes apparent when the distribution of the different types of limestone in relation to the depth conditions is examined more closely. In the following list the bottom samples are arranged according to the depth of the sea, which also corresponds to their location counting from south to north. The distance between the two samples lying the farthest distance from each other (K 7—K 8) is approximately 15 kilometers.

Sample	Depth	Baltic limestone	Red Orthoceras limestone	Unclassified
K 7	37 m	61 %	3 %	36 %
K 7a	38 m	45 %	26 %	29 %
L 87	50 m	32 %	42 %	26 %
K 8	60 m	10 %	68 %	22 %

Here as well as in the Finngrunden area the limestone types are thus quite clearly divided in accordance with their stratigraphic positions. This could hardly be the case if the material had drifted from a long distance. After some hesitation the author is inclined to consider these observations as arguments supporting the assumption that the skeleton of the sub-marine ridge in this place is composed of solid Paleozoic sediments.

After having presented this assumption it is not easy to find a satisfactory explanation for the scarcity of limestone. Knowledge about the structure of the ridge and its glacigenic quality is very limited. It is important to bear in mind that in the samples taken on the north side of the Finngrunden shoal, the amount of limestone is extremely small, although it might be assumed on the basis of the prevailing depth conditions that these samples are situated within the limestone area. In addition, it has to be stressed that the stone grains in the samples taken along the northern part of the ridge as well as of the shoal, are more rounded than usual. These facts might point to the material having been transported a somewhat longer distance, and it might at the same time account for the scarcity of limestone material.

In this connection one should keep in mind that the samples are from the surface of the sea bottom — even in the most successful cases the *van Veen* marine grap does not »bite» deeper into the loose material than 10—15 centimeters. Particularly regarding the soluble limestone one might well assume a difference in the amount of material in the surface and in the more underlying parts. This relatively rapid decrease in the limestone could well be assumed to be effective, in particular, on the slopes of the elevations of the sea bottom facing the permanent water current.

Bottom samples L 103 and L 104 were taken at the submarine ridge approximately 45 kilometers south of the former group of samples. The amounts of limestone in these samples are 14 % and 22 %, respectively. L 103 was taken at a depth of 53 meters, L 104 at a depth of 58 meters. In both cases the division of the limestone into various limestone types has had to be undertaken by investigating a very small amount of material and in the 4—8 mm fractions. Baltic limestone proved, however, to be predominant in both samples, whereas the amount of red Orthoceras limestone is small. In comparison with the previous more northerly samples, the relation between the depth conditions and the proportions of the different types of limestone is quite incongruous. Taking into consideration the comparatively large amount of limestone in these samples the author is inclined to believe that there is a solid formation of limestone also near this ridge area. It is perhaps necessary to point out in this connection that in the case of sample L 104, the decrease of limestone is exceptionally rapid when changing over from coarser to more fine grained material. In the 8—16 mm fraction the amount of limestone is as large as 41 %.

Before turning to the samples taken farther south it is worth noting that the uninterrupted continuation of the sub-marine ridge between both the assumed formations referred to above might give one cause to presume that this could be one complete formation. On the other hand, the almost total lack of limestone in sample K 6 (depth 31 meters) does not fit into this assumption.

The depth of the sea at the ridge increases by degrees from about Lat. 61°30′N southwards until it is nearly 60 meters. During the following 20 kilometers the ridge cannot be clearly distinguished from its surroundings. However, it grows more distinct again on the north-northeast side of Finngrunden, where the ridge and the Finngrunden shoal meet. The results of the following bottom samples taken on the south side of the shallow part of the ridge are available: K 2, K 1 b, and K 1 c. The amounts of limestone in these samples are: 32 %, 8 %, 34 %. All samples have the common feature that the »unclassified» limestone group is predominant. The main part of this group is a limestone type of green colouring. The samples also contain a fair amount of Baltic limestone, whereas hardly any red Orthoceras limestone can be found in them.

The large amount of limestone in two of the above mentioned samples might indicate that the parent rock is situated comparatively near the place where they were taken. A more detailed estimate of their location or range cannot, however, be given.

The small Sylen shoal is to be found on the marine chart at a distance of 25 kilometers north of the Finngrunden shoal. The Sylen shoal rises to an altitude of 9.1 meters below the surface, while the average depth level of the surrounding area is approximately 60 meters. The curve derived from the echo sounder (Fig. 20) shows that the slopes of the shoal are very steep, so steep, in fact, that at some points the echo has been reflected sidewards. At a depth of 60 meters, the diameter of the entire formation is approximately 1.5 kilometers. Another smaller elevation is to be seen in the echo picture almost immediately northeast of the Sylen shoal. The amount of limestone in sample K 1 a, which was taken at the northeastern part of the shoal, is 84 %, the depth being 27 meters. With the exception of a few grains of Baltic and red Orthoceras limestone, the material in this sample is of the green type. (As this limestone is rather fossiliferous it is likely that later fossil research will be able to throw additional stratigraphic light upon this limestone type.) Judging by the amount of limestone it can hardly be doubted that the Sylen shoal represents a solid Paleozoic sediment bed.

Going eastwards from the Finngrunden shoal, along the research line (see depth profile Fig. 21) the depth of the sea increases fairly rapidly. At Long.

19°20'E it already amounts to 120 meters. The deep water area continues for a distance of approximately 25 kilometers after which the sea becomes shallower again on approaching the Finnish coast. There is a noticeable amount of limestone in samples L 152—L 157 and H 11 taken along the research line.

Bottom sample L 154, the lime content of which amounts to 66 %, is the most central of this group of samples. Baltic limestone is predominant in the sample, the amount of red Orthoceras limestone being small. The depth of the sea at the sample point is 102 meters.

In the chapter dealing with the method of echo measurement (p. 122) the site of sample L 154 was pointed out as an example of a likely Paleozoic sediment bed resting upon a pre-Cambrian rock base, which assumption was supported by the large amount of limestone found in the sample. The diameter of the assumed sediment formation is estimated to be about 7 kilometers in the research line direction.

According to the echo curve the assumed sediment bed has been observed to incline slightly westwards. A more exact measurement reveals that the difference in height between the most westerly point of the bed and a point situated on the base of a small elevation 5.5 kilometers east of the first mentioned spot, is 14 meters. The inclination is about 1: 400. This is of the same order as the general deepening gradient of the sea bottom outside the Finnish coast. The latter has been assumed to represent the level of the sub-Cambrian peneplain (see p. 138). If the above inclination is considered a reality, if it, in other words, is believed to indicate the original sedimentation horizon, it is on these grounds possible to determine the approximate thickness of the sediment bed as being about 20 meters.

No detailed information can be given about the extension of the limestone formation in the northern and southern directions. The continuous and comparatively large amount of limestone in the samples taken along the above mentioned research line may be an indication, however, of an abundant appearance of limestone on the northern side of the research line. In some cases, e.g. regarding the samples L 153, limestone content 19 %, and L 156, limestone content 20 %, the parent rock cannot be situated very far from the sample points. Whether we here have one large or several separate formations is not clear, either. As far as the extension eastwards is concerned, it must be noted that the easternmost sample containing limestone, L 157 (12 %), has been taken at a distance of approximately 35 kilometers from the Finnish coast. This may explain the existence of the limestone boulders found in the southwestern coastal area of Finland.

All samples, the contents of which could have been classified into various types of limestone, contained both Baltic limestone and red Orthoceras limestone. In all cases the former type has been predominant, however.

The appearance of limestone is presumably less frequent south of the research line. The average limestone content of 7 % in samples H 4—H 7, does, however, indicate that there might be a solid formation of limestone in the region lying in the direction south-southeast of sample L 154.

Sample L 79 derives from a point approximately 8 kilometers east of the Brämö island, southeast of Sundsvall. In connection with the description of the sample it has been mentioned that the bottom material changed between two liftings from predominantly Archean to being extremely rich in limestone. A pebble count showed the material of the first lifting as containing 8 % of limestone, the latter lifting showed as much as 97 %. Arriving from the northern direction to the sample point and continuing from there southwards, the echo curve described a bottom relief characteristic of Archean bedrock. To start with, the echo sounder measured a depth of 34 meters. The depth increased by degrees while the ship was drifting amounting to 52 meters when the work was completed. The limestone »appeared» at a depth of 38 meters. It was estimated that the ship had drifted approximately 1.5 kilometers in an east-southeast direction while the sample was being taken.

The classification proved the latter part-sample to be composed almost entirely of Baltic limestone. Only in two finer grained fractions was there a small amount of red Orthoceras limestone. In the former part-sample the proportion of red Orthoceras limestone was somewhat larger, amounting to 8 %.

If, on the one hand, it is taken into consideration that the echo sounding of this region does not afford any proof of a sediment bed rising from the average bottom level, and if, on the other hand, it is recalled that the limestone almost entirely consists of one limestone type (of a rather high stratum), it is justifiable to assume that the limestone formation appears in a depression, probably in graben.

The fact that the sediment series includes Orthoceras limestone and Obolus conglomerate and that also these strata become exposed somewhere in the region is proved by observations made by Schön (1911), cf. p. 16.

In this connection special attention should be paid to the fact that the sample point is situated directly on the marine prolongation of an obvious tectonic line, which runs along the north side of the Brämö island and along the northern margin of the Lörudd peninsula. The same tectonic line obviously continues inland coinciding with the bed of the Ljunga river for a distance of approximately 85 kilometers, Fig. 24. The coincidence was not anticipated when the site of the bottom sample was chosen. The position of the sample on the tectonic line is thus accidental.

It has not been possible to determine the size of the assumed solid formation on the basis of the bottom samples. Sample L 80, taken approximately

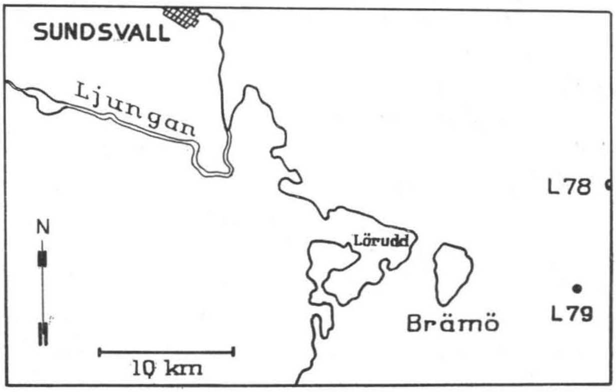

Fig. 24. The position of the bottom sample L 79.

12 kilometers farther south-southeast, does not contain any limestone whatever. Nor is any limestone to be found in sample L 78 taken approximately 9 kilometers further north either. It is probable that the limestone forms a comparatively narrow formation connected with the tectonic zone.

The fact that the movement direction of the continental ice sheet of this region is very close to the direction of the tectonic line, makes it easier to understand why such a great change in the quality of the drift may occur within a very short distance.

Samples L 109 and L 110 were taken outside Hudiksvall. Their limestone amounts are 81 % and 44 %, respectively. Both samples consist almost entirely of Baltic limestone. The samples were taken at a depth of 60 meters, which corresponds to the general depth level of the region. In the case of sample L 109, neither the observations made with the echo sounder, nor the depth figures on the marine charts, point to any appearance of a sediment bed rising above the general depth level. The depth figure of 27 meters, which is marked near sample point L 110 may, on the other hand, be a proof of the existence of such a bed. The aim was to take a sample from this very shoal. It could not, however, be found at once and time did not allow a further search.

Finally it has to be stressed that the samples L 114 and L 116 were taken further south, the former on the east-southeast side of Söderhamn, and the latter on the northeastern side of Gävle. The amount of limestone in these two samples is 27 % and 36 %, respectively. Both samples are similar in that the amount of Baltic limestone is predominant (66 % and 67 %), whereas they contain very little red Orthoceras limestone. The depth at the points where these samples were taken does not differ from the general surrounding depth level.

CAMBRIAN SANDSTONE

The chapter dealing with the treatment of the samples has described the rock type defined as Cambrian sandstone. Since, in the stone facies classification, the Cambrian sandstone and the Jotnian sandstone appear together, the proportions of the two rock types have been determined on the basis of a division performed in the coarsest, 8—16 mm, fraction, or, if this fraction has not existed in a sufficient amount, in the 4—8 mm fraction. The adjoining map shows the percentages of Cambrian sandstone in the bottom samples. In estimating the importance of these amounts account should be taken of the observations presented above (p. 21) according to which this type of rock is crushed rather rapidly in the transportation process of the continental ice sheet.

The map shows that the largest amounts of Cambrian sandstone are to be found in the bottom samples taken on the south side of Finngrunden. Among the single highest percentages should be mentioned samples L 146—21 %, L 145—17 %, and L 129—12 %. It should be regarded as self evident that the Cambrian sandstone appearing in the samples of that area is connected, directly or indirectly, with the sandstone stratum lying below the Ordovician limestone. That the sandstone belongs to the Paleozoic series of the area has been proved by Wiman (1905) in a limestone quarry situated at Wattholm (south of Gävle).

The chapter dealing with the morphology of the bottom of the Bothnian Sea (p. 125) describes a flat bottom area south of Finngrunden, where the average depth of the water is 60 meters and from which depth level the Finngrunden shoal rises in a southerly approach. The flat area has been assumed to be an old degradation level. The said sandstone-rich samples have been taken from the northern part of this level.

In order to obtain a good sample, as free from clay as possible, efforts were made to take the samples from the small elevated points in the sea bottom. In this way the samples are taken at a depth a few meters less than the average depth level, approximately at 55 meters.

The amount of Cambrian sandstone in the bottom samples is, even at its highest, too small to justify the assumption of a uniform larger sandstone bed. The predominance of the Archean rock facies in the samples is also of importance in this respect — in view of the fact that there is a large Paleozoic formation at the proximal direction of the continental ice movement.

From the geological point of view the plain south of Finngrunden is apparently an old sub-Cambrian sedimentation level, the surface of which has been denuded anew by the eroding influence of the ice — in such a way, however, that small sediment remnants have remained as small elevations or in the depression fillings. Admittedly one must assume the existence of

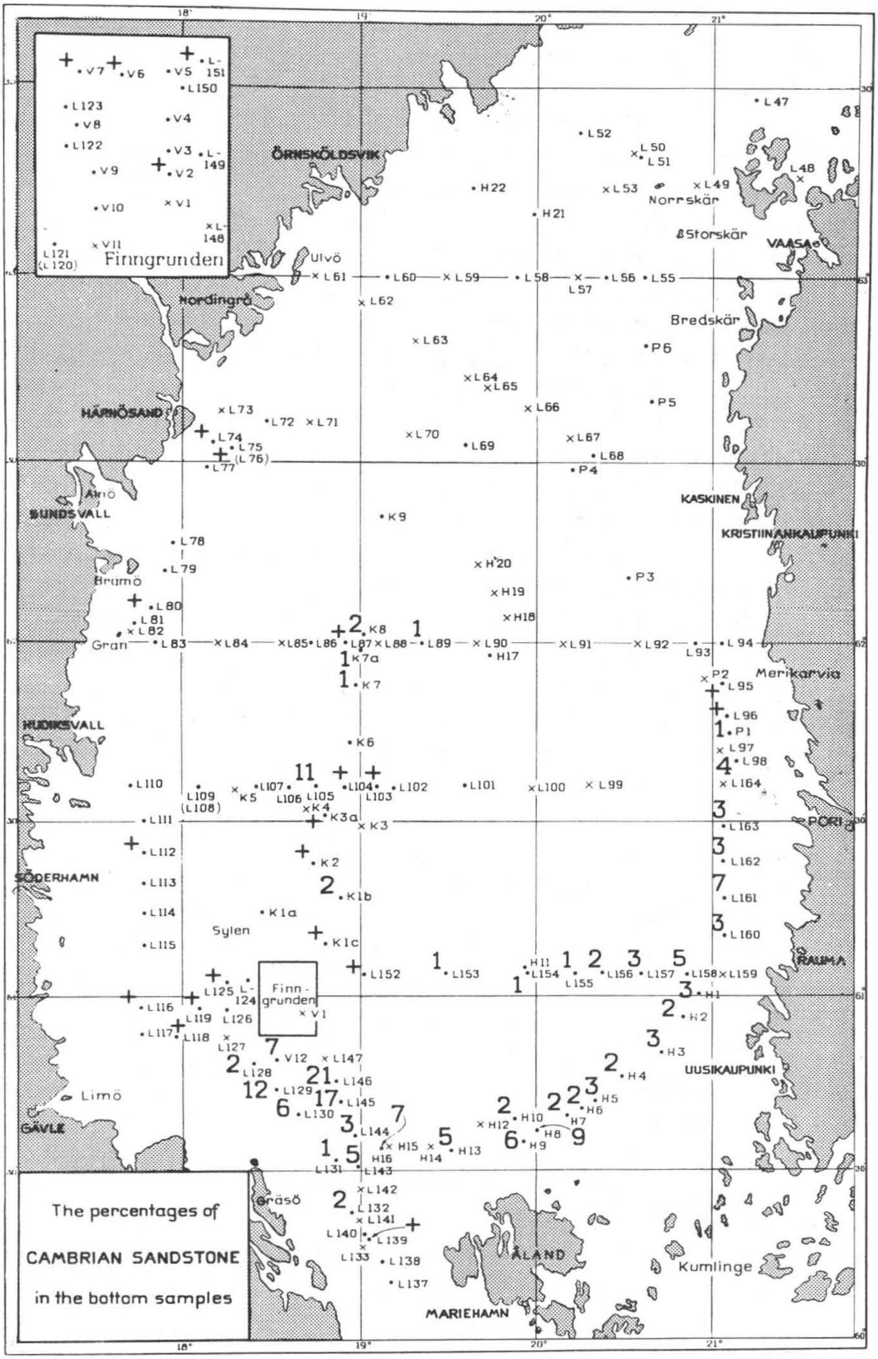
The percentages of
CAMBRIAN SANDSTONE
in the bottom samples
Finngrunden
ÖRNSKÖLDSVIK
Ulvö
Nordingrå
HÄRNÖSAND
Alnö
SUNDSVALL
Brämö
Gran
HUDIKSVALL
SÖDERHAMN
Sylen
Limö
GÄVLE
Gräsö
ÅLAND
MARIEHAMN
Kumlinge
UUSIKAUPUNKI
RAUMA
PORI
Merikarvia
KRISTIINANKAUPUNKI
KASKINEN
Bredskär
VAASA
Storskär
Norrskär

Fig. 25.

a more uniform Cambrian sandstone zone along the outermost marginal zone of the Finngrunden shoal, presumably somewhat below the 50-meters isobate.

Smaller amounts of Cambrian sandstone (1 %—6 %) are found in bottom samples south-southeast of the Finngrunden shoal extending to about Lat. 60°30′N. This area must also be regarded as being on level with the old peneplain although the small scale relief of the sea bottom is somewhat more varied. The chance of there also being remnants of Cambrian sandstone seems possible. In principle this possibility is, in fact, closely connected with the large scale occurrence of Cambrian sandstone in the bottom samples of the southeastern part of the Bothnian Sea which will be dealt with below.

All the bottom samples taken outside the Finnish coast, south of Merikarvia, and north of Åland, contain a few percents of Cambrian sandstone. This amount may be somewhat larger in some samples, such as sample L 161—7 %, taken northwest of Rauma, and sample H 8—9 %, deriving from north of Åland. In connection with the morphology of the Bothnian Sea (p. 124) a hypothesis was presented to the effect that the rather flat region which surrounds the coast on the Finnish side with an average width of 60 kilometers, and which apparently continues to the northern side of Åland, represents an old pre-Cambrian peneplain. The occurrence of Cambrian sandstone may also support this assumption. In view of the weak mechanical resistance and the extensive distribution of Cambrian sandstone, as well as the evenly small amounts throughout this area, one might, in the first place, assume that the material has its origin in small sandstone remnants that still exist in the pre-Cambrian rock crust which, in its entirety, however, represents an old sub-Cambrian peneplain.

In connection with the description of the geology of Åland, reference was made to the fact that a number of fault cracks with Cambrian sandstone fillings have been found in the island area.

At some isolated points, for example near the above mentioned sampling points L 161 and H 9, Cambrian sandstone may also appear in somewhat larger formations.

The bottom samples taken from the region of the sub-marine ridge of the Bothnian Sea and the area between Finngrunden and Rauma also contain small amounts of Cambrian sandstone. Since the occurrence of sandstone seems in this way to follow the occurrence of Paleozoic limestone it can be assumed that sandstone lies beneath the limestone. It is, however, not possible to present any hypotheses on the basis of bottom samples regarding the distribution of sandstone outside the limestone formations. Only at one point, in the centre part of the sub-marine ridge, does the rather large amount of sandstone (11 %) in the sample (L 105) point to a somewhat larger exposure.

The almost complete absence of Cambrian sandstone in the samples taken outside the Swedish coast should be noted. No sandstone is to be found even in the majority of such bottom samples in which the amount of Paleozoic limestone is very high. In looking for an explanation one has to recall the assumption presented in the previous chapter to the effect that on the Swedish coast the limestone, at least in some instances, appears in depressions limited by faults, an assumption which correspondingly must be regarded as being supported by the fact that lower strata of the sediment series are missing from the drift (cf. in particular sample L 79, outside Brämö). It seems justifiable to draw the conclusion that in the marine region on the Swedish side the degradation has extended deeper below the old sub-Cambrian sedimentation level, a fact that can also be deduced from the morphological features of the region.

Regarding the occurrence of the Cambrian sandstone one can finally conclude that its distribution is limited to south of the line Härnösand—Merikarvia. In the samples north of this line not a single grain has been found.

JOTNIAN SANDSTONE

The enclosed map shows the amounts of Jotnian sandstone in the bottom samples. As stated above in connection with Cambrian sandstone, the ratios of the sandstones have been determined on the basis of 8—16 mm or 4—8 mm fractions.

The extensive distribution of the Jotnian sandstone in the drift on the bottom of the sea is particularly noticeable. This may serve to prove the prevalence of baserock of this rock type in the region of the Bothnian Sea.

In the northern part of the Bothnian Sea, approximately half way between Nordingrå and Vaasa, sample L 58 contains 67 % of Jotnian sandstone. This percentage points to the extreme likelihood of the existence of solid Jotnian sandstone on the site of the sample or near it. Interpretation of the dimensions of the formation on the basis of bottom samples is, however, difficult. In this respect there is an unfortunately large amount of bottom samples from the region in which it has not been possible to perform a pebble count.

Approximately 50 kilometers south of sample L 58 there is the sample point L 69, which is rather remarkable in that the amount of Jotnian sandstone it contains is 37 %. Some 35 kilometers east of sample point L 69 there are the samples P 4 and L 68 containing 5 % and 8 %, respectively, of Jotnian sandstone. Some 33 kilometers southwest of L 69 there is sample

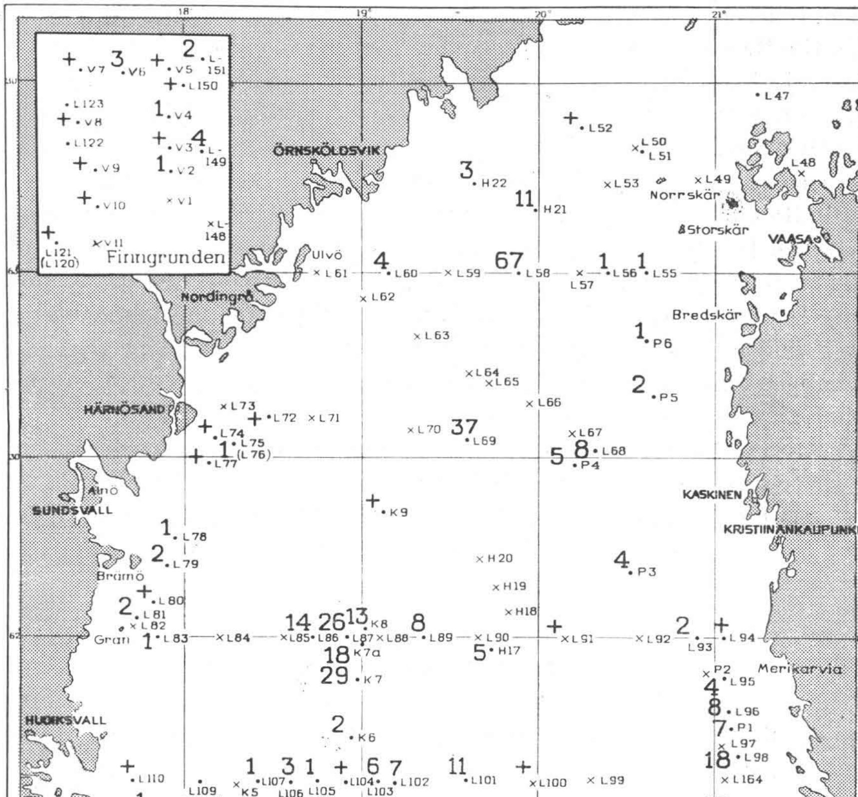
The percentages of
JOTNIAN SANDSTONE
in the bottom samples
Finngrunden
ÖRNSKÖLDSVIK
Nordingrå
HÄRNÖSAND
SUNDSVALL
HUDIKSVALL
SÖDERHAMN
GÄVLE
Limö
Gräsö
ÅLAND
MARIEHAMN
Kumlinge
UUSIKAUPUNKI
RAUMA
PORI
Merikarvia
KRISTIINANKAUPUNKI
KASKINEN
VAASA
Storskär
Norrskär
Bredskär
Ulvö
Sylen

Fig. 26.

K 9 in which only occasional grains of sandstone are to be found. In the westerly direction the nearest sample lies at a distance of some 45 kilometers (L 71); it contains no Jotnian sandstone.

In regard to the Jotnian sandstone formations in the northern part of the Bothnian Sea, observations made on the coast and the outer islands should also be taken into account. Laitakari (1942) and Mölder (Mölder and Salmi, 1955) have drawn attention to the existence of Jotnian sandstone in the coastal zone of Ostrobothnia (see p. 15). On the basis of stone counts Mölder has noted that the maximum distribution of sandstone lies some 20 kilometers south of Vaasa, in the Petolahti—Maalahti area (see p. 35). According to Nykänen (1960) there is an abundance of sandstone boulders on Bredskär, the island situated in front of Petolahti.

In connection with the work in question some observation trips were made by motorboat to the outer islands near Vaasa. The stone count taken from the coarse beach gravel at Östra Norrskär, some 50 kilometers west-southwest of Vaasa, showed that there was little more than one percent (6: 482) of Jotnian sandstone. On the other hand, some 15 kilometers south-southeast from here, on the rocky island of Storskär consisting mainly of large boulders, the amount of Jotnian sandstone proved to be considerable. The largest sandstone boulders measured as much as one meter in diameter. A surprising contrast to this was the smaller island of Gjusan, lying some 4 kilometers to the west, where not a single Jotnian type sandstone could be found among the stones on the shore. The only boulders of sandstone type were two about head size quartzite boulders of an extreme toughness and showing a reddish tint. On the spot it was assumed that the Jotnian sandstone material to be found on Storskär most probably derived from the sea area between this island and Gjusan.

In the gravimetric map (p. 39) an extensive negative anomaly area can be seen in the northern part of the Bothnian Sea. This includes both the above mentioned bottom samples rich in Jotnian sandstone. Since the marine area in question includes also rapakivi (see p. 145) it can be assumed that the anomaly is composed of both rocks, including in addition, probably, a microcline-granite formation (p. 145). The probable distribution of rapakivi, however, can be confined to the northeastern part of the anomaly tract on the basis of bottom samples.

In view of the gravimetric map and of the fact that sandstone is to be found also in the Finnish part of the sea area and on the coastal zone where it may be regarded as being far-transported, one may be justified in assuming that in the northern part of the Bothnian Sea, Jotnian sandstone is to be found within a relatively extensive area. In the central part of the sea region the sandstone possibly forms a more extensive area; farther to the northeast, to the west of Vaasa, separate formations may also exist.

Petrographically the sandstone of the northern part of the Bothnian Sea resembles typical Jotnian sandstone in the form it is found, inter alia, in the region of Satakunta. The most common type is of medium grain size, yellowish red or brick red in colour. In the coastal area south of Vaasa, in particular, relatively large quantities of the finer grained, dark carmine red sandstone type can, however, be found. Along the coast one can easily come across larger sandstone slabs showing ripple marks.

Some 100 kilometers southeast of Sundsvall lies the bottom sample group K 7, K 7 a, K 8, L 86 and L 87, in which the amount of Jotnian sandstone varies between 13 %—29 %, with an average of 20 %. In determining the location of the mother rock of the material it should be noted that there are considerable numbers of bottom samples from the region between Hudiksvall and the island of Gran, in which only minimal quantities of Jotnian sandstone are to be found. On the other hand it should be pointed out that the group of samples in question derives from the submarine ridge of the Bothnian Sea at a spot where the ridge is assumed to include a solid Paleozoic sediment bed (see p. 130). The Jotnian sandstone in these samples may in consequence be taken as deriving from a formation lying in the sea area some 50 kilometers east of Sundsvall. The extent of the solid formation cannot be accurately determined on the basis of bottom samples or other observations. It is possible that the Jotnian sandstone in the region forms part of the base of the Paleozoic sediment deposit. Nor is it impossible that Jotnian sandstone would be found in the rock ground east of the ridge. The 11 % of Jotnian sandstone in sample L 101 points to this conclusion. In order to derive from the above assumed formation east of Sundsvall, the sandstone element in this sample would have been transported some 75 kilometers. In view of the extensive distribution of the material deriving from the Dala sandstone formation (see p. 21) a transport distance like this is in itself not an impossibility. However, in view of the fact that the sub-marine formation most probably is considerably smaller in size than the Dala one, the distribution of sandstone in the above quantity at such a distance does not seem likely.

The Jotnian sandstone found in the samples is of the medium grain type, red or reddish in colour.

In the geological description of the coastal region around the Bothnian Sea (p. 30), the Jotnian sandstone formation of Satakunta was presented. It has been taken for granted that it continues in the sea area, although the extent of the sub-marine formation has received varying interpretations (cf. Laitakari, 1925; Backlund, 1937).

Northwest of Pori, some 25 kilometers from the coast, there is sample L 98, in which the percentage of Jotnian sandstone amounts to 18 %. The same amount, 18 %, is also to be found in sample L 163 some 18 kilometers to the south. The continuation of the sandstone in the sea area may be determined in accordance with these two samples. The amount of sandstone in the samples to the north and to the south of them is smaller. The northernmost limit of the formation can presumably be drawn somewhat to the north of sample L 98, the southern boundary running a slight distance north of sample L 163. This supposition is also supported by the corresponding seaward contact directions of the mainland formation. It is also in accordance with the gravimetric measuring results (see p. 39), the value of which for interpretation purposes is exceptionally great in this case.

The extent in the northwesterly direction of the solid sandstone formation should be interpreted from the gravimetric map. The submarine distance of the formation would accordingly be some 60—70 kilometers.

North of the above mentioned sample L 98 relatively high amounts of Jotnian sandstone can be found: P 1—7 %, L 96—8 %, and L 95—4 %. It is reasonable to assume that this stone material derives from the mainland formation or from its sub-marine prolongation. Since the later movement direction of continental ice, which must be regarded as the principal transportation direction of the glacial drift, is in this area north-northwest to south-southeast, it must be assumed that the sandstone matter in the samples referred to has been transported at the movement stage of the older, more westerly continental ice. It should be noted that the striae indicating a westerly direction are relatively pointed in the Pori area (Sauramo, 1924). Reference should in this connection also be made to the amount, admittedly assumed to be slight, that may have been transported by the ice-floats from the interior of the country. This hypothesis is supported by the fact that the Kokemäenjoki river flowing into the sea from southeast runs through the Satakunta sandstone region, and that the dominant direction of the sea current in the eastern Bothnian Sea is from south to north (Atlas of Finland, 1960).

Samples L 162 and L 161 taken south of sample L 163, show 11 % and 10 % of Jotnian sandstone. It seems likely that this material has its origin in the sub-marine continuation of the Satakunta sandstone formation.

Farther south, outside Rauma, an increase in the amount of sandstone is, however, registered and it seems rather unlikely that it could derive from the above sub-marine source.

In fact, the samples taken outside Rauma form a part of the series of samples rich in sandstone extending in the southwest as far as the northern side of Åland. The average proportion of Jotnian sandstone in these samples is 13 %, the largest sandstone quantities being in samples H 5—23 %, H 10—20 %, and H 1—18 %. Evidently this extensive and continuous group of bottom samples with relatively high sandstone amounts indicates a rather extensive sub-marine area where the proportion of Jotnian sandstone in the rock crust must be considerable. On the basis of the bottom samples it is possible to define this area in different directions even more accurately.

The northernmost limit consists of the series of samples stretching eastwards from Finngrunden up to sample L 156. The amount of sandstone on this stretch is small with the exception of sample H 11 where its proportion amounts to 12 %.

The southern boundary running north of Åland can indirectly be defined with the aid of the rapakivi. In samples H 6, 7, 8, 9, 10 and 13 the amount of rapakivi (13 %—28 %) should be noted in addition to the percentage of Jotnian sandstone. As a working hypothesis it should be assumed that the rapakivi material derives from solid rock crust belonging to the great Åland rapakivi massive which is taken to be more or less continuous.

On this assumption it must be presumed that the said samples are situated in a rapakivi area the proximal boundary of which must in consequence run to the north of the samples. North of this, connecting possibly directly with the rapakivi, lies the Jotnian sandstone. In view of the reciprocal ratio of the said stones in sample H 10: Jotnian sandstone 20 %, rapakivi, 14 % and in the sample taken 7.4 kilometers south of this, H 9: Jotnian sandstone 13 %, rapakivi 28 %, it can be assumed that the sandstone contact (= proximal rapakivi contact) north of Åland lies, taking into account uncertainties in the interpretation, possibly at a distance of half a dozen kilometers north of sample H 10.

Indications of the westward extent of the sandstone formation can be obtained from sample H 13 taken to the west of the samples H 9—H 10. Since the amount of sandstone in this sample is only 9 % it can be taken as being near the western distribution boundary of the boulders deriving from the formation.

The Jotnian sandstone found in the above bottom samples is of medium grain size and reddish in colour.

The amounts of sandstone in the samples taken west of Åland, L 138, L 139 and L 140, are rather large, 14 %, 20 % and 24 %, respectively. Petrographically the sandstone differs from the usual Jotnian sandstone. Macroscopically the stone is grey or pale red, rather coarse and uneven in grain size. In the larger sandstone grains single stone grains up to 4 mm in diameter can be found. In the thin section the sand particles are found to be corroded in the margin. The interstitial mass and in part also the sand grains are dulled by pigmentation. Some 10 % of the sand grains are composed of feldspar, which is, however, to a great extent altered.

RAPAKIVI-LIKE GRANITE

The chapter dealing with the treatment of the samples gives the data for the classification of rapakivi-like granite. The adjoining map shows the percentages of rapakivi-like granite in the bottom samples. It should be recalled that in the main classification of rock facies rapakivi-like granite has been included in the Archean stone group so that the amounts marked are based on divisions carried out in the 8—16 mm, or in some few cases, the 4—8 mm fractions.

The total picture shows that rapakivi-like granite is a relatively common stone along the entire sea area and in particular in its southern half.

In the northern part of the Bothnian Sea, west of Vaasa, is the site of bottom sample L 55, in which the amount of rapakivi-like granite is uncommonly large, 38 %. This percentage presumably indicates the existence of a rapakivi formation rather near to the site of the sample, possibly even on the spot. Other bottom observations do not lend much support, however, to the interpretation of a possible solid rapakivi formation. In this respect there are, unfortunately, no bottom samples available from the area between the sample and the Finnish coast. The nearest sample point to the north lies some 35 kilometers away (L 51) and the sample does not contain any rapakivi-like grains. Some 11 kilometers to the west is the site of sample L 56, where the amount of rapakivi-like granite is 9 %.

About 21 kilometers south of sample L 55 there is sample point P 6. In Archean stone classification the proportion of red granite in the sample is determined at 42 %. In fact, macroscopically this granite greatly resembles rapakivi in that it contains typical drop-shaped, smoke-grey quartz grains. A microscopic examination reveals that the dominant mineral in the rock is pertitic potash-feldspar, which to a large extent is disturbed by alteration products. The quartz appears in roundish grain accumulations. The additional minerals consist of amphibole and biotite. In the thin section it is, however, not possible to observe a micropegmatite structure, a feature that is characteristic of the rapakivi-like granite of this region. The triclinicity degree carried out on the feldspar showed that the potash-feldspar of the stone is microcline ($\Delta = 0.7—0.8$), the rock was thus not considered to be rapakivi-like granite.

Regarding the interpretation of the rapakivi-like granite formation in the northern part of the Bothnian Sea, certain parallel investigations should be taken into account. As reported above (p. 15) Eskola has found that graphic-granite of the rapakivi group occurs as boulders relatively commonly in the coastal zone of the Bothnian Sea, as far north as Vaasa. On the distribution of the boulders Eskola has drawn the conclusion that rapakivi-like bedrock is to be found in the sea area west of Vaasa. In the gravimetric map drawn

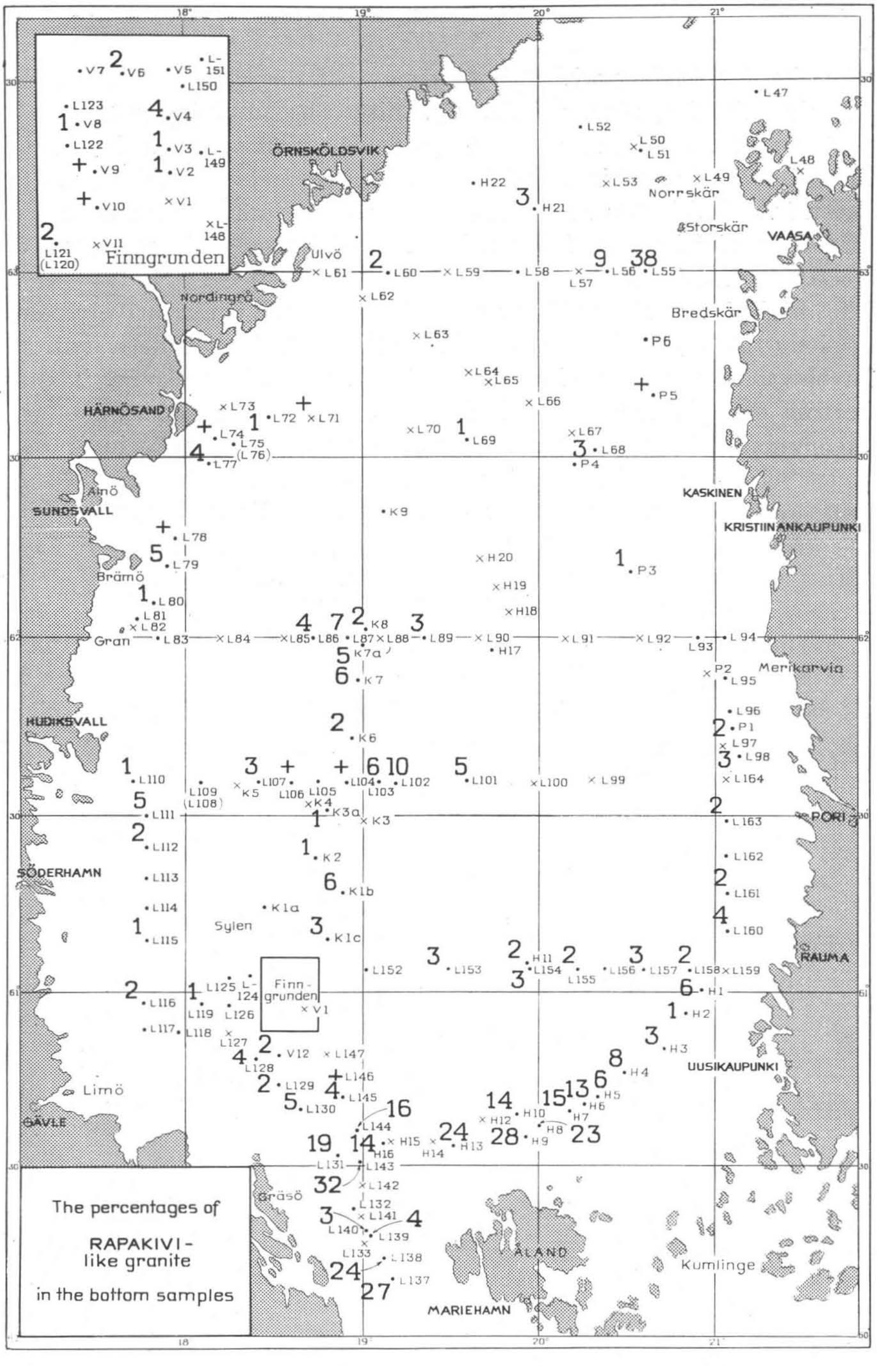
The percentages of
RAPAKIVI-
like granite
in the bottom samples
Finngrunden
ÖRNSKÖLDSVIK
Ulvö
Nordingrå
HÄRNÖSAND
Alnö
SUNDSVALL
Brämö
Gran
HUDIKSVALL
SÖDERHAMN
Sylen
Limö
GÄVLE
Gräsö
ÅLAND
MARIEHAMN
Kumlinge
Norrskär
Storskär
VAASA
Bredskär
KASKINEN
KRISTIINANKAUPUNKI
Merikarvia
PORI
RAUMA
UUSIKAUPUNKI
18°
19°
20°
21°

Fig. 27.

up by Honkasalo (see p. 39) a large negative anomaly area exists in the northern part of the Bothnian Sea. Presumably this area includes both the sub-marine Jotnian sandstone formation (cf. p. 141) and the rapakivi. It should also be taken into account that the aforementioned microcline-granite may come within the sphere of the anomaly area.

The rather rough picture that it is possible to form on the occurrence of rapakivi-like granite in the northern part of the Bothnian Sea shows that this rock, presumably, occurs in a rather limited area west and southwest of Vaasa, some 50 kilometers away from the coast.

A thin section examination performed on the rapakivi-like granite grain of sample L 55 showed that the rock bore great resemblance to the »graphic granites» that Eskola (1928) has come across on the coastal zone, and which are often characterized by graphic quartz inclusions appearing in the potash-feldspar. The triclinicity degree determination made on separated potash-feldspar showed the feldspar to be orthoclase ($\Delta = 0—0.3$).

In the sample group taken some 70 kilometers southeast of Sundsvall (K 7, K 7 a, K 8, L 86, L 87 and L 89) a percentage of 2 % to 7 % of rapakivi-like granite is found in the samples. An amount as small as this does not enable a more definite localization of a possible rapakivi formation. The fact is worthy of note, however, because it seems obvious that the rapakivi material derives from a separate rapakivi formation on the sea bottom. One could, as another proximate possibility, assume that the drift has been transported from north-northwest, from the Nordingrå area containing rapakivi-like rocks. This seems unlikely, however, in view of the distance of some 100 kilometers and of the fact that in between, outside Härnösand, there are bottom samples containing very small amounts of this rock. Nor can one imagine that the rapakivi would have been transported from the previously assumed formation outside Vaasa.

Since it seems likely that a Paleozoic sediment bed (cf. p. 130) exists on the site of the sample group, as well as a Jotnian sandstone formation northwest of this (cf. p. 142), one may take it that the presumed rapakivi formation is located only »behind» these. In this respect the critical area is presumably the sea area southeast of Sundsvall.

A thin section examination performed on a typical rapakivi-like grain in sample L 87 showed that the stone bears a great resemblance to the rapakivi in the northern part of the Bothnian Sea. The graphic circles formed around the potash-feldspar, Fig. No. 28, are a very characteristic feature of the rock. The triclinicity determination made on separated potash-feldspar gave the result $\Delta = 0—0.4$.

Some 50 kilometers south of the site of the aforementioned group of samples is the site of three samples: L 101, L 102, and L 103, in which the respective rapakivi amounts are 5 %, 10 % and 6 %. Although these

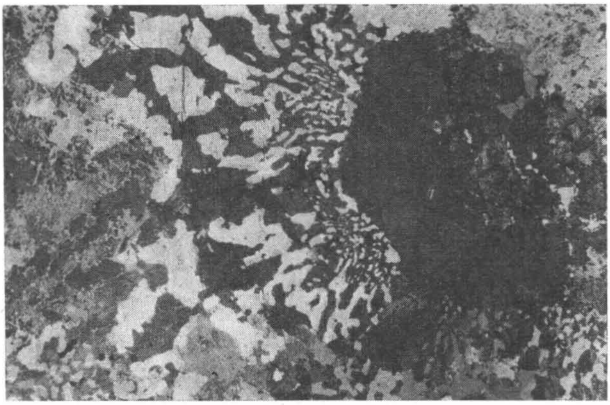

Fig. 28. Graphic texture in a rapakivi-like granite grain of the sample L 87. Nic. +. 15 ×.

amounts do not lend themselves either to a more accurate interpretation, the possibility must be taken into consideration that the material would have its origin in the formation situated not far to the northwest and north of the samples. It is not impossible to assume that the rapakivi material would derive from the formation mentioned in the previous paragraph. The transportation distance would, however, be some 70 kilometers. Thus the possibility that the rapakivi formation would continue beneath the Paleozoic sediment bed and would emerge partly east of this bed should also be taken into account.

Bottom samples can throw additional light on the northerly and westerly sub-marine dimensions of the known large Åland rapakivi massive.

The boundary of the rapakivi formation can very probably be determined in accordance with the four samples (L 137—L 140) west of Åland. In the samples nearer to Åland, L 137 and L 138, the proportion of rapakivi-like granite is 27 % and 24 %, respectively. In the two other samples, L 139 and L 140, which lie only a short distance north-northwest of the others, the rapakivi anounts are only 4 % and 3 %. The rapakivi contact, which here apparently runs approximately in a north to south direction, is probably situated relatively near sample L 139, to the west of it.

Owing to an insufficient amount of material it was not possible to compute the proportions of rapakivi in the two samples, L 132 and L 142, situated north of the aforementioned bottom samples. The samples north of these, for their part, fix the northwestern boundary of the rapakivi with a relatively high degree of accuracy. In samples L 131, L 143 and L 144 the respective amounts of rapakivi-like granite are 19 %, 32 % and 16 %. The percentages of rapakivi in the two samples L 130 and L 145, which are situated only a short distance to the northwest and north of these, are only 5 % and 4 %. Here the proximal contact of the rapakivi formation must be interpreted. The northwestern boundary of the submarine rapakivi formation can thus be assumed to run a short distance from sample L 144, along the northwestern side.

A relatively high amount of rapakivi-like granite, 13 %—28 %, can be found throughout the bottom sample series running in the east-west direction some 25 kilometers north of Åland: H 6, H 7, H 8, H 9, H 10, and H 13. As the same samples also contain a rather high amount of Jotnian sandstone, the contact is presumably determinable on the basis of these two rocks as has been stated above (p. 144). Consequently it is justifiable to assume that the northern boundary of the rapakivi runs, in the east-west direction, some half a dozen kilometers north of the aforementioned series of samples. Sample H 6, in which the amount of rapakivi-like granite is 13 %, must be taken as lying on the northeastern marginal zone of the rapakivi formation. Sample H 5, 6 % of rapakivi, situated some 5 kilometers to the northeast, is, on the other hand, presumably outside the rapakivi region.

Geological map shows that east of Åland the rapakivi boundary runs west of the Kumlinge island group.

The rapakivi-like granite of the bottom samples surrounding Åland is for the most part relatively homogeneous, medium coarse rock that is rather poor in dark minerals. It is nonetheless possible to come across some fine graded porphyric types in the samples. In addition to appearing as roundish larger grains, quartz is often found together with feldspar in a more finely graded graphic form. The triclinicity degree determination of feldspar carried out on a grain of the rapakivi group in sample L 143 gave $\Delta = 0$—0.3. The same determination from a similar grain in sample L 137 gave the result $\Delta =$ approximately 0.45. A third determination, carried out on sample H 9 gave, however, the result $\Delta = 0.75$.

With regard to rapakivi, its occurrence in small amounts in almost all bottom samples from the Bothnian Sea area should also be noted. Specially noticeable in this respect is the southern part of the sea area, roughly from the line Hudiksvall—Pori southwards. In the bottom samples throughout this area one finds a relatively regular amount, one or two percent, of rapakivi-like stone. Percentages somewhat higher than the general level are found, inter alia, outside Rauma (H 1—6 %, L 160—4 %), in the Finngrunden region (V 4—4 %, L 128—4 %, L 130—5 %), and southeast of Hudiksvall (L 111—5 %).

The small amounts found in the samples can, in part at least, be taken as representing so called long distance transportations, i.e. the relatively small part of drift that may have its provenance a long distance away. In this respect it is nevertheless difficult to understand the apparent relative increase in the amount of rapakivi that is found in the above regions outside Rauma and the area of Finngrunden. In these instances it might not be unreasonable to assume that at least a part of the rapakivi material would have its origin in the known large Åland and Laitila rapakivi formations. Since the transport would be »against the current» of the movement of the continental ice sheet, one might take it that the material has been transported by floating icefloes. On the Finnish side this assumption is supported by the fact that the dominant movement direction of sea currents is from south to north (Atlas of Finland, 1960). One dominant wind direction in the spring is also found to be from the south (Säppi Observation station, Venho, 1958).

ARCHEAN BASEMENT COMPLEX

After the successive »removal» of the Paleozoic sediment stones, the Jotnian sandstone and the rapakivi-like granite from the bottom samples, there still remains a stone component, which, if one may express it more freely, reflects the Archean framework in which the above rocks appear on the sea bottom. In the classification of rocks reference has already been made to the difficulties in the Archean group caused by the small grain size. These have limited the classification of this rock facies into only two groups, the sedimentogenic and the intrusive rock types.

In accordance with this division, in the interpretation of the Archean bedrock on the sea bottom one must reconcile oneself to outlining only the areas that are richer in sedimentary or intrusive rock material. It is possible to present the relative proportion of these rock types with a ratio obtained by dividing the amount of sedimentogenic stone with the amount of intrusive stone (excluding rapakivi). The ratios obtained are to be seen in the adjoining map, Fig. 29.

A general glance at the map sufficies to show that quantitatively the intrusive stone material is dominant in the majority of the samples. There are rather few bottom samples in which the amount of the sedimentary stone component exceeds that of the intrusive component (ratio above 1), and the only more extensive area of this kind lies in front of the Finnish coast, between Pori and Vaasa.

In the bottom samples P 1, L 96, L 95, L 94, L 93, P 3, L 68 and P 5 of the said marine area can be found relatively large amounts of sedimentary rocks, the amounts being largest in samples L 96 (ratio 2.4), L 93 (4.2) and P 3 (2.9). The sedimentogenic stone group of this sample group has been dealt with in an earlier connection (p. 47) when it has been established that

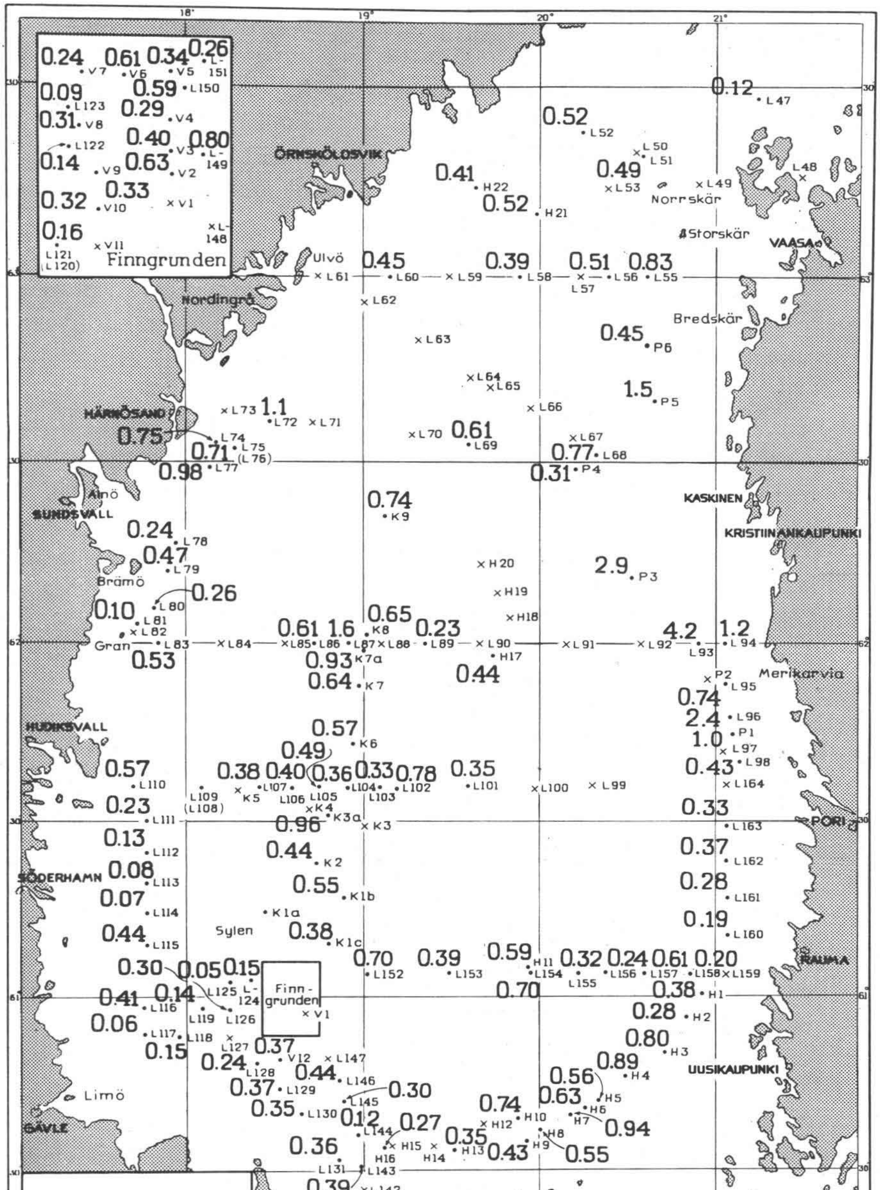
The ratios of Archean
SEDIMENTARY/INTRUSIVE
rocks
in the bottom samples
Finngrunden
ÖRNSKÖLDSVIK
Ulvö
Nordingrå
HÄRNÖSAND
Alnö
SUNDSVALL
Brämö
Gran
HUDIKSVALL
SÖDERHAMN
Sylen
Limö
GÄVLE
Gräsö
ÅLAND
MARIEHAMN
Kumlinge
UUSIKAUPUNKI
RAUMA
PORI
Merikarvia
KRISTIINANKAUPUNKI
KASKINEN
Bredskär
Storskär
Norrskär
VAASA
18°
19°
20°
21°

Fig. 29.

biotite-plagioclase-gneiss forms a large, often the largest, part of the stone components of the group. This stone must be compared with the rock existing on the corresponding site in the coastal region (see p. 28), where it has been established by Laitakari (1942) and Nykänen (1961) as being one of the most common supracrustal rock types. Laitakari has assumed that gneiss in its origin is partly normal weathering sediment and partly tuff sediment. This is a view adopted also by Nykänen.

In a thin section performed on a biotite-plagioclase-gneiss grain of sample L 93 it was determined that the chief minerals of the gneiss were plagioclase (An about 30), quartz and biotite. The quartz and the mica together form a more fine grade basic mass in which the feldspar appears in the form of largish grains.

In view of the geological map (p. 29), in which it is possible to note a supracrustal zone extending towards the coastal strip in question from the northeasterly as well as the southeasterly direction, it is justifiable to assume that these zones join and form a large westerly arch in the sea area. At Kaskinen, the boundary of the supracrustal zone must be regarded as being a good 45 kilometers from the coast judging by the fact that the proportion of sedimentary stones in sample L 68 is still considerable (ratio 0.77) and that the sample still contains biotite-plagioclase-gneiss, which is no longer found in the more westerly sample P 4.

In the two samples, L 138 and L 139, taken west of Åland, the sedimentary stone component is dominant. This is reflected in the ratios 1.7 and 1.3. The sedimentary rock material in each sample consists almost entirely of a very fine grade, dark mica-schist. No support for the interpretation of a possible solid mica-schist formation can be obtained from the geology on the mainland.

If we take a ratio above 0.6 (and below 1) to describe Archean rock material relatively rich in sediment-component, certain sample groups can be defined in the map.

In the three samples outside Härnösand, L 72, L 74 and L 75, the ratios are, respectively, 0.91, 0.75 and 0.71. The major part of the sedimentary stone material of the samples is fine grade, dark mica-schist, although schist grains in a light colour can also be found. On the geological map of the coastal zone (Karta över Sveriges berggrund, mellersta bladet, 1958), at Härnösand, can be seen a supracrustal zone extending as far as the sea shore and marked as containing »sediment, mostly graywackes and schists». Consequently it seems probable that the supracrustal zone continues into the sea area. Regarding its extension eastward no hypothesis can, however, be presented owing to the lack of bottom samples.

Southeast of Sundsvall, in the area where Lat. 63°N and Long. 19°E cross each other, there are five bottom samples, K 7, K 7 a, K 8, L 86, and

L 87, the ratios of which are 0.64, 0.93, 0.65, 0.61, and 1.6. The major part of the sedimentogenic material of the samples consists of mica-schist, although some variation is found in the rock type. The hypothesis has been presented earlier (p. 142) that on the said spot on the sea bottom there may exist a Paleozoic bed, as well as a Jotnian sandstone formation to the northwest of it. An Archean bedrock relatively rich in sedimentogenic material could, accordingly, be assumed to exist farther northwest as seen from the sample group, in the marine area east of Sundsvall. Sample K 9, which likewise contains a relatively large proportion of sedimentary stone material (ratio 0.74) can presumably be taken to reflect the same rock type area.

In the group consisting of five bottom samples (H 3—H 7), west of Uusikaupunki, the relative amount of sedimentogenic stone is rather large (ratios 0.56—0.94). The sedimentary rock material consists for the most part of rather uniform, fine grade mica-schist, although fine grain mica-gneiss also appears in the samples, as well as occasional very small quantities of light coloured leptitic grains. On the map sheet of Turku (Härme, 1958) one notes a supracrustal zone extending towards the sea area at Uusikaupunki. On the map, the base rock has been marked as being »mica-gneiss, mica-schist and phyllite». An Archean bedrock relatively rich in sedimentary component must thus be considered as existing on the northern and northeastern side of Åland, outside the rapakivi and the Jotnian sandstone formations.

The samples richest in intrusive stone material can be found in the southwestern part of the Bothnian Sea. In some of the bottom samples in that area, L 113, L 114, L 117, L 123 and L 125, the amount of intrusive stone material is more than ten times that of the sedimentogenic (ratio below 0.1).

If a ratio that is lower than 0.3 is defined as indicating intrusive rich stone material, regional bottom sample groupings can again be found in the Bothnian Sea area.

In this respect the bottom samples in the southwestern part of the Bothnian Sea, in a southerly direction from southeast of Hudiksvall, as well as those from the western side of Finngrunden, form a rather large and relatively uniform group. The abundance of intrusive stones in the samples from this area is primarily due to the »grey granite — diorite» subgroup. Within this group rather large variation in the rock facies exists in the composition of the rock.

The dominance of intrusive stone in the bottom samples fits in rather well with the geological structure of the corresponding coast area. On the geological map the area south of Hudiksvall has been marked with a basic colour indicating »oldest granites» although the area has also been marked as containing smaller amounts of metamorphic (»ådergnejsomvandlade») rocks of sedimentary origin. On the basis of the bottom sample investigation one can, at all events, assume that the granite dominant bedrock of the coast area in the southwestern part of the Bothnian Sea extends some score kilometers into the sea area, possibly across the 18th longitude though not perhaps very much east of this. In the direction of Finngrunden one must assume that this rock type extends right up to the Paleozoic sediment formation.

The three bottom samples east of the island of Brämö, L 78, L 80 and L 81, show the ratios 0.24, 0.26 and 0.10. The intrusive stone components of the samples consist for the most part of »grey granite — diorite». Considerable variation in type can be found within this sub-group. In comparing the corresponding area on the coast it can be observed that a rather narrow granite formation extends seawards northwest of Brämö.

In the samples taken west of Rauma, H 2, L 158, L 160 and L 161, the ratios are found to be rather low, 0.19—0.28. The abundance of intrusive stone in the samples is largely due to the sub-group of »red granite». The red granite, again, falls in all samples rather obviously into a group of its own. The rock is pink, rather coarse, partly pegmatitic microcline-granite. From the point of view of connection between the sea and the land areas it should be noted that the neighbourhood of Rauma, in particular, is characterized by granitized rocks. Sederholm has marked this area as containing »mica-gneiss» migmatized by »younger granite».

THE TOTAL GEOLOGICAL PICTURE OF THE BOTHNIAN SEA AREA

Presenting the results in the form of the drawn map which accompanies this work, p. 156, has, in many ways, been a difficult task, which has left much scope for different interpretations. A bottom investigation has, in too many cases, established only an indirect contact with sub-marine rock formations, while a more accurate definition of their boundaries has not been possible. For this purpose the »network» of bottom samples of the sea area has been too thin. All results achieved have, moreover, been conditioned by an interpretation of a number of factors which in themselves do not always encourage only one restricted explanation. Although a certain degree of inaccuracy must obviously appear in the map, on a larger scale it presumably throws light on the geological structure of the bottom of the Bothnian Sea. In view of the map and the aforegoing text it seems justifiable to sketch once more, in a concentrated form, the geological outlines and the geological development of the Bothnian Sea area in the pre-Quaternary time.

The Archean basement complex in the bottom of the Bothnian Sea agrees geologically with that on both sides of the sea. High metamorphosis seems, as a whole, to be characteristic also of the rock crust of the sea area.

In the sea area there appear, however, distinguishable regions where either sedimentogenous or intrusive rocks seem to be in predominance, or where their relative quantity is greater than usual. In some cases there are obvious connection possibilities between the geological features in the coastal area and those assumed on the bottom of the sea. Thus, on the Finnish side, the two schist belts between Vaasa and Pori, which point to the sea from the northeast and the southeast, very probably join each other forming a great westerly arch in the sea.

Likewise a zone rich in mica-schist seems to continue from the coast south of Uusikaupunki a considerable distance to the west.

The fact that intrusive rock pebbles predominate in the bottom samples taken outside the Swedish coast, south of Hudiksvall, seems to accord well with the geology of the coastal area, indicating a rock crust rich in intrusive rocks in the corresponding marine area.

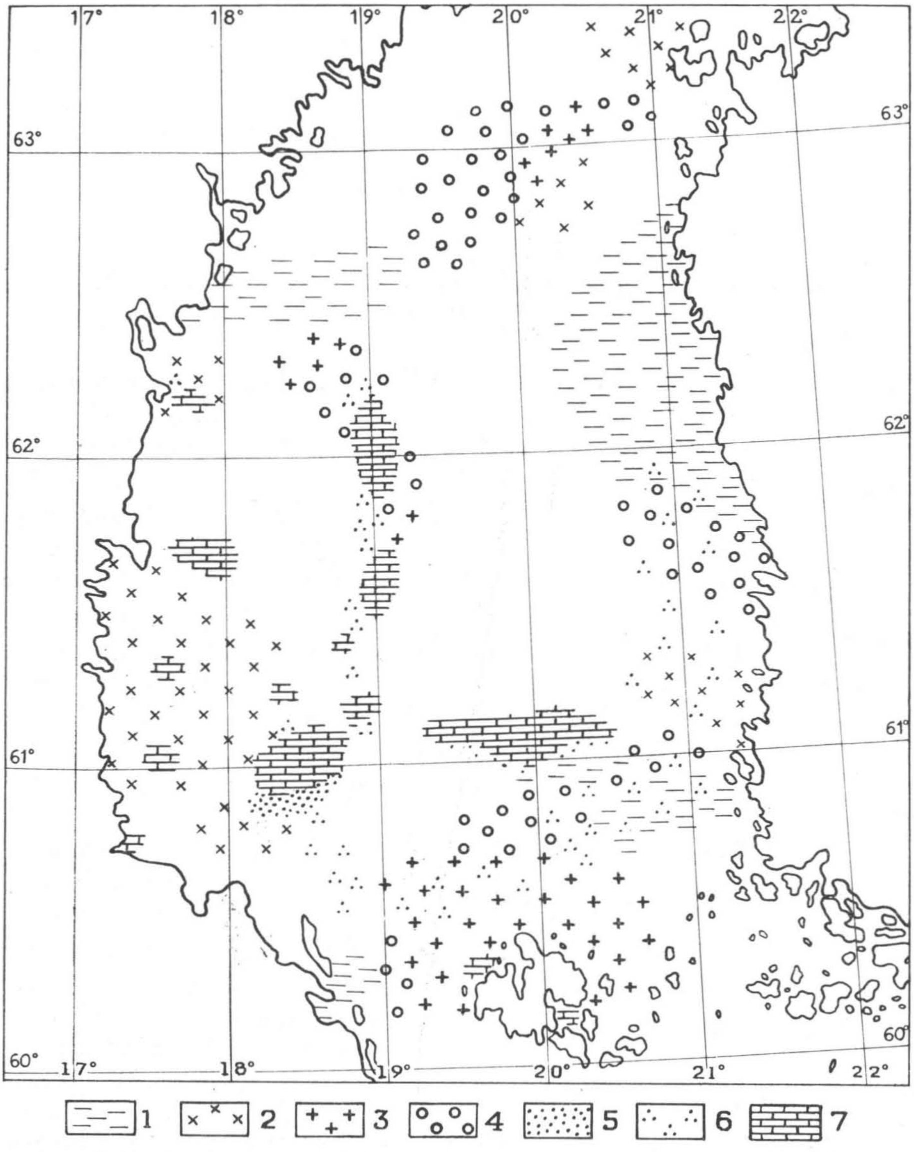

Fig. 30. A sketch of the pre-Quaternary geology of the bottom of the Bothnian Sea. 1 Archean rock rich in sedimentary component, 2 in intrusive component, 3 rapakivi, 4 Jotnian sandstone, 5 Cambrian sandstone, 6 unlocalised rests of Cambrian sandstone, 7 Paleozoic limestone.

In addition, some other combinable characteristics, appearing in smaller features, have been noted. Some independent areas, comparatively rich in either sedimentary or intrusive rocks, have been outlined even in the marine area outside the coast.

There are relatively extensive sea areas, however, in which the samples do not show a special Archean rock type in an indicative amount. One may assume that in those cases the Archean base rock may be composed of a rock type where both components exist in proportional quantities. The fact may be mentioned that bottom samples with such intermediate relations (ratio from 0.3 to 0.6) often appear close to the coast where the bedrock consists of highly metamorphosed rock types, e.g. the veined gneisses on the northern part of the Swedish coast.

Since rapakivi-like granite and its associates generally appear in isolated, well defined formations, this rock has been treated separately from the Archean rock complex. A comparatively small rapakivi formation must be assumed to exist in the northern part of the Bothnian Sea, west of Vaasa. It seems highly probable that this is the same formation from which derive the boulders found along the Finnish coast of the Bothnian Sea, and of which Eskola (1928) has given a comprehensive petrographic description.

Another formation of rapakivi-like granite must be regarded as existing in the sea area southeast of Sundsvall. It is, however, not possible to present any hypotheses regarding the size of this formation because the geology of that rather limited area seems to be comparatively complicated including, in addition, both Jotnian sandstone and Paleozoic sediments. Petrographically, the rapakivi-like granite of the formation resembles to a great extent the rock type found in the above mentioned formation west of Vaasa.

The westerly and northerly boundaries of the known large Åland rapakivi area have been defined comparatively accurately with the aid of the bottom samples. The area containing rapakivi-like granite extends, accordingly, a further 20 kilometers or so west of Åland. North of Åland, the boundary of the rapakivi area runs at a distance of some 30 kilometers, in, presumably, a west to east direction. It should be pointed out, however, that it is not clear whether this limited area is composed solely of rapakivi-like rock. An indication to the contrary is found in the relatively large amount of Jotnian sandstone in the Åland drift.

It seems obvious that early in the pre-Jotnian period the Archean rock crust has become degraded to a level which does not greatly differ from the present surface level of the rock. This is supported by the fact that at Åland and Nordingrå remnants of the old sedimentation level, the so called sub-Jotnian peneplain, can still be found on the present surface level or very near to it.

In view of the extensive distribution of Jotnian sandstone in the Bothnian Sea area, and of the great degree of similarity of this rock type in different formations, it must be assumed that the present Bothnian Sea area has, to a comparatively large extent, been once covered by Jotnian sand. The thickness of the sand layer has possibly been considerable at least in some places. In the area of Satakunta, for example, deep drilling has established that sandstone extends far down to a depth of 591 meters. It should be mentioned that according to Honkasalo's estimate, which is based on a gravimetric measuring interpretation, the thickness of the Satakunta sandstone formation may well be much greater (oral report).

In the pre-Cambrian period, at a time when the area was probably already covered by Jotnian sand or sandstone, considerable dislocations have taken place within the zone of the Bothnian Sea. Submersions of this kind that are now filled by Jotnian sandstone, are the Satakunta and Gävle formations in the coastal zone of the Bothnian Sea. On the basis of the gravimetric map, the formations existing in the northern part of the Bothnian Sea and north of Åland, should also be classified in this group, the latter, however, probably only in part. No feature pointing to a gravimetric anomaly does, on the other hand, exist in the third formation in the Bothnian Sea area, southeast of Sundsvall.

Prior to the Cambrian period — very possibly at a considerably earlier date — the Jotnian sediments have been degraded almost in their entirety and the Archean rock crust has again been denuded in the major part of the region.

In the initial stage of the Cambrian transgression, the Bothnian Sea area has formed a sedimentation level for the sediments to come. The Bothnian Sea basin in its present form has, however, scarcely taken shape as yet. The sedimentation level, the sub-Cambrian peneplain, has not greatly differed from the present level of the rock crust in the Bothnian Sea, although its vertical location has probably not been on the present level of the rock crust. The old sub-Cambrian peneplain is still represented by the flat bottom zone, some 60 kilometers in width, outside the Finnish coast, with a probable continuation in the area north of Åland and in the level area south of Finngrunden. It can further be proved that the sub-Cambrian peneplain lies at the bottom of the Paleozoic sediment formations of Finngrunden, the submarine ridge of the Bothnian Sea, and between Finngrunden and Rauma. In the western part of the Bothnian Sea, outside the Swedish coast, the sub-Cambrian peneplain must, however, be regarded as having very largely been destroyed.

It can be assumed that Cambrian sandstone has once covered the major part of the present Bothnian Sea area. Grains in the bottom samples define the northern limit of the sandstone distribution as running from Härnösand to Merikarvia. By now very little remains exposed of the formation. The most notable Cambrian sandstone formation is presumably situated south of Finngrunden, where it can be regarded as forming a sandstone stratum protruding from under the Ordovician limestone. It must, however, be assumed that small remnants of Cambrian sandstone exist throughout the area where the sub-Cambrian peneplain has been better preserved.

Very little can be said about the thickness of the sandstone stratum. If one keeps in mind that the Paleozoic sequence found outside Rauma, which is composed of the Ordovician limestone sediments, including Baltic and red Orthoceras limestone, as well as of Cambrian sandstone, presents a total thickness of approximately 20 meters only, the thickness of the sandstone layer on this spot cannot be considerable. At Finngrunden, on the other hand, it may be somewhat thicker.

According to observations made by Wiman and Hessland in the coastal area of Uppland, the Paleozoic series also contains shale (Cambrian alum shale and Ceratopyge shale). Within the framework of bottom samples, observations on Paleozoic shale are almost non-existent. The only grains that could possibly have their origin in this rock type, have been found in only few samples e.g. in L 116 taken west of Finngrunden. It should be pointed out, however, that the absence of this rock type from the bottom samples does not necessarily mean that it would not exist also in the Paleozoic sediment sequence of the sea area. Wiman has already shown that the proportion of shale in the sequence is comparatively small. Paleozoic shale is, on the other hand, one of the least resistant rock types which accounts for its rapid disappearance in the transportation process of continental ice.

The distribution of Paleozoic limestone in the Bothnian Sea area is somewhat smaller that that of Cambrian sandstone. On the basis of the limestone grains found in the bottom samples, the northern, or rather the northeastern, distribution boundary can be drawn along the line Härnösand—Uusikaupunki. It can be assumed that southwest of this line there has once existed a continuous limestone bed. Later, a major part of it has been destroyed by erosion, though surprisingly much has also remained considering the fact that Paleozoic limestone formations are extremely rare in the surrounding coastal area.

The largest continuous limestone formations are probably to be found in the areas of Finngrunden, of the sub-marine ridge of the Bothnian Sea, and in the sea area between Finngrunden and Rauma. Separate smallish remnants may be found here and there, in particular in the western part of the marine area.

It can be assumed that a regional variation exists in the thickness of the limestone sediment. At Finngrunden, the bottom level of the Paleozoic sediments (i.e. the sub-Cambrian peneplain) lies some 60 meters below the present sea level. The highest points in the shoal, on the other hand, are only a few meters beneath sea level. The assumed thickness of the limestone sediment, after the subtraction from the total thickness of the Cambrian sandstone and the drift covering the solid limestone (no observations on the thickness of drift are available so that the estimates must very largely be based on conjecture) must be put in the neighbourhood of 50 meters. East of Finngrunden, approximately half way between the shoal and the Finnish side of the coast, the corresponding total thickness is approximately 20 meters. When the sandstone and the covering drift are, again, eliminated, the thickness of the limestone sediment may be taken as being considerably smaller than that of the Finngrunden formation. Judging by observations made in the northern part of the sub-marine ridge in the Bothnian Sea, the thickness of the limestone there can be assumed to be of the same class as that west of the Finnish coast.

It should be noted that in all the formations referred to, both the limestone types that have been classified into separate groups on the basis of macroscopic examination, are represented: the Baltic limestone, which presumably represents the topmost Ordovician stratum, and the red Orthoceras limestone, which represents a considerably lower limestone series.

After the deposition of the Baltic limestone the Bothnian Sea area, or some parts of it, has indicated vertical movements.

In the eastern part of the Bothnian Sea, the sub-marine bottom zone facing the Finnish coast, together, probably, with a coastal zone on the mainland, has inclined westward in a degree that corresponds to an approximate inclination of 2.5 meters in one kilometer.

It seems probable that the eastern border of the present Bothnian Sea basin has come into being through this inclination.

In the western part of the sea area, in front of the Swedish coast, displacement after faulting can be found. Graben depressions, filled at present with Paleozoic sediments, may be assumed to occur at least in some places in front of the coast, as for example near the Brämö island and in the Gävle Bay. In the former case a connection with a long distance mainland fault can, presumably, be taken to exist.

In a sense, Finngrunden and the areas of the sub-marine ridge, form an intermediary part between the eastern and the western parts of the Bothnian Sea. No feature pointing to an eventual displacement in the district of these areas has been observed. On the other hand, the bottom level of the sediment bed lies considerably higher than the western border of the same level outside the Finnish coast.

Our present knowledge does not permit discussion on the question of the age of the above mentioned inclinations and dislocations on the bottom of the Bothnian Sea. Generally, the post-Caledonian faultings have been connected together with the heavy displacements that took place in the Fenno-Scandian region in the Tertiary period, and which has been supposed to account for the main geomorphic features of the whole Fenno-Scandia.

Within the framework of this study, the last geologico-historical event is the passage of the large continental ice sheet over the entire sea area during the Pleistocene epoch. It is interesting to note that glacial erosion in the surrounding continental areas has been very much heavier than in the bottom area of the Bothnian Sea, which apparently has to be connected with the obvious fact that this area has been covered by the sea.

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