THE CONTINUATION OF THE UPPSALA ESKER IN THE BOTHNIAN SEA AND ICE RECESSION IN THE GÄVLE AREA

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The northernmost part of the Uppsala esker, near to the point where it plunges under the Bothnian Sea, is briefly described in the text accompanying the geological map sheet "Eggegrund" (Wahlqvist 1868). Billudden (Figs. 1 and 2), a well-known excursion site for various natural scientists, is considered there as a tributary esker to the east. Later, however, it has come to be interpreted as an integral part of the main esker. Sandberg (1930, p. 71) stated, as one reason for this interpretation, that whereas a continuation of the Uppsala esker is lacking on the sea bottom directly outside of the mouth of Dalälven ("älv" = river), toward which the esker extends from the south, a series of shallow areas (Flatbotten, Hansbådan, and Petres bank) mark a definite continuation northward from Billudden. At an early stage Blomberg (1895, pp. 133, 137 ff.) suggested that the Ljusnan esker[1] represented a continuation of this esker. In the same way the Enånger esker was supposed to be a continuation of the Vässland esker, and the Hudiksvall esker a continuation of the Börstil esker (see Fig. 1). According to Blomberg the last-mentioned connection is supported by the fact that andesite from the Lake Dellen area, Hälsingland, has been found in the Börstil esker as well as in the Hudiksvall esker. It should be mentioned here, however that andesite is found also in the block material on Billudden (Sandberg 1930, p. 74; 1948, p. 120).

In Sweden numerous studies have been made of the morphology of the sea bottom on the basis of soundings and depth contours. To my knowledge, however, no one has attempted previously to follow the Uppsala esker any significant distance in the Bothnian Sea. At the present time the "Swedish Board of Shipping and Navigation: Hydrographic Department" (Kungl. Sjöfartsstyrelsens sjökartebyrå) has available a relatively large amount of data for studies of this kind in the area under discussion. The area has been completely sounded, mostly by means of echo-sounding between 1952 and 1956. Depth information is plotted on charts at scales varying between 1 : 10,000 and 1 : 50,000. Soundings are most scattered in areas which are uninteresting from the charting point of view; i.e., especially where the depth is significant and/or where the bottom is relatively flat. In such areas soundings are 250 m apart, and thus a total of 16 soundings have been made for each square kilometer.[2] Where the bottom topography is uneven the soundings are much more closely spaced, and even in areas with depths of about 50 m the distance between soundings is still 175 m or less. Nearer the coast, e.g., off Billudden and between Hudiksvall and Agö, the number of soundings increases to 400/km²; i.e., only 50 m between soundings. The errors which are inherent in the method of sounding[3]

[1] All names of eskers in Fig. 1 and in the text are according to the Atlas över Sverige (Atlas of Sweden), sheets 17—18, 1954.

[2] West of the so-called Västra banken, within a smaller area which was hand-sounded in 1928, the distance between soundings can be as much as 400 m. The soundings are considerably closer together, however, in the areas where it is possible that the esker may continue.

[3] E.g., within the very level area on both sides of the esker at about 61°5′ N, 17°45—50′ E (Fig. 4) every second E—W profile of soundings indicates a depth 1—2 m greater than the other profiles. According to the Hydrographic Department this is because the profiles consist of two alternating sets of soundings made on two different occasions. In one or both sets of soundings a small systematic error has occurred.

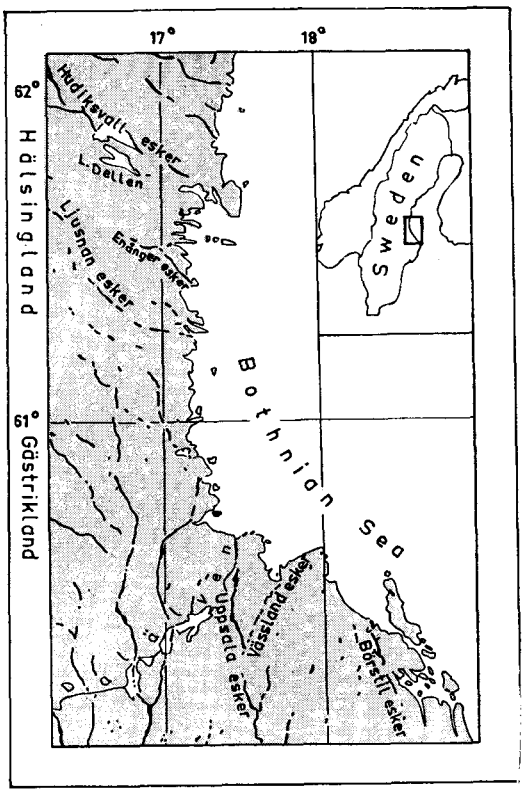

Fig. 1. Location map.

are for the most part unimportant for the problem under consideration.

Fig. 2 shows the general location of the eskers which it has been possible to trace in an area which extends from the coast to an easterly limiting line at approximately 17°50′ E, and from Billudden in the south to the latitude of Hudiksvall in the north.

The Uppsala esker continues northward from Billudden to Petres bank as a high underwater ridge which passes a few kilometers east of Eggegrund. Profiles 1–4 in Fig. 3 show that the ridge rises considerably above its surroundings–in Profile 4 not less than 50 m–whereas its breadth can exceed 1 km. In certain places (see Profile 3) well developed trenches (Swedish: "åsgravar") can be observed on the sides of the esker. In other places depressions (Swedish: "åsgropar") occur on the esker, and indications of such can be seen in Profiles 2 and 4. These depressions sometimes appear to be open on one side.[4] Well defined esker centers[5] have not been observed in this section. The top of the esker sinks continuously, although irregularly, northward from Billudden, but even at Petres bank the water depth is less than 10 m, and in places is only 1–2 m.

The esker loses its ridge-like character at 60°48–49′ N. Instead there appears a 3–4 km wide bank ("Blockbanken" and its continuation to the northeast) with well marked sides, which are up to several tens of meters high. These banks are outlined in Fig. 2 with a dashed line. The banks are covered by different small-scale landforms, which for the most part are oriented approximately NNW-SSE. When the width and the morphology of the banks are taken into account it seems quite doubtful that they really represent the continuation of the Uppsala esker. The fact that we are here within an area of supposed Cambro-Silurian rocks (e.g., see Rudberg 1960, Color map 2) obliges us to use caution, as the flat banks may represent remnants of these sedimentary beds. It is perhaps more probable that a rather short and narrow ridge situated immediately to the west of the banks may represent the continuation. This isolated ridge segment is very well defined and is up to 20 m high; it has also been outlined in Fig. 2.

North of about 60°55′ N the esker is again clarely defined and continues without interruptions over a distance of nearly 30 km. Fig. 4 is a map with depth contours of the greater part of this area; it is supplemented by Profiles 5–10 in Fig. 3. Here the esker is usually 10–25 m high, and its crest lies 30–50 m under the surface of the sea. Trenches ("åsgravar") can be observed along this part of the esker also. There is a tendency, especially in the north, for division into separate centers, situ-

[4] Such depressions above the present sea-level (but below the highest strandlines) have very often become closed by the formation of recurved and other spits during the passing of the strand zone. The development of Billudden during the last few hundred years provides several fine examples of this.

[5] Esker centers, as defined by De Geer (e.g., 1940) refer to the series of hillocks, which make up an esker. These are believed to represent successive positions of a receding ice front, and according to De Geer each center represents the proximal part of an annual sedimentary layer (which distally consists of varved clay).

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At 61°10′ N the esker definitely separates into isolated hills. At the same time the character of the bottom topography in the surrounding area changes completely. Instead of being strikingly even the bottom is now extraordinarily uneven with elevation differences of 25 m and more within short distances. A certain tendency toward an orientation of the topography in a NW-SE direction can be observed. With the material available at present it is impossible to determine the exact position of the esker among this jumble of ridges, if it is there at all.

The Uppsala esker's continuation northward from 61°10–15′ N is thus uncertain. However, the eskers which extend out toward the coast of Hälsingland should be considered in this regard. The Ljusnan esker (see Figs. 1 and 2) plunges under the sea near Söderhamn and can be followed in a southeasterly direction on the sea bottom and via a number of small islands (in the latter case by means of air photos) to 61°12′ N, 17°20′ E; and perhaps some smaller sections of the esker occur up to about 5 km farther southeast. The orientation of this esker practically excludes the possibility that it represents the continuation of the Uppsala esker. The same seems to be the case with the rather insignificant Enånger esker, although it has not been possible to follow this esker out onto the sea bottom. The next esker to the north is the Hudiksvall esker, which plunges under the sea a few kilometers east of Hudiksvall. From this point it extends 20 km southeastward, is wide and high, and in many places nearly reaches the sea surface. It stops suddenly, however, a few kilometers NNW of Agö.[6] Since both the esker itself and the striae in the area point toward the place where the Uppsala esker disappears, it seems most probable that *the Hudiksvall esker should be regarded as the continuation of the Uppsala esker*. Naturally it is impossible to completely ignore the possibility that some other more northerly esker should be considered. If such were the case, however, it would be reasonable

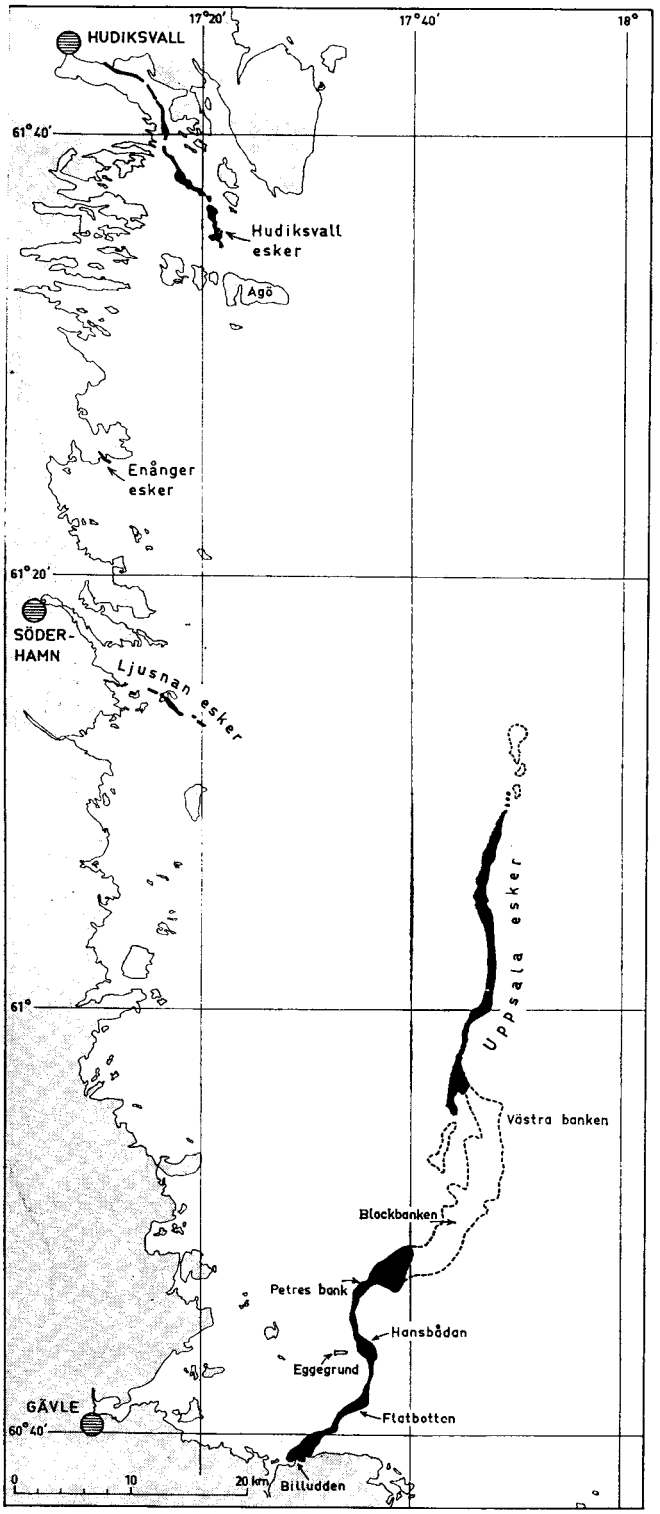

Fig. 2. Underwater eskers in a part of the Bothnian Sea.

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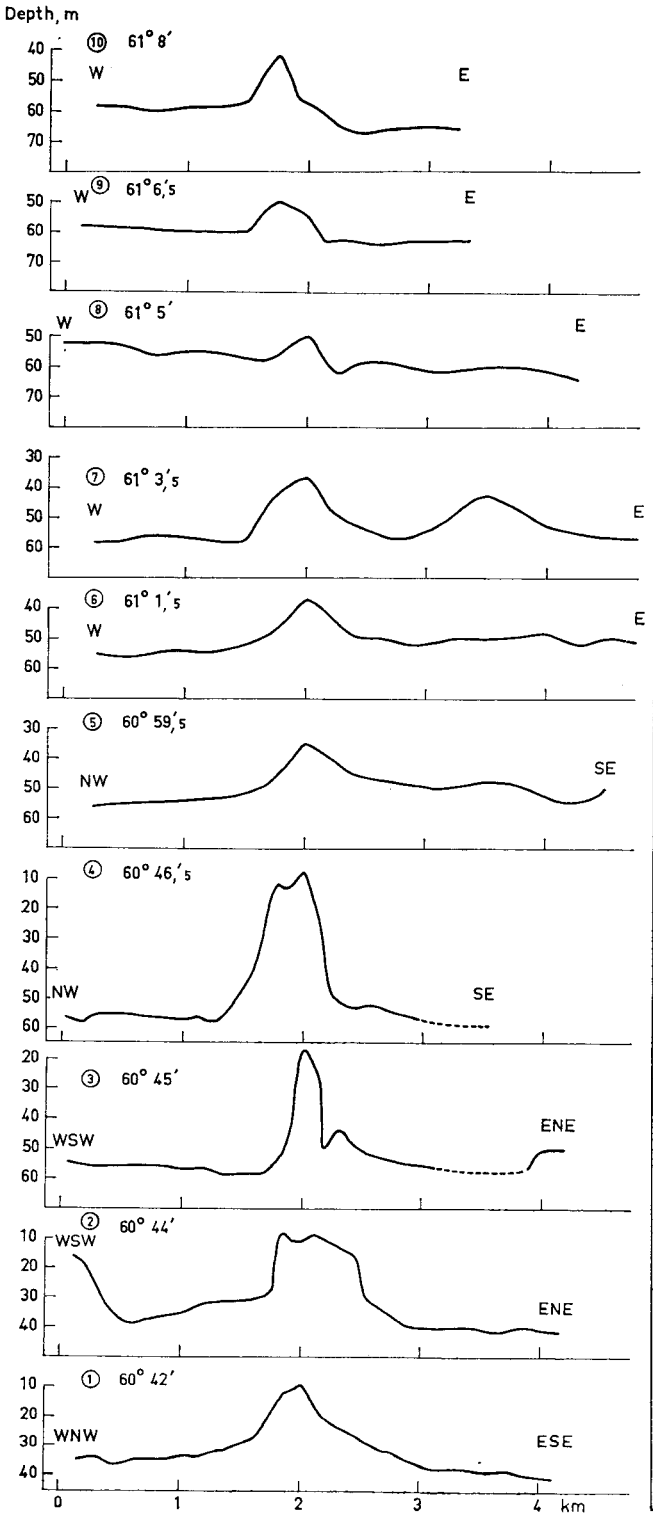

Fig. 3. Cross profiles of the underwater part of the Uppsala esker.

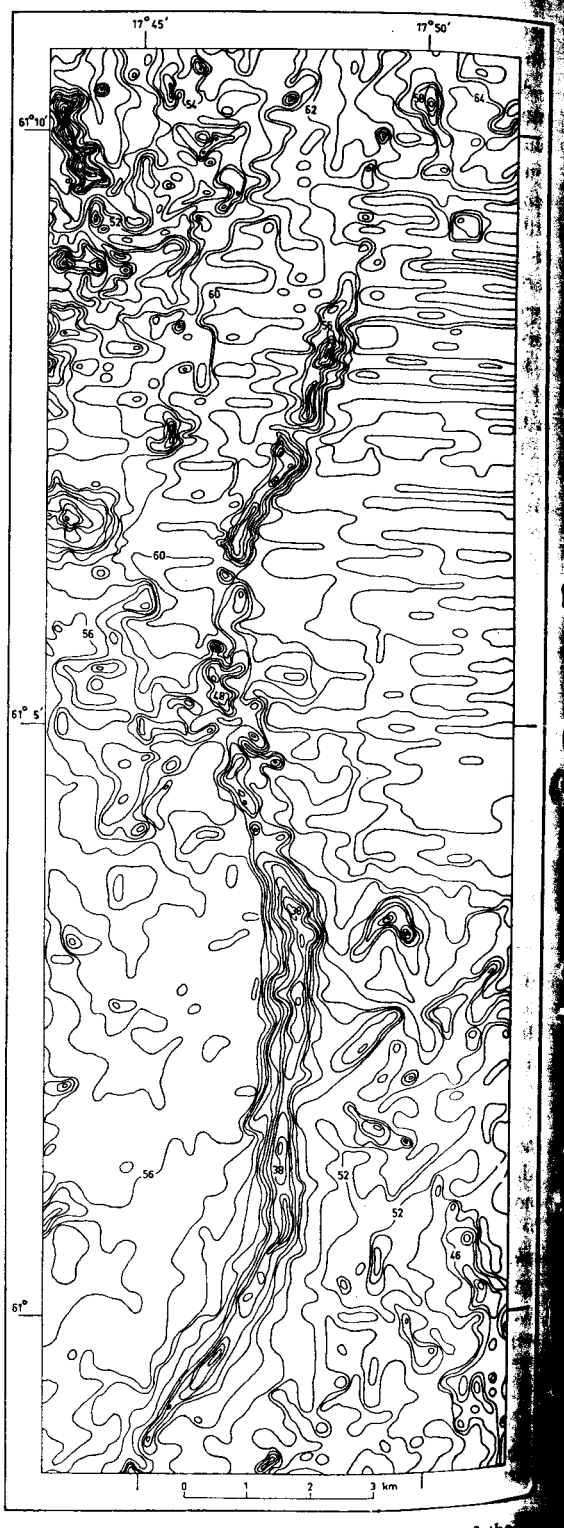

Fig. 4. Depth contour map showing a section of the underwater Uppsala esker in the Bothnian Sea. Contour interval 2 m.

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As is well known eskers normally are oriented in the direction of the last ice motion; i.e., at approximately right angles to the ice edge. They can therefore be used for reconstructions of the orientation of the ice edge and the successive stages in its recession. Such possibilities for reconstruction are of especial value for areas below sea-level, as other evidence on which reconstructions could be based is generally lacking. It is obvious that the subaquatic parts of the Uppsala esker, as well as those of the Ljusnan and Hudiksvall eskers, can be used in this way.

The recession of the ice in the coastal districts of Gästrikland and Hälsingland is one of the most discussed chapters in Sweden's glacial history. One group of workers has suggested that deglaciation in the Gävle district was interrupted by an ice advance from the northeast i.e., from the Bothnian Sea (e.g., Sandegren 1929). The other group has proposed that the ice recession had a more normal character but that complications were caused by the occurrence of calving bays (e.g., De Geer 1929). I have earlier stated my support for the latter interpretation (Hoppe 1948, p. 95). At different times the supporters of this interpretation have presented sketch maps showing their conception of how the ice recession took place in the coastal district mentioned above. Some of these sketches are reproduced in Fig. 5.

De Geer's reconstruction of ice recession is based essentially on varved clay connections. According to these the Hudiksvall district became ice-free at approximately the same time as the Gävle district much farther south. A result of this interpretation was that an ice tongue whose edge De Geer also indicated, was thought to have extended to the southeast between these areas. It has been known for a long time, as De Geer himself emphasized in an article as early as 1897 (cf. Hoppe 1948, p. 85) that the youngest striae are oriented mainly at right angles to the ice edge. I believe that nearly all ice edge reconstructions must satisfy this condition, although complications may occur within very small areas (see Hoppe 1957, p. 1 ff.). Thus this consideration must be taken into account in all varved clay connections. De Geer carefully observed this requirement in the Gävle district, but in the Hudiksvall area he sketched the ice edge nearly parallel to the striae. His reconstruction must therefore be rejected in regard to the area north of Söderhamn and likewise for the neighboring sea areas. For the latter region his reconstruction is also completely incompatible with the evidence from the underwater part of the Uppsala esker.

Lundqvist's reconstruction in the "Atlas över Sverige" (1954, sheets 21–22) is essentially based on De Geer's work but is considerably more careful. However, the same objections as those noted above hold true in regard to the changes of the receding ice edge in the Söderhamn-Hudiksvall area. One of his ice recession lines continues out into the Bothnian Sea; its orientation does not completely agree with the evidence from the striae and the esker.

Järnefors' (1960) recent presentation, which is based on new varved clay measurements, agrees fairly well with the ideas held by the present author. The necessity for a correlation between striae and ice recession lines has to a great extent been observed, with certain reservations for the area around Hudiksvall. Perhaps as an attempt to compromise between the older contradictory theories about ice recession Järnefors has suggested that, "north of the Gävle region two local ice fronts have been developed, one retreating to the northwest and the other to the northeast in the direction of the Bothnian Sea." This interpretation is also depicted by one of the ice recession lines, which has a break at the present coast immediately south of the 61st parallel (20–30 km N of Gävle); there the two segments of the ice edge are nearly perpendicular to each other. The meaning of the expression "local ice front" is uncertain, but an evaluation must be postponed until further evidence is presented.

A reconstruction of the ice recession within the sea area adjoining Gästrikland-Hälsingland based only on the recently traced underwater eskers must naturally be relatively hypothetical. This is especially true for the area between 61° 15′ N and Agö, where the continuation of the Uppsala esker was not found. The probable development of an estuary in the ice edge at the esker has not been considered in my re-

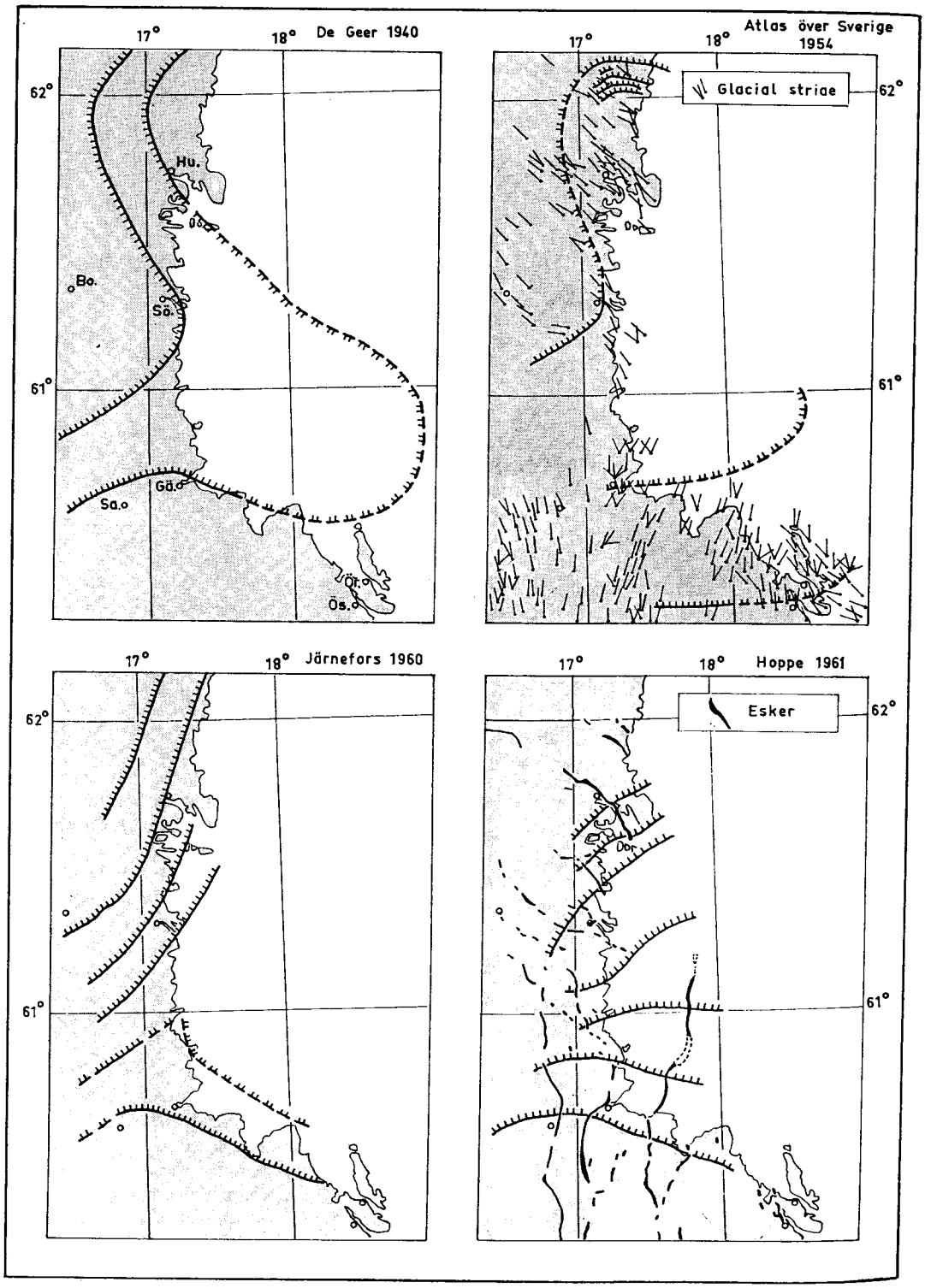

Fig. 5. Ice recession in the Gävle — Hudiksvall area according to different authors.

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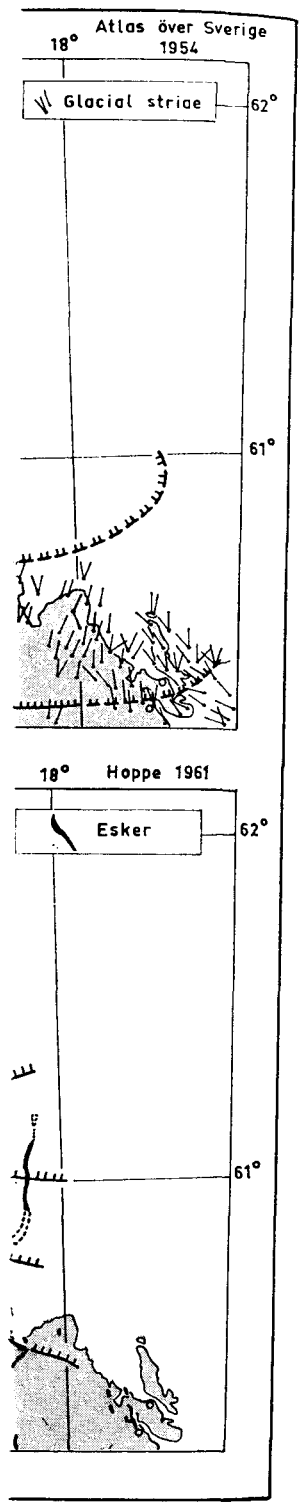

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construction.–What is especially striking in this reconstruction is the relatively rapid ice recession which occurred in the Bothnian Sea as compared with the recession inside the present coastline. The effect of the greater water depth is obvious here; an intensified calving can easily be imagined. Finally, it should be emphasized that this rapid ice recession in general supports the ideas which De Geer presented concerning this point, although his ice recession lines gave a wholly different course of recession.

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