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Ice-Pushed Boulders on the Shores of Gotland, Sweden

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ABSTRACT

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Boulder accumulation and movements are described from four localities on Gotland. Two types of cliff-platform relationship and associated boulder accumulation are represented on the NW coast, illustrated by examples from Hall and Stenkyrka. Due to morphological—limestone bedrock—and climatic conditions the movements on the wave-cut platform the *pall* or *pallen* are not traceable in detail. In contrast, the shallow water inlets Gansviken and Furillen on the E coast demonstrate the boulder movements in the form of tracks in the soft bottom sediment. The tracks were made when the boulders were ice-bound and the ice-floes were wind-pushed over the slightly thawed bottom. New tracks are easily seen from the air and can be recognized after several years despite later infilling with new sediment. The boulder movements are clearly induced by ice-pushing related to certain climatic conditions in cold winters, whereas development and growth of beach ridges normally occur in mild winters.

ADDITIONAL INDEX WORDS: *Gotland, Baltic Sea, boulder accumulation, boulder movements, boulder tracks, ice-pushing, coastal morphology.*

INTRODUCTION

The island of Gotland is situated in the Baltic Sea 80–120 km east of the Swedish mainland, and 160–200 km distant from Estonia and Latvia (Figure 1). The central Baltic Sea is practically tideless (<1 cm), but water level registered at Visby Harbour varies in relation to air pressure and wind direction. High water maximum is 80 cm above mean sea level (msl); low water may drop to −70 cm. High air pressure appears to coincide with low water, and vice versa (SMHI 1981). High pressure is generally associated with easterly winds, low pressure with westerlies. This gives a generalized explanation of water-level changes in the Baltic Sea over and above that given by RICHTER (1936) and WITTING (1943).

The climate is intermediate between temperate and European continental. The mean January and July temperatures are 0.0°C and +16.2°C, respectively. Very exceptionally the Baltic Sea becomes completely ice-bound. Severe winters occurred in 1939/40, 1940/41, and 1941/42 when the ferries to the mainland were icebound for months. Since then, extensive ice cover occurred only in 1946/47, 1966/67, and 1970/71 (SMHI, 1981). During the winter of 1986/87 a thick ice cover connected Gotland with the Swedish mainland for several weeks. Usually, however, the central Baltic Sea is kept ice-free by wave action and currents. Because of the morphological differences (shallow water in the lee of the predominant NW winds) the bays on the east coast of Gotland become ice-bound earlier than the deeper west coast even during normal winters.

The exposed bedrock of Gotland is mainly Silurian limestone. The cuesta-like NW coast is characterized by a cliff averaging 30 m in height, and at its foot a wave-cut platform, locally called the *pall* or *pallen*. The width of this platform is 50–200 m. (Figures 2, 13).

The SE coast and parts of the central west coast have only low cliffs or none at all, and the off-shore SE gradient follows the gently sloping Silurian bedrock. The 3 m isobath here lies 500–1500 m offshore, giving a slope gradient of 2–6 m/km. The low offshore gradient prohibits the waves from reaching the shore with full strength.

Land uplift on Gotland ranges from 0.6 mm/yr in the SW to 2.3 mm in the NE. Series of raised beach ridges reflect periods of a former

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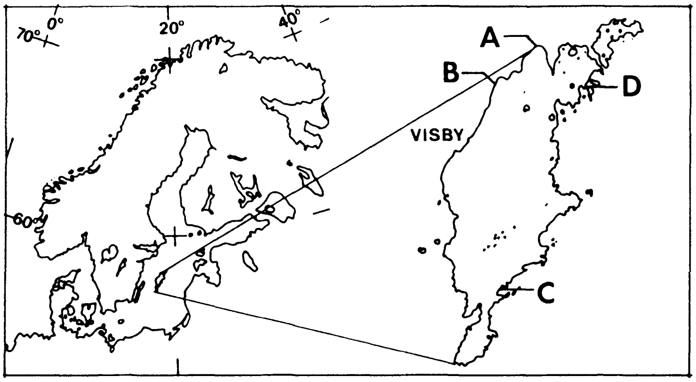

Figure 1. Map of Gotland, with localities described in the text. (A) Hasselriv, (B) Stenkyrkehuk, (C) Gansviken, and (D) Furillen.

mild climate (PHILIP, 1984). Isolated raised boulders probably reflect shoreward ice-pushing during extremely cold winters.

The movement of boulders on the coasts of Gotland is a well-known phenomenon. Boulder tracks, ice-pushed boulders with front mounds, ice-pushed boulder ridges and other ice-pushing features have been reported from lakes and peat-bogs (von POST *in* MUNTHE *et al.*, 1925; MUNTHE *et al.*, 1933; LUNDQVIST *et al.*, 1940; ERIKSSON, 1963), but studies of the mechanisms involved have not been made. In this article, the characteristics and mechanisms of present-day boulder movements along the coast are described in relation to the climatic conditions.

Four coastal localities are described: two on the W coast and two on the E (Figure 1, A-B, C-D). Localities A-B are examples of boulder deposits, while C-D give evidence of boulder movements by ice-pushing. The areas have been studied from the air and documented on oblique air photographs. They have also been examined in the field.

BOULDER DEPOSITS

Two types of cliff-platform relationship are distinguished in connection with boulder deposits: Type I, with the cliff immediately adjacent to the shore (Figures 2, 3); and Type II, with the cliff separated from the shore by a wide back-beach. In the first the boulder material consists mainly of local cliff-derived talus, whereas in the second the boulder portion contains a large amount of crystalline erratics.

Locality A: Hasselriv, Hall parish (Figure 4)

The locality is situated in the NE, with coordinates 642565/167145 according to the grid system *Rikets nät.* It is a Type II locality, with a back-beach up to 3 km wide in front of the inland cliff. This wide area is forested, cultivated and partly covered with raised beach ridges and in between those peat bogs. The beach ridges here are now forested and most peat bogs cultivated. The actual *pall* has a width of 200–400 m and a very low gradient dipping NW. The feature is clearly a result of glacial erosion. Holocene shore processes have had very little impact on the form elements.

As seen from the air (Figure 4) boulders on the *pall* are arranged in ridges running parallel to the shoreline. Field investigations show that the main proportion consists of well rounded Precambrian crystalline rocks. They cannot be observed unless the water level is low. The boulder accumulations have been found to grow during periods of ice-pushing or rafting, probably from a supply of boulders yet resting on the sea floor. The resulting ridges are similar to patterns of accumulation found on the tidal flats of the St. Lawrence estuary in Canada (DIONNE, 1981a).

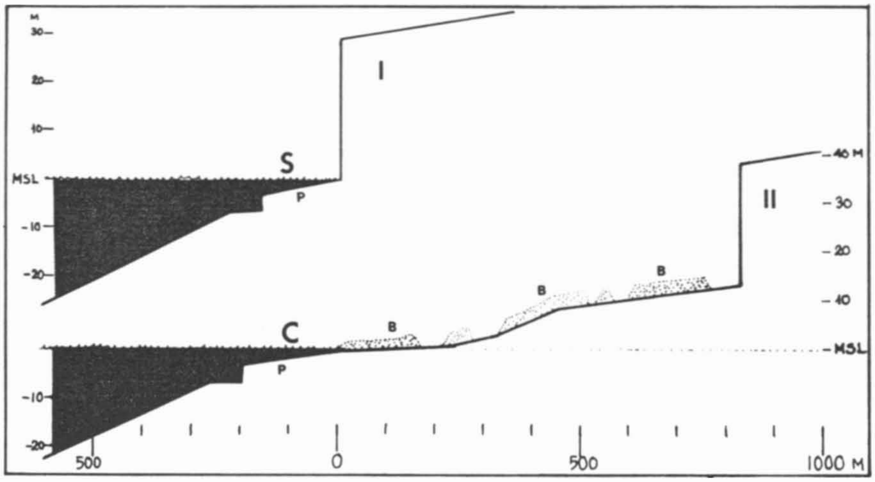

Figure 2. Cliff-platform types characteristic of Gotland. Type I has the cliff immediately adjacent to the shore. The boulders on the beach consist predominantly of local, angular Silurian limestone talus (S) from the cliff. Type II has a wide back-beach with beach ridges (B) which may cover older block deposits. On the *pall* and foreshore not yet covered with beach gravel the boulders are mostly rounded, predominantly Precambrian crystalline (C) rocks. P denotes the wave-cut platform *pall*. For details see also Figure 13.

Locality B: Stenkyrkehuk, Stenkyrka parish (Figure 5)

This is a Type II locality. Its coordinates according to *Rikets nät* are 641280/165735 (Figure 1B). The cliff is low (5–7 m), formed in Lower Silurian marl. The thin strata of calcareous mudstone and shales have contributed to the rubble—*klapper*-stone—of the back-beach ridge. Outside this *klapper* ridge, *pallen* has a large accumulation of Precambrian crystalline boulders, covering an area 300 m long and up to 50 m wide. The surrounding wide platform retains only isolated boulders (Figure 5 and Table 1).

The accumulation is a dramatic morphological element, with the boulders concentrated in a single layer directly on the bedrock. The feature closely resembles a boulder pavement assembled piece by piece (Figure 6). Boulders weighing 20–25 tons are mixed with thousands of smaller size. The arrangement is irregular, except for the outer, seaward contour which is uneven but sharp (*cf.* MANSIKKANIEMI, 1970). However, this "pavement" differs from boulder pavements described from Baffin Island, the South Shetland Islands and Subarctic Quebec (DIONNE, 1974; McCANN *et al.*, 1981; HANSOM, 1983) where boulders are wedged tightly in position and with their upper surfaces abraded by sea ice.

Stenkyrkehuk presents two main questions: where did the boulders come from and why is this the only concentration of its kind on the coast? A probable boulder source might be the Tingstäde-Stenkyrka ice-marginal deposit once resting on *pallen* and now reworked. A similar deposit still occurs five km to the south, where an *in situ* raised beach of the Baltic Ice Lake is extremely rich in big boulders (*cf.* MÖRNER and PHILIP, 1974; SVANTESSON, 1976). Cut by later erosion this marginal arm has successively contributed material to the platform during the last 10,000 years.

Wave action may be responsible for the outer contour of the Stenkyrkehuk "pavement" but not for the boulder transport and deposition. The NW coast is exposed to the gales and drift-ice. Large ice sheets driven along the coast by winds and current probably bulldozed the boulders to this accumulation area. Such ice sheet movements have been observed by the author; the maximum speed was estimated to be 0.5 m/second. Bulldozing ice frequently destroys groynes and wave-breakers around the island.

Because of the hard *pall* floor, no tracks are left from boulder movements at Stenkyrkehuk or Hasselriv localities. It is therefore necessary

Figure 3. The cliff at the NE-coast of Hall parish approximately five km NE of locality A, Hasselriv (Figure 4), showing a typical example of Type I cliff-platform relationship. The main part of the talus on the narrow beach is angular Silurian limestone boulders fallen from the cliff. However, some well-rounded crystalline Precambrian boulders, presumably ice-pushed along the coast, are mixed with the local rocks, 81 04 19, msl −20 cm.

to turn to other areas in order to analyze the type, intensity and effects of boulder transport on Gotland. With regard to drift-ice, only the low gradient soft-bottom shore environment along the east coast is suitable for study.

BOULDER MOVEMENT

Two sites on the east coast were found to contain striking evidence of boulder movements across near-shore shallow sea-floor. The locali-

Figure 5. Locality B, Stenkyrkehuk, seen from W. The inland cliff is further 700 m to SE (right in the photograph). In front of the much younger low marly limestone cliff at the beach face a layer of predominantly crystalline boulders resting on the wavecut platform appears as a light, wavy band. The water depth is maximum 1.5 m to the left where the waves break and is diminishing with the distance to the shoreline (*cf.* Figure 13). Normally most boulders are below water, some of them never. The highest one, on the center edge, is the one in Figure 6, where my wife has climbed. (Outside the accumulation of boulders the bedrock shows regular concentric structures representing undulating strata in the limestone or depressions by former reef bodies. The pattern is set off by dark stripes of algal growth.) 74 04 07, msl −50 cm.

ties are Gansviken in the SE and Furillen in the NE (Figure 1, C-D).

Figure 4. (*preceding page*) Locality A, Hasselriv, on the northwest coast of Hall parish, seen from the N. Ice-pushed crystalline boulders along the beach form wide accumulations which are exposed only at low water. The inland cliff is further three km to the east (left in the photograph). Seaward the wavecut platform is 200–400 m broad, scattered with erratics, and probably the platform face is missing (see Figure 13). This may explain the abundance of boulders outside the shoreline on this part of the coast, 74 04 07, msl −50 cm.

Table 1. *Count of different rock types in the boulder accumulation at Stenkyrkehuk (courtesy by S.-I Svantesson).*

Rock type	Percentages
Limestone	1.5
Sandstone, red Jotnian	18.
Granite, various types	20.
Granite, Rapakivi	15.5
Pegmatite	2.5
Gneiss/granitic gneiss	17.5
Amphibolite	10.5
Diabase	4.
Porphyry, 'almond'-stone, porphyrite	3.
Quartz-porphyry, Baltic Sea-type	1.5
Quartzite	2.5
'Hälleflinta'	1.5
Mica schist/phyllite	2.

Locality C: Gansviken, Eke and Grötlingbo parishes (Figures 7–8)

The bay Gansviken is a broad V open to the east, with a W-E long axis of five km. The whole bay is shallow)<3 m), with water allowing only low-energy waves. The bottom consists of sand and/or clay.

On the N coast of the bay lies the small fishing village Bybod (*Rikets nät* coordinates 633910/165860). At the village, a striking set of boulder tracks was discovered from the air in 1973. Tracks are complex records of boulder movements, involving both shoreward and seaward directions. Shoreward tracks were then 10–20 m long, while seaward tracks measured up to 90 m (Figure 7). One track, formed in three phases, exceeded 120 m. In June 1989 the tracks were still visible from the air. Most furrows have a boulder at the end indicating the final direction of the ice-push.

In 1977 a second set was found 500 m SW of Bybod. This time most of the tracks were shoreward (Figure 8), demonstrating the dynamics involved in filling the coastal area with numerous scattered boulders. The length of the tracks exceeded 80 m. Some showed evidence of reciprocal motion, indicating a 180 degree change of wind. In 1989 the tracks were still visible, although partly filled with sand and silt. Loose boulders still lie at the end of the tracks observed twelve years earlier.

The patterns are explained as tracks made by boulders bound in sheets of drift-ice. When the ice sheets are pushed by wind, the boulder bottoms plow tracks in the soft, shallow sea-floor. Thermal expansion of ice is an unlikely mechanism because of the length of the tracks and the lack of continuous ice cover during the winters in question. However, although a continu-

Figure 6. The same boulder accumulation as in Figure 5, here seen from the N on the beach 10 years later. The person on the big boulder is 1.65 m tall, the boulder about 1.5 m. Note the varying size of the boulders resting in a single layer on the Silurian bedrock. The light coloured boulders are only exposed when the water level is very low. Mean sea level is indicated by a sharp boundary (black and white) on several boulders. After our visit on the place, the accumulation has been destroyed by "human" bulldozing for a landing place for small boats.

Figure 7. Locality C, Gansviken, seen from SE. Bybod landing-place can be seen in the upper right corner with a breakwater to the left of the channel leading to the landing-place (boat approximately 6 m). On the sand/silt sea floor tracks from ice-pushed boulders can be seen in both shoreward and seaward directions. Most often the boulder remains at the end of the track (lower center). This, in all 120 m long track, also shows reciprocal motion illustrated by smaller blocks and stones pushed sidewards. The long track starting near the breakwater and ending with a boulder close to the lower left is approximately 90 m long. All tracks are filled with finer sediment (silt/clay). 76 08 30, msl —5 cm.

ous ice cover was present during the winter 1986/87 no tracks were formed at Gansviken due to other unfavourable conditions such as for example wind direction and water level.

Locality D: Furillen, Rute parish (Figures 9–12)

This locality (coordinates 641075/169000) is a small bay closed-off by the island Furillen. It has a sheltered inlet only open towards the N (Figure 9). The shallow (<1 m) sea-floor provides evidence of the recent displacement of boulders. From the air the tracks are very distinct in their form (Figures 10–11). The photograph was taken April 11, 1981 from a height of 150 m. Sea level that day was msl −20 cm and the southern part of the inlet completely dry and frozen. The rims had a fresh appearance because they were quite new and consequently not yet reworked by wave action.

The weather conditions leading to formation of the patterns are known. For more than a month the temperature had been below 0°C. Ice had formed first in the inlet N of the locality, and later, when the water level rose in combination with a 9 m/sec N wind (14 days before the photograph was taken), the ice cover was driven across the area. Finally, when the water level dropped to −25 cm, the tracks were hidden for a while by the ice cover. Melting of the ice revealed abundant tracks with boulders still *in situ*. (Meteorological and hydrological data are from Visby, 40 km W of Furillen.)

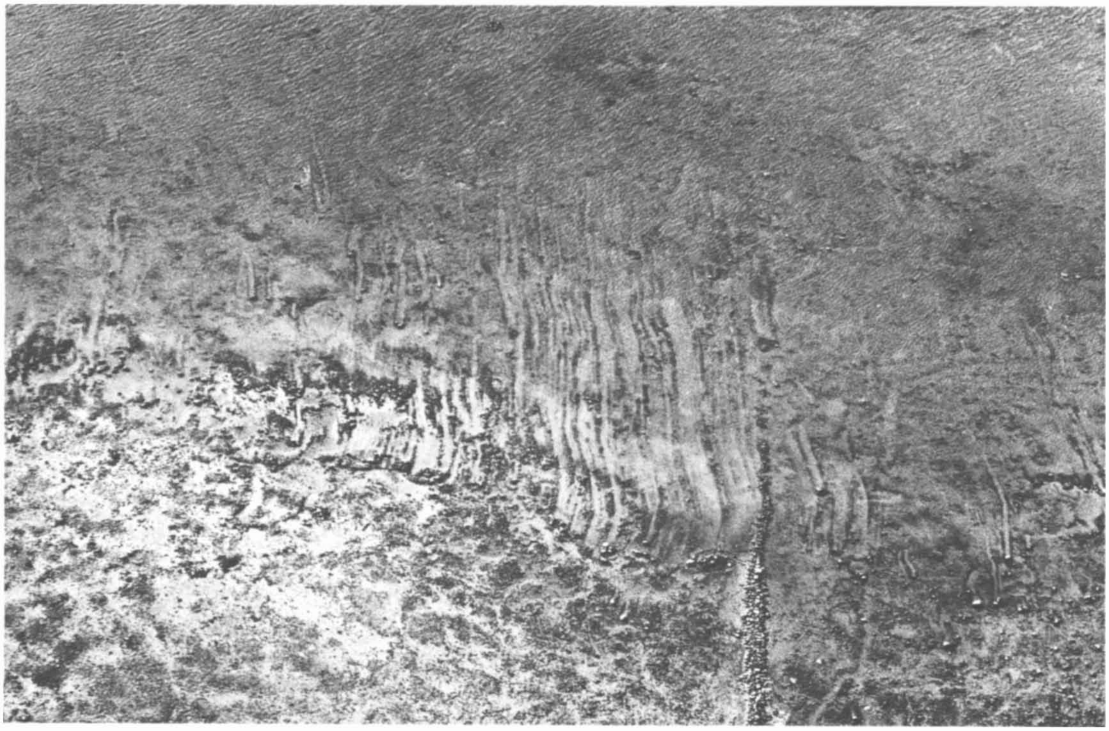

Figure 8. Same locality as Figure 7 but 500 m SW of Bybod. Ice-pushed boulders and small ridges with numerous tracks give the impression of a giant comb having swept across the bottom apparently at the same occasion. The length of the tracks exceeded 80 m. Most boulders are pushed landwards (downwards on the photograph). A reciprocal motion is seen in the upper left, near a 1–2 tons boulder. The boulders to the left of the man-made stone wall (lower right) are of approximately the same size and weight as the boulders in the wall itself. In June 1989 these loose boulders were still lying at the end of the clearly visible tracks without any change. 77 06 14, msl −10 cm.

In June 1985, most tracks were filled with sand, but small pebbles which had been pushed sideways to form the rims were still visible and permitted identification of the furrows (Figures 11–12). In Table 2 the dimensions and estimated weights of selected boulders are given.

DISCUSSION

Gotland

At Furillen, the ice-cover could not have been much thicker than the actual water depth (20–25 cm). Ice-floes of that thickness and 5 m in diameter would be competent to raft even the largest boulders at the locality (*cf.* DRAKE and McCANN, 1982). Exceptionally, however, smaller boulders were rolling and sliding between the moving floe and the sea-floor, creating very characteristic tracks (Figure 10). Water depth below the floes is estimated to 10–15 cm during this process. There are also several unmoved boulders in the area, which evidently cracked the ice cover while other boulders passed by. In the E part of the bay most of the boulders close to the shore of Furillen Island were not moved at all (Table 2, a-g).

According to the discovery record, the boulder tracks at Gansviken and Furillen appeared during a decade. This indicates that ice-pushing leading to boulder movement on Gotland is not common. A number of factors must coincide: cold winter, proper water level, and suitable direction of wind. Furthermore, there is a restricted number of places on the island where conditions allow these features to be documented, *i.e.* narrow, shallow-water bays, with soft bottom sediments.

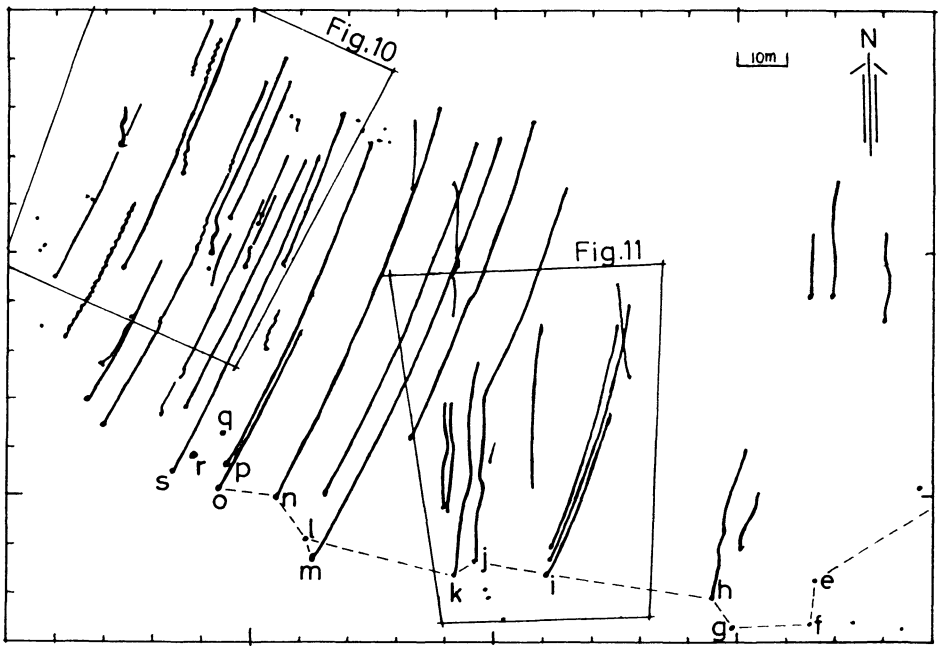

Figure 9. Map of the entire Furillen track area, locality D, drawn from air photograph. The extent of the enlarged parts shown as Figures 10 and 11 are indicated. Letters at the end of tracks refer to boulders in Table 2. Stippled track indicates the route of levelling. Grid net, 10 × 10 m, in "Rikets nät."

Table 2. *Dimensions and estimated weight of crystalline boulders at Furillen (cf* Figure 9).

Boulder	Dimensions (cm)	Weight (kg)	Track (metres)	Direction (360)
a	40 × 30 × 30	63	unmoved	—
b	50 × 70 × 40	245	unmoved	—
c	70 × 60 × 40	295	unmoved	—
d	90 × 65 × 50	510	unmoved	—
e	80 × 50 × 60	420	unmoved	—
f	60 × 55 × 40	230	unmoved	—
g	60 × 40 × 40	170	unmoved	—
h	30 × 25 × 30	40	31	180
i	75 × 50 × 40	260	35	210
j	50 × 30 × 35	90	80	210, 180
k	40 × 40 × 30	85	44	180
l 1	50 × 40 × 40	140	unmoved	—
l 2	65 × 40 × 30	135	unmoved	—
m 1	50 × 40 × 35	120	95	210
m 2	30 × 20 × 25	25	95	210
n 1	50 × 40 × 30	105	88	210
n 2	50 × 40 × 40	115	88	210
r	9 × 6.5 × 7	700	unmoved	—

Other areas

Ice-pushed ridges and boulder tracks with frontal mounds were described by GUSTAFSSON (1904) after observations in Småland lakes, Sweden. Other authors in Scandinavia reporting on the subject are LEIVISKÄ (1905), HAMBERG (1919), TANNER (1939) who also worked in Labrador, FRÖDIN (1956), STRÖMBERG (1956), VARJO (1960, 1964), NORRMAN (1964), ARNBORG and PEIPPO (1967), ÅSE (1968), MANSIKKANIEMI (1970, 1976), ALESTALO (1979, 1980), ALESTALO and HÄIKIÖ (1975), AXELSSON (1985), and ALBJÄR (1985).

Dionne has published several papers concerning erosion, transport and deposition by ice cover in the tidal flats of the St. Lawrence estuary and in James Bay, Canada (See also MARTINI, 1981). Descriptive examples of furrows,

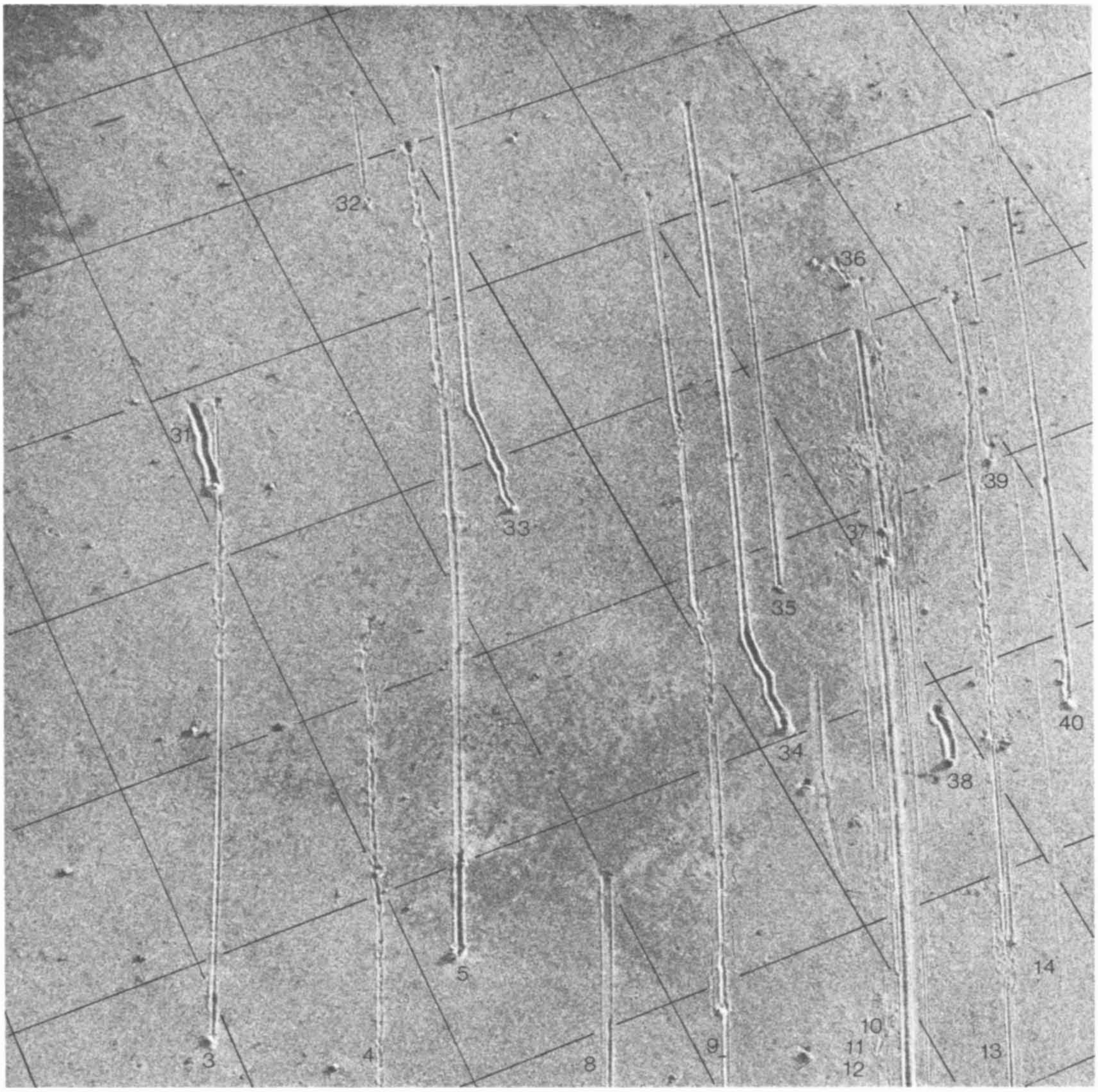

Figure 10. Enlargement of photograph of western part of Furillen area (Figure 9) showing tracks from boulders moved probably at the same time by wind-blown ice. Therefore most tracks show evidence only of sliding although rolling also occurs. Tracks crossing tracks in acute angle to the dominant direction are either related to a second phase of ice-pushing or the same ice cover given a new direction by a change of the wind from NNE to N. The lowering of the sea level between the pushes is small but a deadlock (touch and go) obvious. Grid net as in Figure 9 (numbers are to be ignored). 81 04 11, msl −20 cm.

depressions, pans, scattered boulders, pavements, boulder mounds and ridges are given in DIONNE (1972, 1976a,b, 1981a,b). He has also published a comprehensive bibliography on the aspects of drift-ice (DIONNE, 1974).

Sea-ice scour of bottom mud, leaving parallel striae about 1 cm apart, and marked by occasional "jiggles" (due to ice blocks bumping into each other), has been observed and photographed in various ancient glacial formations, *e.g.* in the Late Ordovician (base of stage IV, Iherir) of the Algerian Sahara (R.W. Fairbridge, *personal communication* 1987).

Among other papers of interest is that of

Figure 11. Enlargement of photograph of the eastern part of Furillen (Figure 9). Note that the tracks are dry, frozen and not yet filled with sediment, which proves that the photograph was taken when the pushing just had taken place. Rolling is not recognized in this part of the area but as in Figure 10 change of direction, crossing, and "touch and go" marks after temporary stops in pushing can be seen. The i-boulder is one of three characteristic boulders lying close together at the end of 35–55 m long tracks (see next figure). 81 04 11, msl —20 cm.

STANLEY (1955) who described the tracks of Racetrack Playa (1140 m above sea level) at Death Valley, California, USA. These tracks are very similar to the Furillen tracks. Stanley suggested they were formed by ice-pushing whereas SHARP and CAREY (1976) stated that the stones were both pushed and rolled, but only by the force of winds.

In a paper, DRAKE and McCANN (1982) theoretically analyze various movements of boulders by ice-floes, such as rafting, and rolling on different types of beds. They claim that rolling is the preferred mode on a deformable bed, and that sliding will not occur. Evidently they did not consider ice-bound boulders and stones in a large coherent ice cover.

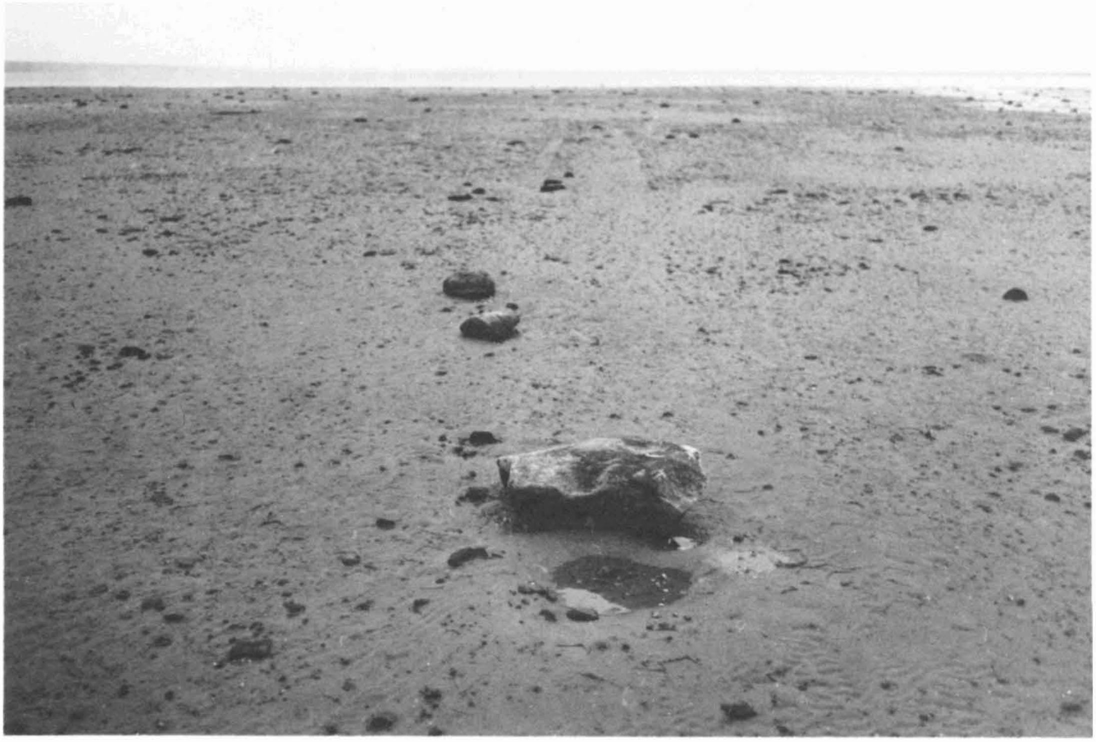

Figure 12. More than three and a half years later: The three i-boulders lying in a row in Figure 11 (lower right) of which the largest is 0.75 m long. Despite later filling with sediment the tracks are still visible. Evidently there has been very little wave action and no favourable conditions for forming of new track during these years. 84 11 22, msl −24 cm.

CONCLUSIONS

(1) Effects of ice-pushing in the form of accumulation and tracks of boulders occur sparsely on the shores of Gotland.
(2) Suitable conditions, namely a winter ice cover, rising water level and favourable winds, are most common on the E coast. They seem to appear a few times per decade.
(3) Ice-pushing phenomena occur also on the W coast but are even more rare due to the more unfavourable bottom conditions on this part of the coast.
(4) Mild and cold winters have different effects on the morphology of the coasts. Mild winters give the ordinary form of storm deposition on Gotland: beach ridges of cobbles. Cold winters with ice cover and strong winds result in ice-pushed boulders, boulder ridges or, occasionally, boulder "pavements."

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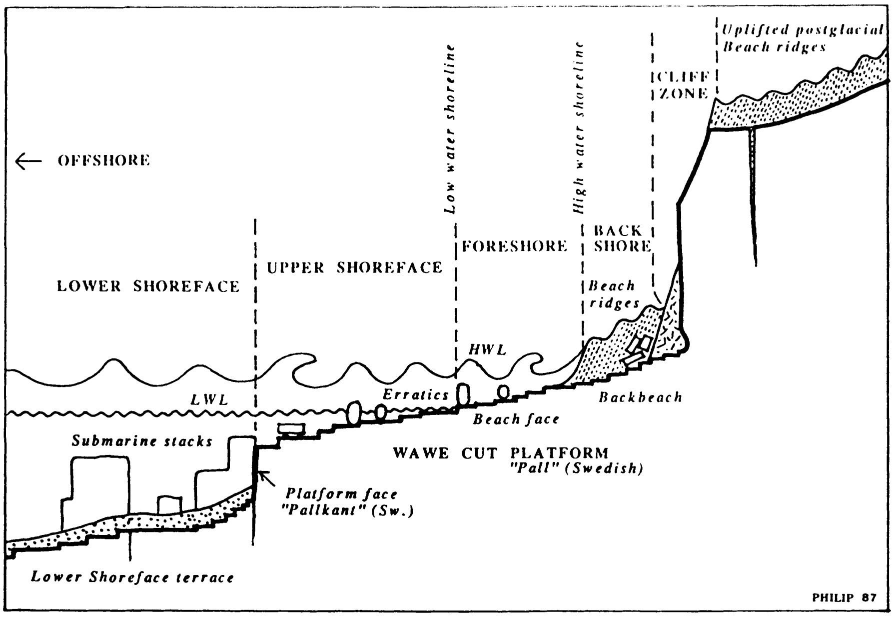

APPENDIX

Figure 13. A generalized figure showing the terminology related to the dynamics of the two limestone bedrock cliff-platform types of Gotland. For Type II the back-beach including several generations of raised postglacial beach ridges can be extended as far inland as three to four km. The age of the cliff is uncertain. It may be pre-Quaternary or have been formed during the last glaciation or both. However, the beach ridges on top of the cliff are all of postglacial age as Gotland during and after the deglaciation became submerged by the Baltic Ice Lake. Since then land uplift have raised the beach ridges as high as 85 m in the central part of the island. Nomenclature modified from GUILCHER (1958), NORRMAN (1967), BLOOM (1978), ELLIOT (1978), REINSON (1981), and NIELSEN and NIELSEN (1982).

□ RESUMEN □

En este articulo se describe las acumulaciones y movimientos de morrenas en cuatro puntos de la costa de Gotland. Dos tipos de relaciones plataforma-acantilado y acumulación de morrenas asociadas están presentes en la costa NW, en Hall y Stenkyrka. Debido a los condicionantes morfológicos y climáticos, los movimientos en la plataforma no han podido ser recogidos; sin embargo, en las zonas someras de los estuarios de Gansviken y Furillen en la costa Este, los movimientos de las morrenas se muestran en forma de sendas en el sedimento del fondo. Las nuevas morrenas son fácilmente vistas desde el aire y pueden ser reconocidas despue s de varios años a pesar de ser rellenadas por nuevo sedimento. Los movimientos de las morrenas están inducidos por el movim. ento del hielo a su vez relacionado con ciertas condiciones climáticas de inviernos severos, mientras que su desarrollo y crecimiento ocurre normalmente en inviernos suaves.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ RÉSUMÉ □

Décrit dans quatre sites du Gotland des accumulations de blocs et leurs mouvements. Il y a deux types de relation falasie-platier et blocs associés représentés dans cette région. Ils sont illustrés par des exemples pris à Hall et Stenkyrka. Les mouvements de blocs sur le "pall" ou "pallen" n'est pas déterminable dans le détail, à cause des conditions morphologiques (lit calcaire) et climatiques propres au platier. Au contraire, les mouvements des blocs sont démontrés sous forme de traces sur le sédiment mou des petits fonds des goulets de Gansviken et Furillen sur la côte Est. Ces traces ont été faites lorsque les blocs étaient enrobés de glace et que les glaces flottantes étaient foussées par le vent sur le fond légèrement fondu. De nouvelles traces peuvent être vues d'avion et reconnues après plusieurs années, en dépit du remplissage postérieur par de nouveaux sédiments. Les mouvements des blocs sont clairement induits par l'effet de poussée des glaces, lors de conditions climatiques d'hiver très froid, tandis que ce sont normalement des beach ridges qui s'élaborent pendant les hivers plus doux.—*Catherine Bressolier (Géomorphologie EPHE, Montrouge, France).*

□ ZUSAMMENFASSUNG □

Blockansammlungen und -bewegungen werden von vier Lokalitäten auf Gotland beschrieben. 2 Typen von Beziehungen zwischen Kliff und Plattform mit vergesellschafteten Blockansammlungen sind an der NW-Küste ausgebildet und werden mit Beispielen von Hall und Stenkyrka repräsentiert. Wegen der morphologischen (Untergrund aus Kalk) und klimatischen Bedingungen können die Blockbewegungen auf der Schorre—*pall* oder *pallen* genannt—nicht im Detail nachgewiesen werden. Dagegen sind an der Ostküste in Flachwasserbuchten bei Gansviken und Furillen die Blockbewegungen in Form von Schleifspuren im weichen Bodensediment abgebildet. Sie entstehen, wenn die Blöcke im Eis eingefroren sind und das Eis mit dem Wind über die wenig angetauten Flächen geschoben wird. Neue Schleifspuren können leicht aus der Luft erkannt werden und erhalten sich jahrelang trotz allmählicher Sedimentbedeckung. Die Blockbewegungen können demnach klar der Eisdrift kalter Winterbedingungen zugeschrieben werden, während Ausbildung und Wachstum von Strandwällen normalerweise in milden Wintern auftreten.—*Dieter Kelletat, Essen/FRG.*