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Inter- and subtidal sedimentation in the Nottingham Bay, South Spitsbergen

ABSTRACT: In the Nottingham Bay, southern Spitsbergen, three sedimentary areas were distinguished: the Brattega-Kvisla delta, the region of skerries and interskerry depressions, and the bays of the Kvartsitsletta shore. The Brattega-Kvisla delta is composed of gravel-sandy sediments with silty-clayey covers and small admixture of organic deposits. In the region of skerries and interskerry depressions a clayey-silty sedimentation prevails, with a considerable participation of organic deposits, and formation of abundant biogenic structures. The sedimentary environment in bays of the Kvartsitsletta shore is much varied, and the whole sequence of biogenic to sandy-gravel deposits is recognized. The Nottingham Bay is thought to be an instructive example of a modern estuary-type bay in the polar zone.

INTRODUCTION

The fieldworks in the Nottingham Bay (Norwegian: *Nottinghambukta*) in southern Spitsbergen were carried through in summer 1980. These works included echo-sounding, examination of sediments at the bay bottom, and collection of structurally undisturbed samples. The samples were collected into pipe containers and impregnated with vinyl polyalcohol (GIŻEJEWSKI & ROSZCZYNKO 1981).

MORPHOLOGY OF THE NOTTINGHAM BAY

The Nottingham Bay is the largest bay devoid any ice cliff along the seashore from Hornsund to the Torell Glacier. It is located on a vast strandflat, the outer edge of which runs to the west of the Dunøyane Archipelago. The bay border, delimited by a line connecting capes of Kvislodden and Kvartsitsodden (Text-fig. 1), is underlined by numerous islets and rows of skerries, emerging at low tide (*see* Pl. 1, Fig. 1). Rows of skerries divide the bay into several basins of NNW-SSE elongation. About 30% of the bay area is occupied by the Brattega-Kvisla delta (*see*

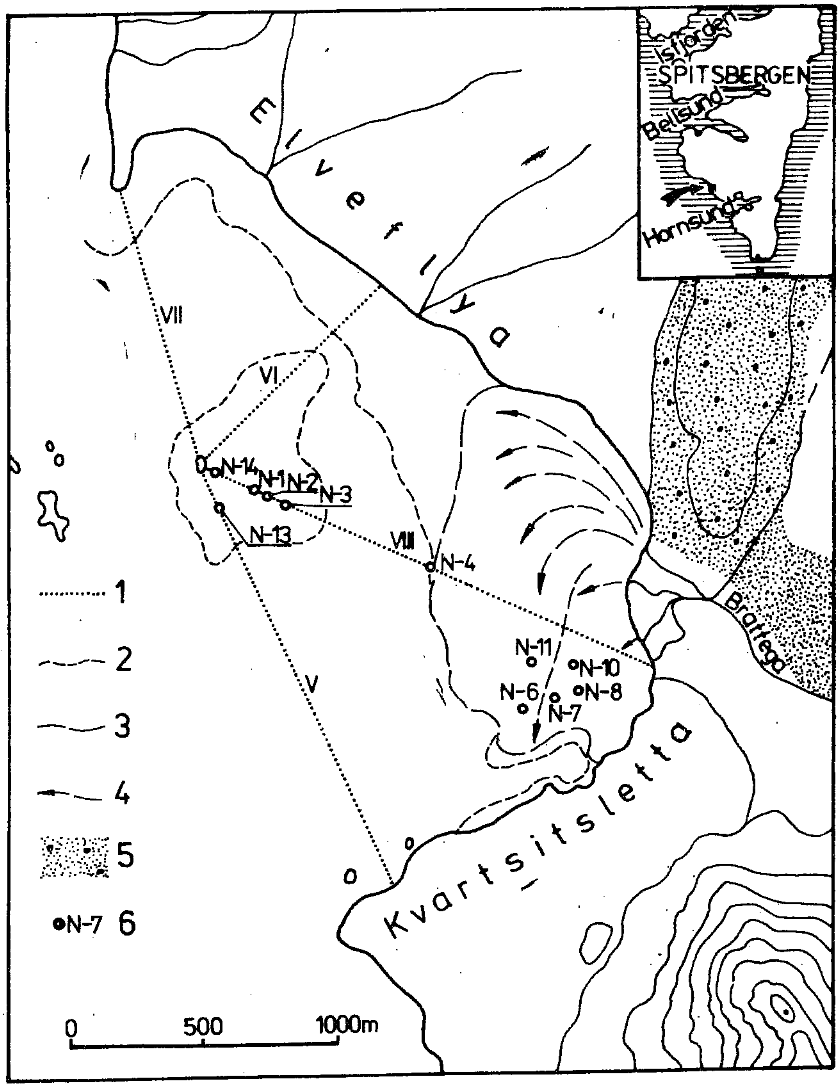

Fig. 1. Sketch-map of Nottingham Bay, South Spitsbergen

1 — echo-sounding profiles, 2 — low-tide boundary, 3 — outline of Kvisla-Brattega delta, 4 — inflow directions, 5 — ice-cored moraine of Werenskiold Glacier, 6 — sampling sites

Text-fig. 1 and Pl. 1, Fig. 2). The Brattega river drains the Bratteg Valley, whereas the Kvisla river drains the southern forefield of the Werenskiold Glacier (*see* Text-fig. 1).

The bay is very shallow (*see* Text-fig. 2), with its depth to 2.5 m below the maximum low tide. At a low tide over 50% of the bay area is emerged and thus many observations could be carried through without the scuba-diving equipments.

The shores can be divided into two distinct sectors. The Kvartsitsletta shore, from Kvartsitsodden to the Brattega mouth, has steep slopes passing locally into cliffs. This area is built of schists and quartzites of the Late Precambrian Hecla Hoek Succession (RADWAŃSKI & BIRKENMAJER 1977), covered by the deposits of the Holocene raised marine beaches (CIEŚLIŃSKI 1979). Along a short distance, north of the Brattega-Kvisla mouth, the bay shore is developed as a cliff, which is incised into an ice-cored moraine of the Werenskiold Glacier. Further northwestwardly, the shore is composed of sands and gravels of the Elveflya outwash plain.

HYDROLOGY

During winter the bay freezes completely, and the ice cover is based directly on the bottom and is mantled by icings. In early spring, melt- and ablation waters flow over the ice cover far into the bay, transporting sediments of very varied grain sizes onto the ice.

After the ice cover retreats, hydrological conditions show a distinct daily variation connected with a tidal cycle. At low tide the bay waters get fresh to 0.5‰; at high tide, particularly at western winds, sea waters predominate and salinity increases to 25‰ (WĘSŁAWSKI 1981).

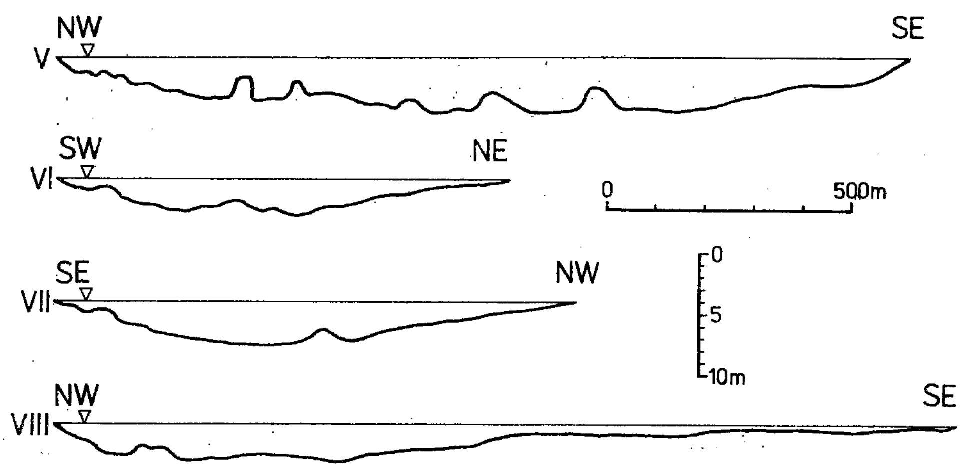

Fig. 2. Echo-sounding profiles of Nottingham Bay (for location *see* Text-fig. 1)

Wind waves are generated in the bay by inland winds, i. e. from a sector: south, through east to north. Due to small size of the bay, a wind fetch is also insignificant and waves reach a height of 0.3 m and length of 2—3 m in the lee part of the bay. In spite of such small sizes the waves are usually deformed; their crests are steep and troughs are wide and flat. Thus, they represent a cnoidal to single wave types (DRUET & KOWALIK 1979). The shape of waves proves their transformation caused by the influence of the bottom. Waves generated by winds from the sector NW-W-SW have a considerably more complex characteristics. During such windy periods the bay is reached by open sea waves, after several transformations at the strandflat edge and successive rows of skerries as well as after a diffraction, caused by numerous islets. The waves that reach the bay are already small, to 0.5 m high, but of varying length due to the presence of higher harmonic components of primary waves (BOCZAR-KARAKIEWICZ 1975). The open sea waves are superposed by the wind waves, originated in the bay. The waves, generated in this way, are usually the short cresced ones (WIEGEL 1964), and they show a great dispersion of movement directions. This is reflected by complex, multidirectional systems of wave ripples at isochronous bottom surfaces.

SEDIMENTATION

A strong variability of bottom morphology and hydrodynamical conditions results in a similar variability of the sedimentary environment in the bay. The field observations allowed to distinguish the three sedimentary regions: the Brattega-Kvisla delta, the skerries and interskerry depressions, and the bays of the Kvartsitsletta shore.

BRATTEGA-KVISLA DELTA

The Brattega-Kvisla delta is a vast and flat alluvial fan, with a system of braided channels (Text-fig. 1 and Pl. 1, Fig. 1). It is located within an intertidal zone, and the tides impose cyclic changes in its sedimentary environment. At low tide, the erosion, transport and sedimentation occur within the braided channels. A bed load consists of gravels and sands which are deposited as numerous channel and point bars and as secondary alluvial fans at channel mouths.

Silty and clayey suspension sediments flow into this part of the bay that is flooded all the time. Only some suspended sediments are deposited at once whereas most of them remain suspended and are distributed during high tide over the whole bay. At high tide, the transport and sedimentation of the bed load are limited to the proximal part of the delta. In the remaining bay area silty-clayey covers are formed (Pl. 2, Fig. 2). At high tide, the delta surface is permanently modelled by waves. Due to long-spanned, juxtaposed sedimentation and transport in wave ripples, the lower gravel-sandy delta member is mainly covered by silty sediments. A stratification of these sediments is indistinct, and locally it displays a flaser and lenticular bedding with rare ripples (Text-fig. 3: *e. g.* samples *N-5, N-6, N-11*). Although wave ripples are common on a sediment surface (Pl. 2, Fig. 2), they are quite seldom preserved in the sediments. A possible conservation of ripples as well as of other marks is probably connected with mantling of the sediment surface by secondary alluvial fans, formed at channel edges during a drop of the water level (Pl. 2, Fig. 1).

Organic sediments in the delta area are mainly composed (as in the whole bay) of fronds of the Laminariales group, settled on deeper offshore bottom areas, limited by outer skerries and the Dunøyane Archipelago (GIŻEJEWSKI & ROSZCZYNKO 1982), and also on a small scale of algae of the Fucales group that overgrow the skerries. The latter group inhabits small offshore spots and their insignificant role in sediments is obvious.

Algal remains, transported by wave and tidal currents at high tide, are noted in small quantities allover the bay (Pl. 3, Fig. 2). Larger concentrations of organic sediments are formed occasionally in depressions at the foot of the delta front (Text-fig. 3: sample *N-4*) and in cut-off reaches of braided channels. Buried organic remains are indicated in a sediment surface by the presence of numerous bubble impressions (Text-fig. 3: sample *N-4*), and by the development of irregular depressions due to greater compaction and higher plasticity of surface sediments.

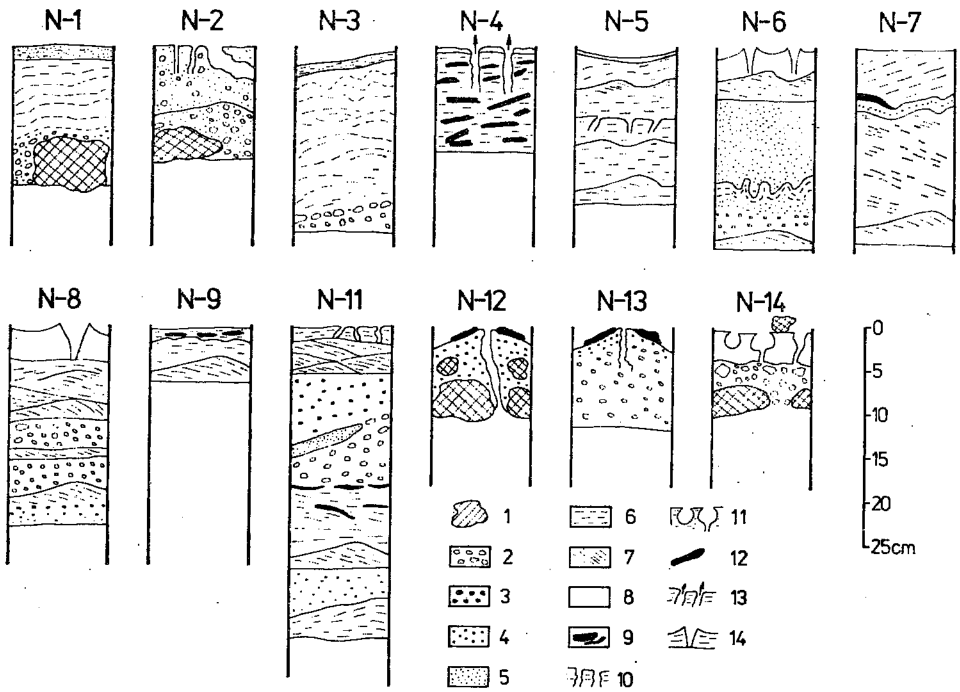

Fig. 3. Profiles of the investigated samples (*N-1* through *N-14*)

1 — boulders, 2 — gravel, 3 — coarse sand, 4 — medium sand, 5 — fine sand, 6 — silt (without lamination), 7 — laminated silt, 8 — clay, 9 — organic detrital grains, 10 — polychaete traces, 11 — sea-squirt traces, 12 — coprolites, 13 — bubble impressions, 14 — mud cracks

The delta sediments contain no traces of a mechanical action of ice although it is well known that the bay water freezes completely in winter and the action of ice during cracking and carrying away of the ice cover by spring storms must be intensive. Much sediments seem to be destroyed in this time, and the remaining sediment patches are quickly redeposited by waves and traces of ice action get easily blurred. The absence of ice action on a bottom in the deeper part of the offshore (*see* GIŻEJEWSKI & ROSZCZYNKO 1982) results in turn from a lack of fine-grained sediments in which such traces could be preserved.

SKERRIES and INTERSKERRY DEPRESSIONS

Similarly as in other parts of the seashore north of the Hornsund, the skerries of the Nottingham Bay are formed of more resistant inserts of quartzites within schists of the Hecla Hoek Formation. In agreement with a general tectonic pattern of this formation (SMULIKOWSKI 1965), the skerries form parallel rows running from north-northwest to south--southeast. Some of them are permanently emerged, but most of them are exposed only at low tide (Pl. 1, Fig. 1).

The skerries have a discontinuous sedimentary cover that occupies a small area, and which is from several to a dozen centimeter thick. Lithologic types vary from gravels to clayey-organic sediments (Text-fig. 3: samples *N-1, N-2, N3, N-13, N-14*). The skerries are frequently overgrown by the *Fucales* and form a habitat for a very rich assemblage of benthic organisms.

The traces of life activity, noted in a subsurface part of the sediment, are represented by: **(1)** escape *U*-shaped canals of polychaetes, with distinct cones of expelled sediment and abundant coprolites (Text-fig. 3: samples *N-12, N-13*), interpreted (*see* GAEVSKAYA 1948, ELDERS 1975) as traces of *Arenicola marina* (LINNAEUS); **(2)** fine vertical pipes with organic walls that correspond to the *Scolithos*-type, connected among others with the genera *Owenia* and *Pygospio* (Text-fig. 3, sample *N-2;* Pl. 4, Fig. 1a-1b; *compare* GAEVSKAYA 1948, WĘSŁAWSKI 1981); **(3)** depressions formed due to the burial of the Ascidia, *i. e.* the sea squirts (Text-fig. 3; sample *N-14*); **(4)** small burrows of the *Thalassinoides*-type (Text-fig. 3, sample *N2*; Pl. 4, Fig. 3a-3b).

The polychaetes having fine vertical pipes of the *Scolithos*-type are common components of surface sediments, and their frequency reaches 6 000 specimens per a square metre (WĘSŁAWSKI 1981). It is apparent that the analyzed sections of sediments represent only a single, annual sedimentary cycle and they are completely destructed during storms and transport of a winter ice cover.

KVARTSITSLETTA SHORE

The southeastern shore of the bay, from Kvartsitsodden to Brattega-Kvisla mouth, is composed of schists and quartzites of the Hecla Hoek Formation as well as sandy-gravel sediments of raised marine beaches (CIEŚLIŃSKI 1979). The shoreline is irregular and the bedrock outcrops form narrow peninsulas with cliffs, separated by small bays incised in sediments of marine terraces.

The present relief of the area is a result of exhumation of an ancient shoreline, formed before the development of raised marine terraces. Along the southeastern shore there occurs the deepest zone within the bay. A width of the intertidal zone is small, but very varied: it is only several meters wide in front of peninsulas and it occupies almost the whole bays. The exposition of the shore to prevailing

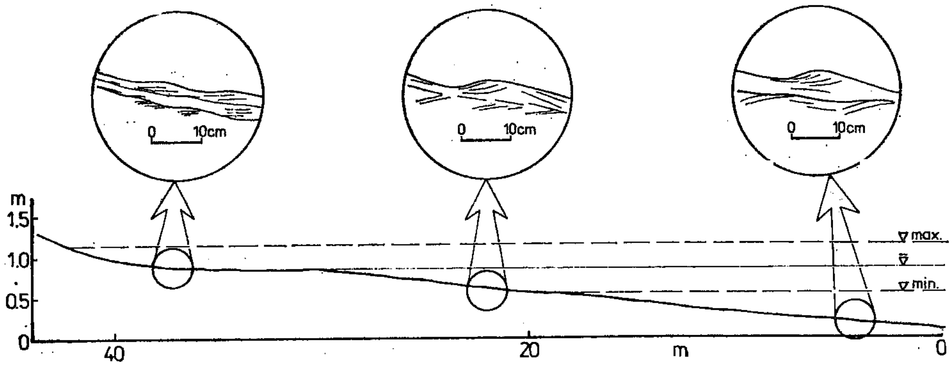

Fig. 4. Ripple cover in sand and mud of the intertidal zone; Kvartsitsletta Bays

northwestern winds, a relatively long fetch of wind, no obstacles by skerries parallel to wave movements as well as small diffraction angles of waves, make this region to have a relatively high energy of wave processes. Besides, the greatest concentration of organic remains occur in this zone. These concentrations are covered by clayey-silty sediments coming from the suspended matter, and by sandy sediments brought in spring into ice by meltwaters. Under favorable waving conditions and supply of sandy sediments, fields of wave ripples are formed on a sedimentary surface at depths (*see* ONOSZKO, TARNOWSKA & ZEIDLER 1982) from wave base (h = 2H) to wave breaking (h = 2/3 H). As this depth-zone moves with the tidal cycle, characteristic ripple covers are formed with a marked small-scale oblique stratification (Text-fig. 4).

CONCLUSIONS

The Nottingham Bay represents an estuary-type bay. It is strongly influenced by ablation waters from the Werenskiold Glacier although the latter has no active ice cliff (*see* FILIPOWICZ & GIŻEJEWSKI 1986). A sea influence is distinctly indicated by tides, waves, and influx of organic matter.

Cyclic changes of water salinity are a characteristic feature, as the water is almost completely fresh at low tide and marine conditions occur at high tide. These changes influence, due to flocculation, considerable changes in sedimentation rate from a suspended matter (*see* FILIPOWICZ & GIŻEJEWSKI 1986).

An easy access, small depths and high dynamics of sedimentary processes proclaim the Nottingham Bay to be an area of model studies of a present-day estuary-type bay in the polar zone.

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SEDYMENTACJA W ZATOCE NOTTINGHAM NA POŁUDNIOWYM SPITSBERGENIE

(Streszczenie)

W pracy przedstawiono wyniki badań* nad przebiegiem procesów sedymentacji w Zatoce Nottingham, leżącej na platformie przybrzeżnej zachodniego wybrzeża południowego Spitsbergenu. Około 50% powierzchni zatoki (pl. 1, fig. 1) znajduje się w strefie międzypływowej, zajętej w dużej części przez deltę Brattegi — Kvisli (*patrz* fig. 1-2 oraz pl. 1, fig. 2). Pozostała część zatoki podzielona jest pasami szkerów na szereg basenów o rozciągłości NNW — SSE. Pływy i dopływ wód słodkich powodują wahania zasolenia wód zatoki od 0.5‰ do 25‰.

Osady delty Brattegi — Kvisli składają się ze żwirowo-piaszczystego członu dolnego, tworzonego w wyniku transportu w trakcji dennej, oraz mułowo-ilastych pokryw pochodzących głównie z sedymentacji zawiesiny przy znacznym udziale flokulacji (*patrz* FILIPOWICZ & GIŻEJEWSKI 1986). Struktury powłok wskazują na redepozycję w wyniku procesów falowych (*patrz* pl. 2, fig. 1-2; pl. 3, fig. 2).

Powłoka osadowa szkerów i zagłębień międzyszkerowych odpowiada rocznemu cyklowi sedymentacji. Składa się ona z osadów ilasto-mułowych ze znacznym udziałem składników organicznych i licznymi strukturami bioturbacyjnymi (*patrz* fig. 3 oraz pl. 4, fig. 1-3).

Warunki sedymentacji w zatokach wybrzeża Kvartsitsletty są bardzo zróżnicowane — powstają tu duże nagromadzenia osadów biogenicznych oraz żwirowo-piaszczyste osady przybrzeżne posiadające charakterystyczne zespoły struktur (*patrz* fig. 4).

Duże zróżnicowanie warunków sedymentacji oraz łatwość prowadzenia obserwacji decydują o tym, że zatoka może stanowić obiekt badań modelowych dla estuariów strefy polarnej.

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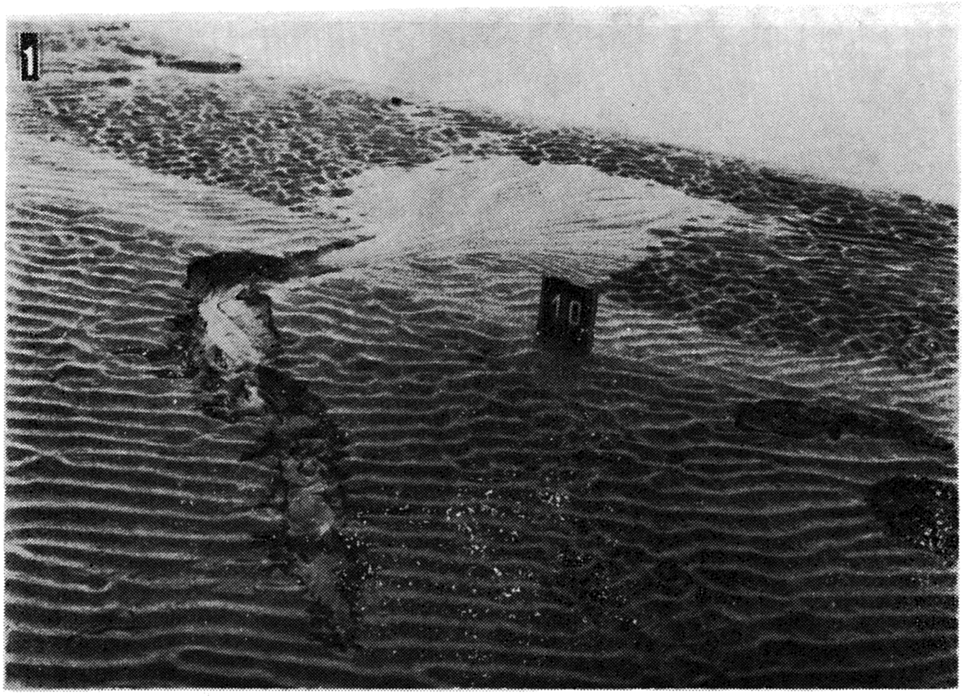
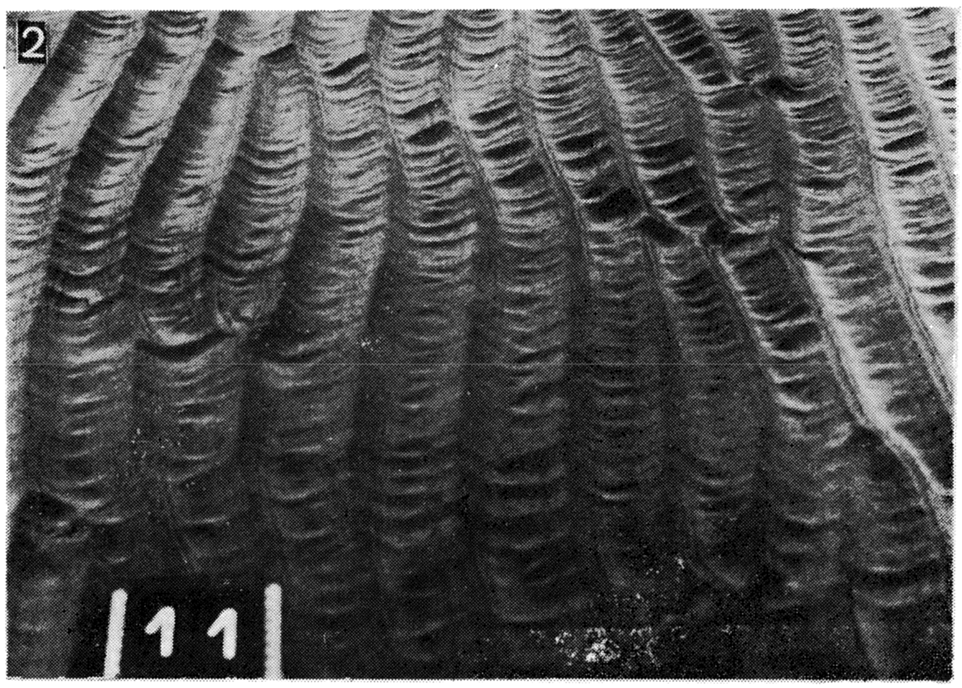
* Materiały terenowe zebrano w ramach prac Centralnej Wyprawy PAN i opracowano w Instytucie Geologii Podstawowej Uniwersytetu Warszawskiego w ramach problemu *MR. I. 29. B.*

1 — General view of the Nottingham Bay from Gulliksenfjellet: Brattega-Kvisla delta and rows of skerries are visible

2 — Northern part of Brattega-Kvisla delta at low tide (view from ice-cored moraine of Werenskiold Glacier)

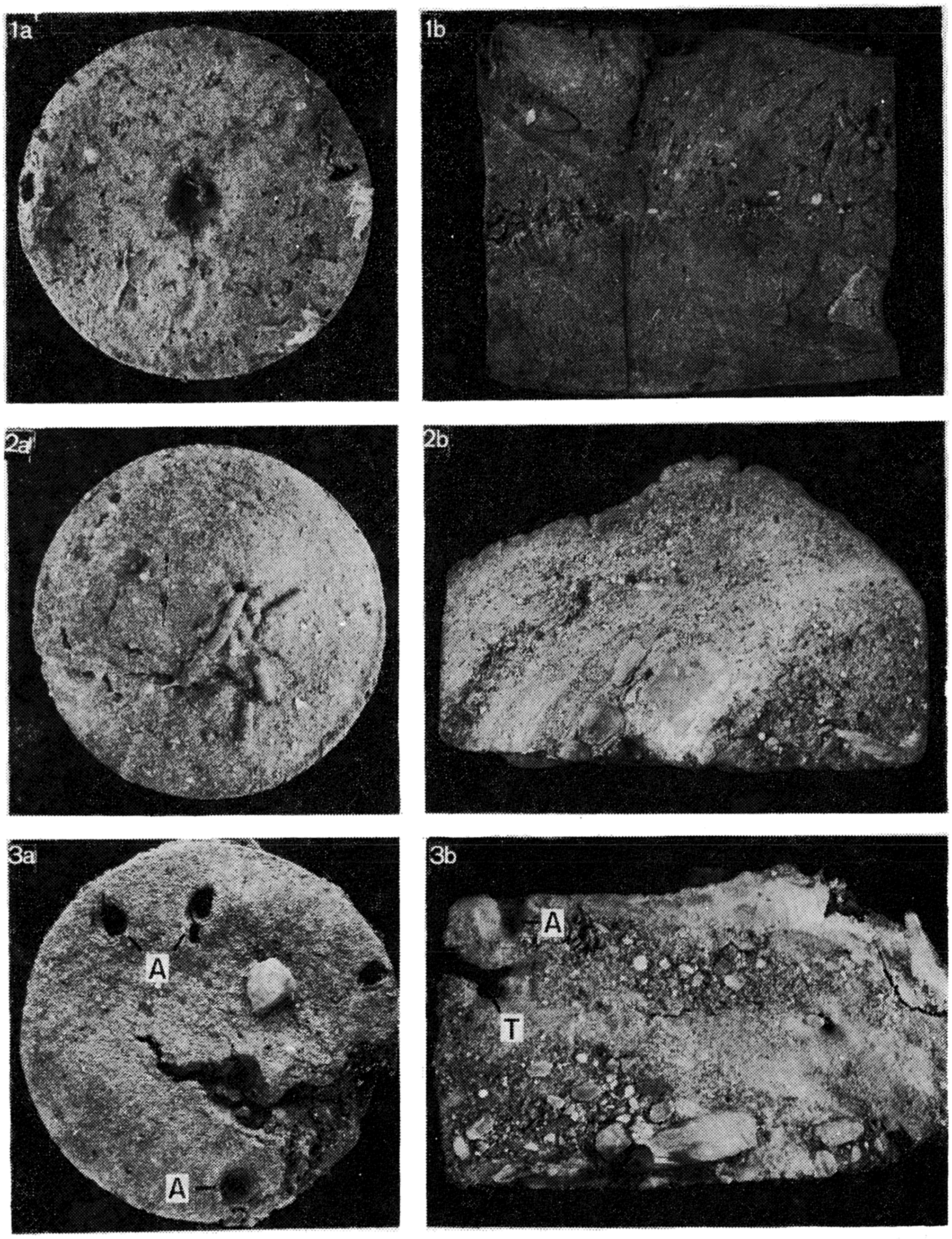




1 — Secondary alluvial fan on the edge of distributary channel of Brattega-Kvisla delta; low tide

2 — Wave ripples at Brattega-Kvisla delta; low tide

1 — Silty covers on the surface of Brattega-Kvisla delta; low tide
2 — Frond fragment of Laminariales on the surface of delta at low tide



1 — Tube-form domichnia of polychaetes: 1a — top view, 1b — cross-section; sedimentary cover of skerries; sample impregnated with vinyl polyalcohol; core diameter 110 mm

2 — Polychaete trace: 2a — top view, 2b — cross-section; interskerry depression; core diameter 110 mm

3 — Domichnia of Ascidia (**A**) and a small trace of the *Thalassinoides*-type (**T**): 3a — top view, 3b — cross-section; sedimentary cover of skerries; core diameter 110 mm