Titill
The sea-bed of the southern part of Faxaflói, Iceland.

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ABSTRACT

Some 500 km² of sea-bed in the bay of Faxaflói, SW-Iceland have been surveyed with side-scan sonar. A map of the area, based on complete sonar coverage, shows the sea-bed to be made up of solid rock, gravel and sand. Dredge samples of the solid rock show it to be of sedimentary origin. Grab samples of the gravel and sand are very carbonate rich and a pattern of decreasing carbonate content with depth is observed.

The orientation of sand patches and ripples in the gravels indicate sediment transport from west to east, i.e. into the bay. Boomer profiles indicate sediment buildup in the eastern part of the area.

INTRODUCTION

The southern part of the bay of Faxaflói is incised by a channel entering the bay from the northwest. Inside the bay the channel makes an elbow bend to the southwest, thus separating extensive shallows to the west from the shallows of the eastern shores of the bay (Fig. 1). The 40 m isobath traces the outlines of the channel, which has maximum depths of 50—60 m inside the bay. The shallower ground to the west of the channel rises gently from about 40 m depth towards the two topographic highs of Sydra Hraun and Vestra Hraun. These two

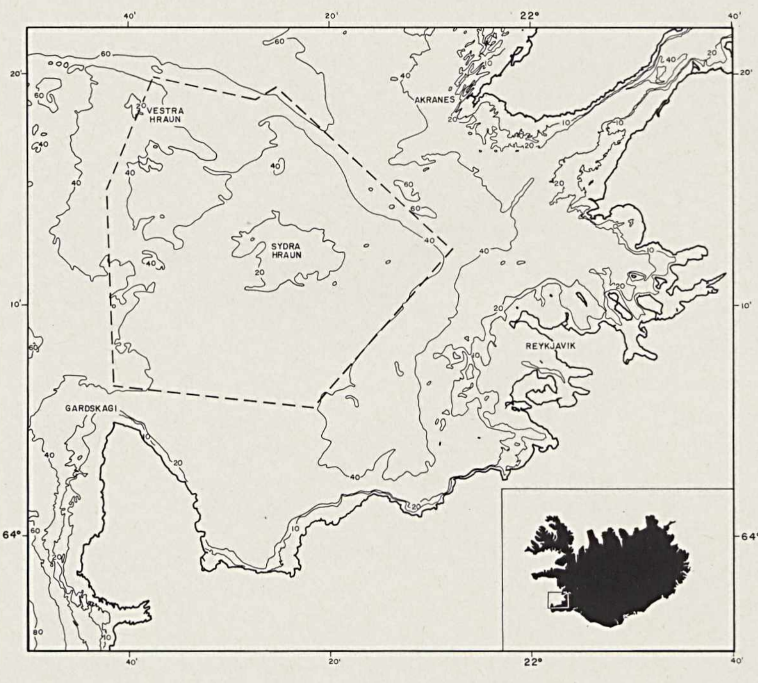


Fig. 1. Map of the southern part of the bay of Faxaflói showing outlines of study area. Isobaths in metres.
Mynd 1. Mælingasvæðið í Faxaflóa. Dýpi í metrum.

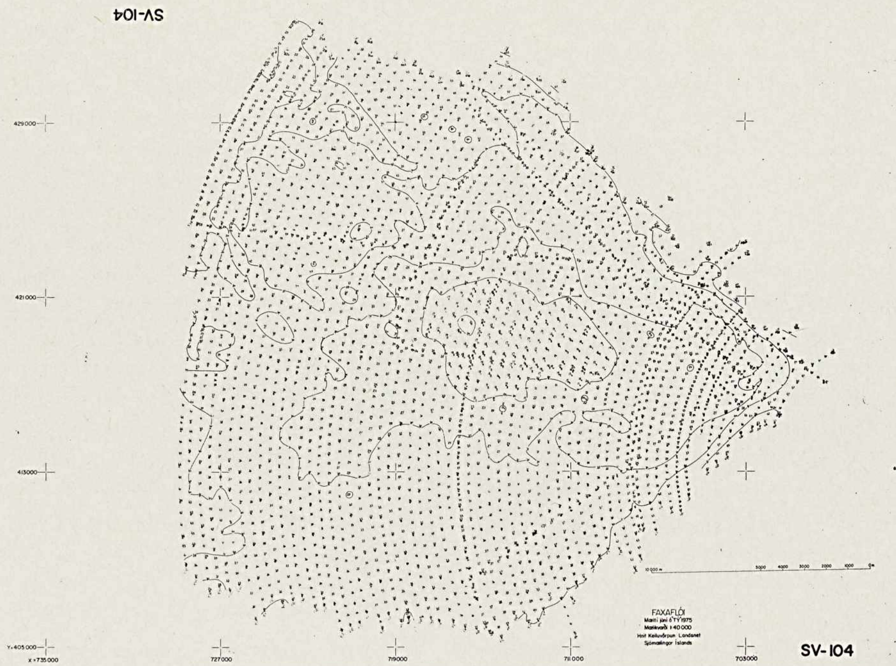


Fig. 2. Sounding sheet of the study area showing curved survey tracks and broad outlines of bathymetry. Isobaths are sketched at 20, 30, 40 and 50 m depth. The survey tracks were curved in order to facilitate navigation (Raydist). Sounding sheet from the Icelandic Hydrographic survey.

Mynd 2. Mælingakort af svæðinu, sem sýnir m.a. mælingalínur sem siglt var með botnsjá og dýptarmæli. Á kortið eru skissaðar dýptarlínur fyrir 20, 30, 40 og 50 metra. Sjómælingar Íslands.

"hraun" areas are characterised by rough topography (Icel. "hraun" means lava field or rough, rocky terrain) and depths of less than ca. 25 m. Minimum depths are about 10 metres.

The "hraun" areas of Faxaflói have been rich fishing grounds for centuries and topographic names, like Sydra Hraun and Vestra Hraun are indicative of fishermen's knowledge of the nature of the seabed. The knowledge that the flat seabed around the "hraun" areas is of shell sand and gravel led to a study of the feasibility of using these shell beds as a source of lime for the production of Portland Cement (*Vestdal,* 1949). This shell material is now used by the Iceland State Cement Works for that purpose.

The demand for fuller knowledge of the occurrence of carbonates in Faxaflói was one of the reasons for a survey carried out in the southern part of the bay in June 1975. The survey covered an area of some 500 km² and included echo — sounding, side — scanning, sediment sampling and some Boomer profiling. This was a cooperative venture of the Icelandic Hydrographic Service and the Marine Research Institute, Reykjavík, and was carried out on board the survey launch TÝR. The following report describes the results of the survey.

INSTRUMENTS AND METHODS

The survey was carried out in three phases. The first consisted of echo-sounding and sidescan sonar surveying on parallel tracks, 450 m apart, positioned so as to give complete sonar coverage of the area (Fig. 2). The instruments used were an Atlas surveying echo-sounder and an EG&G Mk II side-scan sonar system. Positioning was by Raydist. Secondly, a Shipek grab was lowered at 264 stations in the area in order to sample unconsolidated sediments. Thirdly, Boomer profiles were obtained by the use of EG&G equipment operated by engineers from the National Energy Authority, Reykjavík. The Boomer tracks are shown in Fig. 7.

The echo-sounding profiles were processed by the Hydrographic Survey and made available to the author in the form of a sounding sheet (Fig. 2).

Isometric reproduction of the sonographs was made manually in the usual manner (see e.g. *Flemming*, 1976), originally in the scale 1:25000.

Some 150 sediment samples were analysed for carbonate content by the Cement Works laboratory, using standard titration methods, and sieve analyses of grain size were made at the Marine Research Institute.

RESULTS

Bathymetric and Sonar maps

The sounding sheet (Fig. 2) broadly illustrates the bathymetry of the area. A comparison with the sonar map (Fig. 3) shows how the consolidated rocks of the "hraun" areas rise from the surrounding sediment-covered floor. The contrast between the rough topography of the "hraun" areas and the smooth topography of the surrounding floor is also well brought out. The relatively steep slopes into the channels on the northeastern and southeastern flanks of the area are indicated.

The sonar map (Fig. 3) illustrates that the sea-bed in the area may be divided into four map units on the basis of difference in character of the sonographs. The four broad subdivisions are:

Unit 1. Sea bed characterised by dark, blotchy appearence on the sonographs, mapped as "rock" in Fig. 3. The limits of this unit are defined by steep slopes in many places, such as near both "hraun" areas which occur within unit 1. Rock floor is not limited to the "hraun" areas, however, but occupies the main portion of the central and western parts of the map. Small "islands" of rock occur on the northeastern and eastern sides of the otherwise contiguous rock floor. Their elongate shape and often pointed southeastern and northwestern terminations are suggestive of glacial erosion. Glacial striae on the coast also show the same northwesterly trend (*Kjartansson*, 1960). Two sets of lineations or structural trends observed in sonographs from unit 1 and outlined on the map are thought to represent strike and fault trend (SW—NE, cf. *Jónsson*, 1965) and ice scour (SE—NW). Most depressions in the rock floor contain sediments.

Thirteen dredge samples taken in 1974 by the author, from the rock floor of Sydra Hraun and Vestra Hraun were all made up of sedimentary rocks, siltstones, sandstones, and conglomerates.

Unit 2. An area of gravel (dark tone on sonographs) bordering the rock. The low ground between the two "hraun" areas has extensive cover of gravel, but otherwise gravels occur as a continuous border around unit 1, interrupted only at one place in the south, where a strip of finer sediment appears to dissect it. The boundaries of this strip are not well defined on the sonographs. The sonographs show that much of the gravel surface is in the form of ripples with a wavelength of 1—2 metres. The rippled gravel is shaded on Fig. 3. Long, narrow strips of light tone (sand) occur within this map unit.

Grab samples from unit 2 show that the gravels are made up almost entirely of shell material, complete and broken shells mainly of bivalves, gastropods, and barnacles, along with calcareous worm tubes. Living individuals were commonly found.

Unit 3. On the downslope side of the

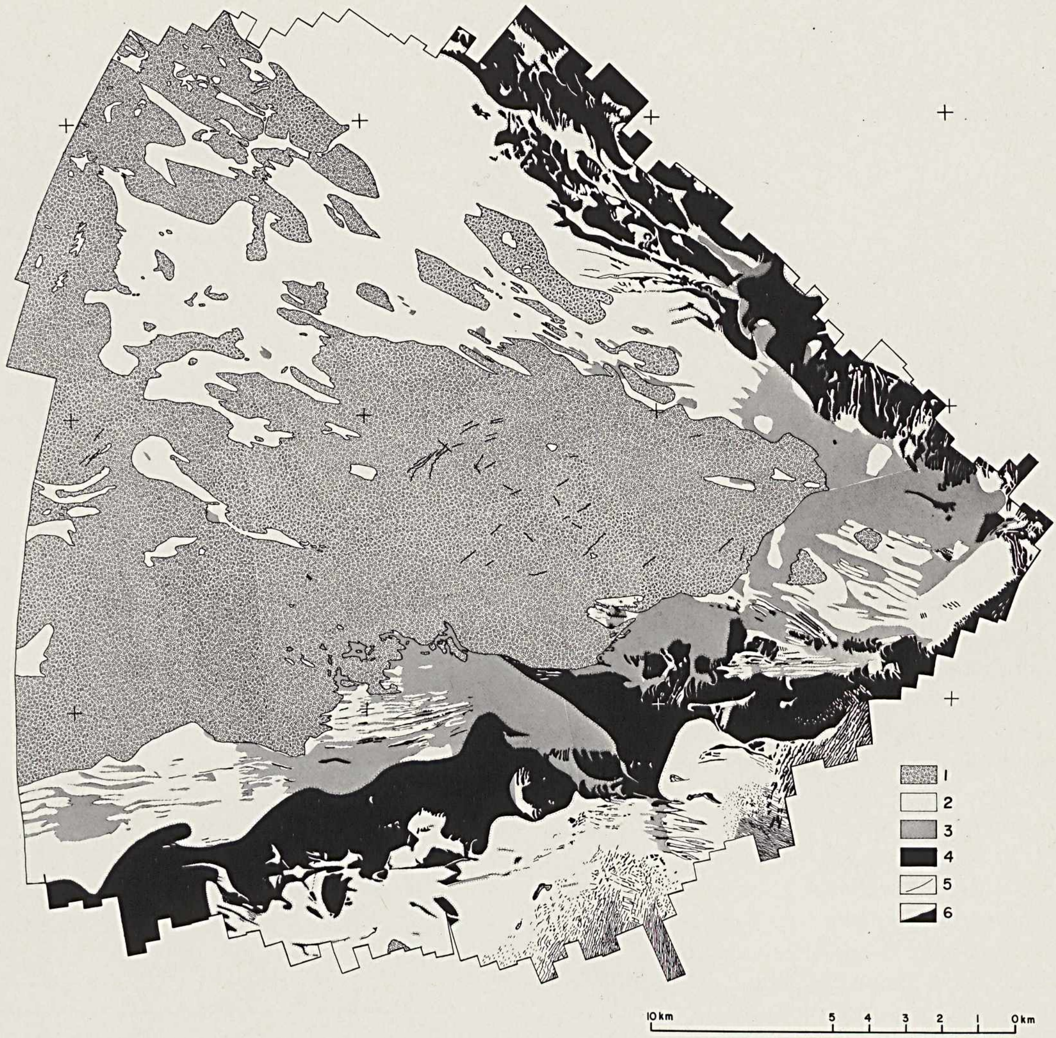


Fig. 3. Nature of sea-bed as determined from sonographs. Shading as follows: 1) Rock (unit 1), 2) Gravel (units 2 and 4), 3) Rippled gravel (of unit 2), 4) Sand (unit 3), 5) Landscape, or structural trends in rock floor, 6) Indistinct, or gradational, sand/gravel boundary.

Mynd 3. Kort af botngerð svæðisins, byggt á botnsjármælingum. 1) Harður botn, 2) möl, 3) gáruð möl, 4) sandur, 5) línuleg landslagseinkenni í hörðum botni, 6) ógreinileg mörk sands og malar (punktaröð).

gravels there occurs a strip of fine sediment, appearing as a very light tone on the sonographs. This type of floor is mapped as "sand" on Fig. 3. The sonographs indicate that this bottom-type is generally flat and featureless. In the south the sand/gravel boundary is gradational and its position on the map is somewhat arbitrary. Farther to the east it becomes sharp and takes up an intricate, often crescentic form, with the convex side of the

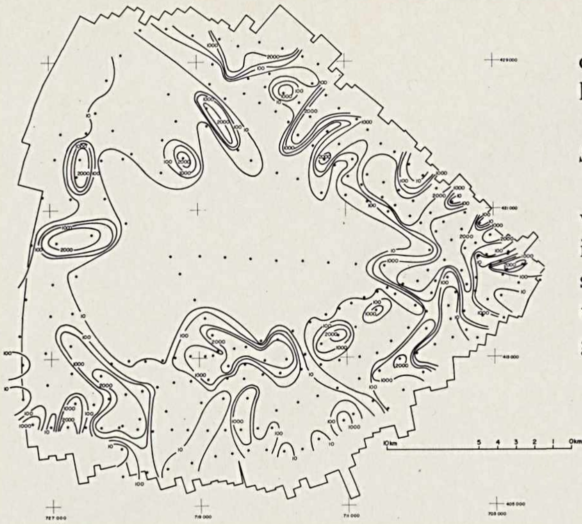


Fig. 4. Shipek sampling stations and contours of weight of samples obtained, measured in grammes of dry sample.

Mynd 4. Botnsýnastöðvar (punktar). Á kortið eru dregnar jafngildislínur fyrir þunga botnsýna, mældan í grömmum.

crescentic shapes described by the boundary consistently facing west. Along the northeastern border of the map the sand/gravel boundary defines elongate strips of sand and gravel, trending N—S and NW—SE. The strips of gravel are seen here to have negative relief in some places.

Grab samples show the sand to be mainly made up of shell fragments with some complete shells.

Unit 4. The southernmost part of the study area is floored by dark-toned material (gravel) of variable character. The easternmost part of this area is characterised by long and narrow stripes of light material (sand) set in a darker background. These stripes are seen to have two orientation trends, at right angles to one another. Farther to the west this pattern is replaced by more irregular, diffuse patches of fine-grained sediment. Rock outcrops in a few places.

Grab samples of gravel from this unit reveal a terrigenous component of pebbles and grains of well rounded basalt, and a biogenic component commonly of worn and discoloured shell fragments.

Size of samples

The amount of sediment recovered at the various sampling stations varied greatly. To illustrate this variation, the dry weight of the samples has been charted on Fig. 4., and contours drawn for sample weight, expressed in grammes. The pattern observed is difficult to

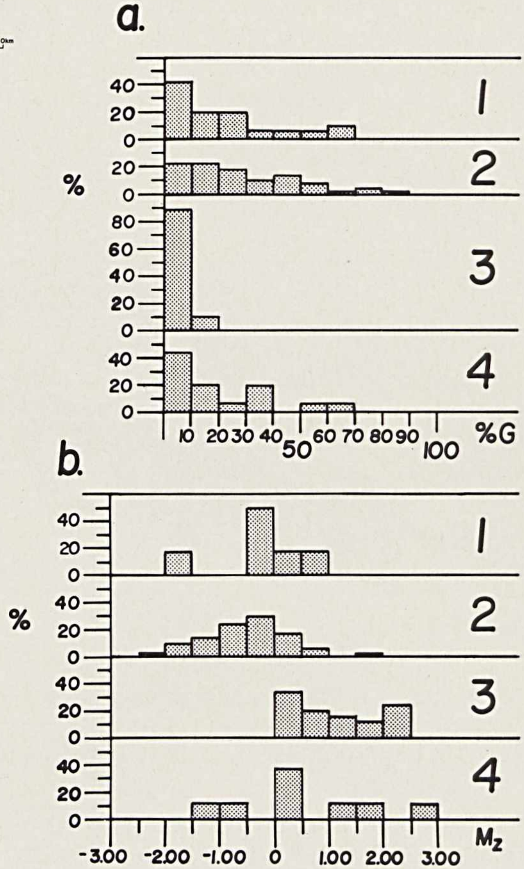


Fig. 5. a) Histograms showing percentage of gravel (coarser than 2 mm) plotted against percentage of stations in units 1, 2, 3 and 4b) Histograms of mean size (M_z) of sediments from units 1, 2, 3 and 4.

a) Malarinnihald setsýna (% G) á móti prósentu af stöðvafjölda af hinum ýmsu einingum botngerðarkortsins.

explain or correlate with other observations. Variable thickness of unconsolidated sediments seems to be one likely cause of this variation.

Grain-size of sediments

Grain size of sediment samples from the area conforms with the interpretation of the sonographs (Fig. 5). All samples were of sand and gravel size, and about 90% of samples from unit 3 (sand) contain less than 10% gravel (> 2 mm). In unit 2, on the other hand, the gravel content is much more variable and reaches more than 80%. The mean size of sediments from unit 2 is considerably coarser than that of the unit 3 sand (Fig. 5b), whilst the mean size of sediments from units 1 and 4 is variable.

Carbonate content

The distribution of (calcium) carbonate (Fig. 6) is seen to form a definite pattern of decrease in carbonate away from the central part of the area. Samples obtained from unit 1 (rock floor) and parts of unit 2 (gravel) are made up almost entirely of shell material whereas minimum values of some 47% are found in the deepest parts of the study area, along its northern, eastern and southern limits.

Boomer profiles

The Boomer profiles obtained covered parts of the rock, gravel, and sand floor of map units 1, 2 and 3 (Fig. 7). Unfortunately no profiles were obtained from the gravel of unit 4.

At least two stratigraphic divisions seem to be present in the profiles. These are the consolidated sediments (rock) on the one hand, and the younger unconsolidated sediments on the other. The latter appear to be thin near rock outcrop, but form a wedge-shaped deposit at the eastern and northeastern borders of the area (Fig. 8). Internal stratification seen in the eastern profiles seems to indicate progradation to the east or into the channel bordering the study area.

In the southern part of the study area the situation seems somewhat different. The few profiles crossing this part of the area show only a very thin cover of sediment lying on an uneven substratum. Only in one place to the southeast of Sydra-Hraun did the Boomer tracks cross a sediment deposit of significant thickness. On Fig. 7 this is tentatively joined to the thick deposit at the eastern end of the area.

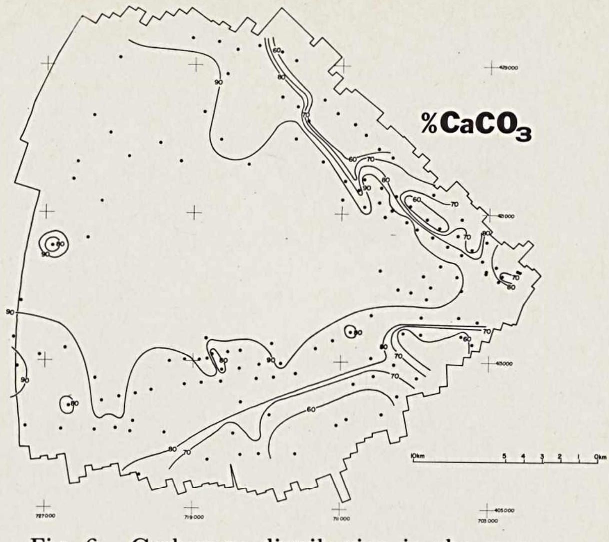


Fig. 6. Carbonate distribution in the area, expressed as percentage by weight of $CaCO_3$.

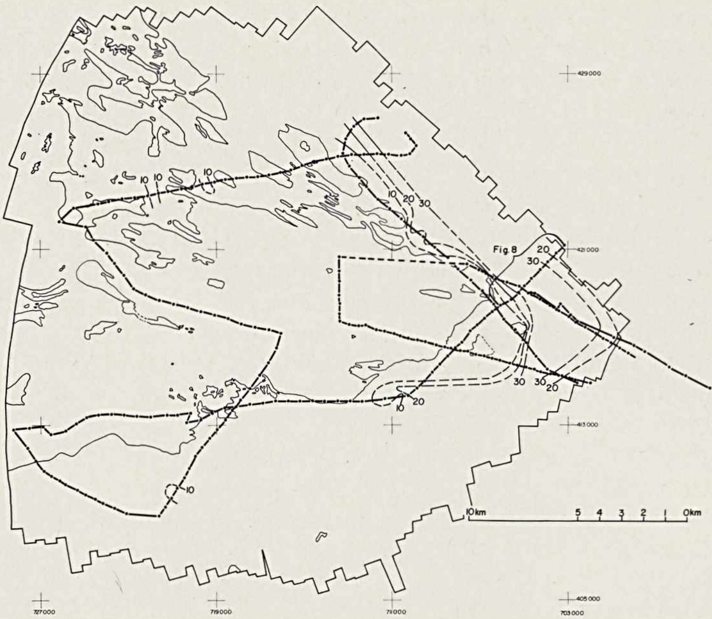
Mynd 6. Kalkinnihald lauss sets á svæðinu.

DISCUSSION

Water movements. Density distribution in Faxaflói indicates counterclockwise flow within the bay. On the average there is a net flow around the tip of Gardskagi into the bay and out of the bay again in the north. Direct current measurements were made on August 12—13 1966 in the channel to the north of the study area (*Malmberg* 1968). In the 18-hour measurement period the current had a maximum velocity of 18 cm/sec at 20 m depth and 15 cm/sec at 50 m depth, towards the northwest in both cases. These measurements were made near neap tide and do not indicate maximum current velocities. It should also be pointed out that currents in the study area are

Fig. 7. Boomer tracks in the area with dots indicating position fixes. Broken lines are isopachs in milliseconds of the wedge-shaped deposit discussed in the text. Outlines of rock floor are indicated.

Mynd 7. Siglingalínur með setþykktarmæli (slitnar línur með punktum) ásamt jafnþykktarlínum sets, þar sem þykkt er mæld í millisekúndum. Útlínur harða botnsins eru dregnar á kortið.



expected to be considerably faster due to shallower water depths.

The bay is open to the west, and as waves from that direction have the longest fetch, it is to be expected that they are the likeliest to cause water motion of geological importance. Storm waves entering the bay have been observed to break on the submerged rocks of the "hraun" areas (*Vigfússon* et al. 1974).

Sediment transport. The information available on water motion in Faxaflói is not sufficient to show whether currents will periodically reach sufficient velocities to transport sediments in the area. Tidal currents appear to be weak, although peak velocities are not known. By analogy with studies of the British shelf it seems highly likely, however, that wave-induced currents, combined perhaps with tidal currents, could frequently move sediment of sand-size or even coarser. *Hadley's* (1964) estimate of oscillatory bottom currents in the Celtic Sea and *Draper's* (1967) results for various areas around the British Isles indicate that wave-induced oscillatory currents frequently reach velocities of geological significance. Later estimates by *Ewing* (1973) indicate that the two authors may even have underestimated the importance of wave oscillations.

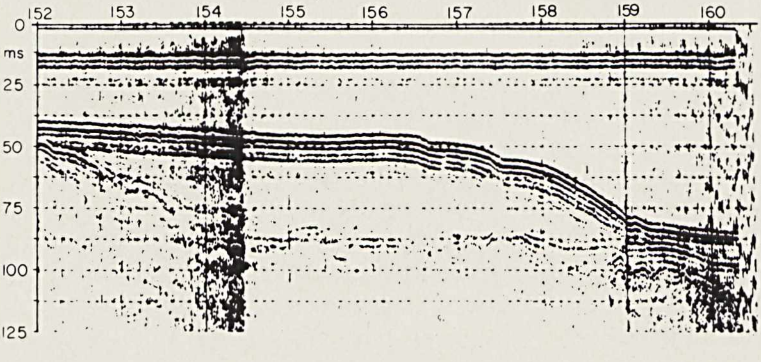


Fig. 8. Boomer profile of sediment wedge in the easternmoust part of the area. Vertical scale in milliseconds.

Mynd 8. Þykkt set ofan á föstu bergi. Lóðréttur kvarði í millisekúndum. Setþykktarmæling frá Sviðsbrún. Orkustofnun.

Three lines of evidence from the present survey may be used to make inferences about sediment transport in the study area. These are a) grain size of the sediments, b) the distribution of carbonate and c) the bedforms observed on the sonographs.

a) A general guide to sediment grain size in the area is the sonar map (Fig. 3), which broadly shows a pattern of decreasing grain size downslope, away from unit 1, with coarser material appearing again in the south.

b) The carbonate distribution illustrated in Fig. 6 is roughly parallel to grain size trends in that carbonate content appears, broadly, to decrease with water depth.

Taken on their own, these two properties, viz. grain size and carbonate content, might be taken to indicate downslope sediment transport radially away from the central shallow areas. The carbonate distribution would then indicate high carbonate productivity in and around the "hraun" areas, and the outwards decrease in carbonate content would represent decreasing productivity or mixing with terrigenous material. This suggestion is not supported by the bedforms, as discussed below.

c) Bedforms observed in the study area are defined by relief patterns on the one hand, and variations in grain size on the other. Those bedforms defined by relief are the ripples of map unit 2. The fact that these ripples occur in gravel, and their wavelength is of the order of 1 m, suggest kinship with ripples described by *Flemming and Stride* (1967) and *Channon and Hamilton* (1976) off the southwestern coast of England, which were ascribed to the action of oscillatory wave currents.

The orientation of the gravel ripples found here is generally near N—S (i.e. parallel or subparallel to the survey tracks). They are thus indicative of E—W (oscillatory) motion. A piece of evidence indicating that the rippled gravel is indeed in motion is provided by some dredge marks observed to the east of Sydra-Hraun. At the time the survey took place, the suction dredger SANDEY was at work in the area on her annual 1-month dredging operation for the State Cement Works. The marks left by the dredger were the only ones observed in this area where dredging has taken place for a number of years. It seems clear that dredge marks from previous years have been filled in by the movement of the bottom sediment.

Bedforms defined mainly by variation in grain size make up the rest of bedforms observed in the area and were found in map units 2, 3 and 4. They are perhaps best brought out where they occur on the boundaries of these units. The bedforms include the elongate sand and gravel bodies along the northeastern border of the map, the crescentic forms at the boundary between units 2 and 3 in the southeast, the striped and criss-cross pattern of unit 4 and the irregular boundary between units 3 and 4 in the south. All these bedforms have been identified as falling in the category of *sediment patches*. Analogous bedforms have been found to be widespread on the shelf of the British Isles, for example (*Belderson, Kanyon and Stride*, 1971), and to occur in areas of weak tidal currents (less than about 50 cm/sec). Linearity of sand patches has been found to be parallel or transverse to peak tidal currents.

Although sand patches occur in areas of low transport rates, suggestions of transport direction may be made on the basis of the nature of the sand/gravel boundary, mainly its sharpness. Sharp, well defined boundaries often represent a steep edge of the sand body overlying the gravel (*Channon and Hamilton*, 1976), whereas a diffuse, or gradational, boundary suggests a more gradual thinning of the sand. A sharp boundary is thought likely to represent the downcurrent side of a sand patch.

A direct comparison of the Faxaflói sand patches with British examples shows a degree of similarity. Some of the longitudinal, NW—SE-trending features in the northern part of the area resemble features found by *Belderson, Kenyon, Stride and Stubbs* (1971, Fig. 71) in the Celtic Sea, although there is a transverse component to the shape of the Faxaflói patches. This transverse trend is not a right angles to the elongation of the sand and gravel bodies, but is nearer to a N—S orientation. An inspection of the sonographs shows that in most cases the sharp sand/gravel boundary is on the eastern and northeastern sides of the gravel outcrops. The fact that there exist two non-perpendicular orientation trends may indicate that there are two main directions of transport, i.e. an easterly and a southeasterly one.

The transverse patches running N—S across the slope to the east of the patches discussed above resemble in many ways features described by *Kenyon* (1970, right-hand side of Pl. 1) although less curved. The boundaries are quite sharp, but where a distinction can be made, the sharpness is greater on the eastern side. Easterly transport of sand is therefore indicated.

On the southeastern side, the border between units 2 and 3 describes numerous cresentic shapes. Similar shapes are seen within unit 3 and in the border zone between units 3 and 4. These shapes are regarded as being transverse and patches of a barchan-like appearance in plan. Again, where a distinction can be made, the boundaries suggest eastwards transport. Crescentic sand patches occur in the Celtic Sea (*Kenyon*, op. cit.), but their inferred sense of movement is opposite to the present ones.

The criss-cross sand patches observed in unit 4 are similar to patches found in the Celtic Sea. and to the west of Ireland (*Belderson, Kenyon, Stride and Stubbs*, 1972, Figs. 67, 69, 70), and although their boundaries give no information on transport direction, it seems very likely that their orientation indicates that instead of the easterly transport in unit 3 the direction here is more southeasterly.

The direction of sediment transport, as evidenced by bedforms in the area is summarised in Fig. 9.

Fig. 9. Directions of sediment transport as inferred from the orientation and shape of sand patches.

Mynd 9. Flutningsstefna sets á svæðinu. Byggt á lögun sandflekkja.

CONCLUSIONS

The rock floor of southern Faxaflói is made up of indurated sediments. The coarse grain-size of these suggests that they are of glacial or fluvio-glacial origin. After cementation of these sediments took place, the rocks were scoured by ice.

The second oldest deposit in the area is thought to be the gravel of unit 4. The worn and discoloured appearance of shells from this area lends support to the suggestion that the gravels are relict.

Recent sediments are represented by the shell gravels and sands of units 2 and 3. In the virtual absence of terrigenous sedimentation these sediments are made up dominantly of biogenic carbonates. Although their grain-size appears to decrease with depth, the orientation of sand patches indicates transportation towards the east rather than downslope. Considerable accumulation of sediments is indicated in the eastern and northeastern parts of the area.

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ÁGRIP

BOTNGERÐ Í SUNNANVERÐUM FAXAFLÓA

Sumarið 1975 voru gerðar fjölþættar mælingar í sunnanverðum Faxaflóa og voru þær notaðar ásamt 260 botnsýnum til þess að draga upp mynd af gerð hafsbotns á svæðinu, svo og til túlkunar á jarðsögu svæðisins. Auk þess hafa gögnin verið notuð til þess að greina flutningsstefnu nútímasets á svæðinu.

Gagnasöfnunin fór fram á sjómælingabátnum Tý og var unnin í samvinnu Sjómælinga Íslands, Hafrannsóknastofnunarinnar og Orkustofnunar. Var svæðið fyrst kannað með dýptarmæli og botnsjá, þá tekin sýni af botninum og loks gerðar setþykktarmælingar.

Í stuttu máli eru niðurstöður þær að Syðra- og Vestra-Hraun og stór fláki á milli þeirra eru gerð úr samlímdum framburði, sandsteini og völubergi. Umhverfis þennan harða botn liggur breiður kragi af möl og síðan annar af sandi. Syðst á svæðinu tekur svo við grófur malarbotn (Mynd 3). Sandurinn og mölin næst harða botninum eru ákaflega kalkrík, oft nær eingöngu úr skeljum og skeljabrotum. Kalkinnihald lausa setsins minnkar jafnt og þétt út frá hraununum (Mynd 6).

Botnkortið (Mynd 3) sem byggt er á botnsjármælingum sýnir að mót sand- og malarbotns eru mjög fjölbreytileg. Af sömu mælingum má sjá að þar sem sandur og möl mætast, stendur sandurinn víða hærra en mölin. Ástæða þessa er talin sú að sandurinn liggi ofan á mölinni og sé á hreyfingu yfir hana í mynd stórra sandflekkja. Af útlínum sandjaðarsins má ráða flutningsstefnu sandsins. Kemur í ljós að sandurinn virðist flytjast inn í flóann (Mynd 9). Er talið að úthafsalda í samvinnu við sjávarfallastrauma ráði setflutningi á svæðinu.

Laust set virðist víðast hvar þunnt á svæðinu, en talsverð upphleðsla á seti hefur orðið á því austanverðu.

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