Trends in Postvolcanic Development of Surtsey Island. Progress Report on Geomorphological Activities in 1968

By

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INTRODUCTION

During the phase of volcanic activity from November 1963 to June 1967 „the course of events" has been followed by Thórarinsson and his reports include maps of the coast line at different times (Thórarinsson 1965, 1966, 1967, 1968). During this period changes in the coast line were due to combined effects of volcanic activity and shore processes.

From June 1967 the geomorphic development has proceeded without interference of volcanic activity. In September the same year the shore morphology was preliminary investigated (Norrman 1968). These studies were merely intended to form a basis for a research program that was later drawn up.

The submarine slopes of Surtsey, the nearby former islands of Syrtlingur and Jólnir and the main part of the shoal of Surtla were surveyed in July 1967 by B. E. T. Humphrey, Royal Navy, within an oceanographic program carried out by H. M. Surveying Ship Hecla. This survey has been reported on by Sigurdsson (1968). Unfortunately, the graphic quality of the sounding chart reproduced in that report is extremely poor.

From early June 1968 the author accompanied by Mr. T. Alexandersson and Mr. T. Lindell, both of Uppsala University, stayed for 4 weeks in the area. Mr. Alexandersson has given a separate report in this volume on his studies of sea bed sediments found in the craters of Surtsey. During our stay shore sections surveyed in 1967 were resurveyed and new sections were added. A ground survey for a detailed photogrammetric mapping was accomplished. Monuments were permanently signalled for repeated air photography. The submarine slopes of Surtsey and the shoals of Surtla, Syrtlingur and Jólnir were studied by SCUBA diving down to at most 40 m of depth. Samples of bed material were taken and the bottom topography was studied by scattered echo soundings.

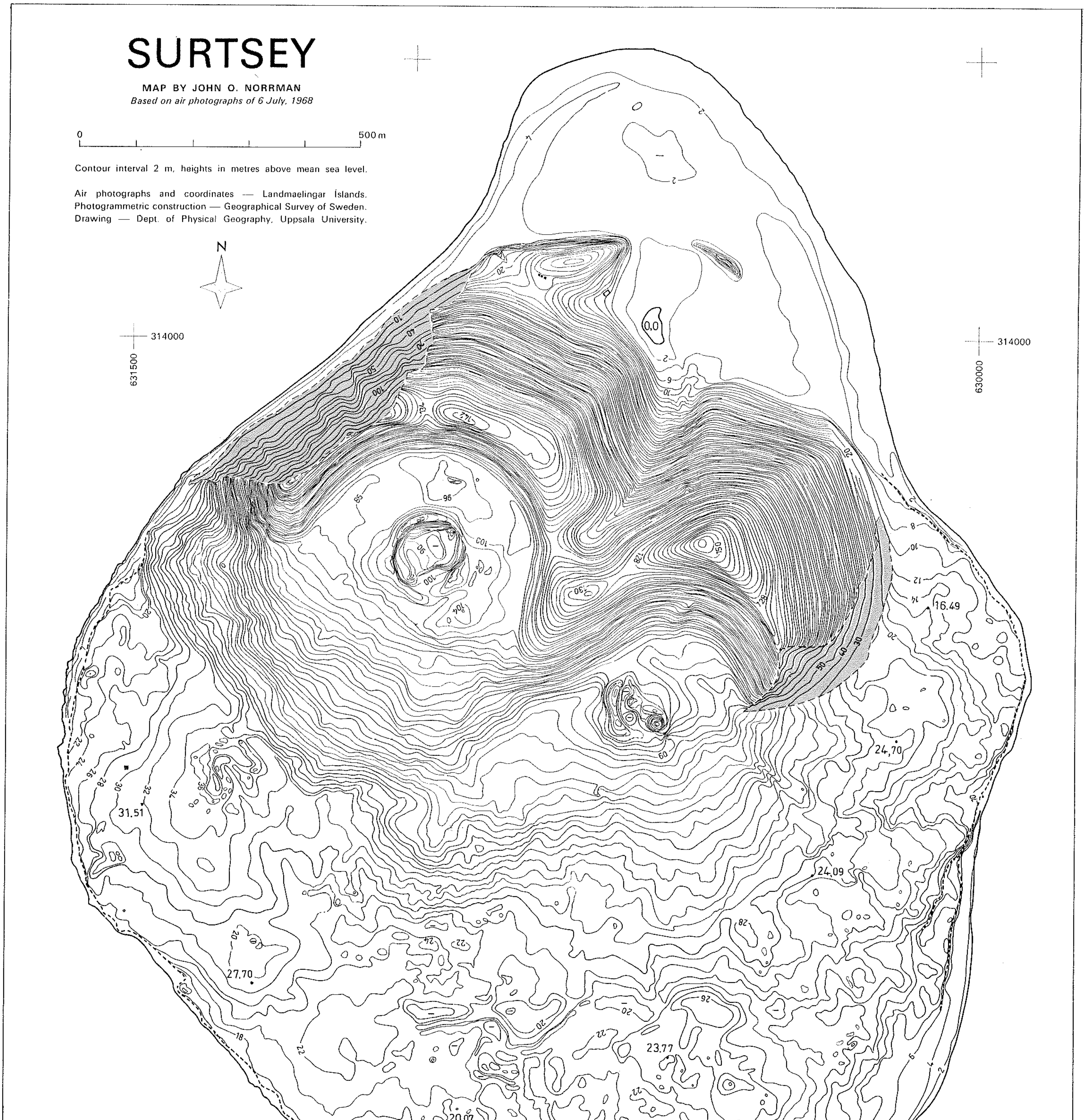
The aim of this paper is to give a description of Surtsey, especially its coastal morphology, in the summer of 1968—one year after the end of volcanic activity—and to discuss the development of the morphology in relation to acting forces.

GENERAL CONDITIONS

From a water depth of 130 m Surtsey was primarily built up by the two tephra cones of Surtur Senior and Junior. The crater of the Junior is situated WNW of the Senior (Fig. 1 and Pl. 1). During the deposition of tephra slumping occurred in the slopes.

The loose tephra material is easily eroded and, as is proved by the short stories of the tephra islands of Syrtlingur and Jólnir (Thórarinsson 1966, 1967), Surtsey had no longer been present as an island if not lava had come to cover the slopes of its southern quadrants. The lava did not only cover the subaeril tephra slopes but also advanced into the sea, thereby considerably enlarging the island (Thórarinsson 1968, Fig.1). An unknown part of the glowing lava that flew into the sea was by the rapid cooling fragmented into cubic particles of pebble size. This size well fits the bed load transportation of the swash zone that is of fundamental importance for the formation of beaches. Presently the main source of new material brought to the beaches is the lava cliff of the southern and southwestern coast that by abrasion produces heavy pieces of lava.

In dry weather wind moves sand from the


SURTSEY
MAP BY JOHN O. NORRMAN
Based on air photographs of 6 July, 1968
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500 m
Contour interval 2 m, heights in metres above mean sea level.
Air photographs and coordinates — Landmaelingar Íslands.
Photogrammetric construction — Geographical Survey of Sweden.
Drawing — Dept. of Physical Geography, Uppsala University.
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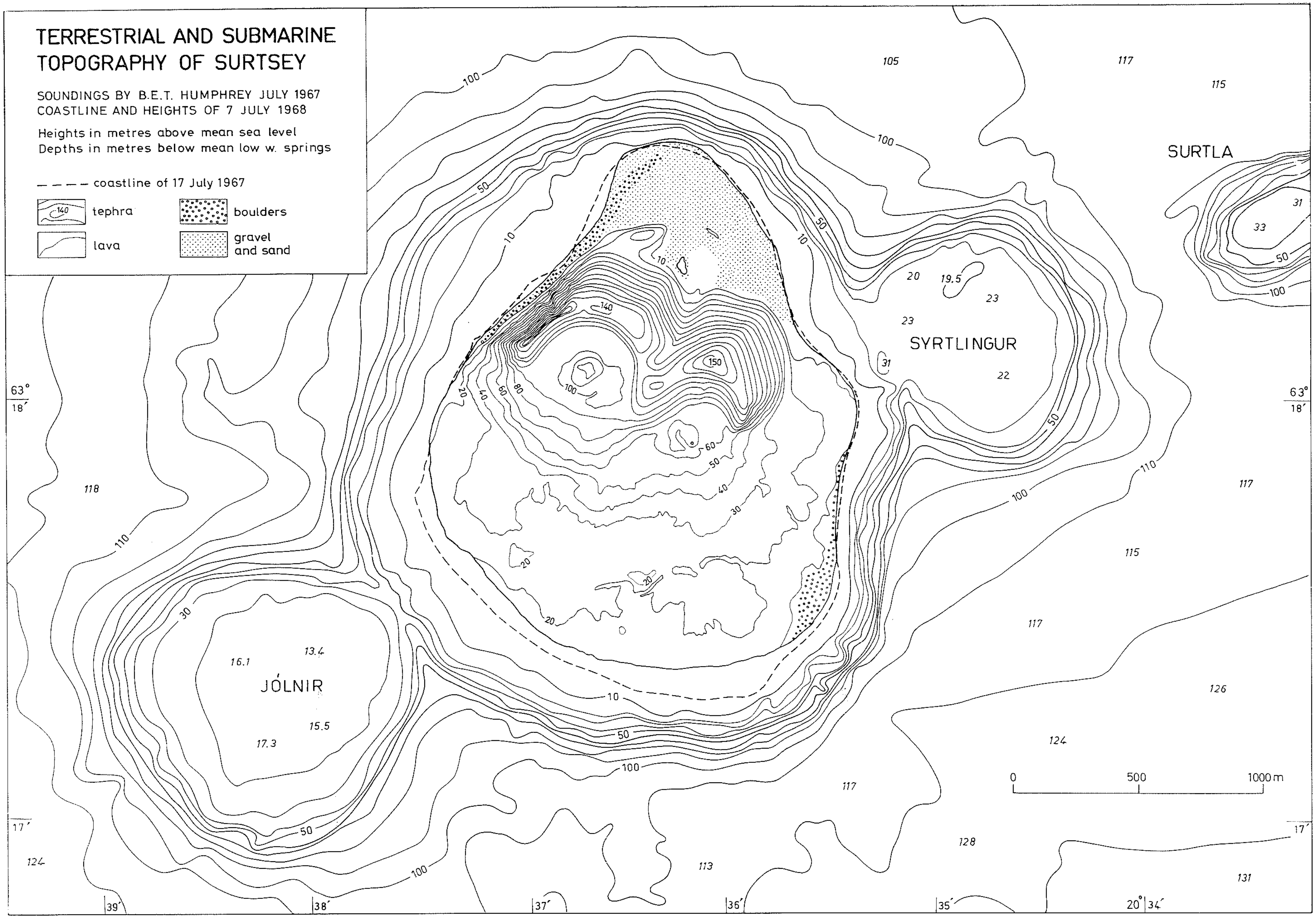

Fig. 1. Terrestrial and submarine topography of Surtsey.

tephra slopes of the craters. The material is partly deposited at the base of their northern and eastern slopes and partly blown into the sea. The tephra slopes are also affected by mass movements. In the western wall of Surtur Junior undercutting by waves have caused falls and slumps which give this wall a characteristic scar face. In the northern slopes mudflows have formed a regular furrow pattern.

The coast of Surtsey as developed in 1968 could be divided into a limited number of sections of specific morphological character (cf. Fig. 1). High lava cliffs generally with a notch at the base and vertical walls constitute the southern and southwestern coast. A lava cliff of less height and partly covered by a boulder talus forms the projecting head of the eastern coast. Boulder terraces are found on the southern part of the east coast and along the cliff of Surtur Junior on the northwestern coast. Finally there is the northern ness built out by beach ridge accretion.

This distribution of coastal morphology implies that the southern to southwestern coast is of a purely erosional character. The western and eastern coasts are characterised by a transport process that only permits extremely coarse material to be deposited. The transportation has predominantly been directed towards the north resulting in deposition on the northern coast.

The shore processes have considerably changed the primary coast line configuration. By cliff retreat irregular projections of the original lava coast have disappeared. In direct connection to those by abrasion smoothly curved flanks of the southern coast, the boulder terraces fill up concave sections. The characteristic pear shape of the island is completed by the northern ness.

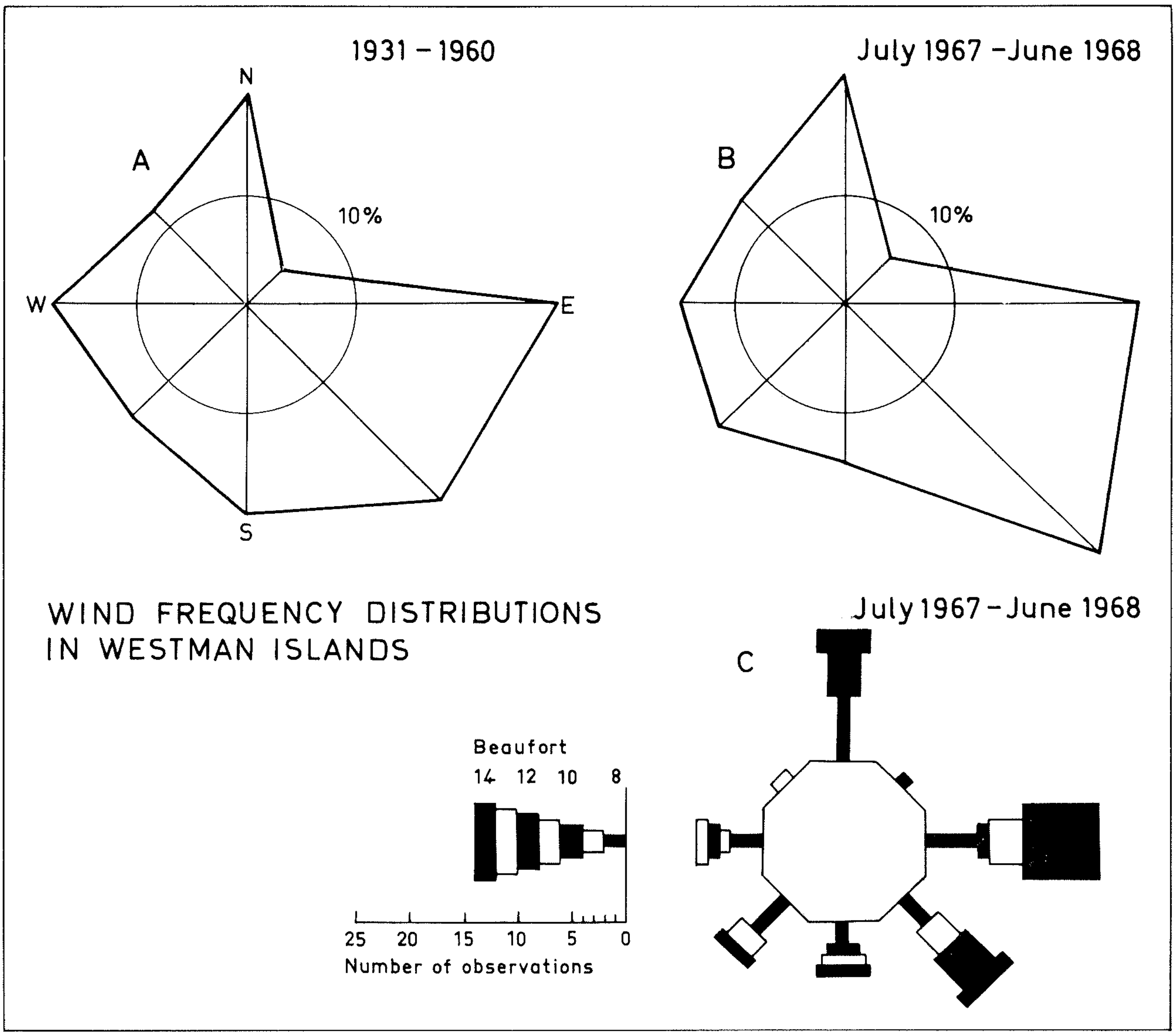

Fig. 2. Wind frequency diagrams for the periods 1931—1960 and July 1967 — June 1968.

WAVE EXPOSITION

The distribution of wave force can only be qualitatively discussed on basis of wind statistics fram Heimaey in the Westman Islands as there are no wave records and there is yet no quantitative analysis of wave generation based on air pressure gradients of synoptic charts. Because of the short distance to Heimaey (20 km) wind statistics from this island can be regarded to be valid for Surtsey.

The azimuthal wind distribution for the period 1931–60 (Fig. 2) shows a rather even distribution for winds from N to S in the western sector. Winds from SE and E dominate and the frequency of winds from NE is very low. For the period from 1 July 1967 to 30 June 1968, of special interest to this report, the distribution is essentially of the same character but for a greater dominance of SE winds. Observations of strong winds of 8 to 14 Beaufort in the same period are shown in Fig. 2 (C). Again E and SE winds dominate. The lack of strong winds from NE and also from NW is striking.

With respect to the wave generation by wind the limited fetches in directions covered by the Icelandic mainland must be considered. The fetch is limited by the south coast of Iceland in a sector of wind directions from NW to ENE, and most strongly in directions from N to NE where the length of the wave generating surface is only 30–50 km. The importance of the fetch may be illustrated by a single example. With a fetch of 50 km a 15 m/sec wind will generate a wave spectrum with a significant wave height of 2.2 m. An almost fully developed sea generated by the same wind will have a significant wave height of 6.1 m that will be reached at the end of a 2000 km fetch.

In the sector open to the ocean fetch is not a function of the distance to coasts but determined by the extension of so called moving fetches, that in this case generally means areas of wave generation associated to the low pressure cells which move over the North Atlantic Ocean. A preliminary study by Mr. Lindell of synoptic charts covering the 1967–68 period does not indicate any strong bias in the distribution of the lengths of these moving fetches with respect to wind directions in the Westman Islands.

From this discussion it may be concluded that wave exposition in a northern sector from NW to NE is significantly lower than from other directions. In the remaining southern sector westerly and easterly components are not in full balance but the easterly ones prevail. In the 1967–68 period this skewness was more pronounced than for the long time average. Of outmost importance to the coastal development are the E and SE strong gales and hurricanes recorded.

BEACHES

The eastern boulder terrace

This beach is deposited along and partly on top of an indented lava cliff (Fig. 3). Off the shore there is a platform gently sloping from 4 to 15 m of depth. This platform is covered by large sand ripples and scattered boulders.

The air photograph of Fig. 3 demonstrates how the terrace shore line perfectly fits the curvature of the cliff coast to the south. As can be seen in the same figure the retreat of this shore line from 1967 to 1968 is insignificant as compared to that of the southern cliff coast. In September 1967 the outermost part of the beach consisted of two shore parallel ridges. The bottom

Fig. 3. Air photograph of the SE coast of Surtsey 6 July 1968. Coast line of 17 July 1967 marked by white contour line and shore section across the boulder terrace marked in black.

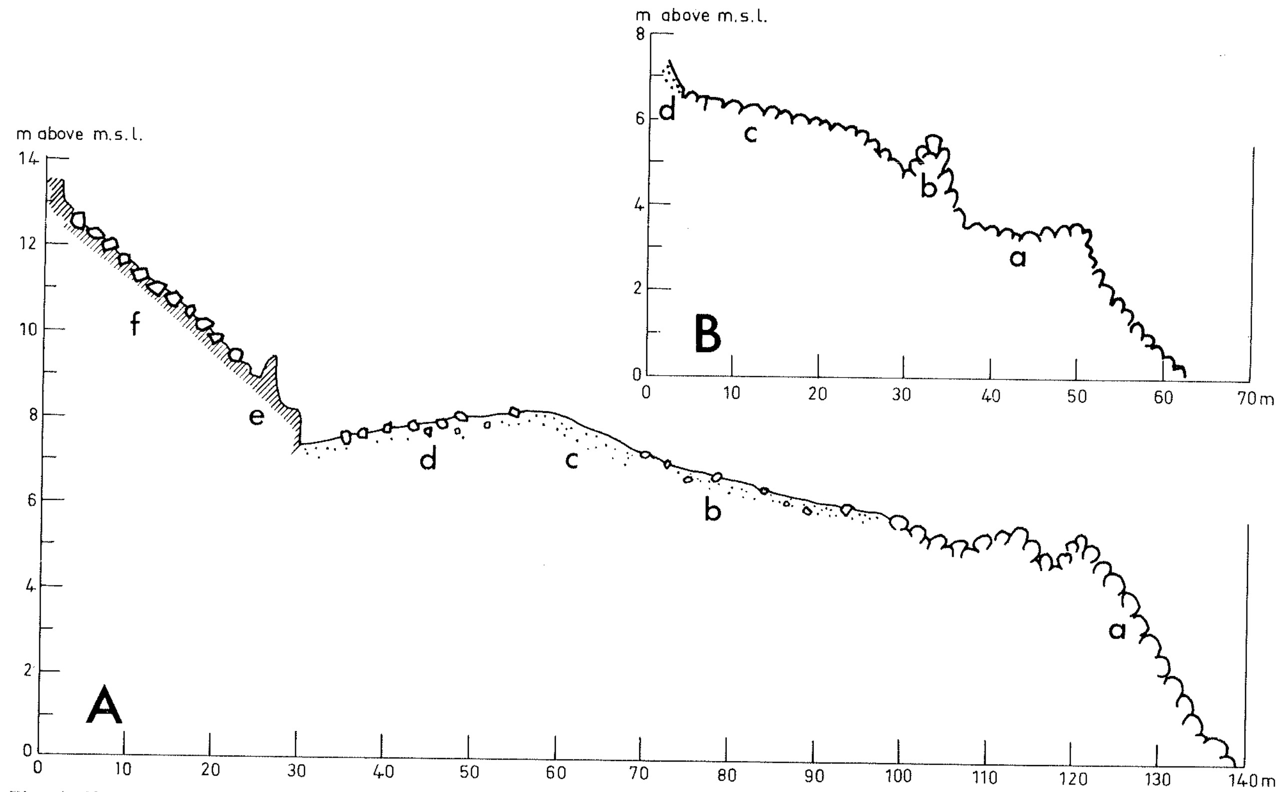

Fig. 4. Shore profiles levelled in June 1968. A. Profile from the eastern boulder terrace (cf. Fig. 3). a, well-rounded boulders 0.5—1.5 m in diameter. b, sand gravel and cobbles. c, sand. d, sand with scattered angular cobbles and boulders. e, lava cliff. f, angular boulders, about 0.5 m in diameter. B. Profile from the western boulder terrace. a, summer berm. b, beach ridge. c, winter berm. d, talus of Surtur Junior.

of the runnel that separated them was at about 0.5 m below m.s.l. By the shore retreat these ridges have disappeared. From comparisons of terrestrial photographs it seems most probable that the material of the ridges has been thrown up by easterly gales and thus been incorporated in the terrace.

The terrace profile is illustrated in Fig. 4 by one of 6 cross sections surveyed in June 1968. The uppermost part of the profile is strewn with boulders which at an early stage of development were thrown on top of the lava cliff 12.5 m above m.s.l. These boulders are all very angular. In the upper part of the section there is also angular lava gravel that was fragmented by rapid cooling in the sea. The sand of the middle part has been redeposited by wind.

The terrace surface slopes evenly towards the north. Its height at the southern end is 6.5 m above m.s.l. and at the northern end 4.1 m. There is a covariation in size and roundness of the boulders along the shore. Size decreases and roundness increases towards the north. At the southern end boulders of about 1—1.5 m in diameter dominate whereas at the northern end their size is of the order of 0.3—0.4 m. Already in the middle part of the terrace the boulders are well rounded (cf. Norrman 1969, Fig. 6).

The morphology of the terrace and the morphometric characteristics of the boulders clearly show that the material originates from lava blocks abraded on the southern coast. The predominant transportation is towards the north and wave energy decreases in the same direction. The future development of the terrace mainly depends on the retreat of surrounding cliffs. A continued retreat of the southern coast can be expected to entail some supply of boulders and an adjustment of the shore line in the southern part of the beach. However, it should be noticed that an insignificant part of the enormous masses abraded on this coast in the winter 1967/68 was brought to the beach (Fig. 3). This is partly explained by the prevalence of easterly gales (Fig. 2, C). (For further discussions on this problem see chapters on cliff retreat and submarine development). A recession of the head north of the beach will eliminate the hindrance to a northerly transportation from the beach. A loss of material in this direction will cause an adjustment along its full length.

The western boulder terrace

The terrace runs along the foot of the more than 100 m high tephra cliff of Surtur Junior. The shore line is almost straight up to the north-

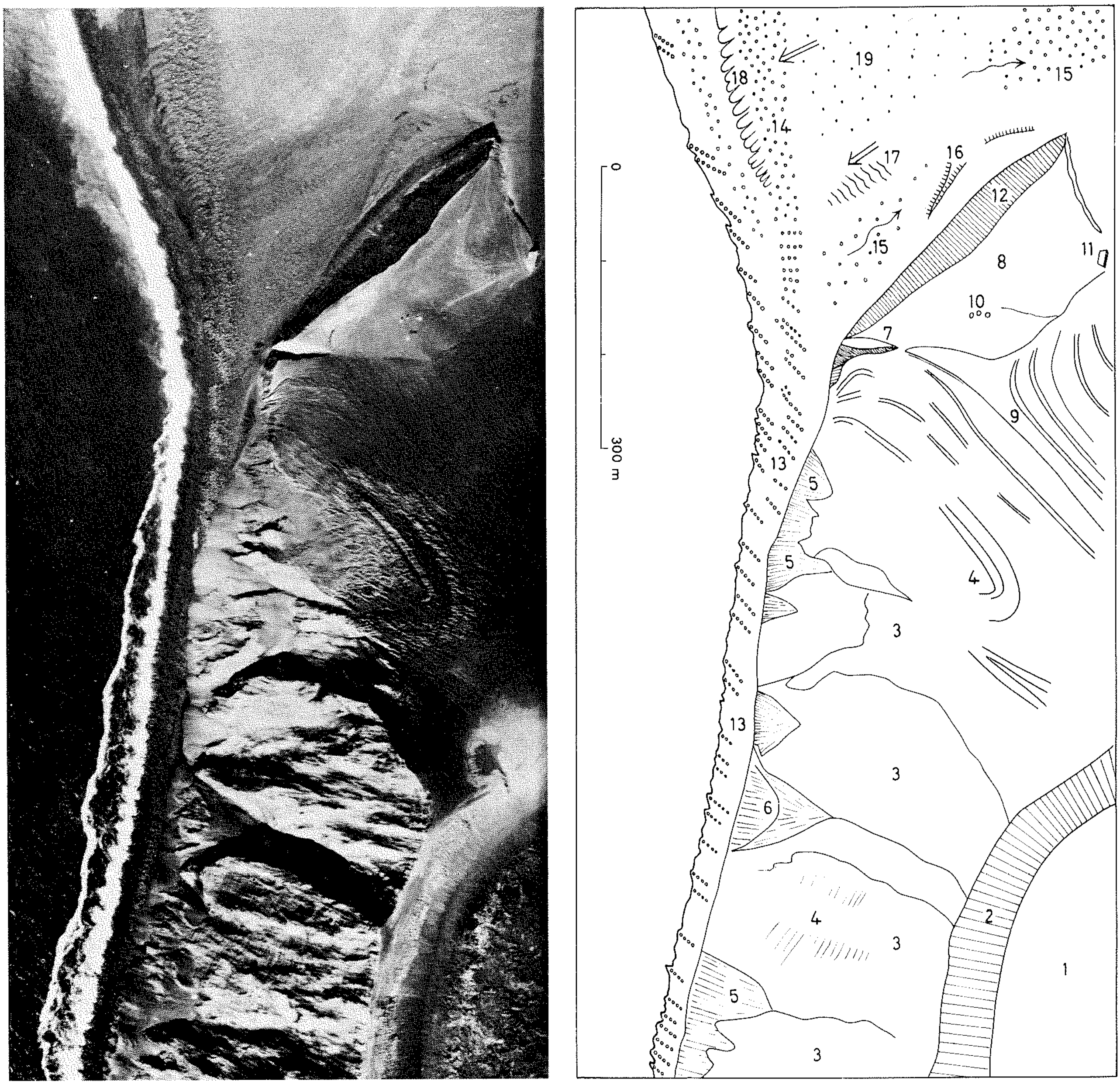

Fig. 5. Geomorphological elements of the northwestern coast. 1, lava in the crater of Surtur Junior. 2, tephra vall in the crater. 3, slump scars. 4, sediment structures in the tephra. 5, talus cones. 6, abrasion in talus. 7, mudflow ravine. 8, large subsided slide block. 9, mudflow tracks. 10, meteorological instruments. 11, research station. 12, abraded cliff. 13, beach ridges. 14, extension of western boulder terrace. 15, cobbles and boulders swept in during storms, arrow marks transport direction. 16, erosion scars. 17, low dunes, arrow marks wind direction. 18, sand drift. 19. deflation surface.

ern ness where it sharply deviates by 25° to the west (Fig. 5). Before the terrace was formed the cliff was rapidly abraded (cf. Thórarinsson 1968, Fig. 1). In September 1967 the terrace was not yet complete. In a section of the northernmost part of the cliff there was a narrow sand beach and swash directly hit the tephra wall. The single source area of boulders is the lava cliff to the south. In the winter 1967/68 considerable amounts of material were brought to the beach and also travelled further to the northern ness. In the ness the boulders form a distinct ridge that curves off to the east (Fig. 7).

In detail the shore line is found to be sawtoothed, the teeth pointing northwards (Fig. 5). Each one of these marks the position of a boulder ridge that transverses the terrace. The ridges are superimposed on a two-step berm morphology. The direction of the ridges illustrates how because of the offshore depth conditions the dominant waves from SW to W are insignificantly refracted. The direction of dominant wave action is also seen in the orientation of the boulders (Fig. 6).

The terrace profile is illustrated in Fig. 4 (B) by one of 9 cross sections surveyed in June 1969. The profile is characterized by two berms

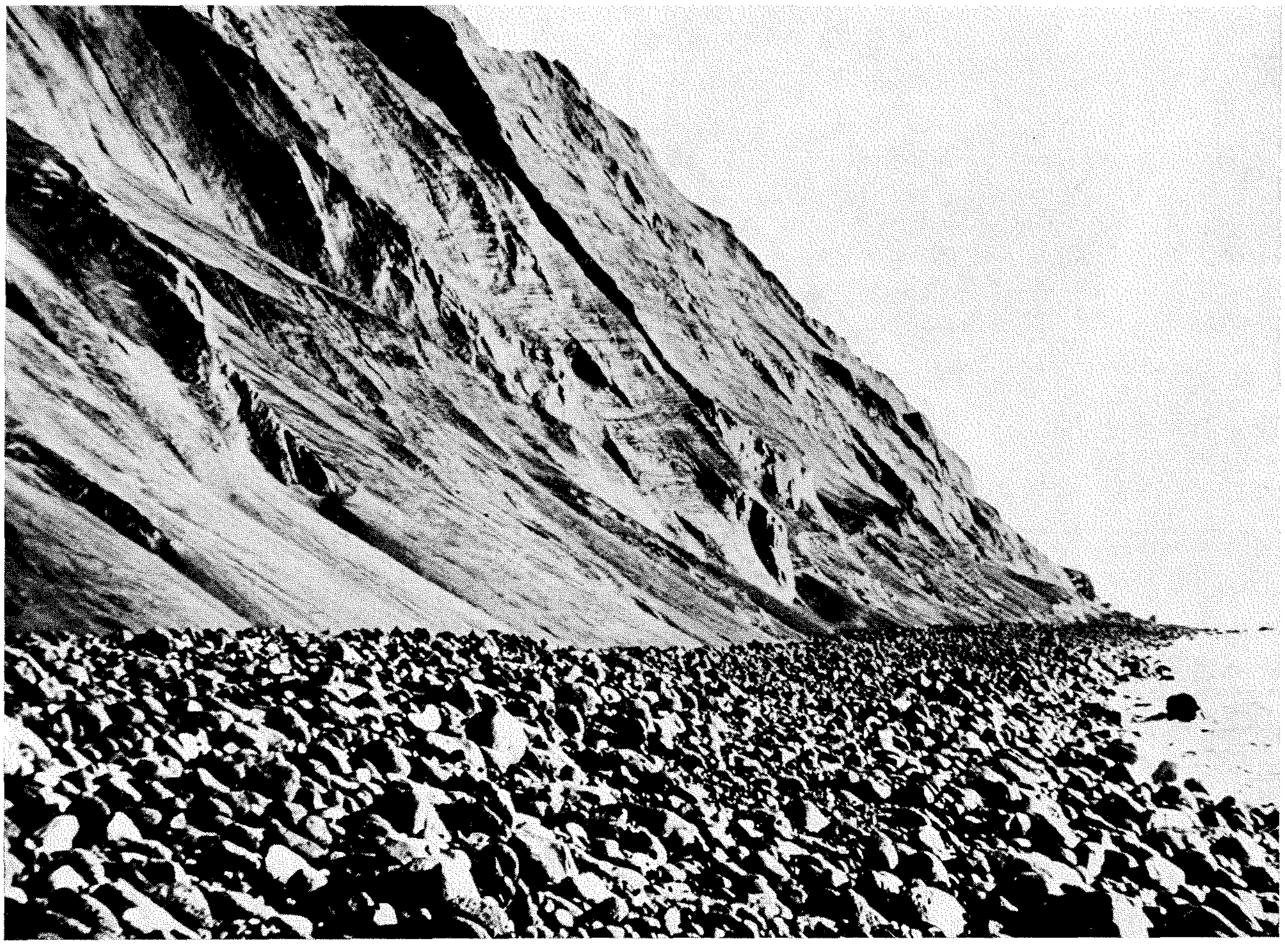

Fig. 6. The western boulder terrace and the cliff of Surtur Junior viewed from the north. Observe the boulder orientation. Photograph by T. Lindell, June 1968.

and a transverse ridge. With respect to wave conditions the upper berm can be regarded as a storm or winter berm and the lower one as a summer berm. Because of the boulder ridges the berms cannot be continuously followed and it is difficult to determine any specific slope along the terrace. Towards the south the winter berm narrows and the summer berm lacks in the southernmost part because of erosion. It seems probable that the eroded material forms part of the transverse ridges.

There is not such a distinct variation of boulder size along this terrace as in the eastern one. On the berms boulders of 0.4—0.7 m are most common but in pockets of the lower slope of the summer berm there is a high frequency of 0.2—0.4 m boulders. In this zone and just off the shore line some huge boulders (2 m and larger) are found.

The distribution of boulder size may be explained by the conditions of the source area immediately south of the beach. The cliff in that area is mainly composed of rather thin lava beds with a thickness of about 0.5—1.0 m, but there are some beds 3—4 m high. Thus from origin two different size classes are formed.

Because of the oblique incidence of predominant wave action the terrace must be regarded as highly unstable and dependent on a continuous supply of new material from the south. If this supply fails the tephra wall will soon suffer severe abrasion.

The northern ness

Only on the northern coast, beach processes have extended the island by forming a cuspate foreland. The inner part of the ness was originally occupied by a large lagoon fringed by a barrier of tephra of which only a narrow steep ridge remains (cf. Pl. 1). The primary morphology was formed by large scale slumping in 1964. The barrier was rapidly broken down by sea action and the lagoon was gradually filled up by beach material and by windblown tephra. Its size was also reduced by a small lava flow in January 1967 (cf. Fig. 1 and Thórarinsson 1968, p. 144).

Material has more or less continuously been brought to the ness by beach drift along

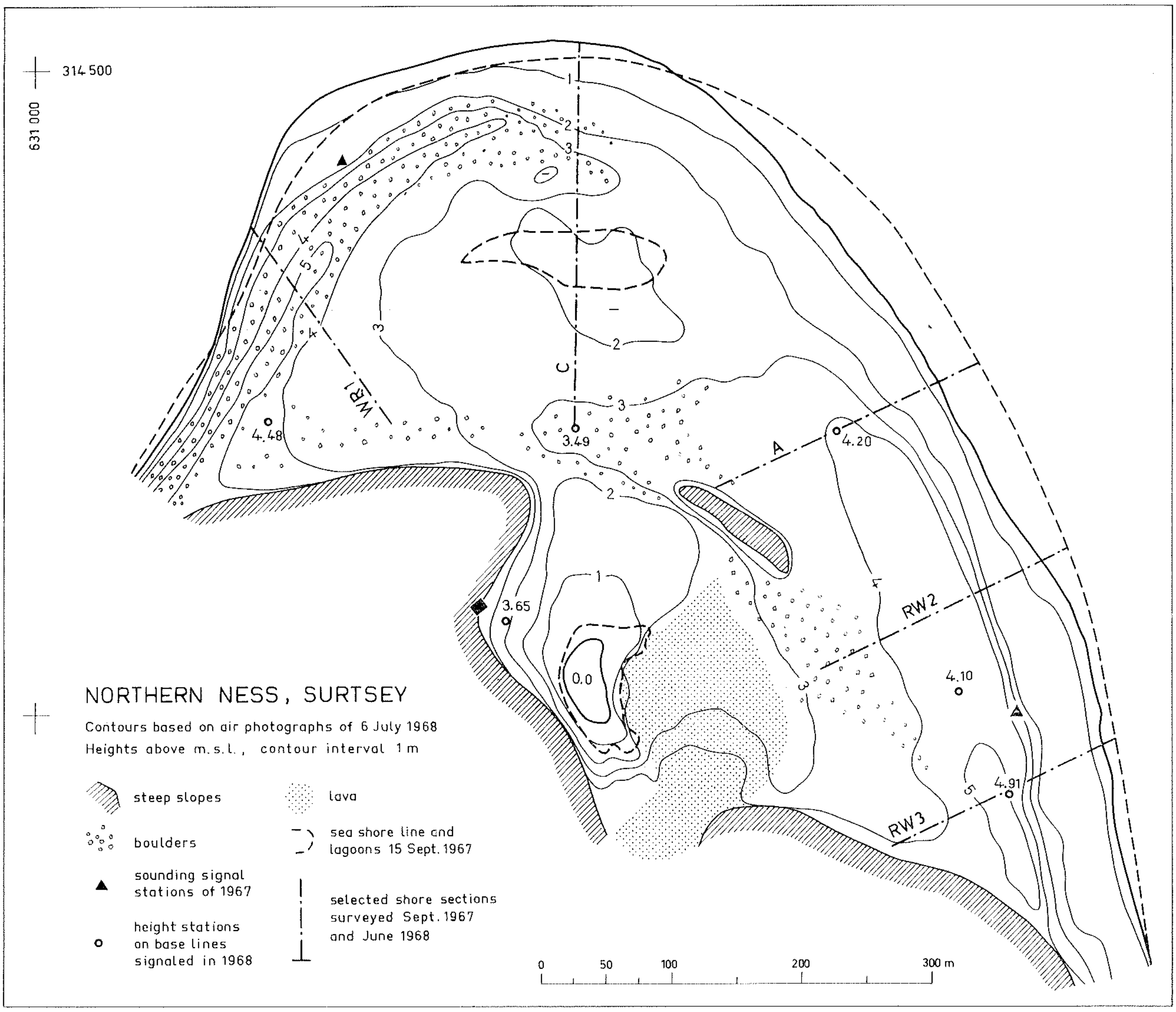

Fig. 7. Map of the northern ness.

the eastern and western coasts. This material originates from three different main sources; the tephra cones which by abrasion essentially produces particles of granule and finer size, the lava that flew into the sea and by rapid cooling was split into fragments of pebble size (cf. Norrman 1968) and the solid lava beds the main part of which initially is broken down to boulder size by fall at cliff retreat. During transportation in the swash zone a large part of the medium sand and almost all finer particles are washed out, which means that the ness above sea level is essentially composed of material coarser than medium sand, the bulk being very coarse sand to pebbles. The character of this grain-size range--including "the missing fraction" (1—6 mm) of fluvial deposits--as being specific to the beach environment has recently been discussed by Russell (1968). As the ness had developed in 1968 the boulders appeared in two positions, concentrated in a ridge forming a continuation of the western terrace and spread out in flat tounges (cf. Fig. 7). This distribution in relation to the development of the ness will be further discussed below.

The morphology in the summer of 1968 is rather well illustrated by the 1-m interval contours in Fig. 7. The map is complemented by some profiles selected from 16 cross sections surveyed in September 1967 and resurveyed in June 1968 (Fig. 8). The ness is fringed by ridges with northwards sloping crests. These ridges form the highest parts of the ness (except for the residual tephra ridge). Their inland slope is gentle. The highest crest level marks the limit of winter storm swash. Traces of previously formed ridges can be seen in the central part of the ness.

The profiles of the eastern shore (sections RW3, RW2 and A) illustrate that in the period from September 1967 to June 1968 a certain, quantitatively unknown, deposition has been

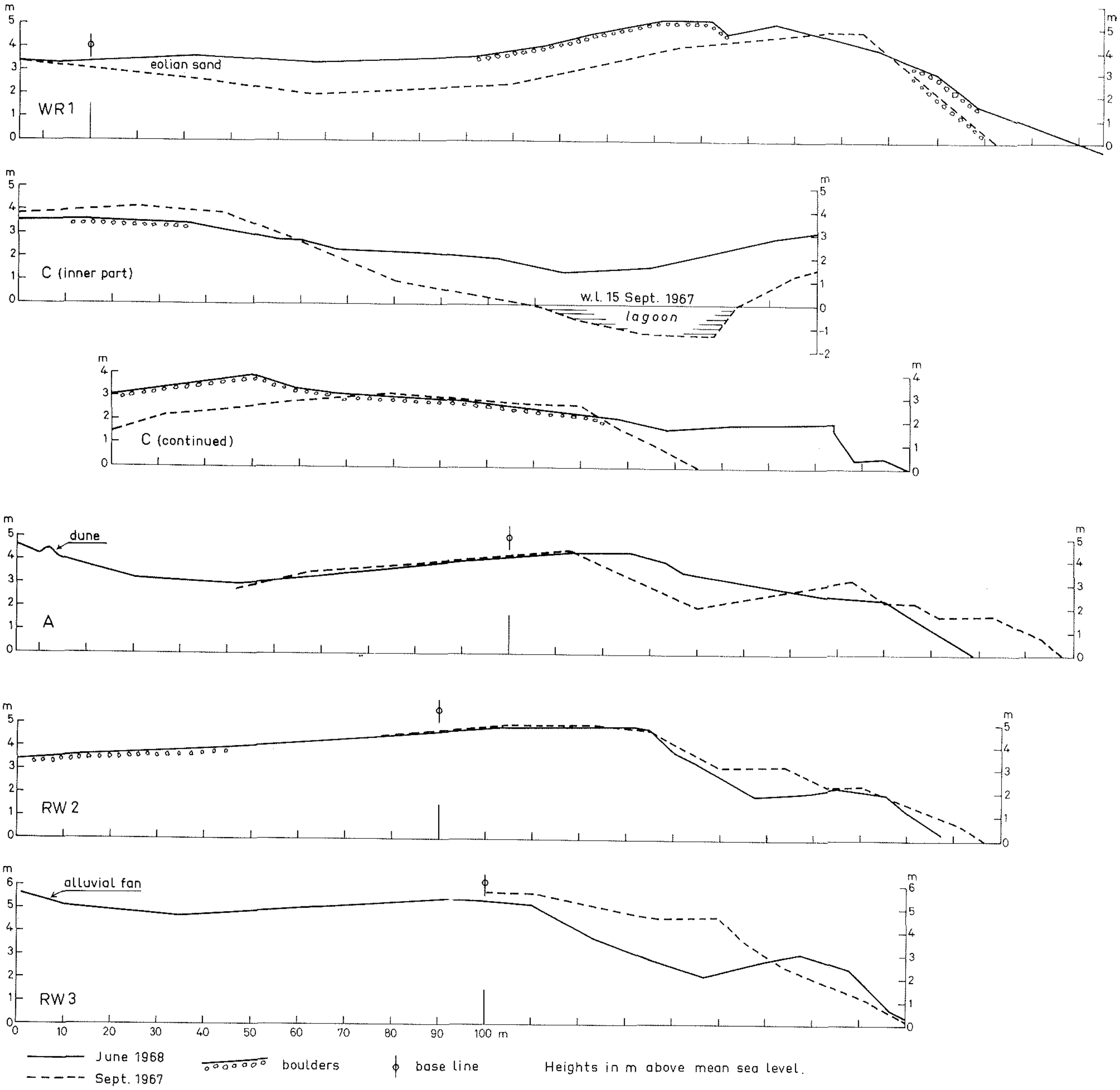

Fig. 8. Shore profiles from the northern ness levelled in September 1967 and in June 1968. For positions see Fig. 7.

followed by erosion and finally a low summer berm of beach ridge character has been formed.

In the northern part of the ness there was in 1967 a lagoon enclosed by spits built out from E and W (cf. Fig. 7). Section C (Fig. 8) shows how the lagoon has been filled up by a layer of sand and gravel up to 3.5 m thick. The material has mainly been brought in from the eroded eastern shore. Section RW1 proves that boulders have accumulated on the western ridge in the winter 1967/68.

The swash that overrides the beach crest and carries material inland brings large quantities of water which are slowly seeped back through the beach. Thus during storms the inner lower part of the ness is gradually filled up by sea water. In June 1968 the highest water level of the preceding winter was well marked by drift wood south of the tephra ridge and close to the research station at a height of 3.3 m above m.s.l. The wash of water over the ness reworks previously deposited material and levels the surface. The tongues of scattered boulders found on the ness have in this way been formed from boulder ridges.

The position of the shore line shifts from day to day with the winds. A lasting gale with steady direction shifts the position of the whole ness. From Thórarinsson's map of the Surtsey coast line at six different times from July 1965 to July 1967 (1968, Fig. 1) and the 1968 map it can be seen that the western shore of the ness in July 1965 was situated about 230 m W of its position in July 1968. In February 1966 it had moved 170 m further to the west but in the following June it had moved back east 130 m, and since then there has been a gradual retreat to the east.

The extreme western position of February 1966 was caused by an extremely hard storm from E to SE that lasted from 1 to 5 February. On February 5th there was high water spring and the wind reached a velocity of 45 m/sec (Thórarinsson 1967, p. 89).

The fact that the foreland has been built out in deep water is most important for the understanding of its development. The rapid increase in depth off the shore means that waves are very little refracted around the ness and thus recurved spits will not be fully developed. Instead, beach material brought to the outer end of the windward shore will follow the course of suspended material off the leeward shore where it is deposited. By continued deposition the ness will be built out on this shore but, as the submarine slope stands at angle of repose down to a depth of 60–70 m every metre of shore advance per metre of shore length requires at least 70–80 m^3 of beach material. The part of this deposit situated at depths greater than about 10 m will never be recovered to the beach (cf. 10-m contour line in Fig. 7).

The process described means that a shifting in the position of the ness causes a loss of large quantities of beach material. This entails a need for large supplies of new material to maintain the terrestrial area of the foreland. From September 1967 to June 1968 there was a loss of 1.4 hectares.

CLIFF MORPHOLOGY

Lava cliffs

The morphological character of the lava cliffs has previously been described by Thórarinsson in his yearly reports and by Norrman (1968, 1969). The development from the autumn of 1967 to the summer of 1968 has not principally changed the morphology.

The cliff walls are vertical or overhanging. Abrasion operates by corrasion at the cliff base

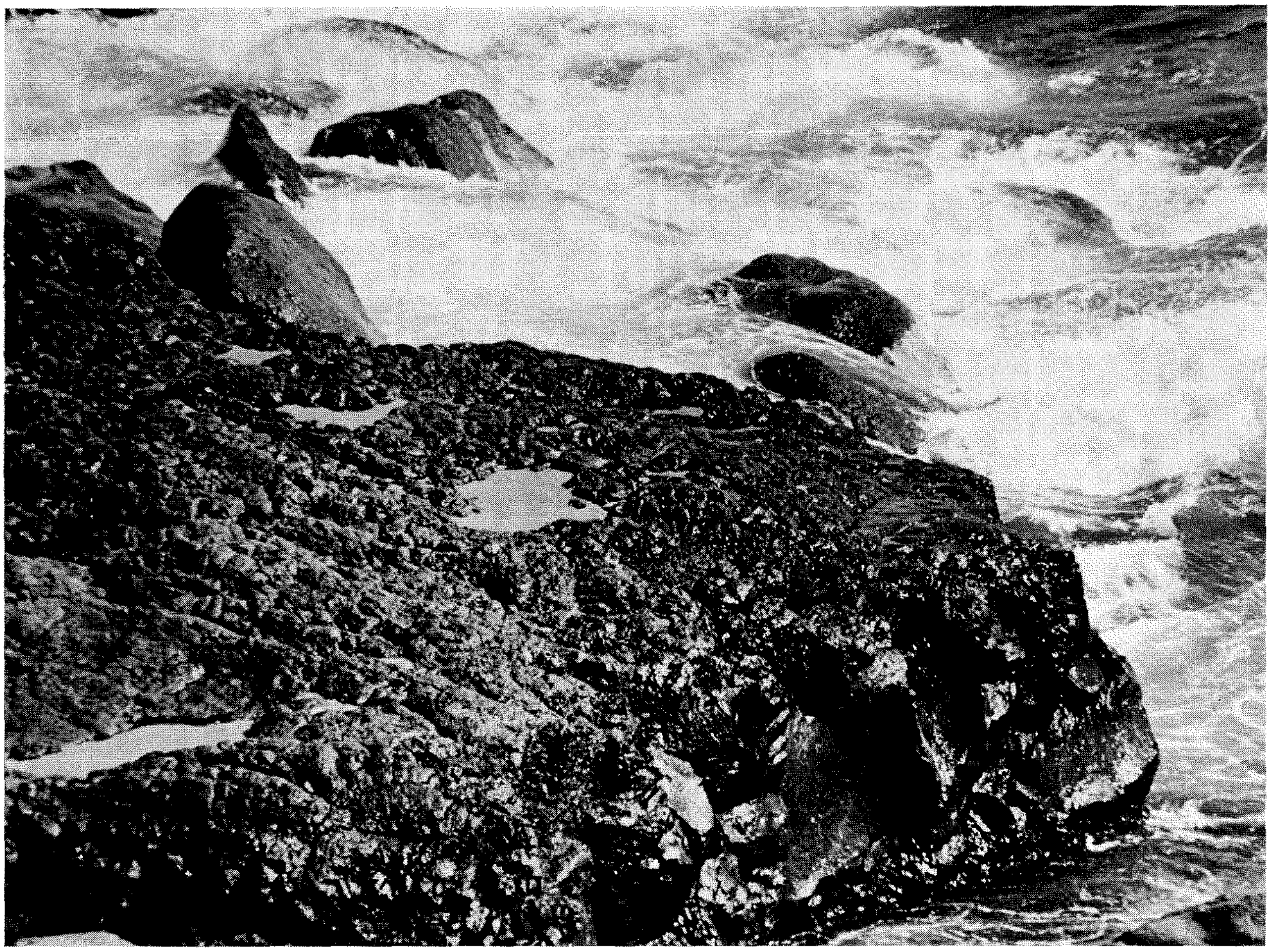

Fig. 9. The swash and breaker zone of the southern coast is composed of residual lava outcrops and large boulders. Photograph by J. O. Norrman, June 1968.

whereby a notch is formed and by impact of waves directly hitting the cliff wall. The lava is brittle and there is a pronounced weakness in the more or less horizontal boundaries in the sequence of lava beds and a structural weakness along planes at right angle to the bed surfaces. After a heavy wave attack one can sea how vertical fissures parallel to the cliff edge have been formed on the lava plateau up to 20 m from the cliff. When the cliff collapses a block talus is formed. The loose material is sucked out by back wash, and in the breaker zone it can be transported along the coast.

In places abrasion follows a bed surface and a platform is developed (Fig. 10). However, nowhere any permanent, exposed abrasion platform has been found above or below sea level. The breaker zone is characterised by projecting tongues of more resistant lava that has cooled in subcrustal tunnels and by irregular masses of huge blocks and worn boulders (Fig. 9). These masses also cover the offshore bottom and the submarine slope.

By retreat the cliff grows higher and becomes less stable provided that the mechanical properties are constant. In 1968 the cliff height along the continuous lava cliff of the S and SW coast varied from 12 to 24 m. The highest cliff is found on the SW coast (Pl. 1). The cliff of the projecting head of the E coast is 10—12 m high.

In the winter 1967/68 abrasion was heavy on the southern coast (cf. Fig. 1). The maxium retreat was in the eastern part (up to 140 m, cf. Fig. 3), and there was almost no abrasion of the cliff facing W to WNW on the western coast, which well reflects the storm distribution of the period. The average retreat of the S and SW coast was about 75 m and the amount of lava abraded is estimated at $2 \cdot 10^6$ m³.

Fig. 10. A narrow high abrasion platform on the SE coast. Photograph by J. O. Norrman, September 1967.

The tephra cliff of Surtur Junior.

The morphology of this cliff may be visualized by Fig. 6, the interpreted air photograph of Fig. 5 and the 10-m contours of Pl. 1. The tephra is of semi-cohesive character. The content of fine flaky particles is high enough to enable the cliff to stand at angles far steeper than the normal frictional angle of repose. Mass movements in the cliff are of both cohesive and frictional type. There are slumps but also falls and the later produce dry sand flows which form talus cones at the cliff base.

The top of the scar has reached the crater rim and by further retreat the cliff will be lowered. The tephra material has a very low resistance to swash action because it flows easily when saturated. This means that although the cliff is situated in a sheltered position with respect to wave action its retreat will be rapid if the protecting boulder terrace is lost. In the autumn of 1967 the northern part of the cliff was abraded but when the terrace was completed the recession ceased.

SUBMARINE MORPHOLOGY

Previous surveys

As far as can be judged from the sea chart (Icelandic Hydrographic Survey Nr. 16) before the eruption the bottom at the site of Surtsey was at about 130 m and fairly level. At the end of July 1966 the submarine slopes of Surtsey were echosounded and a map with 5-m contour intervals was drawn (Rist 1967, Fig 1). In this map the morphology is characterized by a sloping platform around the island with a width of 100-200 m, an average slope of 1:7 (8°) and a depth at its outer margin of 25—30 m. Off this platform the slope sharply steepens to about 1:2 to 1:3 (27° to 18°). The steep slope gradually flattens below a depth of 60 to 100 m.

As mentioned in the introduction of this paper a wider area around Surtsey was echosounded in July 1967 by Humphrey. Based on a blue-print from these soundings on the scale of 1:10,000 with sounding figures and 10-m contours the submarine contours of Fig. 1 were drawn. Before the submarine morphology of this map is commented upon some basic data concerning the former islands of Surtla, Syrtlingur and Jólnir should be given. (For details see Surtsey Research Progress Reports, I—IV).

At the site of Surtla a submarine eruption was noticed 23 December 1963. A volcanic cone was built up close to the water surface but no deposit above sea level was observed. Syrtlingur was seen above sea level 28 May 1965 and disappeared by abrasion 24 October the same year. Jólnir reached sea level for the first time 28 December 1965 and finally disappeared in September 1966. In all islands only tephra could be observed.

In Fig. 1 the formerly islands form a series of linearly arranged small "guyots" or tablelike seamounts, and the map reveals an interesting relation between the time that had passed since the islands disappeared from sea surface and the depths of the shoals:

Surtla	43 months	31—34 m
Syrtlingur	21 months	22—23 m
Jólnir	10 months	13—16 m.

The figures indicate a continuously, rapid lowering to considerable depths.

Around Surtsey Fig. 1 shows a platform with its outer margin at a depth of 20—30 m (as in 1966) and with a width of 50 m to 400 m. The platform is broadest west of the northern ness from which area the ness has moved towards the east, and it is most narrow east of its tip where the ness has recently been built out into deep water. The slope morphology as represented by the depth contours is to a certain degree dependent on the arrangement of the sounding sections. They ran roughly at right angle to the shore and were spaced at intervals of 50 m to 100 m. Nevertheless, it may be noticed that the contours of the slope are more irregular west of the northern ness and off the southeastern coast. In the latter area the contours were thought to reflect submarine lava flows.

Off the southern coast there is a rather sharp transition from the steep slope to an almost flat sea bed, whereas off the northwestern coast the transition is smoothly concave. This difference could be attributed to the deposit of coarse material abraded from the lava cliffs of the southern coast and the deposit of fine material brought in suspension along the shores of the northern ness.

Investigations in 1968

The field investigations of June 1968 included studies of the shoals of Surtla, Syrtlingur and Jólnir and the submarine slopes of Surtsey. The studies were carried out by SCUBA diving to at most 40 m of depth. The diving operations were guided by echo soundings. The equipment of the small open fishing boat, that was rented in Heimaey, and the weather did not permit a precise echographic surveying.

The aim of the investigation of the shoals was to determine the character of the deposits, to make observations of details in the bed morphology which could indicate the nature of acting forces and to record possible changes in their top level.

The minimum depth recorded on Jólnir was 19 m and over large areas the level was at 22—24 m. Thus this plateau had been lowered about 6 m during the last year. According to divings in its northern part the surface was covered by large symmetric straight ripples with crests running in N—S. The length of their flat crests (measured in E—W) was about 0.5 m and the crests were covered by small current ripples running at right angle to the large ones. The symmetry of the small ripples indicated a current of southerly direction. The large ripples have probably been formed by waves of easterly storms. The material was of granule size but for a few small cobbles in the large ripple troughs.

Because of bad weather only one short diving could be made on Syrtlingur. The depth in the northwestern part of the plateau was found to vary from 24 to 22 m. The bed consisted of very coarse sand and granule. Indistinct ripples were reported. It is possible that the easterly storms have eroded the eastern part of the plateau and brought material towards W and NW, and if so the depth figures reported above may give a false impression of rather stable conditions.

Echograms of soundings run in several directions over Surtla all show a slightly undulating level surface at 40 m of depth, which means a lowering during the last year of 6—9 m (cf. Figs. 1 and 11). The surface of the plateau was found to be covered by angular lava fragments, mainly of granule size. During the diving a northbound current of about 1 m/sec. forced the diver (Alexandersson) to go down along the chain cable. The bed was reported to have a "patterned" appearance but no distinct ripples. Some material was whirled up but there was no general transport activity.

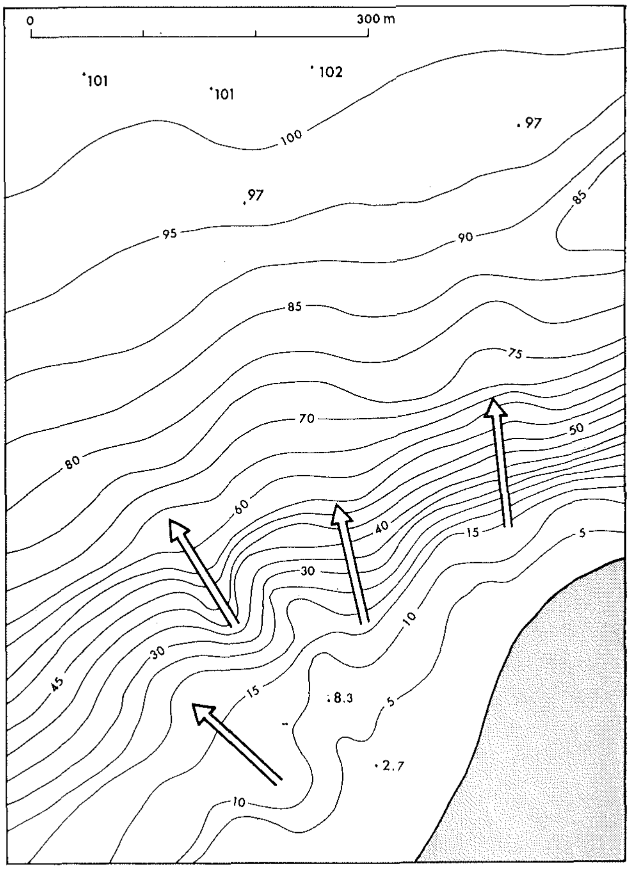

Fig. 12. Map of the submarine slope off the western shore of the northern ness based on 1967 soundings. Avalanche scars (arrows) in the upper part of the slope and debris tongues at its base.

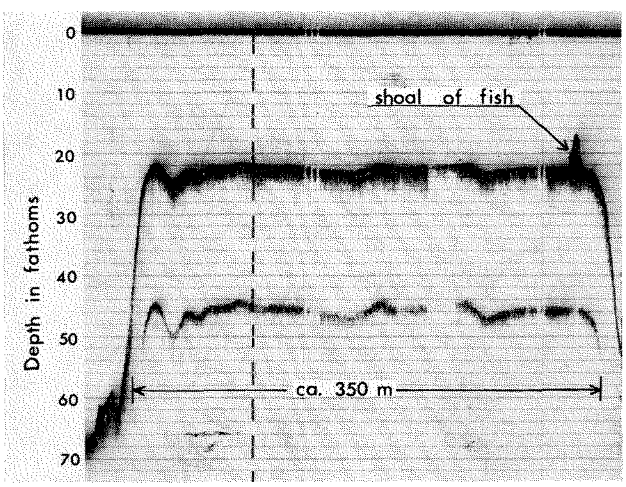

Fig. 11. Echogram of the Surtla shoal from WSW-ENE recorded on June 28, 1968. According to soundings of July 1967 (cf. Fig. 1) waves and currents have lowered the plateau from 18 to 22 fathoms in one year.

The studies show that the volcanoes of Surtla, Syrtlingur and Jólnir down to at least presently exposed levels are built up by tephra and eventually some lava fragmented by rapid cooling. Nowhere any traces of solid lava beds have been found. Erosion by currents and waves is active on all shoals. The relative importance of direct wave action is uncertain. It has been possible to give some figures of the lowering of the plateaus from July 1967 to June 1968, but for a reliable estimate of the total changes since 1967 a complete echographic resurveying is necessary.

The time available did not permit divings along the entire submarine slope of Surtsey. It was thought most important to study the slope west of the northern ness where the deposition of beach material has been most active, and the slope of the southern coast where lava has flowed

Fig. 13. Boulders at the top of the submarine slope off the northern ness. Depth 12 m. Photograph by T. Alexandersson, June 1968.

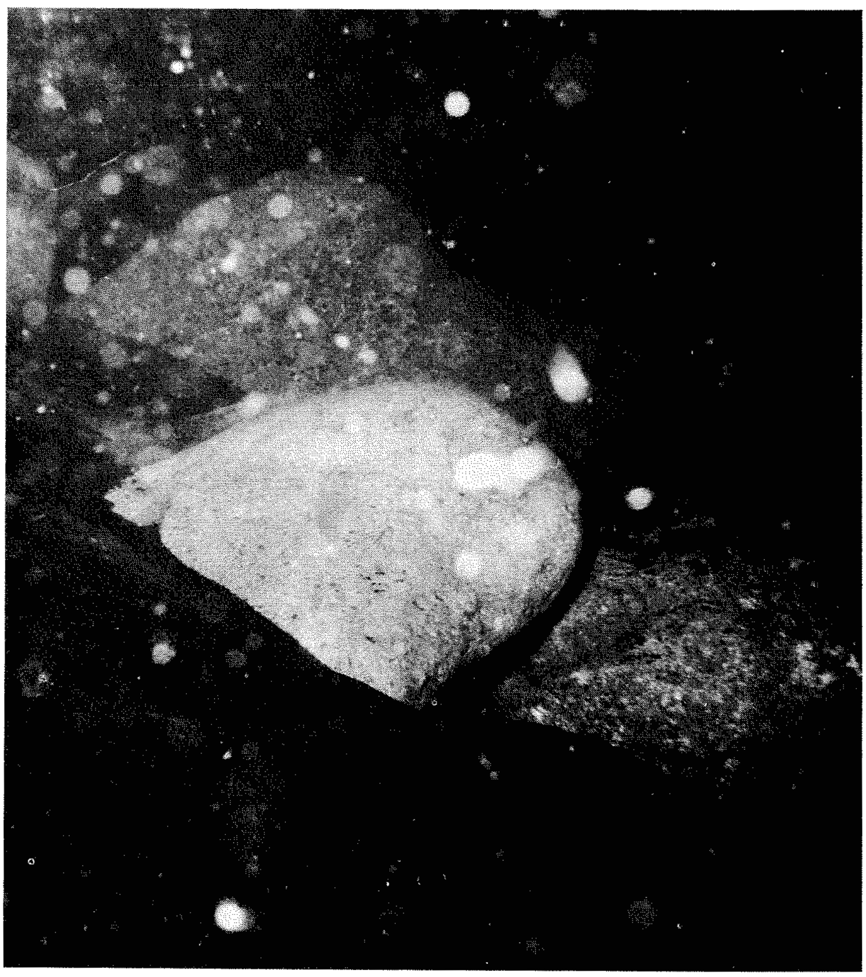

Fig. 14. Boulder stream in the western submarine slope of the northern ness. Dip of sand surface is at angle of repose. Photograph by T. Alexandersson, June 1968.

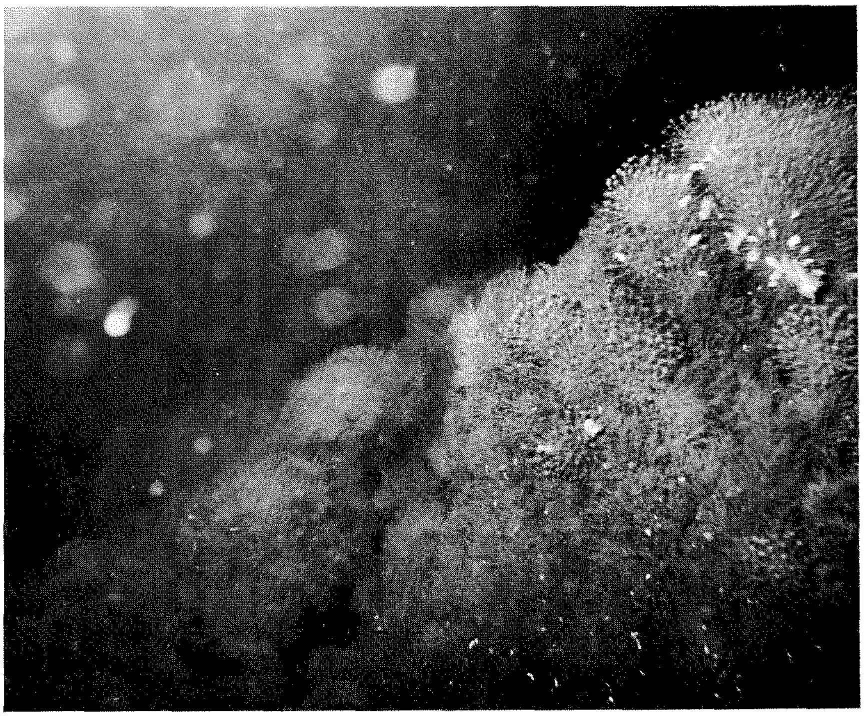

Fig. 15. Vegetated boulders in the steep submarine slope off the SE coast. Depth 35 m. Photograph by T. Alexandersson, June 1968.

into the sea and the abrasion of the lava has been most severe.

From the soundings of 1967 a map of the slope NW of the northern ness with 5-m contour intervals has been constructed (Fig. 12). The concave forms of the contours in the upper part of the slope followed by convex forms at lower level indicate a series of slumps. The slumping may have generated turbidity currents which have spread material far over the sea bed. Echo soundings along the coast in June 1968 pointed to a more pronounced slump morphology than that of Fig. 13 which is based on 10 sounding sections principally running in direction of slope dip.

Divings and echo soundings in the northern part of the area showed a sharp transition from the nearshore platform to the steep slope at a depth of 12 m. This slope was at angle of repose (30°– 34°) down to 73 m and then gradually levelled. Boulders were deposited at the top of the slope (Fig. 13) and coarse material that had

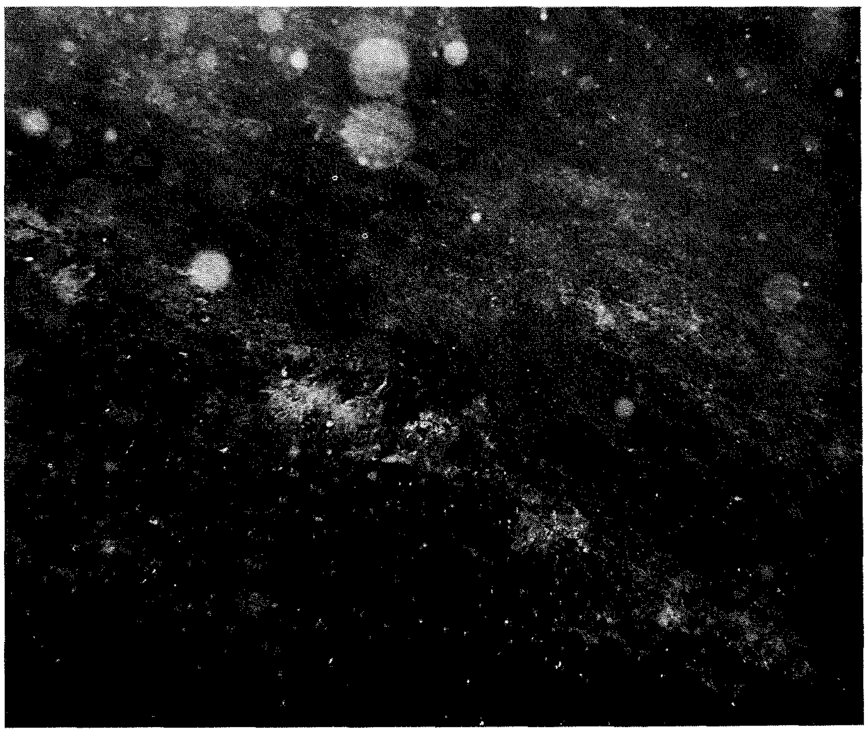

Fig. 16. From the slope off the SE coast. Sand bed at angle of repose with an angular small boulder in the centre of the picture. Depth 42 m. Photogarph by T. Alexandersson, June 1968.

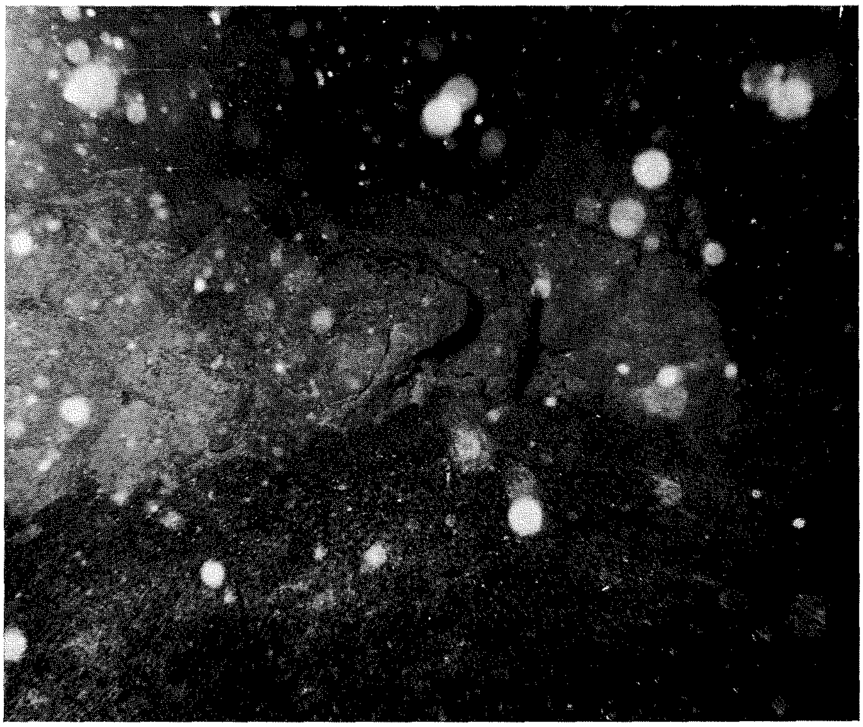

Fig. 17. Outcrop of lava and deposits of coarse sand. Off the SW coast. Depth 12 m. Photograph by T. Alexandersson, June 1968.

moved down the slope formed boulder streams (Fig. 14). A touch of the slope caused widespread avalanching.

In the chapter of shore morphology the transportation of sand and gravel by wave currents to the edge of the platform on the leeward shore has been discussed. This material dropped at the top of the slope will continue downslope in shallow flows and the slope will be built out at the frictional angle of repose. However, internal friction may permit an accretion to form at the top of the slope. When this load becomes too heavy it will start avalanching and bring large masses into motion.

Off the lava cliff immediately S of the eastern boulder terrace on the SE coast, the platform was found to be covered by large boulders. At the top of the steep slope, 150 m from the shore and at a depth of 20 m, giant blocks some with a diameter of 5 m were loosely heaped on top of each other. Farther down their size decreased (Fig. 15) and coarse sand started to fill up the space between boulders at a depth of 30—40 m. The sand below 40 m (Fig. 16) was deposited at its frictional angle (about 30°) but this part of the slope was not as steep as the upper boulder and block brink. Some boulders that had slipped down the sand surface were observed. No outcrops of lava beds were found. It seems most probable that the irregular morphology demonstrated by the depth contours of Fig. 1 represents heaps of lava blocks and not lava flows.

On the western coast the bottom off the lava cliff 500 m N of the Jólnir plateau was investigated. The divings started about 50 m from the shore where the depth was 6 m. At this point the bed was covered by rounded boulders of about 1 m in diam. Between the boulders lava beds could be seen. The platform descended in steps to about 12 m. In the vertical walls broken off pillars of lava were exposed. At 12 m of depth the bed started to be covered with coarse sand and granules (Fig. 17) which formed 0.3 m high ripples. Angular cobbles were found in the ripple troughs. This bed was followed to a depth of 18—20 m at about 175 m from the shore where a steep slope of boulders was met.

The study indicates that no level abrasion platform is still formed in the lava beds, but the rather even character of the submarine platform is caused by deposits of boulders which fill up cavities between projecting outcrops.

SUMMARY

Investigations on the shore and offshore morphology in June 1968 are reported. A photogrammetric map with 2-m contour intervals based on air photographs of 6 July 1968 has been constructed.

During the winter 1967/68 there was a rapid retreat of the lava cliff on the southern coast. The maximum retreat was 140 m and the average retreat about 75 m. The amount of lava abraded is estimated at 2 mill. cubic metres.

During the same period there was a slight decrease in the area of the northern ness (1.4 hec-

tares). The northwestern coast and the southern part of the eastern coast are protected by boulder terraces.

On the shoals of Surtla, Syrtlingur and Jólnir only loose deposits are exposed. The plateau level of Surtla and Jólnir was proved to have been lowered several metres during the winter. Information on the conditions of Syrtlingur is incomplete.

The submarine slopes of Surtsey were studied by SCUBA diving. The sandy material of the slopes of the northern ness is deposited at the frictional angle of repose. There is active avalanching and slump scars in these slopes. In the upper part of the slopes of the southern coast coarse angular boulders dominate. Some blocks are of the order of 5 m in diameter.

The future development of the island will be covered by air photographs and repeated surveying of fixed sections. In the summer of 1969 the submarine topography will be resurveyed by echographic soundings.

Acknowledgements

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References:

Norrman, J.O., 1968: Shore and offshore morphology of Surtsey. Report on preliminary studies in 1967. Surtsey Res. Progr. Rep. IV.

– 1969: Kustmorfologiska studier på Surtsey. (Coastal morphology of Surtsey island.) Svensk Naturvetenskap 1969. Stockholm.

Rist, S. 1967: Echographic soundings around Surtsey. Surtsey Res. Progr. Rep. III.

Russell, R. J., 1968: Where most grains of very coarse sand and fine gravel are deposited. Sedimentology, vol. 11 no. 1–2.

Sigurdsson, P., 1968: Report on Hydrographic Surveys at Surtsey 1967. Surtsey Res. Progr. Rep. IV.

Thórarinsson, S., 1965: The Surtsey eruption: Course of events and the development of the new island. Surtsey Res. Progr. Rep. I.

– 1966: The Surtsey eruption: Course of events and the development of Surtsey and other new islands. Surtsey Res. Progr. Rep. II.

– 1967: The Surtsey eruption, course of events during the year 1966. Surtsey Res. Progr. Rep. III.

– 1968: The Surtsey eruption. Course of events during the year 1967. Surtsey Res. Progr. Rep. IV.