Some observations on the sediments of Surtsey

By

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INTRODUCTION

Surtsey is geomorphically very active. The island marks the southernmost point of Iceland (Fig. 1), and due to the relatively steep submarine slope, the ocean waves first break on the island itself (Norrman 1970). The tephra of Surtsey is still largely unconsolidated (Jakobsson 1972, 1978), and this, along with the lack of vegetational cover, allows wind and running water freely to erode the island. The purpose of the present investigation is to observe erosion and sedimentation on the island, and to map the distribution of the various sediments.

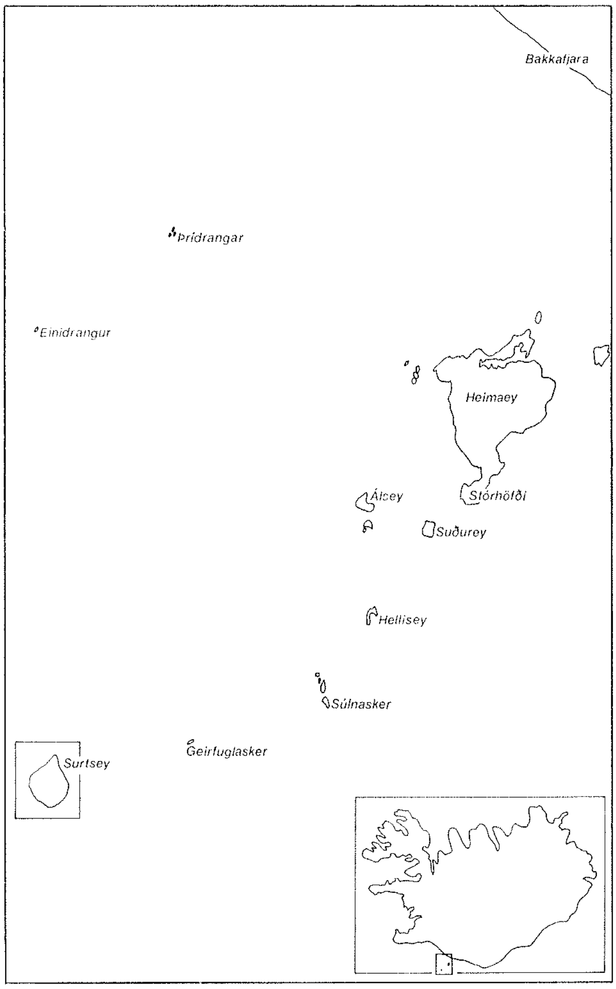

Fig. 1. A map showing the location of Surtsey.

Volcanic activity in Surtsey

Thorarinsson (1965a, 1965b, 1966, 1967, 1968) followed the course of events of volcanic activity in Surtsey. He also made valuable comments on the morphological development of the island. In a very brief summary, his observations were the following:

On the 14th of November 1963 it was first noticed that a submarine eruption was in process about 20 km SW of Heimaey. During the following days an island was built up, hooflike in shape, usually open towards SW. By the end of the year, the island had grown to the height of 145 m a.s.l., with a diameter of 1100 m. By that time only one crater, later to be called Surtur I (SI), was active.

On the 2nd of February 1964 volcanic activity started in another vent, Surtur II (SII), west of SI, and by 7th of February only SII was active. In April 1964 the phreatic activity had built a tephra wall thick enough to seal the vent off from the sea, and the eruption changed from phreatic to an effusive phase. For the next 13½ months lava flowed at intervals, considerably enlarging the island. On the 17th of May 1965 the activity of SII stopped.

During the next 14 months, phreatic eruptions built successively up two islands: Syrtlingur, ENE of Surtsey, and Jólnir, SW of Surtsey. Both islands reached a stage where they were more than 60 m in height and 650 m in length. The sea rapidly broke down the small islands after the volcanic activity stopped.

On the 19th of August 1966 effusive activity started in SI. Lava was seen flowing at intervals for the next 10 months, last on the 5th of June 1967. During this phase, few small parasitic cones around SI were active, but for a short time only, and without any considerable lava production.

Thorarinsson (1968) estimated the total production of eruptives during the Surtsey eruption to be 1.1–1.2x10^9 m^3, and he suggested that 70% of the total volume was tephra.

Review of research concerning the sediments of Surtsey

The contribution of Thorarinsson has already been mentioned. Norrman (1968, 1970, 1972a, 1972b, 1978, 1980) has monitored morphological changes in Surtsey, with special reference to the development of the northern ness and beach developments on the island. He points out, that costal erosion is rapid and that the coastline changes markedly from year to year. According to Norrman (1978, 1980) the coastal erosion amounts to 60 hectares between the years 1967 and 1975. Norrman et al. (1974) map the distribution of beach material on the island, and publish grain size distribution curves for 15 samples of sand from the lava area of Surtsey. Fridriksson et al. (1972) publish a substrate map of Surtsey, intended for comparison with a vegetation map compiled in 1970. Jakobsson (1971, 1972, 1978) discusses the consolidation and palagonitization of the Surtsey tephra, and publishes grain size distribution curves for some tephra samples (Jakobsson 1971). Sheridan (1972) deals with grain sizes of tephra and beach sand on the island. Lorenz (1974) discusses various aspects of the tephra, and deals with the structural properties of the tephra cones. Einarsson (1966) discusses various physical properties of the Surtsey tephra. Walker & Croasdale (1972) compare surtseyan tephra with strombolian-hawaiian tephra.

The origin of the Surtsey sediments

The primary source of unconsolidated sediments in Surtsey is tephra, formed during the phreatic phase of activity in SI and SII. The tephra is found bedded in the tephra cones, in the form of palagonite tuff and in the form of reworked sediments. Another source of sediments is the lava (Norrman et al. 1974).

Primary tephra is characterized by poor sorting and grain sizes ranging from silt to boulders, while eolian deposits are characterized by better sorting, and dominant grain sizes of silt and sand (Sheridan 1972, Norrman et al. 1974). Material transported by the force of gravity and running water is characterized by poor sorting (Norrman et al. 1974). The beach sand and the boulder ridge bordering the northern ness originate from two sources: a) glassy sand formed by fragmentation of the lava by rapid cooling when it entered the sea, and b) sand and boulders formed by the crushing effects of the breakers and grinding by the surf (Thorarinsson 1965b). Tephra eroded from the island constitutes but a small fraction of the beach sand (Thorarinsson 1967, Norrman 1968). A small fraction of the tephra found on Surtsey originates from phreatic activity in the small islands of Syrtlingur and Jólnir (Thorarinsson 1967).

METHODS AND TREATMENT OF DATA

The field work was carried out as a part time study in July and August 1979, with a check up in June 1980. Observations were made all over the island, with particular reference to structural and textural properties of the sediments. Many samples were collected for future analyses. When samples of tephra were collected, precautions were made to collect representative samples, usually from single beds, around 10 cm thick. Samples of eolian sands were collected as horizontal cores through dunes and ripples. One sample was collected from a deep pit formed by

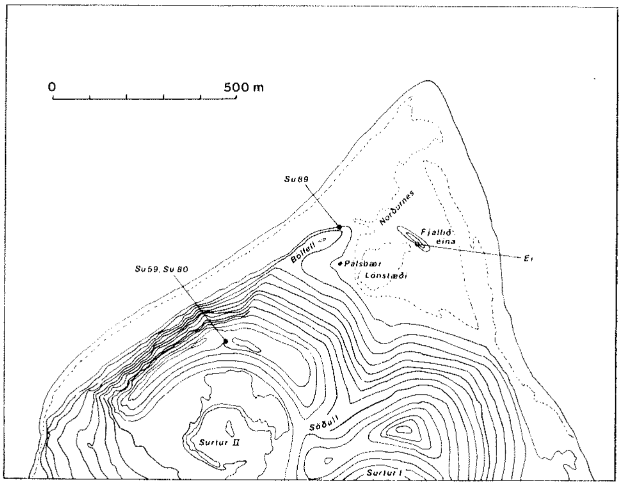

Fig. 2. Location of tephra samples. Major localities on the island: Pálsbaer: Scientist hut; Lónsstaedi: Old lagoon site; Nordurnes: Northern ness; Södull: Saddle. Base from Norrman (1978).

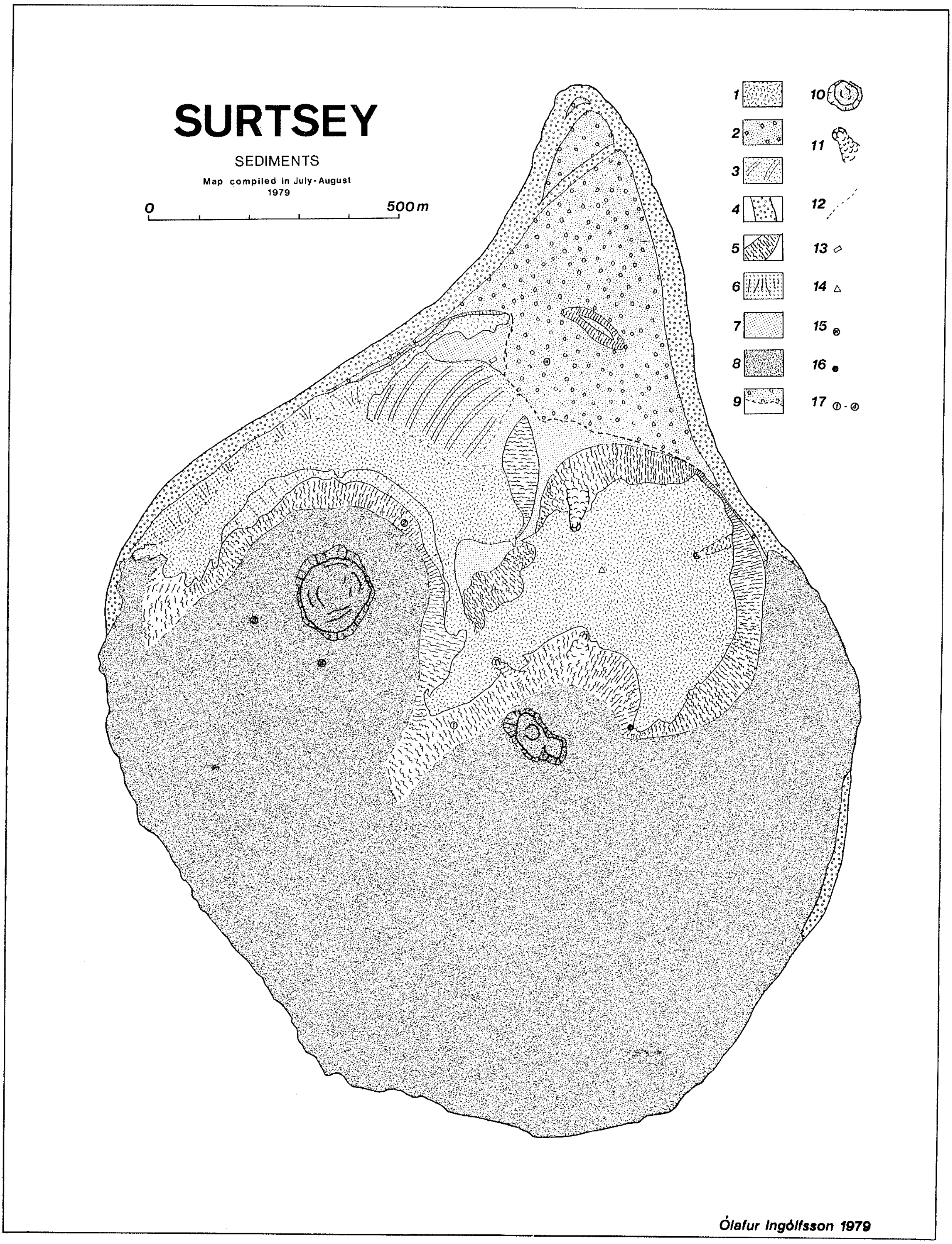

Fig. 3. Map showing the distribution of various sediments on Surtsey, as in the summer of 1979. Legend: 1) Tephra and palagonite tuff, 2) Beach sediments, 3) Mudflows and solifluction, 4) Boulder ridge, 5) Eolian sand in ripples and dunes, 6) Talus, 7) Assorted sediments, 8) Windblown sandcover on lava, 9) Evidence of swash as marked by driftwood, 10) Lava craters, 11) Parasitic cones, 12) Boundary not clear, 13) Pálsbaer (Scientist hut), 14) Lighthouse, 15) Pit in the old lagoon site, 16) Drill site, 17) Location of samples of eolian sand. Base of map: Air photograph of Surtsey, no. 4410, taken in July 1979 by the Icelandic Geodetic Survey.

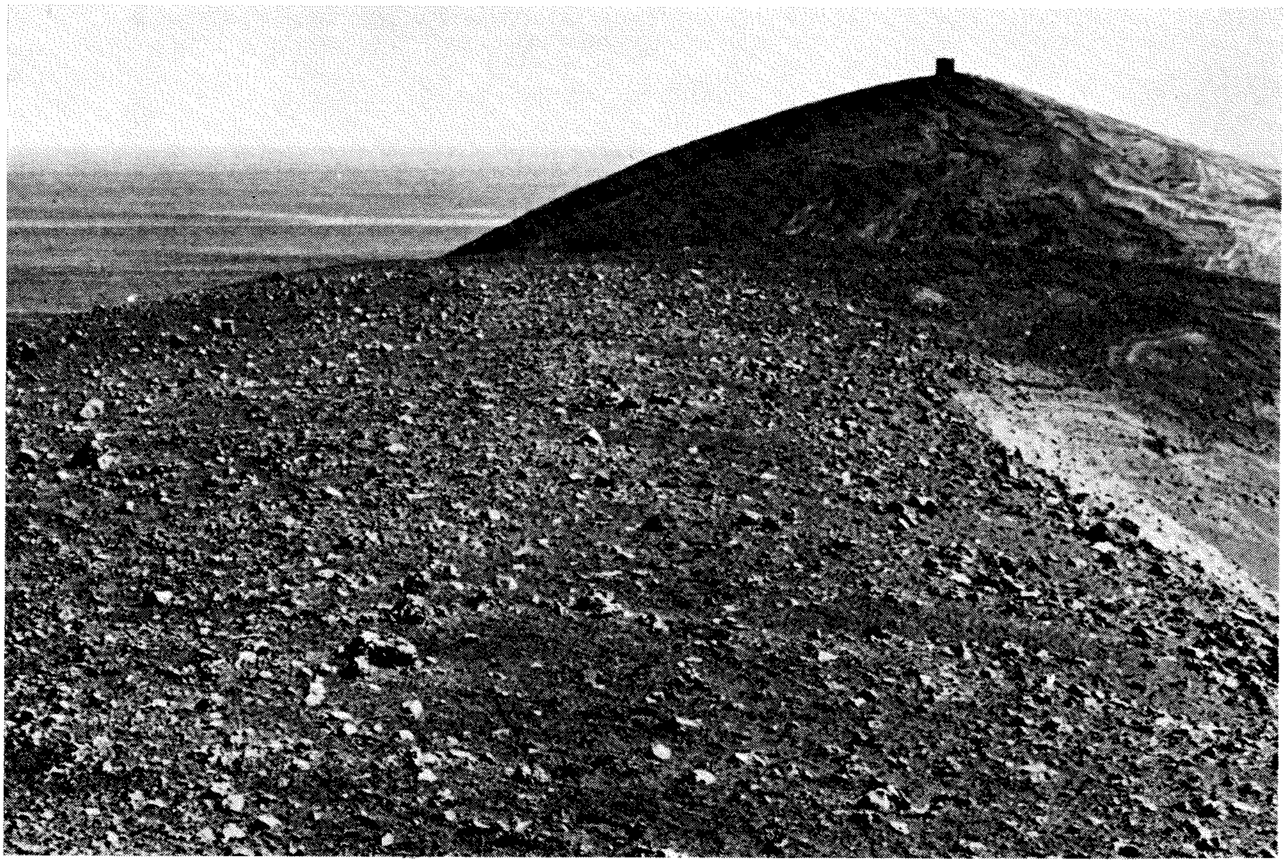

Fig. 4. Top of the SII tephra cone, viewing towards ESE. SI cone in background, with lighthouse on highest point.

a cave-in in the lava south of SII. The structure of the northern ness was observed in a pit dug in an old lagoon site on the inner part of the ness (Fig. 2). The size of the samples collected ranged from 250 to 600 grms.

After randomly halving the samples down to a size of 90—200 grms, they were washed in about 200 ml of distilled water. Jakobsson (1971) warns that seasalt may cause cohesion among the silt particles, which could cause the silt fraction to be underestimated if the samples were not washed before sieving. In order to check this statement, washed and unwashed parts of the samples were sieved for comparison. Only washed samples are represented in the grain size distribution curves in this paper. After washing, the samples were dryed for 24 hrs at 90°C, and then sieved with one phi interval. The grain size scale used is the phi scale, as proposed by Krumbein (1934). For calculating the mean, the equation presented by Folk & Ward (1957) was used, but equations presented by Inman (1952) for calculating sorting and skewness.

Figure 3 shows the distribution of the various sediments on Surtsey as mapped in the summer of 1979. The sediments of Surtsey have only been transported over short distances, so the classification of sediments in a given locality usually is matter of qualitative estimation. When preparing the map, units were chosen for each locality on the basis of which group of sediments was the most abundant one.

CLASSIFICATION AND RESULTS

Mapping unit 1: Tephra and palagonite tuff

Primary tephra is found in the tephra cones of SI and SII, in Bólfell and Fjallid eina (Figs. 2 and 3). Jakobsson (1978) points out, that consolidation and palagonitization of the tephra is almost entirely confined to the eastern tephra cone (SI). On the top of SII, pebbles to cobbles are the most abundant grain sizes (Fig. 4), as the wind blows away finer particles. Thorarinsson (personal communication, 1980) has monitored the lowering of the tephra cones due to wind erosion, taking readings from stakes, vertically inserted in the cone rims. According to his observations, the maximum denudation measured during the period July 1967 to August 1970 occured on the northern rim of SII, 92 cm. During the same period of time, the central part of the highest rim of SI was lowered by 52 cm. The maximum denudation during the period 1970

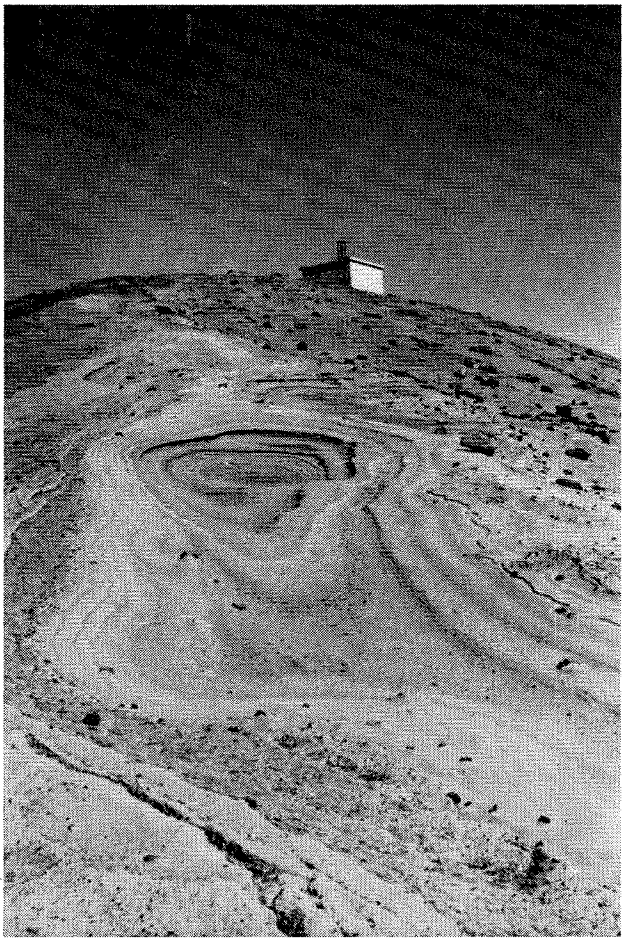

Fig. 5. Wind -eroded pothole in palagonite tuff on the interior of SI. The pothole is 0.4 m deep, with a diameter of 1.5 m.

to 1976 occured on the central rim of SI, 40 cm, but only 10 cm on the rim of SII. Between 1976 and 1979 the rim of SII was lowered by 5 cm. Thus the maximum denudation measured between the years 1967 and 1979 equals about 110 cm, and the rate of wind erosion on the tephra cones is slowing down. Thorarinsson (personal communication, 1980) estimates that since phreatic activity stopped in Surtsey, the maximum lowering of the tephra cones due to wind erosion equals 1.5—2.0 m.

The palagonite tuff on the interior slope of SI is being wind eroded, often resulting in erosional features such as potholes (Fig. 5). The erosion has left the small lavas from the parasitic cones on the interior of SI standing on pillars of palagonite tuff. By measuring the vertical pillar span, the average denudation on the interior of SI can be estimated to be 30—45 cm since the time of the lava flows (January 1967).

Four samples of tephra, collected by S. P. Jakobsson (Table I) were sieved (for location see Fig. 2). The results correspond fairly with those obtained by Sheridan (1972). The cumulative frequency curves (Fig. 6a) show the very poor sorting of the material, the curves bein concave in form as a result of high percentage of silt.

TABLE I
Size distribution parameters of tephra.

Sample no	Mz	Sorting	Skewness	Date coll.
Ei	1.28	2.77	0.21	1970
Su 59	0.06	3.25	0.40	7/7 1971
Su 80	–0.05	2.50	0.36	10/8 1974
Su 89	0.87	2.92	0.32	5/9 1975

After washing, two samples, Ei and Su 59, showed a bigger proportion of silt than before washing. Samples Su 80 and Su 89 showed no significant changes in the silt proportion after washing. Samples Ei and Su 59 were collected at an earlier date than samples Su 80 and Su 89 (Table I). The result that the older samples show changes in silt proportion after being washed, could lead to the conclusion that seasalt

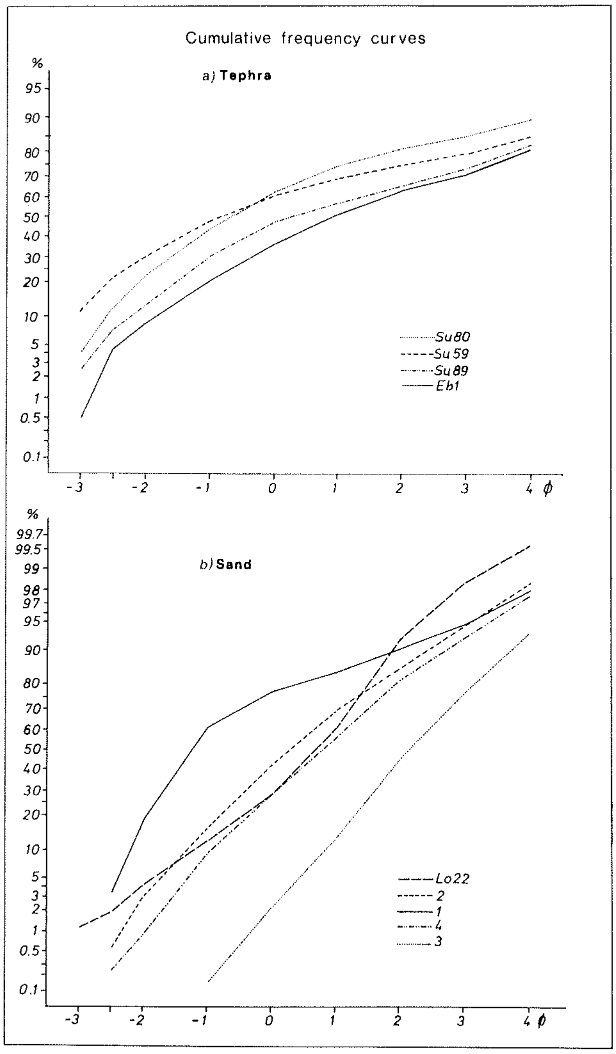

Fig. 6. Cumulative frequency curves.

indeed causes cohesion among the finer particles of the tephra, but is being washed away by rainwater as time passes. More data are needed to test this hypothesis further.

Mapping units 2 & 4 : Beach deposits

Beach deposits are mainly found north of the tephra cones. The most frequent wind directions in Surtsey are southerly- and easterly winds (Norrman 1970, Einarsson 1976) with corresponding wave directions. Norrman (1980) suggests that winds from WSW and SW are the most importand ones for the morphological development of the island. The SW-coast of Surtsey is constantly being eroded, and material is transported by ocean streams and wave action north along the east- and west coasts of the island. The northern ness is thus being built out, forming a cuspate foreland (Norrman 1970). The position of the ness is up to a point dependant on the most frequent wind directions, and has changed somewhat over the years (Norrman 1968, 1970, 1972a, 1972b, 1978, Norrman et al. 1974), though the average trend in recent years has been a move towards the east (Norrman 1980). The northern ness is bordered by a boulder ridge, reaching in some places 6 m a.s.l. At times, especially during heavy winter storms, the swash overrides the boulder ridge, carrying driftwood up to 5—6 m a.s.l. on the inner part of the ness.

The inner part of the ness was originally occupied by a lagoon, formed by large scale slumping and subsidence of the tephra pile (Norrman 1970). The lagoon was reduced in size by a small lava flow in January 1967 (Thorarinsson 1968), and has since then been gradually filled up by sediments. The surface of the former lagoon site is now roughly 2 m a.s.l. (Moore 1982), and the lava is almost entirely buried in sand.

In the summer of 1979 a pit was dug in the old lagoon site (for location see Fig. 3). In the walls of the pit, the structure of the lagoon filling could be observed (Fig. 7). The filling is built up of thin beds and laminae of silt, sand and gravel. The sand and silt appears to be deposited in water, with characteristic ripples and load casts. The silt-sand contact is frequently deformed, which could be due to the force of gravity in a saturated environment. A plausible explanation is, that swash, overriding the boulder ridge, carries material from the beach to the inner parts of the ness and deposites it there. The swash also erodes the foot of the tephra cones above the ness, and deposites the material in the area between the cones and the boulder ridge. The silt beds and laminae suggest that the area is flooded for some time, long enough to allow silt to be independently deposited from the water.

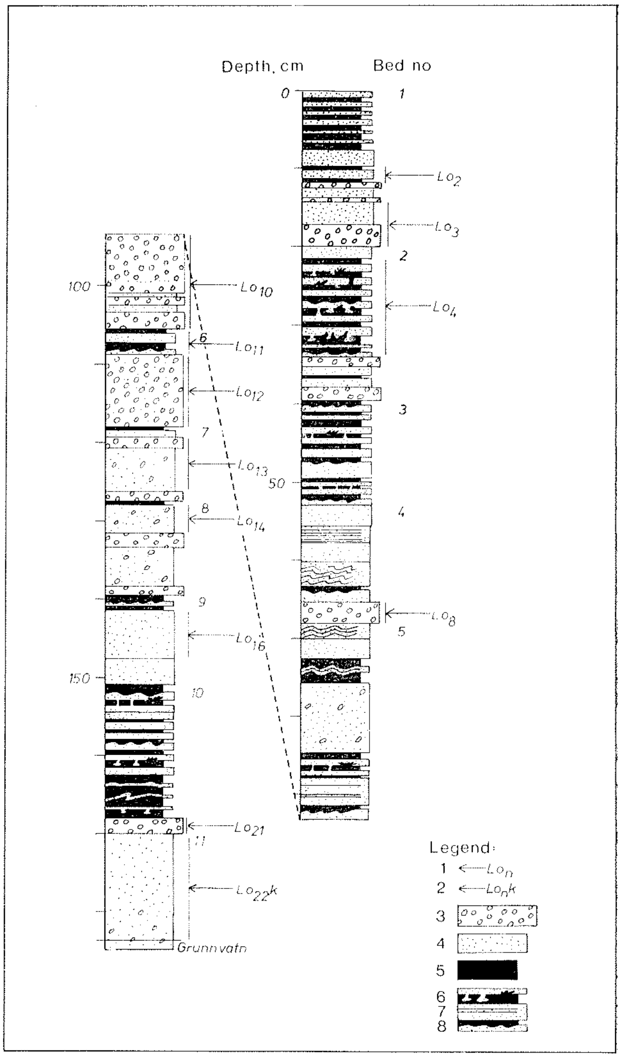

Fig. 7. Columnar section through the lagoon sediments. Legend: 1) Sample no, 2) Grain size analysis no, 3) Pebble gravel, 4) Sand, 5) Silt, 6) Load casts, 7) Laminae, 8) Ripples. — Grunnvatn: Ground water.

According to this reasoning, wind, mudflows and solifluction contribute to the northern ness by transporting material to the foot of the cones, making it available for the swash to transport and deposit on the ness.

Fieldwork in the spring of 1980 confirmed previous observations. Following heavy April storms, the swash had obviously overridden the boulder ridge. On top of the surface bed of 1979 in the old lagoon site, about 15 cm thick bed of rippled sand, coated by a laminae of silt, had been deposited.

In dry weather, the ness is subject to deflation. The dominant grain sizes at the surface of the

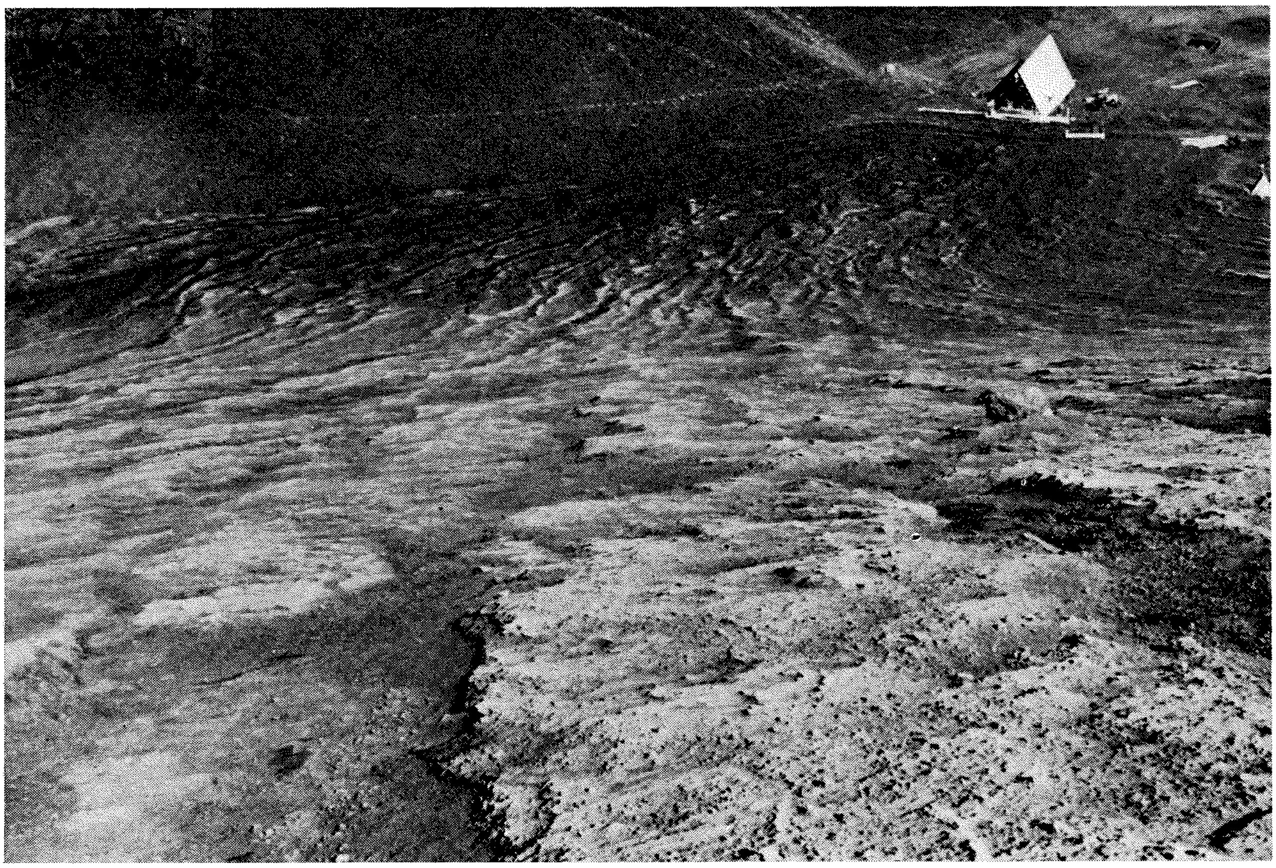

Fig. 8. Mudflow channels on the north facing slope of SII.

ness range from coarse sand to boulders (see foreground of Fig. 9). This corresponds with the observations of Norrman (1980).

In the pit, brackish groundwater was reached at the depth of approx. 1.85 m (bed no. 11 on Fig. 7). Grain size analysis shows that the material of bed no. 11 is poorly sorted (So: 1.15) with mean grain size of coarse sand (Mz: 0.52), and markedly low proportion of silt (see sample Lo_{22} on Fig. 6b). Measurements of the waterlevel in the pit clearly showed the tidal cycle, ranging in height from 1.5 to 5 cm between adjacent high and low tides. The time of high tide in the pit was out of phase with that of the open ocean, with an average of 5.82 hours after the last peceding high tide in Vestmannaeyjar, as determined from tidal tables (Moore 1982). The pit is 260 m distant from the ocean, and the damping of the tidal flux and the retardation of the tidal cycle clearly demonstrate the limited permeability of the material constituting the northern ness (Moore 1982).

Mapping unit 3: Mudflows and solifluction

The north facing slope of SII is characterized by numerous mudflow channels. Usually the channels are 1-3 m wide, reaching down the entire length of the slope, turning eastward at its foot, away from Bólfell. The mudflow material is very poorly sorted, with grain sizes ranging from silt to boulders. The north facing slope of SII is shiftingly affected by mudflow and wind drift activity, depending on weather conditions. Westerly and northerly winds, usually without precipitation, cause deflation in the area (Fig. 9).

Field observations in 1979 and 1980, as well as the evidence of air photographs, suggest that most of the mudflow channels are old and relatively stable phenomena, changing but minimum from year to year. During heavy rains, water flows down the slope, eroding the channels, and building fans at the foot of the slope.

Solifluction on the slope above Pálsbaer (scientist hut) is considerable. A stake set up for measuring purposes in August 1979, had been transported 2.5 m down the slope in June 1980. The load of sediments pressing against Pálsbaer also bears witness to the solifluction (Fig. 8). In July 1979, an estimated 70 tns of material had to be dug away from the hut in order to prevent the load from pushing the hut off its foundations or further tilting it. In June 1980 an estimated

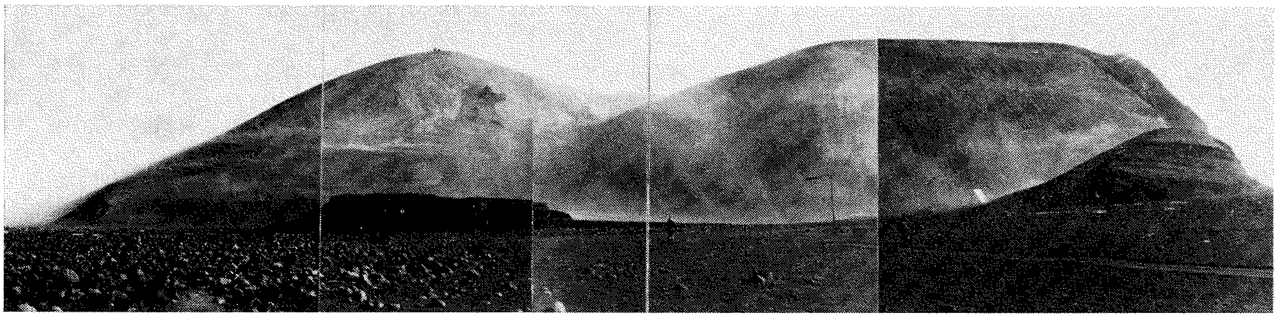

Fig 9. Deflation east along the north facing slopes of the tephra cones. Also notice the coarse material on surface of the northern ness in foreground. Photographed on August 7, 1979. Estimated wind force is 30—35 knots from WNW.

8 tns of material which had accumulated since July 1979 had to be dug away from the hut.

Mapping units 5 & 8: Eolian sand

Eolian sand in Surtsey can be assigned to two groups: Sand dunes and ripples around the tephra cones (mapping unit 5), and windblown sand cover on the lava area (mapping unit 8). The difference between the two groups is demonstrated in Table II and Fig. 6b.

Table II
Size distribution parameters of eolian sand

Sample no	Mz	Sorting	Skewness
1	–0.77	2.02	0.47
2	0.38	1.45	0.34
3	2.23	1.12	0.11
4	0.82	1.37	0.02

Samples no. 1 and 2 were collected from ripples and dunes, but samples no. 3 and 4 from the lava area (for location see Fig. 3). The former group is characterized by poor to very poor sorting, with dominant grain sizes of coarse and very coarse sand. Samples representing the second group, show better sorting and dominant grain sizes of medium and fine sand. Both groups have an upper size limit of grains at –2.5 phi (6 mm), and considerable better sorting than the tephra (Table I and Fig. 6a).

The differences between the two groups reflect different modes of transport. The dune-ripple material is transported by saltation and creeping along the surface, while the sand on the lava has been transported in suspension and by saltation.

Sample no. 3 was collected from a 10 m deep pit, formed by a cave-in in the lava south of SII during the winter of 1965-66. At the bottom of the pit, on top of the Jólnir tephra, windblown sand accumulated over the years. Sample no. 3 shows dominant grain size of fine sand, with a high silt percentage, and markedly best sorting of the samples analysed.

The ripple and dune sediments show a tendency to bimodality, with a higher percentage of finer material on the lee sides. It is difficult to recognize any characteristic dune pattern in Surtsey, probably due to the short transport of the sediments and the ever shifting wind directions.

The main source of dune-ripple material is probably the unconsolidated NW-facing cliff of SII. Another source is the northern ness. Huge mass-transport of windblown material takes place east along the tephra cones (Fig. 9), and the largest dunes are found on the NE and E-side of SI. The most important wind directions for dune- and ripple formations are proably the relatively dry westerly and northerly winds.

Quantitative measurements of how much of the windblown material actually is blown off the island are lacking. Such data, however, could give valuable information on the probable future development of soils and vegetation on the island. An efforts was made to estimate this, by using planimeter, maps, air photographs and the data of Norrman (1978, 1980) on aerial changes of the island due to coastal erosion. This effort did not give any convincing results, as the unknown factors and variables are too many for the results to pass statistical tests.

Mapping unit 6: Talus material

Talus material, extremely poorly sorted, with small tops in coarse sand and cobbles, is found almost everywhere on and beneath the slopes of the tephra cones. However, it only forms independant sediments on the interior slopes of SII and beneath the NW-facing cliff, elsewhere not readily distinguishable from other sediments. The material is transported by force of gravity from the top of SII, transforming the western rim into sharp edges. Material falling down the NW-cliff tends to be directed by erosion scars in the cliff, resulting in typical interwoven colluvial fans at the foot of the cliff.

Mapping unit 7: Assorted sediments

Sediments belonging to this unit are too mixed to be successfully assigned to any of the other units described in this paper. This material is a conglomerate of eolian sand, mudflow- and talus sediments. As a whole, the material is very poorly sorted, though lenses of better sorted material occur, and structurally diffuse. These sediments are mainly found in the saddle between the tephra cones, and they reach from the saddle onto the northern ness.

DISCUSSION, FUTURE RESEARCH ACTIVITY

Due to the short transport of the sediments of Surtsey, identification and mapping of the sediments is a difficult task, were qualitative estimates are unavoidable. Still, one can within reasonable limits of confidence distinguish between sediments transported and deposited by sea, wind, running water and gravity. The use of grain size parameters is justifiable, as it leads to convincing results. The island is an excellent spot to observe the interaction between erosion and deposition, and further research could give important clues as to the formation of soils in Iceland. Future research could also give answers to questions concerning the role of pyroclastics and reworked sediments in the Icelandic móberg-formation.

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