Dredge hauls from Vestmannaeyjagrunn, Iceland

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INTRODUCTION

The Vestmannaeyjar volcanic system forms the southernmost part of the Eastern Volcanic Zone of Iceland (Jakobsson 1979). Vestmannaeyjar (Westman Islands) are made up of 17 islands (>100 m long) and numerous skerries and shoals. The volcanic activity of this system has apparently always been of low intensity. The oldest exposed rocks belong to the so-called Nordurklettar formation on Heimaey, and are probably of late Glacial age (Jakobsson 1979). A 1565 m deep drill hole on Heimaey indicates that this formation rests on marine tuffaceous sediments at about 180 m below sea level (Tómasson 1967); the sediments are of Quaternary age and the uppermost part being probably of Pleistocene age (Símonarson 1982). There have been identified 17 Holocene (Postglacial) eruption sites (single eruption units) with remnants above sea level, including the recent Surtsey and Heimaey eruption sites. In addition, a submarine eruption may have occurred south or southeast of Hellisey in 1896 (Thorarinsson 1965a).

Petrological studies of the Vestmannaeyjar volcanic system have hitherto been limited to the islands and the skerries. Bathymetric maps reveal numerous steep hills on the surrounding shelf (Vestmannaeyjagrunn), and it has been suggested that these hills and peaks have been built up in Recent submarine eruptions (Jakobsson 1968). According to local fishermen fresh volcanic rocks („brunagrjót") have been carried up with fishing-nets from several of these hills, including the unnamed hill southeast of Surtsey, and Trintur northnortheast of Thrídrangar (Eyjólfur Gíslason, pers. inform. 1966).

In August 1974 rock samples were dredged from eight prominent submarine hills by Dr. Kjartan Thors, on board the r/v Hafthór, of the Marine Research Institute, Reykjavík, — the submarine hill Surtla, which formed in the Surtsey eruptions, was included for comparison. In November 1982, rock samples were in addition dredged from the submarine hills of Syrtlingur and Jólnir by Kjartan Thors and the author, on board the r/v Árni Fridriksson. Previously, a few sediment grab samples had been collected from the sea bottom around Surtsey, and they will also be briefly discussed.

THE ROCK DREDGE HAULS

The dredge hauls were obtained with the common rock dredge, which has a mesh measure of 7 cm (cf. Kristjánsson et al. 1976, Fig. 3). In some cases, however, smaller rock pieces than 7 cm across were obtained if embedded in mud.

A summary of data for the eleven locations is given in Table I, altogether there are 16 dredge hauls. The location of the dredge hauls is shown in Fig. 1. All the collected material is considered to be *in situ* material with the exception of dredge haul H74—D7, 2 (Bensaklakkur) and dredge haul H74—D9 (hill E of Bensaklakkur). In the following brief description, the dredge hauls are arranged according to estimated age, judging from the degree of roundness, alteration (palagonitization), weathering and erosion, e.g. with reference to experience from Surtsey, cf. Jakobsson & Moore (1982).

1. Dredge hauls from the recent Surtsey eruption sites

Four dredge hauls were collected from the submarine hills Surtla, Syrtlingur and Jólnir which formed in the Surtsey eruptions of 1963-

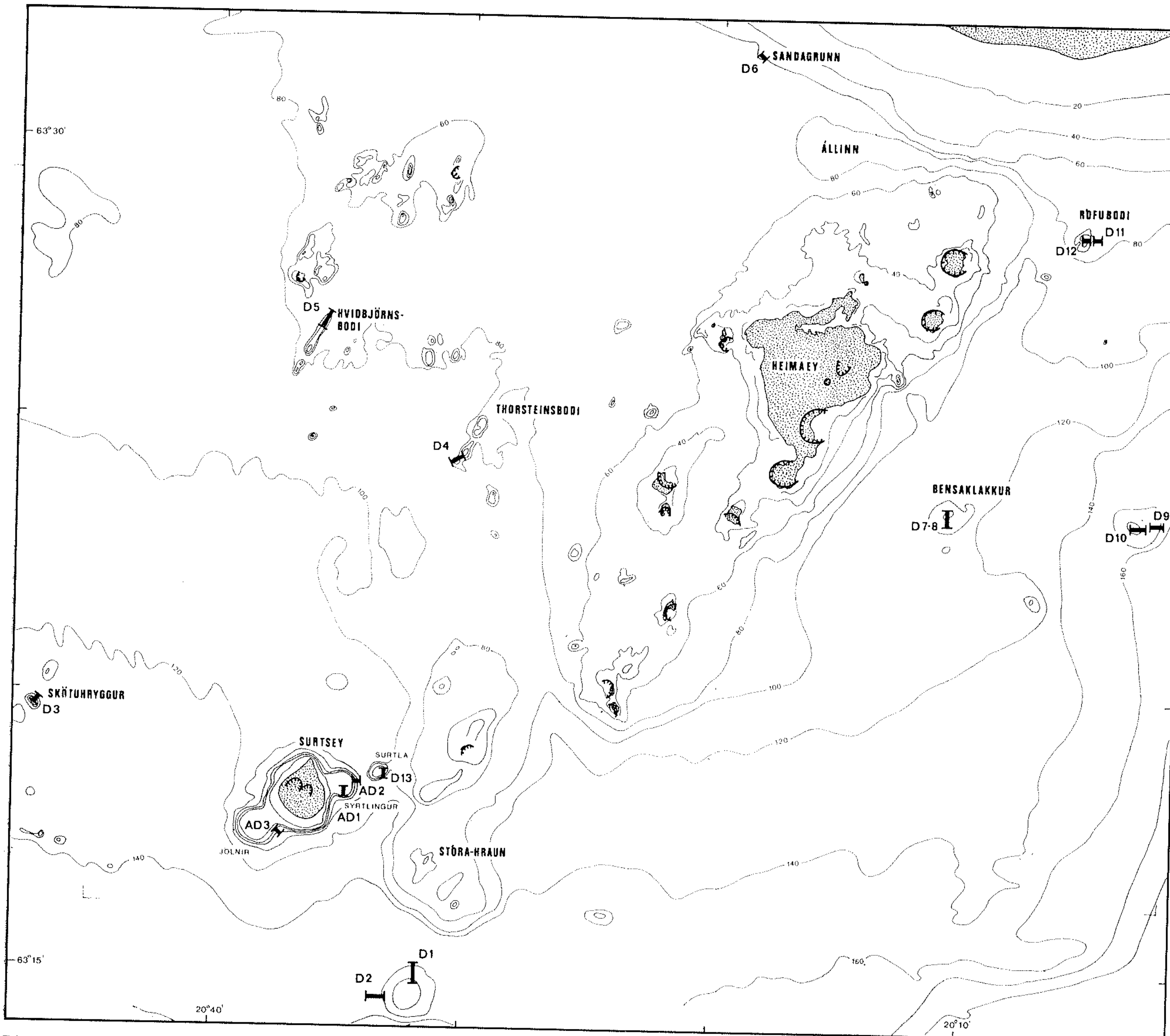

Fig. 1. Bathymetric map of Vestmannaeyjagrunn, after Map. no. 321 (Vestmannaeyjar), Icelandic Hydrographic Service, 1982. The Hafthór rock dredge hauls of 1974 are indicated with D-numbers, and the Árni Fridriksson of 1982 with AD-numbers, cf. Table I. Also shown are Holocene phreatic eruption sites above sea level.

1967: H74—D13 (Surtla), A82—D1 and D2 (Syrtlingur) and A82—D3 (base of Jólnir). Islands were built up but subsequently washed away at the sites of Syrtlingur and Jólnir, but at Surtla a submarine ridge remains. The samples from Surtla and Syrtlingur consist of coarse, angular, dense and fresh scoria, and pieces of fresh vesicular basalt, but no pillow lava was observed. Many of the pieces are covered with a considerable amount of biological growth.

The dredge haul A82—D3 was collected from the southeast base of the Jólnir hill, i.e. from the rugged part of the reflection profile in Thors & Jakobsson (1982, Fig. 3), and consists solely of fragments of pillow lava with fresh glassy surfaces. This is probably part of the flat submarine ridge, which is believed to have formed during May—June 1964, when there was a lull in the subaerial lava flow from the lava crater of Surtsey (Einarsson 1965, Thorarinsson 1965b).

2. *Dredge hauls of supposed Holocene (Postglacial) age*

Four dredge hauls each of which contains only one rocktype, are considered to have formed after the last glaciation: H74—D1—D2 (hill SE of Surtsey), H74—D3 (Skötuhryggur), H74—D10 (hill E of Bensaklakkur) and H74—D12 (Rófubodi), cf. Table I and Fig. 1. Some of the pieces in these dredge hauls are obviously broken off solid mass of rock, but many have been lying loose. Surfaces are fresh and angular, although glass occasionally shows incipient palagonitization; only traces of secondary minerals are found. No traces of mud or glacial erratics were found in these samples, except in the case

TABLE I

Data on the rock dredge hauls from Vestmannaeyjagrunn. Compare Fig. 1 and Table II. Samples collected from r/v Hafthór in August 1974 are marked H74; those collected from r/v Árni Fridriksson in November 1982 are marked A82.

Location, and dredge haul no.	Latitude and longitude	Depth. Sample weight	Rock-type populations; references to chemical analyses
Hill SE of Surtsey H74-D1(4637)	63°14.8′N 20°31.7′W	125-150 m 2 kg	1. Subrounded basalt scoria (lapilli) embedded in mud, with traces of palagonite. Possibly Holocene (Postglacial).
Hill SE of Surtsey H74-D2(4639)	63°14.4′N 20°33.3′W	140-155 m 18.5 kg	1. Angular pieces of fresh, vesicular basalt. Probably Holocene. Probably same rock-type population as H74-D1. Chemical analysis in Table II, no. 3.
Skötuhryggur H74-D3(4640)	63°19.8′N 20°47,0′W	60-100 m 20.5 kg	1. Tuff-breccia, incoherent, traces of palagonite. Probably Holocene. Chemical analysis in Table II, no. 2.
Thorsteinsbodi H74-D4(4641, 4643)	63°24.2′N 20°30.5′W	40-80 m 5.5 kg	1. Tuff and tuff-breccia, with eroded and weathered surface; slightly palagonitized and with calcite fillings. Probably pre-Holocene.
Hvidbjörnsbodi H74-D5(4642, 4644)	63°26.8′N 20°35.8′W	20-70 m 2.5 kg	1. Tuff with eroded and weathered surface; palagonitized, with a few calcite fillings. Probably pre-Holocene.
Sandagrunn H74-D6(4645)	63°31.6′N 20°18.5′W	20-40 m 2.0 kg	1. Tuff, with eroded and weathered surface; considerably palagonitized. Probably pre-Holocene.
Bensaklakkur H74-D7(4646)	63°23.4′N 20°10.7′W	70-100 m 24.5 kg	1. Tuff and tuff-breccia, with weathered surface; palagonitized; covered with mud. Probably pre-Holocene.
			2. Rounded boulder of transitional basaltic andesite. Glacial erratic.
Bensaklakkur H74-D8(4647)	63°23.4′N 20°10.7′W	70-100 m 6.0 kg	1. Coarse tuff, considerably palagonitized, partly covered with mud. Probably pre-Holocene. Not same rock type population as H74-D7.
Hill E of Bensaklakkur H74-D9(4648)	63°23.3′N 20°02.1′W	125-150 m 0.8 kg	1. Fine sand and silt, semiconsolidated, no layering visible. Possibly mainly Holocene.
Hill E of Bensaklakkur H74-D10(4649)	63°23.2′N 20°03.0′W	110-125 m 1.0 kg	1. Angular pieces of scoria and tuff, traces of palagonite, partly embedded in mud. Probably Holocene. Chemical analysis in Table II, no. 1.
Rófubodi H74-D11(4651)	63°28.4′N 20°04.9′W	50-70 m 45.0 kg	1. Tuff-breccia, palagonitized, with eroded and weathered surface. Probably pre-Holocene.
Rófubodi H74-D12(4650)	63°28.4′N 20°05.3′W	50-55 m 10.0 kg	1. Angular pieces of fresh scoria (mostly lapilli) and coarse tuff, traces of palagonite. Probably Holocene. Chemical analysis in Table II, no. 5.
Surtla H74-D13(4638)	63°18.5′N 20°33.1′W	50-100 m 19 kg	1. Dense, fresh scoria. Submarine eruption Dec. 28, 1963-Jan. 6, 1964. Chemical analysis in Table II, no. 4.
Syrtlingur A82-D1(8066)	63°18.2′N 20°34.7′W	30-40 m 7 kg	1. Angular pieces of fresh vesicular basalt. Submarine and subaerial eruptions from May to October, 1965.
Syrtlingur A82-D2(8067)	63°18.4′N 20°34.2′W	60-80 m 0.6 kg	1. Angular pieces of fresh scoria. Submarine and subaerial eruptions from May to October 1965. Same rock-type population as A82-D1.
Jólnir (base of hill) A82-D3(8068)	63°17.4′N 20°37.3′W	85-95 m 70 kg	1. Fragments of pillow lava with fresh glass surface. Submarine lava flow from Surtsey in May-June 1964?

of H74–D10, were scoria of lapilli size was partly embedded in fine sand and silt.

Dredge haul H74–D9 (hill E of Bensaklakkur) consists of semiconsolidated fine sand and silt (mud). This material has not been investigated in detail, but judging from the apparently rapid process of consolidation of the bottom sediments in the area (Alexandersson 1972), it may be suggested that it is mainly of Holocene age.

3. Dredge hauls supposedly pre-Holocene

Six dredge hauls (each of which contains one rock-type population) from four submarine hills are considered to be of pre-Holocene age. With reference to the results from the drilling in Heimaey (Tómasson 1967), it seems likely that these rocks are of Upper Pleistocene age, and then most probably of Late Glacial age: H74—D4 (Thorsteinsbodi), H74—D5 (Hvidbjörnsbodi), H74—D6 (Sandagrunn), H74—D7,1 (Bensaklakkur), H74—D8 (Bensaklakkur) and H74—D11 (Rófubodi), cf. Table I and Fig. 1. All the rock samples of these six dredge hauls are broken off a solid mass. The pieces are, with one exception, tuff or tuff-breccias, usually showing eroded (glacial?) and weathered surface; alteration is distinct to considerable. Many of these samples have been covered by unconsolidated to semiconsolidated thin layers of mud (fine sand and silt). An investigation of the petrography of these dredge samples strongly indicates that they belong to the Vestmannaeyjar volcanic system.

4. Dredge haul containing erratic material

One dredge haul, H47—D7 (Bensaklakkur), contained one piece of rounded erratic rock. Judging from thin-section analysis, this is a transitional basaltic andesite, very similar to some of the lavas of the Eyjafjöll volcanic system, as e.g. the 308—Hamragardar lava (Jakobsson 1979). In this connection it is of interest to note, that in the tephra deposits of Surtsey, and Saefell of Heimaey, a wide assortment of erratic rocks are found, including rocks of foreign origin, as gneiss, granite, schist and carbonate sediments. These erratics must have been transported to the area by drift ice.

SEDIMENT GRAB SAMPLES

During a biological investigation in August 1966, Nicolaisen (1967) collected seven samples of the uppermost unconsolidated sediment on the seafloor around Surtsey. The samples were collected by means of a Smith-MacIntyre bottom sampler. By estimate the sampler may have reached some 10—20 cm into the soft sediment.

One sample was collected 0.1 nautical mile due north of Surtsey, and consists of fresh and angular basaltic glass and basalt fragments, all of sand size (Jakobsson 1971). The material is a mixture of watersorted Surtsey tephra and detritus from the Surtsey lava.

The other samples were collected at a distance of 1, 3, 7 and 12 nautical miles due west of Surtsey, and 7 and 12 miles due east of Surtsey, cf. Fig. 1. The samples collected 1 and 3 miles west of Surtsey consist solely of fresh and angular basaltic glass in the silt and sand fractions. The material is watersorted tephra, and there is no doubt that it stems from the Surtsey eruptions. Although the samples contained many living bottom animals (Nicolaisen, pers. inform. 1967), no erratic material could be detected by microscopical investigation.

The sample collected 7 miles west of Surtsey contains, besides basaltic tephra from Surtsey, a considerable amount of erratic material, and a few shell fragments. The samples collected 12 miles west of Surtsey, and 7 and 12 miles east of Surtsey, contain, besides tephra from Surtsey, a large amount (some 40-60 percent) of erratic glass and rock fragments, and shells.

Although it is not possible to state it explicitly, the investigation suggests that the deposition of Surtsey pyroclastics on the seabottom around Surtsey was mainly within a radius of 3 to 7 miles ($5\frac{1}{2}$—13 km) from the island.

PETROLOGY

The dredged rocks of Vestmannaeyjagrunn bear a close resemblance to the investigated rocks of the islands (Jakobsson 1979). Phenocrysts of euhedral olivine are ubiquitous, often enclosing picotite (chromium spinel) which, however, occasionally is found free; plagioclase is common as microphenocrysts and is found more disperse as macrophenocrysts, whereas augite and magnetite are not found as phenocrysts.

Chemical analyses and CIPW-norms of five of the rock-type populations which are supposedly of Holocene (Postglacial) age, are presented in Table II. The major element analyses indicate mild alkali olivine basalts with normative content of nepheline varying between 2.4 and 5.4 percent. The Vestmannaeyjar basalts have been divided into two groups, called VE—I and VE—II, the latter group being more common (Jakobsson 1979). The MgO— content of VE—I has been found to vary between 9.1—10.0 percent and that of VE—II between 5.6—8.2 percent. Thus H74—D10 (hill E of Bensaklakkur) is of the primitive VE—I type, whereas the others belong to the VE—II type.

Available chemical analyses of the Surtsey lavas have hitherto indicated that they belong to the VE—I group (Jakobsson 1979). It is thus a surprise to learn that the chemical analysis of

TABLE II.

Chemical analyses and CIPW-norms of dredged rocks of Vestmannaeyjagrunn, compare Table I. Analyses 1-3 and 5 have been previously published in Jakobsson (1979, Table 1.). Analyst: Greenl.Geol. Survey, Chem. Lab., I. Sørensen.

	1.	2.	3.	4.	5.
Loc.	E of Bensaklakkur	Skötuhryggur	SE of Surtsey	Surtla	Rófubodi
Dredge no.	H74-D10	H74-D3	H74-D2	H74-D13	H74-D12
Sample no.	4649	4640	4639	4638	4650
SiO_2	46.40	46.24	46.50	46.99	46.66
TiO_2	2.14	2.27	2.49	2.38	2.82
Al_2O_3	14.77	15.87	15.88	16.22	16.19
Fe_2O_3	1.56	1.76	2.88	2.34	2.26
FeO	9.71	10.68	9.93	9.90	10.77
MnO	0.23	0.26	0.27	0.19	0.27
MgO	9.49	8.21	7.36	7.01	5.75
CaO	10.53	9.30	9.64	9.68	9.76
Na_2O	2.83	3.78	3.37	3.80	3.60
K_2O	0.64	0.59	0.67	0.68	0.82
P_2O_5	0.17	0.25	0.25	0.36	0.31
H_2O	0.97	1.14	0.56	0.25	0.32
Sum	99.44	100.35	99.80	99.80	99.53
C I P W weight-norm					
OR	3.78	3.49	3.96	4.02	4.85
AB	19.62	21.97	24.72	23.93	24.72
AN	25.71	24.59	26.23	25.19	25.60
NE	2.35	5.43	2.05	4.46	3.11
DI	20.66	16.31	16.31	16.84	17.19
OL	19.64	19.99	16.49	17.38	14.40
MT	2.26	2.55	4.18	2.30	3.28
IL	4.06	4.31	4.73	4.52	5.36
AP	0.39	0.58	0.58	0.83	0.72
FeO*/MgO	1.17	1.49	1.70	1.71	2.23

Surtla (H74–D13, Table II) shows it to be of the VE–II type. A number of new, unpublished analyses of the Surtsey extrusives have in fact shown, that there is a distinct, gradual chemical gradient with time during the Surtsey eruption (Jakobsson, in prep.), where the Surtla rocks are among the most evolved in composition. This indicates that the above-mentioned grouping of the Vestmannaeyjar basalts has to be revised.

THE SUBMARINE REMNANTS OF SURTLA, SYRTLINGUR AND JÓLNIR

During the Surtsey volcanic activity of November 1963–June 1967, there were eruptions at three sites outside Surtsey itself. At the first site no island was formed, at the other sites islands were formed but subsequently washed away by wave action. It will be of interest here to examine the fate of these three submarine hills in connection with the study of the other submarine hills and peaks of Vestmannaeyjagrunn.

Surtla was built up by submarine activity 2.5 km eastnortheast of Surtsey from about December 28, 1963 to January 6, 1964. An eastnortheast trending ridge more than 100 m above the seabottom was built up, but no island was formed. The depth to the top of the ridge was 23 m on February 23, 1964 (Thorarinsson 1965b).

In early May, 1965, volcanic activity started 0.6 km eastnortheast of Surtsey, and on May 28 an island, Syrtlingur, was formed by phreatic activity. In September 1965 the island reached a height of more than 70 m and a length of 650 m. In early October the eruptions ceased, and on October 24, 1965 the island had disappeared.

On December 26, 1965, explosive volcanic activity was observed 1 km southwest of Surtsey, and on December 28 the island Jólnir was born. Jólnir reached a height of about 70 m, and a length of 560 m. Eruptions were last observed on August 10, 1966, and in late October, 1966, the island had completely disappeared (Thorarinsson 1968). In the above-mentioned eruptions only tephra (pyroclastics) was formed, as far as the record goes.

A detailed bathymetric map of the Surtsey area was made in July–August 1964 by the Icelandic Hydrographic Survey (Kjartansson 1966, Fig. 5); another map was made by B.E.T. Humphrey in July 1967 (Norrman 1970, Fig. 1). In July 1973 the Icelandic Hydrographic Service made another map of the area (Sea Chart No. 321 (Vestmannaeyjar), Reykjavík 1982). Finally, echosoundings were made from the r/v Árni Fridriksson in November 1982. An examination of these data, and other unpublished data reveals that the morphology of these submarine hills has changed considerably since the volcanic activity ceased. The top of each hill has been eroded continuously down as shown in Fig. 2, and at the same time each hill has become wider to form platform with steep slopes (Fig. 1). According to Norrman (1970) who investigated the three hills in June 1968, their erosion is due both to currents and wave action. The fact that both the Jólnir and Surtla hills seem mainly to have been enlarged towards southwest and south also indicates that (westerly) bottom currents are at least partly responsible for the erosion, — possibly mainly below a depth of 17–22 m where the curves in Fig. 2 become flattened. The fact that the Syrtlingur hill does not show this feature may be because this hill is on the lee side of Surtsey with respect to the heavy southwest waves, which appear to have the greatest erosional force on Surtsey. According to local fishermen (Eyjólfur Gíslason pers. inform. 1966)

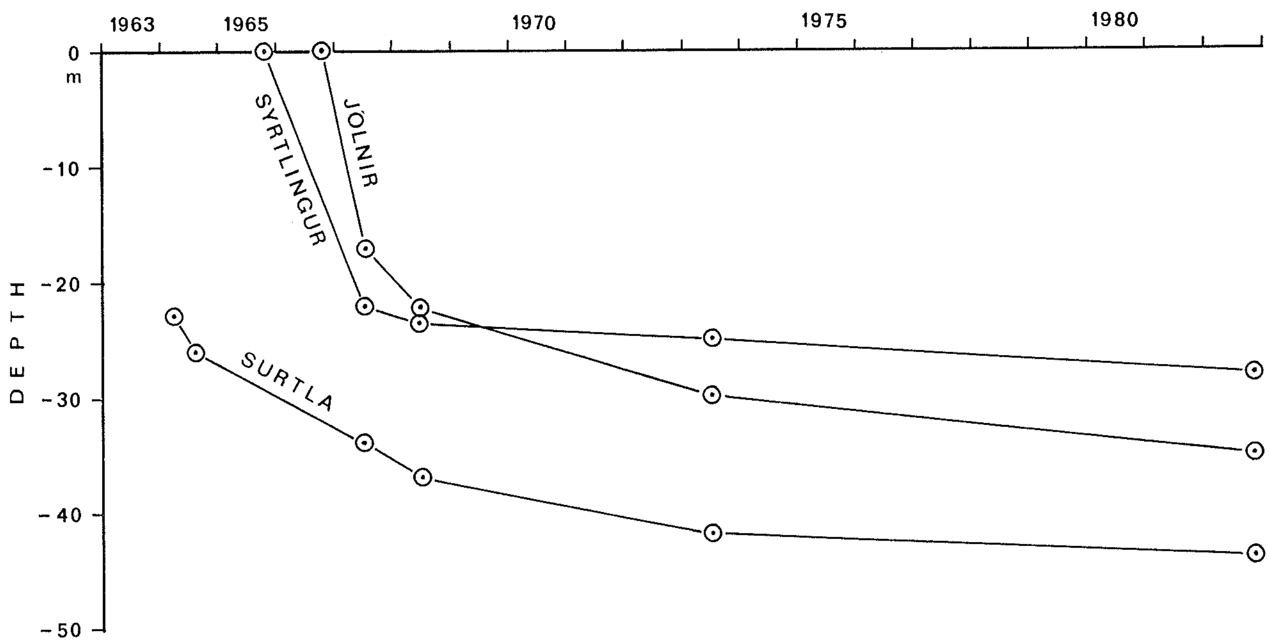

Fig. 2. The lowering of the submarine hills of Surtla, Syrtlingur and Jólnir with reference to mean depth of the top platform, according to various sources.

there is always less amount of sediments and coarser sediments on the east side of the submarine hills of the Vestmannaeyjagrunn. This is in accordance with unpublished results of the Marine Research Institute (Svend Aage Malmberg, pers. inform. 1982), that the resultant near-bottom currents in this region are towards the west.

DISCUSSION

This investigation on Vestmannaeyjagrunn shows that the submarine hills and peaks of this area are both of Holocene (Postglacial) age, and pre-Holocene age. With the exception of the Surtsey eruption sites, four out of eight hills investigated are likely to have erupted during Holocene time (four eruption units), and five hills at earlier times, most probably during Upper Pleistocene time (six eruption units); two hills, Rófubodi and Bensaklakkur, contain two distinguishable eruption units (Table I). The petrologic investigation shows that all these rocks belong to the Vestmannaeyjar volcanic system.

The collection of sediment grab samples on the sea floor around Surtsey indicates that during the Surtsey eruptions, appreciable amounts of pyroclastics were deposited on the bottom but mainly within a radius of a few nautical miles from Surtsey.

The most recent submarine hills Surtla, Syrtlingur and Jólnir, formed in 1963—1966, have suffered rapid continuous erosion (Fig. 2), probably both by wave action and currents, and are now shaped into flat-topped hills (Fig. 1), with a minimum depth of 28—44 m below sea level. The rapid erosion shows the hills to be built up of loose pyroclastics down to this depth interval, if not further down.

It is noticeable that the four submarine hills, where Holocene eruptions have taken place outside the Surtsey area (Fig. 1), have all been eroded down to a level below the abovementioned depth interval, with the exception of a small peak on Rófubodi which reaches 12 m depth. Moreover, these Holocene hills mostly exhibit broad features, whereas the identified older hills are steep and may reach shallow levels. This suggests that the pre-Holocene hills have suffered glacial erosion, where the loose material of their sides has been scraped away. According to Egloff & Johnson (1979) the insular (continental) shelf and the insular margin off SW and S-Iceland has been extensively modified by glacial action, and morainal debris has been deposited on the erosional surface. To the southwest of Vestmannaeyjar, moraine-like deposits have been discovered at the insular margin.

On the other hand, if a Holocene eruption is large enough to build up an island, where there are conditions for the loose tephra to be consolidated through the process of palagonitization as in Surtsey (Jakobsson 1971), the consolidated core may withstand erosion, as is the case for the present islands and skerries of Vestmannaeyjar, with the sole exception of Nordurklettar, Heimaey, which probably is subglacial.

With these results in mind, it is not probable that there are many additional submarine hills of Holocene age in this area, the most likely cases will be Hólar, Stóra-Hraun, Bankahryggir, Nýja-Hraun og Sandahraun.

The submarine and subaerial volcanism of the Vestmannaeyjagrunn is most probably the main source of the material which has built up the shelf in this area, as Alexandersson (1972) has noted. The following calculation supports this assumption. As mentioned above, the Vestmannaeyjar formation probably extends down to about 180 m below sea level, judging from the information from the drill hole (Tómasson 1967). The Vestmannaeyjar volcanic system probably covers an area of 800—1000 km^2, and the average water depth in the area is thus about 60—80 m, depending on how large an area is credited to the system. The volume of the formation is then 80—120 km^3, and the bulk of it will be pyroclastic sediments. The volume of material produced by the volcanic system during the last 12 thousand years has been estimated $\geqslant$3.5 km^3 (Jakobsson 1979). Assuming that the sediments will make up 3 times the volume of solid volcanic rock, and that 90 percent of the material is deposited within the area of the system, it will, with the present rate of production, take 80—125 thousand years to build up a formation of the size of the Vestmannaeyjar formation, and this is about the age previously suggested for this formation.

The reason for the present shape of Vestmannaeyjagrunn (Fig. 1) is probably as follows. The main zone of volcanism (Jakobsson 1979) runs from Surtsey/Stóra-Hraun towards northeast through Heimaey and to Állinn. The most vigorous volcanic activity has been in the Heimaey area. Outside this zone there are only a few scattered eruption sites. As westerly currents are dominating near bottom, there is a rather steep slope southeast of a line between eastern Heimaey and Stóra-Hraun, whereas the shelf dips gently towards southwest on the other side of the active volcanic zone.

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