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LITTORAL DRIFT ON THE ICELANDIC SOUTH COAST

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INTRODUCTION

Part of this paper was published in Proceedings of the 12th Conference on Coastal Engineering, Washington D.C., 1970 under the title "Use of vulcanoes for determination of the direction of littoral drift". Due to the fact that it was presented at the "Iceland Session" as an integrated part of a review of harbour problems in Iceland it was decided to print it again in the POAC 2 proceedings. The first 10 pages are identical with the paper published earlier. The remaining 6 pages have not been published earlier.

Abstract - The title of this paper may sound like a joke. Correctly the title ought to be "Determination of Direction of Littoral Drift on the Scuth Coast of Iceland by Geomorphological Approach". In order to check the results of such study based on the movements of river entrances and their geometry the use of an accelerometer buoy to be placed in offshore open waters for collection of wave data combined with the results of meteorological data was discussed. Then the volcano Surtsey suddenly emerged from 400 ft depth (Nov. 1964) and its huge outpours of volcanic material built up an "offshore pole station", where the shoreline development provided some information which supported conclusions from the shoreline study on the mainland. Computation of wave energy input provided further information.

GEOMORPHOLOGICAL APPROACH

OBSERVATIONS OF RIVER OUTLETS

The littoral drift on the Icelandic south coast was investigated by means of topographic surveys and aerial photos including:

Survey by the Danish Geodetic Institute, 1906		
Survey by the Danish Navy, ab. 1926		
Aerial photography, 1945	(Icelandic Survey Dept.)	
Aerial photography, 1960		
Aerial photography, 1960	U.S. Navy	
Aerial photography, July 1963		(Icelandic Dept. of Lighthouses and Ports)
Aerial photography, Aug. 1963		(Icelandic Dept. of Lighthouses and Ports)

Most of these surveys were undertaken during the summer period, when the littoral drift because of winds from South East tends to be westward. This may have considerable influence on the geographical direction of the outlets of minor rivers on the South Coast while the major streams will not change the general orientation of the outlet which points in the direction of the predominant littoral drift.

The results of studies of this material are depicted on Fig. 1, indicating that the littoral drift at Holsá is eastward, that the drift at the shore between Affall until west of Holtsos is neutral, that the drift from west of Jökulsá and up to Dyrholaey probably is eastward although some minor outlets demonstrate westward direction which, as mentioned above, most likely is a seasonal phenomenon. Furthermore that the littoral drift just east of Dyrholaey is westward.

Professor Trausta Einarsson in his article on "Suðurströnd Islands og mundunarsaga hennar" published in Timarit, Verkfrædingafelag Islands (Proceedings of the Icelandic Engineering Association), No. 1-2, 1966 in section IV "Raðir foksandshóla og forsöguleg staða strandarinnar" explains the development of shore and shoreline configuration west of Dyrholaey from the outlet of Thorsá and up to Reynisfjall towards the East. He takes a closer look at the shores at Dyrholaey. Based on the development of ancient and recent shorelines it is quite clear that the shore between Klifandi (Figs. 1 and 3) and Skogá (Figs. 1 and 2) has been a "neutral area", which means that the net drift has been relatively small or the drift has taken place in opposite directions

α = angle between wave crests at the breaker line and the shore line, or the angle between orthogonals and the normal to the shore line (i.e. $\alpha = \alpha_b$).

k_1 = factor depending on dimensional units and empirical relations. It varies with beach slope, grain size, and other variables.

The wave energy coefficient may be written $e = \cos\alpha_o / \cos\alpha_b$ and $\sin 2\alpha_b = 2 \sin\alpha_b \cdot \cos\alpha_b$

hence: $e \sin 2\alpha_b = 2 \cos\alpha_o \cdot \sin\alpha_b$ (2)

The relationship between $\sin\alpha_o$ and $\sin\alpha_b$ for different steepness ratios of the waves is given in Fig. 8.

Neglecting energy dissipation and reflection the total work may be written:

$$w = \frac{\gamma \cdot H_{1/3}^2 \cdot C_{1/3}}{16} \quad \text{ft-lbs/sec/ft of crest} \qquad (3)$$

Eqs. (1), (2) and (3) combined gives:

$$Q = \tfrac{1}{2}\, 6{,}3 \cdot 10^8 \cdot k \cdot H_{1/3}^2 \cdot T_{1/3}\, e \sin 2\alpha_b \ \text{ft-lbs/year/ft of crest} \qquad (4\ a)$$

$$Q = 6{,}3 \cdot 10^8 \cdot k \cdot H_{1/3}^2 \cdot T_{1/3} \cos\alpha_o \sin\alpha_b \ \text{ft-lbs/year/ft of crest} \qquad (4\ b)$$

where $H_{1/3}$ and $T_{1/3}$ are the significant wave height and period.

Wind conditions in Iceland are characterized by cyclones moving from SW giving rise to variable wind fields. The average duration of a cyclone moving from SW towards Iceland is 1 to 3 days. The predominate direction of wind wave

Figs. 6 and 7 show the development of shorelines at Surtsey during the period from 1964 to 1967 when coarse lava and pebbles normally were available in a narrow beach around the island for longs. migration by wave action. During extreme storms the solid lava could become exposed, however, in certain sections of the shore. As it may be seen from the figures, the general trend of shoreline development was towards a rectangular shape with rounded cornes against SW. The island has two almost parallel sides running SW-NE and an accumulation area on the NE side which developed a lagoon between two beach ridges growing out from SW, typical for an "angular foreland". The orientation of the two parallel sides is given in the figures. It may be seen that the average orientation of the two parallel sides in 1964 was 27 degrees E of N, <u>which is identical with the orientation of the shoreline west of Dyrholaey</u>.

WAVE ENERGY APPROACH

An attempt was made to study this situation in a more rational way by evaluating the wave energy input on the south coast of Iceland in order to find the direction of shoreline with "neutral drift". No wave energy data were available however. The procedures were based on the Los Angeles formula:

$$Q = \tfrac{1}{2}\, k_1 w\, e \sin 2\alpha_b \qquad (1)$$

where Q = the total amount of sand moved in littoral drift past a given point per year by waves of given period and direction.

w = total work accomplished by all waves of a given period and direction in deep water during an average year.

e = wave energy coefficient at the breaker line for waves of a given period and direction. It is the ratio between the distance between orthogonals in deep water and at the shore line.

according to season and in almost equal quantities on a year round basis. The sediments which washed down to shore by the rivers apparently drifted in part towards the Dyrholaey (Dyrhola-island) building up a tombolo (barrier connecting island and main land) and partly westwards towards Vestmannaeyjar (islands south of Iceland - see Fig. 1) which caused the development of another major tombolo inside the wave shadow of these islands (Fig. 2). With enough "patience" and material available the Vestmanna Islands would finally become connected to the mainland provided current concentrations between island and mainland would not make this development impossible.

This confirms the results of the observations of direction of outlets mentioned above. The orientation of the shoreline west of Dyrholaey is almost constant 27 degrees north of west.

OBSERVATIONS OF SHORELINE DEVELOPMENT OF VOLCANOE SURTSEY

It is in this respect interesting to note the development of shorelines at the volcanoe Surtsey as studied by Thorarinsson (Surtsey Research Progress Reports Nos. II and III 1966 and 1967) and by Norrman (Surtsey Research Progress Report No. IV, 1968).

Surtsey is a submarine volcanoe, which erupted on Nov. 14th, 1963 (Fig. 4) at ab. 100 meters depth. In 6 days an island 600 m long and almost as wide with top elevation of 60 meters came into existence.

Gradually the configuration of the island changed to hoof shape, which immediately after Nov. 26th (Fig. 5) normally was open towards the southwest. Sometimes a barrier blocked the opening, however, but it only lasted, until it was broken down by the surf, or until it was blown away by explosions from the volcanoe. After the middle of December the island became nearly circular, later more squared because two sides developed to be almost parallel as explained below.

propagation is towards NE. Usually the cyclones pass south of Iceland but they may also pass north of Iceland. Fig. 9 shows the characteristic situation during the winter and sommer seasons. Fig. 10 demonstrátes the characteristic wind direction for the three paths of the cyclones. As it may be noted from Fig. 10 the cyclones give rise to strong winds from the east when they pass south of Iceland. In this situation waves propagate from three directions, SW, S and E. Field experiments show that high waves from SW occur although the wind has blown from E for some time.

Because of the fact that no wave data were available and the Los Angeles formula refers to an average year, it was necessary for a preliminary evaluation to use the average wind conditions. Available wind data are meteorological observations covering a period of 10 years. Wind data from three meteorological stations, located in the area between Vestmannaeyjar and Dyrholaey, were statistically evaluated. Fig. 11 shows frequency diagram. The average wind speed ranged from 12 to 22.5 knots. Hindcasting was based on the SMB method. The problem here, as usual, is to determine the fetch. A 22.5 knots wind generates a fully developed sea at a fetch of about 135 NM (nautical miles) and a duration of about 14 hours. The wave energy is a function of H^2 and T, and the SMB diagrams indicate that wind speeds of 12 to 20 knots have no practical influence on the significant wave height,when the fetch increases from 100 NM to 250 NM. However, there is an increase of one second in the significant wave period. For waves generated by the cyclones moving from SW, it is therefore realistic to select a fetch of 250 NM for W and SW. For the other directions a fetch of 135 NM was selected. This agrees with results of Danish investigations on wave action for the harbour of Vestmannaeyjar. The results of hindcasting as well as the calculation of the deep water energy is shown in Table 1.

Each direction represents a sector of 45 degrees. The actual shore boundary conditions including true shore orientation west of Dyrholaey are shown in Fig. 12. In Fig. 13 the shoreline was turned 5 degrees clockwise in order to observe the possible influence of this on the drift direction computed on the basis of input of longshore wave energy.

As shown in Fig. 12 the W and SE sectors are bounded respectively 39 and 36 degrees, and only half of the E sector is represented west of Dyrholaey. Wind direction from the E tends to concentrate in the area around Dyrholaey, partly due to the Bernoulli effect from the nearby Myrdalsjökull (glacier) east of Dyrholaey. West of Dyrholaey the wind blows along the shore and increases the longshore wave energy. Moreover the wave energy west of Dyrholaey also increases due to a combination of diffraction and refraction at Dyrholaey. In this preliminary evaluation, it is difficult to calculate the wave energy from east representing the average year. It is possible however, to estimate roughly the wave energy coefficient "e" in Equation (1).

The maximum input of wave energy is determined approximately by the geometric shadow line which gives $e = 0.5^2$. The minimum input of wave energy is determined approximately by the 27 degrees diffraction ray which gives a diffraction coefficient of about 0.10 approximately 1 km west of Dyrholaey or $e = 0.1^2$. Due to the refraction, one may expect a wave energy coefficient between $e = 0.5^2$ and $e = 0.3^2$.

Diffracted waves are only of importance in the area immediately west of Dyrholaey. They break under an angle of approximately 25 degrees with the shoreline. Further westwards refraction of waves towards the shore takes place, developing low swells which are superimposed by wind waves corresponding to actual fetches west of Dyrholaey.

The numerical calculations carried out in Tables 1-5 with $e = 0.4^2$ and ave. $H/L = 0.025$ (Table 1) refer to the area immediately west of Dyrholaey. It may be noted that the H/L-ratio plays an important role, and that turning the shoreline 5 degrees clockwise from the actual direction (Fig. 13) changes the resultant energy balance from eastward predominance to westward predominance thereby causing westward drift. This still refers to the area just west of Dyrholaey. Further westward the importance of E winds tends to decrease because of the shadow by the Dyrholaey headland. This in turn would create more tendency to eastward drift. Assuming that this is correct, the shoreline should develop slightly convex (turn clockwise) up towards the Dyrholaey apart from a small area influenced by leeside erosion just west of the Dyrhola-point. As it may be seen from Figures 2 and 3 this is actually the way shoreline configuration developed. It is therefore evidenced that the orientation of shoreline of ab. 27 degrees N of W is close to the direction which causes neutral drift. The correct average direction may be a few degrees more as is in fact also indicated by the early development of shorelines at Surtsey.

CONCLUSION

Although none of the methods used are <u>exact</u> in the true sense of the word, the similarity of the results are noteworthy. The development of shorelines of volcanoes popping up from the bottom of the sea,like Surtsey,may be used to determine the direction of littoral drift on nearby shores. As a good luck other methods are available,however.

QUANTITY OF DRIFT

With respect to quantity of drift no surveys exist which could be used for such evaluation. Historical accounts may give an impression of the order of magnitude of the drift. Arni Ola in his book "Thusund ára sveitathorp" (Icelandic) mentions on p. 164 the difficulties in maintaining the outlet of the Holsá river (Fig. 2). The about 200 m wide barrier extended about 500 m per year eastward which with an average fill height of about 6 m gives an amount of approximately 0,5 mill. cub. m per year as "beach drift" up to 1 or 2 m depth. As waves coming in from the open Atlantic almost always break at greater depths because the offshore area is rather shallow and is subject to action by waves of 4 to 8 m height during storms, the quantity of beach drift may be multiplied by 2 or 3 which gives an approximate annual quantity of ab. 2 mill. cub. m. That kind of drift quantities may also be found on the upper Pacific Ocean Shores in the United States and Canada.

Table 1 Hindcasting

Direction	Wind	Fetch	$H_{1/3}$	$T_{1/3}$	$H_{1/3}/L_{1/3}$	Duration	$W_{Eq. (3)}$
	Knots	NM	ft	sec		hours	ft-lbs/ft/year
E	22.5	135	8.5	7.9	0.027	14	$3600 \cdot 10^8$
SE	12.5	135	3.6	5.8	0.021	20	$474 \cdot 10^8$
S	12.0	135	3.3	5.7	0.020	21	$390 \cdot 10^8$
SW	14.5	250	5.0	7.3	0.018	30	$1150 \cdot 10^8$
W	12.0	250	3.5	6.5	0.019	35	$500 \cdot 10^8$

Table 2 $e \sin 2\alpha_b$ corresponds to Fig. 12 for various steepness ratios

Fig. 12		Fig. 8		$e \sin 2\alpha_b = 2 \cos \alpha \cdot \sin \alpha_b$	
Direction	α_o	H/L		H/L	
		0.02	0.03	0.02	0.03
S-43° E	70°	0.31	0.37	0.212	0.253
S	27°	0.19	0.23	0.321	0.41
SW	18°	0.13	0.16	0.24	0.304
W-3° S	60°	0.32	0.373	0.32	0.37

Table 3 $e \sin 2\alpha_b$ corresponds to Fig. 13 for various steepness ratios

Fig. 13		Fig. 8		$e \sin 2\alpha_b = 2 \cos \alpha \cdot \sin \alpha_b$	
Direction	α_b	H/L		H/L	
		0.02	0.03	0.02	0.03
S-40° E	72°	0.31	0.366	0.192	0.229
S	32°	0.215	0.262	0.365	0.434
SW	13°	0.092	0.118	0.179	0.23
W-3° S	55°	0.312	0.364	0.358	0.418

Table 4 - Littoral drift west of Dyrholaey Fig. 12
(Solution of Eq. (4 a) and (4 b))

Direction	α_o	Reduction of wave energy from dom. direct.	Q in cubic yards per year	
			H/L	
			0.02	0.03
E	~	$0.5(0.4)^2$	$-110 \cdot k \cdot 10^8$	$-110 \cdot k \cdot 10^8$
S-43° E	70°	2·20/ 45=0.89	$-43 \cdot k \cdot 10^8$	$-51 \cdot k \cdot 10^8$
S	27°	1.0	$-63 \cdot k \cdot 10^8$	$-80 \cdot k \cdot 10^8$
SW	18°	1.0	$+142 \cdot k \cdot 10^8$	$+175 \cdot k \cdot 10^8$
W-3° S	60°	2·19.5/45=0.87	$+69 \cdot k \cdot 10^8$	$+80 \cdot k \cdot 10^8$
			$-5 \cdot k \cdot 10^8$	$+14 \cdot k \cdot 10^8$
			ave. $Q = +5 \cdot k \cdot 10^8$	

+ means eastward drift
- means westward drift

Table 5 - Littoral drift west of Dyrholaey when the shoreline is turned 5 degrees clockwise. Fig. 13
(Solution of Eq. (4 a) and (4 b)

Direction	α_o	Reduction of wave energy from dom. direct.	Q in cubic yards per year	
			H/L	
			0.02	0.03
E	~	$0.5(0.4)^2$	$-110 \cdot k \cdot 10^8$	$-110 \cdot k \cdot 10^8$
S-40° E	72°	2·18/145=0.8	$-36 \cdot k \cdot 10^8$	$-43 \cdot k \cdot 10^8$
S	32°	1.0	$-72 \cdot k \cdot 10^8$	$-85 \cdot k \cdot 10^8$
SW	13°	1.0	$+103 \cdot k \cdot 10^8$	$+132 \cdot k \cdot 10^8$
W-3° S	55°	2·19.5/45=0.87	$+78 \cdot k \cdot 10^8$	$+91 \cdot k \cdot 10^8$
			$-37 \cdot k \cdot 10^8$	$-15 \cdot k \cdot 10^8$
			ave. $Q = -26 \cdot k \cdot 10^8$	

+ means eastward drift
- means westward drift

The quantity of drift, however, may be smaller in most part of the area just west of Dyrholaey. On the other hand the drift may be much greater on the shore west of Kötlutangi (Fig. 1) because of ample supply of material from the glacial meltwater rivers. The predominant drift is norteastward.

STEEPNESS OF BOTTOM PROFILES

Table 6 gives distances from the shoreline and up to the 20 m depth contour for various sections of the shore (Figs. 1 and 2).

Table 6. Distance between shoreline and 20 m depth contour

Holsá	ab.	1.800 m
Holtsos	ab.	1.600 m
Skogásandur	ab.	1.400 m
Dyrholaey	ab.	1.000 m
Reynisfjall	ab.	1.000 m
Vik	ab.	2.200 m
Kötlutangi	ab.	1.200 m

These data together with the above mentioned investigations indicate that a nodal point for littoral drift may exist in the area east of Skogá's outlet where the bottom profile at Skogásandur is relatively steep. They are an indication that the predominant drift at Dyrholaey is (slightly) eastward because the headland works as a groin causing a relatively steep offshore bottom on its updrift (west) side. Meanwhile the situation is that some areas of this shore receive considerable material supply from glacial rivers which also helps maintaining the offshore steepness. Relative steepness therefore is no clear indication and gives no definite proof of direction of drift on the Icelandic south coast.

No continuous wave records are available. Wave action at an exposed location like Dyrholaey is being investigated by an accelerometer buoy.

The general offshore current picture is that flood-currents run westward while ebb-currents run eastward. The nearshore longshore currents are determined by the direction of the nearshore wave action which is related to bottom topography which is fairly smooth apart from areas with rocks. Because of the very coarse beach material (1-2 mm) and the corresponding high permeability all beaches are steep. Uprush currents therefore are swift and may cause very heavy transport of material longshore as e.g. evidenced by the rapid migration of the outlet of Holsá and by the magnitudes of fluctuations for shorelines e.g. at Dyrholaey, up to 200 to 300 ft in one storm.

DISCUSSION ON THE BEST LOCATION FOR A PORT INSTALLATION FOR THE PART OF THE ICELANDIC SOUTH COAST UNDER CONSIDERATION

The natural technical conditions which speak for or against construction of a port on an alluvial (littoral drift) shore are listed below.

For	Against
small distances from shore to deep waters	great distance from shore to deep water
depth contours curved shoreward	depth contours curved seaward
small littoral drift	heavy littoral drift
little or no sediment transport from rivers	heavy sediment transport from rivers
current conditions not objectionable to navigation	currents very adverse to navigation
soils conditions satisfactory	soils conditions unsatisfactory
good land connections (roads, rails etc.)	poor land connections (roads, rails etc.)
land areas available for development	land areas very restricted in size

With reference to Table 6 and to the description of sediment transport and nearshore bottom topography on the part of the Icelandic South Coast under consideration it is obvious that the shore east of Vik or Kötlutangi (and up to the area at Höfn) is not very useful fo the construction of a port facility, particularly because the wave-induced longshore littoral drift and the sediment transport by river to the shore both have considerable magnitude. An outbreak of glaci water or a vulcanic eruption (like the Katla eruption in 1918) will within a short period of time be able to choke a port installation completely. In the area at Holsá littoral drift is heavy and the nearshore bottom profile is shoal. Length of a jetty extending up to 16 m depth would be about 1.400 m and great difficulties would ur doubtedly be encountered with respect to deposits of littoral drift material in the port entrance because of the strong eastward drift. The area just north of the Vestmannaeyar seems to be rather neutral with respect to resultant drift but the bottom profiles are relative gently sloping so the length of jetties to 16 m depth will be about 1.400 to 1.600 m. Furthermore difficulties can be expected because of sediment transport by rivers. The littoral drift in the Holtsós-Skogá area is westward but does not seem to be very predominant. Th azimuth of the shoreline is west 20 degrees north and the distance u to the 16 m depth contour is 1.400 to 1.600 m averagely. The littoral drift is predominantly eastward in the Jökulsa-Klifandi area eve if some minor river outlets seem to demonstrate a (seasonal) drift toward the west. The direction of the shore is west about 25 degre north. West of Dyrholaey at Klifandi the drift is eastward but it may be smaller than elsewhere on this shore. The direction of the shoreline is west 27 degrees north. The distance up to the 20 m depth contour is about 1.500 m and about 900 m up to the 16 m conto but at Dyrholaey the 20 m contour is located only 1.000 m from the shoreline and about 500 m from the Portland rock, which protrudes about 300 m from the Dyrholaey headland. The corresponding distanc from the 16 m depth contours are 800 m and 300 m. Between Dyrholae and Reynisfjall the predominant drift is westward in the nearshore area. The direction of the shoreline is west about 4 degrees north and the distance up to the 20 m depth contour is about 1.800 m aver agely. For the 16 m contour distance is about 1.500 m. At Reynisfjall the 1957 survey demonstrates a very local landward turn in th depth contours which brings the 20 m contour about 1.000 m and the 16 m contour about 700 m from the shoreline. East of Reynisfjall a Vik with an almost East-West running shoreline the littoral drift i westward but not very predominant. The distance up to the 20 m depth contour is about 2.200 m (1.800 m to the 16 m contour). The littoral drift at Mulakvisl still seems to be westward, but it may not be very predominant. The direction of the shore is west about 22 degrees north, and the distance up to the 20 m depth contour seems to be of the order 1.000 m.

Technically, it is possible but difficult to build a port everywhere on the shore in question, but the conditions at Dyrholaey seem to offer certain technical advantages compared to the shore at Holsá and Holtsós, because the jetty length up to 16 m depth will be smaller and littoral drift and wave conditions are more advantageous at the same time as the land connection and the possibilities for local rock useful for jetty work seem to be relatively better than elsewhere. The small free island-reefs located offshore may be used for construction purpose. Because of the small difference in direction between shores with eastward and westward drift the predominantly east drift at Dyrholaey can hardly be of very large magnitude. The drift must also be rather small from east. If a jetty is built, it will undoubtedly cause accumulation on its west side where coarse material may be removed by scraper pans or by a hydraulic method. Finer material may find its way along the jetty to the entrance area of the port but at Dyrholaey currents are strong and little accumulation if any at all may be expected in front of the entrance. The littoral drift problem at Dyrholaey therefore is not considered being too serious.

The bottom topography derived from local survey in 1957 shows a considerable inward bend of the 20 m depth contour, 1.500 m long and 500 m wide at Dyrholaey. The distance up to the 16 m depth contour has decreased to 700 to 800 m thanks to the progradation of the shoreline west of Dyrholaey and a smaller shoreward movement of the 16 m contour compared to the surrounding bottom. The offshore bottom therefore is steep and the reason for this steepness is undoubtedly mainly to be found in the longshore current situation. Tidal and other currents tend to concentrate at the headland. This is probably responsible for the deepening of the offshore area. In addition bottom samples from the shore and the offshore bottom demonstrate coarse material close to shore. The average grain size of material from the offshore bottom shows a considerable increase of the average grain size (from about 0.15 mm to about 0.25 mm) in the area off Dyrholaey. This undoubtedly is caused by the currents whic based on preliminary current observations seem to concentrate particularly in the area indicated by the coarsest grains. The size of these grains indicate an approximate up to 1 to 1.5 m/sec or 2 to 4 knots under maximum conditions.

The conclusion of the above mentioned is that Dyrholaey probably is the best place for a future harbour on the south coast of Iceland between Holsá and Kötlutangi. The construction of a small harbour will be impractical or impossible, however, and a large harbour witl entrance depth ab. 16 m at M.L.W. making the harbour an "allweather harbour" will be very expensive.

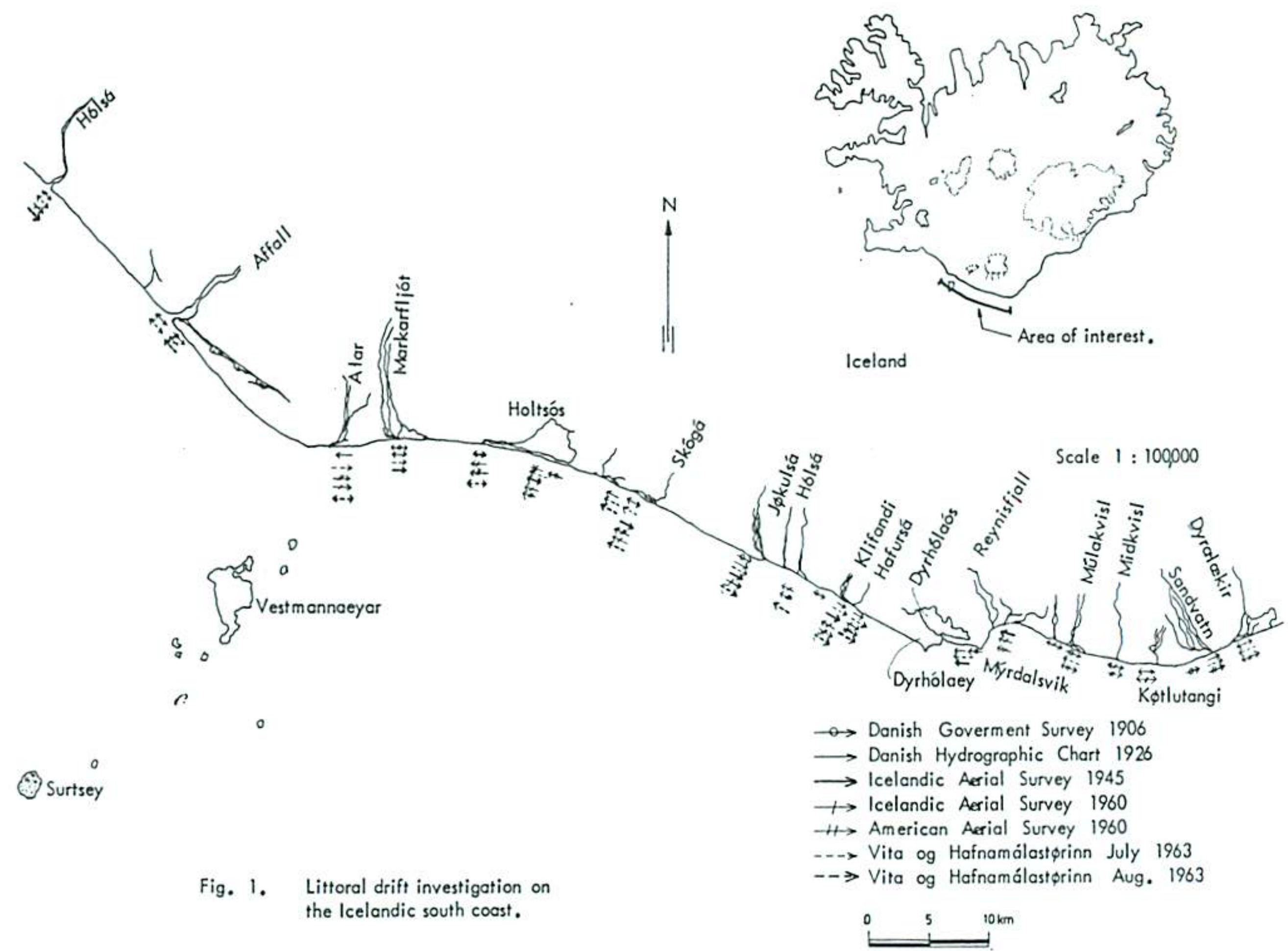

Fig. 1. Littoral drift investigation on the Icelandic south coast.

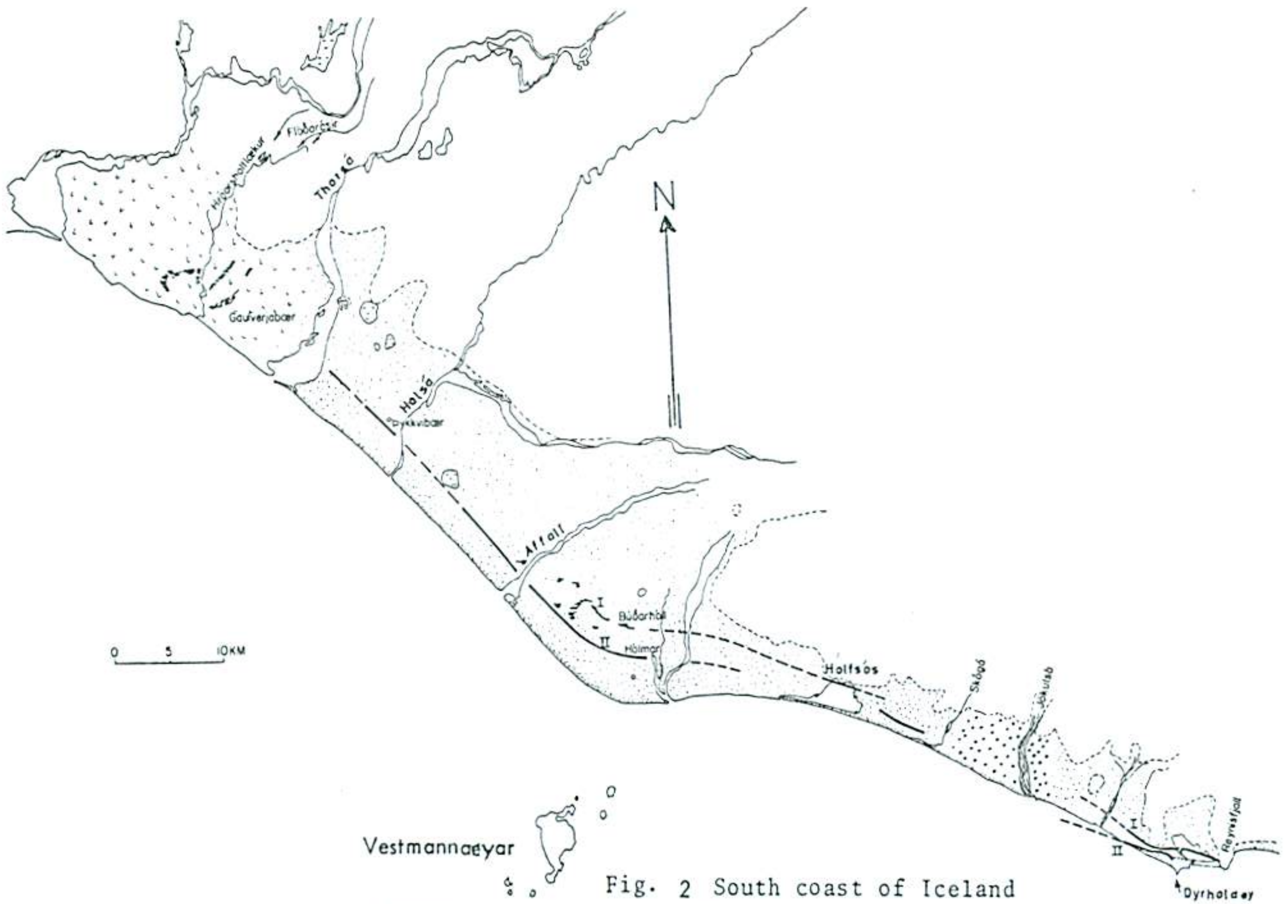

Fig. 2 South coast of Iceland
From Dyrholaey to Thorsá

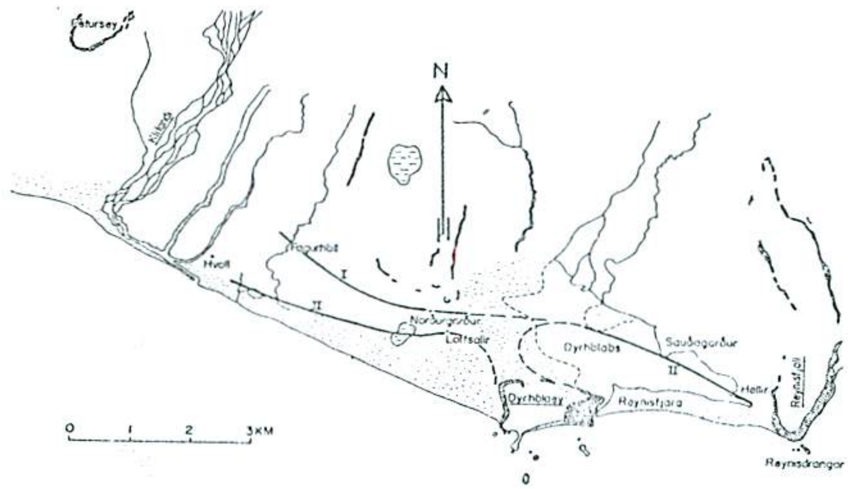

Fig. 3 South coast of Iceland
The area around Dyrholaey

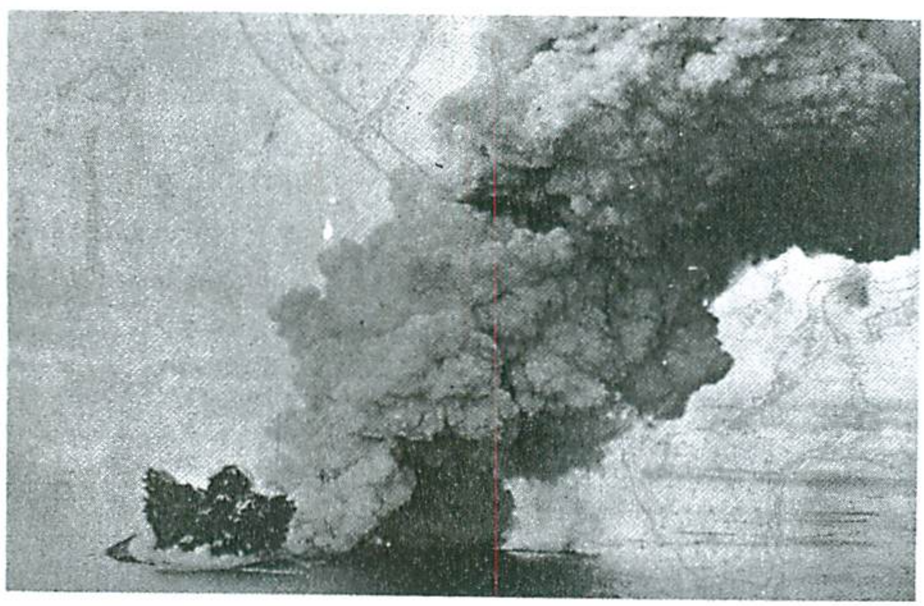

Fig. 4. Surtsey two days after its eruption, Nov. 16, 1963

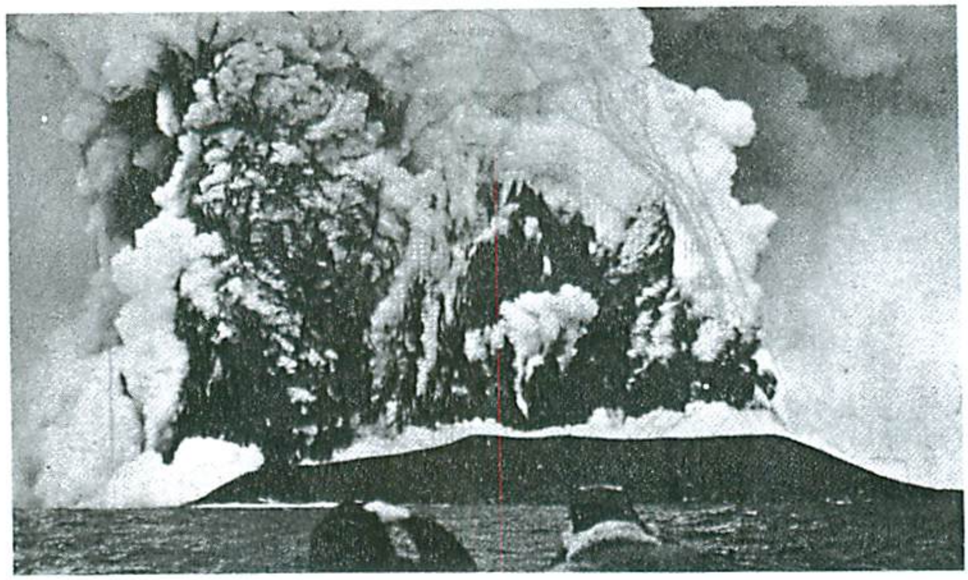

Fig. 5. Surtsey has emerged from the bottom of the sea on Nov. 26, 1963

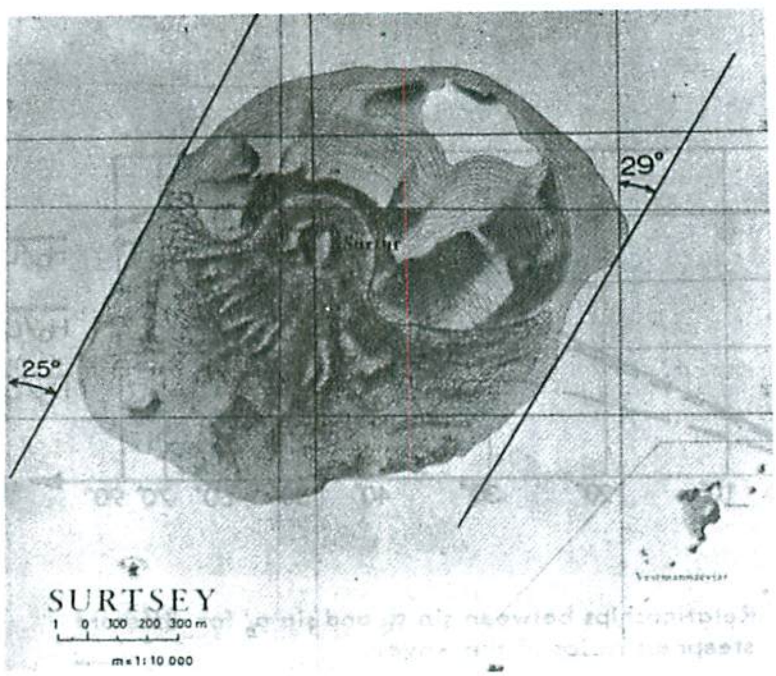

Fig. 6. Surtsey, October 23, 1964

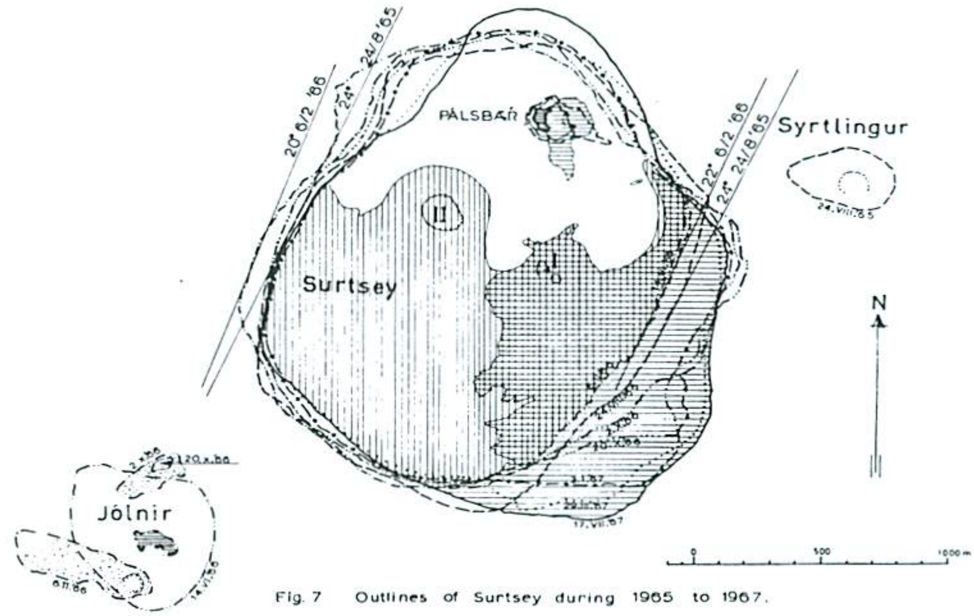

Fig. 7 Outlines of Surtsey during 1965 to 1967.

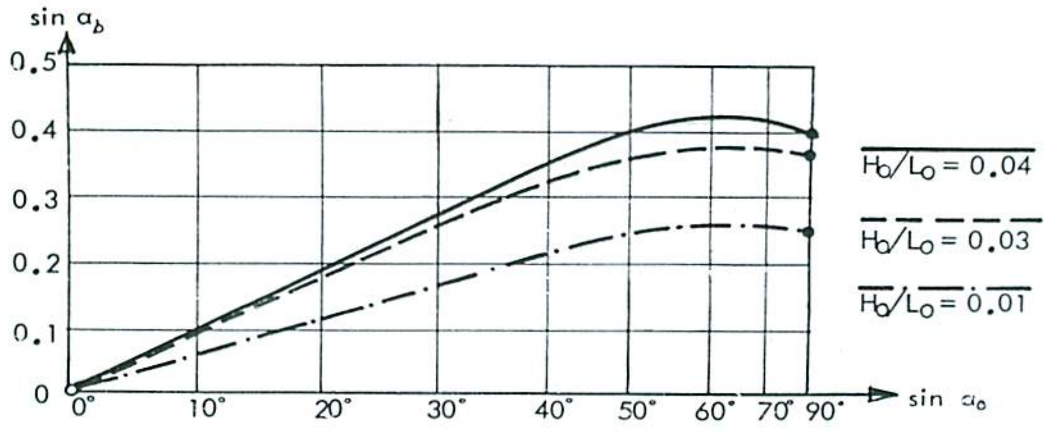

Fig. 8.
Relationships between sin α_o and sin α_b for different steepness ratios of the waves.

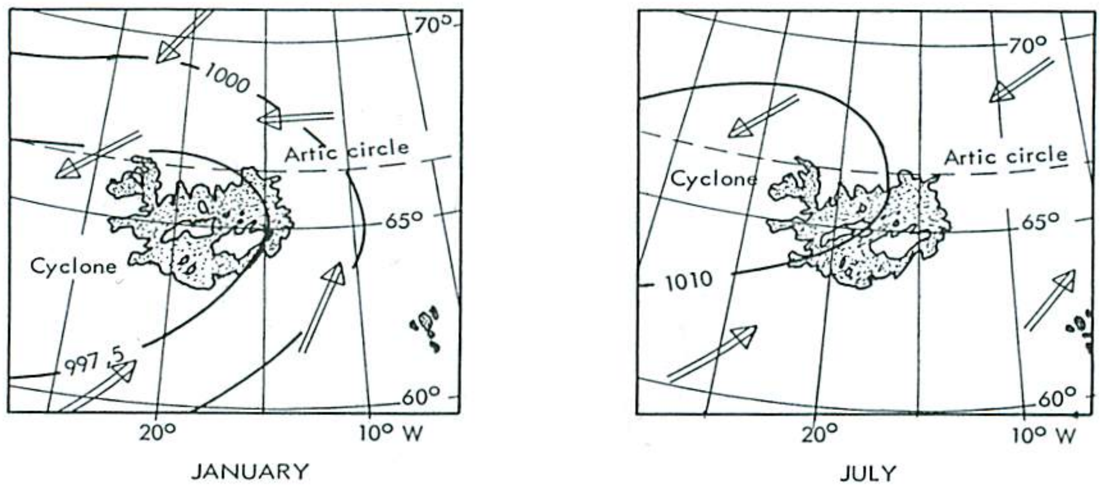

FIG. 9 Characteristic cyclones and dominat. wind directions.

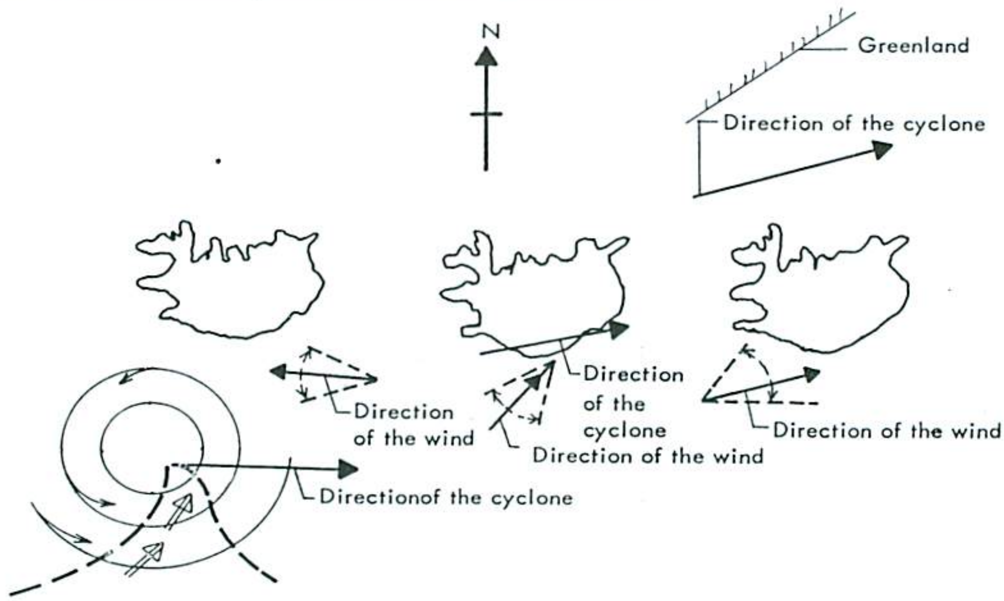

FIG. 10 Characteristic wind dirc.:tion fc: the iree paths of the cycl.:.es.

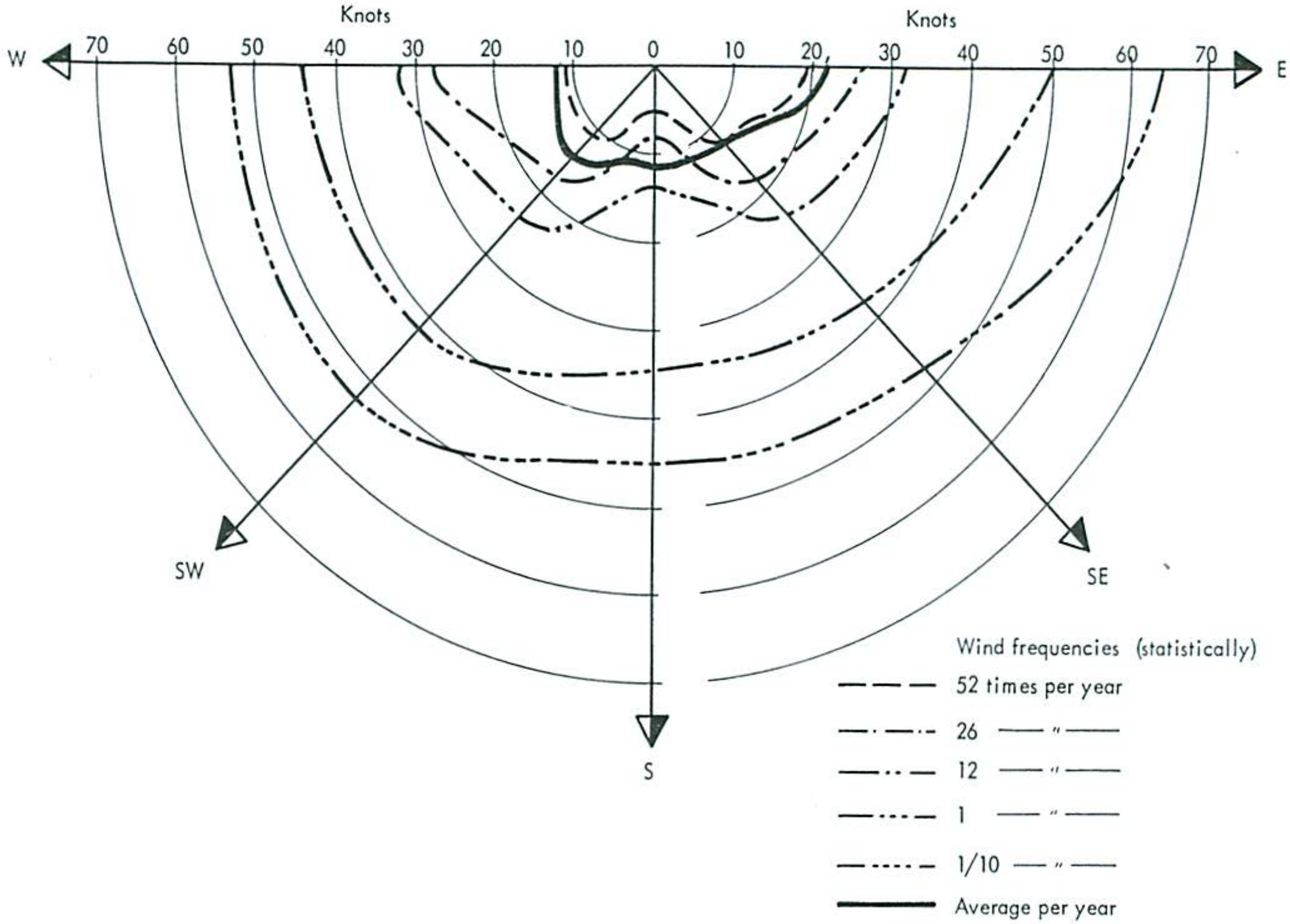

FIG. 11 Wind freqency diagram, the South coast of Iceland.

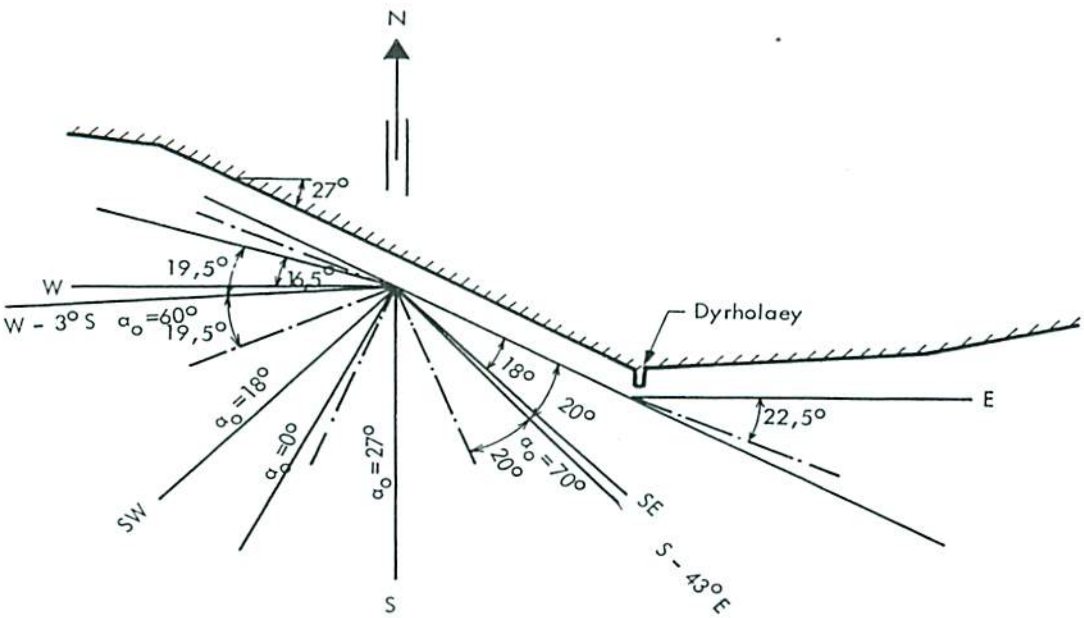

FIG. 12 The boundary conditions west of DYRHOLAEY

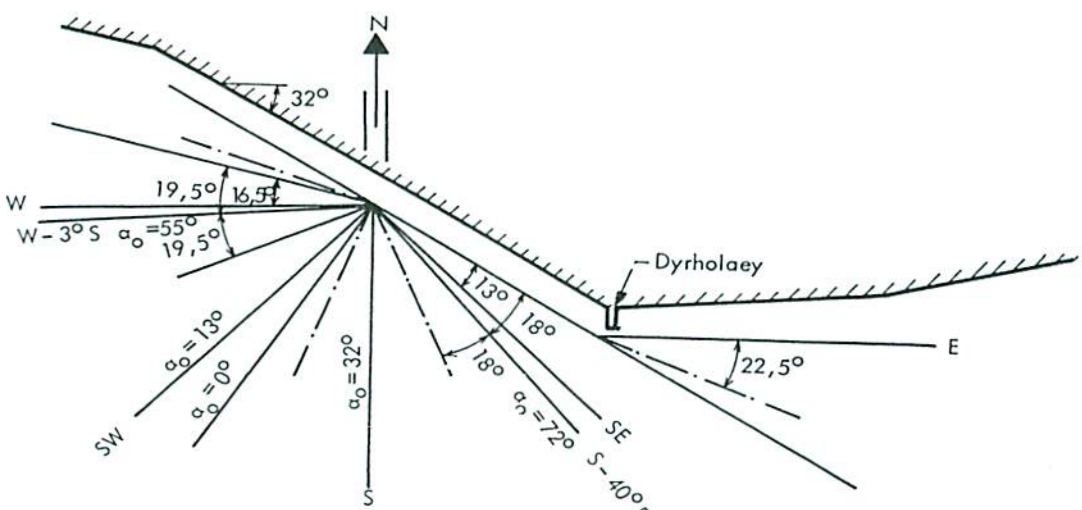

FIG. 13 The boundary conditions west of DYRHOLAEY when the shoreline is turned 5 degrees clockwise.