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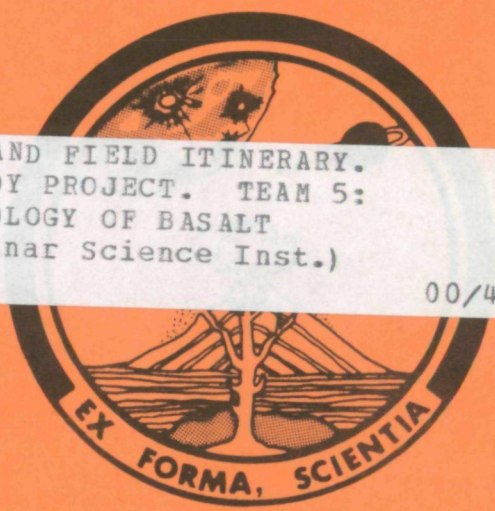

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TEAM 5

DISTRIBUTION AND MORPHOLOGY OF BASALT DEPOSITS ON PLANETS

COMPILED BY: CHARLES A. WOOD, JAMES L. WHITFORD-STARK, AND JAMES W. HEAD

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TINENTAL SLOPE
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-1740 (14260)
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BRITISH ISLES
London
-306 (15694)
Le Havre
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FLEMISH CAP
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-4500 (11500)
BISCAY ABYSSAL PLAIN
-15400
MILNE SEAMOUNT -336 (15664)
Marseille
-17280
-17700
-15300
IBERIAN PENINSULA
AZORES
Pico
7615 (23615)
Lisbon
-16680
OCEANOGRAPHER FRACTURE ZONE
BALEARIC IS.
-8520
-4560
AMPERE SEAMOUNT -132 (15868)
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-960 (15040)
6106
MADEIRA ISLANDS
Jebel Toubkal
ATLAS MOUNTAINS

Introduction

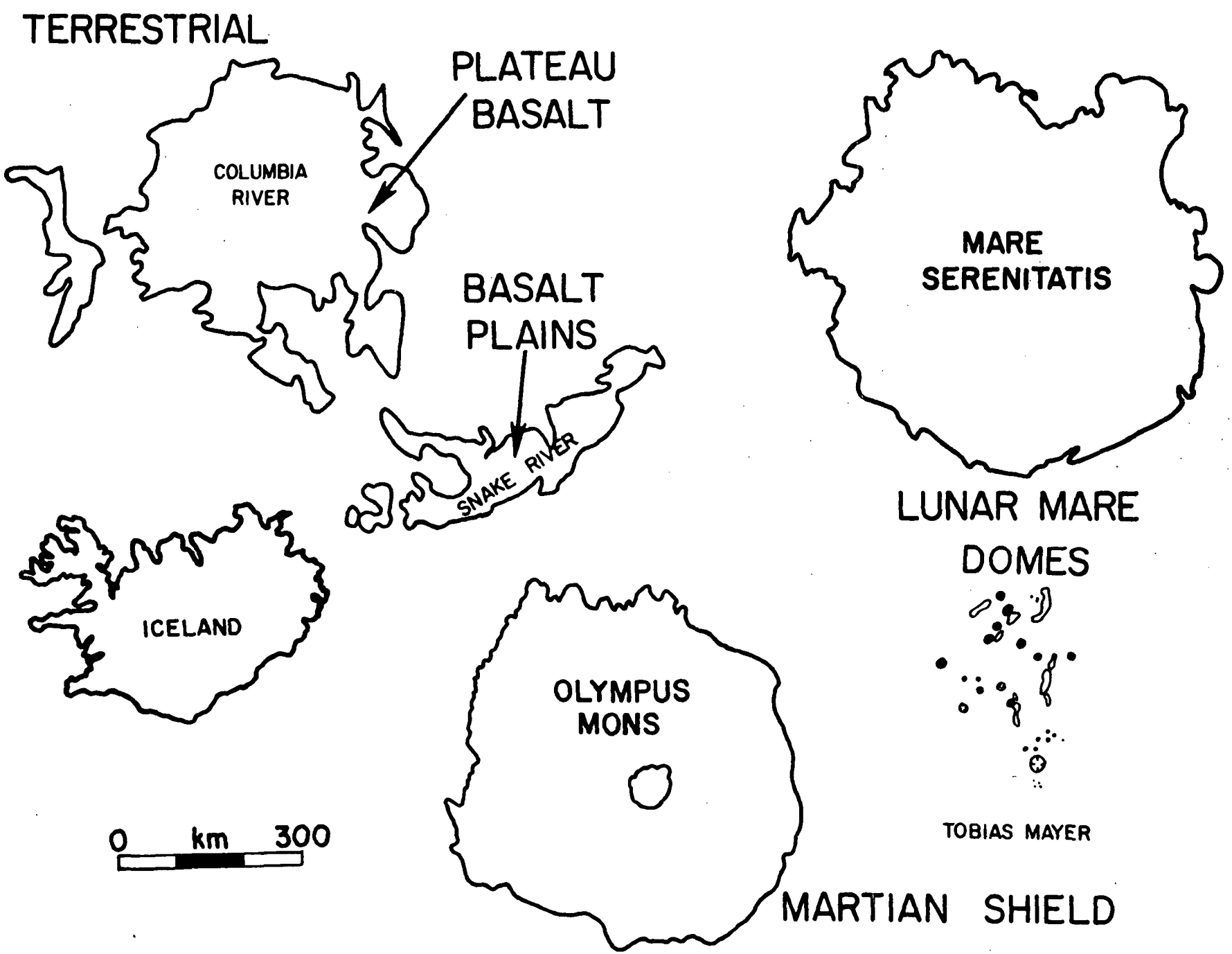
Iceland offers a fascinating opportunity to view the influence and interaction of various factors on the morphology and structure of volcanic landforms, many of which have analogs on other planets. The diverse volcanic landscape we will see on this trip owes its stunning variety not only to its tectonic setting (extension of the mid-Atlantic ridge), but also to the interaction of eruptions with the atmosphere and hydrosphere.

Submarine extrusions have been lifted above sea-level, glaciers have retreated to reveal strange table-mountains, and outpourings of lava have reacted explosively with ground-water to produce lunar-like cratered landscapes.

On the Moon, most lava surfaces appear analogous to terrestrial flood basalts or lava plains (Head, 1976; Greeley, 1977). The lunar maria are composed of basaltic lavas extruded from a variety of sources over a period of about a billion years. Terrestrial lava tubes and channels appear to have their counterpart in giant sinuous rilles (Greeley, 1971). The flat mare plains are interrupted occasionally by fields of low domes strikingly similar to the small Icelandic shield volcanoes (Head and Gifford, 1977) and representing the source of ancient flows. A few tracts of the lunar lowlands are dotted with small features similar to terrestrial cinder cones or spatter cones, but the exact comparison is uncertain because of the possible effects of the Moon's different gravitational and atmospheric environment (McGetchin and Head, 1973; Head, 1975; Wood, 1977).

Nothing on Earth can compare, however, with the awesome giant shield volcanoes of Mars, which dwarf even the largest terrestrial structures (Carr, 1973). But the changing martian polar caps, the thin but vigorous atmosphere, and the compelling evidence for subsurface water, all suggest the possibility of abundant analogs with Iceland. Some martian pedestal craters mimic the form of table mountains, local concentrations of small martian craters may be related to pseudocraters, and the enigmatic morphology of many larger martian craters may be related to maar-type origins. In addition, the tremendous Icelandic floods released by subglacial eruptions may be related to the mechanism causing the gargantuan channels on Mars. Finally, eolian redistribution of tephra and soil in Iceland locally produces vistas not unlike those seen through the eyes of the Viking spacecraft.

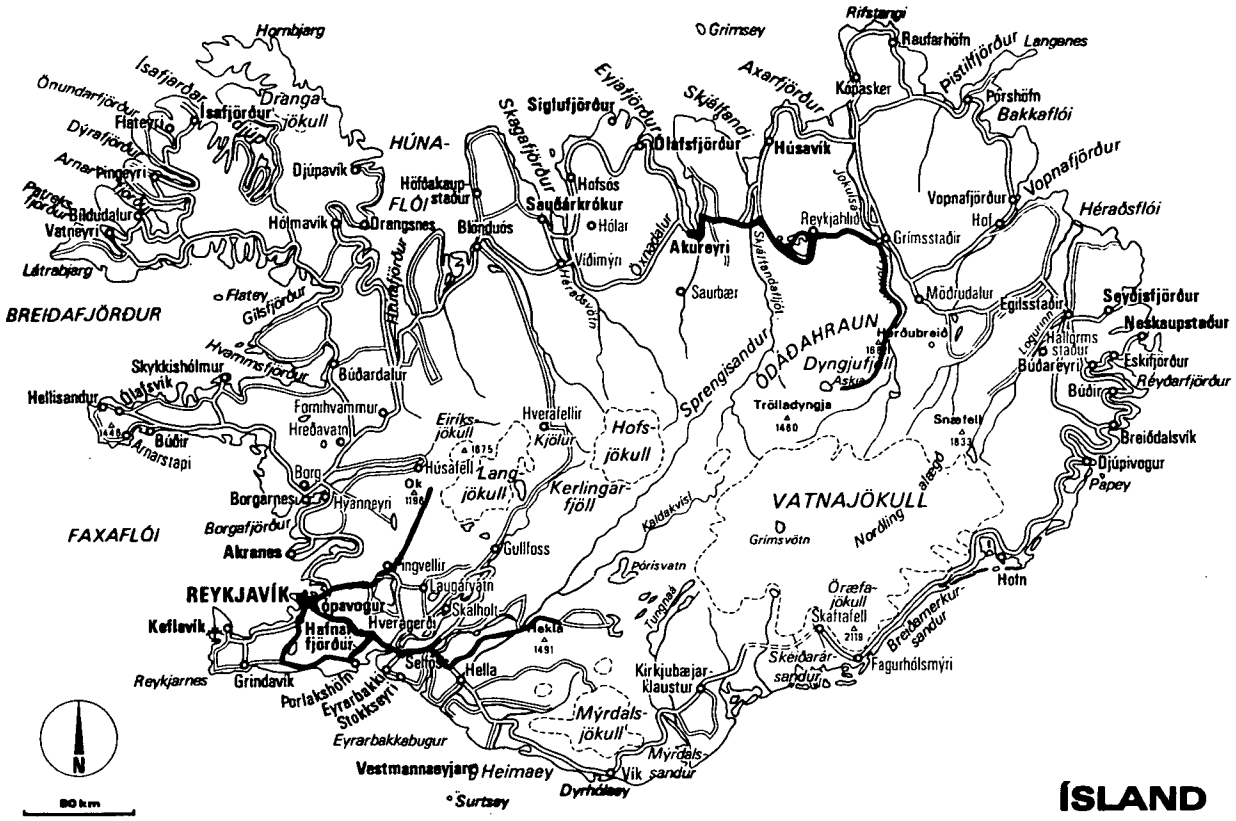
Consider the morphology of volcanic landforms on Venus, with its extremely dense atmosphere and high surface temperature and pressure. Although it is hard to imagine what an extended trek across the venusian countryside would be like, the best earth analog for volcanic features there may be those formed at submarine depths of comparable pressures.

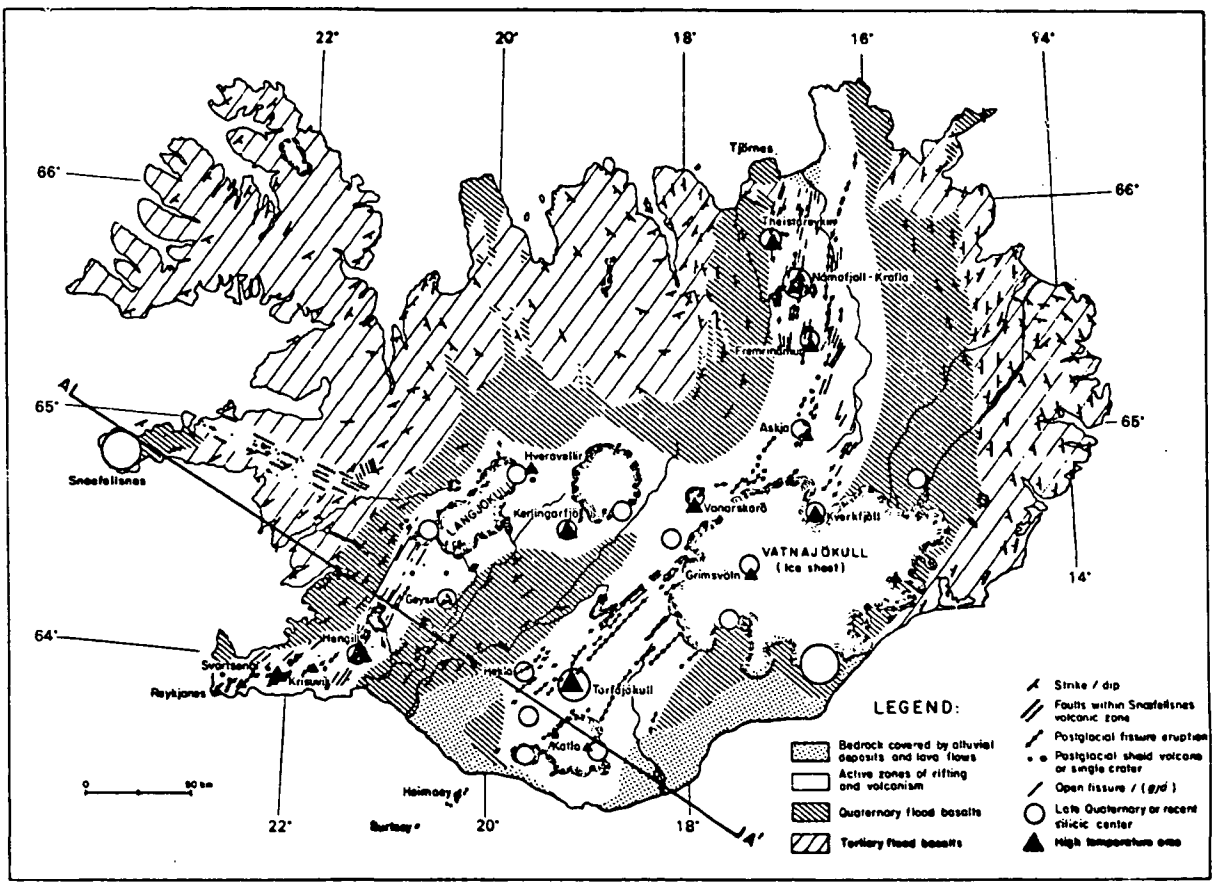


From Head and Gifford, 1977.

The plains of Mercury are equally enigmatic in their lack of large volcanic features and the resulting uncertainty about their origin. Perhaps comparisons of features on other planets will lead to knowledge of emplacement mechanisms that might bear on the origin of these extensive units.

The discussions and itinerary in this guidebook are designed to provide a view of the spectrum of possible Icelandic analogs to such planetary volcanic features.



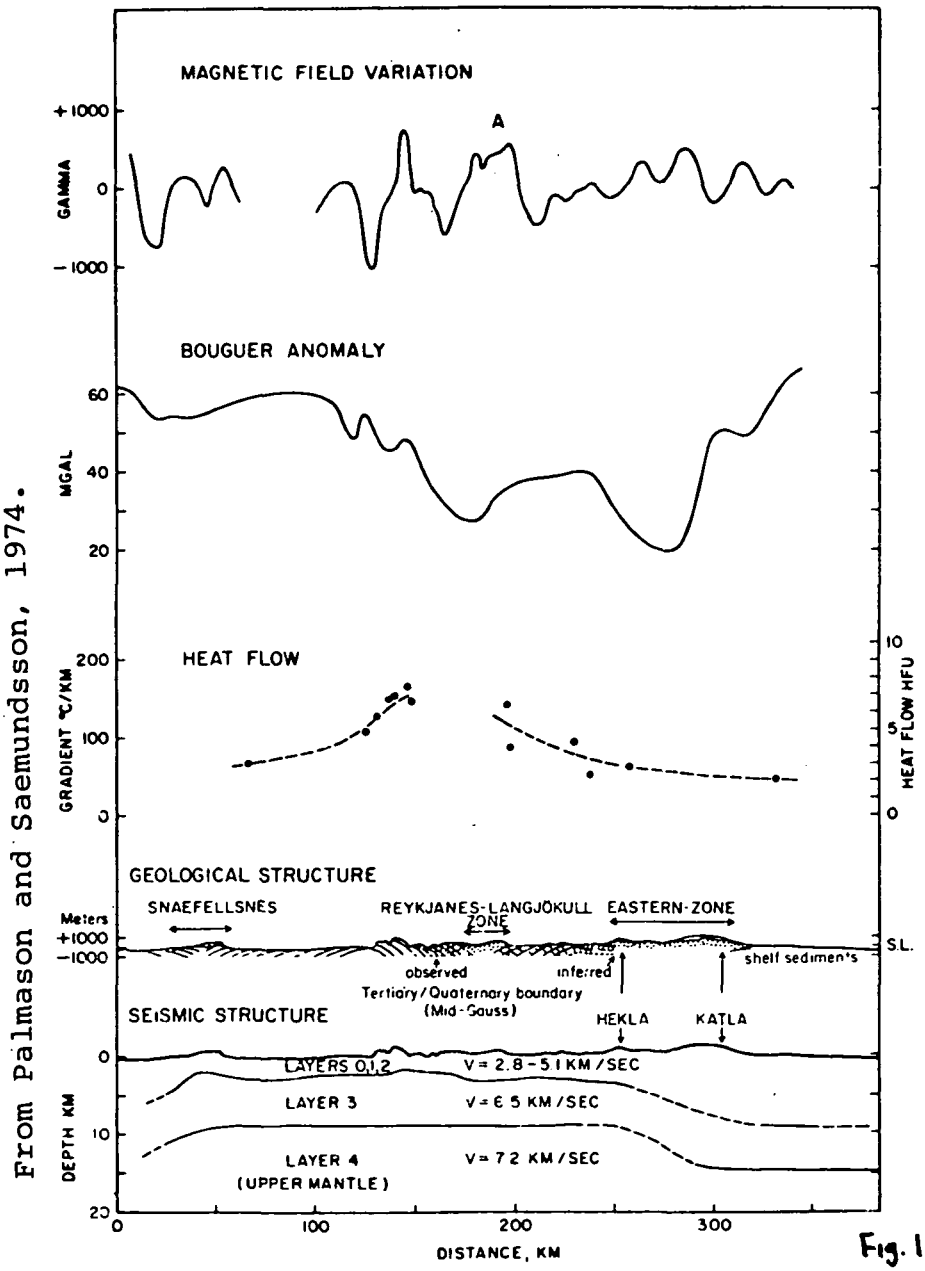


From Palmason and Saemundsson, 1974.

Geophysics and Structure of Iceland

Astride the Mid-Atlantic Ridge, Iceland is both a key to oceanic volcanic processes and a riddle because of its very existence. The topography of Iceland and its crustal structure mark it as different from the ocean floor and yet Iceland has grown up from the floor. Although many geophysical studies have elucidated the structure of Iceland (summarized here from the review of Pálmason and Saemundsson {1974}), and hot spots and mantle plumes have been evoked, there is still uncertainty in Iceland's origin.

Fig. 1 summarizes basic geophysical results for Iceland. Seismic refraction studies reveal a layered structure similar to that of oceanic crust, but thicker. Bott has suggested that its peculiarities warrant the title "Icelandic type crust."



From Pálmason and Saemundsson, 1974.

Fig. 1

Details of the crust are tabulated below (Walker, 1975).

Crustal Layers in Iceland

Layer	Thickness km	P velocity km s^{-1}	Density g cm^{-3}
0	0·5	2·8	2·1–2·5
1	1·0	4·2	2·6
2	2·15	5·1	2·65
3	6	6·5	2·9
4 (mantle)	—	7·2	3·1

Layers 0-2 are correlated with rock exposed at the surface, but the nature of layer 3 is unclear. The high velocity of layer 3 has been ascribed to metamorphism of basaltic rocks and/or massive intrusions of dikes.

Magnetic investigations such as those that documented the history of the seafloor have traced oceanic magnetic lineations onto Iceland and along the volcanic rift zones. Unlike ocean floor magnetization, which is due to thin layers of highly magnetic lavas, Icelandic magnetic anomalies appear to represent magnetite rich rocks as much as 2 km thick.

Bouguer gravity values are low (-30 mgal) in central Iceland, increasing toward the coasts (+40 to 50) and reaching considerably higher values (+100 to 200) in the surrounding oceans. This gravity low is not due to variations in crustal thickness but rather reflects anomalies in the upper mantle that extend to a depth of ∿200 km.

Heat flow measurements (away from disturbed geothermal areas) show high values (max 7 HFU) near the volcanic rifts and lower values (min 1.7 HFU) away from them. Thermal models by Pálmason indicate that the solidus of basalts is reached at a depth of 10 km. A similar depth was deduced from resistivity measurements made by Hermance.

The geophysical data for Iceland imply that the upper mantle is in a state of partial fusion extending to a depth of 200 km. Thus the explanations for Iceland's uniqueness should not be sought only in near surface processes.

Structurally, Iceland surmounts a plateau rising more than 1000 fathoms above the Atlantic floor, and connected to the European continental shelf by the Iceland-Faeroe Ridge. This is a tectonically inactive connection, however, and Iceland is not linked significantly to continental masses but rather to the ocean floor fracture system. The Reykjanes Ridge is the transition between the Mid-Oceanic Ridge and the rift zones of Iceland, and the Iceland-Jan Mayen Ridge links Iceland to oceanic fracture zones to the north. The locus of earthquake epicenters marking the ocean ridges is offset ∿150 km to the east in Iceland, following the eastern rift zone. Another rift (the western) zone lies in line with the Reykjanes Ridge but bends to join the eastern rift in central Iceland. A third, abandoned rift whose relation to the other rifts is unclear exists in the Snaefellsnes Peninsula. The rifts are defined by volcanoes, thermal areas, and fissures, and are areas undergoing subsidence and extension.

Petrology Introduction

Traditionally the volcanic history of Iceland has been divided into five distinct stages: the Tertiary Plateau basalts, the Old Grey Basalts, the Moberg, the Young Grey Basalts, and the recent volcanics.

The Tertiary basaltic plateau forms the oldest rocks of Iceland and was previously thought to form part of the Thulean Province comprising Iceland, Greenland and Britain, however, the oldest Icelandic rocks (16 m.y.) are much younger than Thulean rocks elsewhere (30-60 m.y.). In Iceland the Plateau basalts are some 5-6 km thick and are presently exposed on the western, northern and eastern coasts of the country. The basalts were erupted subaerially and have since been tilted toward the rift axes. Dykes are extremely abundant within the basalts and there are occasionally intrusions of gabbro and granophyre.

There is a large variation in the composition of the Plateau "basalts;" Walker has calculated the following abundances for each lava type:

Tholeiites	48%
Olivine basalt	23%
Porphyritic basalt	12%
Acid lavas	8%
Andesites (Icelandites)	3%
Detrital beds	6%

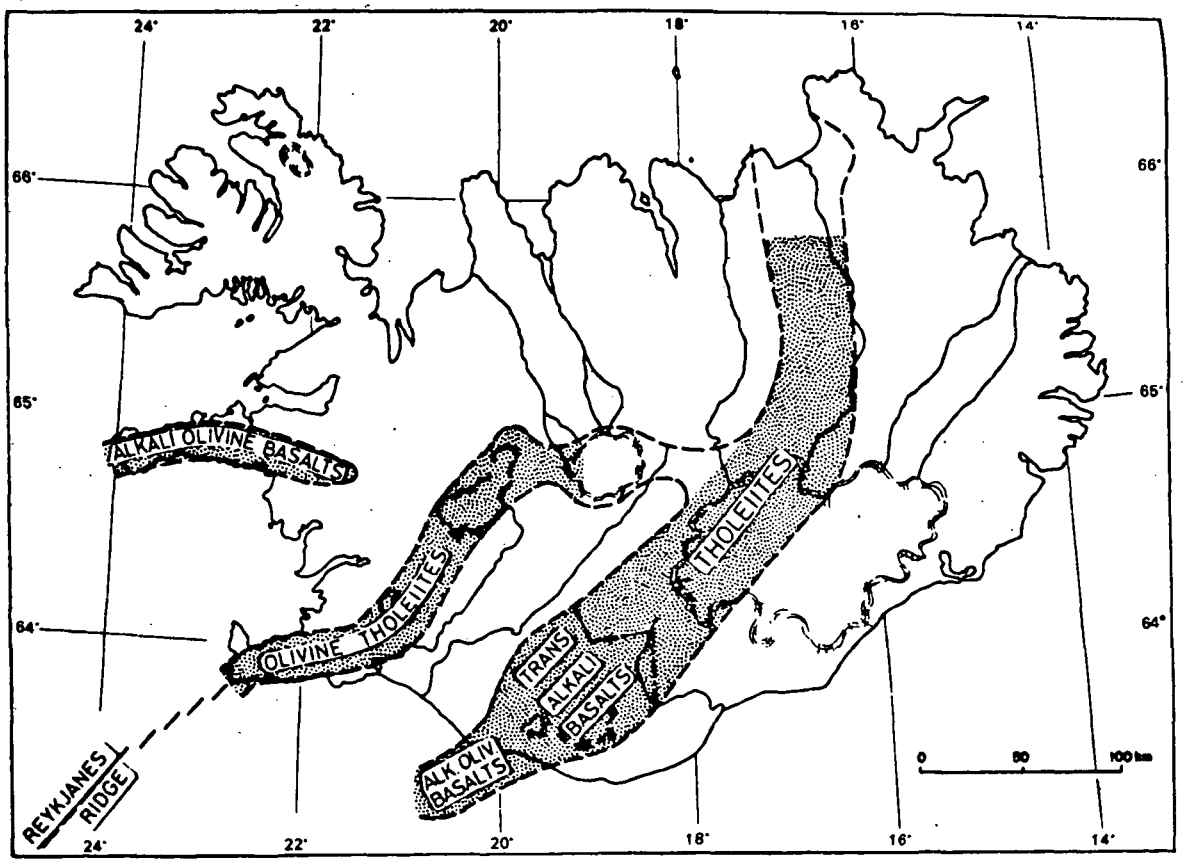
The Old Grey Basalts are lighter in color than the plateau basalts and contain an approximately 50% intercalation of clastic volcanic material. The O.G.B.'s were succeeded by the Moberg formation and the Young Grey Basalts. In some cases the Y.G.B.'s are older than the Moberg, in other cases, younger. It is probable that the Y.G.B.'s were erupted during interglacials and the Moberg during glacials. Moberg is Icelandic for "brown rock" and is the subglacially erupted palagonite sequence. The Y.G.B.'s are similar to the O.G.B.'s though the former can sometimes be coarser-grained. They are distinguished from the O.G.B.'s by being traceable to their sources and in having glacially striated surfaces. Most of the Y.G.B.'s were erupted from shield volcanoes.

The recent volcanics are described in the local excursions and their spatial-composition relationships are illustrated on Fig. 2.

The table below indicates the volcano-tectonic evolution of Iceland according to Einarsson and Kjartansson.

Geomorphology	Tectonics	Volcanism
	1. Tilting	Tertiary Plateau Basalts
	2. Main movement of entire plateau	
1. Planation	↓	
	3. Vertical displacements	
2. Deepening of valleys		
3. Uplift of 200 m, valley deepening and formation of coastal rock terrace 2-3 km wide		Old Grey Basalts
		Young Grey Basalts
4. Pleistocene glaciation		Moberg formation
		Young Grey Basalts
		Neovolcanics

From Palmason and Saemundsson, 1974.



Petrological division of the volcanic zones in Iceland, based on postglacial lavas

Fig.2

Volcanic Morphology

Iceland is a paradise for volcanologists because of its many and varied forms of basaltic eruptions. There are small shield volcanoes that may be comparable to the domes on the Moon and Mars, there are calderas, fissure eruptions and crater chains, all of which can be found in extraterrestrial settings, and there are maars and other pyroclastic craters that may be analogous to such features as dark-halo craters. Iceland also has the peculiar landform, the table mountain, which is a product of a subglacial eruption. Specific features of the martian surface have been interpreted to have formed in a glacial or periglacial setting.

Icelandic shield volcanoes are quite small compared with those of the Hawaiian or the Galapagos Islands but larger than those of the scutulum-type which were described by Noe Nygaard in the Faeroe Islands (Fig. 3). Typically the Icelandic shields are 100-900 m in height and 2-20 km in diameter. Some may have been the products of a single eruption whilst others were the products of multiple eruptions; opinion is divided since no shield volcano in Iceland has been observed in formation. The Icelandic shields are similar, in terms of size, to those domes within the lunar maria (Fig. 4) so investigation of the morphological variations of the Icelandic shields may enable us to more closely characterize the conditions of formation of their lunar counterparts. Fig. 5 shows the variation in profile of some Icelandic volcanoes.

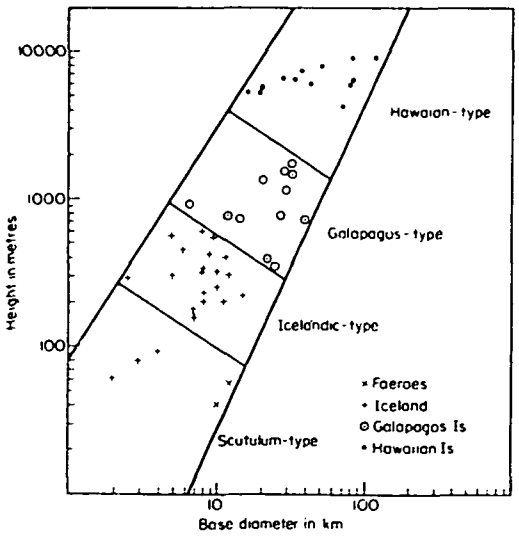


Fig. 3 Height-diameter relation for terrestrial shields

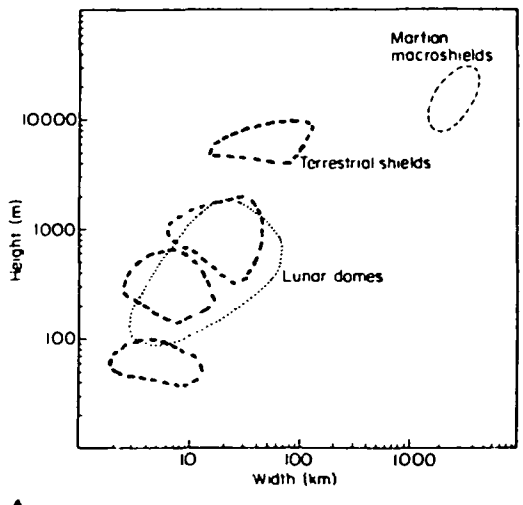


Fig. 4 'Height-diameter relation for different groups of planetary shield volcanoes.

From Whitford-Stark, 1975.

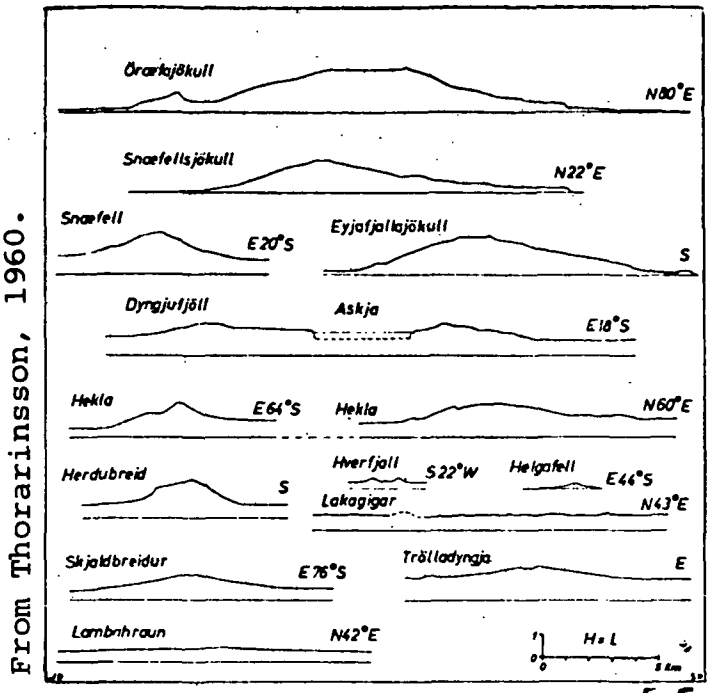


Fig 6

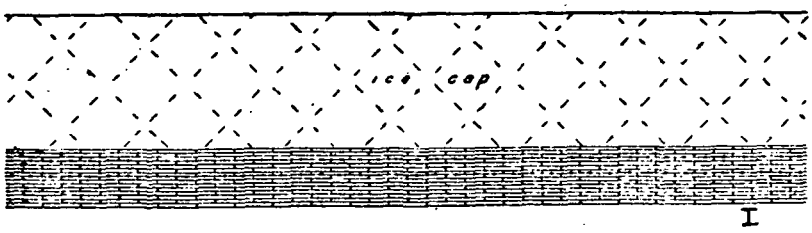
The outlines of Icelandic volcanoes constructed from topographical maps. Height scale the same as length scale. The horizontal lines mark the sea level.

All the large shield volcanoes on Mars have summit calderas and certain lunar craters have, in the past, been ascribed an evolution by caldera-producing processes. Askja, an Icelandic caldera that we shall visit (see section on Askja), is one of less than ten calderas that have been observed to form on Earth. Contemporary accounts indicate that caldera formation, in this case, was not an instantaneous process but proceeded over several decades. In terms of current caldera classification schemes Askja falls within the Krakatoan group in that collapse followed the pumice eruption; however, the volumetric difference between the pyroclastics ejected and extent of collapse necessitates the draining of material in other channels and thus also places Askja within the Hawaiian group (Steve Sparks will expand further his ideas of the formation of Askja).

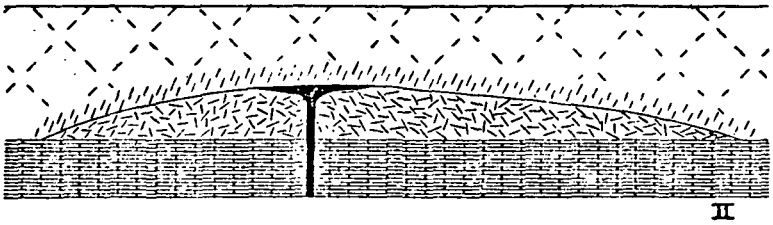
In the semi-circular mare to the south of the lunar crater Copernicus there are a number of fractures which have small cones superimposed on them. Iceland, with its numerous fractures, has many similar crater chains, some of which we shall visit (see section on Myvatn).

Iceland has also been the site of the largest historic eruption of lava - from the Laki fissure - and, although we shall not visit this lava, we will be able to investigate similar types of eruptions. Hopefully, the fissure zone to the north of Myvatn will still be active when we arrive. It is possible that some of the lavas near the edges of the lunar mare were the product of fissure eruptions. In particular, Hadley Rille commences at an elongate cleft in the lunar crust.

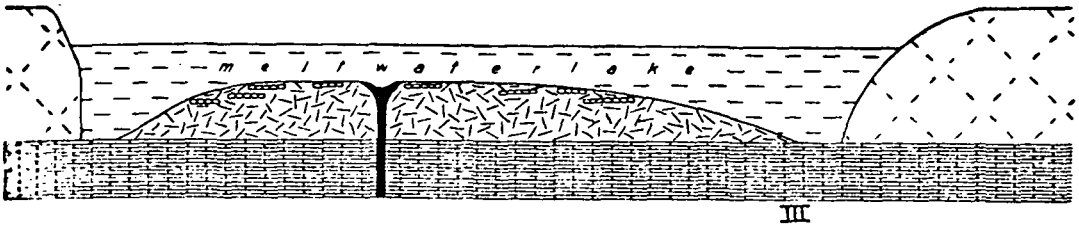
Although table mountains may not have counterparts on the other planets of the solar system, they have features in common with the products of volcanism at the other frontier of human exploration, namely the ocean floor. The confinement of the eruptions by ice caps has led to a distinctive steep-sided morphology and, when the magma has broken through the ice, a flat top. The interaction between the lava and ice melt water has led to the development of pillow lavas and palagonite tuffs, features common to submarine eruptions. One interpretation of the development of table mountains is illustrated in the accompanying diagram.



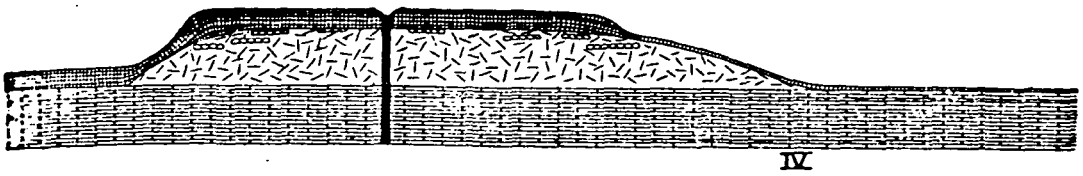
I. Before the eruption. The icecap rests on older basalts, subaerially extruded, with tillite intercalation(s); the Laxárdalur Series.



II. Subglacial eruption, forming palagonite tuff and breccia.



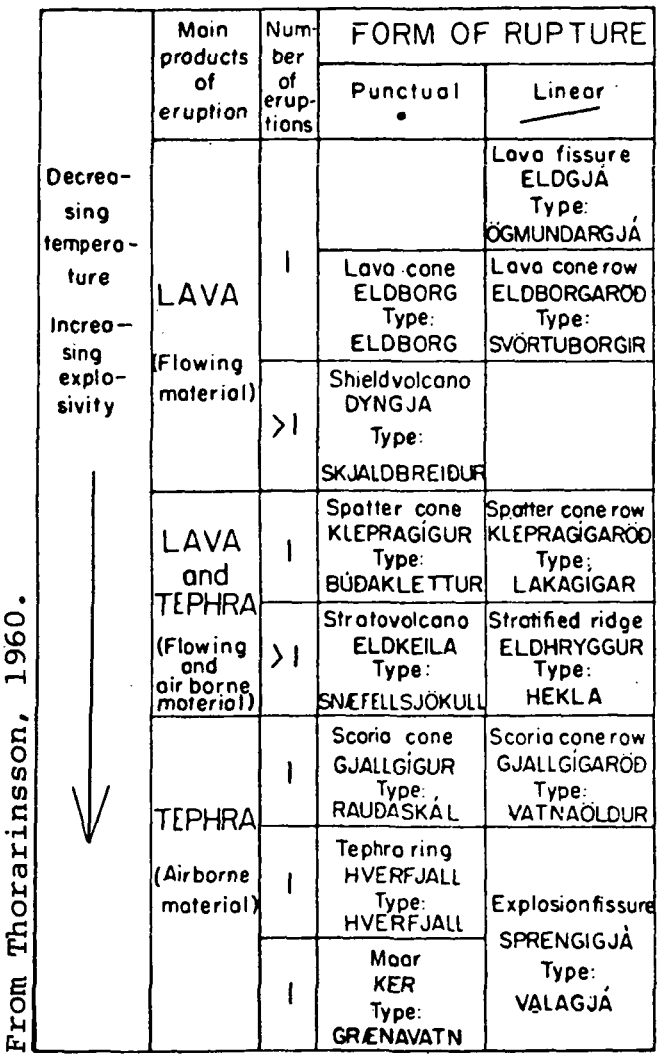
III. Local melting of the icecap, formation of irregular layers of nodular lava, in a lake of meltwater



IV. Complete regression of the icecap surrounding the eruption centre. Formation of subaerially extruded basalt series of topplateau. Local formation of lavas in the surrounding plains. Hrafnabjörg Series.

From Van Bemmelan and Rutten, 1955.

There are numerous variables in volcanic eruptions that may account for these differences including viscosity, temperature, eruption rate, composition, volatile content and length of eruption. Thorarinsson has explained the variation in morphology of Icelandic volcanic features in terms of decreasing temperature and increasing explosivity (see Fig. 6) whilst Walker has interpreted variations in lava flow morphology in terms of eruption rate.



The main types of Icelandic volcanoes.

Fig. 6

Field Guide to Reykjanes Peninsula

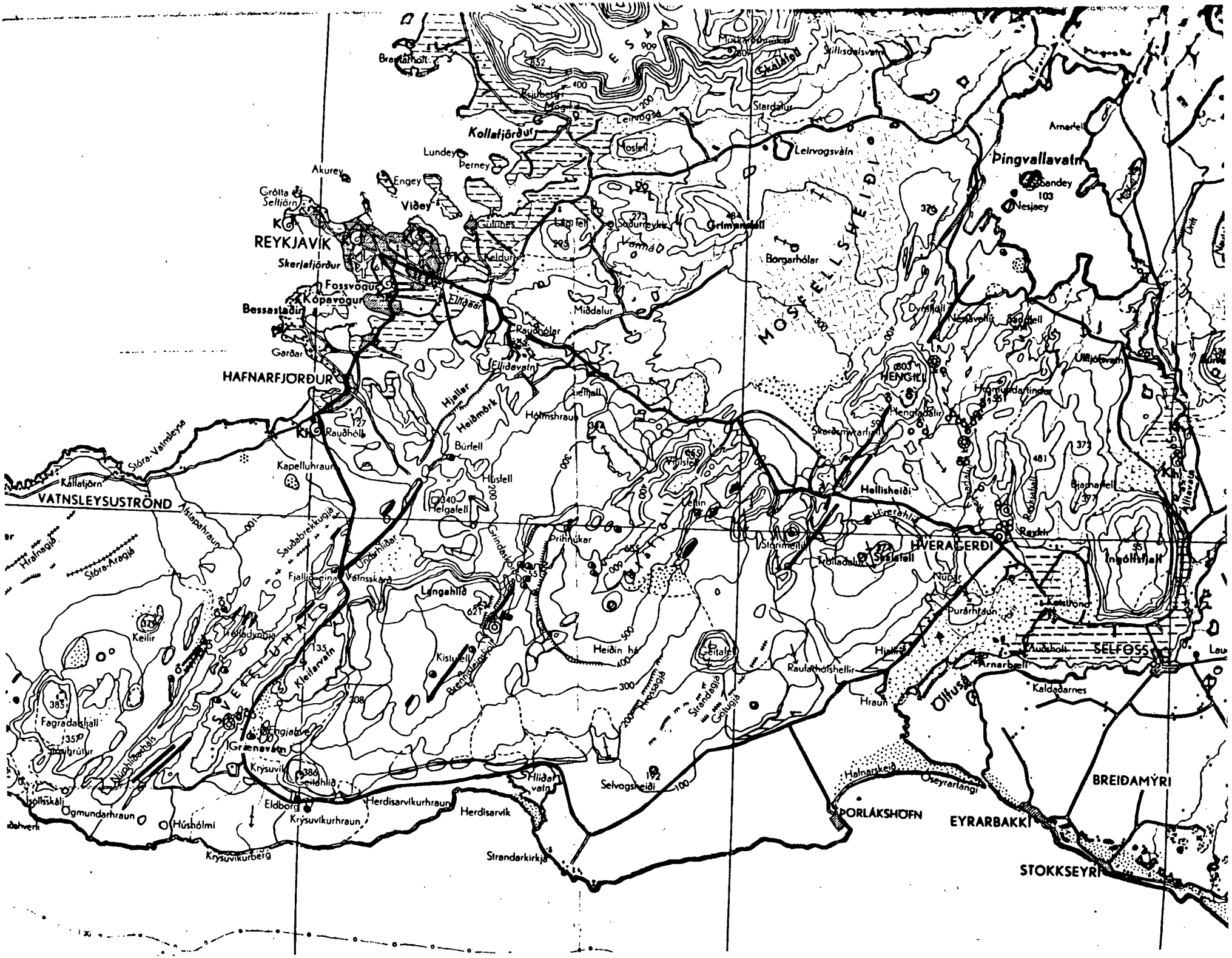
Although the Reykjanes Peninsula (RP) lacks major volcanic centers, it is of immense interest because it marks the emergence of the Mid-Atlantic Ridge (MAR) onto Iceland. The axial magnetic anomaly of the MAR continues onto and along the RP (Sigurgeirsson, 1970), as do earthquakes, intense thermal activity, fissuring, and volcanic eruptions. But before concluding that the RP provides a dry opportunity to investigate ocean ridge style spreading, consider Walker's (1975) cautions that Iceland is anomalous because (1) it is above sea level, (2) it has six active rift zones rather than one, and (3) it has a spreading rate ∿4 times faster than the MAR. Thus, there should be 2 principal questions put to the landforms of the RP: (1) How do they resemble submarine features of MAR?, and (2) What different characteristics do they possess that may account for Walker's anomalies?

RP is characterized by en echelon sets of NE-SW trending fissures, some with craters and lava flows and others without (gja). Fissure and fault systems are commonly 3-10 km long and normal faults with displacements up to 10's of meters occur. Geodometer measurements across fissures and graben near the tip of RP show extensional (∿9 mm/yr) and left lateral movements, suggesting that RP is a leaky transform fault (Brander et al., 1976) offsetting the MAR to the more active Eastern Rift, and via the Tjörnes transform fault in northern Iceland, to the Iceland-Jan Mayen oceanic ridge (Ward, 1971).

Reykjavik, and the road southeastward from it, are built on interglacial Young Grey Basalts (Kjartansson, 1960a,b). About 10 km from the center of Reykjavik is a small field of pseudocraters along the shore of Ellidavatn (vatn = lake), and for the next 10 km there is a good view of the 585 m high móberg mt., Bláfjöll. To the south, Bláfjöll grades into a 10-12 km wide, 400 m high shield volcano (Heithin ha) with a summit crater. About 25 km from Reykjavik the road enters a field of younger basalts and ∿5 km further on reaches a major series of NE-SW eruptive fractures in line with Hengill, a palagonite mt. north of the road, and the Thingvellir fractures further north.

The area between Hengill and Skalafell is rich in cratered fissures, recent flows, hot springs, and geysers. Hot water from these springs is pumped to Reykjavik for heating purposes. The Hellisheidi (or Thurárhraun) lava flow of 1000 A.D. issued from NE-SW fissures lined with craters 20-30 m wide and 50 m long (Barth, 1950).

The road continues on to the town of Hveragerdi where we turn south (right) toward Reykjanes. This turn takes us around


REYKJAVÍK
Kóp
Kóp
HAFNARFJÖRÐUR
VATNSLEYSUSTRÖND
HENGILL
HVERAGERÐI
SELFOSS
BREIÐAMÝRI
EYRARBAKKI
STOKKSEYRI
ÞORLÁKSHÖFN
Kollafjörður
Skerjafjörður
Faxaflói
Hvalfjörður
Þingvallavatn
Leirvogsvatn
Mosfellsheiði
Hellisheiði
Svínahraun
Selvogsheiði
Strandarkirkja
Herdisarvík
Eldborg
Krýsuvík
Grænavatn
Kleifarvatn
Vesturháls
Austurháls
Reykjanes
Reykjanesfólkvangur
Reykjanesskagi
Reykjanesvirkjun
Reykjanesbraut
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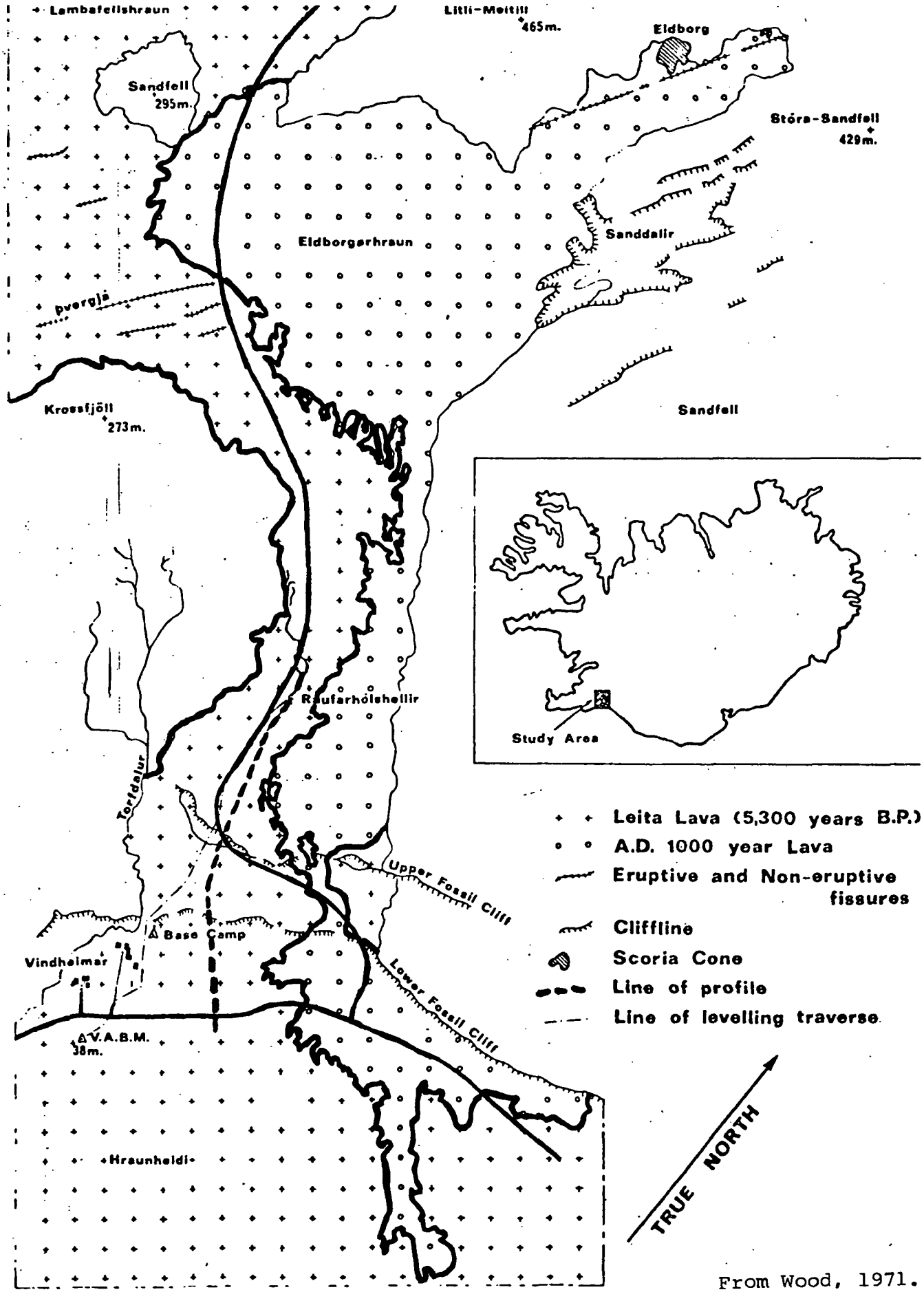


From Wood, 1971.

The Post-Glacial Lava Flows around Vindheimar, South-West Iceland.

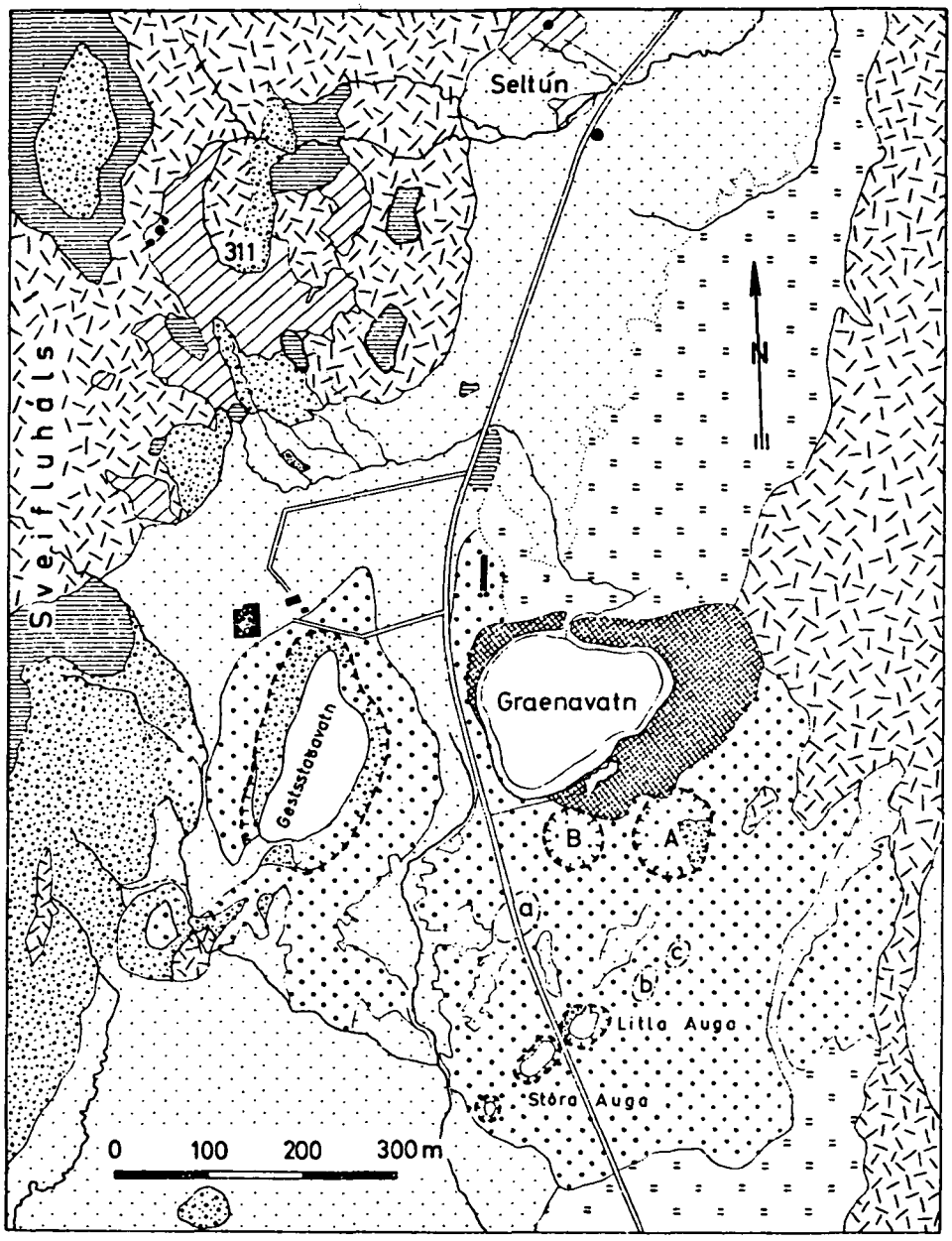
to the SE flanks of the Pleistocene shield volcano Skalafell which was a source for Young Grey Basalt.

The next major landform is a large table mt., Geitafell, ∿5 km north of the road, but a few km before closest approach to this table mt. the road skirts two raised shore lines veneered with lava flows. Within these flows (dated as younger than 5300 BP) is the sinuous Raufarholshellir lava tube formed by the draining of molten lava from crusted flows (Wood {no relation}, 1971). The tube is 1.1 km long, ∿11 m high, and contains normal lava tube features such as lateral benches, grooved walls, stalactites, and stalagmites.

For most of the next 50 km beyond Hveragerdi the road passes between the flanks of Heidin ha shield volcano and the sea, passing 1 km SW of a small shield crater ∿25 km after the turn from the road to Selfoss. After this long stretch through tectonically undisturbed post-glacial basalts the road passes a table mountain, Geitahlid, and two cinder cones, and then turns north at Krisuvik, passing along the base of the linear mountain, Sveifluhals. This, and other móberg mts. (Kjartansson, 1960a) are composed of palagonite and were probably erupted under icecaps.

The Krisuvik area has numerous hot springs and solfataras, from some of which sulphur was mined in the 18th and 19th centuries. There are also a number of lake-filled explosion craters or maars, the largest of which is Graenavatn. Nöll (1967) has carefully studied these craters. Graenavatn is 340 x 260 m wide, 45 m deep, with a smoothed rim ranging 2-11 m above the surrounding terrain. The rim is littered with blocks up to 4 m in diameter, originally thought to be moraine deposits, but now considered to be ejecta thrown out during eruptions. On the west side of the road is another large maar, Gestsstadavatn, which is 350 m x 160 m wide and whose floor is 16-29 m below the rim crest. A shallow lake (2.6 m deep) fills the floor. The slopes of the outer walls are ∿10-12°, while the inner ones are 27°.

Regretfully leaving the maars, the road continues NEwards along the flank of the móberg mt., Sveifluhals, toward the lake, Kleifarvatn. The volcano Trölladyngja may be visible through a notch in Sveifluhals, but in any case it will be seen after the road rounds the end of the long mountain. Trölladyngja is another Pleistocene móberg mt., but it has been cut by recent fissures (perhaps explaining the "gja" in its name?) and is the site of numerous historical eruptions. Trölladyngja was active 6 times between 1151 A.D. and 1510 A.D. but has not erupted since. The northern continuation of the western edge of Sveifluhals is the site of a cinder cone and eruptive fissures that fed a 2 km wide young flow that the road crosses enroute to the part of Hafnarfjorthur, 11 km S of Reykjavik.

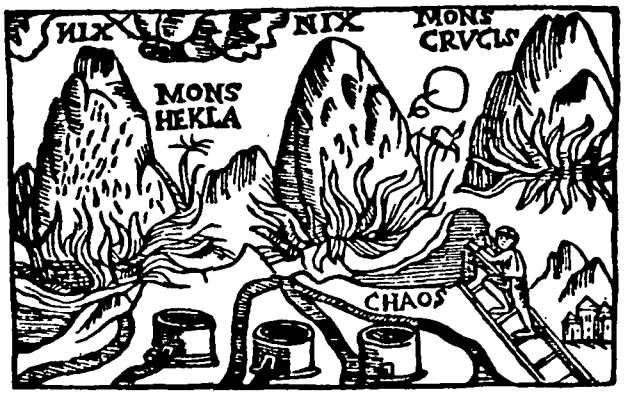


Geologische Karte von Krísuvík

- Palagonitbrekzie
- Basaltische Wurfschlacken
- Schweißschlacken-Laven
- Sprengschutt von Graenavatn
- Juvenile Auswurfmassen von Graenavatn
- A — Wälle von Schlackenkratern
- a — Fragliche flache Hohlformen
- Solfataren-Gebiete und Schlammtöpfe
- Äolische Überdeckung u. verschwemmte Zersetzungs-Produkte d. Solfataren-Gebiete
- Anmooriges Gelände

From Nöll, 1967.

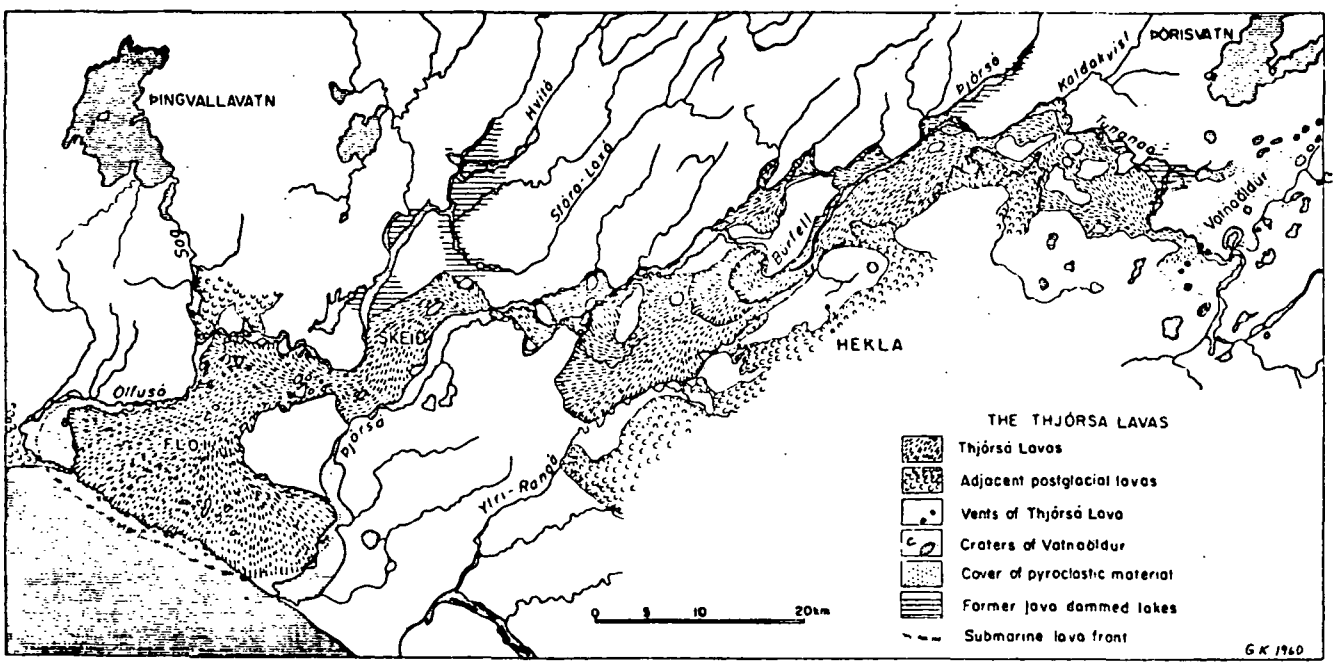
From Thorarinsson, 1970.



Field Guide for a Trip to Hekla

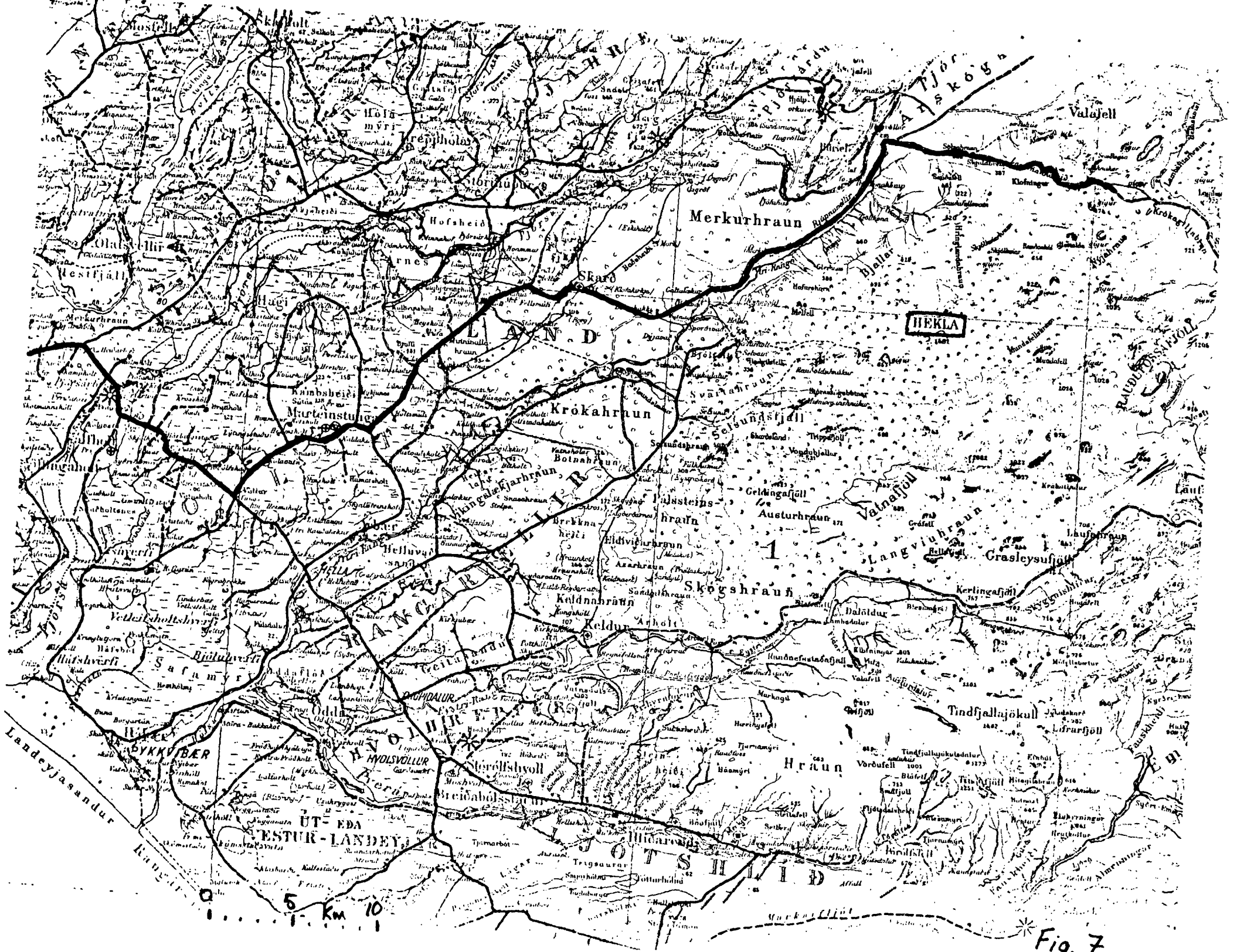
Hekla is the most active volcano in Iceland with 15 eruptions recorded since 1104; the most recent being in 1970. Hekla is of great petrologic interest because its lavas are basaltic andesites or icelandites (a more acidic composition than the bulk of Icelandic lavas) suggesting the existence of a sialic layer under Iceland. Tectonically, Hekla is within the eastern rift zone that stretches from Surtsey to Heimaey, Katla, Askja, Krafla and beyond. These are the only volcanoes to have erupted during the last 40 years, and all eruptions in Iceland since the 16th century have been along the eastern rift.

The route to Hekla is along the same road as the first part of the Reykjanes trip but at the town of Hveragerthi we do not turn but stay on the main road to Selfoss. The road passes over alluvium and through meadows and farmland. At Selfoss (58 km from Reykjavik) the Olfusá River is crossed and the road continues across extensive dairy land and bogs for another 18 km, where we turn right towards the bridge over the Thjórsá River. The name of Iceland's largest river is also the name of possibly the largest post-glacial lava flow on Earth. According to Kjartansson (in Thorarinsson {1960}), an 8000 year old porphyritic basalt poured out of vents now hidden by younger volcanics and flowed 130 km to the sea. This single flow covers an area of $\sim$770 km^2 and has an estimated volume of 15 km^3. From Walker's (1973) graph of flow length vs effusion rate the Thjorsa flow would have been extruded at a rate of 3000-5000 m^3/s.



From Thorarinsson, 1960.

The Thjórsá Lavas (G. Kjartansson).



Merkurhraun
Valafell
HEKLA
Skarð
Krókahraun
Marteinstunga
Selsundsfjall
Vatnafjöll
Langvíuhraun
Grasleysufjöll
Skógshraun
Keldur
Tindfjallajökull
Hraun
Landeyjasandur
Kangar
Hvolsvöllur
Stórólfshvoll
Breiðabólsstaður
Hlíðarend
Ut-eda
Estur-Landey
Hvolhreppur
Rangárvellir
Hvolsvöllur
Hellu
Odda
Bjólu
Safamýri
Vetleifsholtshverfi
Hafshverfi
Landeyjasandur
Kangar
0 5 Km 10

Fig. 7

Good profile views of Hekla, obtained from Selfoss eastward, reveal that the volcano has an unusual form. Viewed from the SW Hekla appears to be a shield volcano crested with tephra cones, but seen from the NW it has a steeper, more irregular profile. Hekla is built on a fissure that opens up during eruptions forming scoria cones and explosion craters as well as venting lava flows. Normally Icelandic fissures erupt only once, additional eruptions opening up new fissures, but Hekla has had re peated activity. Thorarinsson (1967) proposed that Hekla may ultimately grow into a normal stratovolcano similar to the eleven other silicic centers in Iceland.

Eruption in Hekla and the Hekla region in historical times

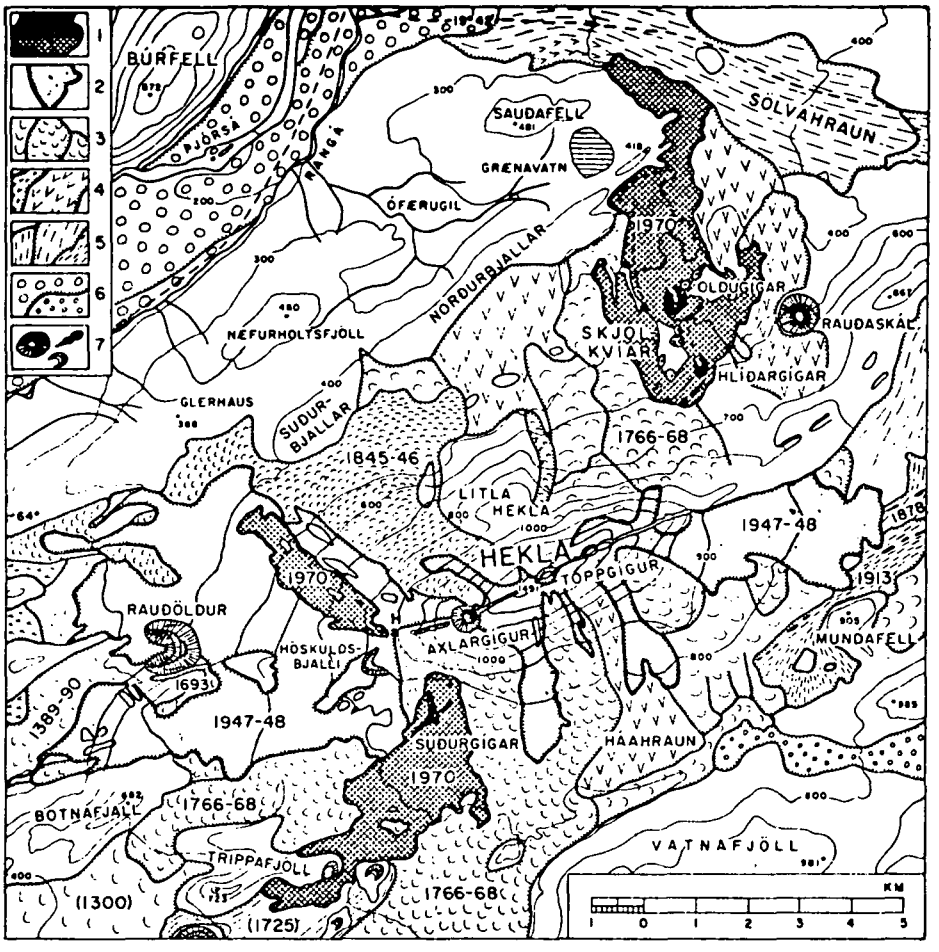
Hekla							Hekla region
Beginning of eruption	Duration Months	Length of preceding repose Years	Volume of lava 10^6 m³	Volume of tephra 10^6 m³	Direction of axis of max. thickness near Hekla	Damage caused by eruption	Beginning and location of eruption
1970, 5 May	2	22	200	70	W 65° N	Some	1913, 25 April, near Mundafell and on Lambafit
1947, 29 March ...	13	101	800	210	S 15° W	Little	
1845, 2 Sept.	7	77	630	280	E 10° S	„	
1766, 5 April	24	73	~1300	400	W 75° N	Considerable	
1693, 13 Febr.	7 to 10	56	Not known	300	W 55° N	Great	1878, 27 Febr., near Krakatindur
1636, 8 May	12	39	„ „	((80))	N 30° E	Little	
1597, 3 Jan	>6	86	„ „	(240)	E 20° S	„	
1510, 25 July	Not known	120	„ „	320	S 55° W	Great?	1725, 2 April, E and SE of Hekla
1389, early winter .	„ „	47	>200	((80))	(E 40° S)	Considerable	
1341, 19 May	„ „	40	Not known	((80))	S 85° W	„	
1300, 11 or 12 July.	12	78	>500	500	N	Great	1554, May, in Raudubjallar
1222, ?	Not known	15	Not known	((10))	N 60° E	Little	
1206, 4 Dec.	„ „	46	„ „	((30))	N 40° E	„	Ca. 1440, SE of Hekla
1158, 19 Jan.	„ „	53	>150	Not known	SSE?	„	
~1104, autumn? ..	„ „	>230	No lava?	2500	W 80° N	Very great	

From Thorarinsson, 1970.

Resuming the itinerary at the Thjórsá bridge, we proceed through a patchwork of roads passing bogs and meadows, as indicated in Fig. 7 , and finally regain the Thjórsá lavas near the village of Skard. Continuing, the road turns NE and parallels Hekla at a distance of 8 km from the summit fissure. It is uncertain how far our vehicles will be able to continue along this track, but we will try to drive to the N end of Hekla to the 1970 flow and then on to where the track crosses the central fissure zone. Local conditions and expertise will determine our exact route and goal.

Mount Hekla

Mount Hekla is the most famous volcano in Iceland. It is located in the southern part of the country, 110 kilometers east of Reykjavík and 55 kilometers from the southern coast. It is an elongate ridge 27 kilometers long and 2–5 kilometers wide, fissured in the direction of its length with a row of craters along the fissure. It is built of succes-



From Thorarinsson and Sigvaldason, 1972.

Hekla lava flows. 1: 1970-lava. Dash line shows the extent of the Hlídargígar lava beneath the Öldugígar lava. 2: 1947/48-lava. 3: Other Hekla lava flows younger than the settlement of Iceland. 4: Hekla lava certainly or probably prehistoric. 5: Lava from fissures in the Hekla region. 6: Thjórsá lava and Vatnafjöll lava. 7: Craters (the 1970-craters quite black). H: Hraungígur (Lava Crater), Axlargígur (Shoulder Crater), Toppgígur (Summit Crater).

sive sheets of lava and ash with a maximum height of 1,500 meters above sea level and 1,000 meters above the lava plateau on which it is situated. It is regarded by some as a strato-volcano, but to others it seems more closely related to the shield volcanoes of the Hawaiian type, although Hekla produces more ash than is generally true for typical shield volcanoes. The activity at Hekla is a modification of the typical fissure eruption of Iceland, in which successive outpourings of lava and ash-forming explosions have occurred along a fissure but in a restricted area, piling up the present mass of Hekla.

The first historic eruption of Hekla was in 1104, about 200 years after the settlement of the country. Since that time, Thorarinsson (*1970b*) lists 15 major eruptions with an average interval of about 60 years between eruptions, ranging from a minimum of 16 years to a maximum of 121 years. In recent centuries the intervals between eruptions have been longer than the earlier ones, with the 22-year interval between the 1947–1948 and the 1970 eruptions being an exception. The average duration of the eruptions has been about a year. An exception was the 1766–1768 eruption, believed to have been the longest in Hekla's history, which lasted for more than 2 years. Eruptions occurred in the following years:

1104	1222	1389	1636	1845
1158	1300	1510	1693	1947–1948
1206	1341	1597	1766–1768	1970

Most of the damage from an eruption of Hekla is due to the heavy ash falls. Ash from the great eruption of 1300 is conspicuous in the soil profiles on Iceland. The 1947–1948 eruption of Hekla, which was typical, has been well described by Thorarinsson (1950; 1956). A brief résumé of this eruption, based on his account, will be of interest.

The 1947–1948 eruption. On the morning of March 30, 1947, at about 6:00 A.M. a farmer near Mount Hekla was looking at the mountain, which at that time was covered with snow. He observed a yellow-brown cloud growing rapidly in size to a height of 100–200 meters. Several severe earthquakes were felt at about this same time. Shortly later the Hekla Ridge was split lengthwise by a fissure 5 kilometers in length, from which issued throughout its entire length clouds of ash-laden gases and outpourings of lava. As the snow melted, huge volumes of water flooded the Ytri Rangá River. By 7:00 A.M. the ash-laden cloud had reached the astonishing height of 27,450 meters! The surrounding area was enveloped in darkness and covered by pumice and ash which, 30 kilometers south of Reykjavík, reached a thickness of 10 centimeters. Forty hours after the eruption began, ash falls occurred in Finland. The main ash discharge took place during the first two hours of the eruption, and this initial phase might properly be termed a Plinian phase, but it was soon replaced by outpourings of lava. Activity decreased markedly after the first day. During the first day lava flowed from the whole length of the fissure; on the second day activity was concentrated at the summit crater and at points on either side; and on the third day lava flowed mainly from the ends of the rift at an elevation of about 830 meters. After that the activity oc-

curred almost exclusively at the Lava Crater at the southwest end of the fissure. Here the flow continued until April 25, 1948, ending a period of almost 13 months. The lava at the vent had a temperature of 1,020°–1,040° C. In the initial phase the silica content of the lava (as well as of the ash) was 59.6 percent, but later this dropped to 57–58 percent. Thus, as has been true of previous eruptions of Hekla, the lavas are more acidic than typical flood basalts. The total volume of lava from the eruption is estimated at 1 cubic kilometer (1 billion cu. m.), while the volume of clastic ejectamenta is estimated at 220 million cubic meters. This lava output is the greatest in Iceland since the Laki eruption of 1783 and ranks among the greatest in the world for the present century.

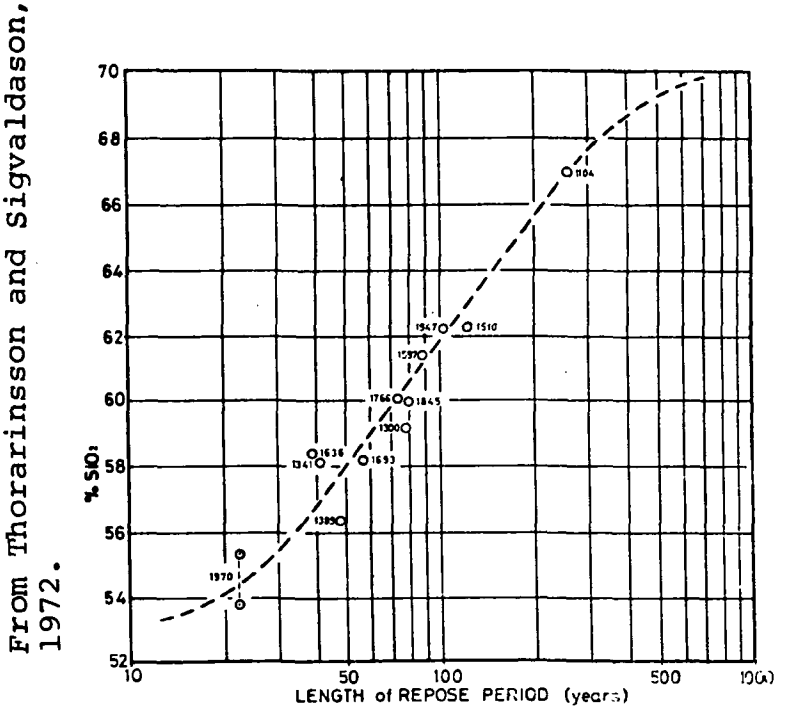
When lava stopped flowing in late April, 1948, escaping CO_2, on calm quiet nights, accumulated up to nearly two meters in depth in surface depressions. About 20 sheep and numerous other animals were killed when they wandered into these depressions. Although the reasons for the gas are not clear, it appears that when the CO_2 emerged it had the same temperature as the ground water, and it was taken into solution under pressure and then escaped as the pressure decreased on reaching the surface. In addition to the animals killed by CO_2 poisoning, some animals were killed by fluorine poisoning. This phase of activity lasted only a few weeks, but the streams originating on the slope of Hekla still contain dissolved CO_2 and precipitate calcium carbonate when they issue at the surface. On the whole, little damage was caused by the eruption.

The 1970 eruption. After a quiescence of only 22 years, Mount Hekla again erupted in 1970. The eruption, as described by Thorarinsson (1971), began on May 5 and ended on July 5, having lasted exactly two months. The eruption was not from the main Hekla fissure which splits the mountain lengthwise but from fissures at the south-southwest and northeast bases of the Hekla Ridge. As is typical, the first phase of the eruption was a huge ash-filled cloud which attained a height of 15,000 meters. The main ash eruption lasted only about two hours, and during this time the ash production averaged 10,000 cubic meters per second. The total volume of ash, which covered an area of about 40,000 square kilometers, was estimated to be 70 million cubic meters. The ash, which had a silica content of 54–55 percent, was high in fluorine (800–2,000 ppm), and 7,500 sheep were killed by fluorine poisoning. The lava from the 1970 eruption covered an area of 18.5 square kilometers on the slopes of Mount Hekla and added a volume of 0.2 cubic kilometers.

From Bullard, 1976.

As mentioned by Bullard the silica content of Hekla's lavas and ashes vary during a single eruption. Thorarinsson (1967) discovered that the percentage of SiO_2 in the initial products is a nearly linear function of the length of the previous repose period - the longer the interval between eruptions the more siliceous the initial volcanics.

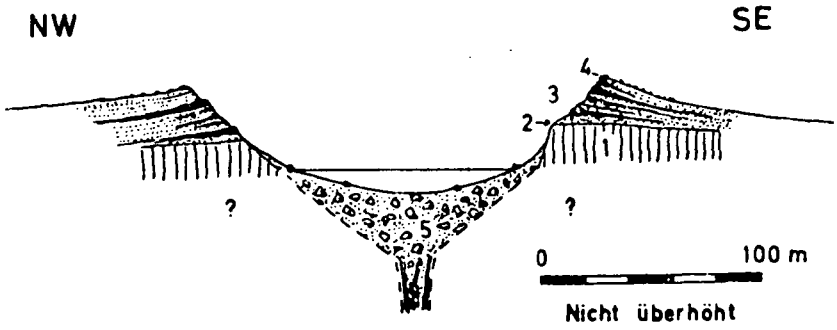
As an eruption continues the SiO_2 falls to a value (∿54%) that is nearly the same for later stages of all Hekla eruptions. Whereas Thorarinsson, Tomasson, and others believe that the observed SiO_2 variations require contamination of mantle derived basaltic magma by sialic crustal material, Baldridge et al. (1973) proposed that fractional crystallization in a shallow (∿6 km) magma chamber could explain the eruption characteristics of Hekla. This latter interpretation is supported by low Sr isotope ratios that are inconsistent with a sialic substratum (O'Nions, et al., 1973).



Variation in SiO_2-content of initial products of Hekla with length of the preceding repose.

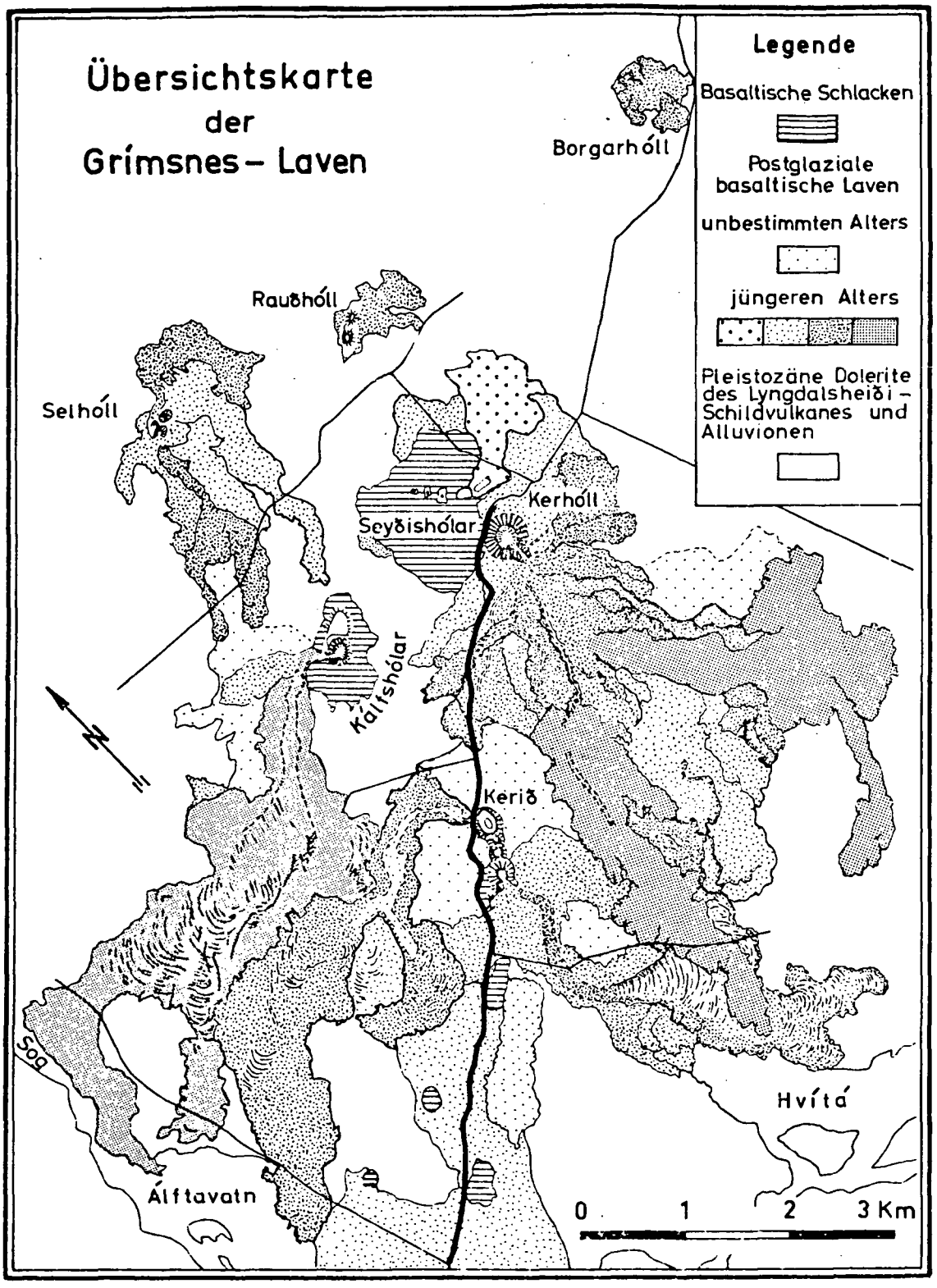
As a final word on Hekla, geodometer measurements showed that during the 3 year period prior to the 1970 eruption there was an extension of 65±31 mm across a traverse NE of Hekla (Decker et al., 1971). A remeasure in 1973 showed no new spreading (Brander, et al., 1976). These results suggest that, like Hawaii, Hekla may undergo subtle topographic changes that may allow prediction of future eruptions. However, since the average repose period between eruptions is 62 years, an eruption is not expected to be imminent.

The return from Hekla reverses the above route, with the possibility of an extra stop at the crater group of Tjarnarholar. Just north of the town of Selfoss is a junction at the foot of the 500 m high table mountain, Ingólfsfjall. To the left is the road to Reykjavik, and 15 km to right and over the bridge crossing the river Sog is the crater group. This field consists of 5 eruption centers with cones and associated flows that were active before 6420 BP (Nöll, 1967). The most interesting group is a 1 km long line of 6 craters, the youngest of which is Kerid maar. Kerid erupted through glaciated lavas and fluvial-glacial deposits resulting in a crater 220 to 180 m wide and 50 m deep. There is no juvenile material in the ejecta and thus the explosion must have been primarily phreatic. Interestingly, the earlier eruptions in this alignment produced normal scoria cones, and lava rose up in Kerid itself and fed a flow that covered an area of 3.78 km^2. The capricious interaction between ground water and magma is well illustrated.



From Nöll, 1967.

Section through Kerid, Iceland. 1) Basalt of the Lyngdalsheidi shield volcano; 2) fluvioglacial deposits; 3) cinders and spatter of cone No. 6; 4) thin layer of Kerid explosion debris; 5) explosion-debris in the funnel.



From Nöll, 1967.

Skjaldbreithur Trip

We take the road northeastwards from Reykjavik toward Thingvellir. The route crosses areas flooded by the sea after the last glaciation, late Tertiary and Pleistocene basalts, and glacial drifts.

Depending on the interests of the group, we may pay a tourist visit to Thingvellir, the site of the oldest parliament in the world, having already celebrated its 1,000th anniversary. It has also been the site of a geophysics experiment to measure crustal distance changes along an active rift axis (Brander et al., 1976, Tectonophysics, 31, 193-206). At Thingvellir there is a 5 km wide graben cut by numerous fissures and bounded at each side by 60 m high 10 km long normal faults striking at N40^{o}E. Over the period 1968-72 Brander's group recorded an extension rate of 2-5 mm per year. Other work by Tryggvason indicates that the graben is also subsiding at 2 mm per year.

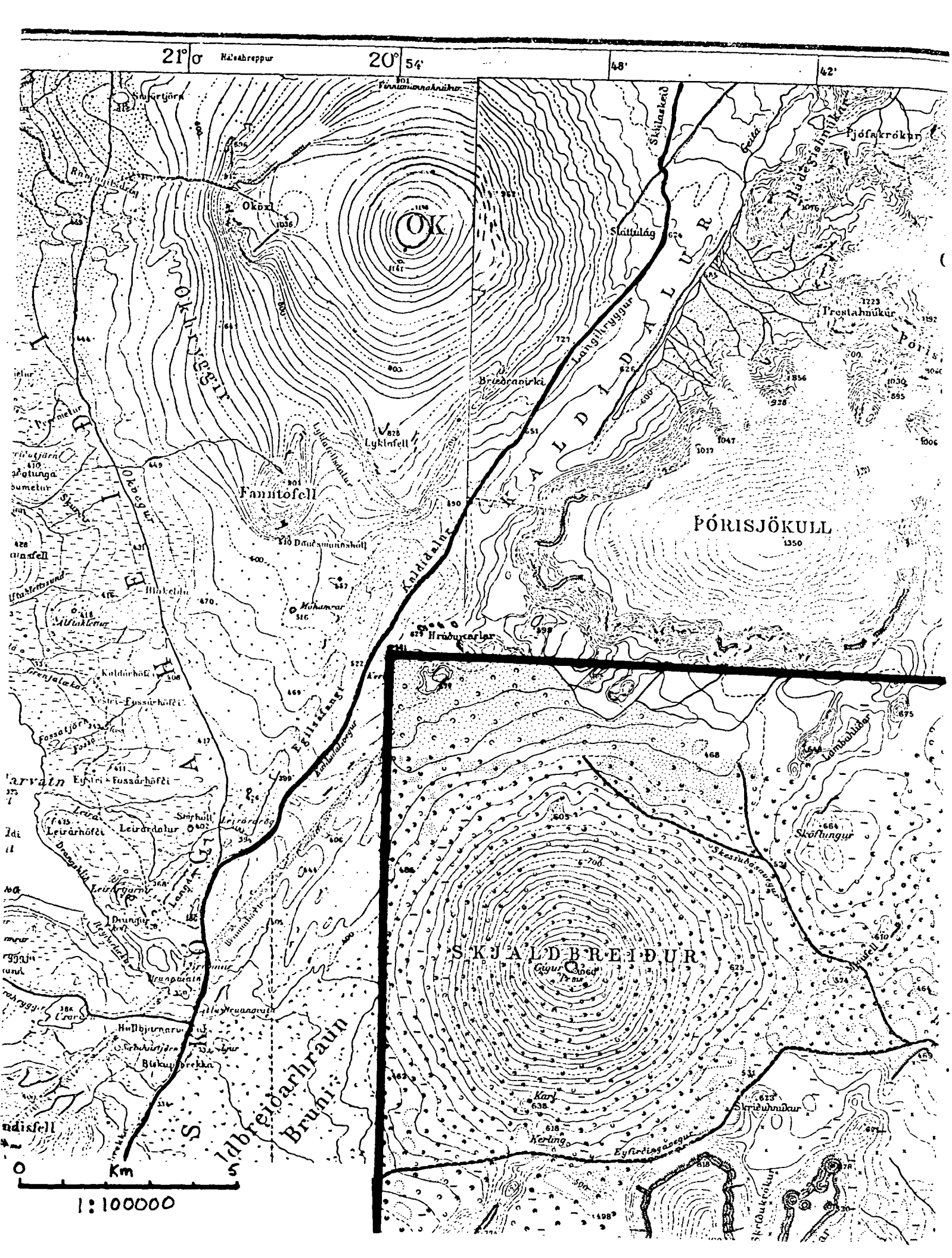
Moving northwards from Thingvellir we will next stop to inspect the palagonite and Pleistocene basalts of Armannsfell and Lágafell. These eruptions produced subglacial palagonites with the basaltic andesite lavas being formed as the lava broke through the ice cover.

Still moving northward, we will next explore a shield volcano. This volcano will be either Skjaldbreithur or Ok depending upon the time available and the degree of exhaustion of the group. Skjaldbreithur is the prototype of a postglacial shield volcano. It has a height of 550 m with a slope of 7-8°, a diameter of 10 km and a volume of 15 km^{3}. At the summit there is a 350 m diameter elliptical crater. Walker (1965) considers Skjaldbreithur to be the product of a single voluminous eruption of tholeiite which started from a fissure and eventually became concentrated at one point. The total volume of all postglacial shield volcanoes in Iceland is 60-65 km^{3} and none have erupted during the last several thousand years.

An alternative climb to Skjaldbreithur is the shield volcano Ok. Ok lies some 15 km to the north of Skjaldbreithur, is less high, and located nearer the road. The summit crater is also larger, measuring some 800 m in length.

These Icelandic shield volcanoes are of comparable dimensions to those domes within the lunar maria.

Time restrictions may force us to return to Reykjavik after the shield volcano visit. Alternatively, we may be able to return down the eastern side of Thingvellir and visit the fissures at the southern end of the lake.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20° 54'
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Guide to the Mývatn Region

Thorarinsson calls the Mývatn area an "Eldorado for volcanologists" and Barth speaks of the "enchanting volcanic lake in a peculiarly desolate landscape." It is true, however, that Mývatn is Icelandic for mosquito lake and Barth's enchantment was at least partially provoked by the observation that everything was "artificial, black, silent, lifeless." Nonetheless, Mývatn is a strangely beautiful area and is built up by fascinating and accessible volcanic landforms.

Mývatn lies within the northern arm of the eastern rift zone of Iceland. The area is characterized by NNE trending fissures, grabens, and crater chains that have erupted frequently in the last few thousand years. Additionally, the area is famous for the astonishingly high number of small pseudocraters on the shores of the lake, and for two tephra cones/maars east of the lake.

The lake is about 7 km across and only ∿5 m deep, having formed about 3800 years ago when an enormous lava flow (Graenavatnsbruni) from the Kefildyngja shield volcano, 25 km SE of Mývatn, flowed over the area and dammed its outlet (Thorarinsson, 1960). Lava from this eruption reached the sea, 60 km to the north, illustrating that small (∿10 km diameter) shields can be sources for widespread flows.

Remnants of the earlier history of the Mývatn area are preserved in palagonite ridges (Namafjall, Dalfjall) and table mountains (Burfell, Blafjall, Sellandarfjall). A still-stand during the retreat of the last glaciers deposited moraines and fluvial-glacial sediments near the village of Reykjahlid. Following this began a long series of volcanic eruptions that continues today. The table below summarizes the volcanic history of Mývatn.

PSEUDOCRATERS

The south and west shores, and islands, of Mývatn are saturated with small overlapping craters known as pseudocraters. Their "pseudoness" stems from the fact that they appear to be surface features or "roofless" vents. Their concentration is a crater-counter's nightmare; the isle of Mikley (area <0.5 km^2) is said to have more than 100 craters (Barth, 1950). Barth summarized Rittmann's (1938) findings about pseudocraters: (1) The craters are randomly aligned; they are not controlled by obvious fissures. (2) The craters are commonly small (2-300 m in diameter)

Volcanic Chronology of Mývatn Area*

Post-Glacial

Continuing activity: NAMAFJALL solfataras

1976-7: KRAFLA fissure eruptions/ground movements

1875: SVEINGJA crater row eruption
DYNGJUFALL/ASKJA flows and caldera collapse

1724-29: MÝVATN fires fissure eruptions

1724: HELVITI/KRAFLA maar eruption

c2000 BP: LUDENT crater 6; SVORTUBORGIR/THRENGSLBORGIR-

2500 BP LUDENTSBORGIR/KRAEDUBORGIR crater row eruptions; younger LAXA lava flows with formation of pseudocraters

c2500 BP: HVERFJALL tephra ring formation

2700 BP: HEKLA ash layer H_3

c3800 BP: KETILDYNGJA shield volcano eruption→older LAXA lavas (Graenavatnsbruni)

4000 BP: HEKLA ash layer H_4

c5000 BP: STOREGJA tension fissure

c6000 BP: LUDENT crater rows; NAMAFJALL fissure eruptions

c9000 BP: LUDENT tephra ring formation

Late-Glacial

Reykjahlid moraines and glacial-fluvial deposits. NAMAFJALL scoria cones (YTRI and SYDRIHOFDI)

Glacial

NAMAFJALL and DALFJALL palagonite ridges; BURFELL, BLAFJALL, SELLANDAFJALL table mountains

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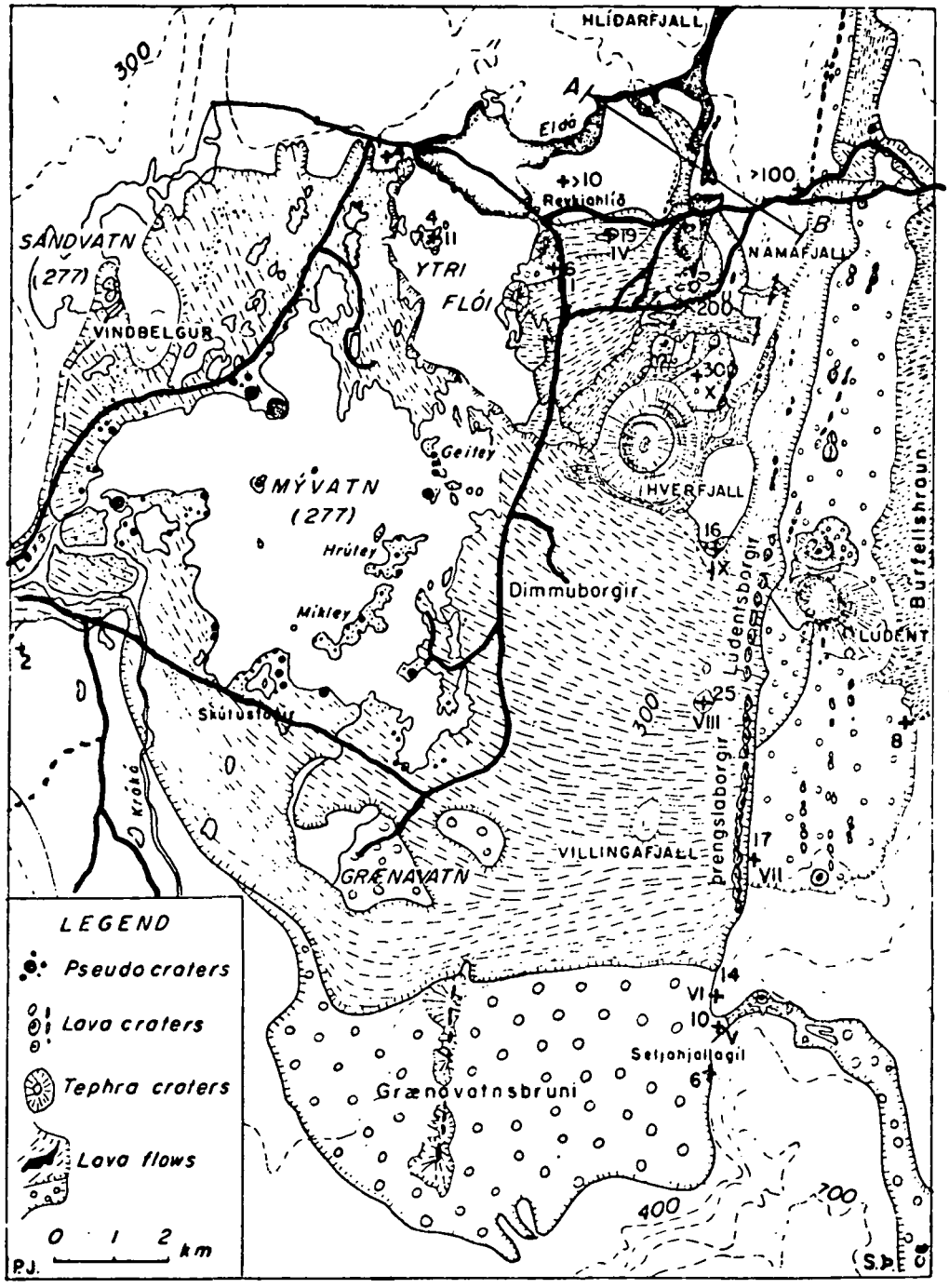
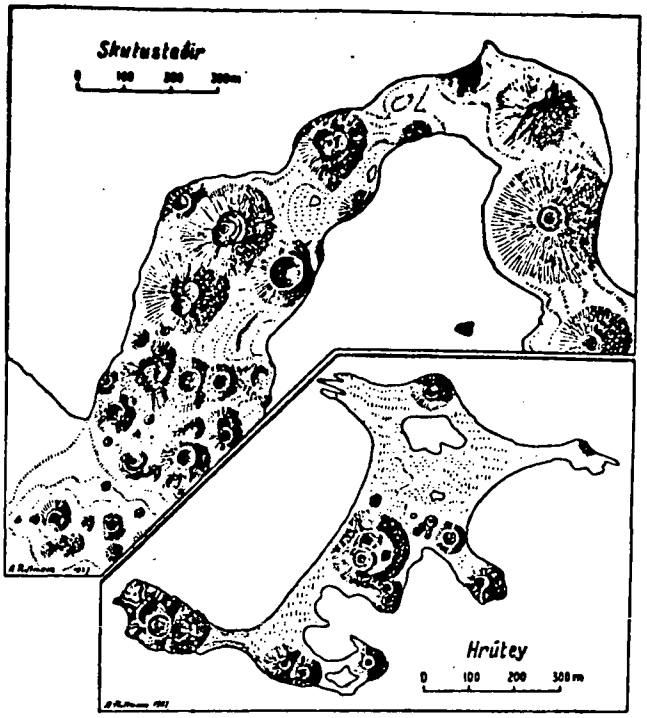
*Slightly amended from Kelly and Pinkerton (1972) and ultimately based on Thorarinsson (1960).



From Thorarinsson, 1960.



From Thorarinsson, 1960.

Crater groups at Skutustaðir and on Hrútey. (After Rittmann.)

and are closely spaced. (3) The craters are simple explosion vents that ejected lapilli, ash, and gases but not lava. Rittmann/Barth believed that the craters formed essentially by "boiling" of magma in a shallow reservoir. This theory ignores the concentration of craters around the lowest lying and wettest spot of the Mývatn region. Thorarinsson (1960) takes this factor into account and believes that the pseudocraters formed as a result of steam explosions when the younger Laxa lavas overflowed older water-saturated lavas.

DIMMUBORGIR (the Dark Castles)

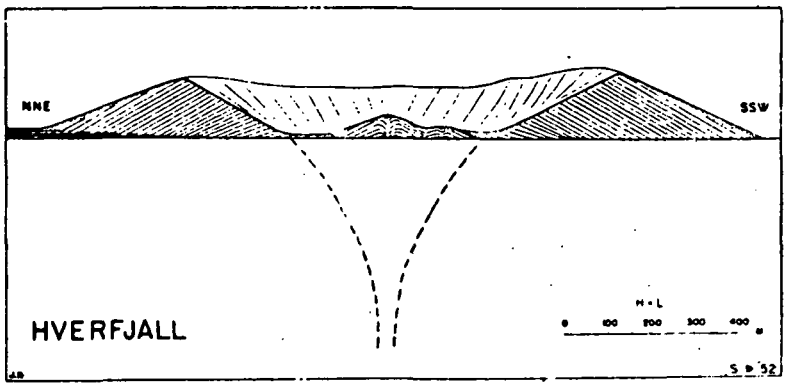
1½ km east of Mývatn there is a 1-2 km wide shield like formation called Dimmuborgir, formed in the younger Laxa lavas. Barth (1950) describes this feature as follows:

> Dimmuborgir (the Dark Castles) represent a slightly elevated, shieldlike area, 1 to 2 km across, in the lava plain. The central part of the low shield has foundered and forms a remarkable circular depression bounded by vertical lava walls, about 15 m deep. The interior has a scoriaceous floor with lava tunnels and passages coated with glazy lava. A considerable number of projecting lava pillars stand up as ragged peaks 10 to 20 m high, the summits thus reaching the level of the surrounding lava surface. The rock of which these consist appears to have been sufficiently solidified to remain standing when the crust around them sank because the liquid lava ran out from below it. They, like the side walls, are chiefly interesting as showing vertical marks like slickensides, where the subsiding part of the crust rubbed against and scratched the wall in its descent. They also present horizontal marks, where the crust halted long enough to become attached to the still plastic mass.

Barth interpreted Dimmuborgir as the remnant of a small lava lake which drained internally before overflowing. The description above is remarkably fitting for the lunar "D caldera," a 3 x 2 km wide D-shaped depression with an irregular floor (Whitaker, 1972; El Baz, 1973), and so, perhaps, is the interpretation.

HVERFJALL

Hverfjall is a spectacular 2500 year old tephra ring/ maar of basal diameter 1.6 km, crater diameter 1.0 km, rim height from 75-150 m, and volume ∿0.5 km (Thorarinsson, 1960; Murray, 1967). The floor, which has been partially filled in by rim material, is level with the surrounding terrain, and contains a central hill 42 m high. The crater rim is composed entirely of tephra (sideromelane) with no evidence of lava. Accretionary lapilli and ejecta blocks in impact sags are also found. Most of the rim beds dip outward at angles of 20°-42° but some beds along the SE interior-dip inward.



From Thorarinsson, 1960.

Fig. 20. Section through Hverfjall. Striated: Stratified tuff. Dots: Gravel and blocks.

LÚDENT AND HRAUNBUNGA

A few km SE of Hverfjall are the tephra ring Lúdent and the andesite/dacite center of Hraunbunga. Lúdent is 800 x 1000 m across with walls rising 35-115 m above its floor, which is ∿18 m higher than the plain to the west (Murray, 1967). Pyroclastic beds dip outward at angles of 7° to 36° with an average of 21° and Lorenz has detected some moderately steep inward dipping beds on the inner walls (Lorenz et al., 1970). The rim is littered with many blocks of lava as large as 2 m in diameter. Satellitic

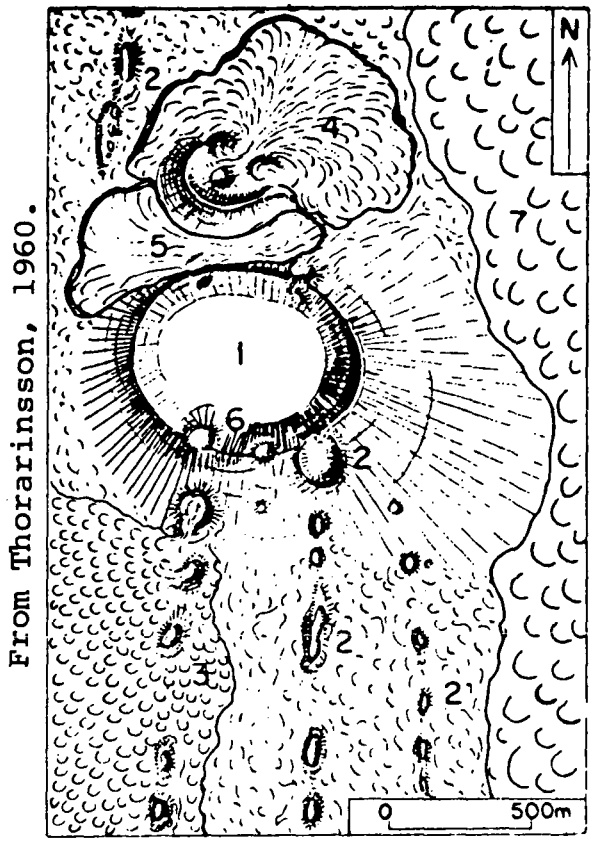


Fig. 19. The Lúdent group. 1: Lúdent (about 9000 years). 2 and 3: Crater rows older or nearly as old as H_s. 4 and 5: dacite flows. 6: crater younger than H. 7: Búrfellshraun.

vents have formed on the rim of Lúdent and crater chains are aligned with it. Hraunbunga appears to be a small, wide-rimmed crater that has been surrounded by one or two massive lava flows. Van Bemmelen and Rutten (1955) remark on the very steep and high (some 10's of meters) front of these flows, which is indicative of viscous lava. Van Bemmelen and Rutten consider the flow to be an augite andesite, and as such it is the only post glacial acid lava in the Mývatn area.

FISSURES

Volcanism in Iceland is nearly synonymous with fissure eruptions and many superb examples are found in the Mývatn area. The main locus of recent activity is a 35 km long zone east of Mývatn passing between Hverfjall and Lúdent. There are hundreds of individual fissures 1-2 km long and tens of cm to m across. Small scoria cones have formed along many fissures and vast outpourings of lava have occurred. Historic examples are given in the excerpt from Barth on the eruptions of 1724 to 1729 (below), and Rittmann (1938, 1960) has summarized the eruption sequence.

The Eruptions of 1724 to 1729

The whole region east of Mývatn is presumably underlain by magmatic melts, in which during the five-year period 1724 to 1729 a mass upheaval took place. With irresistible strength the molten masses made their way to the surface, broke through at several places, and staged, according to old descriptions,[33] a magnificent display of volcanic manifestations that throw interesting light on the mechanism of certain eruption types peculiar to Iceland.

The new lava that was formed during this period has been marked separately on the map (pl. 4); the geographical names used in the description are also given. It is therefore suggested that the map be consulted during the reading of the description, so that the significance and sequence of the volcanic events may be fully understood.

The eruptions started on May 17, 1724, with the catastrophic explosion of the crater Helviti at the foot of the western slope of the mountain Krafla ,[34] and on the same slope a large rent developed through which vapor and gases escaped.

Simultaneously with these explosions, the whole neighborhood around Mývatn was shaken by terrific earthquakes; several of the farmhouses collapsed and nobody dared stay indoors. Cracks were formed and large segments of the earth were thrust up several meters. Ash, lapilli, and volcanic bombs were thrown out, and the entire growth of grass was ruined by ash deposits almost 1 m thick. Great flames arose from Helviti's crater, and to the people that lived on the south shore of Mývatn it looked as if the whole northern sky were burning. Black columns of dust and vapor were expelled, and the odor of hydrogen sulfide tainted the air for a long time. This eruption lasted all summer. In the fall it became more quiet, but for many years afterward black smoke and sulfur flames ascended from Helviti.

The explosions at Krafla's foot were, however, only the beginning of a long series of eruptions.

After New Year 1725, another series of earthquake shocks was felt around Mývatn, and on January 11 several fissures and craters developed at Leirhnúk, belching forth torrents of boiling mud, burning gases, and some lava.

On April 19 of the same year a great fissure opened up at Bjarnarflag, where several craters were formed in a row and much lava was poured forth. The earth surface was in constant movement, up and down, thus spoiling the growth of grass and the fishing.

On September 8 the river Laxá went dry all of a sudden. It soon started to flow again, but the water level at lake Mývatn permanently subsided almost 2 m. No effusion of lava occurred for about two years.



Sketch map of a part of Threngslaborgir, Iceland. Small volcanic cones have colonized the offset fissures of a linear eruption.

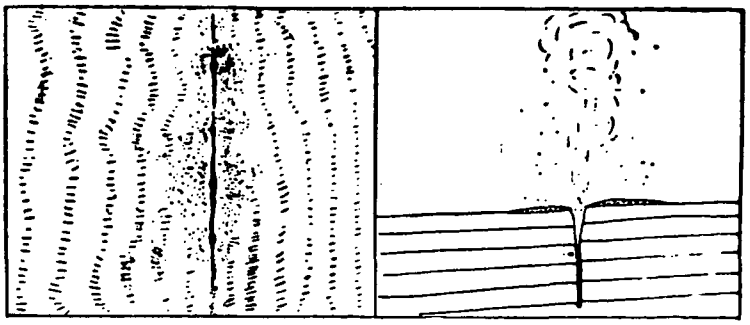
From Rittmann, 1960.

On August 21, 1727, Leirhnúk again erupted, flooding large areas both to the north and to the south.

Again, on April 18, 1728, several new craters were formed at Leirhnúk, and copious lava was poured out, flowing south and west toward Reykjahlið. The same morning the crater at Hrossadal erupted, sending forth a tearing lava flow that reached the lowland north of

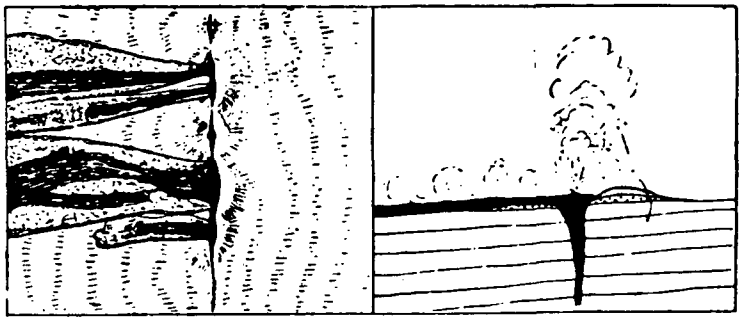
[33] The best descriptions of these eruptions are given by Jón Sæmundsson (Gammel Kgl. Samling No. 2860; Kgl. Bibliothek, Copenhagen) and by Jón Sigurðsson (No. 422, Landsbibliothek, Reykjavík). Later narratives by Svein Pálsson, Jónas Hallgrimsson, and others take their information from Sæmundsson's manuscript. All these documents have been collected and printed by Thoroddsen in *Safn til sögu Islands*, vol. 4, pp. 385–411 (Copenhagen, 1911).

[34] Krafla is a high, rather conical-shaped mountain, marked on the map. In the earlier literature it was described as one of the most terrifying volcanoes in Iceland. But, as has been pointed out by Thoroddsen, this is an error. Krafla itself is made up exclusively of sedimentary rocks of the palagonite formation, and has no crater. The eruptions attributed to Krafla must have been those that occurred at Helviti.



Phase 1: A fissure opens to the accompaniment of earth tremors, and is cleared and widened by explosions. Deposition of a vent-opening breccia.

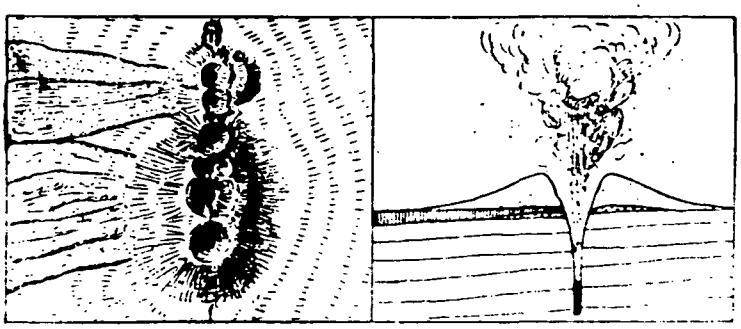
Bjarnarflag. Bjarnarflag also became active again and erupted new lava that flowed westward almost to Mývatn. This lava was said to have remelted and altered the older lava over which it flowed, and to have remained hot for a long time, so that "the ground in the neighborhood of Reykjahlið and the adjacent shores of Mývatn became very hot, vapor and smoke ascending everywhere from caves and cracks."



Phase 2: Outflow of large quantities of fairly gas-rich, fluid magma, which pours out over the land surface and solidifies to rubbly lava. Formation of a basalt sheet.

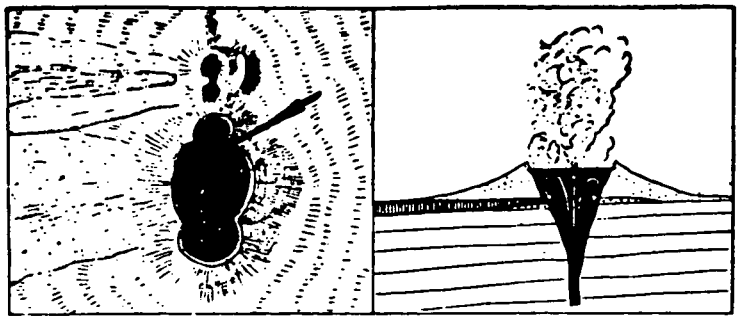
Two days later a crater at Dalfjall erupted, and much grassland was ruined by the lava.

These eruptions appreciably altered the topography of Mývatn, making the eastern part so shallow as to prevent the inhabitants from reaching the islands by boat.



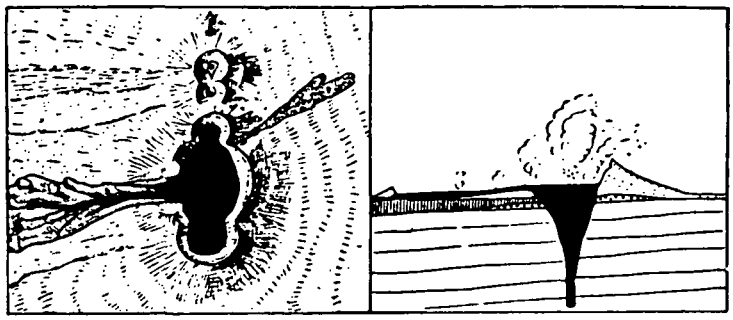
Phase 3: Ejected scoriae and clots of lava build up a row of cones.

From Rittmann, 1960.



Phase 4: Lava-lakes form in the craters of the cones, in which the lava becomes largely devolatilized through the activity of lava fountains. The crater walls tend to be melted due to exothermic gas reactions; fresh magma is continually brought to the surface by two-phase convection.

In December 1728, again new lava streamed forth from Leirhnúk; it flowed toward the settled district of Reykjahlið, remelted the old lava, filled up all depressions, and was often covered with a skin of slag which again burst and gave rise to miniature cinder cones and lava pots. On December 20 the lava stopped its westward extension about 2 km east of Reykjahlið, and veered southward.



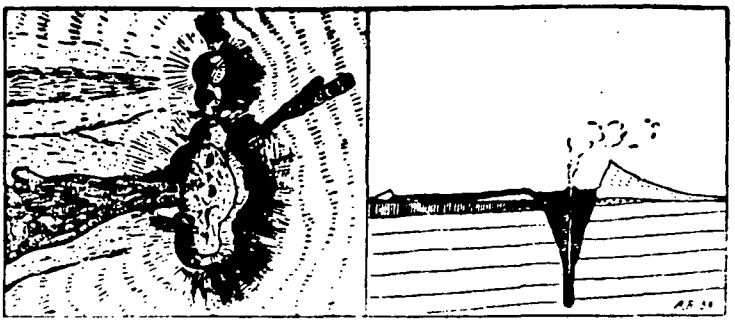
Phase 5: The largely devolatilized, but very hot lava breaks through the crater wall, flows out slowly and solidifies to platy and ropy lava.

On January 30, 1729, again the crater rows at Leirhnúk produced copious lava that followed the course of the older flows.

Through repeated eruptions the lava made steady progress westward, and on July 6, 1729 it reached the settled district at Reykjahlið. Several farms and much grassland were destroyed, and on August 27 the lava flooded the lowland all around the church, which thus became beset by the lava; but because it was erected on a small eminence that escaped complete submergence, the church was miraculously saved from devastation.

(In Hawaiian terminology, the church would stand on a *kipuka* [hole], an island-like area of older land surface exposed within a lava flow.) Then the lava flowed into Mývatn, which was brought to a boil, and gave off clouds of vapor. The water receded over large areas, but the lava progressed farther out along the bottom, where lava rocks still emerge from the water.

From then on the eruptions abated, but in 1730 clouds of vapor still hovered over the lava fields, and columns of smoke rose from the craters.



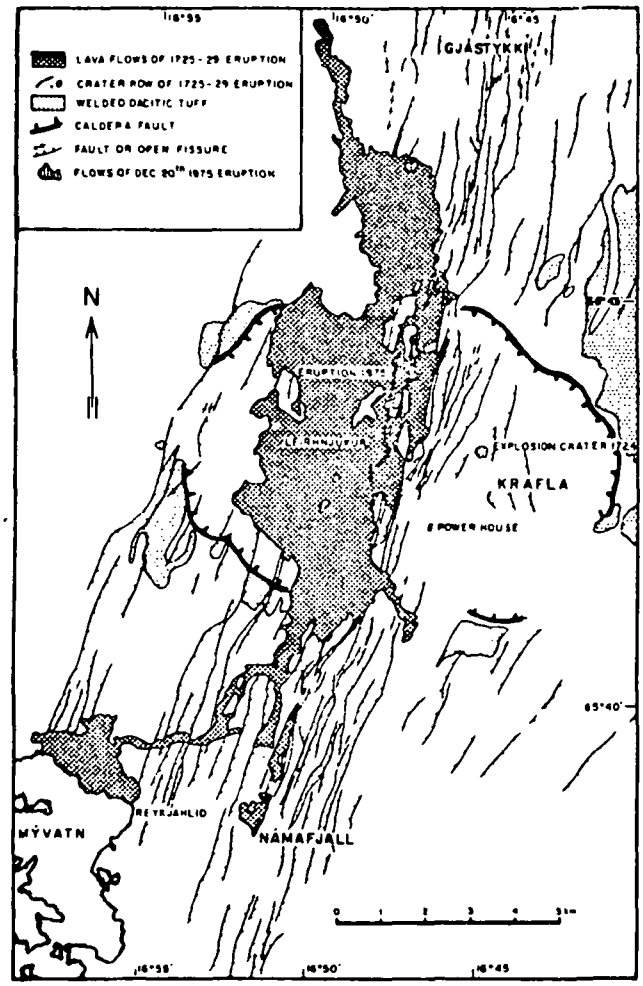
Phase 6: The magma sinks back. The eruption dies away with diminishing vapour emission and fumarole activity

According to Jón Benediktsson (1747), still another eruption occured at Leirhnúk in 1746, which, accordingly, would represent the youngest eruption in these parts. For the past 200 years no volcanic events, other than thermal activity, have taken place around Mývatn.

Trip to Krafla

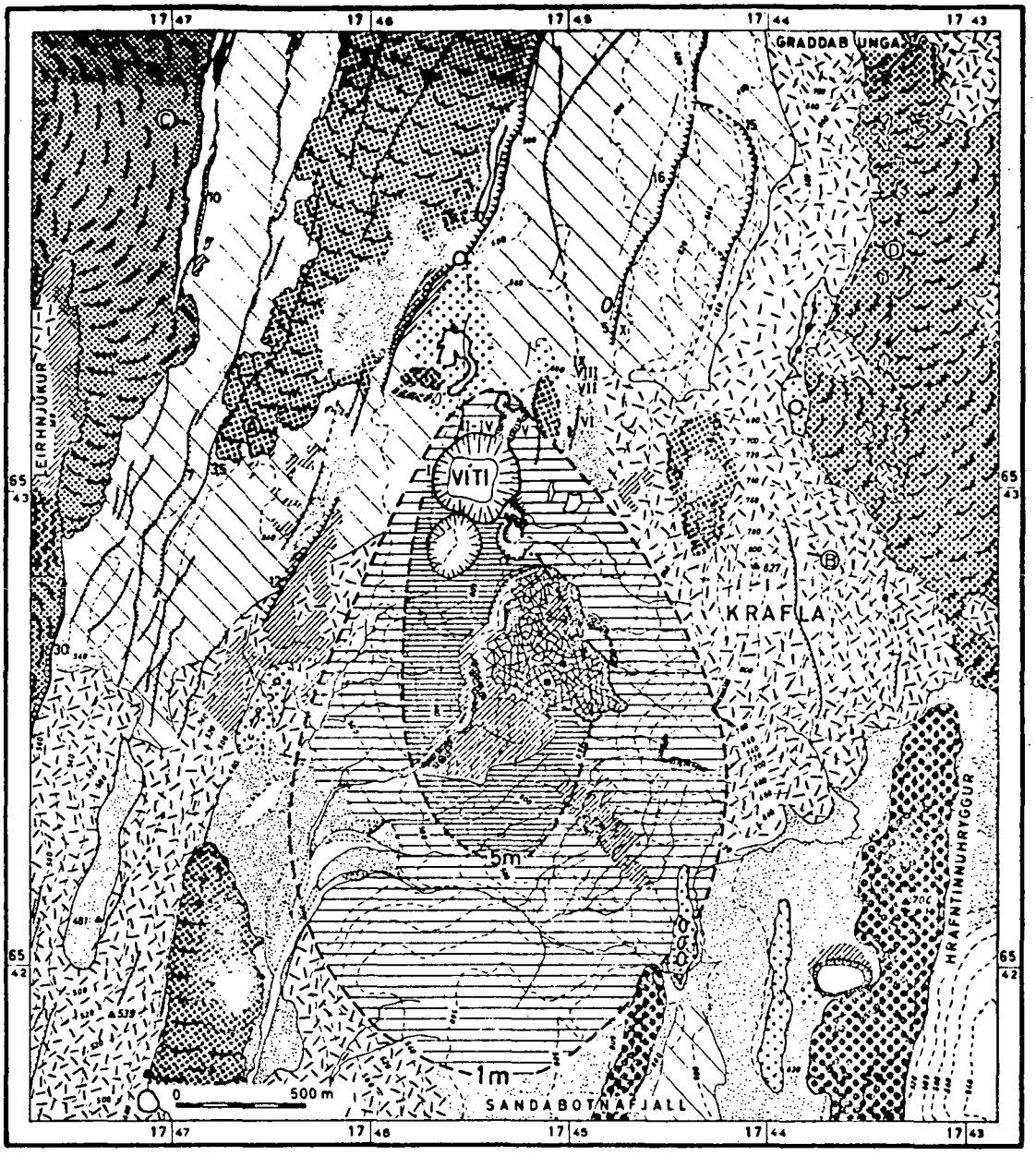
Taking the road eastward from Reykjahlith we turn left after about 5 km and take the road up to the new geothermal power station (60MW). The power station lies within the floor of the 10 x 8 km Krafla caldera.

Originally Krafla was a 20 km diameter shield volcano formed previous to the last glaciation. The lavas from this shield are exposed on the western and eastern walls of the present caldera while dykes and fissures can be found all around the caldera. The formation of the Krafla caldera followed the eruption of a sheet of dacitic welded tuff and an airfall tuff during the last interglacial. Since the collapse, the caldera has almost been filled to the rim with volcanic material.



From Björnsson et al., 1977.

Krafla is located across the fissure zone that extends down the eastern side of Iceland. The most recent activity has been along a 100 x 10 km belt at this northern end of the rift zone. The compositions of materials erupted within this zone have been extremely variable. The majority of the materials erupted from the fissures have been quartz normative tholeiites while four subglacial edifices of silicic composi-



From Nöll, 1967.

Geologische Karte des Krafla - Gebietes

- Palagonitbrekzie
- Rhyolith
- Ältere postglaziale Basalte
- Jüngere basaltische Laven (vor 1724)
- Basalt. Schlackenkrater u. Kraterreihen, und Pseudokrater
- Basaltische Lockerprodukte
- Innere Böschung von Sprengkratern
- Auswurfmassen d. Víti-Ausbruches (17.5.1724)
- Lava d. Ausbruchsperiode von 1725 - 1729
- Aktive Solfataren - u. Fumarolen-Felder
- Hydrothermale Zersetzungsprodukte
- Schwemmkegel, Talalluvionen, äolische Überdeckung
- Verwerfungen (mit Sprunghöhe in m), Z.T. klaffende Spalten (isl. gjár)
- Abrißlinie von Erdrutschen, Erdrutschmassen
- Warme Quellen
- Schlammpfuhle, aktiv u. erloschen
- I - X Nummern der Bodenprofile

tion surround Krafla, and the caldera itself contains explosive craters that have ejected pyroclastic pumice. Most of the Krafla eruptions have been basaltic though there are, locally, materials of andesitic and dacitic composition.

In this northern section of the rift, studies have indicated two main episodes of volcanic activity; in early postglacial time, and within the last 3000 years. These may have been separated by a period of repose of 4000 years.

Historic eruptions begin with the Viti explosion crater in 1724 which ejected silicic pumice, basaltic scoria, alkali-granite, mud and rock debris, material that is concentrated in a sector that opens southward. Between 1725 and 1729, 11 km of discontinuous fissures opened and issued 35 km^2 of lava. The area then remained inactive until the episode associated with the 1874-75 activity centered on Askja (see Askja trip). Activity recommenced in Dec. 1975. This periodicity of activity appears to be typical of the rift zone; namely, an eruptive period of a few months to years along about 50-100 km of rift, followed by 100-150 years of quiescence.

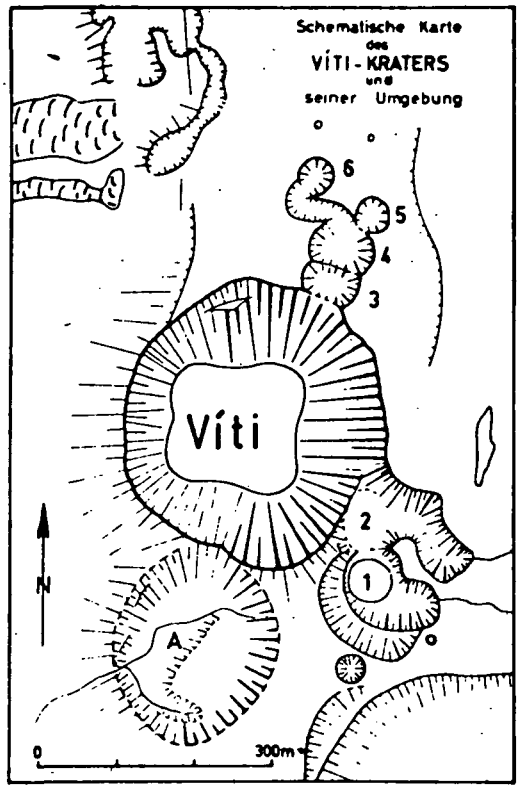


Abb.10
Lageskizze des Víti-Kraters, seiner Nebenkrater 1 bis 6 und des älteren Sprengkraters A
From Nöll, 1967.

Krafla eruptions: December 1975 - ?

Earthquake activity began on 20 Dec. 1975 and within half an hour a small lava flow had been erupted. The eruptions were accompanied by horizontal and vertical movements of 1 m. Following the eruption the floor of Krafla dropped 2.5 m and has since been oscillating periodically (see table). Each deflation of the caldera floor has been accompanied by northward migration of the earthquake hypocenters. Seismic evidence indicates the magma chamber to be at greater than 3 km depth. Earthquake activity was still being recorded in June 1977 though I do not know if the area is still active.

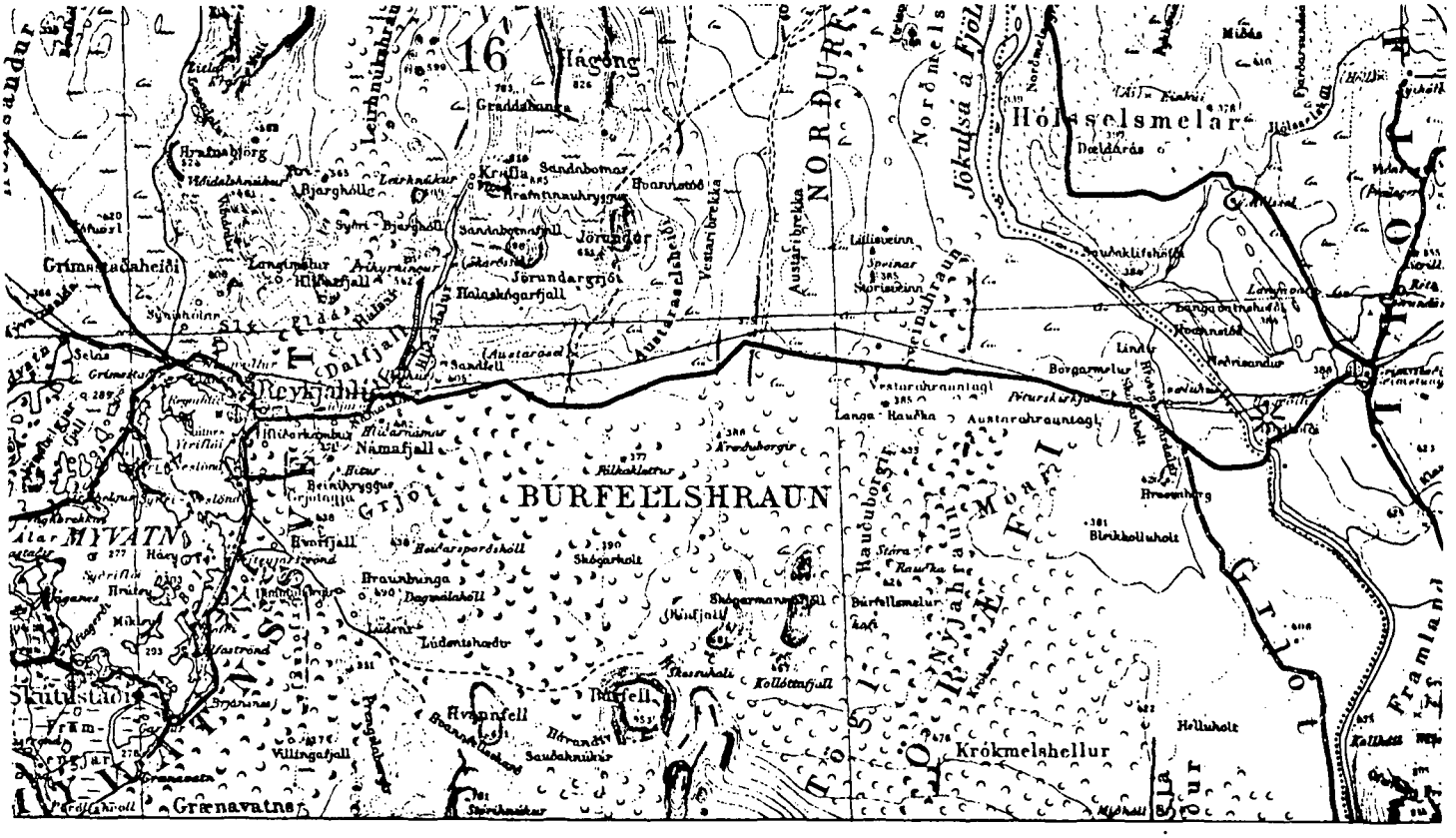
Date	Activity at Krafla	Duration
20 Dec. 1975	2.5 m subsidence	
March-July 1976	inflation	
July-Sept.	deflation	5 days
Immediate	inflation	
End October	deflation	2 days
Immediate	inflation	
20 Jan. 1977	deflation	24 hours
Immediate	inflation	
27 April	deflation	
29 April	inflation	
↓		
?		

Short Field Guide to Askja Area

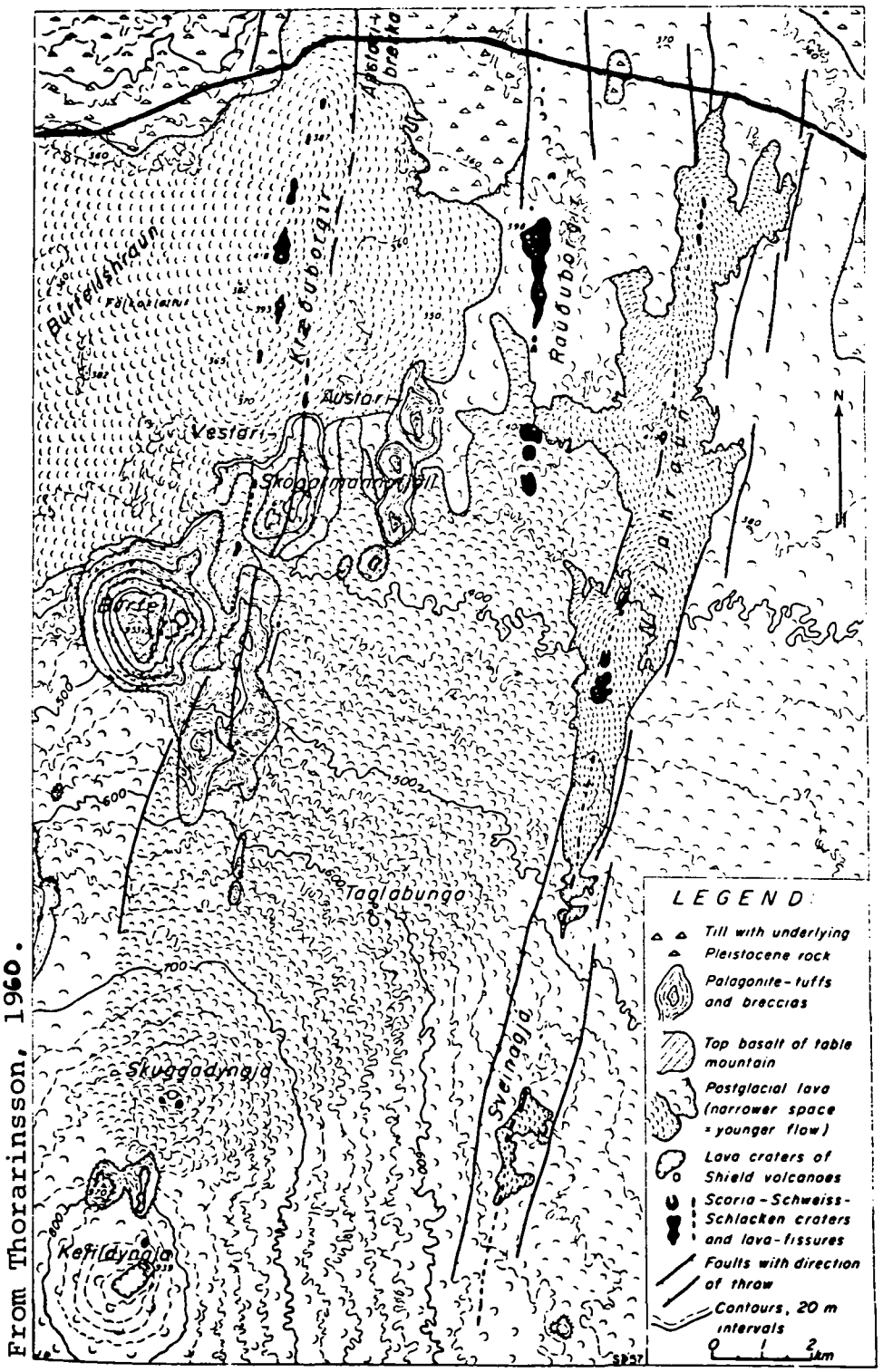
The road leads eastward from Reykjahlíd, marking the approximate northern boundary of a stillstand during the last glaciation. The area to the north of the road is dominated by end moraines and sandur plains deposited during this period of stagnation, and since rifted into a series of grabens.

The area to the south of the road is composed of subaerial fissure eruptions of dacitic composition which marked the first postglacial volcanism in the area (>6000 yrs).

Where the road crosses the Námafjall ridge one can see southeastwards across the northern part of the lava wastes of Odádahraun with many shield volcanoes, table mountains and tuff ridges. The Búrfellshraun lava to the south of the road is approximately 2000 yrs. old and was emitted from the Kraeduborgir crater row.


Reykjahlíd
Námafjall
BÚRFELLSHRAUN
MÝVATN
Grænavatn
Krókmelshellur
Hólsselsmelar
NORÐURF
Jökulsá á Fjöl
Dalfjall
Grímsstaðaheiði
Hlíðarfjall
Leirhnúkur
Hverfell
Sandbomar
Jörundur
Jörundargjóll
Hálsskógarfjall
Austaraselsheiði
Austaraselshraun
Austurbrekka
Vesturbrekka
Sandfell
Vesturhraun
Lange-Raufka
Austurhraunstagl
Kraeduborgir
Raufka
Stóra
Búrfellsmelur
Skógarholt
Skógarmannafjall
Kollóttafjall
Hvannfell
Saudahnúkar
Villingafjall
Helluholt
Birkihólsholt
Hrossaborg
Borgarmelur
Lindir
Hafrisandur
Dalsárás
Lúdentshorn
Lúdentshardi
Braunhunga
Dagmálahóll
Hrútey
Hrútey
Hrútey

Farther to the east, the road marks the northern terminus of the Nyjahraun lava flow. This flow was erupted at the same time as the 1875 Askja eruption from Viti. The eruption was from a fissure which has since developed into a rift (the Sveinngja) as a result of the magma evacuation.

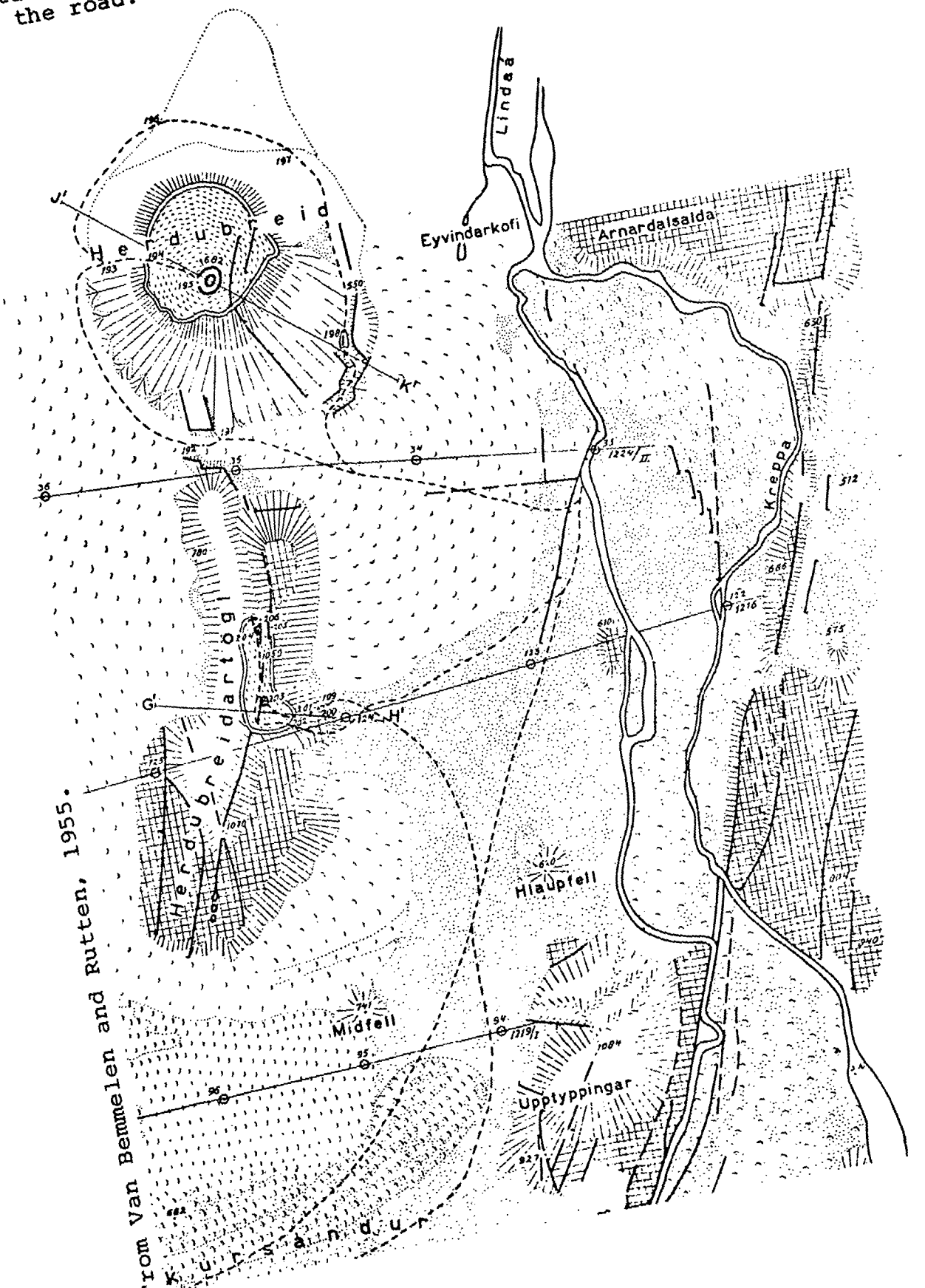


Nýjahraun and its surroundings.

The road eventually leaves the lavas and continues across pastureland and sands. We leave the main road near Hrossaborg and proceed southward along the west bank of the Jökulsá á Fjöllum river. The Hrossaborg is a small isolated cone approximately 750 m long, 50 m high and a rim diameter

of 400 m. The cone is composed of subaerial basa
dipping outward at 15-25° and the eastern and western wal
are more eroded than the north and south walls. This lack
of symmetry of the walls has been attributed to glacial strip-
ping, faulting.

The road crosses pahoehoe lavas until reaching the
1682 m table mountain Herthubreith which rises above the western
side of the road. Herthubreith is the most prominent of Ice-

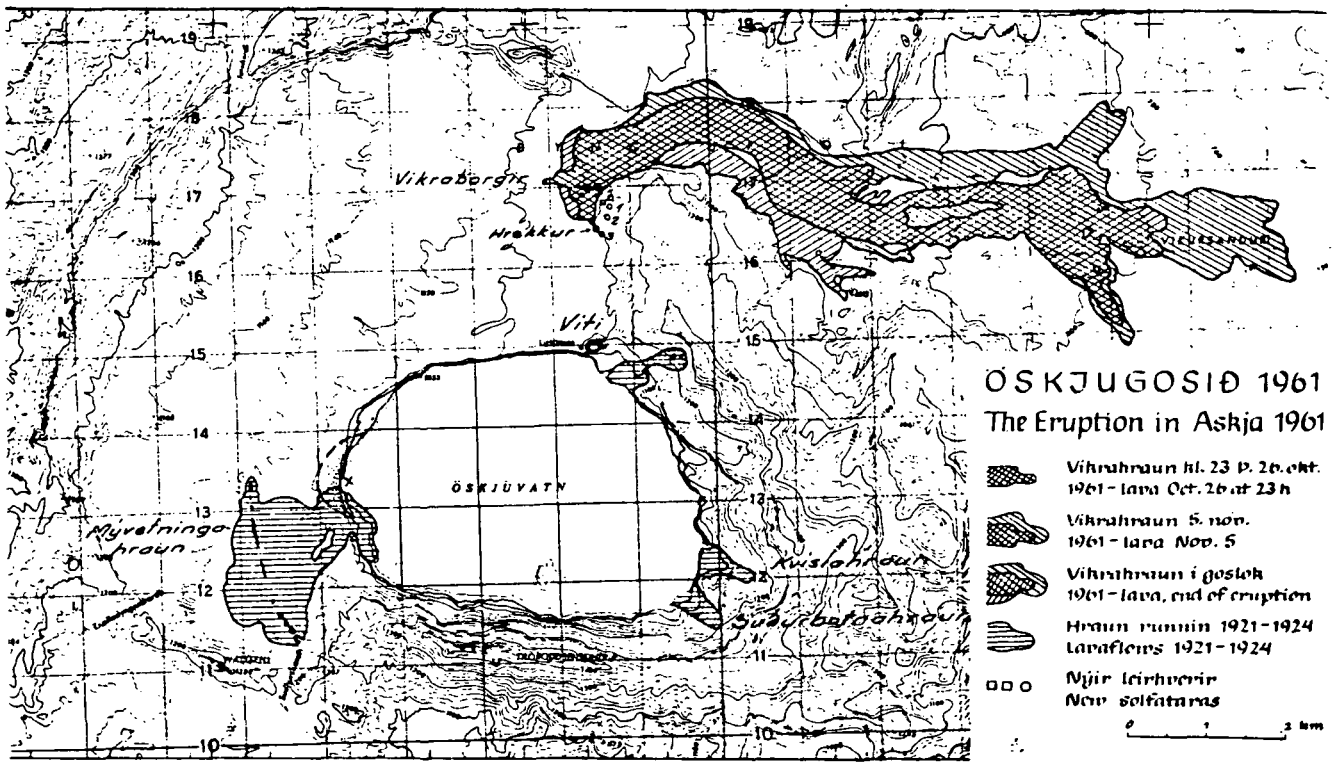


landic table mountains, almost circular in outline with a 5 km diameter base rising 1000 m above the plain to a summit plateau 2 km in diameter. The lower slopes are protected by columnar basalts which enclose the palagonite mass. On the top there is a cone which rises 150 m above the plateau surface and a cap of plagioclase porphyritic basalt. The location of the vent for this basalt is not established and, indeed, may have been eroded.

Further south the road splits, the tracks going either side of the dissected table mountain, Upptyppingar. Where they reunite, the track crosses the yellow-grey pumice of the 1875 Viti eruption which overlies aa flows. Abundant lava flows with ropey surfaces and caves abound in this area. Stalactites of natrium sulphate can be found in some of these caves though woe betide anyone who tries to remove them.

Recent History of Askja

The large caldera Askja (45 km^2) lies in the mountain called Dyngjufjöll (250 km^2) which is rectangular in outline and rises 600-750 m above the surrounding plain. Dyngjufjöll is of late Pleistocene age, composed mainly of móberg and basaltic lavas with some rhyolites. Exposures on the NW of the mountain contain stratified tuffs and a welded layer near the base. The tuffs contain large feldspar phenocrysts.



From Thorarinsson, 1963.

The 1961-lava flow and the Askja lava flows from the 1920ies.

The floor of the large Askja (Box) caldera is flat and lava covered. The most recent lavas have issued through a break in the NE wall and continued some 10 km to the E. The crater was rarely visited prior to the early 19th century and the first recorded eruption was that of Viti in 1875.

The Viti (Hell) eruption was a rhyolitic pyroclastic eruption from a 100 m wide (now 150 m) vent with a 12 m high pumice cone. The products of the maar eruption consist of a lower, very light, fine grained pumice succeeded upward by a coarse brown pumice and overlain by "porous cinders" containing grey quartz and black obsidian. The tephra was blown eastwards by the prevailing winds and was recorded in E. Sweden some 38 hours after the start of the eruption.

With the Viti eruption, the smaller "askja" caldera began to form and continued growing for several years. In the early part of the year of the eruption the depression was some 200 m across and 15-20 m deep. By midsummer it had grown to encompass an area of 3-4 km^2 and was 120-150 m deep but still dry. Midsummer the following year the caldera was 7 km^2 and contained a lake 1.2 km across, the altitude difference between the water level and rim being 232 m. Eight years later the lake had grown in size and depth, the water level being now only 150 m from the crater rim. Prior to the 1961 eruption the caldera had grown to 11 km^2 and the lake was 50 m from the rim.

Dyngjufjöll remained quiescent till the 1920's following the Viti eruption, and then experienced a series of eruptions commencing in 1921. The first eruption was of basaltic lava from craters along a fissure located 1 km E of Viti. This was followed in 1922 by a 2.2 km^2 lava which issued SW of the lake. In the 1922/23 period two small flows formed to the SE of the lake and in 1924(?) a 6 km fissure opened on the southern flank of the volcano and 16 km^2 of lava issued forth. The last event of this active period was the formation of the scoria cone within Oskjuvatn.

The volcano remained quiescent until 1961 when fissures, up to 20 cm wide, were created along with intense solfataric activity. One of those solfataras (Hrekkeir) ejected "head"-sized blocks 100 m into the air. The main eruption consisted of 4 lava fountains, the largest of which reached a height of 500 m. The cloud from the first eruptive phase reached a height of 10,000 m. The lava (Vikrahraun) flowed down from the main caldera through a breach (the Oskjuop). At this point the flow was some 200 m in width and may have had a flow rate of 1000 m^3/s; the average flow rate was nearer 600 m^3/s. The flow velocity was of the order of 3 m/s and on the first day the lava had advanced at 10-12 m/s. Up to Nov. 5th the flow was largely aa with few phenocrysts (plag., An_{60-70}; Pyrox., diopsidic augite and lesser enstatite bronzite) set in a matrix of ore-stained glass, microlithic plag. and pyrox. lathes and magnetite. Between Nov. 5th and the end of the eruption in the first week of December, the lava changed to a more phenocrystic pahoehoe with idiomorphic olivine and a groundmass of translucent brown glass. The ashes associated with this eruption are 0.5-1.0 cm lapilli which, if one digs down, can be found to overlie snow which in turn overlies the 1875 tephra, itself overlying snow. The eruption contributed 11 km^2 of lava to the surface of Iceland along with 3-4 million m^3 of tephra.

The craters produced during the 1961 eruption are called the Vikraborgir, the two largest of which are Austari-borg (E. hill) and Vestari-borg (W. hill). Austari-borg is elliptical and breached at either end. Its highest point is 30 m above the lava plain and the crater is 210 m in diameter and 20 m deep. Near the base of the crater is a ledge of congealed lava from a lava pool that once existed. Two conduits can be seen near the rim of the crater.

Vestari-borg is about the same size but more circular and opens only to the N which is a lava-walled trench. A 5 m diameter, 0.5 m high lava crater formed under the west wall of the crater near the end of the eruption.

80 m south of Vestari-borg is StakaBorg, an elliptical crater some 18 m at its highest point, around which used to be, and still might be, bombs and cinders galore.

The Return

We will spend two nights at Askja and then will retrace our route to Myvatn unless, with weather and track permitting, we take the western, more arduous, route back. I have no idea of the geology of the western route but, from the ERTS photos, it appears that the track crosses a series of large flows which have travelled northwest from the vicinity of Dyngjufjöll. It then crosses a number of wind blown dark streaks (good analogy with Mars), proceeds along the river Suarta and then swings northward to Mývatn across what appears to be a dense concentration of NNW-aligned fractures.

MEANING OF ICELANDIC PLACE-NAMES

Most Icelandic place-names, both of towns, villages and natural features in the landscape, mean something and thus help the reader to identify and understand them. For instance, words containing the compounds **hver, laug** and **reyk(ja)** indicate the proximity of hot springs. It should be noted that words or compounds in declension sometimes appear rather different from the nominative. The following list is intended primarily as an aid to map-reading.

alda — hilly ridge (plurual öldur)
á — river
ás — small hill
bær — farm, township
bakki — river bank
bjarg — cliff, rock
borg — town, crag
botn — bottom, head of valley (or fiord)
brekka — slope
brú — bridge
bunga — rounded peak
dalur — valley
djúp — long inlet, deep
drag — watercourse (plural drög)
drangur — isolated column of rock
dyngja — dome
ey — island
eyri — sandspit, delta
fell — mountain or hill
fjall — mountain (plural fjöll)
fjörður — fiord, broad inlet (sometimes valley) (plural firðir)
fljót — large river
flói — large bay, marshy area
foss — waterfall
gígur — crater
gil — gorge, ravine
gjá — chasm, fissure
grunn — shoal, shallow
háls — ridge, isthmus
hamar — crag
heiði — heath, moors
hlíð — mountain side
hnjúkur — peak
höfði — promontory
höfn — harbour
hóll — rounded hill (plural hólar)
hólmur — islet
holt — stony hill
hraun — lava-field, lava
hryggur — ridge
hver — hot spring
hvoll — hill
jökulsá — glacial river
jökull — glacier
kirkja — church
klettur — rock, cliff
kot — small farm
kvísl — river (or branch of same)
lækur — brook
laug — warm spring
lón — lagoon
melur — gravel
múli — headland
mynni — mouth
mýri — swamp (plural mýrar)
nes — headland, ness
núpur — peak
oddi — point, tongue of land
öræfi — desert
ós — estuary
rif — reef
reykur — smoke (often equivalent of hot spring)
sandur — sand(s)
skarð — mountain pass
sker — skerry
skógur — wood
sléttа — plain
staður — place, parsonage (plural staðir)
stapi — bluff
súlur — (mountain) peaks
svartur — black
tangi — narrow peninsula
tindur — summit
tjörn — small lake
tunga — tongue (of land)
vað — ford (plural vöð)

Additional words of volcanic interest

apalhraun	aa lava	gufa	stream
brenna	burning	helluhraun	pahoehoe
brennisteinn	sulfur	hrafntinna	obsidian
dal	valley	ölkelda	mineral spring
eld	fire	suda	boiling
eldfjöll	volcano	vatn	water, lake
gig	crater	viti	hell
gos	eruption		

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