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National Energy Authority

Laugavegur 116
Reykjavik, Iceland

DISTRIBUTION OF LARGE BASALTIC INTRUSIONS IN THE ICELANDIC CRUST

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ABSTRACT

Iceland is built almost entirely of volcanic rocks, mainly basaltic in composition. Dykes, many of which have served as feeder channels, are abundant, and their distribution in the upper crust is fairly well understood. The thickness of the majority of the dykes falls in the range 0.5-5 m. Basaltic intrusions more than 20 m thick are relatively rare in Iceland, and are mainly associated with central volcanic complexes. A literature survey shows that the majority of large (≥ 1 km^2 in area) basaltic intrusions are intruded into "soft" and "structureless" host rocks such as tuffaceous hyaloclastites, sediments, vent and caldera agglomerates, hydrothermally propylitized lavas, and hot and still partly liquid acid intrusive material. It appears that upon entering host rock that breaks irregularly the upwelling magma may expand within that host rock rather than penetrate upwards along a narrow fracture to form a dyke. The "soft" and "structureless" rocks are generally of lower density than the surrounding lava pile, and it is thought that they may serve both as density traps and as structural traps for the basic magma. Examples are given for the lithological control on the size of intrustions from an area of intense volcanic activity and characterized by strata of variable lithology.

The evidence of the large basaltic intrusions being accommodated in the "softer" rock types (including propylitized lavas) suggests that magma may tend to spread out laterally within the highly altered base of seismic layer 2 (lava layer) rather than penetrate the progressively harder lava pile. The boundary of layers 2 and 3 (intrusive layer) could therefore be controlled by a metamorphic boundary at which the degree of alteration makes the lava pile loose its strength and accommodate large intrusions. This model is compatible with the correspondence in Iceland between observed depths to seismic layer 3 (Vp=6,5 km/s) and crustal temperatures as inferred from borehole data.

1. INTRODUCTION

Iceland, which lies astride the Mid-Atlantic Ridge, has been the site of volcanic eruptions continually from the Upper Tertiary to the present day (Thorarinsson, 1965). The volcanism is mainly basaltic, but intermediate and acid rocks erupted in central volcanoes interdigitate with the flood basalts (Walker, 1963). The oldest dated rocks in Iceland are about 16 M.y. (Moorbath et al 1968) and from that time until about 3 M.y. ago (Saemundsson, 1974) the volcanism was mostly subaerial and the volcanic products therefore subaerial lavas and much subordinate airborne tuffs (Walker 1959, 1964). Some 3 M.y. ago the climate changed and since then to the present day there have been over twenty glaciations with intermittent warmer periods. During the glaciations most of the island has been covered by thick sheets of ice. The products of subglacial volcanic eruptions (here referred to as hyaloclastites) consist mainly of pillow lavas, pillow breccias and tuffs (Jones, 1970). The uppermost crust of Iceland (the host rock to the basaltic intrusions dealt with in this paper) thus consists dominantly of subaerial lavas in the Tertiary provinces, but in the Quaternary provinces it comprises successions of subaerial lavas intercalated, at intervals corresponding to glaciations, with volcanic hyaloclastites, morainic horizons and glacial tillites.

Each volcanic eruption is fed by at least one feeder channel, most commonly a dyke. Field evidence indicates that many dykes never reach the surface to feed an eruption and some of these may expand at depth to form intrusions of varying size and shape. The purpose of the present paper is to discuss the relations between the size and shape of basaltic intrusions and the lithology of the host rock, and subsequently to discuss the distribution of large basaltic intrusions in the Icelandic crust.

2. DYKES AND OTHER MINOR INTRUSIONS

The distribution of basaltic dykes in the Icelandic crust is fairly well understood. Walker (1960) demonstrated the progressive increase of dyke density with depth in the lava pile in eastern Iceland, and showed (Walker, 1963) that narrow dyke swarms (where dykes make up 10 to 20% of the country) are commonly associated with the central volcanoes. Lenticular lava units produced by these swarms were recognised by Gibson (1966). Gibson and Piper (1972) suggested that the increase in dyke density with depth was non-linear, and that at a relatively shallow depth (a few km), perhaps determined by lithostatic pressure conditions, the intensity of dyke injection increases rapidly to produce 100% dyke intensity. This can, however, not be verified by measurements as exposures are too shallow.

The basaltic dykes range in thickness from a few centimeters to several tens of meters, but the majority fall within the range of 0.5 to 5 meters both in the Tertiary rocks of eastern Iceland (Walker, 1959) and in the Quaternary rocks of southwest Iceland (Fridleifsson, 1973). Characteristically the dykes cut the lava pile perpendicular to the lava stratification. Parallel cracks are formed in the brittle lavas giving rise to regular, uniformly thick and parallel sided dykes. In the Quaternary hyaloclastites, however, the dykes are sometimes most irregular in shape. The "soft" and most commonly "structureless" hyaloclastites break irregularly when subjected to stress and a dyke may split up into thin anastomosing veins or expand to form a large intrusion, as will be discussed in the next section.

Minor intrusions are abundant in the immediate vicinity of volcanic centres (Walker, 1964). Centrally inclined sheet swarms have been found in the majority of the central volcanoes investigated to date in Iceland. Walker (1975) proposed a simple mechanism for the generation of inclined basic intrusive sheets based on the contrasted density gradients of crust and uprising magma. Outside the altered core regions of central volcanoes, minor intrusions, other than dykes and thin regular sheets, appear to be preferentially accommodated in the softer country rocks (as compared to tholeiite lavas) such as tuff horizons, rhyolite flows and olivine tholeiite compound lavas (Fridleifsson, 1973). Examples of this can be found in descriptions of Tertiary rocks in e.g. the Reydarfjordur area (Walker, 1959) and the Faskruds-fjordur area (Gibson et al, 1966), and similarly in the Esja Quaternary region (Fridleifsson, 1973).

3. LARGE BASALTIC INTRUSIONS IN ICELAND

Basaltic intrusions more than 20 m thick are relatively rare in Iceland, and are mainly found associated with the central volcanoes. Perhaps due to their scarcity the distribution of "large" intrusive bodies in Iceland and their relations with the host rocks have gained less attention than the distribution of dykes and other minor intrusions.

A survey of much of the published literature and several unpublished thesis on Icelandic geology shows (Fridleifs-son, 1973) that the majority of large (≥ 1 km^2 in area) basaltic intrusions in Iceland are intruded into "soft" and "structureless" host rocks such as tuffaceous hyalo-clastites, sediments, vent and caldera agglomerates, hydrothermally propylitized lavas (which behave structurally similarly to tuffaceous hyaloclastites) and hot and still partly liquid acid intrusive material. All the main basaltic intrusion localities which have been studied to date in Iceland are listed in Table 1, and the locations of the intrusions are shown in Fig. 1.

(Fig. 1)

Exceptions* to the generalization of the host rock being "soft" and "structureless" are listed separately in Table 1.

The majority of the large basaltic intrusions in Iceland are in sheet form (as opposed to laccolith form), which reflects the stress conditions, and have formed by multiple injection of magma, which may vary in composition. The grain size commonly decreases towards the margin of each sheet, but true chilled contacts between multiple sheets are rare, indicating that the time lapse between the intrusion of individual sheets was not sufficiently long to allow any marked cooling.

Walker (1974, 1975) suggested that low density rocks (such as acid lavas and pyroclastics), buried in the strata may serve as traps for higher density basic magmas rising up through the crust. When the frequency of uprise of basic magma batches along the same path is sufficiently high multiple dolerite sheets or even gabbro intrusions may be formed at the level where the density of the basic magma exceeds the bulk density of the host rock.

*It is striking that four of the five apparent exceptions are associated with dense cone-sheet swarms. Furthermore the Lýsuskard gabbro is, in fact, enveloped by a granophyre sheet, which forms a 200 to 400 m wide screen between the gabbro and the basaltic country rock on the three exposed sides. Chilling of granophyre against gabbro found at one locality indicates that the granophyre is a later intrusion (Sigurdsson, 1970). Sigurdsson´s descriptions, however, suggest to the present author that the Lysuskard gabbro-granophyre intrusion may possibly be yet another example of gabbro intruding granophyre, i.e. that the granophyre intrusion is older, but in places, rheomorphic. Similarly the Hrappsey-Purkey exception may be more apparent than real as one of the few exposed contacts of the base of the Hrappsey-Purkey sill shows that a part of the sill is intruded along an acid and basic tuffaceous breccia horizon that intercalates the basalt lavas (Kristmannsdóttir, 1970).

Walker's simple trap mechanism based on the contrasted density gradients of crust and uprising magma may give a sufficient explanation for the emplacement of most of the intrusions listed in Table 1. Evidence discussed in later chapters of this paper, however, suggests that the host rocks to the intrusions may not only serve as density traps for the basic magma, but also, and in some cases more so, as structural traps.

4. LITHOLOGICAL CONTROL ON THE SHAPE OF INTRUSIONS

The author has recently been working in the Esja Quaternary volcanic region in southwest Iceland (Fridleifsson 1973). Volcanism was active in this region from about 2.8 M.y. for just over one million years, and during this time span at least ten glaciations occurred in the region. The stratigraphic succession (which is about 2.4 km thick) is therefore characterized by sequences of lava flows intercalated at intervals corresponding to the glaciations by thick subglacial hyaloclastite units, which range in thickness up to 400 m. In an area of some 300 km^2 the minimum number of volcanic eruptions is estimated 400 (on the basis of the number of lavas and dykes). Each of these had at least one feeder dyke. With such intense volcanic activity and such variable lithology of the strata the area may be looked on as a type locality to compare and contrast the size and shape of intrusions within the "soft" hyaloclastites and the hard, brittle lava piles. The intrusive activity of the area will therefore be described in some detail.

Two central volcanoes were active in the region (Fig. 2). The Kjalarnes volcano was active for about 0.6 M. years and was succeeded after a short interval by the Stardalur volcano. Flood basalt volcanism was concomitant with the central volcanism. Both the volcanic centres are deeply dissected by erosion.

(Fig. 2)

TABLE 1

Locality	No. in Fig. 1	Area km^2	Host rock	Reference:
Vesturhorn	2	20*	Hot and still partly liquid acid intrusive material.	Roobol 1969, 1972.
Austurhorn	1	11*		Blake 1966.
Vidbordsfjall	5	10	Tuffaceous hyaloclastite, vent and caldera agglomerates, sedimentary rocks.	Annels 1967.
Valagil	4	2		"
Geitafell	3	1.5		"
Kolgrafarmúli	12	6		Sigurdsson 1966, 1970.
Stóra-Laxá	6	10		Fridleifsson 1970.
Kjalarnes	9	2		Fridleifsson 1973.
Thverfell	8	4		"
Stardalshnúkur	7	2.3		"
Hríshóll	14	1	Hydrothermally propylitized lavas.	Hald et al 1971.
Exceptions:				
Hrappsey-Purkey	13	10	Basalt lavas.	Kristmannsdóttir 1971.
Hólar-Skessusæti	16	1.2	Basalt lavas; associated with cone sheet swarms.	Annells 1968
Borgarvirki	15	0.7		"
Lýsuskard	10	2.5		Sigurdsson 1970.
Thorgeirsfell	11	3		"

* acid and basic intrusives.

Intrusive activity in the Kjalarnes region can be divided into three phases. The first phase comprises a dyke swarm and contemporaneous sheets dipping towards the western part of the Kjalarnes volcano where the intrusive activity culminated in the formation of a multiple dolerite sheet intrusion (Kjalarnes, see Table 1). This intrusion may have been preceded by a caldera collapse in the Kjalarnes volcano. The intrusion is formed of multiple sheets which are intruded into a fault zone (possibly a caldera fault) and a post-faulting hyaloclastite (possibly a caldera filling). Individual sheets are up to 30 m thick and together measure about 350 m. The second intrusive phase comprised a narrow dyke swarm (representing up to 20% dilation) which probably extended across the central volcano. The dyke swarm was succeeded by cone sheets focusing on the eastern part of the Kjalarnes volcano and this third phase culminated in the intrusion of a sill and multiple dolerite sheets (Thverfell, see Table 1). The sill is intruded into hyaloclastite and the dolerite sheets are emplaced at the boundary of hyaloclastites and overlying lavas. The dolerite sheets are commonly of the order of 20 m thick, but much thinner where apophyses extend from the margin of the multiple intrusion into the overlying lavas which show signs of uplift associated with the intrusion. The thickest sheet is probably over 200 m. A conservative estimate of the total thickness of the multiple dolerite intrusions is 1 km. It is of interest to note that the sheet with the most basic composition (and hence probably the highest density magma) of the multiple sheets that have been chemically analysed (Fridleifsson, 1973) is found at the highest stratigraphical level.

Following a brief interval, during which flood basalt volcanism was dominant in Esja, the Stardalur central volcano became active. During its life span of about 0.3 M.y. minor intrusions in the area were predominantly in sheet form. Caldera collapse in the Stardalur volcano was followed by the intrusion of basic cone sheets, large dolerite sheets, a sill and finally a laccolith (2.3 by 1 km in size) within the hyaloclastite caldera-filling.

It is worth noticing that this large intrusive body is by far the most basic in composition (Fridleifsson, 1973) of all the intrusions exposed in the Stardalur centre. Yet it was emplaced at the highest stratigraphical level. It may also be of importance to note that this very basic magma was emplaced in the upper part of the hyaloclastite body in question and not at its base as one would expect if the hyaloclastite served as a density trap. Relatively "intrusion-free" hyaloclastite is exposed below the base of the intrusion.

Cone sheets in the Stardalur volcanic centre were probably intruded just after the caldera collapse, as the sheets often have similar or only slightly higher dips than the tilted lavas (pre-caldera eruptives) within the caldera. The sheets are most commonly between 1 and 3 m thick where they intrude lavas, but they commonly expand to form 10 m thick sheets where they intrude the tholeiite hyaloclastite formed in the caldera lake. At the contact between the tilted lavas and the hyaloclastite some of the sheets expand to form sills with weakly developed horizontal layering. The hyaloclastite had been very recently formed and was presumably scarcely consolidated when the sheets intruded. The tholeiite hyaloclastite within the caldera is overlain by basaltic andesite hyaloclastite which probably filled the caldera completely. The basaltic andesite hyaloclastite is finer in grain size, harder and more coherent than the tholeiite hyaloclastite and the sheets within it are thinner and more regular than those within the softer tholeiite hyaloclastite. In a 240 m drillhole sunk within the caldera filling (Fridleifsson and Tómasson, 1972) the thickest intrusion (16 m) was penetrated at the boundary of the tholeiite and basaltic andesite hyaloclastites. Three intrusives penetrated at greater depth in the tholeiite hyaloclastite are each 8-9 m thick.

It therefore appears that the intrusives expand where they enter the hyaloclastite, as demonstrated by the sills at the contact of the tholeiite hyaloclastite and the underlying lavas, and also where they meet a more coherent rock such as the basaltic andesite hyaloclastite.

Outside the intrusive centers described above smaller dolerite intrusions in Esja are also found chiefly within or at the boundaries of the thick hyaloclastite units, and there is evidence of dykes cutting straight through lava successions, but spreading out laterally to form sill-like bodies once they enter the less coherent hyaloclastites.

It is apparent that the degree of consolidation of the host rock controls the regularity of the shape of the intrusions. Upon entering "soft" and "structureless" host rock that breaks irregularly the upwelling magma may expand within that host rock rather than penetrate upwards along a narrow regular fracture to form a dyke. The magma simply "gets lost" in the irregular network of fractures in the "soft" and "structureless" host rock.

5. DEPTH OF LAYER 3 AS COMPARED TO GEOLOGICAL STRUCTURE

It is known from direct observation in Iceland that the crust down to layer 3 is made up predominantly of extrusive volcanic rocks, which show a downward increase in metamorphic overprint (Walker, 1960). A characteristic seismic layering has been found, resembling the oceanic crust in velocity values, but the Icelandic crust is thicker (Pálmason, 1971). Layer 3 (oceanic layer) is found beneath the whole of Iceland, but is never exposed at the surface. The depth to its upper boundary has been mapped in some detail (Fig. 3, from Pálmason, 1971) and is quite variable, usually in the range 1 to 5 km but increasing conspicuously south-eastwards in southern Iceland. The layer has a fairly constant thickness of about 6 km, except possibly in northern Iceland where it may be thicker.

(Fig. 3)

Layer 3 in Iceland, with an average P-wave velocity of 6.5 km/s is probably equivalent to the oceanic layer, although the average P-wave velocity of the latter is commonly given as 6.7-6.8 km/s. The lower velocity in the Icelandic crust cannot be explained wholly by higher temperatures (Pálmason, 1971) but may be explicable in terms of the Icelandic crust having a lower average density than the crust surrounding Iceland because of petrochemical differences (Fridleifsson, 1973), and perhaps partly by the more intense alteration of the intrusive rocks (Fox et al, 1973) in the high heat flow region of Iceland.

The very large variations in the depth to the upper surface of layer 3 in Iceland (Fig. 3) pose in many ways the most interesting problem in the interpretation of the seismic refraction data (Pálmason, 1971). Pálmason found a close correlation between extinct central volcanoes and shallow depths to layer 3, and furthermore he found a clear correlation between small scale features of the gravity field (Einarsson, 1954) and the depth to layer 3. Strong positive gravity anomalies coincide with some of the central volcanoes where shallow depths to layer 3 have been recorded.

All the sites where layer 3 has been recorded at depths less than 2 km are associated with central volcanoes. All these sites, except for the youngest and virtually uneroded Hengill area (Sæmundsson, 1967), are dissected and have large coarse-grained intrusives exposed at the surface, and many of the sites have centrally inclined sheet swarms indicating a local concentration of large intrusive masses at shallow levels in the crust. The fact that central volcanoes with a large bulk of shallow level intrusions also are sites of shallow depth to layer 3 strongly suggests an intrusive nature for layer 3. The shallowest depth to layer 3, 500-600 m, is recorded (Pálmason, 1971) in the Stardalur Quaternary central volcano (Fridleifsson and Kristjánsson, 1972). That the site of the shallowest depth to layer 3 recorded so far in Iceland is in Stardalur may be explained by the easier accommodation of large intrusions in soft hyaloclastites than in the hard and brittle lava piles of the Tertiary provinces in Iceland (Fridleifsson, 1973). At the end of the life span of the Stardalur central volcano the level at which layer 3 is now recorded may have been at a depth of about 1.5 km. This compares well with the depth of 1.9 km recorded in the late Quaternary to recent Hengill central volcano, which is still within the active volcanic zone, and the high temperature area there indicates persistent intrusive activity.

6. WHAT CONTROLS THE UPPER BOUNDARY OF LAYER 3?

From a comparison of the depth to layer 3 with crustal temperatures, as inferred from borehole data, Pálmason (1971) suggested that the layer 2/ layer 3 boundary might be metamorphic, layer 3 perhaps consisting of amphibolite facies metabasics, as suggested by Cann (1968) for the oceanic layer. The highly altered cores of the volcanic centres (Walker, 1964), indicating a rise in the isotherms in the vicinity of the centres, seemed compatible with the relatively shallow depths to layer 3 observed in the volcanic centres.

In later years the following two petrological models for layer 3 have become more generally accepted:

a) Sheeted dykes (often metamorphosed to greenschist and amphibolite facies) for the upper portion of the layer, but the lower portion consists of cumulate gabbro and late differentiates.

b) Metabasalts and metagabbros where gabbros are assumed to occur as dykes and sills which have intruded the metabasalts (greenschist to amphibolite facies).

Both these models are compatible with experimental data on the seismic velocities in rocks (Christensen, 1974). The Poisson's ratios reported for the lower crust of Iceland (Palmason 1971) suggest that metabasalt and metagabbro are abundant constituents of layer 3 (Christensen, 1974).

From field evidence it seems quite likely that both models are applicable to layer 3 in Iceland. The sheet swarms of the volcanic centres are probably analogous with model a). But model b) is probably more applicable outside the volcanic centres where the magmatic activity is considerably less intense judging from manifestations in surface exposures of layer 2.

In both models it is assumed that the boundary between layers 2 and 3 is largely a transition from a porous, but altered lava layer to a layer consisting to a large extent of non-porous intrusives. But how can the apparent sharpness of the boundary between layers 2 and 3 be explained?

Walker (1974, 1975) proposed that this boundary was controlled by the density contrasts between the crust and the uprising batches of magma. We propose that in addition to the density factor there may, however, be a second controlling factor, imposed by the progressive alteration state of layer 2 with depth.

The evidence of the "large" basaltic intrusions being accommodated in the softer rock types ("soft" and "structureless" hyaloclastites as well as propylitized lavas) suggests that magma would tend to spread out laterally within the highly altered lavas at the base of layer 2 rather than penetrate the progressively harder lava pile.

The "metamorphic boundary" would thus primarily function as a degree of alteration at which the lava pile looses its strength and accommodates large non-porous intrusives, and not as a density boundary in itself as proposed by Pálmason (1971).

This model would be compatible with the correspondence (Pálmason, 1971) between observed depths to layer 3 and crustal temperatures as inferred from borehole data.

7. DISCUSSION

It is of interest to note that in Pálmason's (1971) map (Fig. 3) of the depth to layer 3 in Iceland, a large area in southwest Iceland has depths of less than 3 km. This area coincides fairly closely with the outcrops of Quaternary to Recent volcanics in southwest Iceland (Fig. 1) and can be explained by large intrusives being accommodated in the subglacial hyaloclastite units.

The depth to layer 3 in the Reykjanes peninsula is about 2.6 km. A direct comparison cannot be made between the peninsula and the Reykjanes ridge as velocity values typical of layer 3 have not been detected in the axial zone of the ridge (Talwani et al 1971); in the flank zones of the ridge, however, layer 3 is at about 2 km depth. From the evidence on the nature of basaltic intrusives in Iceland and assuming a constant lithostatic/magma pressure ratio the depth to layer 3 in the crust could be expected to increase southwards along the Reykjanes ridge, as with increasing water depth the tuff/pillow lava ratio decreases, the vesicularity of the lithic rocks decreases (Moore, 1965 ; Schilling and Moore, 1973), the density of the pile increases and a higher degree of alteration would be needed to make the pillow lavas "hospitable" to large intrusions. Data is, however, too scanty to test this.

Layer 2 is recorded all over Iceland except on the Reykjanes peninsula, where it appears to be missing (or is too thin to be detected (Pálmason, 1971). This may be explained if the bulk of the volcanics are hyaloclastites, as has been indicated by drilling (Tómasson and Kristmannsdóttir, 1972); alteration of hyaloclastites would not produce densities and seismic velocities corresponding to an altered subaerial lava layer. Intrusives will be easily accommodated in the hyaloclastite piles. The high level of the intrusions is probably reflected in the four high temperature areas in the peninsula, which are the only present high temperature areas in Iceland not connected with central volcanism (Pálmason and Sæmundsson 1974).

Walker´s (1974, 1975) density hypothesis does not offer an explanation of the conspicuous, progressive increase in the depth to layer 3 in central southern Iceland. An explanation may perhaps be found in that the eastern volcanic zone was only recently superimposed on an older crust (Sæmundsson, 1974), where layer 3 had already formed by intrusions into the highly altered base of the lava pile. As this older crust had drifted away from the western volcanic zone and was, at the time of the superimposition, in an area of a relatively low thermal gradient (Pálmason, 1973) the process of alteration of the lavas at the base of layer 2 did not match the rate of subsidence in the new volcanic zone and hence the palaeoboundary of layer 2/ layer 3 sank as the thickness of the overlying layers increased, layer 1 increasing faster in thickness than layer 2. The scanty available seismic data on the relative thicknesses of layers 1 and 2 (Palmason, 1971) appears to support this model.

When volcanism commenced along the new volcanic zone the magma either penetrated the whole way to the surface and was erupted, or was accommodated well below the layer 2/ layer 3 palaeoboundary, as the "old" intrusives had already filled the "readily available space" in the altered lava layer. It is interesting to note that in this area of exceptional depth to layer 3, some of the largest volumes of postglacial lavas in Iceland have been erupted, such as the Lakagígar eruption with a volume of about 12.5 km^3 (Thorarinsson 1969) and the Eldgjá eruption(s) producing between 10 and 20 km^3. The large volume produced by the Eldgjá fissure is particularly surprising in view of the relatively small quantities of transitional alkali basalts produced during postglacial time (Jakobsson 1972), and lends support to the suggestion that the bulk of the lava produced by partial melting in one batch below the crust was brought to the surface, and that a substantial percentage of the total volume was not intruded at the base of layer 2, as may be the case in areas with a "normal" layer 2/ layer 3 boundary. The remarkable chemical uniformity of the Lakagígar lava (with plagioclase, olivine and clinopyroxene phenocrysts) throughout the 1783 eruption (Grönvold 1972, Bell 1973) suggests an undelayed passage of the magma from the zone of partial melting to the surface.

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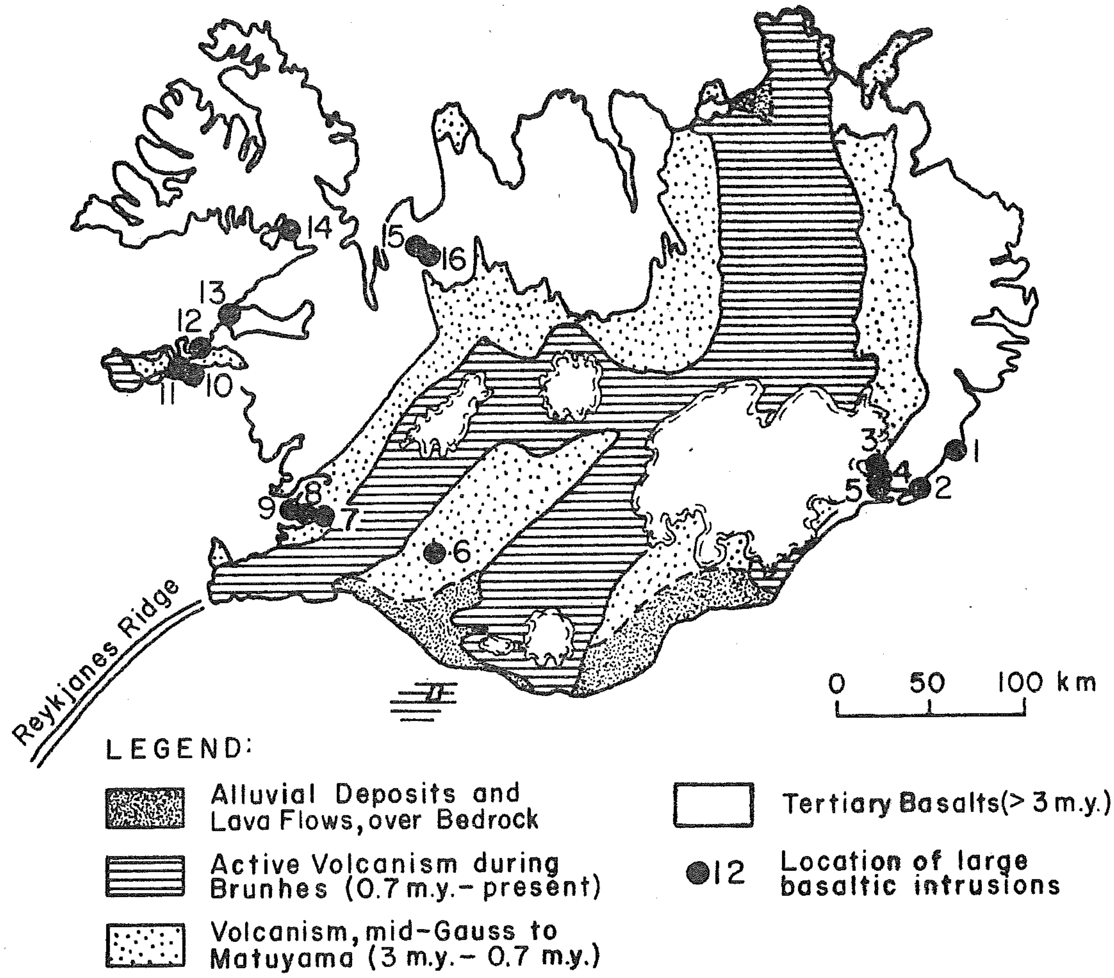
FIGURE CAPTIONS

Figure 1. Location of large basaltic intrusions in Iceland. 1 Austurhorn, 2 Vesturhorn, 3 Geitafell, 4 Valagil, 5 Vidbordsfjall, 6 Stóra-Laxá, 7 Stardalshnúkur, 8 Thverfell, 9 Kjalarnes, 10 Lýsuskard, 11 Thorgeirsfell, 12 Kolgrafarmúli, 13 Hrappsey-Purkey, 14 Hríshóll, 15 Borgarvirki, 16 Hólar-Skessusaeti. The simplified geological map of Iceland is compiled by K. Saemundsson.

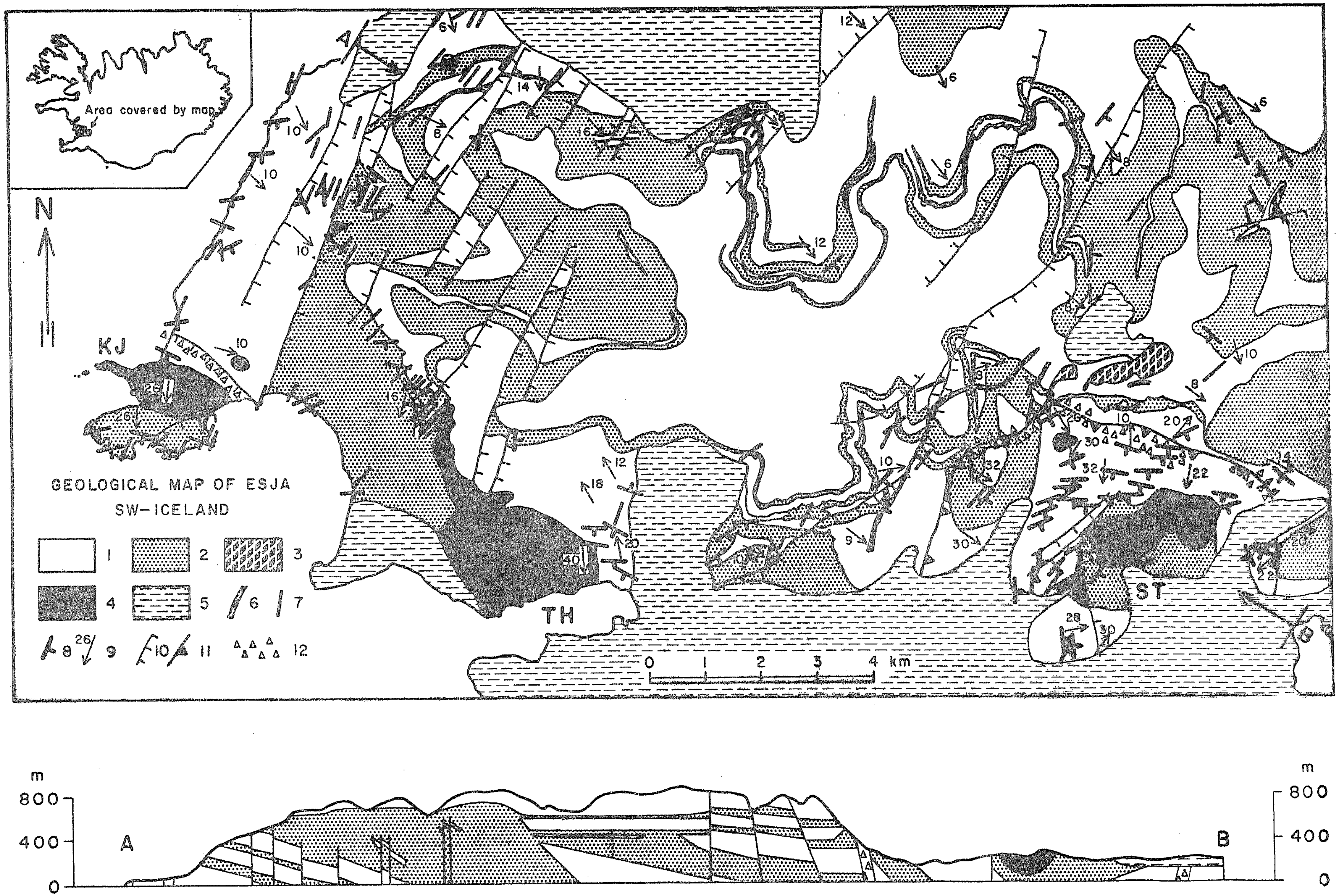
Figure 2. A simplified geological map of the Esja volcanic region, SW-Iceland. The rocks date from about 2.8 m.y. to 1.8 m.y. Only faults with vertical displacement more than 30 m are shown. Approximately every third dyke and sheet is shown. Legend: 1 basaltic lavas, 2 subglacial basaltic hyaloclastites and sediments, 3 rhyolite sheets and domes, 4 gabbro and dolerite intrusions, 5 post-erosional lavas, landslips and alluvial deposits, 6 rhyolite dykes, 7 basic dykes, 8 basic sheets, 9 dip, 10 fault, 11 caldera fault, 12 fault breccia. The main intrusion localities (see Table 1) in the region are marked KJ = Kjalarnes, TH = Thverfell, ST = Stardalur. Note that all the large intrusions are emplaced at the contacts of hyaloclastites and lavas.

Figure 3. Depth to crustal layer 3 (V_p = 6.5 km/s) in Iceland, based on about 80 refraction profiles (from Palmason, 1971).



Reykjanes Ridge
0 50 100 km
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
LEGEND:
Alluvial Deposits and Lava Flows, over Bedrock
Active Volcanism during Brunhes (0.7 m.y. - present)
Volcanism, mid-Gauss to Matuyama (3 m.y. - 0.7 m.y.)
Tertiary Basalts (> 3 m.y.)
12 Location of large basaltic intrusions

Figure 1



GEOLOGICAL MAP OF ESJA
SW-ICELAND
Area covered by map
N
KJ
TH
ST
A
B
1
2
3
4
5
6
7
8
9
10
11
12
0 1 2 3 4 km
m
800
400
0

Figure 2

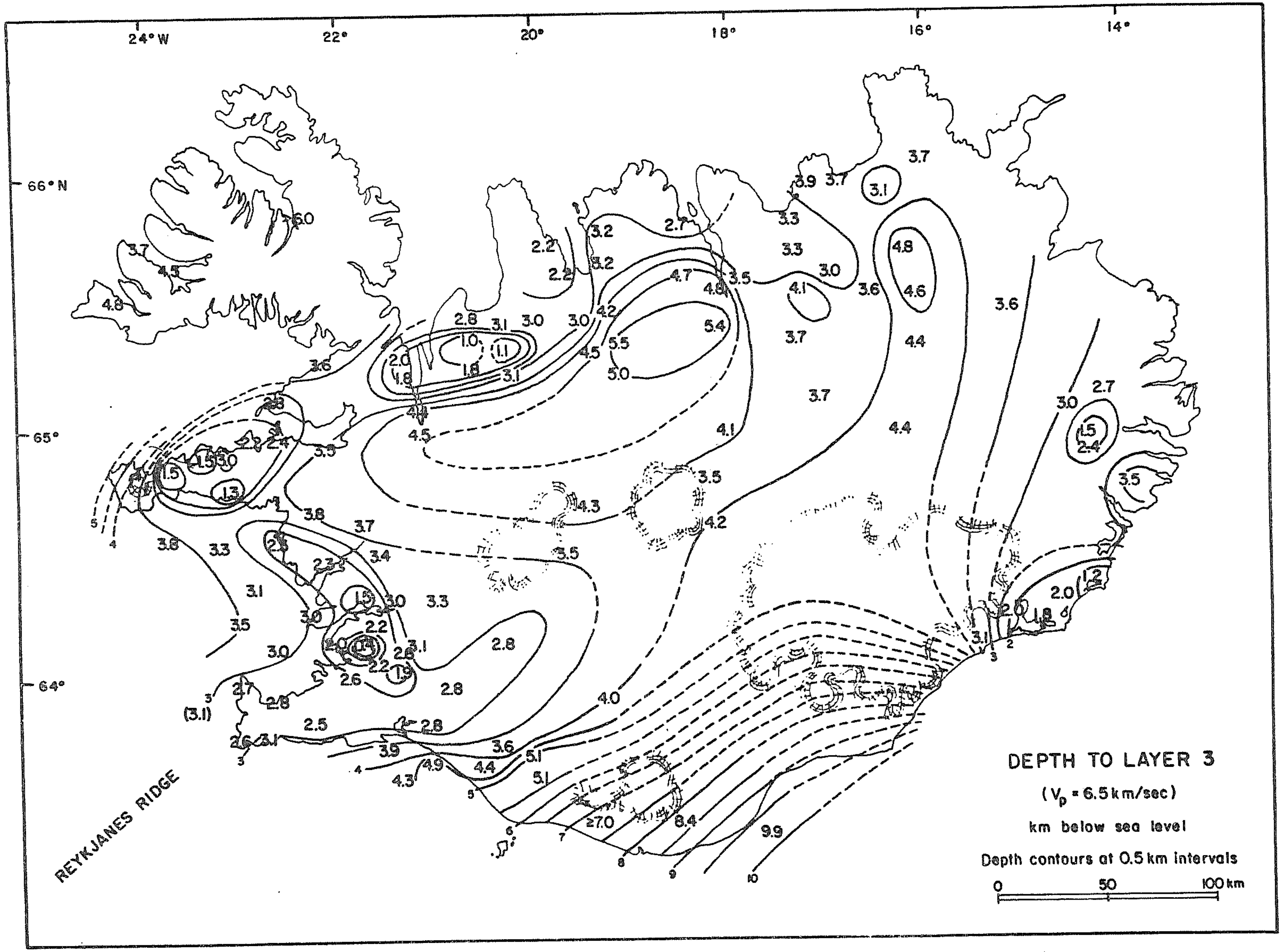

DEPTH TO LAYER 3
(V_p = 6.5 km/sec)
km below sea level
Depth contours at 0.5 km intervals
0 50 100 km
REYKJANES RIDGE
24° W
22°
20°
18°
16°
14°
66° N
65°
64°

Figure 3