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THE KRÓKSFJÖRDUR CENTRAL VOLCANO IN NORTH-WEST ICELAND

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ABSTRACT

The Króksfjördur central volcano lies on the south-west side of the spit of land which connects the north-west peninsula of Iceland with the mainland (Fig. 1).

In the tholeiitic lavas, which make up the area, a central depression is present on the eastern side of Króksfjördur in which at least 200 m of basic and acid tuffs have been laid down. Almost at the same time as this depression was formed a cone-sheet complex, which consists of basaltic rocks, was intruded. The central volcanic activity has besides this led to the formation of a considerable number of small plugs, which vary in rock composition from olivine-tholeiitic to dacitic. The presence of a primary, phenocrystic, green amphibole in a few of the acid intrusive rocks within the complex shows that a high water pressure was built up in some of the underlying magma pockets.

In the central depression is a single horizon rich in inclusions of granophyre and laminated hypersthene gabbro. Laminated diorite and gabbro are common as inclusions in the dacitic rocks which intrude into the tuff series. The fragments are supposed to have been derived from one or perhaps more layered bodies below the tuff basin.

A number of rocks in the central volcanic area have been affected by hydrothermal alteration, which among others has led to the formation of hydrogrossularite and epidote in the inner part of the aureole.

The area was later covered by tholeiitic basalts, the extrusion of which is supposed to coincide with the formation of a NNE-SSW dyke swarm which consists of a characteristic plagioclase-augite-porphyritic basalt, a rock type which is also of common occurrence among the covering basaltic lavas. Traces of central volcanic activity are still recorded from this phase, for example a 20—40 m thick ignimbritic layer enters into the upper lava series.

PREFACE

With the kind agreement of Icelandic authorities a Danish geological expedition took place in the summer 1967 to the north-west peninsula of Iceland. The expedition, which was led by Professor Arne Noe-Nygaard, was made possible through a grant from the Danish Natural Science Research Council. One of its purposes was to carry out a closer study of a locality with acid rocks at Króksfjördur earlier mentioned by Thoroddsen (1888b).

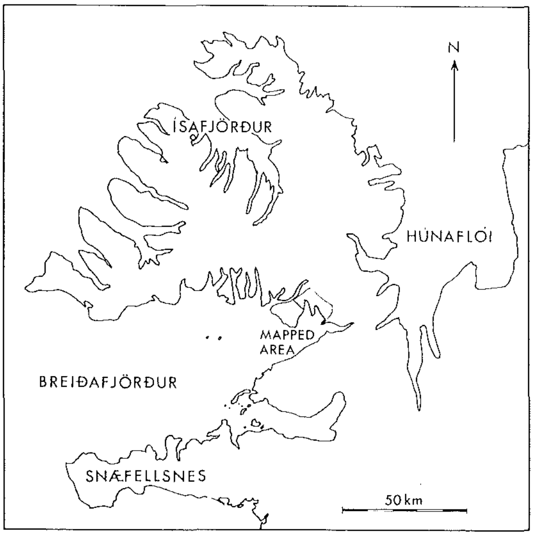

Fig. 1. North-western part of Iceland. The area mapped by the authors is shown by hatching.

A geological mapping of the area was carried out by Niels Hald and Asger Ken Pedersen during a total stay of 2—3 months. Arne Noe-Nygaard took part in the work from time to time during the last month of the season. We have made the present paper in cooperation.

INTRODUCTION

In Iceland there are two plateau basaltic regions, of Tertiary age, one in the east and one in the west (cf. e. g. Áskelsson et al. 1960); they are separated from each other by a belt of lavas and subglacially formed hyaloclastitic deposits of Quaternary age (Icelandic móbergformation) — the active volcanic zone; the main part of late and postglacial volcanic activity also took place in this zone. The Króksfjördur central volcano lies within the western Tertiary region.

Basalt makes up about 90% of extrusive and intrusive rocks in Iceland, the remaining 10% consist of intermediate and acid rocks (Thorarinsson 1967). Investigations, among others by Walker (1966), have shown that the occurrences of acid rocks are concentrated within comparatively small areas and that their emplacement is related to the presence of central volcanoes.

Among the central volcanoes in eastern Iceland the Breiddalur (Walker 1963) and the Thingmúli (Carmichael 1964) volcanoes have been described, from western

Iceland the Setberg volcano on Snaefellsnes (Sigurdsson 1966). The Askja complex in the active volcanic zone can be considered as a recent, still active central volcano.

PREVIOUS GEOLOGICAL INVESTIGATIONS IN THE REGION

The north-west peninsula on Iceland did not enter into the considerations of geologists until Heer's (1868) investigations of the fossil Tertiary flora from here. This flora is found in sedimentary, interbasaltic beds which consist of subaqueous tuffitic rocks which contain carbonised plant material (Icel. surtarbrandur).

Thoroddsen (1888a, 1888b, 1892 and 1906) was the first to give a coherent outline of the geology of the peninsula. After Thoroddsen research work was again concentrated on the plant bearing beds (e. g. Schwarzbach and Pflug 1957, Pflug 1959 and Friedrich 1966) and only few looked into the geological setting of the north-west peninsula (Keilhack 1933, Áskelsson 1936, Winkler 1938, Einarsson 1965; Áskelsson et al. 1960); therefore this is still rather incompletely known. (See for reference map by Kjartansson 1969). Tertiary plateau basaltic lavas make up the main part; they are stated to be almost horizontal in the northern and central parts, whereas the southern part, facing Breidafjördur, has a southerly to south-easterly dip, in general not exceeding 10°.

The basalts to the west are considered to be the oldest, they have been dated radiometrically by Moorbath et al. (1968) to 16 million years, that is Miocene.

Thoroddsen (1888 b) observed the existence of rhyolitic and trachytic rocks on several localities; especially he mentions them as common on the landspit between Breidafjördur and Húnaflói. Our mapping in 1967 around Króksfjördur on the southwestern side of this spit has shown that the acid rocks here belong to the central volcanic complex described later.

SURFACE CONDITIONS OF THE KRÓKSFJÖRDUR AREA

While the Reykjanes peninsula and the terrain around Gilsfjördur (Plate 6) consist of typical plateau basalt landscapes with steep valley sides in which thick lava flows stand out to form escarpments, the Króksfjördur area is governed by smooth erosion in which the pre-glacial rocks only peep out as scattered outcrops. An exception to this is provided by the many plugs which stand out as marked silhouettes, such as for instance Vadalfjöll (Fig. 2); the Borg peninsula offers a special example of this feature.

The uppermost marine level, which is characterised by well developed terraces, lies about 70 m above sealevel; another prominent terrace lies at about 40 m (Thoroddsen 1892). Plains with systems of raised beaches have developed for example around the farm Bakki in Bakkadalur, at Geitafell and on the Borg peninsula. When the sea was at its highest Borg and Hafrafell were islands, which during the later recovery of the land became connected with the mainland through spits.

Larger outcrops of the extrusive rocks are only found along river cuts, along recent and older coastal cliffs and in places which have been laid bare through wind erosion or landslides in glacially overdeepened valleys (e. g. Kambsfjall).

Fig. 2. The landscape north of Hofstadaháls. Vadalfjöll in the background.

ROCKS EMPLACED BEFORE AND DURING THE FORMATION OF THE CENTRAL DEPRESSION AT KAMBSFJALL

Lavas and pyroclastics.

Basaltic lavas dominate the area mapped; they can be referred to two series, a lower which was formed before or is contemporaneous with the most significant phases in the life of the central volcano, and an upper which discordantly covers the lower series as well as the tuffitic layers which were deposited in the central depression. It is not yet clear whether or not this twofold division of the basaltic sequence is valid outside the Króksfjördur area.

The lower lava series is mainly exposed north and west of the Kambsfjall ridge; it is characterised by thin flows. Thicknesses of 2—4 m dominate; single flows can however reach a thickness of about 10 m.

The lavas are very monotonous in rock type, by far the greatest part consisting of a dark grey, fine-grained, aphyric or plagioclase-microphyric, tholeiitic basalt; only few flows contain scattered proper phenocrysts of plagioclase.

Beds of tuff and of coarse breccias have a wide occurrence; in places they can reach a thickness of 5—10 m, in which case they are often rich in fragments of medium- to coarse-grained gabbro, composed of plagioclase, augite and ore with intergranular, or —less often— with ophitic texture.

10—20 m thick basalto-andesitic lava flows enter into the lower lava series at several levels; the best exposed flows are found at Hlídará on Reykjanes and at Sandfell, where a single flow was traced for $1^1/_4$ km. The basalto-andesites are dense, dark grey rocks, which split up in a slate-like manner along the flow planes (Fig. 3), and which may show "folding" features. The groundmass consists in the main of closely packed, parallel-lying plagioclase tablets set in a matrix of devitrified glass. The groundmass further contains equidimensional grains of pyroxene and ore. The phenocryst generation consists of a weakly coloured augite, ore and parallel-lying tabular plagioclases, which, together with the characteristic splitting of the rock, form the typical criteria for recognition of basalto-andesitic lavas in the field.

A 25 m thick basalto-andesitic lava at Hlídará contains in addition phenocrysts of orthopyroxene and apatite.

The general strike of the lower lava sequence is NNE-SSW, the dip is towards the east-south-east and the angle of dip increases towards Kambsfjall from the northwestern as well as from the eastern part of the area. On the north-west slope of Kambsfjall the dip is thus 30°—35° ESE, while at Vadalfjöll at Thorskafjördur it is 15°—20° ESE and in Bæjardalur, 6 km away from the coast, it is 15° ESE.

This pattern is broken on Hofstadaháls where the sequence of lavas forms a flat syncline, which continues to Reykjanes. The direction of the fold axis coincides with the direction of the main strike in the rest of the mapped area. The plunge of the axis is 6°—8° towards the SSW.

It is to be supposed that the present dip of the lower plateau basalt series is secondary and caused by tectonic disturbances which perhaps originated during the formation of the central depression on Kambsfjall (see p. 11).

Because of the lack of marker horizons or groups of flows with a large areal distribution and because the outcrops are few, we have not been able to correlate the single outcrops with one another in a satisfactory way so that a reliable stratigraphy for the lower series could be established. It must be assumed, however, that the apparently very thick basaltseries between Kambsfjall and Thorskafjördur is a faulted lava pile which originally was much thinner.

Around the head of Króksfjördur the outcrops are dominated by brecciated rocks. The few exposures here and the intense hydrothermal alteration (p. 20) have, also for these rocks, made it difficult to build up a stratigraphy, and their age in relation to that of the lower lava series is not known; the only thing which is certain is that the breccias as well as the lower lavas are cut by the same cone-sheet system.

Breccias of basaltic composition seem to dominate; they are well exposed in

Fig. 3. Basalto-andesitic lava showing its characteristic splitting into thin plates.

the river sections of Bæjará and Geitá, and on the east coast of Berufjördur. In the old coast cliff on the south-west side of Gillastadafjall pillow breccias of basaltic composition crop out.

Exposures in acid and intermediate breccias are concentrated between Bæjará and Laxá. These breccias consist here of up to 10 cm large, sharp-edged fragments of altered, light coloured, fine-grained rocks with 2—3 mm big plagioclase phenocrysts.

The basic as well as the acid breccias weather easily and are in all probability widely distributed in the coastal plains north-west of Króksfjördur, where they are covered by late-glacial and alluvial deposits.

During the formation of the basalts of the lower series a subsidence in the area around the southwestern Kambsfjall took place; in the depression thus formed well stratified, mainly finegrained tuffs were deposited. The main part of these strike NNE-NE and dip between 10° and 20° ESE-SE (Fig. 4). The thickness of the exposed part of these rocks is about 200 m. The series tapers out towards north and north-west along the north-west slope of Kambsfjall. Towards W-SW and S erosion has removed a considerable part of the series, the extension of which is therefore not known; in a southeasterly direction it may continue below the bottom of Gautsdalur.

Fig. 4. A sequence of tuffs on south-western Kambsfjall.

The layers in the tuffbasin have the same strike as the basalts in the lower series, but their dip is considerably less, 15° ESE against 25°—30° ESE of the lavas. The existence of minor unconformities within the tuff series points to movements of the basin during the deposition of the tufaceous sediments.

The exposed part of this tuff sequence begins with brownish, coarse-grained volcanic breccias; these are succeeded upwards by finegrained brownish and whitish-

TABLE I.

Anal.-No.	1	2	3	4	5	6	7	8	9
Sample No.	MM 2457	MM 2454	MM 2321	MM 2456	MM 2451	MM 2453	MM 2455	MM 2452	MM 2458
SiO_2	47.02	46.94	48.64	48.96	62.25	66.45	65.76	67.57	68.81
TiO_2	1.84	2.14	2.65	3.37	1.60	1.00	0.63	0.48	0.40
Al_2O_3	17.89	14.32	13.37	12.72	13.58	13.09	13.92	14.91	15.49
Fe_2O_3	3.09	3.28	4.51	2.75	4.02	2.88	1.15	2.94	1.50
FeO	7.10	8.27	8.88	11.70	3.92	2.56	2.64	0.65	1.58
MnO	0.12	0.18	0.23	0.28	0.19	0.19	0.05	0.08	0.0
MgO	6.08	6.94	5.07	4.56	1.62	1.09	1.34	1.47	1.22
CaO	13.88	13.32	11.12	9.83	4.44	3.80	4.60	4.40	4.33
Na_2O	1.92*)	2.21*)	3.04	3.29	4.69	4.29	3.40	4.00	4.27
K_2O	0.19*)	0.27*)	0.41	0.57	1.63**)	1.54	1.99	1.80	2.09
P_2O_5	0.17	0.26	0.37	0.54	0.52	0.22	0.11	0.09	0.08
H_2O+	0.52	1.99	1.34	0.54	0.78	2.87	3.77	1.10	0.51
Sum	99.82	100.12	99.63	99.11	99.24	99.98	99.36	99.49	100.28
C.I.P.W. norm									
q	0	0	1.9	0.7	19.2	27.3	26.7	26.9	25.6
or	1.1	1.6	2.4	3.4	9.6	9.1	11.8	10.6	12.4
ab	16.2	18.7	25.7	27.8	39.6	36.3	28.7	33.8	36.1
an	39.6	28.3	21.6	18.2	11.2	11.9	16.8	17.2	16.9
hy	9.5	6.7	8.9	14.3	2.7	1.6	4.1	2.3	2.5
di	22.8	29.3	25.5	22.5	6.0	4.5	4.4	3.0	3.3
ol	1.7	4.1	0	0	0	0	0	0	0
mt	4.5	4.8	6.5	4.0	5.8	4.2	1.7	0.9	2.2
il	3.5	4.1	5.0	6.4	3.0	1.9	1.2	0.9	0.8
hm	0	0	0	0	0	0	0	2.3	0
ap	0.4	0.6	0.9	1.3	1.2	0.5	0.3	0.2	0.2

*) Anal. Me Mouritzen. H_2O^+: Sample dried for two hours at 105°C.
**) XRF-anal.

KEY TO ANALYSES IN TABLE 1.

1) MM 2457. Plagioclase- and augite-porphyritic olivine tholeiitic basalt from the Vadalfjöll-plug. From the high plateau in the middle of the intrusive body.

2) MM 2454. Faintly plagioclase porphyritic olivine tholeiite with olivine-semiphenocrysts. South western side of the Geitafell-plug at 200 m.

3) MM 2321. Aphyric tholeiitic basalt from cone-sheet. $^1/_2$ km ESE of the farm Hofstadir.

4) MM 2456. Finegrained alkali rich tholeiitic basalt with phenocrysts of plagioclase, augite, olivine (pseud.) and ore. Plug about 500 m south of the farm Borg.
5) MM 2451. Intermediate granophyric sheet from the coastal cliff on the eastside of Berufjördur west of the farm Hafrafell.
6) MM 2453. Black glassy dacite with phenocrysts of plagioclase, augite, pigeonite and ore. Intrusion laid bare in gully on the north-western side of Kambsfjall about 1 km ENE of the farm Bær, 150 m above sea level.
7) MM 2455. Intrusive, orthopyroxene- and plagioclase-porphyritic, darkbrown, dacitic glass. 3 m from contact to the younger Geitafell-plug, 200 m SE of the summit of Geitafell, 250 m above sea level.
8) MM 2452. Dark greyish dacite with phenocrysts of plagioclase, augite and hornblende. North-eastern part of tongue between Bakká and Gautsdalur 70 m above sea level.
9) MM 2458. Light greyish dacite with phenocrysts of quartz, plagioclase, hornblende, biotite, ore and pyroxene. Intrusion in tuff basin at the southwestern slope of Kambsfjall, 400 m east of the farm Kambur 140 m above sea level.

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yellow tuffs with a pronounced stratification; in a few horizons plant remains occur. Higher up in the sequence then follow brown, glass-rich tuffs. In some of these the tuff is cracked in an irregular manner to form blunt fragments; next to these cracks the fragments of tuff are again subdivided into numerous 1—2 mm broad, tiny columns perpendicular to the cracks. The glassy tuffs are covered by a whitish-yellow, almost clayey pumicebreccia rich in decimetre-large, silicified tree trunks. The layer also contains numerous fragments up to 20 cm in size of granophyre and laminated gabbro, to be described later (p. 16).

Outcrops of this tuff are found again in a couple of other localities on the southwestern Kambsfjall and are supposed to belong to one and the same horizon.

Thin flows of aphyric lavas enter into the tuff series at several levels; they can be rich in gabbro xenoliths. The lavas themselves are intensely flow laminated, and sometimes slip-deformation structures can be observed on the separate flow planes.

North-east of the tuff basin, near the top of Kambsfjall, a 50 m thick layer of plagioclase-microphyric basalt is encountered. The layer, which dips towards the north-west, is developed as a pillow lava towards south-east; in a northwesterly direction it grades into a pillow-breccia. It is natural to suggest that this layer, and an underlying basalt flow showing the same dip, reflect an old slope into a depression which now and again was filled with water.

Basaltic and basalto-andesitic plugs.

A large number of plugs cut through the lower lava series, the breccias and the strata in the tuff basin. The individual plugs are small, rarely over a couple of hundred metres in diameter; the rocks of which they are composed vary in composition from olivinetholeiitic basalt to dacite and reflect grossly the same chemical and mineralogical variation as do the extrusive volcanic products. Almost all the plugs are cut by the cone-sheet complex (p. 17), which also cuts the lower lava series, but is thought to be older than the upper, in which no cone-sheets are found. The greater part of the plugs are therefore considered to have been formed while the building up of the lower lava series was still going on.

At Geitá, 3 km north-north-east of Króksfjördur, lies the Geitafell plug, which is one of the most prominent mountains of the region; it covers an area of 300 m × 200 m and reaches an altitude of nearly 250 m above the neighbouring raised-beach plain. Geitafell consists of a fine-grained blackish grey columnar basalt containing scattered, up to 2 mm large plagioclase phenocrysts and up to 0.5 mm large olivine phenocrysts in a groundmass of plagioclase and a weakly coloured augite and ore. The rock has a SiO_2 content of about 47% (Table 1 no. 2), the most basic rock from the plugs of early formation.

Along the east coast of Króksfjördur between Gautsdalsá and Bæjará lies a row of small islands and promontories practically all of which are made up of plugs and lavas. The rest of the more easterly coast is either unexposed or consists of intensely hydrothermally altered rocks. Another stretch with basaltic plugs goes from the coast between the farms Bær and Kambur towards the east upwards along the western slope of Kambsfjall.

The plug basalts are fine-grained to dense, dark grey rocks with up to 5 mm large phenocrysts of plagioclase and augite and — to a minor extent — ore; xenoliths of basalt and gabbro are common.

On the Borg peninsula tholeiitic lavas have been intruded by several plugs consisting of basaltic and basalto-andesitic rocks. Whithin the same region are basaltic lava breccias and pillow breccias common. A prominent basaltic plug is the almost circular Bjartmársstein at the most southwesterly point of the peninsula; with a diameter of only a hundred metres it protrudes to 55 m above sealevel.

To the south of the farm Borg a fine-grained basalt is found with phenocrysts of plagioclase, augite and partly altered olivine in a groundmass of plagioclase, pyroxene and ore. An analysis of this basalt (Table 1 no. 4) shows tholeiitic composition; it is clearly iron-enriched containing about 15% of total iron oxides.

In contrast to this several plugs north and west of the farm Borg consist of glass-rich basalto-andesites and andesites in which the phenocryst generation consists of tabular plagioclase, augite, pigeonite, ore and apatite.

On the Borg peninsula as well as on the east side of Króksfjördur, the basaltic plugs commonly contain sharp-edged fragments of a fine-grained, aphyric basalt; the fragments are rarely more than 5—10 cm large but can make up more than 10% of the rocks.

Dacitic minor bodies.

Dacitic rocks occur in several places as small bodies rich in glass. This is for instance the case at Geitá where the basaltic plug Geitafell has intruded into an area with bodies of a black, dacitic rock which consists of only weakly devitrified glass containing microliths of plagioclase and pyroxene. The rock contains many 1 mm large phenocrysts of plagioclase and bronzite (analysis in Table 1 no. 7). In a single locality scanty phenocrysts of augite also occur.

In the Borg peninsula, north and west of the farm Borg, several acid bodies occur; they consist of columnar, glassy rocks and cut into the basaltic plugs. In the glassy groundmass a great number of 1 mm large phenocrysts of plagioclase and up to 0.5 mm large phenocrysts of augite, pigeonite, ore and apatite occur. Augite is more common than pigeonite, which in part occurs as independent grains, in part as grains surrounded by a coating of augite. In a few cases the opposite sequence of crystallisation is observed, i. e. augite coated by pigeonite. The rock is furthermore rich in 1 mm large fragments which consist of plagioclase, augite and ore.

A glassy rock with the same phenocryst assemblage and also with many plagioclase-pyroxene-ore inclusions is met with in the western part of Kambsfjall, about 1 km east of the farm Bær (Pl. 1 A). A chemical analysis is given in Table 1 no. 6.

A columnar, dark grey rock is exposed at Tindaháls. In a groundmass of perlitic glass with microliths of plagioclase and ore, a phenocryst and semiphenocryst assemblage is found which consists of plagioclase, faintly greenish augite, strongly altered Fa-rich olivine and apatite.

Northwest of Geitafell and at Borg peninsula occurs a plagioclase porphyritic, quartz-bearing rock with a whitish weathering as small bodies less than 50 m in size. The rock splits up in thin plates; as we did not succeed in obtaining fresh samples no detailed petrographic information can be given.

About half a kilometre north-west of the farm Klettur the tuff layers in the central depression have been intruded by a whitish grey, strongly porphyritic dacite (Table 1 no. 9) (cf. Schmidt 1885); along the contacts towards tuffs and breccias small bodies of opal were formed.

Related smaller intrusions occur along the main road north-east of the farm Hólar.

The dacite is a flow-laminated, porphyritic rock with a rich assemblage of phenocrysts and cognate inclusions, both of which are embedded in a glass filled with microliths.

The phenocryst generation consists of quartz, plagioclase, green hornblende, biotite, black ore and apatite. The quartzes are blunt and generally resorbed. The plagioclases form sub- to euhedral, blunt tables, which can be extremely oscilliatory zoned (Pl. 1 B). Green hornblende occurs as up to 1.2 mm long, prismatic phenocrysts often with twinning on (100). Biotite is present as scattered tabular flakes and is strongly pleochroic with α = brownish green and β = almost opaque. Besides the said minerals an older, cognate generation of plagioclase, orthopyroxene, augite and ore is present. The older plagioclases show „patchy zoning" and have an outer capping, which corresponds to the younger generation of plagioclase phenocrysts in composition. In extreme cases the older phenocrysts may appear as strongly remelted spongy masses. The orthopyroxene and augite individuals are often resorbed and in a state of alteration into green hornblende.

The intrusion is rich in gabbro inclusions which may reach a size of 80 cm in diameter. The inclusions are usually laminated and the proportion between light and dark minerals may vary strongly. Coarse-grained pegmatoid fragments, which can be very rich in black ores, occur sporadically. Furthermore a few fine-to medium-grained dioritic laminated rocks have been recorded.

It is probable that this hornblende-porphyritic dacite originated in the same magma chamber in which also the characteristic inclusion-rich, loamy, acid pumice tuff from the tuff-basin was formed.

The xenolith assemblage from the two rock units can briefly be described as follows:

The gabbro fragments are cumulus gabbros and consist of plagioclase, augite, orthopyroxene, Fe-Ti-oxides and apatite. The up to 1 cm large tabular plagioclases lie subparallel to (olo) and are weakly normally or oscillatory zoned. A younger „patchy zoning" superposes the older zonarity. Weakly pleochroic orthopyroxene is found in up to 1 mm large, rounded „grains"; often such a grain consists of aggregates of individuals with weakly differing optical orientation. Symplectic intergrowth of orthopyroxene and magnetite is of common occurrence (Pl. 4 A). Some orthopyroxenes contain exsolution lamellae or small „islands" of augite. Faintly coloured augite is present as prismatic individuals the length of which is the same as that of the plagioclases. The augite contains extremely thin lamellae of orthopyroxene and in some gabbro fragments is in the state of incipient alteration into green hornblende. In a few fragments parts of the older cumulus plagioclase tables have been replaced by a „graphic" hornblende-plagioclase intergrowth.

Table 2. Hornblende from hornblende diorite. 648-xenolith (Electronmicro-probeanalysis). A.K.P.

SiO_2	45.6
TiO_2	1.7
Al_2O_3	8.7
FeO	16.2
MnO	0.75
MgO	12.4
CaO	10.8
Na_2O	1.7
K_2O	0.4
H_2O	n.d.
Sum	98.2

The fragments of cumulus-diorite are up to a few cm large, and are loosely coherent fine-to medium-grained cumulates consisting of andesine, hornblende (analysis in table 2) and Fe-Ti-oxides (Pl. 3). Some of the hornblendes have preserved a core of pyroxene.

The granophyre fragments are light grey, fine-to medium-grained and full of small druses. They contain numerous about 1 mm big tabular phenocrysts of plagioclase, which in the outer zones gradually passes into an almost dense granophyric intergrowth of quartz and potash feldspar. In between residual aggregates of quartz and alkali feldspar are found. The pyroxene, which is generally calcic, occurs as faintly greenish needle- or feather-formed aggregates which often are intergrown with black ore; in a few rocks pigeonite is found surrounded by a coating of calcic pyroxene. The scanty black ore forms sub- to anhedral grains. The pyroxene is completely or partially replaced by light green or brownish clinoamphibole; titanite is common.

Granophyre fragments from other units of the tuff basin are poorer in clinoamphibole.

The hornblende-porphyritic dacite and its supposed equivalent pumice-tuff reflect two stages in the intratelluric development.

1) A phase of evolution under a relatively low water pressure, characterised by the precipitation of augite, orthopyroxene, plagioclase and Fe-Ti-oxides. During this phase the cumulus gabbros were presumably formed.

2) A phase of crystallisation under hydrated conditions, characterised by the crystallisation of quartz, hornblende, biotite, plagioclase and Fe-Ti-oxides. During this stage the cumulus diorites were presumably formed, and a strong equilibration of the mineral assemblage took place in the cumulus gabbro which had crystallised earlier.

The cone-sheet complex.

After the central depression had come into existence a swarm of cone-sheets were injected; they consist of an aphyric, tholeiitic basalt composed of plagioclase, augite and black ores (Table 1 no. 3). Locally xenoliths of a medium grained gabbro occur which has ophitic texture and is composed of the same minerals as the basalt.

The individual sheets are thin, a thickness of more than 2—3 m is unusual; most common are thicknesses of 0.5—1 m (Fig. 5). In spite of this the cone-sheets make up a considerable amount of the rock material in large areas of the mapped region; where they are most concentrated they take up 10—15% of the bulk volume.

The single sheets often show an irregular course, but if many sheets are measured within a smaller area, the measurements of strike and dip will concentrate around definite values which show a regular regional variation.

An accurate description of the shape of the cone-sheet complex must content with the difficulty that the host rock, after its formation (see p. 22) was tilted towards the south-west. In Fig. 6 the present orientation of the cone-sheet complex is shown.

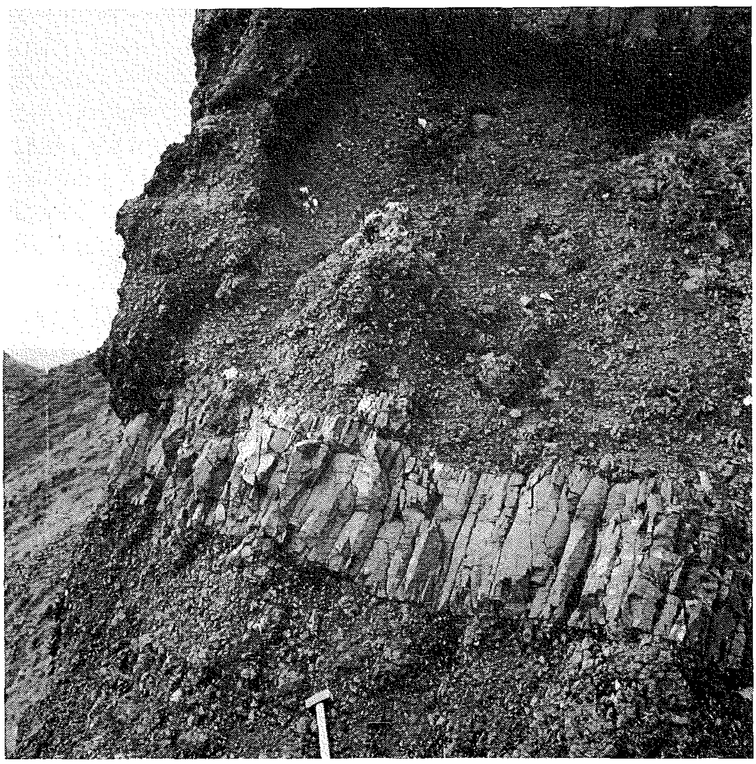

Fig. 5. Cone-sheet which cuts through palagonite breccia on the Borg peninsula.

The cone-sheet complex cuts the present erosion surface in an area which goes from the southern and western part of the Borg peninsula, over Hofstadaháls, Hríshólsháls and Sandfell to Bæjará and the northwestern flank of Kambsfjall. In other words the area is semicircular, it is cut off by the sea towards south and south-west and has its centre in the northwestern part of Króksfjördur. Quite near the centre of the complex, on the northeastern part of the Borg peninsula, cone-sheets are almost lacking; the same is the case outside the arc of the circle at Hlídará and Vadalfjöll.

The cone-sheet complex today only shows a weak tendency towards a diminishing angle of a dip away from the centre.

In the coast cliff on the east side of Berufjördur a number of inclined sheets up to 30 m thick are exposed; they are made up of light coloured, granophyric rocks of an intermediate composition (Table 1 no. 5). Similar bodies were found locally also on Hríshólsháls and at Bæjará. Their orientation is roughly the same as that of the cone-sheets in the area in question. In a single place a granophyre is

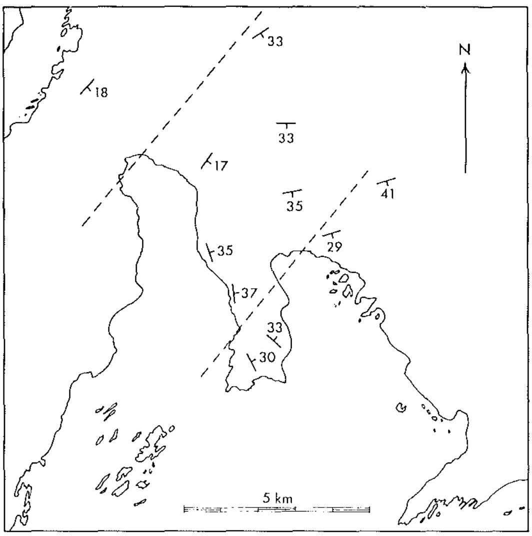

Fig. 6. The cone-sheet-complex with mean strike and dip symbols. The central part of the plagioclase-augite-porphyritic dyke-swarm (p. 25) lies between the broken lines.

seen to grade into a blackish grey, plagioclase-porphyritic, intensely flow-laminated, glassy rock which also occurs in several places along the shore.

The granophyre of intermediate composition in the inclined sheets contains about 40% of blunt, strongly zoned phenocrysts of andesine which attain a lenght of 1 mm; along the border these pass into a mesostasis of quartz and alkali feldspar. The quartz is present as densely packed small plates and needles, often forming optically continuous groups. It is supposed that these plates and needles represent inverted primary tridymite of the same type as that described from the Upper Boundary Group b and g in the Skaergaard intrusion (Wager, Weedon and

Vincent, 1953). In the mesostasis further occur blunt or strongly prismatic individuals of a colourless augite, subhedral grains of black ore, and prismatic apatite. Quartz of late formation is present as an anhedral aggregate in the mesostasis.

Composite sheets with a core of granophyre and an outer coating of basalt have been found in the southern part of the Borg peninsula and on Hríshólsháls.

The gabbro intrusion at Hrísholl.

North of the farm Hríshóll in the southernmost part of Hríshólsháls and Munadstungufjall a gabbro body crops out over an area of about 1 km^2; its steep contacts against the older rocks are visible in several places. The gabbro is not cut by cone-sheets, in spite of the fact that the concentration of these is very large in the surrounding rocks just here.

The gabbro is a medium-grained – seldom coarse-grained – rock with ophitic texture, consisting of plagioclase, augite and black ore which may poikilitically surround plagioclase and augite. Fibrous green phyllosilicates are common interstitially.

Locally the gabbro contains a considerable number of druses, up to 1 cm across; only rarely is it cut by veins of a light quartz-feldspar rich rock.

Hydrothermal alteration.

Almost all of the rocks described have been exposed to hydrothermal alteration. This is strongest in an area between the farm Bær, west of Kambsfjall, and the eastern part of Hofstadaháls, where also the centre of the cone-sheet complex lies.

Due to the hydrothermal alteration the rocks have been propylitised; the rocks of basic composition have acquired a greenish grey colour, while the acid ones have kept a light grey colour. The alteration has worked in a very selective way; compact rock types such as the dense tholeiitic plug-rocks have only been very weakly affected, whereas the breccias and the thin flows rich in slags from the lower series have been strongly attacked and are often almost unrecognisable. As the hydrothermally altered rocks weather much faster than the unaltered rocks, large areas are covered with weathering gravel almost without solid outcrops. This gravel consists of propylitised material.

During his study of the Breiddalur central volcano Walker (1963) could prove the zonal occurrence of a series of hydrothermally formed minerals; a similar zoning has been encountered at Króksfjördur (Fig. 7). In the central part of the aureole the following minerals are identified in the field; epidote, hydrogrossularite, laumontite, „chlorite", quartz, platy calcite and pyrite. At some distance from the centre hydrogrossularite and epidote disappear, whereas laumontite, „chlorite", quartz, platy calcite and pyrite are still present. In the peripheral part of the aureole, where the hydrothermal alteration only betrays itself through a green colouring of the most permeable rocks, laumontite also disappears.

By optical and by X-ray diffraction study of some of the most altered rocks prehnite, clinozoisite, clinoamphibole and diopside were revealed in addition.

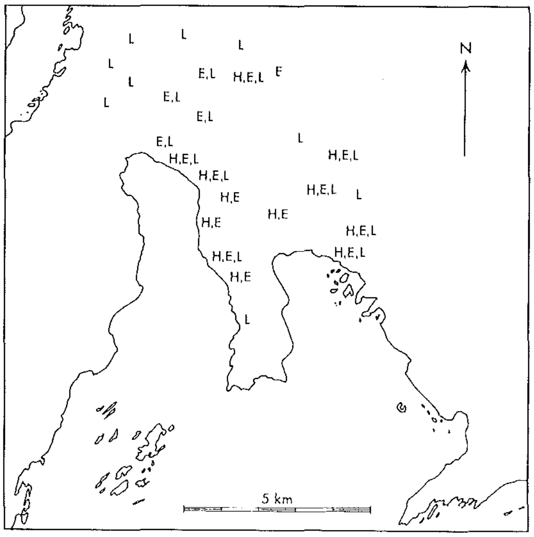

Fig. 7. Selected localities, where hydrothermally formed minerals have been found. E = epidote, H = hydrogrossularite, L = laumontite.

A local hydrothermal alteration has occured on the top of Kambsfjall, where many rock types — especially the more permeable ones — have been altered to whitish, earthy masses. The alteration here affects lavas from the lower as well from the upper lava series.

Also on Strýta and at Tindaháls hydrothermal alteration was observed, as on Kambsfjall probably caused by local fumarole fields.

ROCKS EMPLACED AFTER THE FILLING-IN OF THE CENTRAL DEPRESSION

Lavas.

A series of 10—20 m thick lava flows of faintly porphyritic dark grey basalts is seen near the top of Kambsfjall to rest discordantly upon lavas belonging to the lower volcanic series and also on the tuff deposits in the large sediment-filled basin. While the lavas of the lower series in the area dip between 20°—30° towards the south-east, the thick lava flows have a southeasterly dip only amounting to 5° to 10°; the lower basalt series has in other words been tilted before the formation of the upper began.

In the mapped area the upper lava series occurs south and east of Kambsfjall. The thickness of the individual flows exceeds that of these from the lower quite considerably, flows of 5—15 m in thickness dominate.

The series consists mainly of aphyric or only faintly plagioclase-augite-porphyritic, fine-grained, dark grey, compact, tholeiitic basalts. In Bakkadalsfjall and in Króksfjardarnes the lowermost exposed strata, however, are made up of a basalt type, which is common during the late period in the history of the region. This basalt is characterised by a large content of 1—2 cm large, blunt, almost equidimensional phenocrysts of plagioclase and of 0.1—0.5 mm large, equidimensional phenocrysts of augite in a fine-grained groundmass which is composed of plagioclase, augite and ore (Pl. 4 B). The basalt does not contain fresh olivine, but pseudomorphs after that mineral are often met with. A chemical analysis of this basalt type is presented in table 1 no. 1.

The ignimbrite in Gautsdalur.

In Gautsdalur, intercalated in a succession of thick lava flows which belong to the upper basalt series, there occurs a layer with a thickness of 20—40 m which consists of an acid ignimbritic rock and which varies considerably from place to place. In a general way it can be described as follows:

The bottom layer is made up of a grey, glass-rich breccia with numerous centimetre-large, sharp-edged fragments of basalt. Also characteristic are up to 0.5 cm long, blackish grey, glass-rich schlieren, which are drawn out parallel to the floor. The bottom layer is succeeded upwards by a brownish, compact rock which is similar to a lava; it consists mainly of devitrified glass, and contains drawn-out and welded pumice, but glassy schlieren and basalt fragments are also common as was the case in the bottom layer (Pl. 5 A). The rock contains broken phenocrysts of plagioclase.

From this „central" layer apophyses penetrate into the more agglomeratic bottom layer. The central layer is upwards covered by a top layer made up of an alternation between a glassrich pumice breccia, schlieren of black glass and a loosely knit fine-grained tuff.

The ignimbrite succession is in places overlain by yellowish white or reddish tuffs with a well developed layering.

Dacite bodies between Gautsdalur and Bakkadalur.

Between Gautsdalur and Bakkadalur two elongated bodies, 75—100 m in height, are laid bare; they consist of glassy dacitic rocks. One body lies to the north and west of the farm Valshamar, the other, Strýta, lies on the south side of Gautsdalur, $1^1/_2$ km north-east of the farm which carries the same name.

The dacite at Valshamar is a dark grey, partly devitrified glassy rock with numerous phenocrysts of plagioclase, augite, amphibole and ore. The plagioclase is present as up to 1 mm blunt individuals with a strongly oscillating zoning, augite as up to 0.2 mm equidimensional, weakly brownish grains, and amphibole as prismatic, up to 0.5 mm long grains which are pleochroic from yellowish brown to reddish brown. The amphiboles have often been replaced by phyllosilicates, and, like the augites, are surrounded by a rim of opaque material (Pl. 5 B).

Several smaller outcrops of this rock occur to the west of Gautsdalur; a breccia of metre-large blocks on the east side of Bakkadalur consists of the same rock. An analysis of a fragment of the breccia is presented in table 1, no. 8.

The rock from Strýta is very similar to the dacite at Valshamar, although the amount of phenocrysts is smaller and amphibole is not present. Fragments of medium- to coarse-grained, intergranular or ophitic gabbro are widely distributed in Strýta, but are only rarely seen at Valshamar.

The two bodies are elongated in shape, parallel to the length-direction of Gautsdalur; they are considered to be either near-surface plugs which solidified in a NNE-SSW trending fissure-system in the lavas of the upper series, or as large domeshaped lava flows, which were later covered by lavas belonging to the upper series.

Plagioclase-augite-porphyritic basalt plugs.

The characteristic plagioclase-augite-porphyritic basalt from the upper series, mentioned on p. 22, is found again in several places in the mapped area building up prominent, columnar-jointed plugs.

A group of these plugs lies at the south-west end of Kambsfjall, where two of them, Hrafnabjörg (Fig. 8) and Tindar, intrude into the tuffitic sediments in the central depression. They have steep outer contacts and an almost circular outline; the upper contact is sometimes exposed in part and shows that these plugs are terminated upwards by a saucer- or funnel-shaped depression.

North of Hríshólsháls three plugs occur in a group, of which the two to the north, Vadalfjöll and Búrfell, are very prominent in the landscape (Fig. 9). They reach altitudes of 508 m and 446 m above sealevel, and are clearly seen from the main road between Króksfjördur and Thorskafjördur.

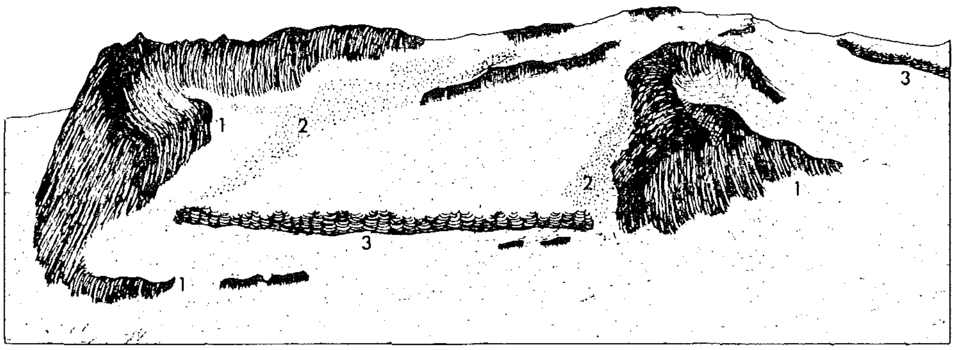

Fig. 8. Hrafnabjörg, a plug with a steep, circular, outer contact and a saucer- or funnel-shaped upper termination. Seen from southeast. 1: Plagioclase-augite-porphyritic intrusive basalt; 2: Pumice-tuff rich in gabbroic and granophyric xenoliths; 3: Basaltic lavas.

The third plug, the one on the south, is in its shape reminiscent of Hrafnabjörg and Tindar, whereas Vadalfjöll and Búrfell are elongated in north-south; in both of these the western contact is visible as a several metres high, almost plane wall, which dips 50°—80° towards the intrusive bodies. Against the contact the basalt in the plug shows exceedingly well developed columnar jointing; the columns are typically $^3/_4$ m across and 10—20 m long and are perpendicular to the contact — that is they have a westerly inclination. As a corresponding zone on the east side of Vadalfjöll has an easterly inclination it must be inferred that at least this plug is built up symmetrically with reference to the length axis.

20—25 m inwards from the contact the regular colonnade is replaced by an „enteblature" consisting of shorter and more irregular columns. The transition is abrupt, but is not accompanied by any macroscopically visible change in rock type.

A 5—10 m broad dyke of plagioclase-augite-porphyritic basalt connects the southern plug with the Búrfell plug and has probably contributed as feeder dyke for both intrusions. A similar feeder dyke was also found at Hrafnabjörg.

The dyke swarm between Thorskafjördur and Kambsfjall.

The formation of a dyke swarm which lies between Thorskafjördur and Kambsfjall belongs to the youngest volcanic events in the area. The dykes consist of a plagioclase-augite-porphyritic basalt identical with that mentioned overleaf on p. 22; almost all the dykes trend NNE-SSW. The dip varies somewhat, but is always steep, as an average 80° ESE. A breadth of 3 to 5 m dominates, but dykes up to 15 m broad have been measured. The amount of phenocrysts varies from dyke to

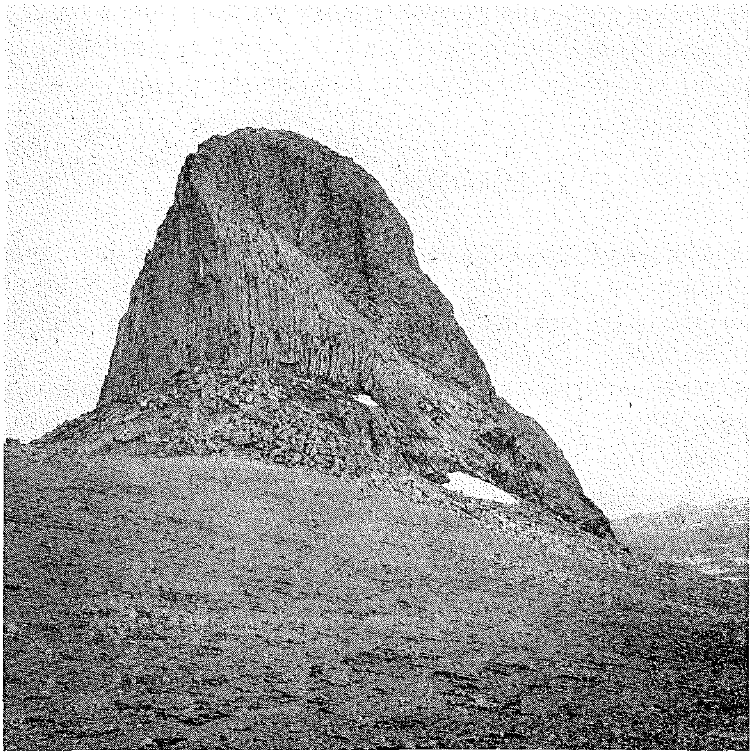

Fig. 9. Vadalfjöll, a plug consisting of plagioclase-augite-porphyritic basalts, seen from the north.

dyke, even within a single dyke there may be a considerable variation in the number of phenocrysts.

Most of the dykes are found in a 4—5 km broad belt with a NNE-SSW direction; the belt cuts the east coast of Berufjördur between the head of the fjord and a point west of the farm Borg and continues towards north-east in the direction of Laxárdalur (Fig. 6)

At the coast the dilatation in the central part of the dyke belt is almost 10%, in the outer parts only about 5%. To the north-west, as well as to the south-east of the main belt the number of dykes is considerably less. Any judgement for the dilatation in the peripheral areas cannot be given, mainly because the amount of exposed rock is so much less than on the east coast of Berufjördur, where presumably almost every existing dyke is exposed; it is probably under 1%, largest on Hofstadaháls.

It is assumed that these dykes are feeder dykes for the plagioclase-augite-porphyrite lavas of which only a small number are found in the upper lava series whithin the mapped area (p. 22), but which is common at a high level on the Reykjanes peninsula, west of the Króksfjördur central volcano (pers. comm. Ole Jörgensen).

REGIONAL FAULTING

In the Kambsfjall area a few steep, normal faults with a throw of more than 100 m were observed; the strike of the faults is the same as that of the plagioclase-augite-porphyrite dyke-swarm, that is NNE-SSW; they cut the upper lava series as well as the lower.

A late phase in the geological development of the region has been characterised by the formation of a system running NNE-SSW. It is possible that the tilting which led to the present 5°—10° ESE inclination of the lavas of the upper series, common also for the lavas in the region north of Gilsfjördur, occurred during this phase of movements.

CONCLUSIONS

During the formation of the Tertiary lava plateau in north-west Iceland a volcanic centre arose around Króksfjördur. Basaltic volcanism dominated in the early stages and basaltic and andesitic lavas and minor intrusive bodies were emplaced from numerous scattered foci. A wealth of ophitic and intergranular gabbro xenoliths included in these older rocks bear witness of a contemporaneous or earlier solidification process at depth.

East of Króksfjördur a central depression was formed in which basaltic, andesitic and dacitic magmas were emplaced, often due to strongly explosive eruptions.

A cone-sheet swarm was intruded and ignimbritic eruptions took place.

With the formation of a basaltic dyke swarm the magmatic activity changed in character into pure basaltic volcanism and the central volcanic area was covered by plateau basalts.

A closer mineralogical and chemical investigation of the rocks from the central volcano is planned, but based on the intratelluric phenocryst assemblages it is possible to give the following qualitative estimation of the course of the differentiation in the magma below the central volcano.

In the tholeiitic basalt plagioclase was the first phase to crystallise apart from sporadically appearing Mg-rich olivine. Within a narrow temperature interval in relation to plagioclase, augite was stabilised. In the Fe-rich, dense, tholeiitic and basalto-andesite rocks the phenocryst assemblage is: plagioclase, augite and Fe-Ti-oxides.

A number of andesitic and dacitic rocks are characterised by the mineral assemblage: plagioclase, augite, pigeonite and Fe-Ti-oxides. A dacitic glassy rock has the assemblage: plagioclase, calcic clinopyroxene, Fe-rich olivine and Fe-Ti-oxides. These „dry" phenocryst assemblages are, apart from the occurrence of pigeonite, typical for the tholeiitic Icelandic central volcanoes as for example Thingmúli (Carmichael 1964).

The assemblages of phenocrysts in several rocks of dacitic composition differ however from one another and from those mentioned above. The dacites which have been analysed (Table 1 no. 6—9) show almost the same composition for the normative plagioclase and quartz, and the normative colour index only varies from 8 to 12; none-the-less the phenocryst assemblage varies considerably as shown in table 3.

Table 3. Phenocryst assemblage in the analysed dacitic rocks from Króksfjördur.

Rock no.	Quartz	Plag.	Fe-Ti-oxides	Ca-cpx	Opx	Pigeonite	Hornblende	Biotite
no. 2453		X	X	X		X		
no. 2455		X			X			
no. 2452		X	X	X			X	
no. 2458	X	X	X	(X)	(X)		X	X

The phenocryst assemblages reflect, according to Carmichael (1967), varying oxygen fugacities; they show that various water pressures were built up in local magma chambers in the late stages in the development of the Króksfjördur central volcano, and that phenocryst assemblages which have not earlier been described from acid rocks in Icelandic central volcanoes could be stabilised here.

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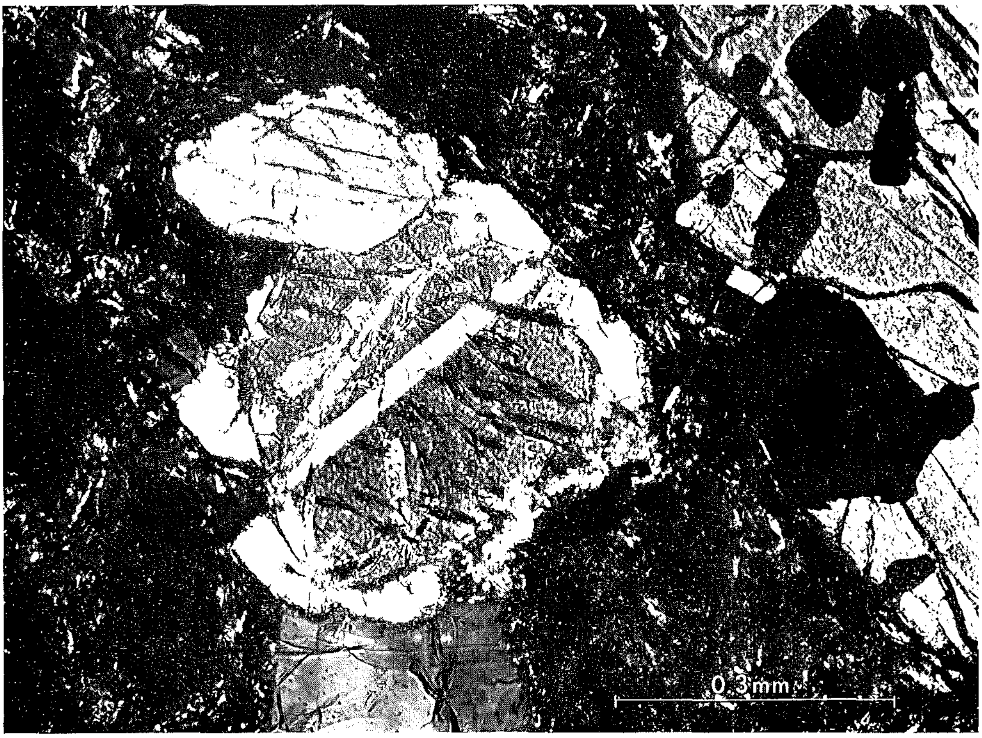
Pl. 1A: Dacite from a plug east of the farm Bær with phenocrysts of plagioclase, pyroxene and ore. The large grain in the center is a pigeonite surrounded by augite. The groundmass consists of strongly devitrified and pigmented glass. Crossed nicols.

Pl. 1B: Oscillatory zoned plagioclase from a quartz-hornblende-porphyritic dacitic plug north-west of the farm Klettur. Crossed nicols.



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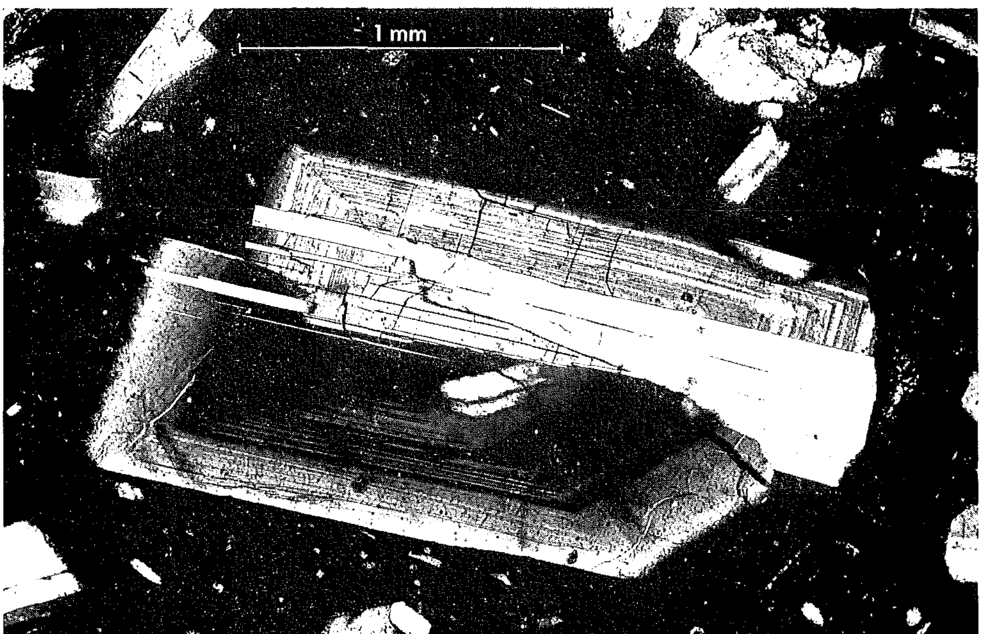

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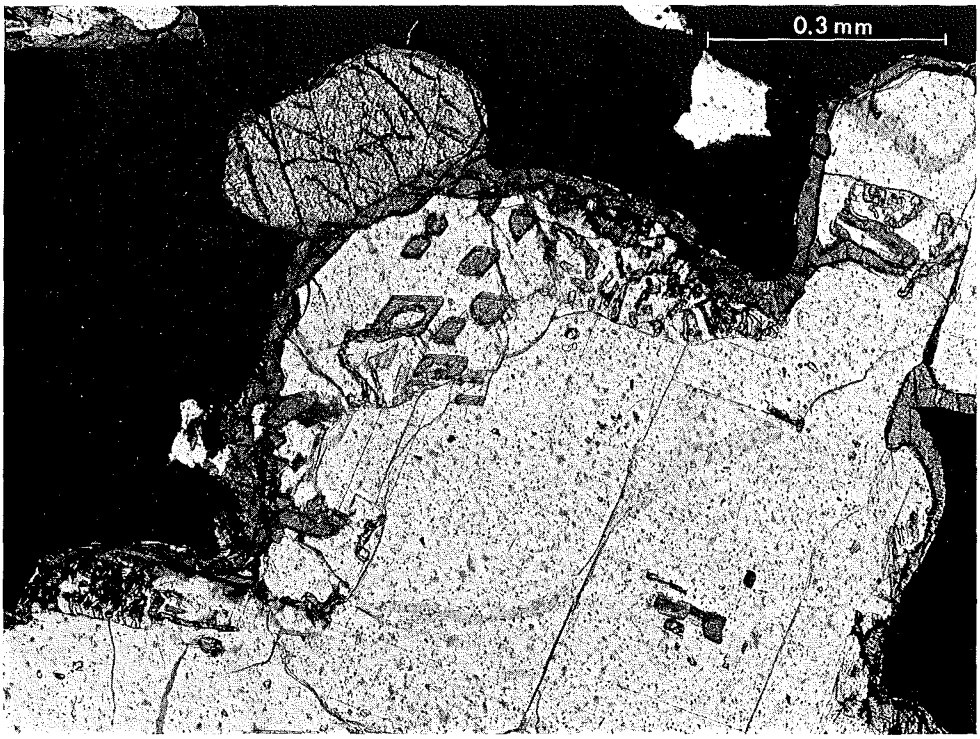
PLATE 1

Pl. 2A: *Gabbro-fragment from the tuffs on south-western Kambsfjall. On the contact between ore and plagioclases the latter have been replaced by a „graphic" hornblende-plagioclase intergrowth.*

Pl. 2B: *As Pl. 2A. Crossed nicols.*



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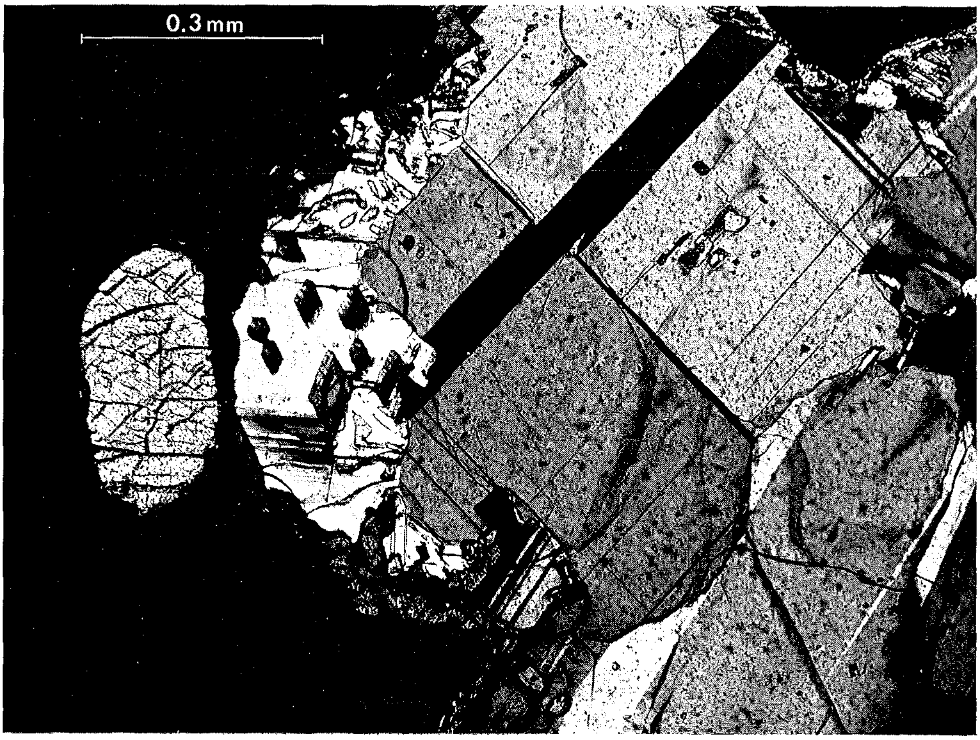

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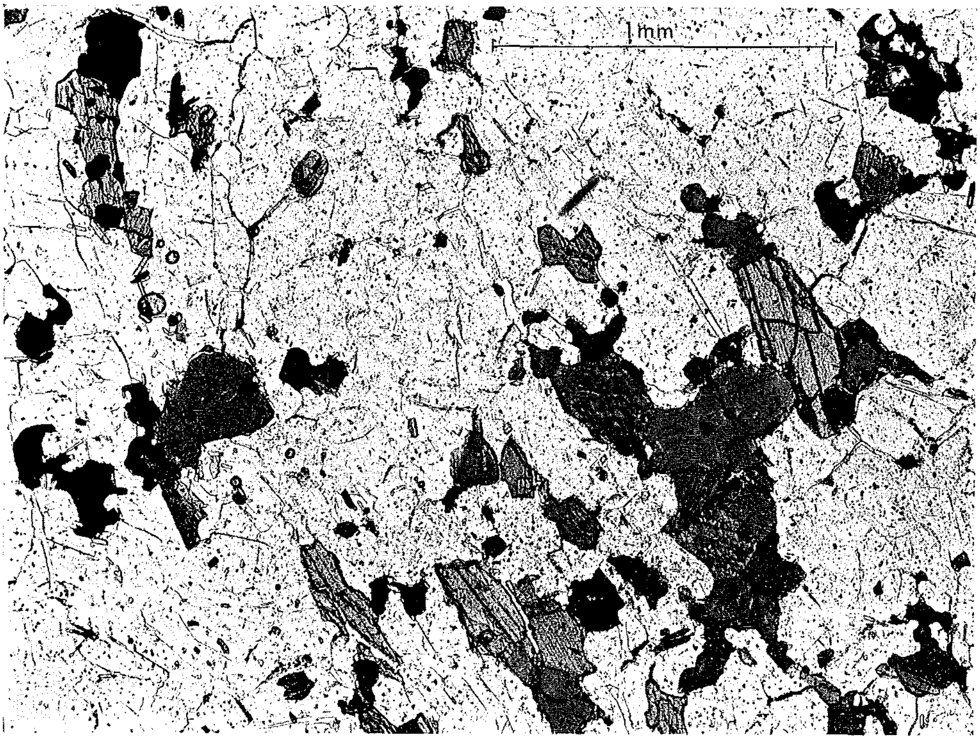
PLATE 2

Pl. 3A: Fragment of a cumulus-diorite from a quartz-porphyritic dacitic plug north-west of the farm Klettur. The diorite is consisting of plagioclase, hornblende, ore and apatite.

Pl. 3B: As Pl. 3A. Crossed nicols.



A

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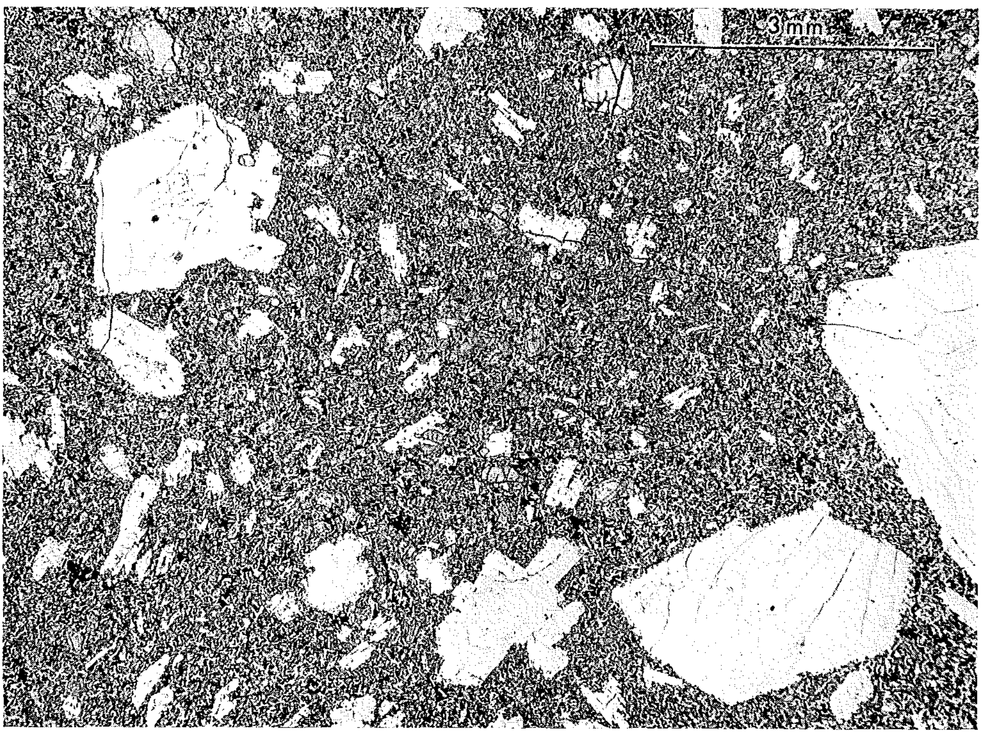
PLATE 3

Pl. 4A: Symplectic intergrowth of orthopyroxene and magnetite in a gabbro-fragment from the tuffs on south-western Kambsfjall.

Pl. 4B: Plagioclase-augite-porphyritic basalt from the Vadalfjöll-plug.

A

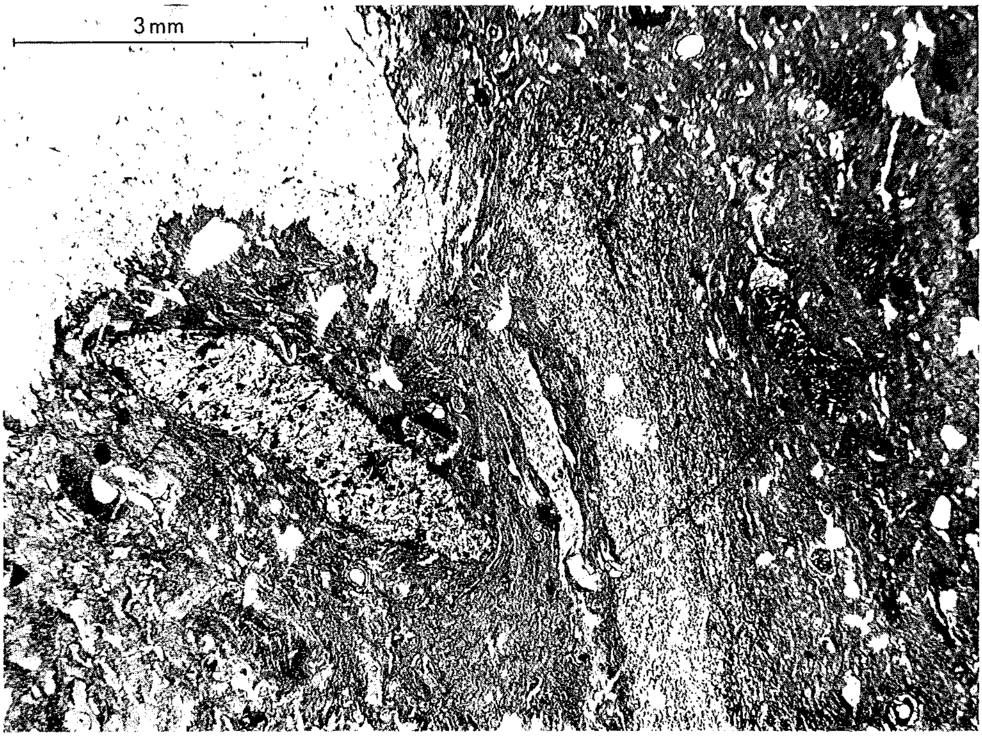


B

PLATE 4

Pl. 5A: Ignimbrite from Gautsdalur.

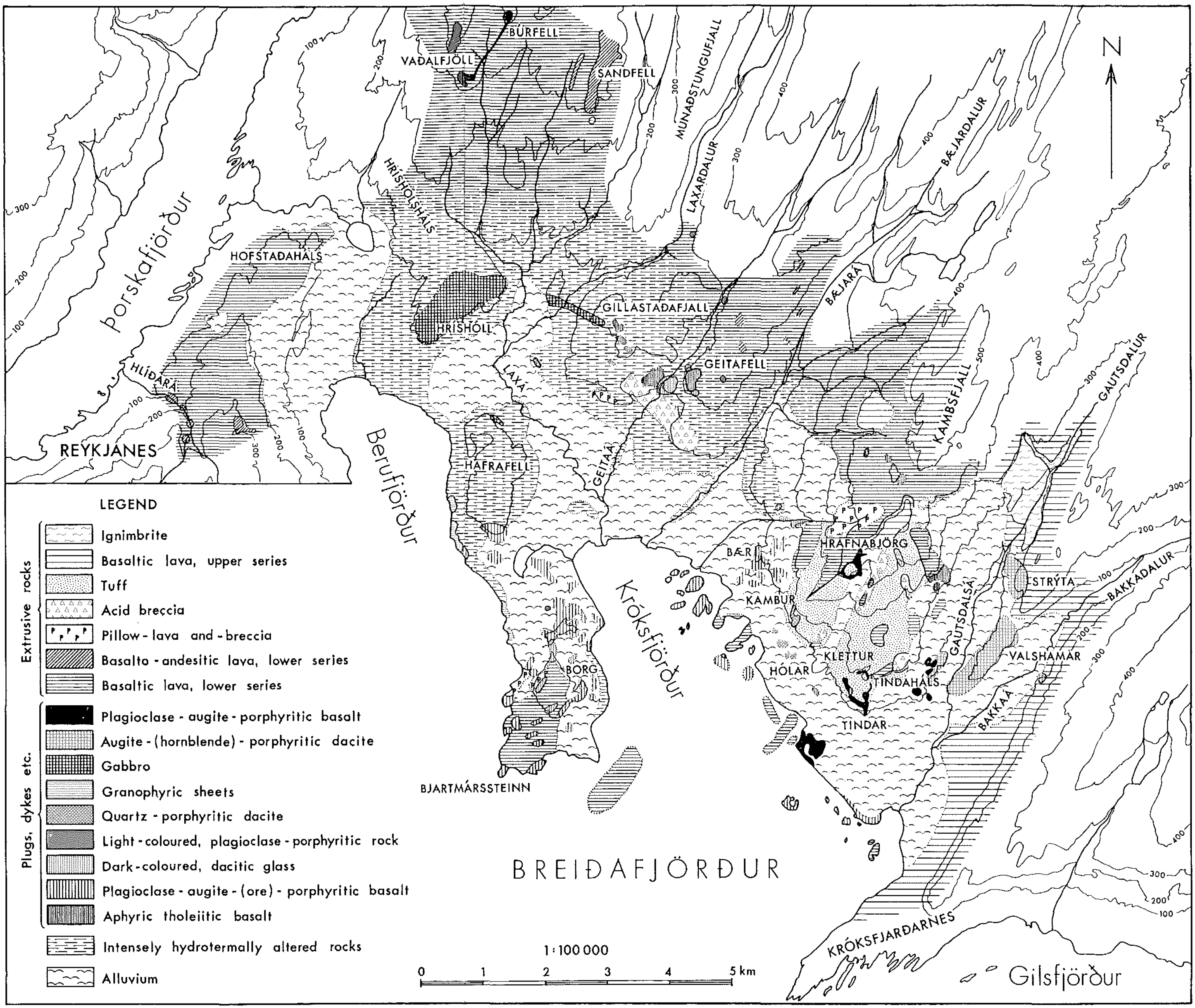
Pl. 5B: Dacite from Valshamar. A partly devitrified glassy rock with phenocrysts of plagioclase, augite, amphibole and ore. The augites and amphiboles are surrounded by rims of opaque material.



A

B

PLATE 5



N
BÚRFELL
VAÐALFJÖLL
SANDFELL
MUNAÐSTUNGUFJALL
LAXÁRDALUR
BÆJARDALUR
Þorskafjörður
HRÍSHÓLSHÁLS
HOFSTAÐAHÁLS
HRÍSHÓLL
GILLASTAÐAFJALL
BÆJARÁ
GEITAFELL
HLÍÐARÁ
LAXÁ
GAUTSDALUR
KAMBSFJALL
REYKJANES
Berufjörður
HAFRAFELL
GEITÁ
BÆR
HRAFNABJÖRG
KAMBUR
Króksfjörður
STRÝTA
BAKKADALUR
GAUTSDALSÁ
KLETTUR
VALSHAMAR
HÓLAR
TINDAHÁLS
BORG
TINDAR
BAKKAÁ
BJARTMÁRSSTEINN
BREIÐAFJÖRÐUR
KRÓKSFJARÐARNES
Gilsfjörður
1:100 000
0 1 2 3 4 5 km
LEGEND
Extrusive rocks
Ignimbrite
Basaltic lava, upper series
Tuff
Acid breccia
Pillow-lava and -breccia
Basalto-andesitic lava, lower series
Basaltic lava, lower series
Plugs, dykes etc.
Plagioclase-augite-porphyritic basalt
Augite-(hornblende)-porphyritic dacite
Gabbro
Granophyric sheets
Quartz-porphyritic dacite
Light-coloured, plagioclase-porphyritic rock
Dark-coloured, dacitic glass
Plagioclase-augite-(ore)-porphyritic basalt
Aphyric tholeiitic basalt
Intensely hydrotermally altered rocks
Alluvium

PLATE 6

ACTA NATURALIA ISLANDICA

PUBLICATIONS OF THE
MUSEUM OF NATURAL HISTORY, REYKJAVÍK, ICELAND
