

Some Composite Rhyolite/Basalt Lavas and Related Composite Dykes in Eastern Iceland

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ABSTRACT: Five composite extrusions are described from the Tertiary volcanic outcrop of eastern Iceland. Each has a lower basic and an upper xenolithic acid component, and the two can be shown to have been erupted essentially simultaneously; three flows are visibly joined, and others can be related, to composite dyke-feeders.

The acid components of the lavas are generally rich in basalt xenoliths. Evidence is presented to show that the latter were formed by the inclusion of 'blebs' of basalt magma in the host rhyolite prior to the extrusion of the composite lava. The effect and significance of this is discussed.

1. INTRODUCTION

DURING the course of geological mapping of two central volcanoes in the Tertiary basaltic region of eastern Iceland we have recognised a number of composite lava flows which in some of their characters are unique. Each consists of two components, a lower basic and an upper acid one, and the field relationships show that both were erupted essentially simultaneously from the same fissure. Several flows are visibly joined, and others can be related, to composite dyke-feeders.

The field evidence leaves no doubt of the effusive origin of the composite bodies. Each has a vesicular or slaggy top similar to that of normal extrusions. Each rests upon a tuff and is in turn overlain by tuff; pyroclastic material forms an envelope about each body which is not veined, disturbed or metamorphosed. Each is in turn overlain by basalt lavas which are undisturbed by, and in some cases clearly banked up against, the composite body.

The lavas under consideration satisfy almost all the requirements attached by Kennedy (1931, 167) to the definition of a composite flow; they are each made of two easily recognisable rock-types, arranged asymmetrically and without intervening slag. There may, however, be chilling at the boundary of the two rock-types in the Icelandic examples described below, which also differ from composite flows described by Kennedy in having components of much more contrasted composition.

We follow the usage of Bailey & McCallien (1956) in using 'composite dyke' to denote a dyke-like intrusion, chilled against the country rock, with

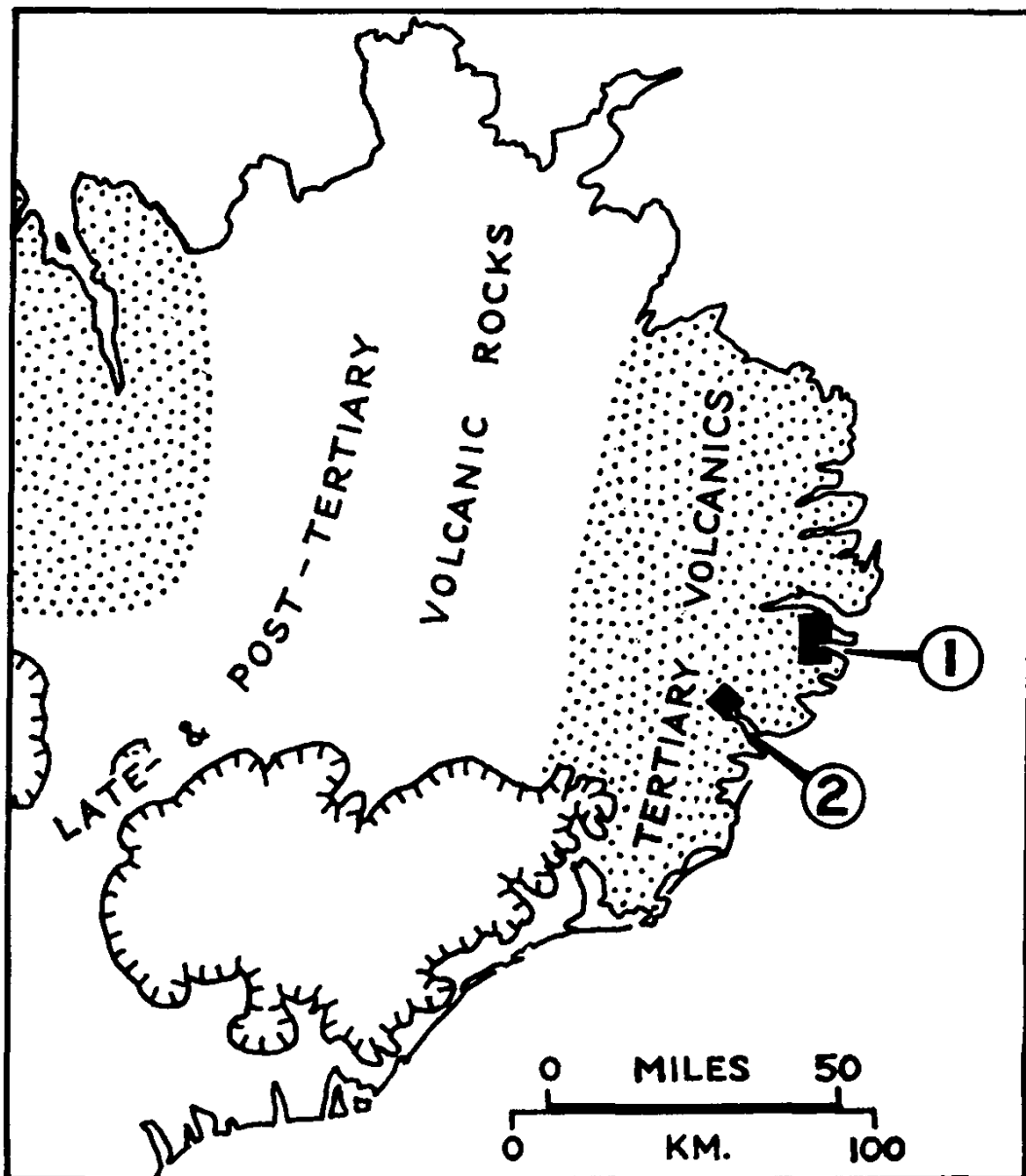


Fig. 1. The eastern half of Iceland showing location of:

1. Fáskrúdsfjörður group of composite flows, Fig. 2
2. Berufjörður composite flow, Fig. 5

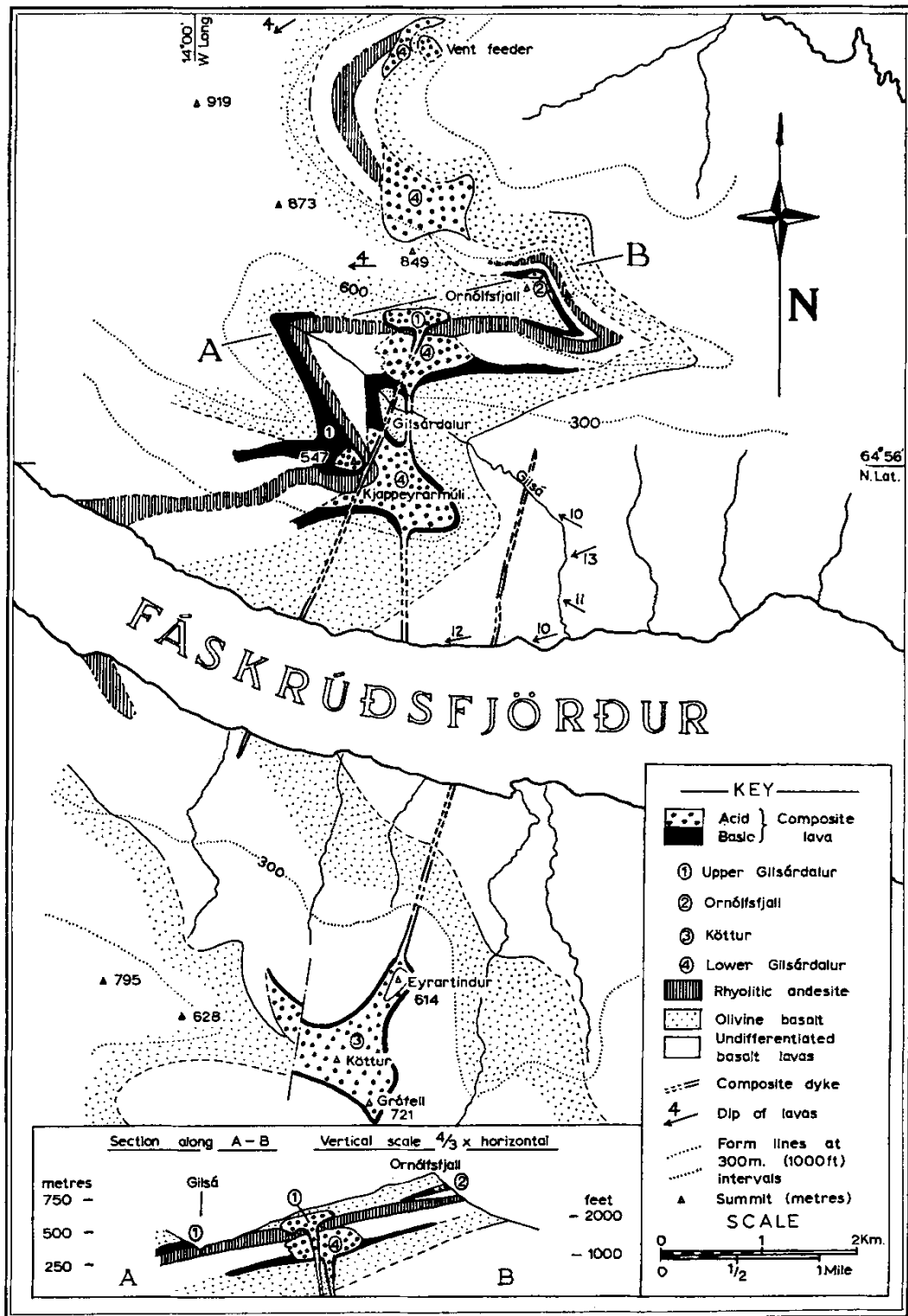


Fig. 2. Map of the Fáskrúðsfjörður group of composite flows

margins differing in composition from the interior which, though later than the margins, is not chilled against them. The dykes described in this paper have relatively thin basaltic margins and a thick rhyolitic interior. We consider there was barely any time interval between the passage of the basic and acid magma.

2. THE UPPER GILSARDALUR COMPOSITE FLOW

Four of the composite lavas under discussion occur in the area surrounding the head of Fáskrúdsfjörður, one of the fjords cutting into the gently inclined basalt pile of eastern Iceland. Two of these lavas, the Lower and Upper Gilsárdalur composite flows, occur directly above one another and are exposed on the northern side of the fjord, while further exposures of the same two flows are found in Gilsárdalur, a deep tributary valley running parallel to, and north of, Fáskrúdsfjörður. Abundant outcrops occur on the 2000-foot high ridge of Kjapperyrarmúli which separates the valley from Fáskrúdsfjörður, and on the precipitous north side of Gilsárdalur, where the best exposed, most compact and most complete section through a composite lava is found. This flow, the Upper Gilsárdalur composite lava, has been erupted from a composite dyke, which is uncovered by erosion for a depth of 1500 feet below the base of the extrusion and is seen on the shore of Fáskrúdsfjörður, where it is forty feet thick. The flow rests upon a massive and readily-mapped flow of rhyolitic andesite which constitutes a useful stratigraphic reference horizon (Figs. 2 and 3; Plate 7 B).

(a) Exposures on the North Side of Gilsárdalur

On both sides of Gilsárdalur the composite dyke is seen to cut the massive rhyolitic andesite flow mentioned above, expanding upwards as it does so to over 100 feet in width, and on the north side passing directly into a composite lava. The basaltic eastern margin of the dyke here continues eastwards as a layer one to two feet thick at the base of the composite lava, and the rhyolite interior of the dyke is continuous with the rhyolite which forms the remaining upper part of the flow.

The composite flow has a maximum thickness of about 200 feet. The two components, the lower of basalt and the upper of rhyolite, are separated by a sharp and welded, but unchilled, contact without intervening slag. The rhyolite is non-porphyrific and is highly spherulitic and cavernous through most of its mass, making the flow structure difficult to trace, although it appears to be steep or vertical in the pitchstone top of the flow. Xenoliths, which are similar in composition to the basalt of the basal layer, are found throughout the rhyolite; they are particularly abundant near to the base, where they make up to ten to twenty per cent of the rock, but decrease to around seven per cent in the interior of the flow. The basaltic

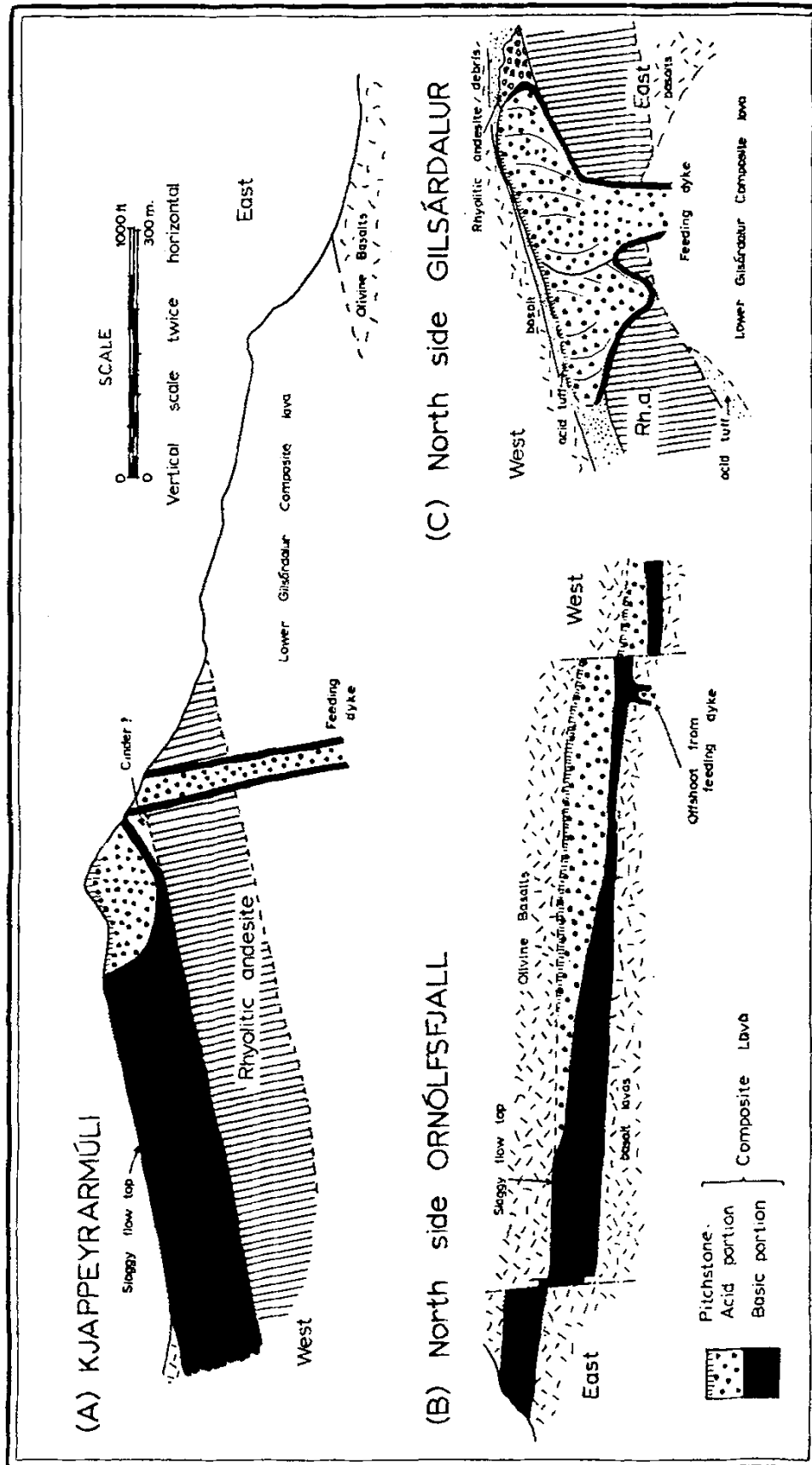


Fig. 3. Sections across some of the Fáskrúdsfjörður composite flows:
 A. Upper Gilsárdalur flow, Kjappeyrmúli
 B. Ornólfssjall flow, north side Ornólfssjall
 C. Upper Gilsárdalur flow, north side Gilsárdalur

layer itself constitutes only one to two per cent of the bulk of the flow, but the abundant basalt xenoliths in the rhyolite bring the total percentage of basic material to about ten.

At the eastern termination of the flow, this basalt selvage curves over the termination and for a short distance overlies the rhyolite. The steeply-inclined basalt layer is here rather fractured and locally discontinuous. Where basalt is missing the rhyolite is chilled marginally to a pitchstone, and a pitchstone layer occurs everywhere along the top of the rhyolite where again basalt is missing.

Exposures of the base of the flow are incomplete west of the dyke feeder, but are sufficient to establish that the basal basalt layer is discontinuous; in places here the acid component rests directly upon a thin tuff bed separating the composite lava from the rhyolitic andesite flow beneath.

To the east this underlying tuff layer and the slaggy top of the rhyolitic andesite flow are missing, the composite lava resting directly on massive rhyolitic andesite. The eastern termination of the composite flow is in contact with, and the toe underlies, a mass of brecciated andesite slag at least fifty feet thick; it is believed that this breccia represents the slaggy top of the andesite flow, stripped off and bulldozed by the advancing front of the composite flow. (Relations are shown diagrammatically in Fig. 4.)

From the section (Fig. 3 and Plate 7 B) it will be noted that the underlying rhyolitic andesite flow has a very much reduced thickness immediately west of the dyke-feeder, and the composite flow in part rests in a depression in this flow. A possible explanation is provided by the presence of the domed top of the Lower Gilsárdalur composite lava, which projects up into the rhyolitic andesite, immediately below the depression (Plate 7 B). It is believed that this resulted in a depression in the top, or a gap in the continuity of, the rhyolitic andesite.

The flow structure in the rhyolite of the western portion of the composite lava above the depression in the rhyolitic andesite flow appears to be cut across by that of the eastern part, without chilling at the contact. This suggests that the former may be slightly earlier and perhaps erupted from a different point along the dyke feeder. The bulldozing of the floor of the composite flow east of the dyke feeder may be due to the restraining influence of this slightly earlier western portion.

(b) The Kjappeyrmúli Exposures

The second exposure of the Upper Gilsárdalur composite flow is seen on Kjappeyrmúli (Fig. 2) where it rests upon the rhyolitic andesite flow referred to above, here 300 feet thick. South-west of the summit the latter flow is overlain by the basaltic portion of the composite lava, here about 170 feet thick, which becomes slaggy and vesicular towards the top. A

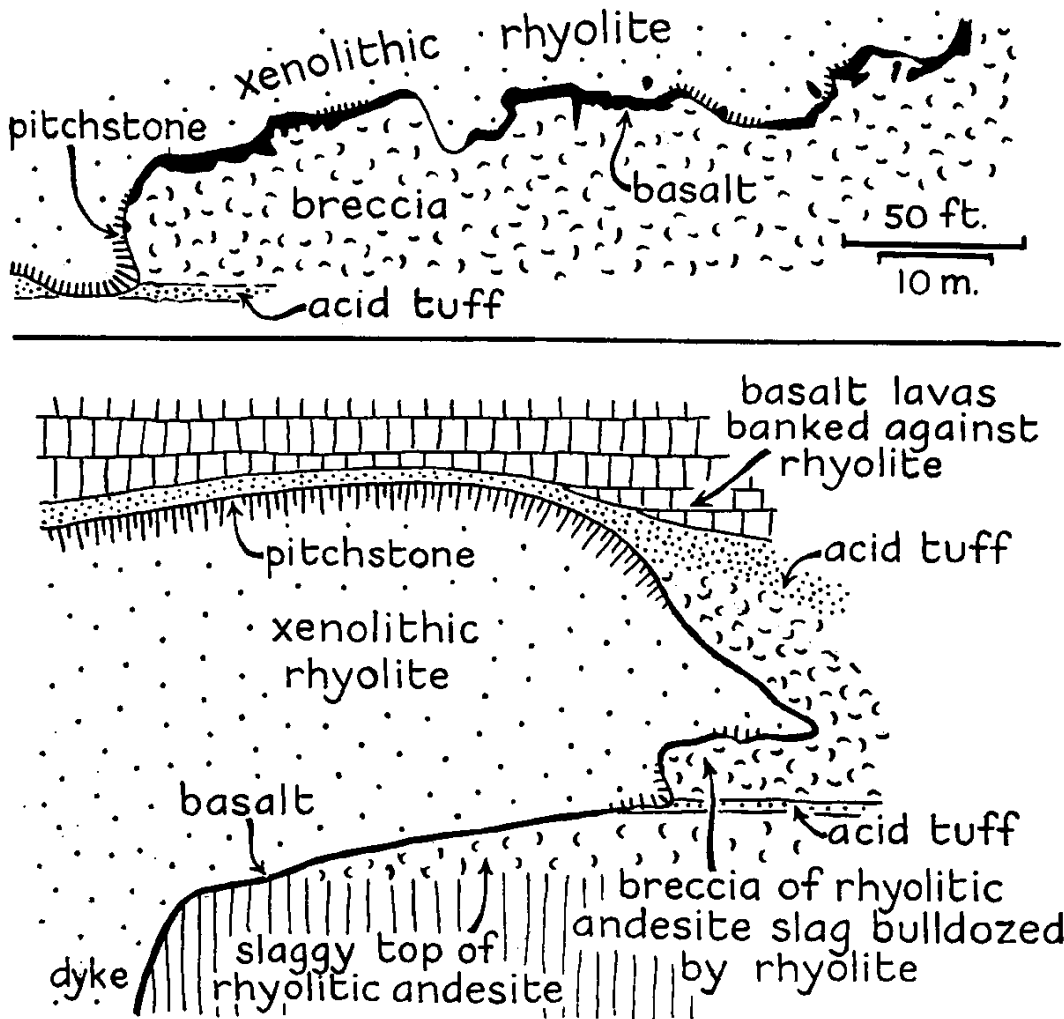


Fig. 4. Eastern extremity of Upper Gilsárdalur composite flow, north side of Gilsárdalur
 Above: Detailed section of part of base of flow
 Below: Schematic section showing relationships in eastern half of flow

short distance further east (Fig. 3) in the whole exposed thickness of the flow, basalt abruptly gives way to rhyolite at a contact the slope of which decreases from nearly vertical at the top to 30° and less lower down. A pronounced streaky flow structure in the basalt is parallel with the contact, and with the platy flow structure in the adjacent rhyolite. There is no marginal chilling or any intervening slag separating the basalt and rhyolite; the latter is commonly spherulitic, particularly so along the contact.

Comparable relationships are observed north of the summit of Kjappey-rarmúli, although here the rhyolite/basalt contact cuts across the flow structure in the basalt, which here includes at least ten thin flow-units; at least one of these units is itself composite in character. Again there is no marginal chilling of the rhyolite against the basalt and the flow structure in the former is parallel to the contact.

In both of these exposures the rhyolite/basalt contact is approximately asymptotic to the base of the flow, and the dip of the contact is centripetal to a point south of Kjappeyrarmúli; the rhyolite thus forms a small basin-shaped mass within the extensive basaltic portion of the composite flow which can be seen extending for about a mile to the north and west. The form of the rhyolite/basalt contact and analogy with the other composite lavas suggests that a thin basalt layer also occurs below the acid portion although it is never exposed. Rhyolite extends to the summit of Kjappeyrarmúli, and pitchstone with steeply-inclined flow banding forms the crest of the summit ridge.

The composite dyke, 130 feet thick, is exposed a few yards east of the composite lava. Although direct continuity cannot be established, there is no reasonable doubt that here as on the north side of Gilsárdalur the dyke is the feeder of the flow. The internal contact in the flow, and the flow-banding of the rhyolite, dip towards a point just off the western margin of the dyke, which is interpreted as meaning that the flow was fed from a funnel-like expansion of the dyke just south of the ridge. Near this feeder the lowermost few feet of the flow consists of red, slaggy basalt, the first material to be erupted.

3. THE LOWER GILSÁRDALUR COMPOSITE FLOW

The lower of the two flows exposed in Gilsárdalur is perhaps the largest composite flow of the four exposed in the Fáskrúdsfjörður area. It is, however, also the least well-exposed owing to the mantle of scree and drift, but exposures suffice to establish the composite nature of the flow in Gilsárdalur; the northward continuation of the same flow is not composite. In one of the most critical exposures in Gilsárdalur, that in the middle of three tributary streams of the Gilsá on the north side of the valley, the base of the flow at 1200 feet is of basalt resting upon a reddened ash deposit containing occasional bombs of basalt of similar character. The ash is regarded as constituting the first erupted portion of the basalt. The basalt itself has a thickness of about ten feet and the rock has a streaky flow structure. Above the basalt is a mass of rhyolite some 300 feet thick, with pitchstone top. The contact between the basalt and rhyolite is sharp and unchilled. The rhyolite veins the basalt in a zone some two feet wide and the veins, which are of very vesicular rhyolite, cut across the flow structure of the basalt. Basalt xenoliths in the rhyolite are apparently identical with the basalt basal layer. The rhyolite is unusual for an Icelandic rhyolite in containing quartz phenocrysts, while the basalt contains sparse quartz xenocrysts.

The rhyolitic part of the flow does not extend far from the feeding fissure and is dome-like in cross-section with later basalt lavas banked up against it (Figs. 2 and 6); locally it is directly overlain by the thick rhyolitic

andesite flow upon which the upper composite flow was erupted. At the western termination of the rhyolite of the lower flow a thick pyroclastic or talus deposit is seen which contains basalt fragments identical in shape, size and character with basalt xenoliths in the rhyolite. The rhyolite appears locally to have overridden these rocks, although exposures are too incomplete to be certain of this. The quartz-bearing basalt lower portion of the flow can be traced for about one mile further west than the rhyolite in the Gilsá.

Two further exposures of what must be a continuation of the same flow are seen on either side of the valley north of Ornólfsfjall (Fig. 2) but in neither is the flow composite. The southern is of almost completely non-xenolithic rhyolite and has an arch-like form, with later basalt lavas banked up against it. The northern is of slightly xenolithic rhyolite and is

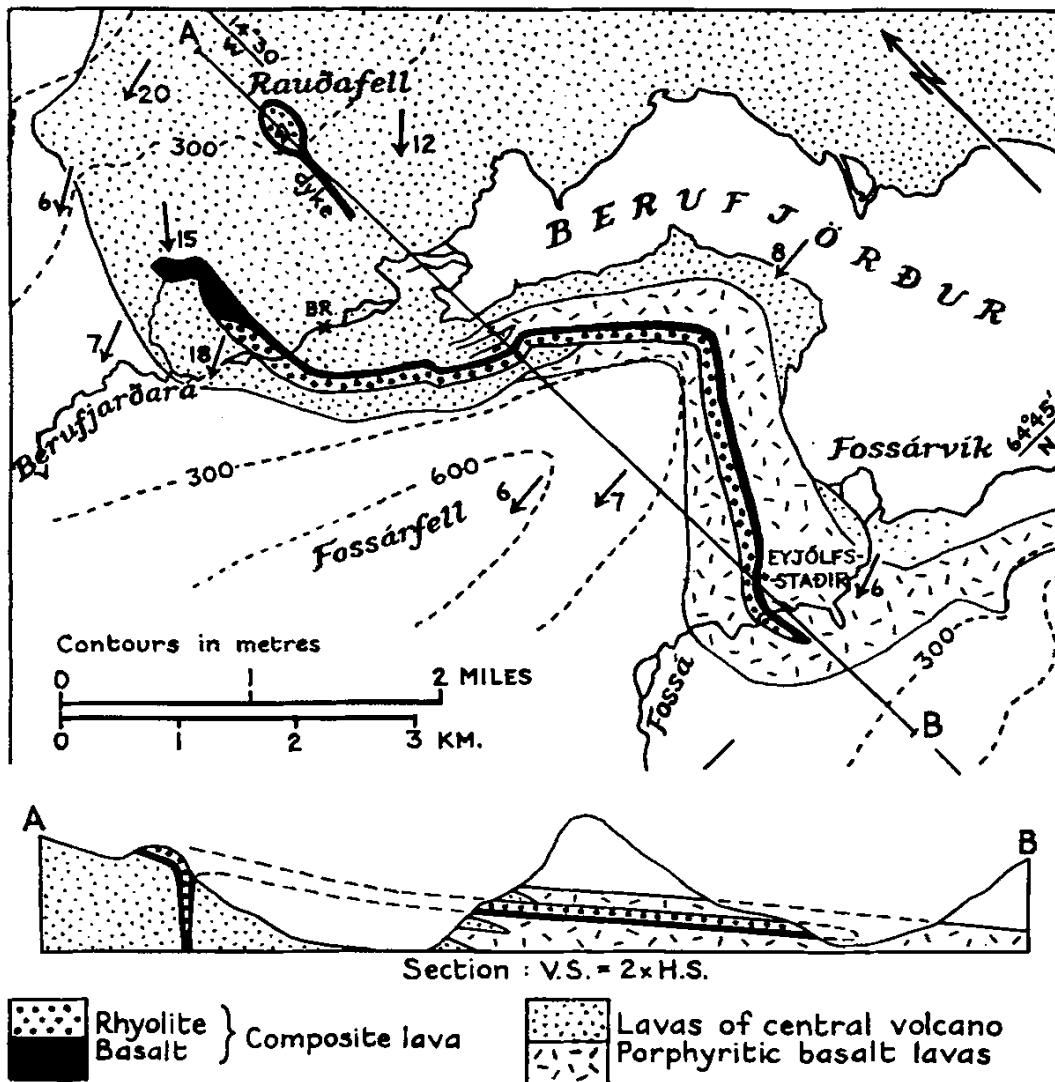


Fig. 5. Map and section of the Berufjördur composite flow

associated with a plug-like intrusion of identical character which is clearly its feeder. This intrusion, which has caused some up-doming of the adjacent basalts, is in line with the composite dyke which feeds the Lower Gilsárdalur flow.

4. THE KÖTTUR COMPOSITE FLOW

The only composite lava on the south side of Fáskrúdsfjörður is a predominantly rhyolitic, dome-shaped flow which constitutes the upper portions of the mountains Köttur and Gráfell (Fig. 2). The existence of the mass was recorded by Hawkes (Hawkes & Harwood, 1932) while the composition of the pitchstone and its phenocrysts has recently been determined by Carmichael (1962 and 1963). The basaltic basal portion of the flow is often obscured by scree from the very much thicker overlying rhyolite, and is best exposed on Eyrartindur, where it is twenty to thirty feet thick (Fig. 2 and Plate 7 A).

On the north-west slopes of Eyrartindur the composite flow is seen joined to its dyke-feeder and this composite dyke is exposed at intervals down to the shore of Fáskrúdsfjörður, where it is forty feet thick. The rhyolite of the dyke is everywhere rich in basaltic xenoliths.

The rhyolitic portion of the flow has a chilled pitchstone top, well seen on the slopes west of Köttur, but pitchstone is also seen at intervals within the rhyolite. Relationships are confused but the rhyolite seems to be made of two or three components or flow units, locally with internal chilled contact. The rhyolite is unusual for Iceland in containing anorthoclase phenocrysts. It is xenolithic only near its base, but spherulitic varieties are common throughout the rhyolite.

Where thin on Eyrartindur, the extrusive nature of the body is clear. South of Eyrartindur the flow rapidly increases in thickness to form the rhyolite dome of Köttur itself. This dome has a pitchstone carapace, and the basalt lavas which cap Eyrartindur are very obviously banked up against the side of the dome (Plate 7 A).

5. THE ORNÓLFSFJALL COMPOSITE FLOW

This composite lava is well exposed at about 2100 feet near the base of the precipitous northern face of Ornólfsfjall (Fig. 2). The thickness varies from 100 feet to a maximum of 160 feet. In the thickest part the flow is composite in character, and a thin basal component of basalt is overlain by a layer of conspicuously xenolithic non-porphyrific rhyolite (Plate 7 C). Traced in either direction from the thickest point, the basaltic layer is seen to thicken at the expense of the rhyolite until the flow is made up entirely of basalt. The rhyolite component is completely missing in exposures of the flow on the southern side of the Ornólfsfjall ridge.

The rhyolite is highly vesicular and spherulitic through much of its mass and has a pitchstone top with steeply-inclined flow structure typical of rhyolite extrusions. The composite body is nowhere transgressive; it rests on a thick basaltic andesite flow and a tuff bed everywhere separates it from the succeeding basalts. Where the flow is not composite and consists of basalt throughout its thickness the basalt has a slaggy and vesicular top.

From a distance the contact between the rhyolite and basalt components of this flow is a smooth and gently curving surface, but in detail rhyolite is seen to vein the basalt over a thickness of several inches—or even several feet (Plate 8 A). In places the basalt is chilled against the rhyolite. At one point where the flow is composite and near where the basal basalt layer is thinnest, the basalt descends abruptly some distance below the normal line of the base of the flow, and exposures of acid rock are also seen associated with this basalt. Scree conceals many of the exposures at this point, but it is possible that the feeder of the flow is located here.

6. THE BERUFJÖRDUR COMPOSITE FLOW

The remaining composite flow does not occur in the Fáskrúdsfjörður area but approximately twenty-five kilometres to the south-west, where it is one of the constituent lavas of the Breiddalur central volcano (Walker, 1963).

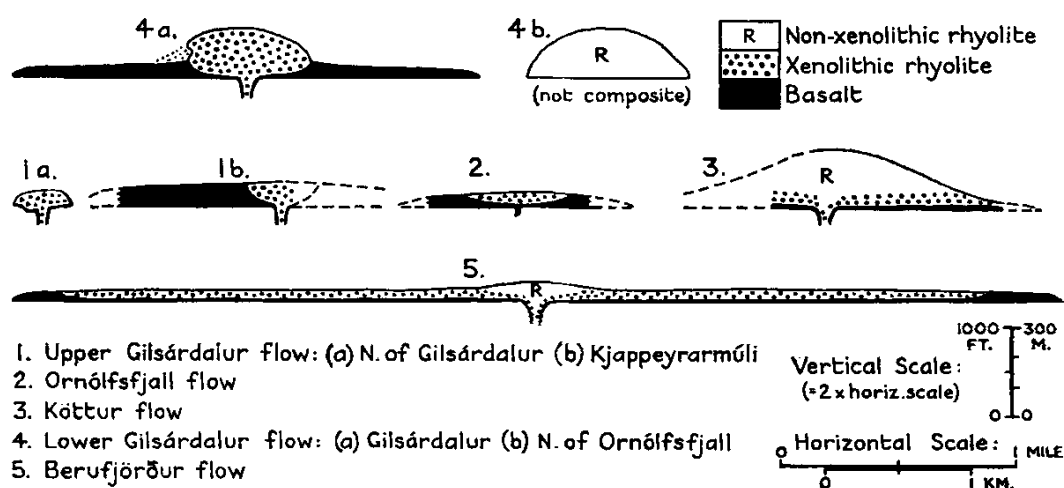


Fig. 6. Comparative profiles across the five composite flows described in this paper

The outcrop of the flow may be traced for a distance of five miles from north of the Berufjardará (the river at the head of the Berufjörður) and along the northern slopes of Fossárfell into Fossárdalur, where the flow terminates near the farm of Eyjófsstadir (Fig. 6). An outlier of the flow caps the hill Raudafell, and on the south side of the hill the flow is visibly joined to its composite dyke-feeder.

In all but the exposures near the termination of the flow in the Selá, the flow is composite in character, with a basal basalt layer averaging five to ten feet thick, and an upper rhyolite component averaging 100 to 150 feet thick. A narrow zone of mixed rocks separates them. The basalt is everywhere rich in phenocrysts of bytownite. The rhyolite bears phenocrysts of oligoclase, and a few of these are also seen in the basalt. The rhyolite is highly xenolithic; the xenoliths range in size up to two feet and are estimated to make up ten to fifteen per cent of its bulk. They are of porphyritic basalt similar to that of the basal layer; they characteristically have carious margins (Plate 8, B and C) and appear to be chilled against the containing rhyolite.

Raudafell is in part an outlier of this flow, with the basic lower part, the mixed zone, and the overlying xenolithic rhyolite traceable round the north and west sides of the hill. Raudafell also marks the site of extrusion of the flow, for the rocks dip inwards and at the southern end of the outlier the western margin (the eastern is obscured by scree) is seen to plunge steeply into a large composite dyke which is more or less continuously exposed to a distance of some 700 feet downwards from the base of the flow. The central and upper parts of Raudafell and the middle of the dyke are composed of non-xenolithic rhyolite, unrepresented in the Fossárfell exposures.

One feature of especial interest concerns the geological environment of the composite flow. In common with practically all of the acid volcanic rocks in eastern Iceland, the rhyolite forms part of a Tertiary central volcano; on Raudafell and the north slopes of Fossárfell the flow is associated with other rhyolites and all have a south-westerly dip of from 10° to 20° down the sides of the volcano. East and south-east of Fossárfell the products of the volcano interdigitate with flood basalts which appear to be quite independent of the volcano and have a regional westerly tilt of 7° . One particularly noteworthy group of flood basalts exposed at Fossárvík consists of some 800 feet of basalts carrying bytownite phenocrysts, similar in composition to the basal layer of the composite flow. West and south-west of Fossárfell this flow is interbedded with the porphyritic basalts and its dip has changed to conform with the regional tilt of these basalts. The impression gained is that the eruption of porphyritic basalt from Raudafell on the flanks of the volcano tapped a body of rhyolite magma and enabled it to erupt, whereas the other porphyritic basalts of Fossárvík were erupted from dykes well outside the limits of the volcano and did not encounter any acid magma.

7. CONCLUSIONS

The five composite lava flows described in this paper belong to two Tertiary central volcanoes. A characteristic feature of the central volcanoes in Iceland is the abundance of acid volcanic rocks in their products, whereas

acid rocks are virtually absent from the flood basalts which completely enclose the volcanoes.

In the two volcanoes referred to above, we have mapped a total of some fifty separate acid flows of which five are composite; around ten per cent of the acid flows studied are thus composite in character.

All the field evidence proves that the basic and acid magmas of these composite lavas were liquid at the same time and emerged from the composite dyke-feeder essentially simultaneously. The form and spatial distribution of the two components—the wrapping-around of the toe of the Upper Gilsárdalur flow by the basalt margin, for instance, and the gradual thickening of one component at the expense of the other in the Ornólfsfjall flow—perhaps constitute the most cogent evidence for the contemporaneity of the two magmas. The finer details confirm this conclusion. Thus rhyolite veins basalt in the Ornólfsfjall flow, but the basalt is itself chilled against the rhyolite. The rhyolite of the Upper Gilsárdalur flow is chilled to a pitchstone only where the basalt veneer is missing; elsewhere the one to two feet layer of basalt, which was hot at the same time that the rhyolite was hot and plastic, has protected the rhyolite from chilling. It is likely, however, that sometimes basalt commenced to erupt before rhyolite and, especially where the rhyolite is dome-like, that rhyolite continued to erupt after the emission of basalt had ceased.

The proportion of basalt in a composite flow varies over wide limits, from ten per cent or less to perhaps over eighty per cent (Fig. 7). Not only does it vary from one flow to another but it also varies in different exposures of the same flow. Thus the upper Gilsárdalur flow is predominantly basaltic in the Kjappeyrarmúli exposure, but mainly rhyolitic north of Gilsárdalur. The lower composite flow seen in Gilsárdalur contains approximately comparable volumes of basalt and rhyolite and has been erupted from a composite dyke. The northward continuation of the same flow, where seen north-west of Ornólfsfjall, is not composite and is wholly of rhyolite; in the northernmost outcrop the rhyolite has clearly been erupted from a plug-like conduit in line with the composite dyke in Gilsárdalur.

Surface conditions were evidently not favourable for the mixing of the two magmas and they retained their individuality in the composite flows to a remarkable degree. This may be due partly to differences in the viscosity of the two magmas, and partly to the formation of a skin of chilled basalt between the two magmas which inhibited their mixing. The zone of mixed rocks in the Berufjördur flow is exceptional, but the mixing in this case may have taken place before extrusion.

Xenoliths are widespread in the rhyolite of most of the composite flows studied and they are almost invariably of basalt similar to the basaltic component of the flow. They are generally more abundant in the rhyolite

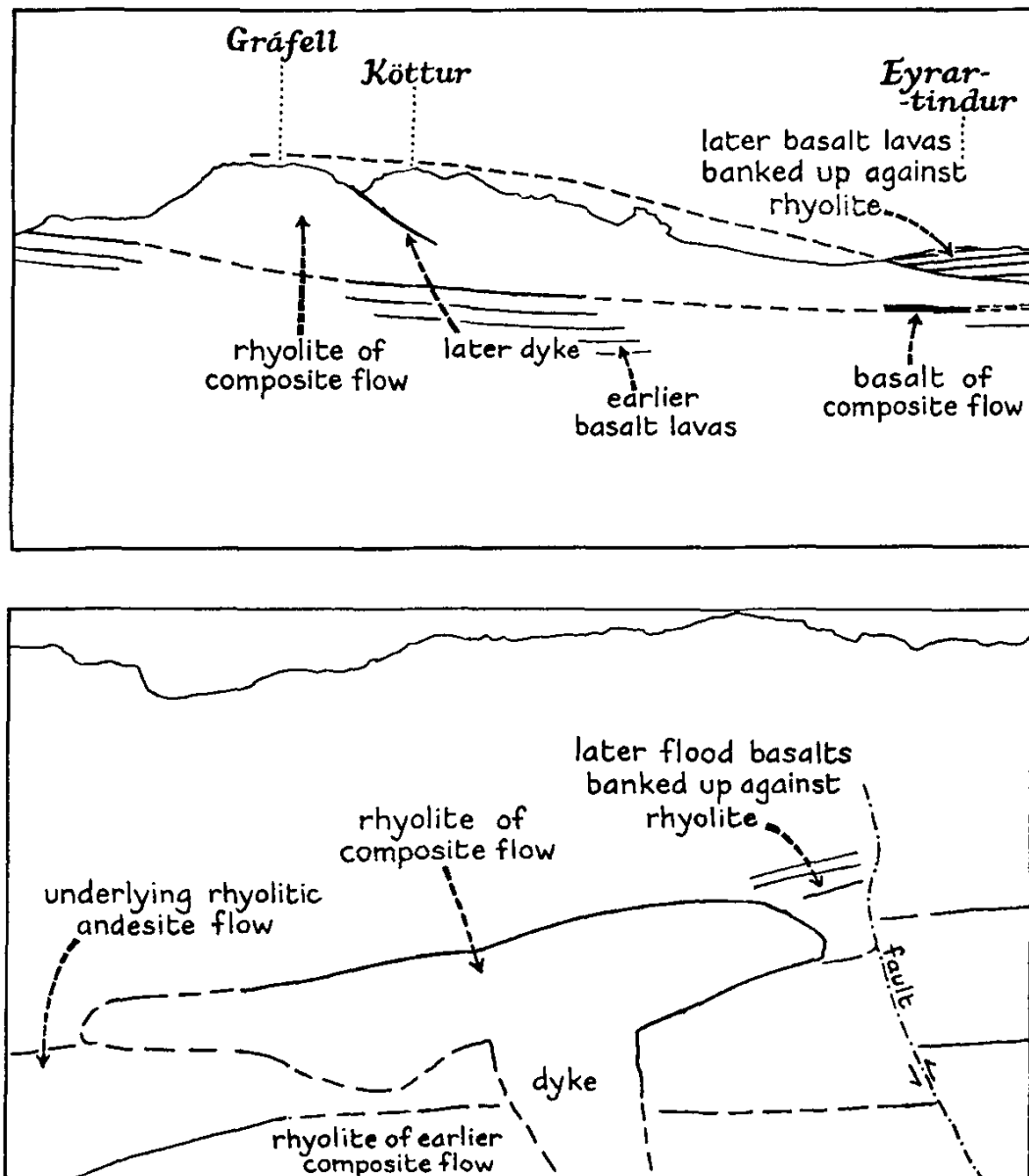


Fig. 7. Line drawings illustrating relationships shown by plates 7A and 7B

EXPLANATION OF PLATE 7

- A. Köttur composite flow, from the south-east. For explanation, see Fig. 7
 B. Upper Gilsárdalur composite flow, on north side of Gilsárdalur, from Kjappeyrarmúli. For explanation, see Fig. 7
 C. Ornólfsfjall composite flow, on north side of Ornólfsfjall.
- A = acid component
 B = basic component

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