CHAPTER IX

Discussion and Conclusions

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(1) The Base of the Reydarfjordur Acid Volcanic Succession

It has been convenient in the foregoing stratigraphic description to assume that the production of the First Phase agglomerates and the tuff T_1 was the first acid eruption from the Reydarfjordur centre; this event marked a change in the type of volcanicity, eruptions from flank and central areas replacing flood-basalt volcanicity. However there are some indications of acid eruptions in the succession below T_1.

The succession between the Gerpir Porphyritic Group (Walker 1959, p.377) and the base of T_1 on the north side of Reydarfjordur contains indirect evidence of co-existing acid activity. Some detreital horizons contain fragments of acid and intermediate rocks, while on the south side of the fjord Kinsman (pers.comm.) has found acid tuff horizons below the Vindhals porphyritic group and directly above and below the Vikurvatn Olivine Basalt Group.

As was noted earlier, the first phase agglomerates contain fragments of acid and intermediate rocks. These are thought to be derived from lava flows underlying the agglomerates, the fragments being produced during the formation of the agglomerate vent. These underlying acid and intermediate flows must pre-date the First Phase.

The dome-shaped uplift at Haugoxl, on the north side of Reydarfjordur, is so strikingly similar to the Sandfell Laccolith, that it seems likely that the former is also the result of a near surface acid intrusion. This intrusion may have pre-dated T_1.

When considering the source of acid material in the succession directly below T_1, one can first eliminate the possibility that it was derived or produced from an acid

centre up-dip of the present exposures. The absence of acid dykes and intrusions and the lack of areas of intense alteration mitigates against this possibility. (The acid rocks on the Skrudur are almost certainly very much earlier and are perhaps contemporaneous with the Bardnes rhyolites and agglomerates)

The tuff horizons may perhaps be correlated with known acid lavas and intrusions 20 miles to the north near Lodmundarfjordur or with acid lavas which may have existed off-shore, east of Berufjordur, a similar distance to the south. While admitting the possibility of either of these two alternatives, the author considers it more likely that some, if not most of the acid material immediately below T_1 was derived or produced from the Reydarfjordur centre - only 4 or 5 miles down dip to the west. Exactly when this centre first erupted acid material is not known but evidence is given later (Chapter IX. (iii)) that it was probably active soon after the eruption of the Vindhals Porphyritic group (V.P.)

(ii) The Relationship between the Reydarfjordur Dyke Swarm and the Acid Centre.

Many, if not all, of the acid centres inEastern Iceland are closely associated with a swarm of basic dykes. The swarm associated with the Reydarfjordur centre is particularly well defined (see fig.38) and is thought to have been produced by the injection of dykes during the whole period of acid extrusions. It is unfortunately impossible to separate the dykes associated with each individual phase.

However, perhaps surprisingly, in some of the areas where acid rocks are particularly abundant, for example

near Eyri, only a few dykes are found. The most likely explanation is that the acid rocks are underlain by a large intrusion which by its massive nature prevents the passage of basic dykes.

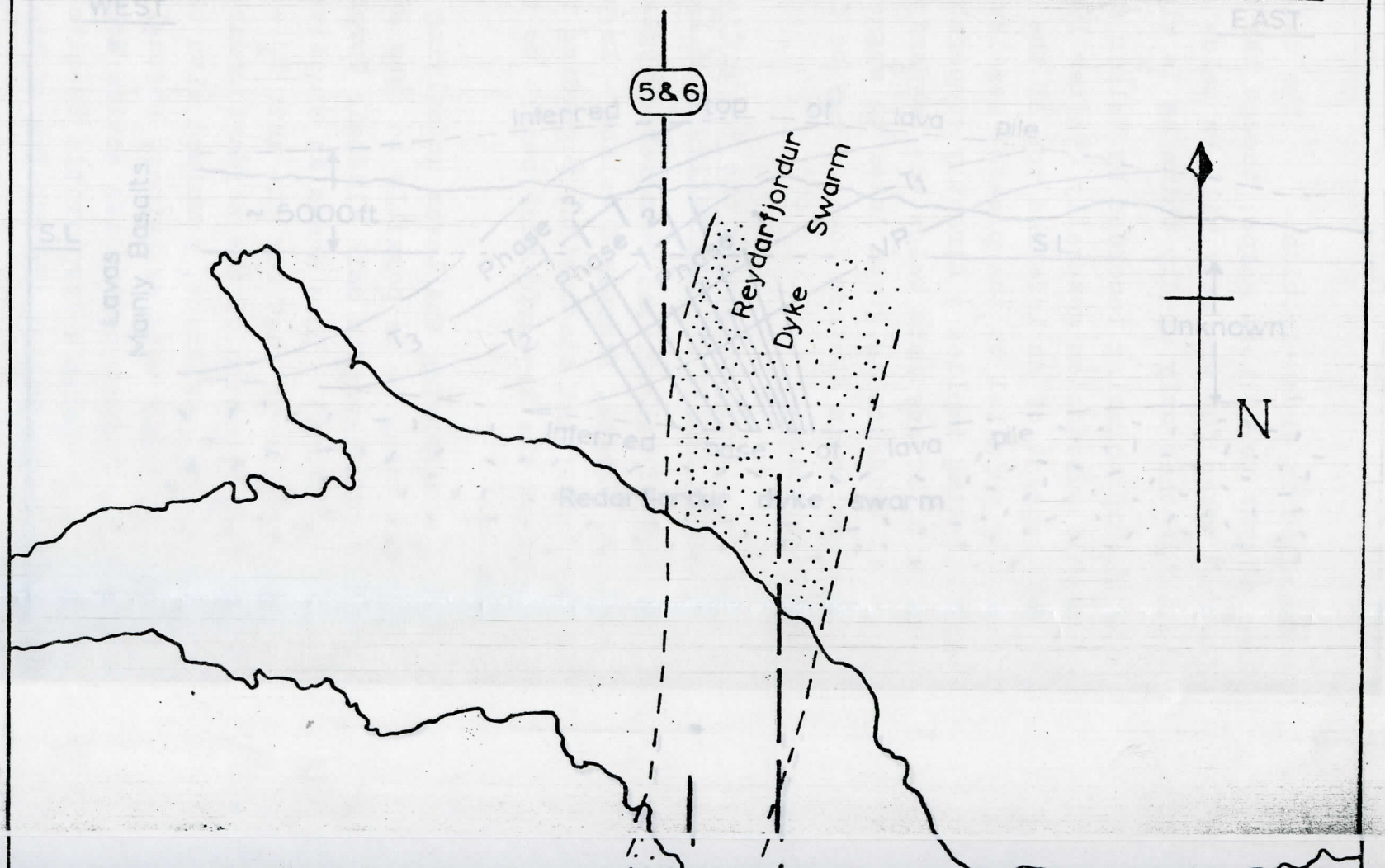
One of the most interesting features of the flank activity is that the positions of the individual flank areas for the six phases are almost co-incident and they all lie in or near the mapped position of the Reydarfjordur dyke swarm (See fig. 42) This, combined with the evidence of Walker (1959) showing that in general the dykes feed the lavas of the Tertiary succession, strongly suggests that at least the majority of the dykes of the Reydarfjordur swarm were feeders for the flank succession lavas.

In the areas north and south of the Reydarfjordur centre, the lavas erupted during the acid phase resemble normal flood basalts. In these peripheral regions the density of the dyke swarm is much lower and it seems possible that some, if not the majority, of these flows were fed from dykes within the Reydarfjordur swarm.

In the previous section it was suggested that the Reydarfjordur centre was active prior to the eruption of T_1. It is probable that these early lavas were also fed from dykes within the Reydarfjordur swarm, although these are not necessarily exposed at the present day. The diagrammatic cross-section (fig.43) summarises the relationships discussed in this section.

This figure also shows the shape of each of the phases as deduced from the isopachyte maps. Each thins both east and west away from the feeding dyke swarm and

THE RELATIONSHIP BETWEEN THE FLANK AXES AND THE DYKE SWARM FOR THE REYDARFJORDUR CENTRE



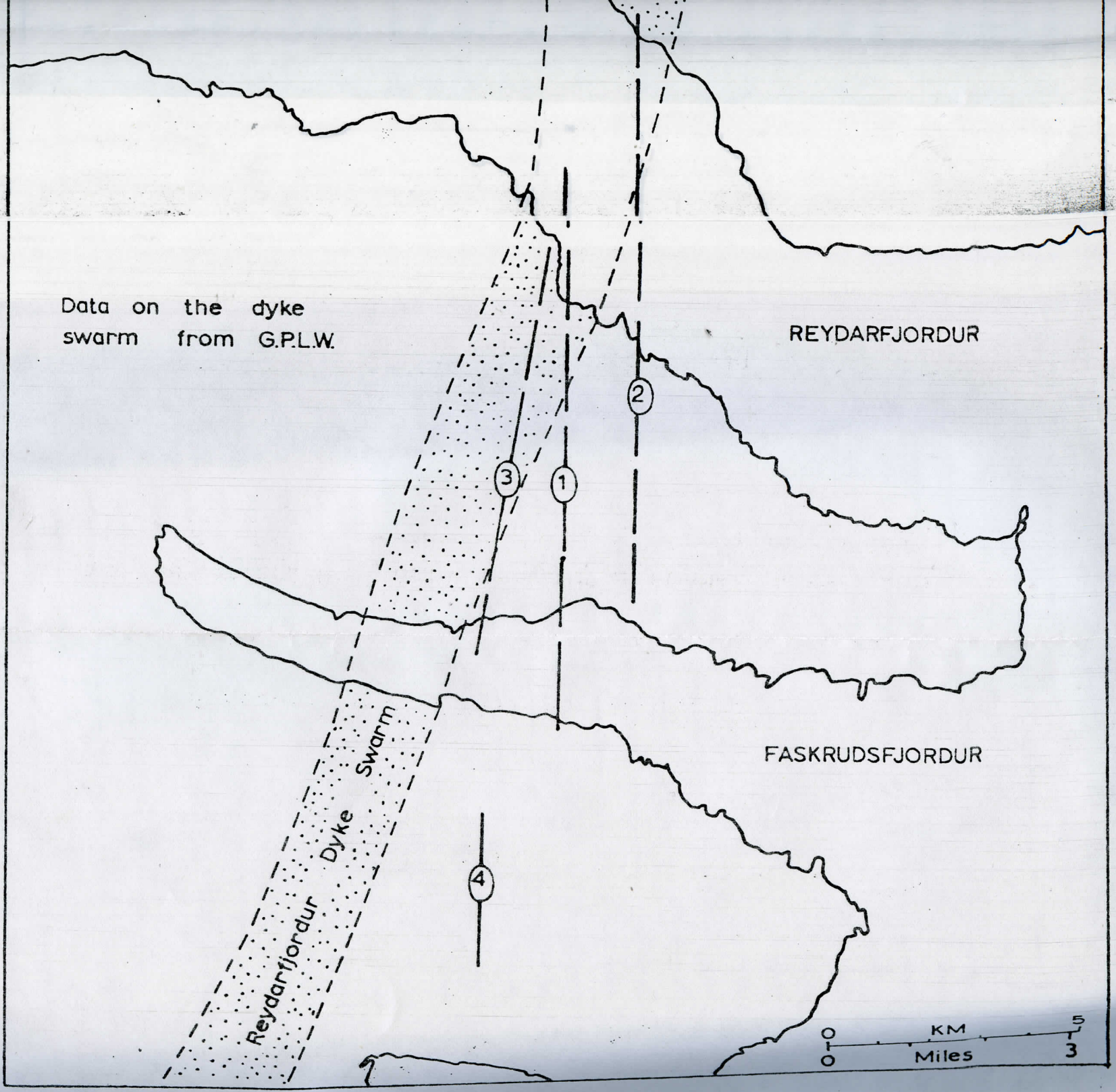

Data on the dyke swarm from G.P.L.W.
REYDARFJORDUR
FASKRUDSFJORDUR
Reydarfjordur Dyke Swarm
1
2
3
4
0 KM 5
0 Miles 3

Fig. 42

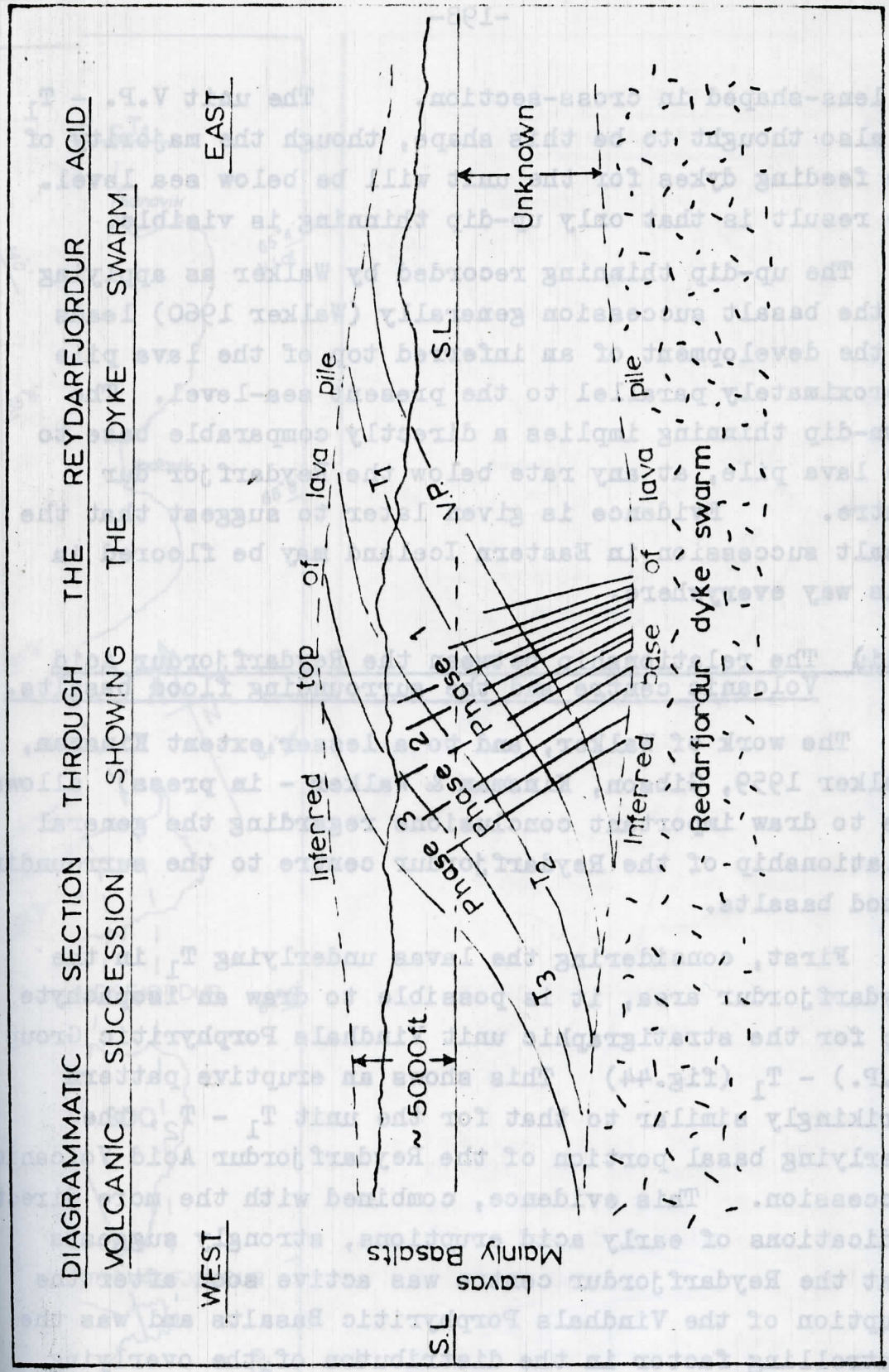

DIAGRAMMATIC SECTION THROUGH THE REYDARFJORDUR ACID VOLCANIC SUCCESSION SHOWING THE DYKE SWARM
WEST
EAST
S.L
~ 5000ft
Lavas Mainly Basalts
Inferred top of lava pile
T1
T2
T3
V.P.
S.L
Unknown
Inferred base of lava pile
Redarfjordur dyke swarm
1
2
3
phase
phase
phase

Fig. 43

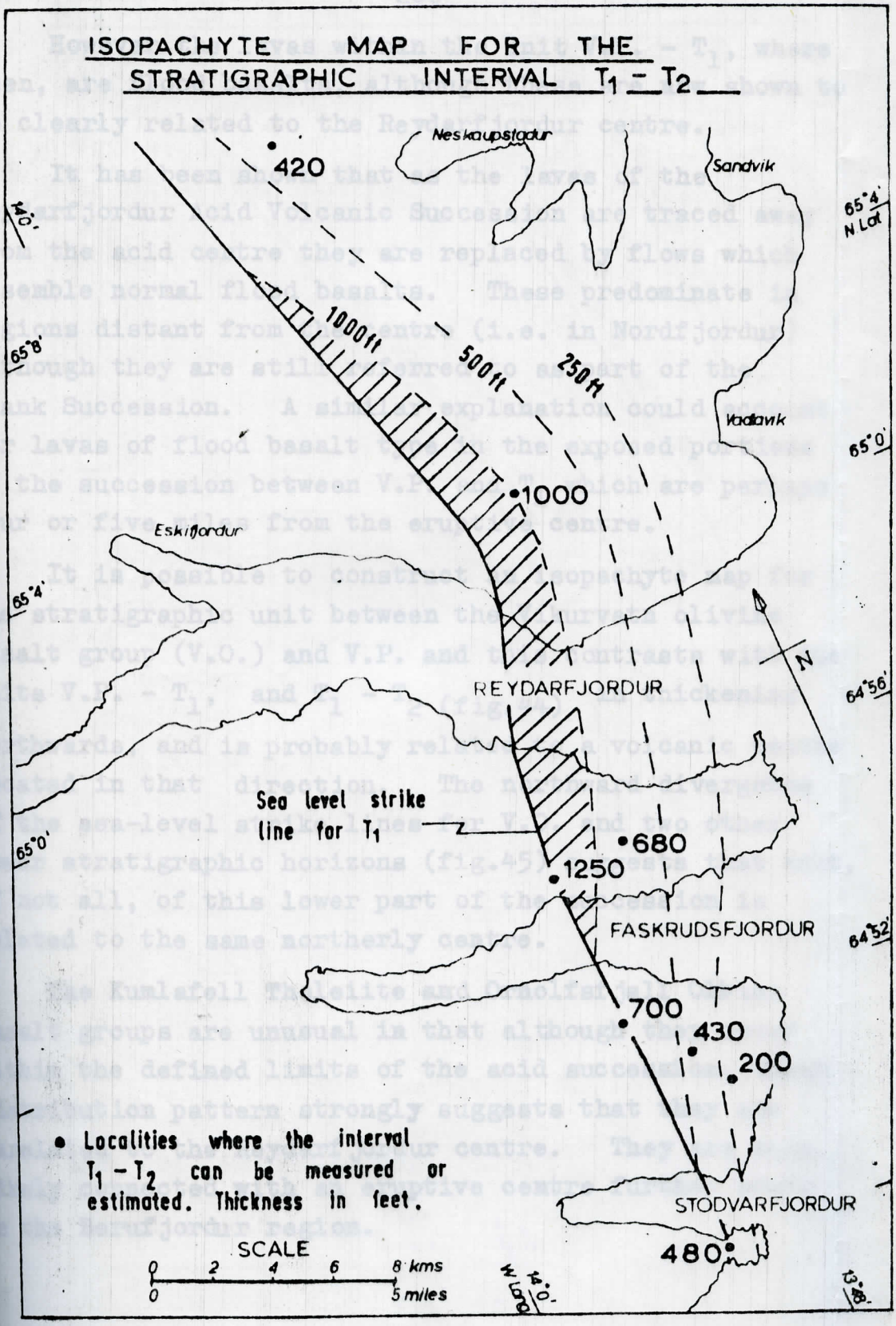
is lens-shaped in cross-section. The unit V.P. - T_1 is also thought to be this shape, though the majority of the feeding dykes for the unit will be below sea level. The result is that only up-dip thinning is visible.

The up-dip thinning recorded by Walker as applying to the basalt succession generally (Walker 1960) leads to the development of an inferred top of the lava pile approximately parallel to the present sea-level. The down-dip thinning implies a directly comparable base to the lava pile, at any rate below the Reydarfjor dur centre. Evidence is given later to suggest that the basalt succession in Eastern Iceland may be floored in this way everywhere.

(iii) The relationship between the Reydarfjordur Acid Volcanic centre and the surrounding flood basalts.

The work of Walker, and to a lesser extent Kinsman, (Walker 1959, Gibson, Kinsman & Walker - in press) allows one to draw important conclusions regarding the general relationship of the Reydarfjordur centre to the surrounding flood basalts.

First, considering the lavas underlying T_1 in the Reydarfjordur area, it is possible to draw an isopachyte map for the stratigraphic unit Vindhals Porphyritic Group (V.P.) - T_1 (fig.44) This shows an eruptive pattern strikingly similar to that for the unit T_1 - T_2, the overlying basal portion of the Reydarfjordur Acid Volcanic Succession. This evidence, combined with the more direct indications of early acid eruptions, strongly suggests that the Reydarfjordur centre was active soon after the eruption of the Vindhals Porphyritic Basalts and was the controlling factor in the distribution of the overlying lavas.


ISOPACHYTE MAP FOR THE STRATIGRAPHIC INTERVAL $T_1 - T_2$
Neskaupstaður
Sandvik
420
1000ft
500ft
250ft
Vaðlavík
1000
Eskifjordur
REYDARFJORDUR
N
Sea level strike line for T_1
680
1250
FASKRUDSFJORDUR
700
430
200
STODVARFJORDUR
480
• Localities where the interval $T_1 - T_2$ can be measured or estimated. Thickness in feet.
SCALE
0 2 4 6 8 kms
0 5 miles
65°4' N Lat
65°0'
64°56'
64°52'
14°0' W Long
13°58'

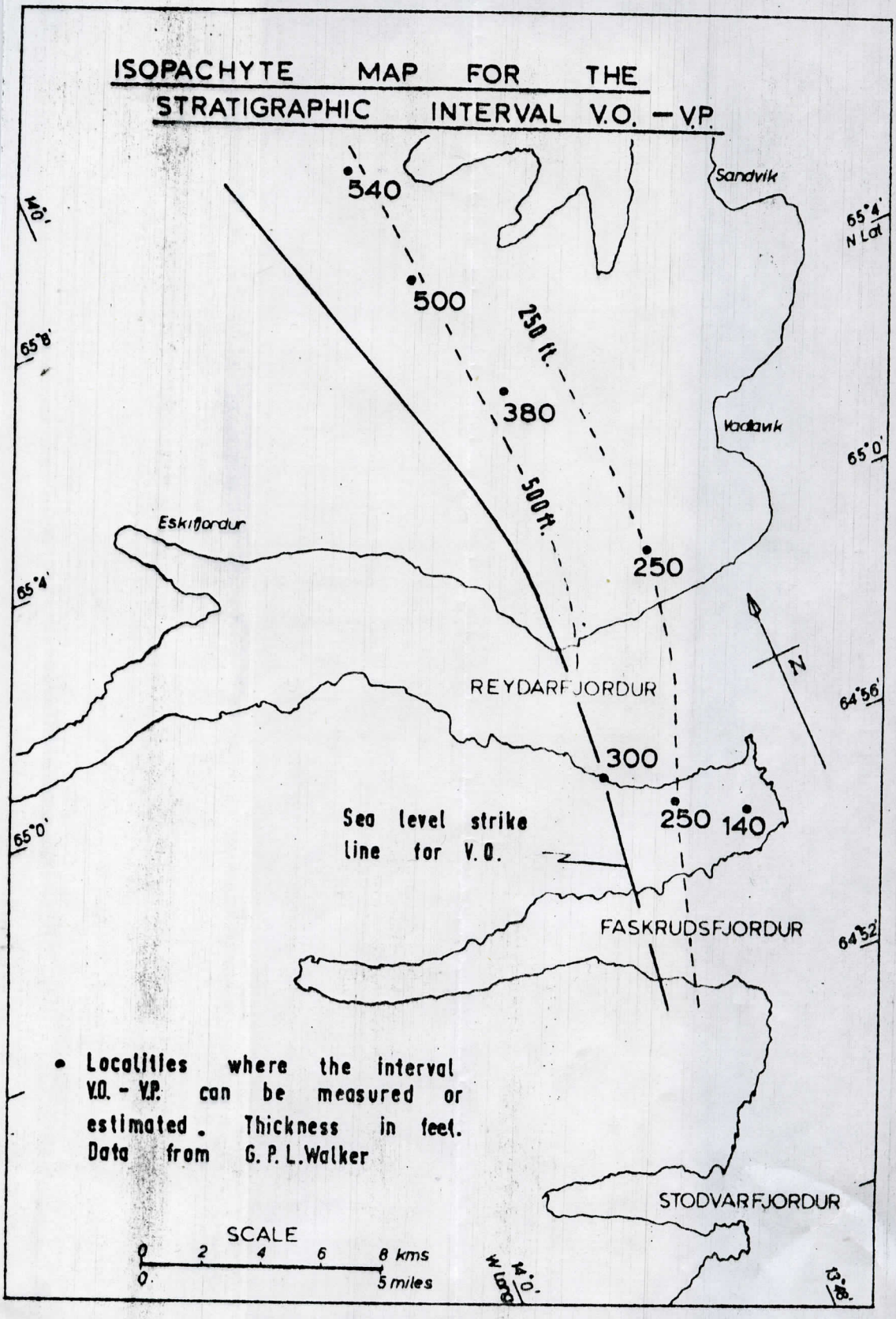

ISOPACHYTE MAP FOR THE STRATIGRAPHIC INTERVAL V.O. – V.P.
540
500
380
250
250 ft.
500 ft.
Sandvik
Vaðlavik
Eskifjordur
REYDARFJORDUR
300
250
140
Sea level strike line for V.O.
FASKRUDSFJORDUR
STODVARFJORDUR
• Localities where the interval V.O. - V.P. can be measured or estimated. Thickness in feet. Data from G. P. L. Walker
SCALE
0 2 4 6 8 kms
0 5 miles
65°4' N Lat
65°0'
64°56'
64°52'
14°0' W Long
13°48'
N

Fig. 44

However the lavas within the unit V.P. - T_1, where seen, are flood basalts, although these are now shown to be clearly related to the Reydarfjordur centre.

It has been shown that as the lavas of the Reydarfjordur Acid Volcanic Succession are traced away from the acid centre they are replaced by flows which resemble normal flood basalts. These predominate in regions distant from the centre (i.e. in Nordfjordur) although they are still referred to as part of the Flank Succession. A similar explanation could account for lavas of flood basalt type in the exposed portions of the succession between V.P. and T_1 which are perhaps four or five miles from the eruptive centre.

It is possible to construct an isopachyte map for the stratigraphic unit between the Vikurvatn olivine basalt group (V.O.) and V.P. and this contrasts with the units V.P. - T_1, and T_1 - T_2 (fig.44) in thickening northwards, and is probably related to a volcanic centre located in that direction. The northward divergence of the sea-level strike lines for V.O. and two other lower stratigraphic horizons (fig.45) suggests that most, if not all, of this lower part of the succession is related to the same northerly centre.

The Kumlafell Tholeiite and Ornolfsfjall Olivine Basalt groups are unusual in that although they occur within the defined limits of the acid succession, their distribution pattern strongly suggests that they are unrelated to the Reydarfjordur centre. They are more likely connected with an eruptive centre further south in the Berufjordur region.

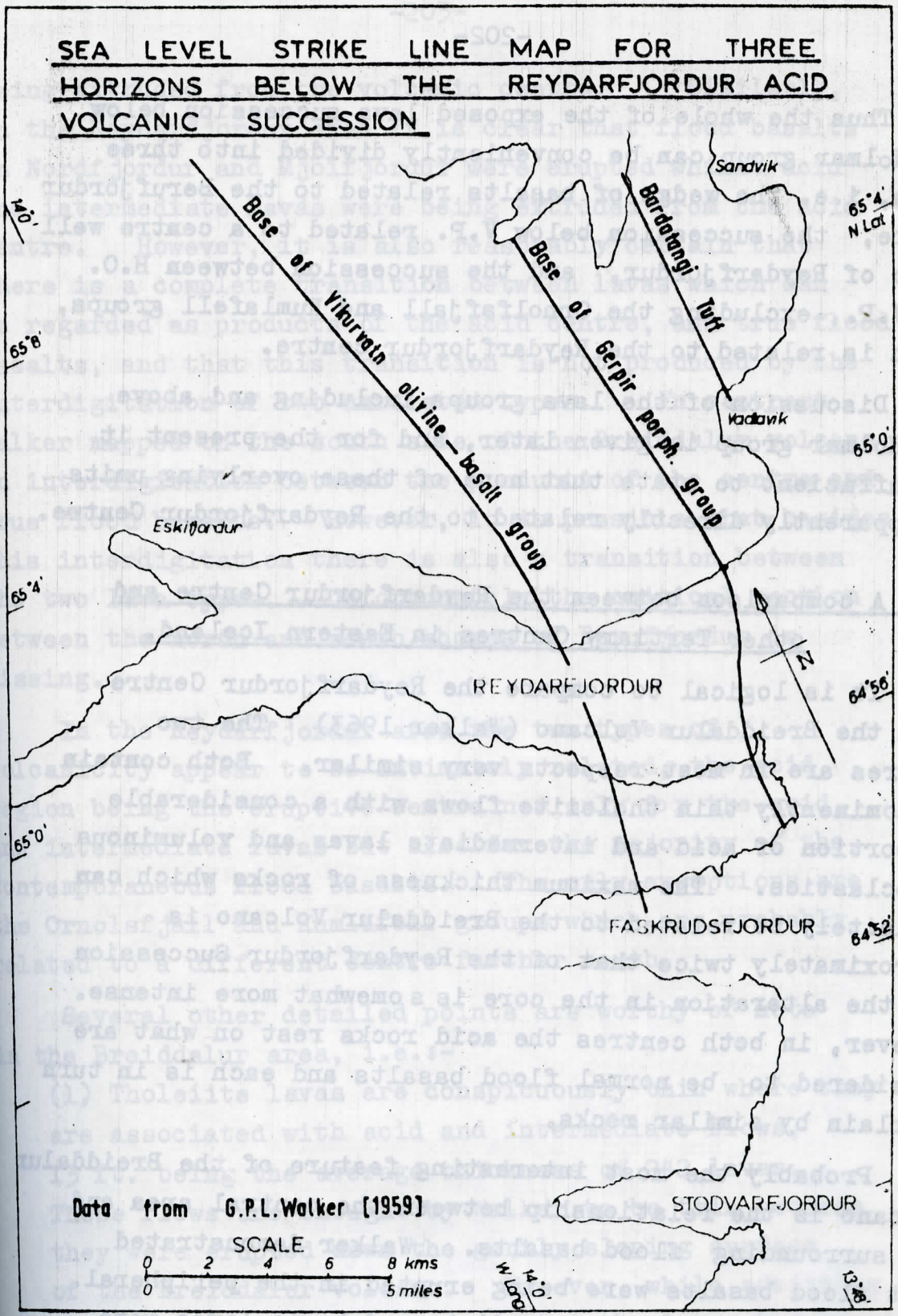

SEA LEVEL STRIKE LINE MAP FOR THREE HORIZONS BELOW THE REYDARFJORDUR ACID VOLCANIC SUCCESSION
Base of Vikurvatn olivine-basalt group
Base of Gerpir porph. group
Barðatangi Tuff
Sandvik
Vadavik
Eskifjordur
REYDARFJORDUR
FASKRUDSFJORDUR
STODVARFJORDUR
65°4' N Lat
65°0'
64°56'
64°52'
14°0' W Long
13°56'
N
Data from G.P.L. Walker [1959]
SCALE
0 2 4 6 8 kms
0 5 miles

Fig. 45

Thus the whole of the exposed lava succession below the Holmar group can be conveniently divided into three parts, i.e. the wedge of basalts related to the Berufjordur centre, the succession below V.P. related to a centre well north of Reydarfjordur, and the succession between H.O. and V.P., excluding the Ornolfsfjall and Kumlafell groups, which is related to the Reydarfjordur centre.

Discussion of the lava groups including and above the Holmar group is given later, and for the present it is sufficient to state that none of these overlying units is apparently directly related to the Reydarfjordur Centre.

(iv) A comparison between the Reydarfjordur Centre and other Tertiary Centres in Eastern Iceland.

It is logical to compare the Reydarfjordur Centre with the Breiddalur Volcano (Walker 1963) The two centres are in most respects very similar. Both contain predominently thin tholeiite flows with a considerable proportion of acid and intermediate lavas and voluminous pyroclastics. The maximum thickness of rocks which can definitely be related to the Breiddalur Volcano is approximately twice that of the Reydarfjordur Succession and the alteration in the core is somewhat more intense. However, in both centres the acid rocks rest on what are considered to be normal flood basalts and each is in turn overlain by similar rocks.

Probably the most interesting feature of the Breiddalur volcano is the relationship between the central area and the surrounding flood basalts. Walker demonstrated that flood basalts were being erupted in the peripheral regions whilst acid, intermediate and basic lavas were

being extruded from the volcanic centre. Similarly, in the Reydarfjordur area it is clear that flood basalts in Nordfjordur and Mjoifjordur were erupted whilst acid and intermediate lavas were being extruded from the acid centre. However, it is also reasonably certain that there is a complete transition between lavas which can be regarded as products of the acid centre, and true flood basalts, and that this transition is not produced by the interdigitation of two unrelated types. In contrast Walker mapped on the south side of the Breiddalur volcano an interdigitation between the products of the centre and true flood basalts. However, it is possible that besides this interdigitation there is also a transition between the two lava types. Unfortunately the critical section between the north and south shores of Berufjordur is missing.

In the Reydarfjordur area the two types of volcanicity appear to be intimately related, the acid region being the eruptive centre not only for the acid and intermediate lavas but also for the majority of the contemporaneous flood basalts. The only exceptions are the Ornolsfjall and Kumlafell groups which are probably related to a different centre further south.

Several other detailed points are worthy of note in the Breiddalur area, i.e.:-

(1) Tholeiite lavas are conspicuously thin where they are associated with acid and intermediate flows, 13 ft. being the average thickness of 242 lavas. These flows are thought by Walker to be thin because they were erupted down the gently sloping surface of the Breiddalur volcano. However, while admitting that there is strong evidence that the lavas had an

initial dip, the author is not convinced that this was the primary factor in determining the thickness of the individual lavas. Outlying flows of the Breiddalur centre occur to the west of Faskrudsfjordur and these are still unusually thin, although there is no evidence for depositional dips in this area. Similarly many of the tholeiite and basaltic andesite lavas associated with the Reydarfjordur centre are also thin, e.g. the Fifth and Sixth Phase lavas in Seldalur. The map of the Reydarfjordur area showing the residual dips after the removal of the regional tilt (fig.46) demonstrates clearly that initial dips were very small. It seems more likely that the thin nature of the lavas is due to some primary characteristic of the magma. A high content of volatiles for instance would make the magma more fluid.

(2) Intermediate lavas are also abundant in the Breiddalur area and it is noteworthy that the thickest mapped group, i.e. that seen north and south of Smatindur and Rondolfur, occurs well east of the contemporaneous rhyolites in Breiddalur. This andesite group is thought to be directly comparable to the groups of rhyolitic andesites which form such an important part of the Flank Succession in the Reydarfjordur area.

(3) In the Ytri Ljosa in Breiddalur there is exposed an alternating succession of pyroclastic rocks and rhyolites, the agglomerate rhyolite sequence being repeated three times. It is possible that this succession is comparable to the thinner agglomerate-rhyolite sequence exposed in the Breiddalsa in

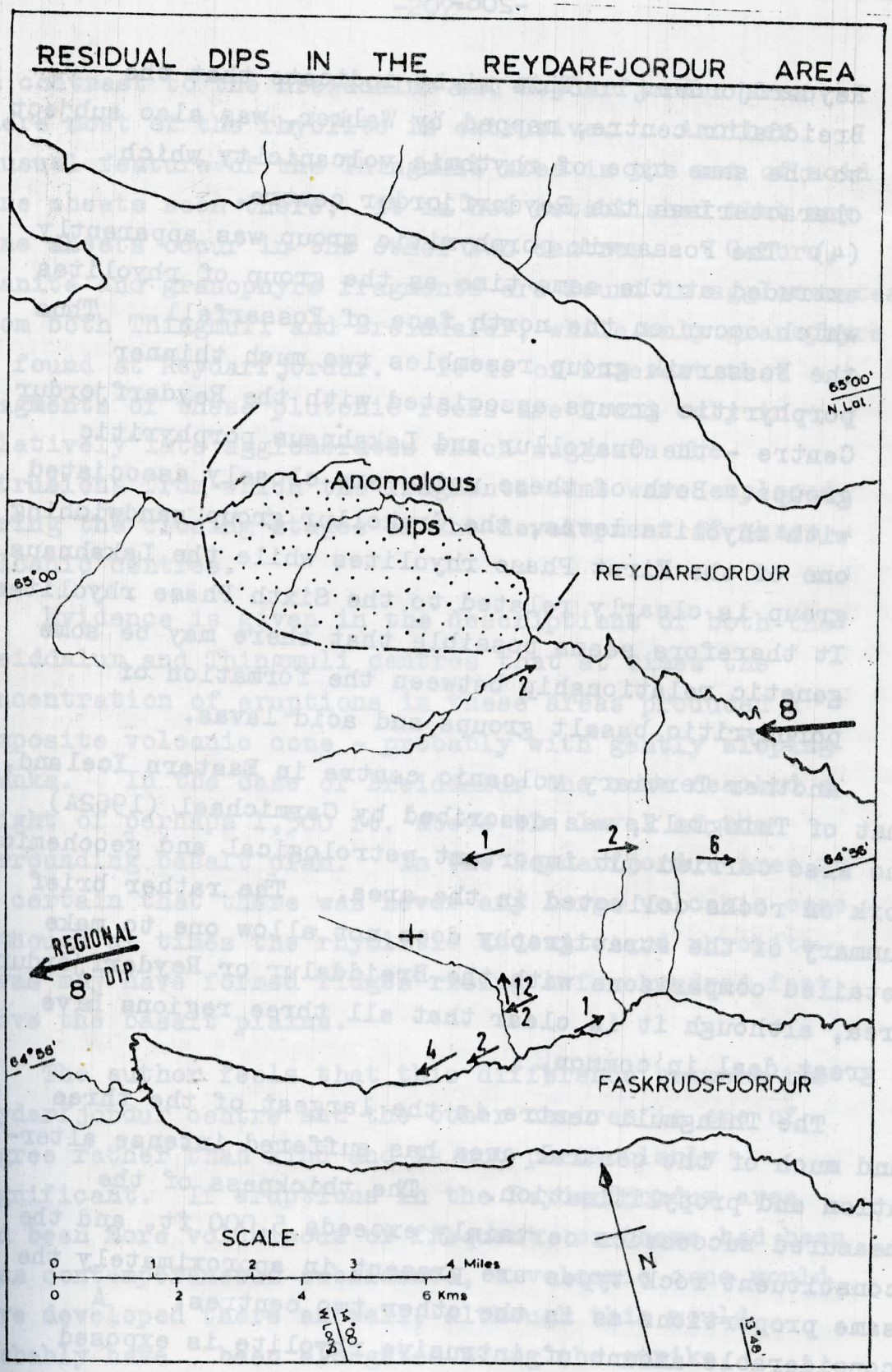

RESIDUAL DIPS IN THE REYDARFJORDUR AREA
65°00' N.Lat.
Anomalous Dips
REYDARFJORDUR
65°00'
2
8
1
2
6
64°56'
REGIONAL 8° DIP
12
2
1
64°56'
4
2
FASKRUDSFJORDUR
SCALE
0 1 2 3 4 Miles
0 2 4 6 Kms
N
14°00' W Long.
13°48'

Fig. 46

Reydarfjordur. This might indicate that the Breiddalur centre, mapped by Walker, was also subject to the same type of rhythmic volcanicity which characterises the Reydarfjordur centre.

(4) The Fossarvik porphyritic group was apparently extruded at the same time as the group of rhyolites which occur on the north face of Fossarfell. Thus the Fossarvik group resembles two much thinner porphyritic groups associated with the Reydarfjordur Centre - the Grakollur and Lakahnaus porphyritic groups. Both of these units are closely associated with rhyolite lavas, the Grakollur group sandwiching one of the First Phase rhyolites while the Lakahnaus group is clearly related to the Sixth Phase rhyolites. It therefore seems possible that there may be some genetic relationship between the formation of porphyritic basalt groups and acid lavas.

Another Tertiary volcanic centre in Eastern Iceland, that of Thingmuli, was described by Carmichael (1962A) who also carried out important petrological and geochemical work on rocks collected in the area. The rather brief summary of the stratigraphy does not allow one to make detailed comparisons with the Breiddalur or Reydarfjordur area, although it is clear that all three regions have a great deal in common.

The Thingmuli centre is the largest of the three and much of the central area has suffered intense alteration and propylitisation. The thickness of the measured succession certainly exceeds 5,000 ft. and the constituent rock types are present in approximately the same proportions as in the other two centres. A considerable amount of intrusive rhyolite is exposed

in contrast to the Breiddalur and Reydarfjordur area where most of the rhyolite is extrusive. Another unusual feature of the Thingmuli area is the set of acid cone sheets seen there; it is not established that any cone sheets occur in the other two centres. Gabbro, granite and granophyre fragments are found in agglomerates from both Thingmuli and Breiddalur, while only granophyre is found at Reydarfjordur. It is of interest that fragments of these plutonic rocks are found only in relatively late agglomerates which suggests the intrusions from which the fragments came were emplaced during the closing stages of the development of these volcanic centres.

Evidence is given in the descriptions of both the Breiddalur and Thingmuli centres that at times the concentration of eruptions in these areas produced a composite volcanic cone - probably with gently sloping flanks. In the case of Breiddalur the cone reached a height of perhaps 1,500 ft. above the level of the surrounding basalt plain. In the Reydarfjordur area it is certain that there was never any large volcanic cone, although at times the rhyolitic andesite and rhyolite lavas may have formed ridges rising a few hundred feet above the basalt plains.

The author feels that this difference between the Reydarfjordur centre and the other centres is one of degree rather than kind and is not particularly significant. If eruptions in the Reydarfjordur area had been more voluminous or frequent, or there had been less contemporaneous subsidence, a volcanic cone would have developed there as well, although this would probably have been elongated along the strike.

In conclusion it is thought that the Reydarfjordur centre is closely comparable to the Breiddalur and Thingmuli areas which differ only in being larger and more complex in structure.

(v) The Structure of Eastern Iceland

One of the most remarkable features of the geology of Eastern Iceland is the great thickness of basalt lavas exposed in the fjord-lands. The gently dipping succession is at least 25,000 ft. thick. Walker (1960) showed conclusively, however, that the original thickness of the lava pile probably did not exceed 5,000 ft. when measured above present sea-level, as each individual lava group thins up-dip. Walker was also able to relate the secondary mineral zones and the decrease in density of the dyke swarm with increasing altitude, to the inferred position of the top of the lava-pile. However, this important structural analysis did not take account of the fact that the dykes were not uniformly distributed throughout the succession inEastern Iceland, and also little account was taken of the fact that acid rocks form an important part of the succession.

As the dyke swarm and acid centres are closely related and both have a bearing on the structure of Eastern Iceland, it is important to recognize all the centres, including those buried down dip.

Two important characteristics of acid centres - the presence of acid rocks and, usually, an intense dyke swarm - leads to the recognition of the following centres:-

(a) Bardnes. (b) Reydarfjordur.
(c) Breiddalur. (d) Thingmuli.

The approximate position of the first three of these centres is shown on figure 47. This map also shows strike-lines drawn for various important flood-basalt or tuff horizons in the Tertiary succession of Eastern Iceland. It is clear in the case of Reydarfjordur and Breiddalur centres that the strike-lines representing approximately the base and top of the acid successions tend to diverge as they approach the acid centre and to converge again when traced away from the centre on the opposite side.

If one now assumes a uniform inclination of the lavas at sea-level throughout Eastern Iceland, the divergence of the strike-lines towards the Reydarfjordur and Breiddalur centres implies that the succession thickens as it is traced along the strike towards the eruptive centres. This evidence is in accord with the detailed results from the Reydarfjordur centre which indicated that it was the eruptive centre for the majority of the surrounding flood basalts.

We thus have an additional criterion by which we can locate acid centres - flood basalt groups thicken towards such centres. Application of this criterion leads to the recognition of three additional centres in the area shown in figure 47 situated :-

(a) Near the seaward end of Berufjordur.

(b) To the north - perhaps in the Mjoifjordur/ Seydisfjordur area.

(c) At the head of Faskrudsfjordur - the Daladalur centre.

One of the most striking features of the Reydarfjordur area is the rapid variation in thickness of the Kumlafell tholeiite and Ornolfur olivine basalt groups. The

The map shows the thickening of the basalt succession towards the deduced or actual positions of acid centres. The exact position of the base of the Daladalur succession is unknown, as are the limits of the Berufjordur succession.

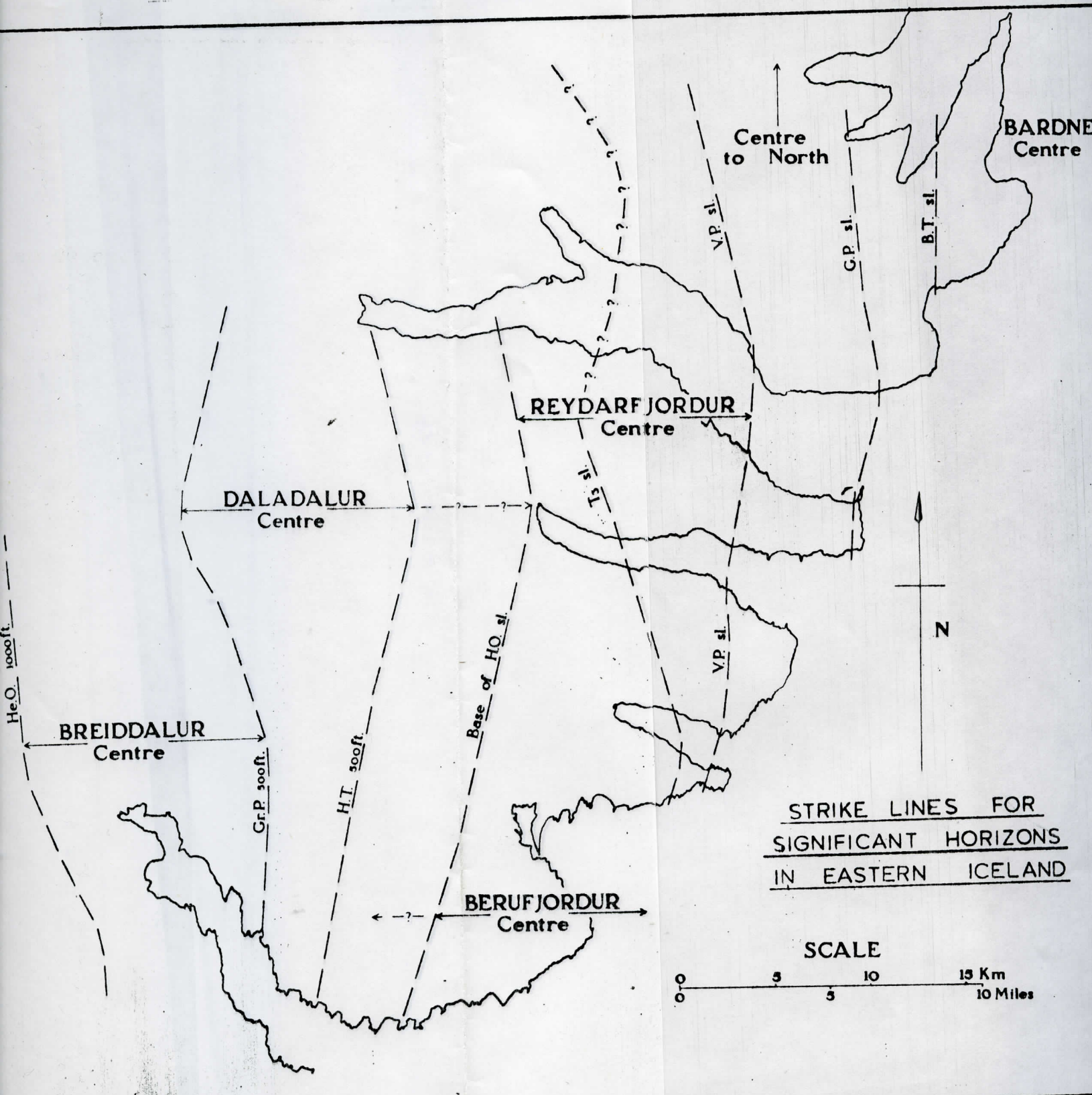

Centre to North
BARDNE Centre
V.P. sl.
G.P. sl.
B.T. sl.
REYDARFJORDUR Centre
DALADALUR Centre
T3 sl.
N
V.P. sl.
He.O. 1000ft.
BREIDDALUR Centre
Gr.P. 300ft.
H.T. 300ft.
Base of HO sl.
BERUFJORDUR Centre
STRIKE LINES FOR SIGNIFICANT HORIZONS IN EASTERN ICELAND
SCALE
0 5 10 15 Km
0 5 10 Miles

Fig. 47

southward thickening of these groups may now be seen as part of a regional thickening of the flood basalt succession below the Holmar Group towards a centre in the Berufjordur region. The centre may be located down-dip, below sea-level and west of the intense dyke swarm at the seaward end of Berufjordur, (Walker 1963. fig.8) and it is possible that only a few of the dykes in this area are in fact related to the Altafjordur volcano. The relationship between the Berufjordur dyke swarm and the acid centre would then be the same as in the Reydarfjordur area, where the dyke swarm occurs west of the large area of acid extrusives.

There is only a limited amount of direct evidence for the presence of a centre below sea-level in this area, and it must be assumed that the majority of the acid and intermediate lavas are concealed. The only acid lava possibly related to it is the Rauthaskritha rhyolite (Hawkes 1924) while a single andesite lava and a conspicuous acid tuff found on the shore of Berufjordur are probably also products of the same centre. Thin tholeiite lavas and local propylitisation - both characteristic of acid centres - are also present (Walker, pers.comm.)

Acid rocks, including rhyolite and agglomerate, occur on the Dalatangi peninsula between Mjoifjordur and Seydisfjordur and are probably the products of a centre in this area. The related dyke swarm extends as far south as Nordfjordur where the sea-level intensity reaches 8% (Walker, 1959, fig. 6)

Probably the most important of the three inferred centres is the one in Daladalur, at the head of Faskrudsfjordur. As can be seen from figure 47 the strike lines clearly indicate a northward thickening of

the succession between the Holmatindur tuff and the Graenavatn Porphyritic Group from the shores of Berufjordur to Daladalur. A complimentary thinning is also visible north of the centre. The succession between the Graenavatn porphyritic group and the Holmatindur tuff can be sub-divided into several smaller units, the thickness of which has been measured directly in the field (fig.48) These detailed measurements also show, in general, a thickening of the succession towards the Daladalur centre. Again the centre is probably located down-dip of the present exposures, although there is very little direct evidence for its presence. A single andesite lava is the only acid or intermediate lava in the Daladalur area.

This centre is the only one of the seven that appears to lack a dyke swarm. However, it is possible that as the statistical treatment of the dyke swarms in Eastern Iceland is incapable of distinguishing between the two co-incident swarms, Walker grouped those associated with the Breiddalur and Daladur centres (Walker 1963, fig8) It is certain from consideration of the strike direction and the shown direction and extent of the Breiddalur swarm that the northern part of the swarm is considerably older than the southern section and it is this northern portion which may be related to the Daladur centre which immediately predated the formation of the Breiddalur centre.

The area of Eastern Iceland shown in fig.47 can thus be divided up into six sub-areas, each characterised by a lenticular group of flood basalts and related to a group of acid and intermediate rocks which may or may not be exposed at the surface. If, as seems likely, each of these units is structurally comparable to the Reydarfjordur acid

STRATIGRAPHIC GROUP	Height at which measurement was taken	North side Reydarfjordur
Graenavatn Porph. Grp. Skessa tuff	Skessa tuff at ~ 1250 ft	250
Skessa tuff Kollur Porph. Grp.	Skessa tuff at ~ 2000 ft	260
Kollur Porph. Grp. Holmatindur tuff	Holmatindur tuff at ~ 1000 ft	430
Holmatindur tuff Reydarfjordur tuff	Reydarfjordur tuff at ~ 1000 ft	~ 530
Reydarfjordur tuff Grjota Olivine Basalt Grp.	top of Grjota O. B. Grp. at 1000 ft	850

THICKNESS DATA FOR PART OF THE BASALT SUCCESSION IN EASTERN ICELAND

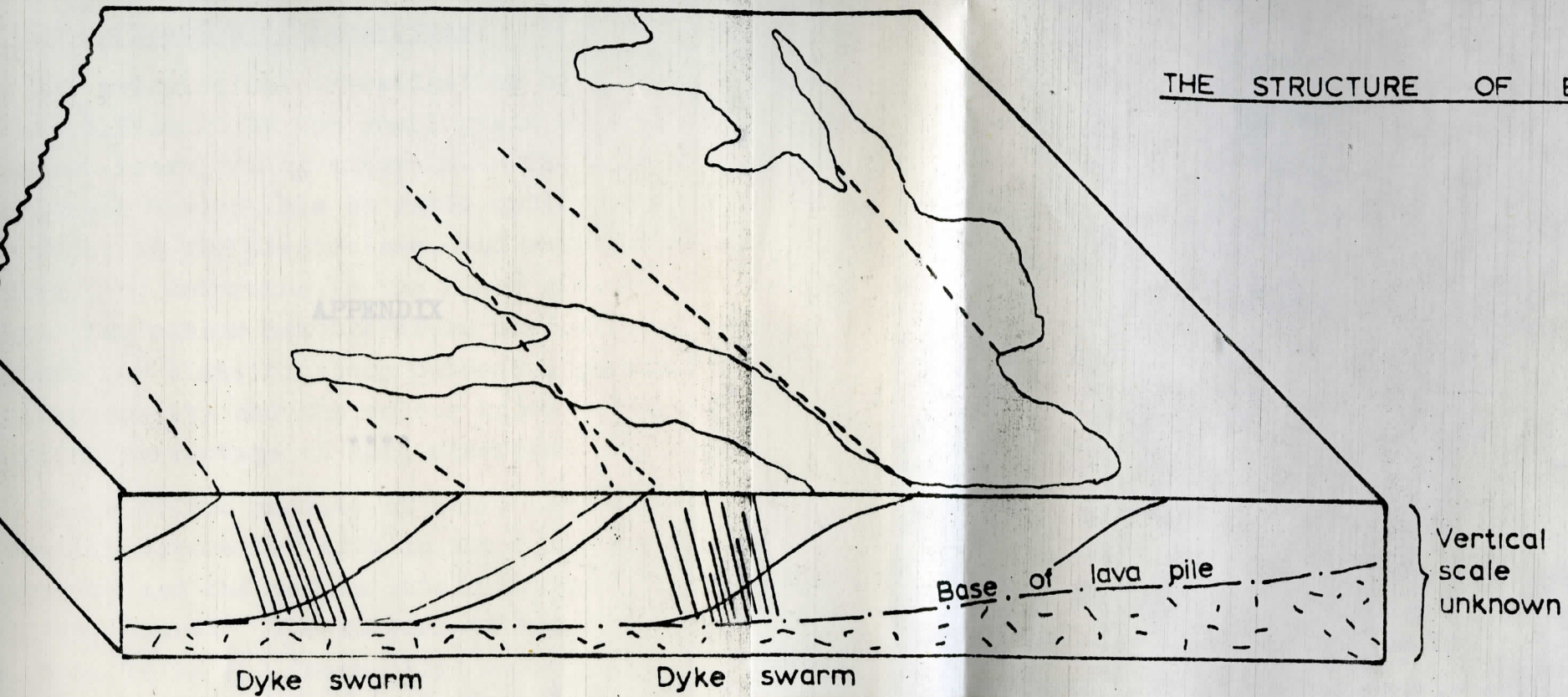
North side Faskrudsfjordur	South side Faskrudsfjordur	North side Breiddalur	South side Breiddalur
650+	540+	400 +	~ 250
350	430	?	150 ?
700?	1000	480	1300 ?
700	750	~630	500
600	—	—	—

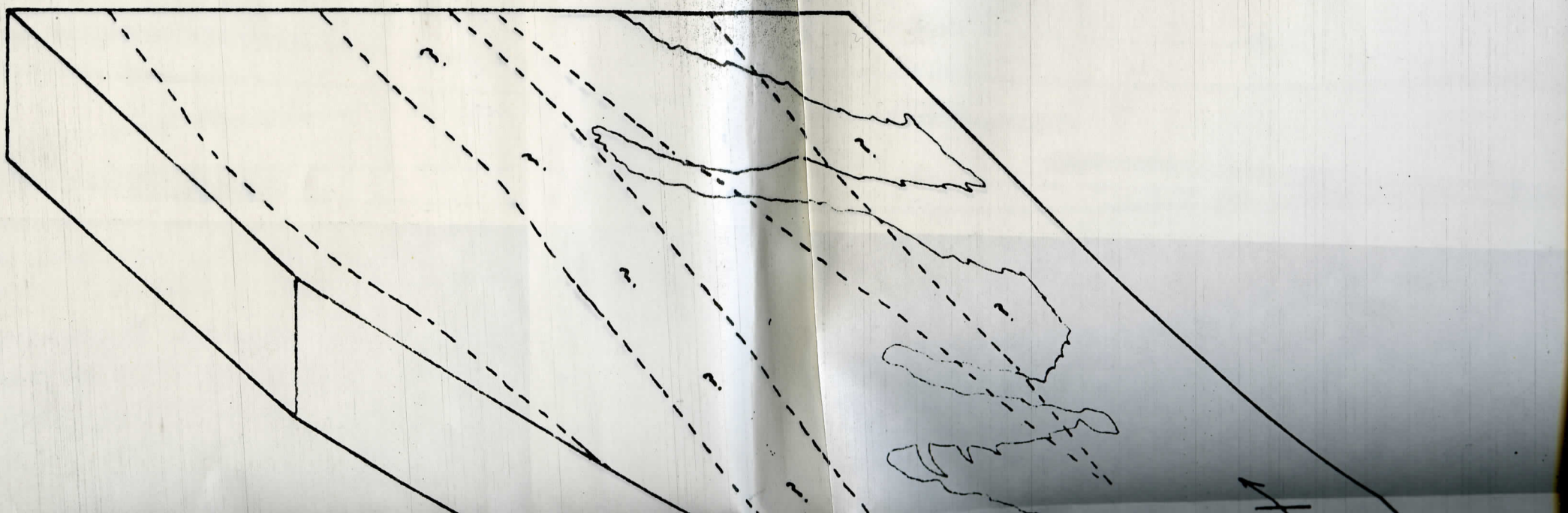
Approximate position of DALURDALUR CENTRE

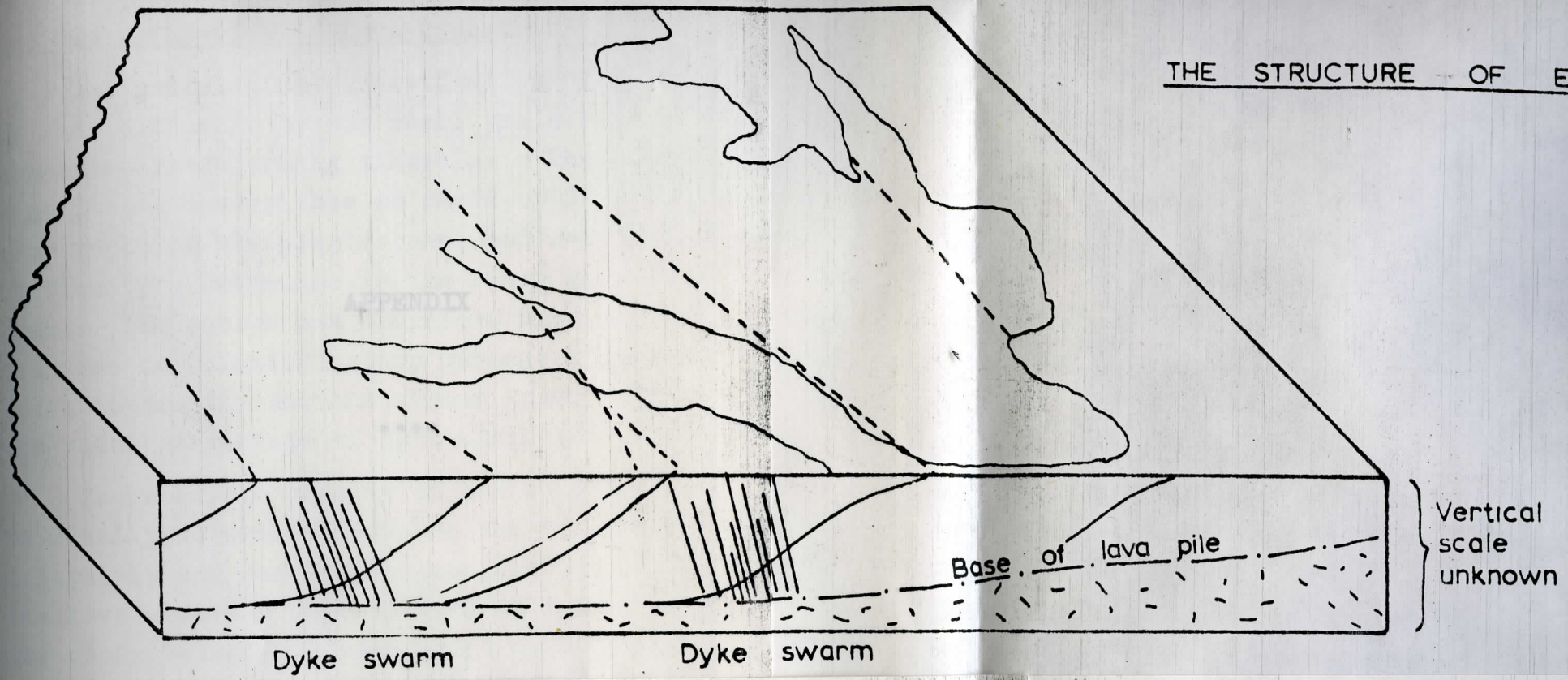
Data from G.P.L.W.

Fig. 48

succession, it is possible to suggest a structure for the whole of Eastern Iceland based on that of the Reydarfjordur centre. This is shown on fig. 49. The main difference between this and that of Walker (1960 fig. 5) is that the proposed structure takes into account both the non-uniform distribution of the dykes and the presence of acid rocks. In addition a hypothetical base to the lava pile is also shown below the lava pile, analagous to the floor beneath the Reydarfjordur centre.


Base of lava pile
Vertical scale unknown
Dyke swarm
Dyke swarm




Base of lava pile
Vertical scale unknown
Dyke swarm
Dyke swarm

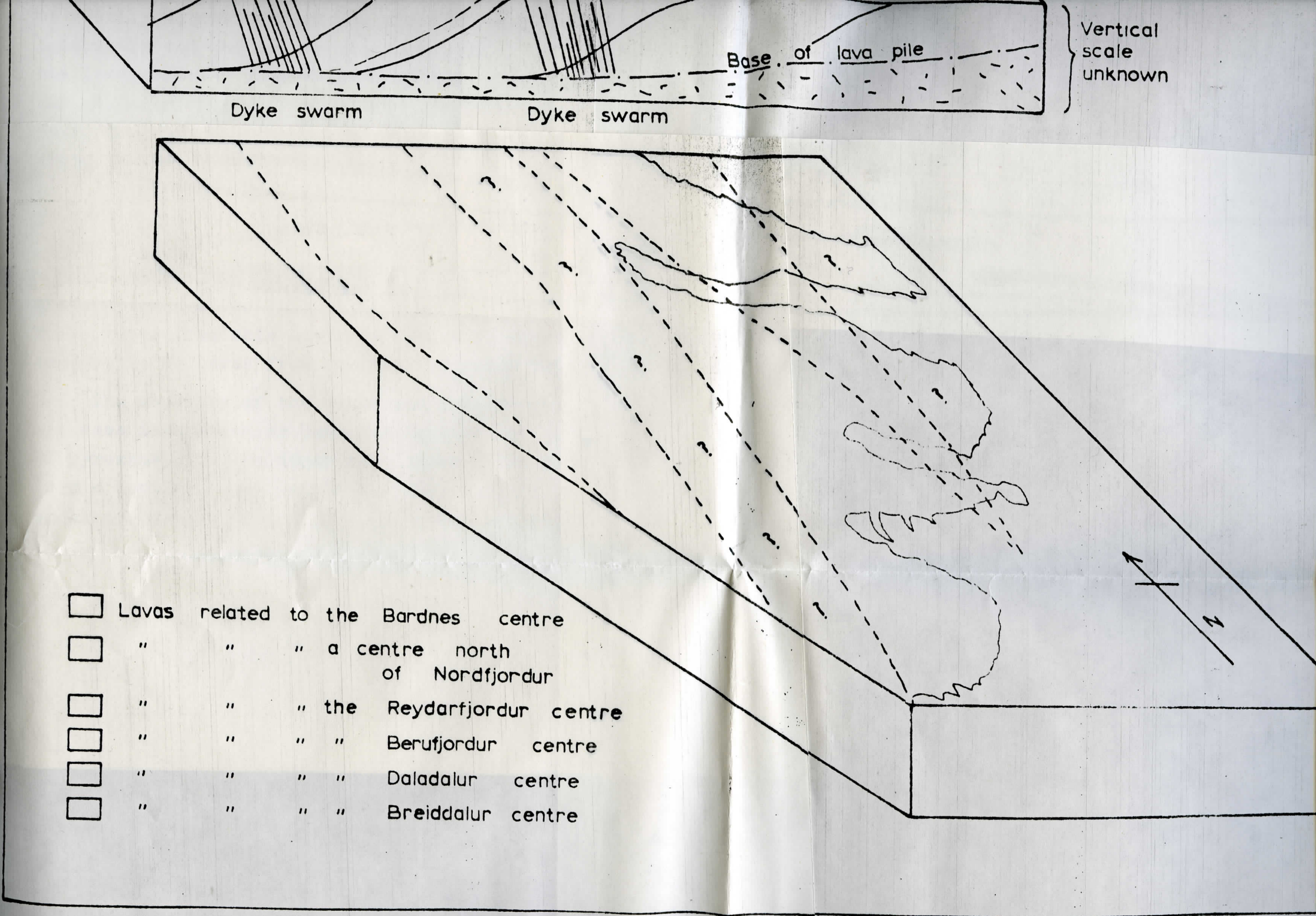

Base of lava pile
Vertical scale unknown
Dyke swarm
Dyke swarm
Lavas related to the Bardnes centre
" " " a centre north of Nordfjordur
" " " the Reydarfjordur centre
" " " " Berufjordur centre
" " " " Daladalur centre
" " " " Breiddalur centre
N

Fig. 49