REPORTS TO THE STATE ELECTRICITY AUTHORITY ON THE GEOLOGY AT SOME SITES FOR POTENTIAL HYDRO-POWER DEVELOPMENTS IN THE ÞJÓRSÁ AND THE HVÍTÁ RIVER SYSTEMS, SOUTHERN ICELAND

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The State Electricity Authority - Reykjavík - August 1959

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CONTENTS

LIST OF FIGURES

0 GENERAL GEOLOGY OF THE REGION

All the rock in the central area of Iceland is essentially of volcanic origin and the rocks exposed at the surface were extruded from Tertiary to historic times. The common rock types are therefore basaltic lavas, tuffs, breccias and unconsolidated ash of widely varying structure and texture. Pleistocene glaciations have also had a profound effect upon the surface geology and in addition to successive layers of volcanic deposits being interbedded with all types of glacial moraine and fluviatile sediments, the laying down of volcanic deposits on ice or permafrost sediments has introduced noteworthy complexity to local structure.

There has been little detailed geological mapping of the region under consideration. Nevertheless from a number of geological reconnaissances undertaken by the Icelandic Museum of Natural History over the past few years, a broad pattern of the gegional geology has emerged and a considerable knowledge has been obtained of the characteristics of the geological features making up this pattern. In a report prepared for the S.E.A. in March, 1954, on the geology of the Þjórsá drainage system, the author postulates the following sequence, in which the oldest rocks are given first :

(i) The Hreppar Series (Hreppamyndunin)
(ii) The Palagonite Series (Brúngrýtismyndunin)
(iii) Pleistocene Moraine
(iv) The Þjórsá Lavas
(v) Sediments of Lava-dammed Lakes
(vi) Post-glacial Pyroclastic Material
(vii) Lavas younger than the Þjórsá Lavas

The characteristics of these systems may be summarised briefly for the purpose of the present discussion, as follows :

The Hreppar Series is found either outcropping or obscured by relatively thin mantles of the most recent of the other members of the above sequence, over the whole of the region to the north-west of a boundary roughly parallel to, and a short distance to the east of the rivers Ytri-Rangá and Kaldakvísl. Its characteristics are therefore likely to require consideration in relation to the Hvítá scheme and the Þjórsá and Kaldakvísl development of the Þjórsá scheme. The rocks of the Hreppar series in general comprise layers of breccia, tuff and basalt which in comparison with their counterparts in the younger members of the sequence are well indurated, with tight joints and infilling of secondary minerals in voids and fissures. From their age and general discription, the Hreppar rocks would not be expected to offer any unduly difficult problems in connection with dam construction or tunnelling. However, attention should be drawn to the occurence in one locality of a weakly cemented sandstone of poor engineering characteristics which was of undoubted Hreppar age, albeit among the youngest of Hreppar rocks.

The Palagonite Series occurs as the underlying rock over the remainder of the region, and is found outcropping only very occasionally from beneath the younger deposits. The palagonite rock, which makes up the greater part of the series, is composed of pyroclastic material indurated to form a relatively opentextured tuff. It tends to be bedded, and intercalated between the beds of palagonite rock are basalts of a more or less typical pillow structure and often of considerable thickness. The primary characteristics of the Palagonite Series from the point of view of the proposed schemes is the high permeability of the mass of the material, which results in a dry barren landscape. Some of the younger members of the geological sequence are less pervious than the palagonite rocks and provide a water retaining horizon which may result in the water levels of lakes and streams over the area being perched above the main water table of the series. The water level of such surface water is probably related quite strictly to the extent, in plan, of the less pervious mantles, and damming of any outlet streams may not produce the elevation of water level hoped for.

The Pleistocene Moraine material has the hetrogeneous character common to all moraine materials. It would appear that on the whole, the moraine present over the region is more likely to be coarse-grained, gravelly soil than to be finergrained and cohesive. It covers large areas of the Hreppar series, but while it must undoubtedly overlie much of the Palagonite series, its actual extent is masked there by younger layers of lava and pumice. The moraine material could possibly be among the least pervious of the deposits found near the surface and could well be a prevalent cause of perched water tables.

The Þjórsá Lavas, which erupted from fissures in the Vatnaöldur district, flowed westwards and northwards across the region under consideration. So far as it affects the present schemes, the Þjórsá lava is confined to the valleys of the rivers Tungnaá, Kaldakvísl (above its junction with river Þórisós) and Þórisós. These lavas are readily recognisable by the large white phenocrysts of felspar which they contain. The Þjórsá lava flow is one of the largest in the world exposed at the surface, and boring has shown the thickness of individual flows, of which there are a number, to be as much as 20 metres. In the author's opinion the age of the Þjórsá lava cannot be more than about 5 to 7 thousand years. This is very youthful in terms of geological time and it stresses the need to consider the chemical reactivity of the rock encountered in tunnels and other deep excavations in terms of attack of concrete and steelwork in contact with it. The same remarks apply with even greater emphasis to the younger volcanics. Joints in the Þjórsá lava are more open than in the case of the older rocks and there is no mineral infilling in vesicles and joints. River Tungnaá flows over the surface of the uppermost lava flows and in the course of time there has probably been a steady decrease in permeability of the rock immediately adjointing the river bed due to silting of fissures and similar seepage channels. Some distance away from this influence, the permeability of the lava is probably high.

Sediments in Lava-dammed Lakes occur in valleys debouching into lava plains and affect impoundment there. The deposits appear, generally, to contain a sufficient proportion of fine-grained soils to make them less pervious than the underlying rocks. Their extent is necessarily limited by the maximum height of the lava dam, prior to any subsequent erosion. Raising of the lake levels might therefore lead to considerable water losses around the margins of the lakes.

The Post-glacial Pyroclastic Material consists predominantly of loose pumic lapilli with larger lumps of other ejectementa, and it is exceedingly pervious. It appears to have similar boundaries to the Palagonite series and over its wide extent it completely "drowns" all the earlier landscape. In the Vatnaöldur district whence it probably originated, it attains a thickness of hundreds of metres, but it thins out away from this centre and at Þórisvatn the thickness is inappreciable other than where it fills pre-existing valleys, where the thickness may be tens of metres.

The high permeability of this material results in a very deep and flat water table and this, together with the configuration of the underlying landscape, could well be the dominant factor affecting the hydrology of the country to the east of Þórisvatn. It would seem that, if not already considered and for obvious reasons dismissed, a study of relative fluctuations of water level in Þórisvatn and all the lakes to the east of it, may give a valuable guide to the amount of replenishment of Þórisvatn which may occur due to seepage. The artificial lowering of the level of Þórisvatn by about a metre, by deepening its outlet channel, would facilitate these observations and should not be too difficult.

None of the lavas younger than the Þjórsá Lava appear to to be present in the areas affected by the present schemes.

1 THE ÞÓRISVATN AREA

1.1 GENERAL

Lake Þórisvatn is lying on the north-western boundary of the so-called Palagonite or Móberg series, which covers almost the whole area between the rivers Kaldakvísl on the north-western and Skaftá on the south-eastern side, and between Vatnajökull on the north-eastern and the motor track Fjallabaksvegur on the south-western side, and, as a matter of fact, in some places extends far beyond these limits.
In the vicinity of Kaldakvísl, however, a different rock formation, the so-called Hreppar series, begins, extending from there over wide areas to the west-northwest.
The boundary between these two rock systems is not very marked, but at a distance of a few kilometres on each side of it a great difference is apparent, both in rock types and in landscape.

I. The Hreppar series is the oldest one in this area.
It will, therefore, be described briefly first, although it is found to a minor degree only at the sites near Lake Þórisvatn.

The Hreppar series is composed to approximately 50% of horizontal or slightly inclined basalt beds, with thickness varying from a few metres to a few tens of metres. In many places these beds may be traced continuously in the hill sides for distances of several kilometres. As to origin, most of them are lava flows, which have spread over a relatively flat ground.

The other components of this series are various types of clastic rocks, found in most places as thin partings between the basalt beds, but occasionally as lenses up to tens of metres in thickness. These clastic intercalations are partly tuff and breccia, which originally were loose volcanic materials, partly sediments such as siltstone, sandstone and conglomerates. Some of the conglomerates are evidently hardened moraines (tillites).

The rocks of the Hreppar series are, as a rule sound and tight, compared to what is usual in this country.

However, in the Þjórsá gorge, east of Norðlingaalda it may be observed that the sandy material of the clastic layers may be unconsolidated and of a loose consistency. But such flaws appear to be rare, and those found are small, hardly more than 10 m across and seem to be seperated from each other by hard rocks.

In the Hreppar series leakage may especially be suspected through (1) contacts between lava flows, as lava surfaces are in general very cavernous and jointed; (2) through breccia intercalations between the lava flows; (3) through vertical faults. But owing to the age of the formation, such leakage paths as were originally existing have to a great extent been clogged with indurated clayey material and with minerals (calcite, zeolites a.o.). The leakage is therefore presumably rather small, and there is, as a rule, no danger of piping at increased pressure; it is rather to be expected that the rock will be further tighted up by silt from the water.

Owing to the watertightness of the bedrock of the Hreppar series, very little amount of water from rain or from snowmelt percolates down through it; most part of it runs off in brooks and small rivers or in the form of ground-water in the loose surface beds overlying the bedrock. Streams originating in these areas are all of the so-called "dragá" type ("direct run-off streams") charasterized by great fluctuations in the discharge, due to seasonal and meteorological circumstances.

II. The Palagonite series is composed of two types of rock, (1) the palagonite rock (or móberg) proper, and (2) "irregular basalt" intercalations. On the map fig. 1. no distinction is made between these two types; both are shown as "palagonite rock".

(1) The palagonite rock is more voluminous, at least on the surface. Many mountains are solely built up of it. It is a clastic rock of basaltic volcanic materials. Its most fine-grained variety is tuff, consisting solely of finely ground basalt glass cemented together to a rather compact mass. Most of it has acquired a brown colour through chemical processes, but some parts still retain the original black colour. Other varieties of palagonite rock contain angular fragments of crystalline basalt of various size; occasionally these basalt fragments constitute the main part of the rock. In such breccias the space between the fragments is, as a rule, filled with tuff-like materials.

(2) The irregular basalt intercalations within the Palagonite series differ from the previously mentioned basalt of the Hreppar series by their irregular shape and jointed structure. Much of them are typical pillow lavas. In its most perfect form such a rock resembles a stack of sacks or pillows. The pillows are from ab. 10 cm up to a few metres in diameter; usual size being 30-50 cm. On their surface there is usually a thin (ab. 1 cm) crust of brown glass, but the interior is of microcrystalline basalt, split up into thin columns (some 5-10 cm across) as a rule radiating from the centre of the pillow. The rock is vesicular with the largest vesicles often arranged into roughly concentric layers within the pillow, and a relatively large cavity is often found in its centre. The pillows may lie almost close to each other, but where they do not, the intermediate spaces are more or less filled with a clayey or tuff-like material or with a breccia of pillow fragments. In many places empty holes also appear between the pillows and form caverns in

exposed rock walls. But possibly these holes were filled to a more or less extent while entirely enclosed within the rock; the filling material might have been washed away upon exposure of the holes by erosion.

Most of the basaltic intercalations in the Palagonite series have not the typical pillow structure described above; but they have all in common that the rock is crowded with joints splitting it up into very thin columns lying in all directions and often irregularly winding. Rosettes of roughly radial columns is a common feature on the rock walls, but most of them are not genuine pillows as they are not coated with a skin of glass nor otherwise distinctly demarcated from each other or from the surrounding rock.

Basalt intercalations with no or slightly developed pillow structure are generally less cavernous and presumably less pervious than those of typical pillow basalt. Both varieties will in the following be referred to as jointed basalts.

The jointed basalts seem to have invaded the palagonite rock from below, in a molten condition, and solidified within it like small intrusions. In a few or no cases at all they are seen to have spread superficially like lava flows.
In general, the amount of basalt in the Palagonite series seems to increase with depth; appearing mainly in the lower parts of slopes and gorges, while most mountain tops are of the palagonite rock only.

Compared to the Hreppar series the rocks of the Palagonite series are both unsound and very pervious. The palagonite rocks themselves (tuffs and breccias) are the most questionable. Although their outcrops use to be rather well indurated, flaws may be found in them with such a soft rock that it would hardly sit fast in the roof of a tunnel. Further, it should be kept in mind that the soft rock varieties are likely to make up a greater percentage of the whole bedrock than they do of the outcrops, because the landscape was modelled by selective erosion, especially by glaciers, and so the more resistant rock was liable to form eminences that became the present outcrops, while the soft rock was eroded to form depressions in which the bedrock is now mostly covered with moraine and alluvial deposits.
All palagonite contains fine pores and thus absorbs water coming into contact with it. During rains, pools may be formed temporarily on the surface of a palagonite rock. In a few hours, however, they will have disappeared again, even if measures are taken to hinder evaporation.

Apparently, the leakage is rather uniform within the palagonite rocks proper, and not confined to distinct channels.

Although much harder than the palagonite rocks, the basalt of this formation may, owing to its fractures be expected to be, in parts, rather badly suited for the roof of a tunnel.
This applies especially to pillow basalts with a tuff-like matrix. The basalts without pillow structure seems to be the most solid rock of the formation, and would presumably sit fast in the roof of a tunnel or a vault. As a whole, the

basalt appears to be less pervious than the palagonite rocks. An evidence of this is that springs often issue at such contacts where basalt is overlain by palagonite. However, springs issuing from jointed basalt, especially pillow-lava, are also frequently found, some of them large, indicating that the water is flowing in channels in this type of rock, rather than in the palagonite.

The boundary of the above-mentioned formations, the Hreppar series and the Palagonite series is not very distinct, because in the vicinity of Kaldakvísl are found some intermediate rock formations, which cannot with certainty be ascribed to the one or the other of them. They will be discussed later in connection with the individual sites at or near which they are present.

The formations mentioned above: The Hreppar series, the Palagonite series and the intermediate formations near Kaldakvísl, constitute the bedrock of the area in question. The building up of this bedrock was completed before the end of the Glacial Period. It mos mostly overlain by post-glacial, poorly consolidated sedimentary layers and by lava flows. The boundary between these "loose beds" and the bedrock is in general quite distinct in Iceland, because of the great difference in hardness of the rock above and below it.

But there are exceptions. (1) Loose beds are found within the bedrock, as already mentioned. (2) Moraine overlying the bedrock may be so hard (especially in its deeper layers) that it can be loosened neither by a pick nor by a bulldozer, and would, in daily language be classified as "rock". Examples of this will be mentioned later, when discussing individual sites. As the "loose beds" above the bedrock are very different from one site to another, they will not be described here, but in the discussion of the site where they are found.

1.2 LAKE ÞÓRISVATN AS A STORAGE RESERVOIR

The basin containing Lake Þórisvatn is lying within the Palagonite series, except for a part of its north-western shore (Ósöldur) where an older-looking formation is present. As to the origin of this basin, three possibilities come into question: (1) Glacier erosion, the rock within the basin having been less resistant than in the surrounding hills. (2) Subsidence, of tectonic origin. (3) Piling up of the surrounding hills by subglacial volcanism.

The last-mentioned explanation is the most probable, for the formation of the main features of the landscape, although both glacial erosion and tectonic vertical movements have certainly played a part too.

The lowest col of the brim of the lake basin is to the north, where the outlet of the lake has been ever since the retreat of the last ice sheet. Later on, a great lava flow poured from the east into the northern end of the lake and dammed it up, whereby the water level rose probably to some 20 m and the present outlet (Þórisós) was formed along the western edge of the lave flow. This happened in postglacial times, but certainly more than thousand years ago. Since then, the water level has been almost constant, or possibly sunk a few metres as the outlet has cut its bed down.

Possibly the damming up of the lake was performed in two stages by two successive flows of lava (cf. Dam Sites, I. 3. 1).

Practically the whole inflow of water to Lake Þórisvatn is subterranean and, therefore, not accessible for measurement. The exact size of the drainage area cannot be determined either, because the whole of it consists of pervious rock formations ; the palagonite series, which is the least pervious one, and lavaflows and pumice deposits, which seem to be extremely pervious. In such rocks, the direction of groundwater flow cannot be determined from the topography of the area.

The discharge of the Þórisós is relatively constant, 6 m^3/s in the outflow from the lake. But this is not the whole outflow from Lake Þórisvatn, there is a substantial leakage from it through the surrounding rocks.

The northernmost leakage area is the lava-dam north of the lake and east of the outlet. But here, the leakage water reappears in some big springs farther down at the eastern bank of the outlet river. As the proposed dam site on the river is situated below these springs, they do not mean any leakage from the reservoir.

The next part of the shore, viz. from the outlet south-west to Rjúpnadalur, mostly consists of solid basalt, and appears to be well watertight. But except for the two above-mentioned sections, viz. the lava and the Ósöldur basalt shore, the whole lake basin is contained within the Palagonite series. Through this formation, there appears to be a great leakage to the west, towards Kaldakvísl, and probably also to the south, towards Tungnaá. The leakage is greatest and most obvious through the thinnest part of the rock-thresold, viz. between Lake Þórisvatn and the Þóristungur area west of it. Numerous great springs rise at the foot of the hills in the uppermost part of Þóristungur (temperature 2, 6 to 3, 1°C). These springs flow together to a single stream, the Tjaldkvísl which, in turn, discharges into Kaldakvísl. The discharge of Tjaldkvísl has been found to be 7 m^3/s and fairly constant, corresponding to a run-off of 200 litres pr. second pr. sq. kilometre of the area within the topographic watershed. This amounts to five times the run-off that might be expected in this part of the country. Accordingly, ab. 80% of the discharge must come from across the topographic watershed, i. e. from lake Þórisvatn. However, not all leakage to the west from the lake reappears in Tjaldkvísl, a part of it reappears in springs feeding the Útkvísl and Blautakvísl and some other brooks flowing to Tungnaá, and probably in brooks discharging into Kaldakvísl far above the mouth of Tjaldkvísl. In the author's opinion, a fair estimate of the total leakage from Lake Þórisvatn through the part of the western shore lying between Fremri Ósalda and the southernmost inlet, Fitjarvík, would be 7-10 m^3/s. Along the eastern part of the southern shore and the eastern shore, water is probably entering the lake, rather than leaving it.

Of course, the leakage from the lake will be increased if the water level is raised, and vice versa, decreasing or increasing, respectively, the discharge available for utilization. It is impossible to estimate the exact amount of this decrease or increase, but the author considers it likely that they are very substantial even at a few metres variation in the water level. This assumption is based on the fact that in an extensive area soth-east of Lake Þórisvatn the ground-water table in the pervious rock formations is very much the same as the water level of the lake, as far as can be concluded from the level of ponds without a superficial outflow lying in this area. It is difficult to assess the direction of ground-water flow in this area, but it seems evident that a very small variation in ground-water level is required to revert the flow of the ground-water either into the lake, or away from it. In the author's opinion, the only possible way to get quantitative information on the effect of a changed water-level of Lake Þórisvatn on the ground-water flow (leakage) is to raise or lower (or preferably both) the level of the lake by means of a temporary dam or a draining trench at the outlet, and to measure the corresponding change in the discharge of the outlet. Even if the change in water-level amounts to a few metres only, this test would give very valuable indications of the effect of greater water-level variations.

1.3 DAM SITES ON KALDAKVÍSL AND ÞÓRISÓS

The crest level of the proposed dams is at 570-575 m above MSL, and two alternative sites are possible. At the upper one, A, two seperate dams are required, one across each river, with a conduit or a canal connecting the impounded water bodies. At the lower one, B, a single dam would extend across both rivers.

1.3.1 The upper dam site (A on map)

On the map (Fig. 3), this dam site is divided into sections designated with letters a to d, starting at the north-eastern end and going south-west. They will now be described in the same order.

At a, there is a small depression between Sauðafell and a low hill extending from it towards Kaldakvísl. Now, its elevation is 575 m or more so that no dam is, in fact, required, except when the dam crest level was to be higher than assumed here. The bottom of the depression and the foot of the adjacent hills consists of a sandy clay, unconsolidated at the surface and for at least several spadesticks down. This is the surface layer of a moraine, disturbed by wind action and solifluction. Presumably, a few metres down there is a better consolidated, undisturbed moraine, overlying the bedrock.. The depth to bedrock can only be assessed by boring or digging pits, but it is not likely to exceed 10 m. It is probable that the boundary between palagonite rocks (to the north) and basalts (to the south) lies through this depression. Both types of rock are sound and tight where they outcrop in the vicinity. The undisturbed moraine is also presumably sufficiently solid and tight to form a dam in itself across the depression, so that probably all that would be needed is a low cut-off through the uppermost loose moraine layer.

The hill between a and b is covered with moraine, except close to the river, where the underlying basalt crops out. Presumably, the depth to bedrock is much less throughout the whole hill than in the depression (a) behind it.

The section, b, accross the Kaldakvísl, will be the highest part of the dam (10-15 m). The dam site is very promising: the river is narrow here, and the river bottom and both abutments consist of basalt. This rock is considerably cracked, especially at eminent spots, but the numerous cracks, which are due to frost action, are probably confined to the surface layer. In the river-bed the rock is solid and tight, and the same is presumably the case elsewhere too, at a depth of 0.5-1 m. A thin, reddish layer may be seen in the basalt on both sides of the river. It is somewhat brecciated and scoriaceous and seems to be the contact between two lava-flows. But is is not appreciably porous and, in the author's opinion, there is little danger of leakage through it. However, if a leakage really appears, there might be a reason to grout the layer by injection.

South of the dam site on the Kaldakvísl, there is a low ridge, ab. 2 km long, and, in most places, sufficiently high to serve as a dam. It consists of basalt of the same kind as described above. The basalt crops out on eminencies, but is covered with moraine containing large boulders in depressions. At c there is a depression, requiring a small dam, if the water level is to be raised much. Otherwise, the ridge is certainly solid enough and presumably tight enough without any further measures.

The southern end of the ridge emerges from a higher hill, through which the water from Kaldakvísl must be conducted to the pond above the Þórisós dam, which, in turn, is a part of the main reservoir, Lake Þórisvatn. This may be done, either by a canal or by a tunnel (x in Fig. 3). The hill is covered with thick beds of moraine, but beneath it is a basalt of the same kind as mentioned above. In a borehole at the top of the hill, elevation 590.3, the basalt surface is lying at el. 575 m. Immediately overlying it (el. 575-583) is a rock of which it is not certain whether it is an exceptionally hard moraine or some clastic deposit belonging to the bedrock. In the borehole, the boundary is indistinct between this little indurated rock and the surface layers which consist of typical moraine (boulderclay).

In order that the roof be sufficiently strong, a tunnel must lie safely within the basalt. The buried basalt surface may be expected to be considerably uneven, and it must be explored by rather closely spaced borings along the tunnel route.

The section d, the site of the dam across Þórisós, is shown in cross section in Fig. 4. This cross section is based on 6 boreholes, designated A to F in direction SW to NE.

The depth to bedrock is great throughout this section, except the very northernmost part of it.

The basalt forming the bedrock to the north of Þórisós (Ib in Fig. 4) is found only in the northernmost borehole, F, where it proved to be very compact with little or no joints; core recovery up to 100%. The borehole did not reach the base of this basalt layer, so that its thickness is not known. In all probability it is underlain by clastic rocks (I a in Fig. 4).

In the southern part of the bore section (holes C, B and A) the bedrock was found to consist of a rather soft clastic rock with poor core recovery (34% in A and 25% in C).
The cores show a fine-grained breccia of basalt fragments in a black or brown, sandy or tuff-like matrix.
A great part of the core-stubs consist of basalt fragments which have got loose from the softer matrix, have been turned around with the drill and ground the rock down.
A considerable part of the core loss may presumably be attributed to this. However, some core stubs consist solely of the fine matrix while in others the matrix adheres to basalt fragments.

Judging from the cores this clastic rock (Ia on Fig. 4) is of the same kind as that outcropping in the banks of Kaldakvísl, some 3-4 km above the moth of Þórisós, where it lies beneath the basalt. The whole of this clastic layer is presumably a part of the clastic (tuff and breccia) formation which makes up the neighbouring mountains Ósöldur and Sauðafell.

(The rocks contituting these mountains and partly the low ground between them are mostly brown (palagonized) tuffs and breccias with some basalt intercalations, and so much reminding of the rocks of the Palagonite series. But the rocks of Ósöldur and Sauðafell look older, as they are in general harder and more compact, and they can hardly be ascribed to the Palagonite series proper. Besides they are in places covered with thick glacier-eroded basalt lava sheets (e.g. Ib in Fig. 4). These lava sheets bear greatest resemblance to the basalt of the Hreppar series. However, they may be much younger than the latter, but they are certainly not younger than from the last Ingerglacial Period. The Palagonite series proper, on the other hand, is most presumably not older than from the last Glacial Period, and nowhere in this area have glacier-eroded lava sheets been found lying on it).

The outcrop of fine-grained breccia at Kaldakvísl (presumably identical with that found in the boreholes) is a well indurated and compact rock in the river bottom, but disintegrated by weathering at the surface, where it is exposed to air, above the water.

The bedrock in Section d (both basalt and clastic rock) described above, appears to constitute safe dam-foundations, both as regards stability and watertightness. But as the depth to the bedrock is very great, up to 24 m, the construction of a cut-off down to it is hardly feasible.

Everywhere in the cross section a somewhat poorly consolidated bed (II on Fig. 4) is overlying the bedrock. Core recovery was very poor from this bed, only short basalt stubs, presumably from boulders lying scattered in the layer. In boreholes E and F, sandy clay adhered to some of the basalt fragments from the lowest part of the layer, indicating some induration, but otherwise the fragments were washed clean. Where this layer is found at the surface, on both sides of the lava, it was so loose that the boreholes had to be lined (A to a depth of 1 m ; F to a depth of 7 m) in order to prevent it from collapsing. Thus, the induration obviously increases with depth, and, as a matter of fact, the boundary between this layer (II) and the bedrock (I) is not marked in boreholes E and F. Fig. 4 shows the boundary in its lowest probable position. Undoubtedly this layer (II) mostly consists of moraine. In the author's opinion, there is every indication that this moraine is sufficiently indurated and tight to serve as foundations for a dam of the height in question here, with exception, however, of the surface layer where the holes had to be lined. Otherwise, the boundary between this moraine and the overlying lava is the most questionable part of the site (see later).

After the melting away of the last Pleistocene ice-sheet a stream flowing from Lake Þórisvatn and discharging into Kaldakvísl has cut its bed into the moraine, at right angles to the line of boreholes. Later, this river bed has been filled up to its banks by lava flowing from the east (III in Fig. 4), the same lava flow as raised the water level of Lake Þórisvatn, as described above. The borings revealed that the bottom of the lava (viz. the bottom of the filled river bed) is at el. 550.5, and that the thickness of the lava is up to 22.5 m. Thus, at the dam site, and obviously, therefore, also from there down to Kaldakvísl, the river bed has been cut almost down to the water level of Kaldakvísl at its mouth. In Fig. 4, the lower boundary is conjectural between the boreholes and may be in error of a few metres. But as the bottom of the gorge obviously was sloping very little, it was probably broad and flat. Therefore, the author considers it very unlikely that the bottom of the gorge is anywhere appreciably higher than in borehole C, viz. at el. 550.5 m. The probability of error in the figure is greater near the edges of the lava, on the banks of the gorge. The lava is of the "helluhraun" ("pahoehoe") type, but its surface is considerably uneven and broken up at the dam site. It contains large white feldspar crystals like the

Þjórsá lavas, and is in most respects of the same appearance. It is possible that there are two seperate lava flows of different age, the older (lower) one just emerging from beneath the other at the dam site at the western edge of the lava. In the banks of Kaldakvísl this same lava is in some places divided horizontally into two sheets by a breccia-like intermediate layer. In other places the lower sheet extends farther than the upper one, the latter forming an edge. Some rather large springs issue at the boundary of the two sheets. All this indicates that there are two lava flows rather than one although not proving it. The borings did not answer this question. As a matter of fact, cavernous zones with great core loss were found in between a more solid lava. But these cavernous zones could not be traced from one borehole to another at corresponding depths and thus do not appear to divide the lava into horizontal sheets, as would be expected if they were forming the contact of two lava flows of different age. On the other hand, the structure of the lava varies just as much in horizontal as in vertical direction, viz.: It is most solid in the middle (hole C), but more cavernous near both edges, where it is also thinner.

Undoubtedly, if a dam was built on the lava without taking any further measures, there would be an appreciable leakage under it through the lava. In order to restrain this leakage completely it would presumably be necessary to carry a cut-off or a grouting curtain down through the lava. If this method was adopted, the cut-off should evidently be carried one or a few metres further down into layer II, as the upper surface of the latter is also questionable, owing to its seemingly poor induration. In the author's opinion, a cut-off through the uppermost, cavernous part of the lava only (e.g. 5-10 m down) would presumably be of great value, and there would probably not be a severe leakage through the lava beneath it. There would presumably be no danger of increase in this leakage due to piping; on the contrary it appears more likely that it would decrease due to silt from the muddy water of the Kaldakvísl.

1.3.2 The lower dam site (B on map)

At this site, a single dam, about 1200 m long with a max. height of approx. 25 m above the river bed of Kaldakvísl would extend across both rivers. The height above the Þórisós river bed would be approx. 15 m.

The geological structure is shown in Fig. 5. The lowest part consists of a clastic rock (I), of a similar structure as the breccia recovered in cores from the boreholes at the upper Þórisós dam site. The latter was described above as a hard, tight rock, which, however, is apt to disintegrate at the surface, where exposed to frost action. West of Kaldakvísl a basalt-roof (Ib) is overlying the breccia. As to origin, it appears to be a single lava sheet and consist of solid rock. These two rocks, the breccia and the basalt, constitute the bedrock. Generally, the latter looks very solid and tight, and should be well-suited as foundations of a dam. The zones where leakage is most likely to occur

through the bedrock is at the contact of these two types of rock, north of Kaldakvísl, and their surface, where it lies exposed and is somewhat fractured by frost action.
The first weakness may be corrected by injection grouting (if necessary) and the second by removing the uppermost, fractured surface layer, which is hardly more than 1 m thick.

In most places the bedrock is covered with moraine and detritus. The moraine covers the whole of the dam site south of Þórisós. But some outcrops of the underlying palagonite breccia, found at the river´s bank and in some shallow ravines near the southern end of the proposed dam, indicate that the moraine is very thin, hardly more than one or a few metres in thickness. Where the rock is covered with moraine, it is presumably solid and without fractures (unweathered). Should the moraine prove to be thicker than this, its bottom layer may be expected to be solid enough and tight enough for the dam to be founded upon.

North of Kaldakvísl, very little or no moraine is covering the bedrock, but there is some scree and talus which, of course, must be removed. This is especially the case in a narrow trench on the northern bank of the gorge of Kaldakvísl. A seperate dam must be built across this trench. The trench may be a fracture or fault in the bedrock, in which case it might cause some leakage, but more probably the trench is water-eroded and the rock unfractured. Which is the case will be decided when the talus is removed.

Finally, poorly indurated layers may be expected beneath the lava tongue between the rivers. Actually, such a layer is seen under the lava in the southern bank of Kaldakvísl. It consists of a sandy, wind-blown soil (a kind of loess) and is poorly indurated. This old soil forms small lenses, up to 1 or 2 m thick, between the overlying lava and the underlying bedrock.

The ancient (pre-lava) river bed of Kaldakvísl, which must be lying buried beneath the lava tongue, cannot possibly be more than a few metres deeper than the present bed at the dam site. More likely, however, the ancient bed was slightly shallower than the present one. In the ancient river bed, poorly indurated and somewhat pervious gravel deposits may be expected, although there is all evidence that it is thin (less than 1 metre) or even wholly absent; the river having flowed on a rocky bottom. It is difficult to guess the width of this ancient river bed; probably it is underlying a substantial part of the lava tongue. A thin moraine layer, similar to the one described above on the southern bank of the Þórisós may be expected on the banks of the old river bed. In general, there is every indication that the loose or poorly indurated sedimentary layer (moraine, gravel alluvium and soils), to be expected between bedrock and lava, is thin and discontinuous.

The lava (III in Fig. 5) is the distal end of the same flow as that of the upper dam site on the Þórisós. It ends abruptedly ab. 0.5 km downstream of the lower dam site;

the foot of its steep front is at el. 547 m. At the dam site, the lava sheet can nowhere exceed 10 m in thickness; probably it is much thinner in most places (cf. the above description of the underlying layer). The lava is also here of the "helluhraun" type and appears to be quite conventional in all respects. On flat spots and in depressions it is to a considerable extent covered by wind-blown sand. It is, of course, pervious. As the height of the proposed dam is considerable, there is hardly any choice but to carry a cut-off through the lava flow and, naturally then, also through the loose layer probably underlying it. The thickness of both may easily be determined by drilling.

1.3.3 The reservoir area

If the crest elevation of the lower dam is 575 m, the inpounded water will reach Lake Þórisvatn, raising its water level by several metres. Apart from this, the reservoir will lie solely in the Kaldakvísl valley. Lake Þórisvatn was discussed above, and it was pointed out that there obviously is a leakage from that part of the reservoir basin.
The Kaldakvísl valley, on the other hand, is different. It is cut into the bedrock, which throughout the proposed reservoir and far beyond it consists of old and relatively watertight formations resembling the Hreppar series (although it can hardly be ascribed to it). These formations are the breccia and the basalt described previously in this chapter. Both appear to be tight and sound rock. The breccia underlies the basalt. It forms all the rapids in the Kaldakvísl along the lava tongue and the lower part of the rock walls of its northern bank. There, its contact with the basalt is almost horizontal. On each side of the river valley this breccia forms two mountains, Sauðafell and Innri Ósalda. The basalt has presumably flowed as lava close to the slopes of these mountains. However, it nowhere appears to be found south of Þórisós. It constitutes the bedrock at the upper dam site on the Kaldakvísl and presumably underlies the whole reservoir area upstream from there.

As already mentioned, the whole reservoir basin (upstream from the lower dam site) has been cut into this bedrock. As a matter of fact, the latter is very extensively covered with pervious layers, especially lava, but also with moraine, gravel deposits and scree. This is, however, of no importance, because everywhere around the proposed reservoir, except at the dam sites and at Lake Þórisvatn, the bedrock reaches far above the level of the impounded water. On the other hand, the pervious layers may possibly conceal some leakage paths in the bedrock, e.g. faults. In the author's opinion however this is very unlikely to occur to any extent; no such fault has been found in the area, except for the possibility that the trench mentioned above at the northern abutment of the lower dam might be of this kind.

Time has not permitted the author to prepare a detailed geological map of this reservoir area. From the point of view of the watertightness of the bedrock, such a map would really not be of much value, as the latter is in most places covered. In this respect hydrological study would not be less informative than a detailed petrological survey. Throughout the whole reservoir area and far beyond its boundary, surface water features (springs ; brooks ; pools) show that the ground-water table is sloping inward, to the centre of the area, and nowhere in the opposite direction. In the author´s view, this latter fact together with the geology of the area, as described above, fully proves that the reservoir basin is reasonably or very well watertight.

1.3.4 Comparison of the dam sites

An advantage of the upper dam site compared to the lower one is that the dam(s) there would be lower for the same water level of the reservoir. A disadvantage, on the other hand, is that the depth to bedrock is very great in a section of the site, viz. at the Þórisós, so that a cut-off trench down to bedrock would be very deep and would, among other things, have to be cut through a thick lava flow. On the lower site, the dam would be higher, but the lava sheet is much thinner there and the depth to sound bedrock is everywhere very shallow outside the lava tongue. Restraining of leakage would be easier at this site.

1.4 DRAINING TUNNEL FROM LAKE ÞÓRISVATN

It has been suggested to lower the water level of Lake Þórisvatn temporarily while the civil engineering phase of the development is being carried out. This lowering might be quite substantial; up to 50 m has been tentatively put forward. There are two possible routes for a draining tunnel. They are shown on the geological map (Fig. 6) and in the cross sections (Figs. 7 and 8). In the cross sections, the rock types shown are, of course, conjectural except at the surface and the error may generally be expected to increase with depth. As a matter of fact, other rock types than those shown are not likely to be present in the tunnel line, but the boundaries between them may in places be quite different from what is shown on the figure.

Clastic rocks are the oldest of the rock types present. They are for the most part (palagonite) breccias similar to those at the dam sites on the Kaldakvísl and the Þórisós, but most of them are probably older and look more compact and harder than the similar rocks of the Palagonite series proper. Basalt intercalations are rare in these clastic rocks.

The tunnel route in Rjúpnadalur (Fig. 8) is obviously for its greatest part lying through the breccia. However, nothing can be said definitly of the easternmost part of the route on account of the thick cover of moraine. If clastic rocks should also be met with there, they are presumably of the younger and less sound type, as this part is within the area of the Palagonite series proper. Another possibility is that the moraine is so thick in this part of the route that it extends down to the line of the proposed tunnel.

Next in order of age is the basalt of the Harðhausar. It is a hard crypto-crystalline rock almost without vesicular and columnar structure but showing strong flow structure. The flow bands or lamellæ are much inclined, in most cases almost vertical, although they may be found having any direction. Where exposed, the rock is weathered into thin, often surprisingly strong, slabs parallel to the flow structure. Where it is unweathered, the rock is presumably very solid. This basalt makes up the Harðhausar hills, extending from Rjúpnadalur a considerable distance to the northeast along Lake Þórisvatn, in the south-eastern slope of the Ósöldur. In the northern slope of the Rjúpnadalur valley the basalt is clearly overlying the breccia, the contact dipping slightly to the east. Farther north-east the dip must be much greater as there the whole slope down to the lake level consists of basalt. However, it is not thereby certain that this basalt reaches farther down than to the proposed tunnel (el. 525 m). To the author, the origin of this basalt is somewhat obscure. It does by no means resemble a lava flow; it is possibly an intrusion exposed by a complete denudation of the overlying rock.

The youngest bedrock formation in this area are some basalt beds lying at the foot of the Ósöldur, on the north-western side. The author has ascertained that they are overlying the breccia, which is the main constituent of the mountain. As to origin these basalt beds are undoubtedly lava flows, which have flowed after the mountain had, in main, acquired its present shape, but before the end of the Glacial Period. Some of these basalts have doleritic (fine-grained), others crypto-crystalline texture; in other respects they are similar to the basalt at the dam site on Kaldakvísl. Only if the proposed tunnel through Ósöldur lies below el. 535-540 m will its northern end reach the basalt.

On both tunnel routes, the loose beds overlying the bedrock mostly consist of moraine. On the northern route the moraine cannot possibly be so thick anywhere that is reaches the tunnel line, except close to the mouths. On the southern route, on the other hand, the thickness of the moraine is very great in places and, besides, the depth to the proposed tunnel is less there than on the other route. The tunnel would presumably lie in moraine for a distance of several hundreds of metres near its western end, and possibly for a much larger part near the eastern end too. At its western end the tunnel would be lying so near the surface in the moraine deposit that the latter would undoubtedly be too loose to support the roof, so that the tunnel would in this zone have to be replaced by an open cut. If the moraine does reach the tunnel line on its eastern part the tunnel will there lie so deep inside the moraine that the latter may be expected to have gained an appreciable induration, although hardly sufficient fo support a tunnel. For the construction of a tunnel at this place, therefore, the location of the contact between the moraine and the bedrock (presumably breccia) is of great importance. On the cross section (Fig. 8) this contact line is drawn according to the author's judgement which is not based on much evidence. Throughout an extensive uneven area to the south of Rjúpnadalur, outcrops of bedrock are nowhere apparent. The depth to the bedrock, therefore, appears very great in this area.

If constructed approximately at the elevation assumed above, the tunnel must be lying below the ground water table for practically the whole of its length on either route. Accordingly, some leakage will undoubtedly be experienced in it. To the author, however, none of the rock types present on the tunnel routes appear particularily pervious except perhaps a young palagonite rock that may be present on the eastern part of the southern line. The basalt of the Harðhausar ridge appears to be very well watertight, as may be seen from the fact that almost every depression in the bedrock is filled with water up to its limits (cf. the small lakes shown on the map). Should this basalt extend well below the proposed tunnel line on the southern part of the northern route, it may be expected to protect the northern part against leakage from Lake Þórisvatn. The same effect might be expected from the moraine on the eastern part of the southern route if it proves to reach below the tunnel intake there.

1.5 TUNNEL FROM LAKE ÞÓRISVATN TO ÞÓRISTUNGUR

Here, three alternative routes have been proposed, designated A, B and C on Fig. 9. The geological structure on routes A and C is shown in cross section on Figs. 10 and 11. It is very similar on both these routes, and route C does not appear to be substantially different except that the tailrace tunnel would be much shorter on this route and be lying at an higher elevation. Of course, the cross sections are schematic only. They may be wrong on one important point: The formation considered oldest there (the basalt in Þóristungur, designated I) and shown disappearing below the palagonite formation (II and III) may actually be younger than the latter, in which case it would terminate abutting against the foot of the palagonite mountains (cf. the basalt at the northern side of Ósöldur, mentioned previously). Otherwise, the Þóristungur basalt is very similar to the basalt beds of the Hreppar series found in Búðarháls, a hill on the west side of the Kaldakvísl, and most likely then, is an extension of this series to the east. However, this assumption can only be proved by tracing the boundary between the basalt and Palagonite series and finding out which one is lying above and which one below the other. At the surface, this boundary is everywhere hidden by a cover of moraine or postglacial deposits, but it may easily be detected by borings.

The Þóristungur basalt is lying in almost horizontal beds, which may be some 5-10 m in thickness. Clastic layers, similar to those of the Hreppar series, may be expected in between the basalt beds. A glimpse of such a layer may be seen in the eastern bank of Kaldakvísl, at the mouth of the proposed tailrace tunnel, consisting of a solidly looking, fine-grained sedimentary rock. The upper surface of this layer lies just above water level of the river; its thickness cannot be assessed. The whole of this formation (both the basalt and the intermediate beds) appears to be quite solid and watertight. The tailrace tunnel will lie through this formation, for its most part at least, regardless of whether route A or route C be chosen, but it is uncertain whether or not the formation will reach the underground power house. On the northern route (A), this rock is everywhere covered by loose overburden, and it must be assumed, therefore, that there may be hidden depressions in the bedrock, which might even reach down to the tailrace tunnel. On the southern route (B), on the other hand, this possibility is remote, as there are rock outcrops at short intervals along this route.

On both routes (A and C) the headrace tunnel will be in the Palagonite series, partly in palagonite rocks (III), partly in basalt of the jointed or the pillow type.
The intercalations of jointed basalt increase with depth, and below el. 400-420 m the rock in the foot of the mountains Hánípa and Stóragilsalda, as well as in the whole of the Blágilsjörvi, consists solely of this basalt. However, bodies of basalt may also be found higher up in the hills, where they presumably are irregular intrusions spreading up through the palagonite. This basalt is much harder than the tuff and should be better suited for a tunnel roof. Besides, it is less pervious as in indicated by the following points :
1) Springs are in many places found issuing at the boundary where the basalt is overlain by the palagonite rock.
2) On the top of the Blágilsjörvi, which appears to consist mostly of pillow-lava, there are pools or small lakes, which had not dried out in the middle of August last summer (1958) and the rivulets present there do indicate that the surface run-off is considerable; a feature generally very little prominent in the area of the Palagonite series. Similar is the case of Lake Efra-Launvatn. It is lying at a high elevation, but it apparently never dries out. It often has an outlet flowing to Lake(Neðra-)Launvatn. On the 12. Aug. last summer, the water level of Efra-Launvatn was only 20 cm below the outlet col, although Neðra-Launvatn, a much larger lake, was at the same time completely dry, which has, as far as is known, never happened before. The ground-water table, therefore, must have been exceptionally low last summer. In the uppermost part of the outlet gully trench from Efra-Launvatn, outcrops of jointed basalt are found. It is the author's hypothesis that this body of basalt may extend below the lake and form the impervious bottom of it, the lake thus being a perched water table, while the natural ground-water table may well lie far below it.
The Efra-Launvatn might disappear if a borehole was sunk through its impervious bottom.

As a matter of fact, from the scattered outcrops of basalt and palagonite rocks on the headrace tunnel routes, A, B and C, nothing can be concluded as to the distribution of each rock type at a depth of several metres (or even tens of metres), except that there is a slightly greater probability to find basalt at depth where basalt is present at the surface. A more detailed geological map would give little or no more information on this point, owing to the irregular shape of the rock bodies. Such information can only be acquired by drilling.

Little indurated or quite loose surface beds (IV) cover most of the bedrock in this area, especially in depressions and on flat grounds. The most voluminous of them is the moraine, lying at their base, immediately on the bedrock.
Besides, it is by far the best indurated of them all, even to such an extent, that its hardness is in some cases slightly or not at all different from that of the softest tuff, and in daily language, such a moraine would also be called "rock". A layer of such a "moraine rock" or "palagonite moraine" is found in some places mantling the palagonite series on the tunnel routes between Þórisvatn and Þóristungur, and it may also be expected to be present under the more recent loose beds in depressions and on flat grounds. The thickness of this mantle is commonly 2-5 m. It forms an intermediate transition between bedrock and "loose surface beds", although it is included in the latter (IV) on Figs. 10 and 11.

Of the loose soil beds, all others are too poorly indurated to support a tunnel. They are: 1. "usual" clayey moraine, a real boulderclay, very loose at the surface. It is probably the most voluminous of these materials, especially in depressions. 2. Loose shingle and sand, free from clay, occurring on the tunnel routes at Snoðnafit (route C) and probably on the bottom of the lake (on routes A and B). 3. Loose alluvial gravel on low flat grounds in Þóristungur, especially near Stóragilskvísl, on route A. 4. Scree on the lower parts of the slopes of Hánípa and Stóragilsalda. 5. Soils (wind-blown soils and peat) in Þóristungur.

It seems evident that the tunnel route should be selected in such a way that the loose surface beds nowhere reach down to it. In the author's opinion, it is unlikely that the tunnel routes, as shown on Fig. 9-11, will anywhere lie through these loose beds, except, perhaps, in the immediate proximity of the ends. This is, however, by no means certain.
On route A there are two questionable zones, viz. the depression south of Launvatn, and the gravel alluvium of the Stóragilskvísl, to the west of Hánípa. The first part may easily be avoided, e.g. by selecting the route Ab, and the second also, by moving the tunnel some 0.5 - 1 km to the south for the part of the route which would cross a possible depression in the bedrock under the Stóragilskvísl alluvium.

On routes B and C the tunnel would almost certainly lie completely within the bedrock. It should be noted that the above statement applies to tunnel lines at the elevations shown on Fig. 10 and 11 (headrace tunnel at el. 495-522 m, tailrace tunnel at el. 335 m approx.). At higher elevations, of course, loose soil beds may be expected at more locations along the route, as will be obvious from the figures.

Evidently, the tunnel lines (as shown on the figures) will lie below the ground-water table for nearly their whole length, except possibly for a 1 km section at the west-end of the headrace tunnel on route A, beneath Hánípa, and a still shorter section on route C, beneath Stóragilsalda, where the tunnel might lie above the ground-water table.

(The lowest elevation of the ground-water table may be assessed by observing the max. el. of springs issuing from the slopes of these mountains. These springs are found at el. 500 m approx. in the innermost part of the Stóragil gorge and up to el. 550 m on route C, on the eastern slopes of Stóragilsalda.

Leakage will inevitably be met with in all sections lying below the ground-water table as the driving of the tunnel proceeds. The intensity of the leakage depends upon the permeability of the rocks and the head of ground-water.

The rocks are most pervious on the headrace sections of the tunnel lines, where it is mostly palagonite tuffs and breccias, and there will obviously be a considerable leakage, increasing towards the intake. - Still greater leakage may, however, be expected in the lower parts of the vertical penstock shaft connecting the power house with the surge basin, because of the great depth below the ground-water table. As a matter of fact, the rock down there may possibly be appreciably less pervious, but this may be expected to be more than compensated for by the increased pressure. - The danger of an objectionable leakage is least in the tailrace sections, owing both to the comparatively tight rock (the Þórisrungur basalt) and to the shallow depth of the tunnel below the ground-water table.

Should the method of lowering the water level of Lake Þóris-vatn nearly down to el. 530 m by draining (cf. 2) be adopted while the civil engineering works are being carried out, then it is likely that the ground-water level in the tunnel routes A, B and C would thereby be lowered to such an extent that an appreciable part of the headrace tunnel would lie above it. On the other hand, the effect of this measure on the ground-water table in the route of the tailrace tunnel would be negligible.

2 THE FOSSÁRDALUR AREA

2.1 GENERAL

Apart from the dam across the rivers Þjórsá and Tungnaá at Sultartangi, all the civil engineering works of hydro-electric developments in Fossárdalur are lying within an area, where the whole bedrock belongs to the Hreppar series. As previously mentioned, the Hreppar series consist of approx. 50% basalt and 50% clastic rocks of various kind, both types generally being a sound and watertight rock (cf. 1.1).

2.2 DAM SITE ON THE ÞJÓRSÁ AND TUNGNAÁ RIVERS

The geological structure at the dam site on the Þjórsá and Tungnaá rivers to the east of Sandafell is shown schematically in Fig. 12. The thickness of the rock beds shown is conjectural only; in places they may well be twice as thick or only half as thick.

The bedrock (I) consists of the Hreppar series until to the east of the nameless hill in the middle of the cross section. In the vicinity of the dam site the bedrock crops out only in this hill and in the western bank of river Þjórsá, 100-200 m upstream from the dam site. In both places it consists of sound basalt.

In the easternmost part of the cross section, the bedrock is presumably made up of the Palagonite series (II); its main constituent being palagonite rocks (tuffs and breccias) similar to those of the Þórisvatn area. But the bedrock here is covered with lava flows, and it is nowhere visible until in Valafell and other palagonite hills to the north-east of it.

Next in an order of age is a thick moraine deposit (III) covering the south-eastern slopes of Sandafell, opposite to the mouth of river Tungnaá. It consists of a sandy clay, light-grey in colour, with pebbles embedded in it. It is so well indurated that it may well be called a "rock", and it also forms the high, steep bank of river Þjórsá. In spite of its hardness, this typical boulderclay can hardly be regarded as a part of the bedrock, on which it is resting discordantly. Basalt is nowhere seen overlying the boulderclay. It is impossible to assess the thickness of this rock at the dam site, but it may be expected to become thinner in direction north, because 100-200 m north of the site, only the underlying basalt is exposed in the bank of the river.
Of course, moraine may also be expected to be overlying the

bedrock in the river bed of Þjórsá and beneath the lava to the east of it, although this is not indicated in Fig. 12. Although all moraine visible on the dam site is rather well consolidated and would apparently form sound and tight dam foundations, weak zones (e.g. sand lenses) may lie buried in it, and thus is should not be fully relied upon until it has been examined by test pits or boreholes.

The lava flow (IV) is a Þjórsá lava and has flowed a long distance (some 30 km)from avolcanic fissure in the east before reaching the dam site. Three successive lava flows are known with certainty to have flowed all this way and spread over all flat ground. Thus, the lava sheets present at this location are three as a minimum, although the uppermost (youngest) one only is visible near the dam site. It is quite possible, however, that deep pools or channels in the bed of river Þjórsá may reach down through it. Layers of poorly indurated material (alluvial gravel, pumice and wind-blown sand) may be expected at the boundary of two lava sheets, as well as a broken-up surface layer in each sheet. The total thickness of all the lava sheets may well amount to 100 m, which is undoubtedly too much for a cut-off under the dam to be carried down through all of them. Grouting by injection would also be a tremendous undertaking. But there is a probability that the lava flows are, in parts, relatively impervious. The reason is that they may have been tighted up to a considerable extent by glacial silt from the water of Þjórsá and Tungnaá rivers. The former beds of these rivers have been completely filled by every new lava flow, forcing the water to flood wide areas of the lava in braided arms. Perhaps, the silting up of the lavas by the muddy river water has made them considerably less pervious than they were originally. Therefore, it is possibly not out of question to carry a cut-off only down through the most jointed and pervious layer at the surface of the uppermost lava flow (e.g. 1-10 m down, depending on the conditions). But there would undoubtedly be a considerable leakage (several m^3/s) under such a dam.

In the easternmost part of the cross section, the front edge of a lava flow from Hekla (V) may be seen. Like all Hekla lavas, it is of the "helluhraun" ("aa") type and consequently very cracked and pervious. This lava is younger than the youngest of the Þjórsá lava flows (which are all of the "helluhraun" type), and may be expected to be still more pervious than these. It is resting on the youngest Þjósrá lava sheet at el. 290 m approximately. A sandy pumice bed of a considerable thickness is presumably present at the boundary. If the water level is raised more than up to this boundary, there is the danger of a great leakage through the bottom layer of the Hekla lava and through the pumice bed.

In parts, quite loose surface beds (IV) are covering the bedrock at the dam site. But they seem nowhere to be very thick, except perhaps some heaps of scree and wind-blown sand at the foot of the basalt hill rising from the Þjórsá lava, and wind and water-borne sand lying in a shallow valley (Leirdalur) at the edge of the Hekla lava flow, where the thickness may amount to 5-10 m.

Finally, there is a loose loessial soil grown with grass on the river banks and some wind-blown sand in depressions of the lava (not shown in Fig. 12). The thickness of these loose beds usually does not exceed 1 metre. Of course, they must be removed before a dam is built at the site.

2.3 TUNNEL FROM SULTARTANGI TO THE FOSSÁRDALUR VALLEY

In the cross section in Fig. 13 is shown, in main, the geological structure on the tunnel route. All rocks here belong to the Hreppar series, although they are rather variable.

In the lower parts of the western slopes of Stangarfjall, there is rhyolite (I) and various kinds of clastic rocks (II). These rocks are mostly hidden by soil and scree on this side of the Fossárdalur valley. It is, therefore, impossible to trace their contacts, which seem to be irregular, in detail. The rhyolite seems to predominate near the foot of the slope but not to reach higher than to el. 320 m approx. Above that the clastic rocks are predominating, although containing numerous irregular basalt intercalations. The structure of all these rock types (I and II in the cross section) as well as their mutual arrangement is much better exposed in the opposite side of the valley, (in Fossalda) and will, therefore, be described in the next section (2.4). The rocks are probably similar on both sides of the valley.

Above the clastic rocks (II), including the irregular basalt intrusives, horizontal beds of very solid basalt (III), make up the flat top of the Stangarfjall. The contact plane between the clastic rocks and the basalt must dip to the east, because the eastern slope of the mountain, down to its foot, appears to consist almost solely of basalt. As a matter of fact, a small outcrop of breccia may be seen in the Bleikkollugil gorge near the tunnel route. But this is presumably only a lens between basalt beds. Otherwise, all rock outcrops near the tunnel route, from the western edge of Stangarfjall until east of river Rauðá are of basalt of a very similar type. The bedrock of Sandafell is to a very great extent covered, especially on the western slope. However, it appears to consist mostly of solid basalt beds, which are best exposed in the bank of river Þjórsá at the foot of the mountain a short distance below Skúmstungur. Higher up clastic rocks appear to be present in a considerable magnitude, presumably as intercalations within the basalt.

There seems to be no danger that moraine or other loose beds (IV) are anywhere on the route of such a thickness that they might reach the tunnel in the position shown in the cross section (viz. at el. 250 m approximately), except, near the intake at the western bank of river Þjórsá, where the relatively hard moraine described above (2.2) covers the bedrock. But as previously mentioned, this moraine extends a short distance only to the north of the dam site. By locating the intake 100-200 m north of the dam, this moraine would be very thin on the tunnel route, or even completely absent.

The tunnel will lie everywhere below ground-water table, and there will, therefore, be some leakage wherever pervious rocks are encountered.

Of the rock types present on the tunnel route (cf. Fig. 13), III is the most promising one, being both solid and relatively tight, whereas II is the most questionable; presumably pervious and, in parts, poorly consolidated.

As a matter of fact, the boundary between these rock beds shown in the cross section is conjectural only. It is evident, however, that the part of the tunnel lying through III may be increased in length by driving the tunnel at a higher elevation than shown on the figure, thereby shortening the part lying through II by a corresponding amount. Before selecting the elevation of the tunnel, the height and dip of the contact between these two formations must be explored by drilling.

2.4 TUNNEL THROUGH FOSSALDA

A hedrace tunnel, ab. 3.25 km in length, lying at el. 470-460 m is comtemplated from a storage reservoir in Fossölduver through the eastern parts of Fossalda, to an underground power house located beneath its south-eastern slope. From there, a 2.15 km tailrace tunnel, at el. 180 m would lead to the Fossá river.

The most voluminous and oldest constituents of Fossalda are clastic rocks of various types. Subsequently, they were invaded from below, first by a massive intrusion of rhyolite and then by numerous small basalt intrusions (veins and dykes).
Much later, after the Fossalda had been shaped as a separate moutain by erosion, basaltic lava flows coming from the north and the east poured up to its sides, but dit not flow over the summit. This took place long before the end of the Glacial Period, and all the rocks just mentioned belong to the Hreppar series. Later still, the Fossárdalur valley was cut into the south-eastern part of the mountain, and now the name Fossalda only applies to the part of it lying to the north-west of the valley, whereas the south-eastern part is called Stangarfjall.
The distribution of the above-mentioned rocks is rather clearly apparent in the north-western slope of the Fossárdalur valley. Owing to the short distance from that slope, the rock distribution must be similar on the tunnel route.

Fig. 14 shows the geological structure to be expected in a longitudinal section of the tunnel route.

The rhyolite is visible only in the lower part of the southern and eastern slopes of the Fossalda. Its max. elevation is ab. 320 m in the southern end of the mountain. But inner in the Fossárdalur valley and nearer to the tunnel route its upper surface is indistinct, as it is in most places covered with soil or scree, as well as the debris of two great rock slides from the mountain. In this section, the rhyolite seems hardly to reach higher than to el. 220-260 m. In the river bed of the Fossá, the rhyolite forms a solid and compact rock, often light-green in colour. In general, the rock may be expected to be of this structure at some depth. On the other hand it is very much disintegrated at the surface, wherever it is exposed to weathering. Innumerable thin basalt dykes cut through the rhyolite in all directions. Many of them are dipping 45°, mostly to the north. These inclined basalt sheets reach beyond the limits of the rhyolite, some distance into the overlying clastic rocks.

In Fig. 14, no distinction is made between the clastic rock and the basalt intercalations (both are designated with II). Neither is such a distinction possible because of the irregular interweaving of the two rock types, nor could it be shown on a map, except one of a much larger scale than available. But even if these details were traced on a map exactly as they appear at the surface, it would not give much information on the rock present in a given location in the tunnel at a depth of more than 20 m, because of the irregular spreading of the basalt veins through the clastic rock. As to the distribution of each rock type, it must suffice here to say that the basalt intercalations seem to increase with elevation. In the precipitous rock wall (el. ab. 480 m) and in the dome-shaped mountain top above, both rocks may be present in approximately equal quantities. The structure of the clastic rocks is that of a coarse breccia with great amount of basalt fragments to a fine-grained tuff. Some of the tuff in strangely light in colour and so soft that it may resemble recent wind-blown earth. The basalt intrusions are mostly fine-columnar, fractured into small cubes; it may be brecciated and pillowy. Its joints and cavities are generally filled with a brownish tuff-like material.

The basalt beds (III) are the continuation of the basalt forming the top of Stangarfjall, described above (2.3). In the steep head of the valley, west of the waterfall Háifoss, this basalt sheet may be clearly seen lying discordantly on the clastic formation and thinning out towards the west, against the eastern slope of Fossalda. This basalt forms the riverbed of the Fossá in the section from Fossölduver to Háifoss, where it has been eroded by the river to a small degree only. But on flat grounds on both sides of the river, the basalt is entirely covered with moraine and soil. Therefore, its western limit is indistinct, except in the side of the valley.

Loose surface beds (IV) on the tunnel route are:
Moraine, on the northernmost part of the route; moraine and scree at the foot of the slopes, down in Fossárdalur on the route of the tailrace tunnel, and alluvial gravel near the Fossá river, on the southern part of the tailrace tunnel.
It is very unlikely that any of these formations is so thick that it reaches the tunnel, as the latter is shown in Fig. 14, with the exception of the river gravel near Fossá. The thickness of this deposit may be considerable (tens of metres), as the river has obviously been dammed by a lavaflow farther down and then presumably filled up its former deeper lying

bed. As the river gravel is undoubtedly too poorly consolidated for a tunnel to be driven through it, the latter must in this section be replaced by an open canal.

Most of the headrace tunnel must be lying above the groundwater table, and presumably the whole of the section lying in the clastic rock formation. This is fortunate, as in the whole length of the tunnel, the probability of encountering porous rocks is greatest in this formation. On the other hand, a part of the headrace tunnel, near the intake and, undoubtedly, the whole of the tailrace tunnel will lie below the ground-water table. Fortunately however, just in these parts of the tunnel route is the rock relatively watertight, consisting of basalt sheets and rhyolite.

2.5 DAM AND STORAGE RESERVOIR IN FOSSÖLDUVER

At the dam site on river Fossá to the south of Fossölduver, the bedrock is nowhere visible, except in the river bottom where it consists of a sound and tight basalt, the same as indicated with III in Figs. 13 and 14. On both abutements, the rock is covered with moraine. The thickness of the latter does presumably not exceed 5 m, but if it should do so, the lower parts of it may be expected to be sufficiently solid to form the foundations of a dam.

If a dam with the crest at el. 500 m is constructed here, all flat ground in the Fossölduver basin will be submerged. In the reservoir area, rock outcrops are nowhere found except at the limits, viz. in the river bed and in a few places along the foot of the hills surrounding the basin. The outcrops are of basalt on the southwestern and southern, but clastic (palagonite) rock on the western sides of the basin. Both belong to the Hreppar series, and both appear to be tight and sound rocks. The reservoir basin has been cut into this formation by glacial erosion. After the melting away of the ice sheet, the basin has undoubtedly at first been filled by a lake which has subsequently been filled up by the sediments of river Fossá and other smaller rivers now meandering on a flat alluvium plain. In many places this plain is now covered with soil and vegetation. It contains great quantities of pumice. Apparently, the pumice (both immediately erupted and wind-blown) has played a considerable part in filling up the lake. These deposits, covering the bottom of the basin, are quite unconsolidated and presumably pervious. But that does not matter, as there is every indication that the bottom is itself a well tight bedrock extending safely above el. 500 everywhere around the reservoir area, except at the dam site.

2.6 TUNNEL FROM RIVER STÓRA-LAXÁ TO FOSSÖLDUVER

On the route of this tunnel, the bedrock is of basalt at the surface in by far most places. The only exceptions are in the proximity of both ends and in a very short section

ab. 1 km from the tunnel end in Fossölduver, where palagonite rock is present, of a similar structure at all these three locations, viz. a well cemented sound breccia. At the Stóra-Laxá, where this rock is least covered and most easily inspected, considerable basalt veins may be seen in it.
In the author's opinion, this palagonite rock most probably underlies the basalt on the whole of the route from river Stóra-Laxá to Fossölduver (and is shown to do so in Fig. 15). However, this hardly applies to the palagonite body in the middle of the route (Ix) which is lying at a considerable higher elevation than the two other outcrops. It may be a lens only, lying within the basalt. West of the Stóra-Laxá, the palagonite rock appears to constitute the main part of the Geldingafell mountains, where it is not overlain by basalt. However, the base of the palagonite rock is nowhere visible near the tunnel route. It may thus be concluded that its depth is considerable in this place and that a tunnel at el. 510 m approximately would be lying through it for the whole length.

In many places within the area of the Hreppar series, landscape features such as long straight-lined escarpments, indicate that fissures in a direction NE-SW are dividing the bedrock into strips, some of which are dislocated.
The Svartá valley might be a widened fissure of this kind; the same is true of the nameless trench between river Svartá and Fossölduver. Dislocations along such fissures might explain the differences ocurring in the elevation of the boundary between the palagonite and the basalt beds.
More dislocation fissures, lying in the same direction may be present here although not apparent at the surface.
The route of the tunnel from river Stóra-Laxá to Fossölduver lies in a driection at right angles to the general direction of the fissures. Most probably then, the tunnel will cross some fissures, especially below the abovementioned trenches (b on Fig. 15). The fissures are presumably filled and cemented by a consolidated breccia. However, the probability of finding a pervious and poorly consolidated rock is greater here than elsewhere on the route.

Nowhere on the tunnel route are loose surface beds (III) of such a thickness that they might reach down to the tunnel, except possibly in the Svartá valley, where the river has formed a considerable alluvial flat. The thickness of this alluvium, and possibly that of a moraine which may lie under it, must be assessed by boring in order to make sure that these loose beds do not reach the tunnel line.

The tunnel line is evidently lying below the ground-water table, except perhaps in the immediate proximity of both ends.

2.7 DAM SITE ON RIVER STÓRA-LAXÁ

At the site, the river is flowing in a narrow gorge, ab. 15 m deep and only a few metres wide at the narrowest point, cut into the palagonite rock, with precipitous and in some places overhanging walls. The rock is a sound and unfractured breccia with basalt veins, similar to what may be expected on the tunnel route (2.6).

2.8 TUNNEL FROM RIVER DALSÁ TO THE FOSSÁRDRÖG

The proposed tunnel will lie at el. 590 m approximately, below the so-called Öræfi area. In this area, the bedrock consists of basalt at the surface in by far most places. With certainty, this basalt extends farther down than to the proposed tunnel at both ends, both at the river Dalsá and in the Fossárdrög. As the basalt appears to be almost horizontally bedded, there is a great probability that the tunnel will lie in basalt for its whole length. In this basalt series very few beds of other rock types are present. However, a lens of clastic rock, of a considerable thickness, is found in between basalt beds in the edge above the Fossárdrög, at el. 610-640 m approximately. This clastic rock is of a breccia-type, and looks sound. Of course, similar beds or lenses may also be expected at greater depths, within the bedrock on the tunnel line.

Besides the lens above Fossárdrög, the hill Öræfahnúkur and another nameless hill 2.5 km southwest of it are of clastic rocks, viz. a coarse conglomerate, presumably an old indurated moraine, or tillite. Apparently this rock rests on top of the basalt series and does not reach farther down than to el. 630 m approx. However, the contact between the tillite and the underlying basalt are nowhere seen, owing to loose surface beds. Therefore, the possibility cannot be excluded that the tillite is underlying the basalt and only extending up through it in the two hills. This question can only be answered with certainty by drilling. If the sedimentary rock should prove to reach deep into the roots of the hills, thers is presumably a reason to avoid it by moving the tunnel route ab. 0.5-1 km to the west from the position shown in Fig. 1.

The bedrock of the Öræfi area may be fissured to some extent, in the same manner and in the same direction as in the area between the Stóra-Laxá and the Fossölduver, described above (2.6). But there is the difference that in the case of the Öræfi, the tunnel would lie almost parallel to the direction of the fissuresinstead of at right angles to it. Thus, there is less probability of crossing a fissure, whereas that of the tunnel lying along a fissure for a large part of the route is greater. In such a part, the danger of an unsound, pervious rock is greater than elsewhere.
In order to avoid fissures and faults the tunnel route should be chosen the length of the hill crests, where the rock seems to be unbroken, and not following trenches or escarpments.

The numerous lakes and ponds in the Öræfi area indicate that the bedrock is well watertight and that ancient fissures which may be present are well cemented up. Lake Helgavatn is shallow and is said to dry out late in the summer, in some years. Its bottom is presumably of sand and clay, overlying a moraine in the lowest part of the bedrock basin under the lake. It is possible - although very improbable - that this basin is so deep that the moraine may reach the tunnel line. This can only be explored by boring.

The tunnel will everywhere be lying below the ground-water table.

2.9 DAM SITE ON RIVER DALSÁ

At river Dalsá, to the north of the Öræfahnúkur hill, the maps of the Danish Geodetic Institute, as well as those of the American AMS are very inaccurate and compare badly. Two alternative dam sites appear to be possible, A and B in Fig. 1.

At the upper dam site (A), situated just below the mouth of river Öræfakvísl, there are moraine hills on both sides of the river, and rock is nowhere outcropping. The moraine is of the usual type; unconsolidated and with large boulders at the surface, but presumably rather well consolidated at depth. It may be expected to be very thick here (even exceeding 10 m in the river bottom), but thinning out in direction downstream.

The lower dam site (B) is situated at the boundary of the moraine and the rock where the former is replaced by the latter in the river bed. In the south-western bank of the river, rock is sometimes outcropping, sometimes it is lying beneath a shallow cover of moraine. Wherever apparent, the rock is entirely of a solid basalt. But in the north-eastern bank of the river, the rock disappears below a moraine hill, similar to those at the upper dam site. Presumably, the depth to bedrock is great here.

At Öræfakvísl, a very short distance west from the upper dam site, there is a flat terrace of sand and gravel, built up by the rivers before they had cut their beds down through the moraine hill at the dam site. The materials of this terrace may presumably be used as concrete aggregates.

3 THE HVÍTÁRVATN AREA

3.1 GENERAL

The bedrock of the area around Lake Hvítárvatn and at river Hvítá downstream from there, down to the southern slopes of Mt. Bláfell may, in main, be divided into two rather different formations. In the following, these formations will be called the Breccia formation and the Grey basalt formation, each named after its characteristic constituent.

The Breccia formation is the oldest of the two. It is the main rock of most real mountains in the area, at least in their foot and somewhat higher up than to the middle of the slopes. (Examples : Lambafell, Bláfell, Geldingafell, Skriðufell, Hrefnubúðir, and Fremri-Skúti). The Grey basalt formation, on the other hand, is found in most of the flat ground (including low hills and flat shields) and the top of Mt. Bláfell may also be assigned to it.

The breccia mountains are voncanoes, built up of loose volcanic materials, which have been cemented together and have hardened into palagonite rocks. Its structure is sometimes breccia, sometimes tuff, and it is in most respects similar to the rocks of the Palagonite series at Lake Þórisvatn (cf. 1), although generally harder and tighter than the latter, presumably owing to its higher age. The formation is not younger than from the last but one Glacial Period. In places, very great number of basalt intrusions are present in the breccia formation, especially in the foot of Mt. Bláfell, where these intrusions have to a great extent replaced the palagonite rock. The whole of this basalt is pillowy, heavily jointed or brecciated, and very different from the solid lava beds of the grey basalts.

The grey basalts cover the whole area between the mountains. Most of these have flowed as lavas over a long distance from the east and north-east, especially those lying to the east of river Hvítá and Lake Hvítárvatn. The grey basalt flows on the western side of the lake, on the other hand, were evidently erupted for the most part by an extinct shield volcano, called Skálpanesdyngja, at the margin of the Langjökull ice cap. The lava flows of this formation are all basaltic. Many of them, including all west of the Hvítá, have a relatively coarse-grained (doleritic) texture, and are grey in colour (hence the name "grey basalts", Icel. "grágrýti"). Others, especially east of Hvítá, are microcrystalline and dark in colour (Icel. "blágrýti") or intermediate.

In the flat grounds upstream of the Áboti waterfall, and along the whole eastern shore of Lake Hvítárvatn there are no cross sections available into the Grey basalt formation, and the author has not been able to find anywhere other rocks than ghese glacier eroded basaltic lavas, except in the Fremri-Skúti, a palagonite hill projecting up from the lava-flows. But downstream of Ábóti, river Hvítá has cut a canyon into the bedrock, reaching from there the whole way west beyond Fremstaver. In this section, the structure of the Grey basalt formation is best revealed. The main rock in the canyon walls is basalt (both grey and black but mostly the intermediate varieties). It is bedded, with brecciated contacts and in places with clastic or sedimentary layers between the lava beds. The dip of the beds is generally the same as that of the surface. It is presumably the same dip as at the time of flowing and there is no evidence of any subsequent tilting of the bedrock. Where the canyon is at its greatest depth, e.g. near the upper part of the Sandártunga tongue (see dam site no. 10), it has been cut down through the basalt flows and deep into the underlying breccia formation. But this is close to the foot of Bláfell and just at the limit of the Grey basalt formation. Undoubtedly, the thickness of the latter increases in direction east from the foot of the mountain, and may be expected to amount to several tens of metres, in most places.

Both the Breccia formation and the Grey basalt formation of Lake Hvítárvatn resemble certain facies of the Hreppar series, and they may possibly be classified as subdivisions within these series. However, the bedrock at Lake Hvítárvatn looks younger than in the Hreppar area, farther south. Its relative youth is indicated by slight development of amydales (mineral filling in vesicles), little dissection by erosion, no dislocations and the present orientation of the magnetic field. To the author, however, as far as soundness and waterlightness is concerned, these rocks appear to be only slightly inferior to those of the Hreppar series, and they are undoubtedly far superior in this respect to the rocks of the Palagonite series at Lake Þórisvatn.

(The best evidence of the watertightness of the bedrock at river Hvítá and Lake Hvítárvatn is the fact that this is a "wet" area, viz: All basins in the bedrock are usually quite full of water and do have a superficial outlet, except during periods of heavy draught; on flat grounds there are swamps or marshes; there are numerous springs, but they are all small and usually have an unsteady flow; brooks usually grow uniformly in size in direction downstream, but there are few or no cases of brooks disappearing into the ground. In "dry" areas, the reverse is usually true (cf. Lake Þórisvatn)).

On flat and low grounds, the bedrock is in most places covered with moraine, containing large boulders. Especially thick and extensive are the moraine deposits in the vicinity of the outflow of river Hvítá from Lake Hvítárvatn. In the river banks, rock is nowhere apparent until below the mouth of the tributary brook Fremri-Hrísalækur, and there are also the uppermost rapids of the river. There the river has presumably reached the basalt rock for the first time. The moraine in this area appears to be in all respects a conventional ground moraine from the Glacial Period.

On the eastern bank of river Hvítá, at the bridge, there are moraine hills of a considerable height. Immediately downstream of the bridge, the river has removed a part of the side of one such hill, forming an approx. 25 m high cross section of the moraine, but its base is not revealed. The bank has a round edge and a steep slope. From a distance, it looks like the slope of a gravel bank only. But opon closer view it will be seen that the material of the bank is so hard, at least in the lower parts and a little higher up than to the middle, that it would be called "rock" in a daily language. In the uppermost part of the slope, the rock is hidden by a loose scree which has been weathered from it, and on the top of the hill there is a usual weathered moraine with loose, clayey sand at the surface and overstrewn with large boulders. Apart from this loose, bouldery surface layer, the material of this slope is a blue-grey sandy clay or claystone with widely scattered pebbles and boulders of basalt. At the surface, the claystone is easily weathered, especially by frost action, and has been disintegrated by the weathering. In the lowest part of the slope foot, on the other hand, where protected from freezing by the river and tiny springs, the claystone forms a tight, hard rock, comparable in hardness with e.g. the hardest varieties of palagonite tuff, or perhaps even with limestone. It should be noted that the thickness of the overlying material is here considerable (25 m), and that the soil beds lying higher up in the bank cannot be expected to show the same hardness. But higher in the bank, only the weathered moraine is visible, and the weathered layer was too hard and too thick for the author to be able to dig down through it with a spade. The hardness of this weathered surface layer increases with depth. The layer may reach 0.5-1 m down into the claystone. There is presumably no distinct boundary between the loosened surface layer and the unweathered, indurated boulder-clay which, to the author, the cross section indicates to be the main constituent of the moraine. Undoubtedly, the loose surface layers of the moraine hills at Lake Hvítárvatn are considerably thicker than the weathered layer of the river bank, just mentioned, and their hardness appears to increase gradually with depth without any distinct boundary until a consolidated clay or claystone is reached. In a newly dug pit, 1 m deep, it is very difficult to loosen the clay with a bulldozer, and it could not be penetrated by an earth boring machine (hole diameter 46 cm) farther down than 230 cm, owing to the consolidation of the clay.

A study of the clay bank downstream of the Hvítá bridge, and experience from the bulldozer-made test pits and some shallow exploratory earth borings strongly indicate that the main part of the thick moraine deposit at river Hvítá and Lake Hvítárvatn is of such a high consolidation that is may be called a rock rather than a subsoil bed, with the exception, however of the surface layer, a few metres in thickness.

The hardness of the material increases with depth, and in the author's opinion it is not unlikely that it will have reached sufficient soundness at a depth of 10-20 m to sit fast in the roof of a tunnel. Wherever an unjointed rock of

a greath depth from the claystone itself, and not from the weathered surface layer of the moraine only. The increased pressure (caused by the raising of the water level) would somewhat increase this insignificant leakage. But owing to the hardness of the claystone, the danger of piping is, in the author´s opinion, small or negligible. Unweathered claystone, of the same kind as in the lowest part of the northern river bank may also be expected in the river´s bottom, although in parts (between the two branches of the river, at least) covered with a loose debris (IV) of sand or gravel and boulders.
On the southern side of the river, on the other hand, the moraine may be expected to be weathered on the surface, and the thickness of the weathered layer presumably increases with the distance from the river. Here, the moraine is in most places covered with a loamy soil, up to 2 m in thickness (III).

3.3.3 Dam Site Downstream of the Mouth of Fremri-Hrísalækur

The proposed dam will be situated exactly at the boundary where river Hvítá starts flowing on the bedrock for the first time in its course, and where outcrops of basalt rock begin to appear in its bank, above the water table (I. in Fig. 18). The rock in the riverbed may be presumed to be uncovered in most places, and nowhere deeply covered.

In the rest of this 2 km long dam site, rock is nowhere apparent. Moraine (II) or soil (III) is there everywhere on the surface. Nothing is known about the thinckness of the moraine, but the surface of the underlying bedrock may be presumed to rise rather than fall in direction away from the river, on both sides. It is possible that the bedrock within the moraine hills on the eastern side of the river may rise above the surrounding ground, but it is equally possible that the hills consist of moraine throughout.
The surface layer of the moraine is of the usual consistency, viz. unconsolidated and with numerous boulders, but undoubtedly the moraine generally gets harder and more clayey with depth. An evidence of this it its bottom layer, which is very hard, appearing at the water level on the dam site, in the western bank of the river. This layer consists of claystone which proved to be very difficult to loosen with an iron lever last summer, when a water level recorder was being installed at the site.

The soil (IV) is marshy in most places, viz. peat and turf, mixed with clay. Especially, the peat cover appears to be thick in the whole section on the western side of the Hvítá, in the so-called Lambafellsver area. In the river bank, the thickness is 3 m or more, and may be expected to be still more in the middle of the area. It is possible that the peat is somewhere in the Lambafellsver area lying immediately on the bedrock, with the moraine layer missing.

3.3.4 Dam Site Upstream of Waterfall Ábóti

The conditions here are in every respect similar to those at the next dam site upstream (cf. Fig. 18), the distance between the two also being very short. However, the moraine generally appears to be thinner on the lower dam site, and the depth to bedrock correspondingly smaller.
A thin (several metres) bed of a rather soft clastic rock is apparent in the western bank of the river, in the uppermost part of the bedrock. Below it is a very solid basalt, which presumably forms the whole of the river bottom on the dam site. The edge of this bed forms the waterfall Ábóti a short distance downstream.

3.35 Dam Site on River Jökulfall (see section in Fig. 19)

In the western bank of the river, basalt rock (I) extends 2-3 m above water level. The rock is somewhat jointed, and is presumably more solid below a depth of 1-2 m. A nice spring (discharge ab. 1 litre per sec.) issues from a single joint in the rock at water level just downstream of the site, indicating some leakage. In the eastern bank, rock is not apparent, but the shape of the bank indicates that the bedrock is thinly covered there. If that is the case, the bedrock under the gravel alluvium (IV) down in the riverbed must also be shallow. On both sides of the river, moraine (II) covers the bedrock. The moraine slopes towards the river are in many places covered with vegetation and a sheet of eolian soil, hardly exceeding 1 metre in thickness. Elsewhere the moraine is loosened by weathering at the surface. This weathered layer (shown in Fig. 19) may be presumed to be present under the soil cover too.

On the western side of the river, a seperate dam is required across a wide and fairly deep depression between two bare moraine hills. In a brook bed at the bottom of this depression, large basalt blocks may be seen, resembling a rock jointed by frost expansion rather than erratics in a moraine deposit. Furthermore, samples taken by the author from two of the blocks showed the same orientation of the magnetic field as the bedrock itself, indicating that the stones have not been much displaced since they broke off from the latter. There is thus a great probability that this is an outcrop of the bedrock itself.

3.4 SPILLWAY CHANNEL WEST OF Mt. LAMBAFELL

Evidently, Lake Hvítárvatn has previously had an outlet over a broad flat col connecting the mountains Bláfell and Lambafell. This occurred at the stage of glacial recession near the end of the Glacial Period when the whole of the flat ground to the east of river Hvítá and close to the slopes of Mt. Lambafell was covered by an icesheet which dammed the present outlet from the lake. This is evident from the direction of striae in the area, as well as from old shore lines at Lake Hvítárvatn. The water level of the lake has then been somewhat above el. 435 m, which is exactly the elevation of the col. The outlet has cut a gorge into the slope south of the col and plunged in a steep waterfall into its northern end. The gorge is all cut in grey basalt of the Skálpanes type. In the edges of the gorge, the surface of this rock is at el. 435 m approximately and appears to be flat. But it does not crop out anywhere else on the col. Last summer, a pit 2 m in depth, was dug on the top of the col with a bulldozer. In the pit sides there was a loamy, eolian soil, but in the bottom a layer of clay-free river gravel was reached. This gravel bed is presumably thin, and underlain by the grey basalt bedrock.

The depression appears to be well suited for a spillway channel from Lake Hvítárvatn at an elevation slightly below 435 m (in fact it has also served that purpose before). The channel would be cut through the soil cover for the most part, only slightly into the surface of the basalt bedrock, which latter presumably is both solid and tight.

3.5 TUNNEL BENEATH Mt. LAMBAFELL

A headrace tunnel is contemplated from dam site 1 or 2 on river Hvítá to an underground power house beneath the southern slope of Mt. Lambafell, and a tailrace tunnel from there in the same direction to river Hvítá in the vicinity of Tæpistígur. The elevation of the headrace tunnel is indeterminate (presumably between 380 and 410 m), but the tailrace tunnel must lie at el. 270 m approx.

Outcrops of bedrock are scarce in the Lambafell, but those present consist mostly of heavily jointed basalt, now with narrow irregular columns, now brecciated.

Undoubtedly, the hill is of the Breccia formation, whose basalt veins are more resistant to erosion than the tuff, so that outcrops consist of the former, rather than the latter. The rocks in the tunnel beneath the hill may be expected to be sometimes tuff and sometimes jointed basalt. There is some probability of an increase in the basalt with depth, recommending a location of the tunnel deep inside the hill. The tailrace tunnel also appears to lie in the breccia formation for by far the most part. The rock conditions to be expected there are thus much the same as beneath Mt. Lambafell.
Only in the immediate proximity of both ends, the tunnel might lie through the grey basalts. As to the upper end of the tunnel, it presumably will do this only in the case the intake is located at the uppermost dam site, (1) where the bedrock, in all probability, consists of grey basalt, similar to that outcropping in the ancient outfall gorge between Mt. Lambafell and Mt. Bláfell, near the proposed spillway channel (cf. 3.4). However, this basalt hardly extends farther downstream on the western side of river Hvítá than about to the uppermost-but-one dam site (2). The basalt is overlying

the Breccia formation and probably gets thinner towards the edges. Its thickness at the upper dam site is probably sufficiently small for the headrace tunnel to penetrate it and get into the Breccia formation right at the intake.

At the lower end of the tailrace tunnel, the Grey basalt formation extends a short distance across river Hvítá, to its north-western bank. The tunnel will there lie through the basalt beds of this formation for a section of 100-200 m nearest to its mouth.

Both the headrace and the tailrace tunnel will lie below the ground-water table throughout their whole length.

3.6 TUNNEL FROM ÁBÓTI TO TÆPISTÍGUR

In this section, river Hvítá flows in a canyon which is wholly cut into the Grey basalt formation. The main rock of the canyon walls is micro-crystalline basalt (blágrýti), usually sound, although in parts somewhat brecciated. The sound rock lies in beds with a dip similar to that of the river surface. These beds are obviously lava flows in origin.
In many places, two - but nowhere more than two - such beds are visible above the water level, with a brecciated boundary between them. Wherever accessible, the breccia appears rather well cemented and solid.

This formation extends a short distance only to the west of the river, viz. to the foot of Mt. Lambafell and Mt. Bláfell, and has probably become very thin on the tunnel route on the western river bank. A horizontal tunnel at elevation 370 m or thereabout would thus presumably lie below the basalt beds, and within the Breccia formation for the most part or even the whole of its length, except in a section of 100-200 m in length near the lower end.
Now, it has not at all been ascertained which of the two formations is to be preferred for tunnelling. Should the choice fall on the Grey basalt formation, there is the possibility of driving the tunnel on the eastern side of river Hvítá, where this formation in all probability reaches a greater depth than on the western side.

3.7 TUNNEL THROUGH Mt. BLÁFELL

The whole of Mt. Bláfell is built up from volcanic materials, which, however, are very versatile. In main, the mountain may be divided into three horizontal zones (1., 2., and 3. zone), each on top of the other, and different in structure, with a fourth rock type lying as a cover on the slopes, discordant to the other three.

(1) At the foot of the eastern and south-eastern slopes of Bláfell, the main rock is micro-crystalline basalt (I a in Fig. 20). All this basalt is pillowy, jointed or brecciated

(or intermediate between these types), and quite different from the basalt lavas of the Grey basalt formation.

Palagonite rocks (cf. zone 2) are also present within this zone, but in its lowest visible parts they are quite subordinate to the jointed basalt, and occur solely as a filling between basalt pillows, or as the matrix of a basalt breccia. The amount of palagonite rocks increases with elevation in the basalt zone, and there is thus no distinct boundary between this zone and the overlying palagonite zone. In the south-eastern slope of Mt. Bláfell, basalt is generally more voluminous than palagonite rock up to an el. somewhat above 450 m.

(2) The palagonite rocks (I b) may be called the main constituent of Mt. Bláfell. They are both tuffs and breccias, with veins and dykes of basalt spreading irregularily through them. These instrusions are most voluminous in the lowest part of the zone, and they may be considered as irregular small apophyses from zone 1.

(3) The top of Mt. Bláfell consists mostly of grey basalt sheets (II). The boundary with the underlying palagonite rocks is at el. 900 m approximately. The grey lava sheets must have penetrated the palagonite from below. However, no distinct traces of a volcanic vent are seen on the top of the mountain, but the dykes and the veins in the palagonite rocks underlying the basalt sheet may be branches from the main magma channel, which latter may be presumed to form a vertical volcanic neck or a dyke of basalt up through the middle of the mountain.

(4) A mantle of "palagonite moraine" covers the mountain slopes (not shown in Fig. 20). This is a formation similar to the one at Lake Þórisvatn previously described (1.5). In some respects, the palagonite moraine resembles volcanic tuff or breccia, in others it resembles a moraine. It is of a sandstone, breccia or conglomerate consistency, or a mixture of all three. In colour, it is usually brown (from palagonite). The more fine-textured rock varieties of this mantle may be roughly stratified, and in addition, they often show shear-planes, produced by the thrust of moving glacier ice. The shear planes may be at so short interval as to produce a structure of rough foliation making the mantle rock weather into slabs. In places stratification and foliation intersect each other, but generally both are almost parallel to the slope of the mountain side.

The mantle of palagonite moraine is clearly discordant to the underlying rock. The hardness of the mantle is in most places similar to that of a moraine of max. hardness (a real "rock"), but beds and lenses of a much lower induration are also found in it. No basalt veins reach the mantle.

In the author's opinion the mantle is mostly a local ground moraine in origin derived from the underlying palagonite rocks. However, scree and alluvial cones of mountain torrents may have played a considerable role in its formation. (The Dutch geologists Bemmelen and Rutten designate

palagonite moraine mantles of maintains of the type of Bláfell as "pseudo-palagonite").
The moraine mantle of Mt. Bláfell is discontinuous and, undoubtedly, very variable in thickness. In general it is of max. thickness at the foot of the mountain and appears to extend from there some distance out onto the flat ground. Such outliers cannot, however, be distingiuished from similar clastic beds belonging to the Grey basalt formation.
In origin, some of these beds may, as a matter of fact, well be a continuous extension of the moraine mantle on the slopes; their material having been transported by mountain brooks onto the lava sheet at the foot, and subsequently buried beneath the next lava flow.

The mantle of local moraine seems to be at its thickest on the south-western side of the mountain, where ravines more than 5 m deep have been cut into the mantle, without reaching its base. This was also the lee-side of the mountain in regard to the ice movement during the last glaciation.
In the south-eastern slope of the mountain, on the other hand, as for instance at the Illagil and Sniðbjargagil gorges, the mantle appears to be a few metres only in thickness.

It is now proposed to drive a tunnel from the uppermost-but-one (2) or the uppermost (1) dam site on river Hvítá, beneath Mt. Bláfell from end to end to an underground power house at the foot of the south-western slope of the mountain ("Bláfell I") and from there to river Hvítá downstream of Fremstaver. The headrace tunnel would lie at el. 380 m approx. and the tailrace tunnel at el. 262 m.

Provided that the division of Mt. Bláfell into three rock zones is the same in the middle of the mountain as in the slopes, the whole tunnel will lie in the upper part of the lowest zone (1). It may thus be presumed that the tunnel has to be driven through the jointed basalts of the Breccia formation for by far the most of its length, but that sections of palagonite rocks will also be encountered. These sections will presumably be both more numerous and longer the higher in the zone the tunnel is driven. The basalt appears to be a more solid rock for a tunnel roof than the palagonite. From this point of view the tunnel should preferably be driven deep rather than shallow within the zone.

Should the intake works be located at the uppermost dam site, the headrace tunnel will lie through the Skálpanes grey basalt for a short section (several hundreds of metres). If, on the other hand, the intake is at the uppermost-but-one dam site, the tunnel will lie in the underlying Breccia formation right from the start.

At the site of the proposed power house for the "Bláfell I" alternative, on the south-western slope of Mt. Bláfell, the palagonite moraine mantle of the slope is so thick that other rocks are nowhere visible. It is conceivable that the thickness may amount to tens of metres, and that the moraine cover may reach the headrace tunnel for a short section. But there is hardly any doubt that the power house (at el. 262 m) as well as the most part of the tailrace tunnel will lie within the Breccia formation. At the mouth of the tailrace tunnel, near river Hvítá, there is a very coarse river deposit, mostly consisting of thoroughly rounded boulders. At first sight it might be assumed to be a very recent (post-glacial) and completely unconsolidated formation. However, ab. 300 m upstream, there is a steep terrace at the river of a similar material, which is there a very hard boulder conglomerate. The sandy matrix between the boulders is so compact that it is very difficult to loosen the boulders from it with a hammer. Possibly, the conglomerate on the tunnel route will also prove to be as hard as that at some depth.

3.8 DAM SITE ON RIVER HVÍTÁ AT SANDÁRTUNGA

At this dam site the Hvítá is flowing in a narrow canyon, ab. 40 m deep, with very steep walls. The canyon has, for the most part, been cut into the Breccia formation. But some shreds of the Grey basalt formation extend here to the western bank of the Hvítá, and form the uppermost part of the walls on both sides, in some sections of the canyon. Fig. 20 shows a schematic cross section of the canyon ab. 200 m downstream from the dam site. On the dam site, there is the difference that layer I reaches quite up to the brim of the canyon, whereas layers II and III are missing. In this latter place, therefore, the whole of the canyon has been cut into the Breccia formation, which here consists almost wholly of pillow basalt. For its kind, this rock appears here exceptionally solid and compact and completely free from palagonite. It is presumably rather well watertight.

3.9 TUNNEL ALONG THE SOUTHERN FOOT OF Mt. BLÁFELL

A headrace tunnel is contemplated from dam site 10 on river Hvítá to the "Bláfell II" power house, and a tailrace tunnel from there to river Hvítá upstream of the mouth of the tail-race tunnel 3.7.

The tunnel elevation is indeterminate, but should not be higher than 370 m for the tunnel to lie safely within the bedrock for its whole length. The lowest depression on the route is at the foot of Mt. Bláfell, north-east of the Sniðbjargagil gorge, where the surface is at el. 370-375 m only. The bedrock is there covered with loose beds (moraine and soil), whose thickness, as well as the qualities of the underlying rock, must be explored by drilling. The headrace tunnel will every-where else lie within the basaltic base of the breccia formation (Ia in Fig. 20; I in Fig. 21). viz. mostly through pillowy, and otherwise jointed, basalt, presumably with some sections of palagonite rocks, just as described above in dis-cussing the headrace tunnel 3.7. At the tunnel intake this formation is overlain by some outliers of the grey basalts, but these are so thin that the tunnel must lie below them, except in the case that some basalt beds might be hidden below the depression north-east of the Sniðbjargagil gorge,

mentioned above. In the section of the route lying between the Sniðbjargagil gorge to the "Bláfell II" -power plant, pillow basalt may be seen in every gorge, but between the gorges it is mostly hidden by the mantle of palagonite moraine, which nowhere appears to be more than a few metres in thickness. In the deepest gorges, viz. the Sniðbjargagil and the Illagil gorges (el. ab. 385 m), very little palagonite is mixed with the basalt, but at the power house (el. ab. 420 m), there is considerably more of it.
In this place, the basalt pillows and veins lie embedded in a hard, tuff-like matrix. The tailrace tunnel will lie at el. 263 m. On its route, the bedrock is nowhere visible, because of overlying moraine deposit, except for a single outcrop of jointed basalt projecting from the moraine at el. 325 m approx., ab. 1200 m above the tunnel mouth at river Hvítá. It is very unlikely that the moraine (including the palagonite moraine) is anywhere of such a thickness that it might reach the tunnel, which presumably will mostly be lying through similar rock as the headrace tunnel. At the mouth of the tailrace tunnel, however, the coarse conglomerate, present at the mouth of tailrace tunnel 9, as mentioned above, will be encountered.

Both the headrace and the tailrace tunnel will everywhere be lying below the ground-water table.

3.10 DAM SITE ON RIVER SANDÁ

At their confluence, the rivers Sandá and Svíná, have filled a bedrock depression by their sediment, but have not at all cut their channels into the bedrock. The rivers are there flowing slowly on an alluvial plain. The damsite on river Sandá is downstream of this alluvial plain, where the bedrock appears first in the river bottom.
Ab. 100 m farther down, rock becomes visible in the western river bank also and hills of angular basalt blocks on the eastern bank indicate that the bedrock is shallow here, too.

See cross section in Fig. 22:

The basalt rock (I) is, in parts, somewhat brecciated though it looks sound and is presumably rather well watertight. The moraine seems to be thin and therefore presumably too poorly consolidated to serve as dam foundations. The dam must therefore be carried down into the bedrock. The soil (III) is loessial (eolian), and the alluvium (IV) is quite loose river gravel.

3.11 CANAL ACROSS THE SANDÁRTUNGA

The col (water divide) between the Sandá and the Hvítá is very low and flat at the site of the proposed canal. Bedrock is nowhere apparent because of the overlying soil and moraine deposits, except in the Hvítá canyon, where a basalt bed is present in the edge (overlying the Breccia formation which is the main rock in the canyon walls). The uppermost visible part of the surface of this basalt bed is at el. 390 m approx. Presumably, the bedrock surface reaches a somewhat higher elevation beneath the crest of the col. Depressions in the bedrock, extending right across the col, enabling the canal to be excavated almost solely in soil and moraine deposits may possibly be detected by very shallow borings.

4 URRIÐAFOSS

4.1 GENERAL

The geological formations near river Þjórsá in the vicinity of Urriðafoss may be divided into four sharply distinct groups. These groups are, in an order of age, and numbered as in the figures: I. The bedrock. II. Sedimentary layers, older than the Þjórsá lavas. III. Þjórsá lavas. IV. Soil beds.

The bedrock

All the bedrock is of the Hreppar series. In the whole of the Þjórsá gorge, from the Heiðartangi until downstream of the Urriðafoss waterfall, the bedrock consists of micro-crystalline basalt for by far the most part. The basalt is bedded, each bed presumably representing a single flow of lava. Sedimentary layers are not to any extent present between the basalt beds, which are in general only separated by a zone of breccia-structure at the boundary. In a very few places, as for instance in the Heiðartangi and at the mouth of the Urriðafosslækur brook, the basalt breccia may reach a thickness of several metres. But it is everywhere well cemented, hard and solid, and appears to be only slightly less watertight than the unjointed basalt beds.

In general, the rock beds of the formation appear to be almost horizontal. However, in the section from Heiðartangi down to the bridge, the beds dip in the same direction as the river, slightly more than the water surface. But as there are no cross sections in this place extending to any depth into the bedrock other than the river gorge the exact value of the dip cannot be determined by surface observations only. (Even in the walls of the gorge, the rock is in some places hidden by a vegetation cover.

Especially, the strata might dip in direction at right angles to the gorge, viz. to the NW or SE, without the dip being apparent.

The author has nowhere in this area found any indications of vertical faults. No faults appear to cross the river gorge itself, but they may be present on both sides of it without being visible, because of more recent soil beds overlying the bedrock in most places. As a matter of fact, it is hardly to be feared that faults in this bedrock are any less watertight or less sound than for instance the breccia-like layers mentioned above.

The author has found only one dyke in the bedrock here. It is projecting from the gorge wall on the eastern side of

the river, somewhat within 100 m upstream from the ledge of the waterfall Urriðafoss and is lying in direction NE-SW. Judging from features on the surface of the river, the dyke appears to be lying in the same direction across the river bed, but it is not clearly revealed again in the western bank. It is shown in this position by a thick line in Fig. 22.
The dyke is of basalt like the surrounding bedrock and would therefore not be very prominent except for the projection from the gorge wall and rapids across the river; the rapids being the uppermost part of the waterfall.

All solid rock to the east of the river, as well as to the west of it and south of the Urriðafosslækur brook is of the bedrock type just described. Further, this rock is present in the Sandholt, a small lava-free area on the western river bank, midway between the bridge and the Urriðafoss waterfall.

The bedrock in the Flói and Holt areas is very old, compared to the overlying formations. It is at least early Quarternary, perhaps late Tertiary in age. The surface of the bedrock is even in by far most places with distinct glacial striae. But the bedrock surface is nowhere visible on flat grounds, owing to much younger formations overlying it, among which is a thick soil.

Sedimentary layers older than the Þjórsá lavas

At the end of the Glacial Period and for a long time afterwards the present lowland in the Flói and Holt areas was below sea level. The uppermost shore line from that time is found about 100 m above the present sea level in the slopes of the hills then extending above the water.
These basaltic hills themselves have not been much eroded by the surf, but the glacial drift has been washed away from them down into the depressions. The large boulders of the moraine, however, have generally remained, but have been tossed about by the waves and, in places, been thrown together to form beach barriers. The more fine-grained materials, viz. gravel, sand and clay have been washed out to greater depths where they now form a sedimentary layer covering the unsorted moraine.

It is thus not to be expected that the undisturbed moraine is very much apparent in the lowlands. But it is presumably present as a layer on the bottom of all the deepest bedrock basins, and is there, of course, overlain by the marine sediments. For instance such a moraine may be expected below the lava flow to the west of river Þjórsá, near Þjótandi, although nowhere visible in the river gorge. There is little danger of leakage or flaws in a moraine buried at such a depth.

Next in order are the marine sediments, the outwashed moraine. This layer is visible in some places in the western bank of river Þjórsá, below the lava sheet, but it is in most places hidden, either by a scree from the edge of the lava or by a loamy soil, covered with vegetation (cf.

Fig. 23). This sedimentary layer also emerges from below a soil cover in some places on the eastern side of the river, south of the Urriðafosslækur. Its materials are rather versatile; in most places thoroughly rounded basalt boulders of various size, embedded in sand. In most places, the sediment is so well indurated that it would be difficult to loosen with a pick. Furthermore, it appears to be well watertight as the springs flowing from beneath the lava issue mostly above the sediment, at the boundary between it and the lava.

In some sections the sediment is of sandy consistence and without boulders, darkbrown in colour (from limonite impregnation) and moderately indurated. This so-called "sandhella" seems to be most prominent at the upper surface of the sedimentary layer, immediately at the base of the lava. It might have been deposited by a slowmoving stream at the time when the land was rising from the sea and the great rivers were extending their courses farther south over the previous sea floor.

In one place, just downstream of the old bridge, a 20 cm thick layer of peat is present between the sedimentary bed and the lava, proving that the land had risen from the sea and a swamp been formed on the surface before the lava flowed over it.

The "sandhella" is somewhat less consolidated than the boulder conglomerate underlying it, and is presumably less watertight too. To the author the peat appears to be of a similar hardness as is usual near the base part of a thick peat bog. There is a danger of piping in these deposits when subjected to a high water pressure if there is a leakage through them at all. But these layers are in some - and perhaps most - places missing from the sediment; the lava lying immediately on a rather well consolidated boulder conglomerate. The dam site may thus presumably be selected in such a way that these loose beds are missing at the site. The beds lying immediately below the lava flow must therefore be carefully explored by drilling.

The Þjórsá lava

At a time when the old sea bed had been transformed into a flat alluvial plain and the formation of a vegatative cover on it had started (cf. the peat), a vast lava flow submerged the whole lowland between Mt. Hestfjall and the hills of the Holt area. This lava flow was the biggest and one of the oldest of the so-called Þjórsá lavas.

On the map (Fig. 22) is shown the edge of this lava flow in the immediate vicinity of Urriðafoss. It nowhere extends to the eastern bank of the Þjórsá, this river is generally following its eastern edge from the Skeið area down to the Urriðafosslækur brook. The lower part of that brook also flows at the edge of the lava, until some distance (beyond the map) west of the river, where the lava extends across the brook and some distance to the south of it.

On the western bank of river Þjórsá there is a small lava-free area, named Sandholt, a short distance north of the Urriðafosslækur. Furthermore, the hills near the farms Skálmholt and Háholt are islands in the lava flow. Both these hills as well as the Sandholt are of the same bedrock (the Hreppar series) described above.

It has not been possible for the author to visit any of the islands in river Þjórsá. But as far as can be seen through field glasses from the banks of the river, all islands upstream of the Heiðartangi appear to consist of a Þjórsá lava, and it may be stated with certainty that most of the river bottom in the wide channel upstream of the head of the gorge consists of lava. To the author, it appears likely that a tongue of lava extends all the way south to Lón, beneath the river water and sand banks.

For most of the rocks protruding from the river bottom up above the water surface at the head of the gorge, near Heiðartangi, the author has been able to ascertain (through field glasses) whether they consist of Þjórsá lava or of the bedrock. This has been possible thanks to the big white feldspar crystals characteristic for the Þjórsá lavas. The result is, as shown on the map, that most of the river bottom off Heiðartangi is of Þjórsá lava; the edge lying near the southern river bank. It may be presumed that the river has cut its deepest channel close to the lava edge, at the boundary between the lava and the bedrock. Possibly, a relatively loose sedimentary layer has been present at the boundary, having later been washed out from below the lava by the current, as assumed in Fig. 24. But it is also possible that no such layer is present, the lava having flowed close to the exposed rocky slope of the Heiðartangi. But even in that case, the boundary between the lava and the bedrock may be expected to be less resistant to the river erosion than the rest of the bottom, so that a channel has been cut at the edge of the lava. It is evident from features on the water surface that a deep, narrow channel is lying close to the southern side of the biggest rock island in the river. Farther south, the evidence of this channel gradually diminishes.

A short distance downstream from Heiðartangi, the river has evidently reached the base of the lava. Moreover, the base is visible above the water surface in the northern river bank (cf. Fig. 23). Farther downstream, the lava nowhere reaches the water surface, and wherever its base is visible (not covered with scree) it consists of the sediment described above.

The lava wall in the northern banks of the gorge is everywhere an almost vertical fracture, as the river has undermined the original lava edge, which then has broken off. The height of this fracture ranges from 3 to almost 15 m, it being lowest in the upper part of the gorge and highest to the east of the Urriðafoss farm. It appears likely that the thickness of the lava increases gradually in direction from the river to the north-west; i.e. that the base of the lava dips in that direction.

In the cross section in Fig. 25 however, the author has shown this base horizontal, as it is impossible to estimate the magnitude of the dip, and it is not certain that there in any dip at all.

The lava is certainly the most pervious rock in the area in question and it would be the only rock through which there would be a significant leakage. On the other hand there would be no danger of piping through the lava. But the horizontal contact between the lava and the underlying sediment is questionable. In case of a high hydraulic gradient, it is conceivable that some material might be washed out from the sedimentary layer, creating a cavern under the lava. However, the upper surface layer of the lava (several metres in thickness) are undoubtedly the most pervious part of it. But here the hydraulic head is lower and, besides, there is no danger of piping in other direction than upwards, into the overlying soil beds. If the water level of the river is raised to el. 40 m by means of a dam across the gorge somewhere upstream of Urriðafosslækur, the water will reach this pervious, jointed surface layer of the lava. Therefore, a substantial leakage will take place through this layer unless some measures are taken to stop it.
This leakage might easily be retained by a cuf-off of some impervious material carried down into the solid part of the lava.

The author has, both above, in some previous reports to the S.E.A. and in various papers, expressed the opinion that postglacial lavas are, in general, pervious, even exceedingly pervious.

But if he was asked to give an estimate of the amount of leakage likely to be encountered at a given dam site, the author would be content if the estimate was within an interval of 1/10 to 10 times the actual value. So far is he from being able to assess quantitatively the perviousity of a lava flow. No experience is available on this point. For the construction of dams on lava flows in the future, every opportunity to study this phenomenon should be utilized.
A dam across river Þjórsá somewhere in the gorge upstream from Urriðafosslækur would yield valuable information in this matter. Most of the leakage water would reappear in the gorge, downstream of the dam, and in the bed of the Urriðafosslækur brook. Some springs are present in this area, all issuing from below the lava. It is necessary to measure the discharge of these springs carefully before and after the construction of a dam. The measurements should preferably extend over a periods of several years both before and after the dam is constructed. The discharge and probably also the number of the springs must be assumed to increase after the completion of the dam, the increase in discharge being a measure of the leakage through the lava.

The water temperature in the springs mentioned above was found to range from 4.1 to 4.3°C, with exception of the uppermost spring of the gorge, the one yielding water to the farm Þjótandi, which was somewhat warmer, ab. 4.9°C.
To the author, this difference in temperature indicates that

the colder, lower springs receive their water from rain or snow falling on the lava dipping towards them, but that the uppermost one is to a more or less extent leakage from river Þjórsá into the lava.

Soil beds

In general, the soil beds are very thick in the area near Urriðafoss and they hide the bedrock in almost every place with the exception of steep slopes and the stream beds. In most places, the soil consists of usual wind-blown materials, except in the vegetative cover of the surface. In depressions and on flat grounds, however, where not underlain by lava, the soil is marshy and more or less of an organic origin (clayey peat).

The loamy soil (in the dry areas) appears to be 2 m thick, in most places. Of course, the thickness is very variable, especially over the lava, where stony mounds may project up through the soil, but where soilfilled holes, several metres in depth may lie hidden between the mounds. The marshy soil is, in general still thicker, but it is not present at the sites of proposed dams, except in the Sandholtsmýri bog at the lava edge to the north-west of Sandholt, and in a bog to the west of Bæjarholt. In these places, the soil may be expected to be exceptionally thick.

4.2 THREE POSSIBLE DAM SITES

Heiðartangi (Fig. 24, Section I)

In this place, as in most other places in the gorge, the northern river bank is of lava, the southern one of the bed-rock. But the difference is that here the most of the river´s bottom also consists of lava.

Possibly, the edge of the lava is abutting immediately against a bedrock slope of the southern river bank, in which case it would form sound foundations for a dam. But equally possible is (as assumed in the figure) that a less solid sediment layer is present between the lava and the bedrock in the deepest channel at the southern bank of the river. This may be explored by drillings on the small rocky island in the river in the place where section I is taken.

Sandholt (Fig. 25, Section II)

At Sandholt, the lava does not reach the river bank, the gorge having been cut solely into the solid, watertight bed-rock. This place, therefore, might be expected to be a safe dam site. As a matter of fact, there would be some leakage from the reservoir through the lava to the north of the hill, but owing to the long leakage path, the hydraulic gradient would be small, which would both reduce the leakage and eliminate the danger of piping in the base of the lava.

At both these dam sites, the pervious surface layer of the lava would cause some difficulties in the raising of the water level to el. 40 m or more. Therefore, the author finds it right to point out a third possible dam site where these difficulties may be avoided.

The ledge of the Urriðafoss waterfall

The eastern abutement of the dam would be the protrusion from the gorge wall of the above-mentioned dyke (shown in Fig. 22), with the western abutement at Bæjarholt ab. 50 m downstream from the mouth of the Urriðafosslækur.

Very sound rock is on both sides of the river in this place, and an uncovered rock of the same type is present in the river bottom. Had a flaw been found there, the swift torrent of the river would have eroded it away. In this place, and nowhere else upstream of the waterfall, would there be no leakage past the dam, through the lava.

A low ancillary dam would be required at this site, across a bog to the west of the southern part of Bæjarholt. The author has not examined this bog, but presumably a thick marshy soil is present there.

5 LANGISJÓR

Lake Langisjór has an area of 27 km^2 and is an elongated lake (length 20.5 km) lying in direction NE-SW (or more exactly: 43° east of N). Nothing is known about the depth of the lake 1), but ab. 20 large and small island scattered over the whole of the lake indicate that it is shallow. According to maps of the Danish Geodetic Institute (1 : 100 000), the surface of the lake is at el. between 660 and 680 m, but on the American AMS maps (1 : 50 000) 656 m is given as the water level elevation. The result of a measurement made by the author with a Paulin barometer was 648 m. This result is based on comparison with a peak lying a short distance north of the south-western end of the lake and shown on both maps to be at el. 750 m. The water in the lake is everywhere milky in colour, owing to glacial silt, so that the bottom is not visible at a depth greater than 10-15 cm. The lake receives an inflow only into its north-eastern end, from the Vatnajökull ice cap. The outlet is the Útfall river, discharging into river Skaftá.

Lake Langisjór is wholly within the great Palagonite Area extending between the Laki crater row on the south-eastern to Lake Þórisvatn on the north-western side and the Vatnajökull ice cap on the north-eastern to Fjallabaksvegur nyrðri motor track on the south-western side. The structure of the bedrock and younger formations in the north-west of this area has already been described (cf. Þórisvatn). However, that description does not in every respect apply to the Langisjór area. The main difference will be described below.

The bedrock of Lake Langisjór consists almost solely of palagonite tuff, in wide areas completely without basalt intercalations of any kind.

This is true to such an extent that it is difficult to find a piece of basalt even in glacial moraines, scree deposits and old and new gravel banks on the shores of the lake.

The author has observed basalt in the bedrock near the lake at three locations only: (1) A nice pillow lava in a peak to the south of the pass containing the motor track, west of the southern end of the lake. (2) A sill, 1-2 m in thickness, above the middle of the northern slope of Mt. Sveinstindur. (3) A small basalt outcrop, presumably intrusive, on the northern slope of the southern ridge of the Fögrufjöll mountains, ab. 1,5 km to the south from the mouth of the Fagrifjörður bay. The palagonite in the bedrock is, in general, fine-grained (more tuff than breccia) and

----

1) The lake will be sounded in the summer of 1959.

monotonous. Stratification by grain-sizes and sliding planes are both rather little apparent, and the author has nowhere fond any signs of recent tectonic dislocations or faults.
In the area between the rivers Skaftá and Tungnaá and to the north of the Fjallabaksvegur nyrðri track, no volcanic eruptions have taken place in plastglacial times except in the Eldgjá and its prolongation to the north-east in a line paralled to the lake at a distance of 3-4 km to the south-east.

The bedrock is covered with glacial moraines and pumice, so that rock is hardly anywhere apparent, except at high grounds, on steep slopes and in gorges.

In depression and on flat grounds the moraine (which is peculiarly free from basalt boulders) is in most places covered with thick pumice beds. The whole of the pumice is black (basaltic) and presumably originates for the most part from Eldgjá and Vatnaöldur, with great amounts having been added later from the Katla volcano and the Laki craters.

Like other parts of the Palagonite Area, the area around Lake Langisjór is mountainous. All mountains are very elongated in direction NE-SW. A broad mountain belt lying in this direction separates Lake Langisjór from river Tungnaá but only a narrow mountain range, Fögrufjöll, separates the lake from river Skaftá to the south-east of it. The Fögrufjöll range is throughout the whole length divided into two ridges by a deep valley lying between them.

In this valley there are numerous lakes without any superficial outflow (except that a brook may sometimes connect a lake with the nearest one). Shore lines are present at each of the lakes showing that the water level fluctuates according to seasonal and climatic conditions, but the basins are far from being at any time full to the brim, as would be the case if the bedrock was watertight. But as the water level of most of these lakes lies considerably above that of Lake Langisjór, there can hardly be any appreciable leakage occurring from that lake through the Fögrufjöll range.
On the contrary, the ground-water table must dip towards the lake in most places on the south-eastern side of it.

The lowest parts (see a map) of the ridges separating the two biggest lakes in the Fögrufjöll valley from Lake Langisjór are hardly more than 10 m above the surface of that lake. If the level of the Langisjór was raised, therefore, the water would reach these two lakes. But the mountain ridge on the south-eastern side of these lakes is so high that raising the level of Lake Langisjór sufficiently for the water to reach the lowest passes in that ridge is out of the question.

There is no surface inflow of any importance to Lake Langisjór except from the Vatnajökull ice cap from whence two short glacial rivers flow into the lake´s north-eastern end. The two rivers have filled the end of the lake by their sediment and now flow in numerous channels on a flat sand plain. The westermost of the two rivers is larger and is the only one shown on the maps of the Geodetic Institute. It appeared to be almost dry on Sept. 2 and 3, 1957. But on July 31, 1956 it was discharging a considerable amount of water and from a distance it looked hard to wade so that the author walked behind the headwaters of both rivers, on the edge of the glacier.

The discharge of these two short glacial streams is undoubtedly extremely variable and is presumably insignificant in the winter.

In very many places along the shores of Lake Langisjór, as well as on the islands in it, two distinct shore lines from a higher water level than the present one are visible, lying 3.5 and 5.5 m, respectively, above the present water level. Presumably, both are centuries in age. The shore lines show that the water level has been lowered in two stages, with a period of almost constant water level between them. Undoubtedly, the lowering has been caused by the outlet cutting down its bed (see below).

The outlet from the lake is through a narrow mountain pass in the north-eastern part of the Fögrufjöll mountain range. It plunges from a control of palagonite and flows with a decreasing slope to a lake of considerable size filling the easternmost part of the mountain pass. The distance from the outlet control to the lake is about 0.5 km but the whole fall in the river, ab. 20 m, is in that section. From the lake, a deep channel with almost a negligible slope leads to river Skaftá, which in this place is a braided stream flowing in a number of channels on an alluvial plain.

Both times the author has visited the outlet river he estimated its discharge at 15-20 m^3/s. Undoubtedly, the discharge is much lower in the winter [1].

Apart from a rather bad acessibility, there is a promising dam site on the outlet from Lake Langisjór. The rock threshold cut down by the river has a height of ab. 8-10 m above the level of Lake Langisjór and a width of only 75 m between steep mountain slopes. The river itself is close to the south-western slope. It is only 15 m wide and flows in a cut with almost vertical walls, lying wholly in palagonite rock. No other rock types are visible in the control or anywhere else in the neighbourhood. In general, the palagonite looks sound and does not indicate leakage channels to be present in it. However, there is presumably some leakage from Lake Langisjór below the outlet control. This is indicated, among other things, by springs issuing in the northern side of the small lake downstream of the outlet control. The author had an opportunity to observe these springs from a distance only, but their discharge appeared considerable. Their water looks clear, an indication that the water is flowing through fine fractures in the rock, and not through continuous channels.

By a dam of only 20-30 m length built across the outlet, the

----

1) On Okt. 18 1958 the Hydrologic Survey measured the discharge of the outlet. The result was 11 m^3/s.

level of Lake Langisjór may be raised 10 m. Raising the water level more would require a dam of 75-100 m length on the outlet, plus some ancillary dams across other deep gaps in the rim of the lakes basin.

The second lowest col in the brim of the basin containing Lake Langisjór is at the south-western end of the lake, at the slopes of the "peak 750" mentioned above, situated on a flat moraine at a distance of several hundreds of metres from the lake. According to measurements made by the author with a Paulin barometer, the col is ab. 10 m above the lake´s water level. It dips southwards, to the Hvanngil gorge in which there is a brook flowing to river Skaftá. The uppermost headwaters of this brook are in the bottom of a cut in a moraine situated just south of the col, ab. 6 m below the level of the Langisjór. Without doubt, this source is to some extent a leakage from the lake, but its discharge is insignificant. The water of the source was clear, its temperature was ab. 2.2°C. The wole of the treshold between this cut and the lake appears to consist of unconsolidated materials (pumice and moraine). Judging from the surrounding landscape, these loose materials may be presumed to be filling a deep trench in the bedrock in this place, and the leakage would presumably increase accordingly as the level of Lake Langisjór was raised.

There are no indications that an outlet from the lake has at any time been over this col, and the latter would also in that case inevitably have been cut down by the water.

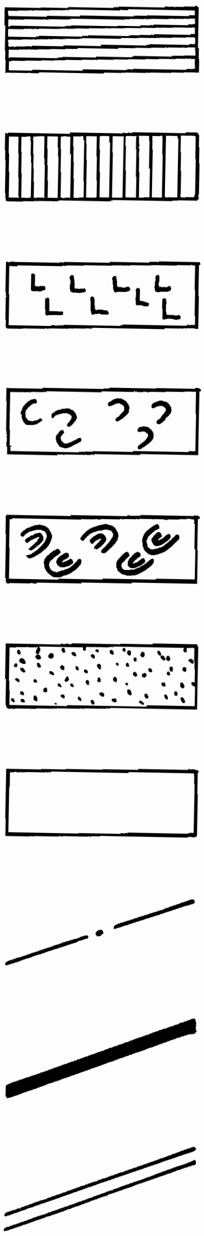
The third lowest pass from the Langisjór basin is between the north-eastern end of the Fögrufjöll range and the margin of the glacier. According to the maps of the Geodetic Institute the elevation of this col is less than 20 m above the lake, but is shown on the AMS maps to be more than 65 m above it, which obviously is more correct. But as the glacier recedes and gets thinner, the col moves in direction north and when/if the glacier becomes free of the end of the mountain range - as it may be expected to do in the next decades - the col has reached the flat alluvial plain, which in that place is hardly more than 10-20 m above the level of the lake. As a matter of fact, there is the possibility that the mountain range may continue beneath the glacier. But in that case the part lying beneath the glacier must be very low, as it nowhere extends up through the ice, and the uniform glacier surface does not indicate any hills in the base. But the opposite is also possible, viz. that there is a depression beneath the ice, in which a lake would be formed when/if the glacier recedes.

As long as nothing more is known about the base of the glacier to the northeast of the Fögrufjöll range, there is hardly any question of raising the level of Lake Langisjór more than until the water reaches the margin of the ice, because a receding glacier cannot be relied upon as a dam.

FIG. 1

ROCK TYPES IN THE ÞÓRISVATN AND FOSSÁRDALUR AREAS

Scale: 1 : 100 000



Basalt

Palagonite rock and other clastic rocks

Rhyolite

Postglacial lava, other than Hekla lava

Hekla lava

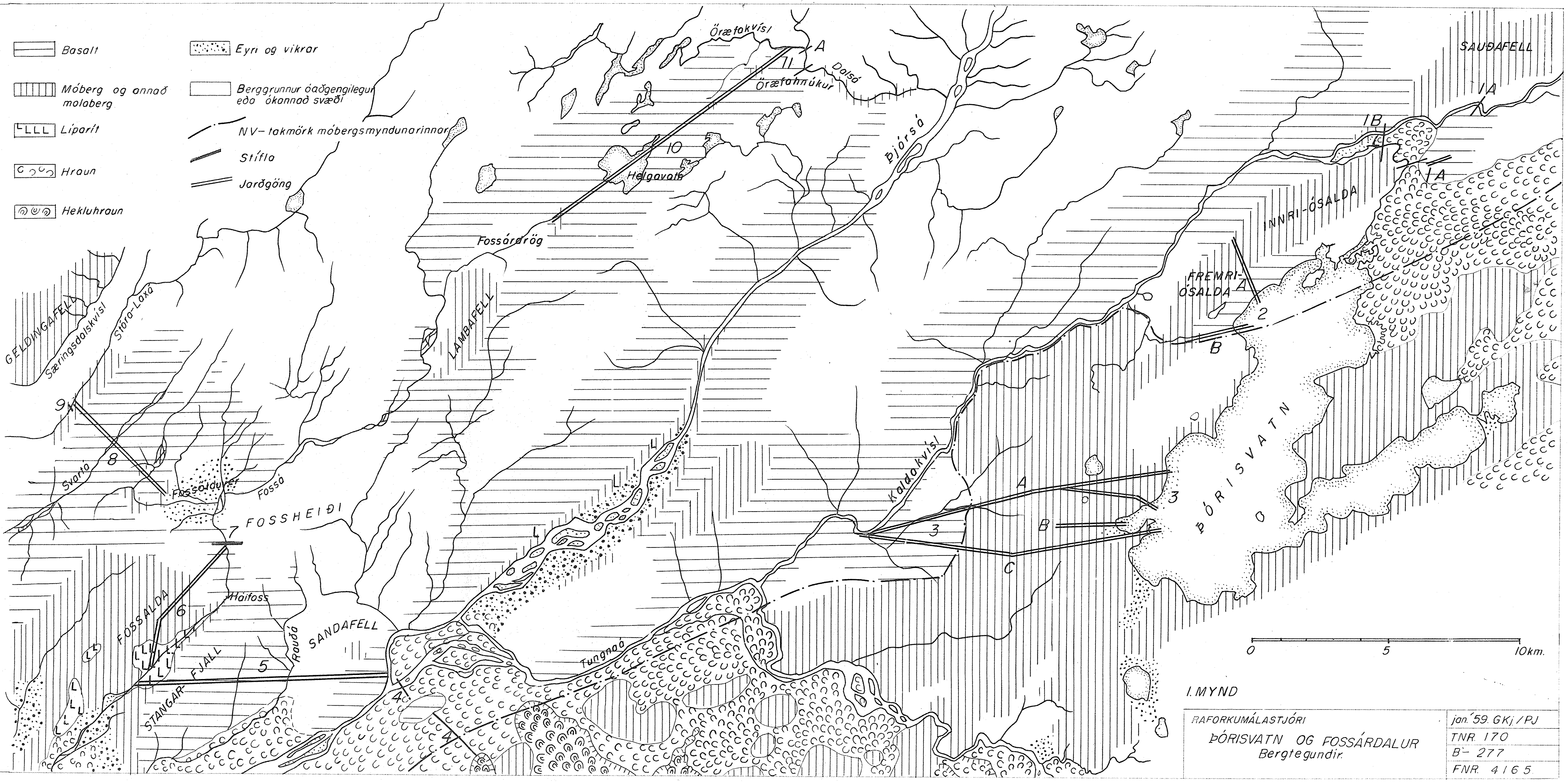
River gravel and pumice

Bedrock difficult to get at
or area not surveyed

NW-limit of the Palagonite series

Proposed dam

Proposed tunnel



Basalt
Móberg og annað molaberg
Líparít
Hraun
Hekluhraun
Eyri og vikrar
Berggrunnur óaðgengilegur eða ókannað svæði
NV-takmörk móbergsmyndunarinnar
Stífla
Jarðgöng
Öræfakvísl
Öræfahnúkur
Dalsá
Helgavatn
Fossárdrög
Þjórsá
SAUÐAFELL
INNRI-ÓSALDA
FREMRI-ÓSALDA
GELDINGAFELL
Særingsdalskvísl
Stóra-Laxá
LAMBAFELL
Svartá
Fossá
FOSSHEIÐI
Kaldakvísl
ÞÓRISVATN
FOSSALDA
Háifoss
Rauðá
SANDAFELL
STANGARFJALL
Tungnaá
0 5 10km.
I. MYND
RAFORKUMÁLASTJÓRI
ÞÓRISVATN OG FOSSÁRDALUR
Bergtegundir.
jan. '59. GKj / PJ
TNR. 170
B- 277
FNR. 4165

FIG. 2

DAM SITES A AND B ON THE ÞÓRISÓS AND THE KALDAKVÍSL

Scale: 1 : 20 000

M B	Exposed bedrock M = Palagonite rock; B = Basalt
	Basalt (in most places covered)
	Palagonite rock (in most places covered)
	Thick moraine (bedrock completely covered)
	Lava
	River gravel
	Proposed dam
	Proposed tunnel
	Shore line of proposed reservoir

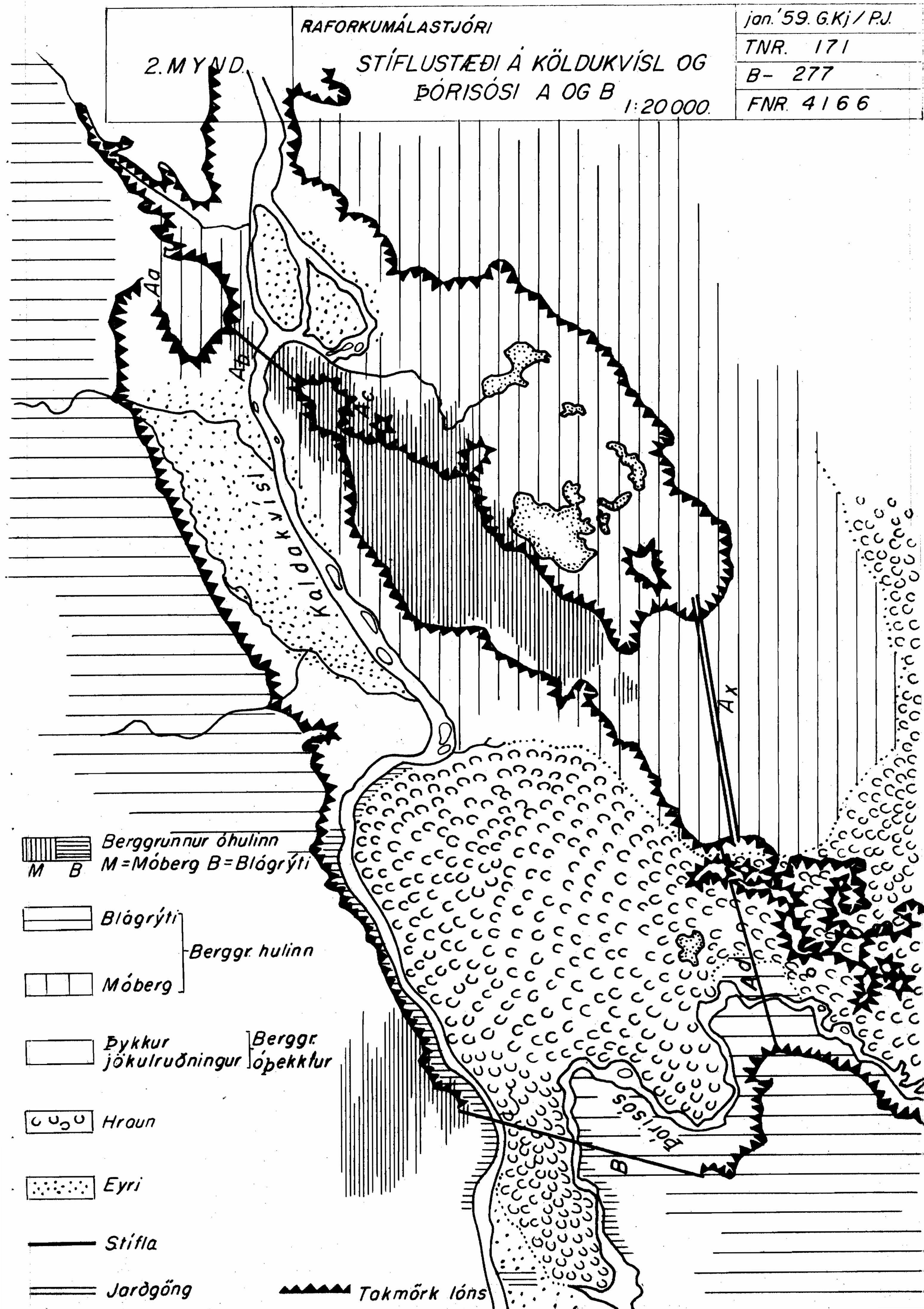

2. MYND
RAFORKUMÁLASTJÓRI
STÍFLUSTÆÐI Á KÖLDUKVÍSL OG ÞÓRISÓSI A OG B
1:20000.
jan.'59. G.Kj / P.J.
TNR. 171
B- 277
FNR. 4166
Aa
Ab
Ac
Ax
Ad
B
Kaldakvísl
Þórisós
Berggrunnur óhulinn
M B
M = Móberg B = Blágrýti
Blágrýti
Berggr. hulinn
Móberg
Þykkur jökulruðningur
Berggr. óþekktur
Hraun
Eyri
Stífla
Jarðgöng
Takmörk lóns

FIG. 3 (top)

UPPER DAM SITE ON THE KALDAKVÍSL

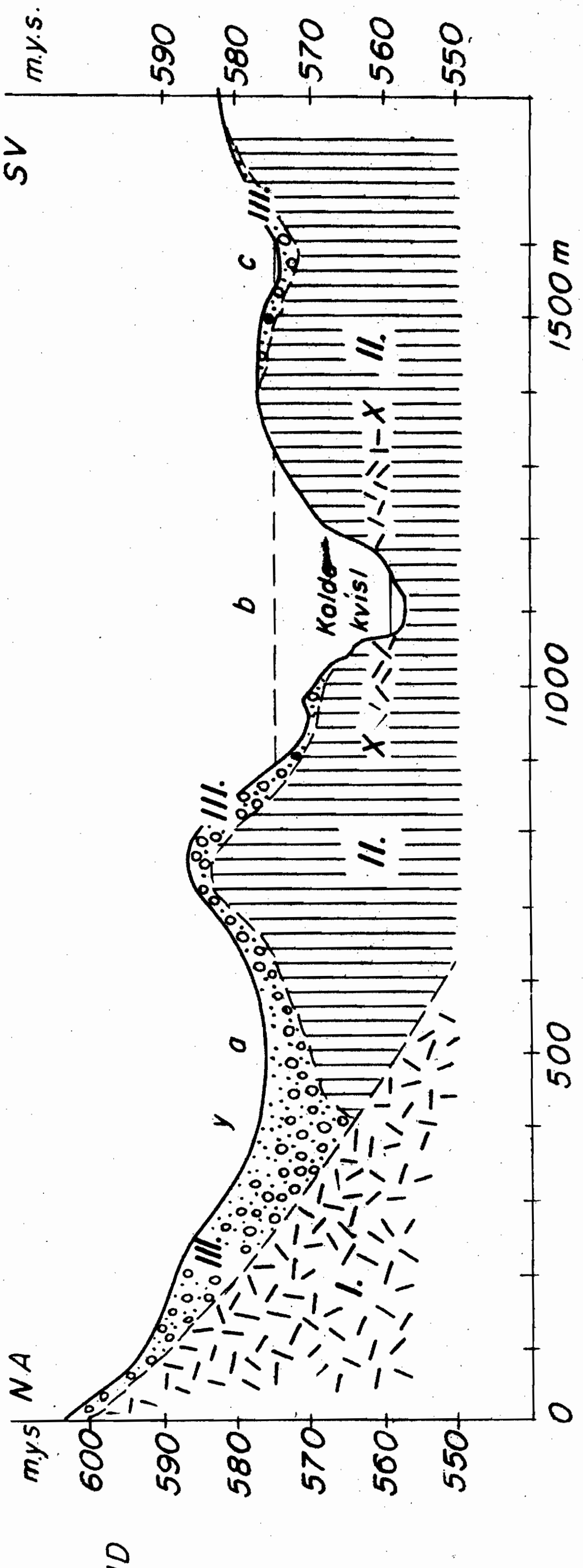
NA	=	North-east
SV	=	South-west
m.y.s	=	metres above sea level
I	=	Palagonite rock
II	=	Basalt
III	=	Loose and sandy surface layer of moraine
X	=	Scoriaceous layer

FIG. 4 (bottom)

UPPER DAM SITE ON THE ÞÓRISÓS

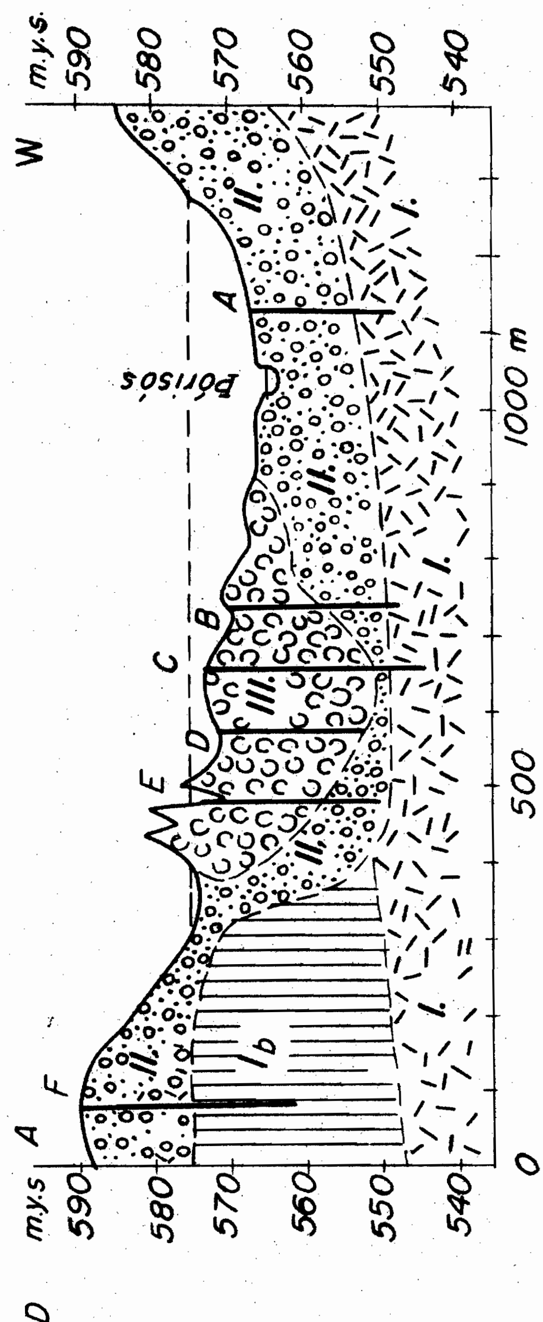
A	=	East
W	=	West
m.y.s	=	metres above sea level
I_a	=	Palagonite rock
I_b	=	Basalt
II	=	Mostly moraine
III	=	Lava
A to F	=	Boreholes

3-4 MYND	RAFORKUMÁLASTJÓRI EFRA STÍFLUSTÆÐI Á KÖLDUKVÍSL (a, b, c) EFRA STÍFLUSTÆÐI Á ÞÓRISÓSI	jan. 59. G.Kj/ P.J. TNR. 172 B 277 FNR. 4167



3. MYND

I. Móberg; II. Blágrýti; X gjallkennt lag; III. Jökulruðningur, y laust, sendið yfirborðslag.



4. MYND

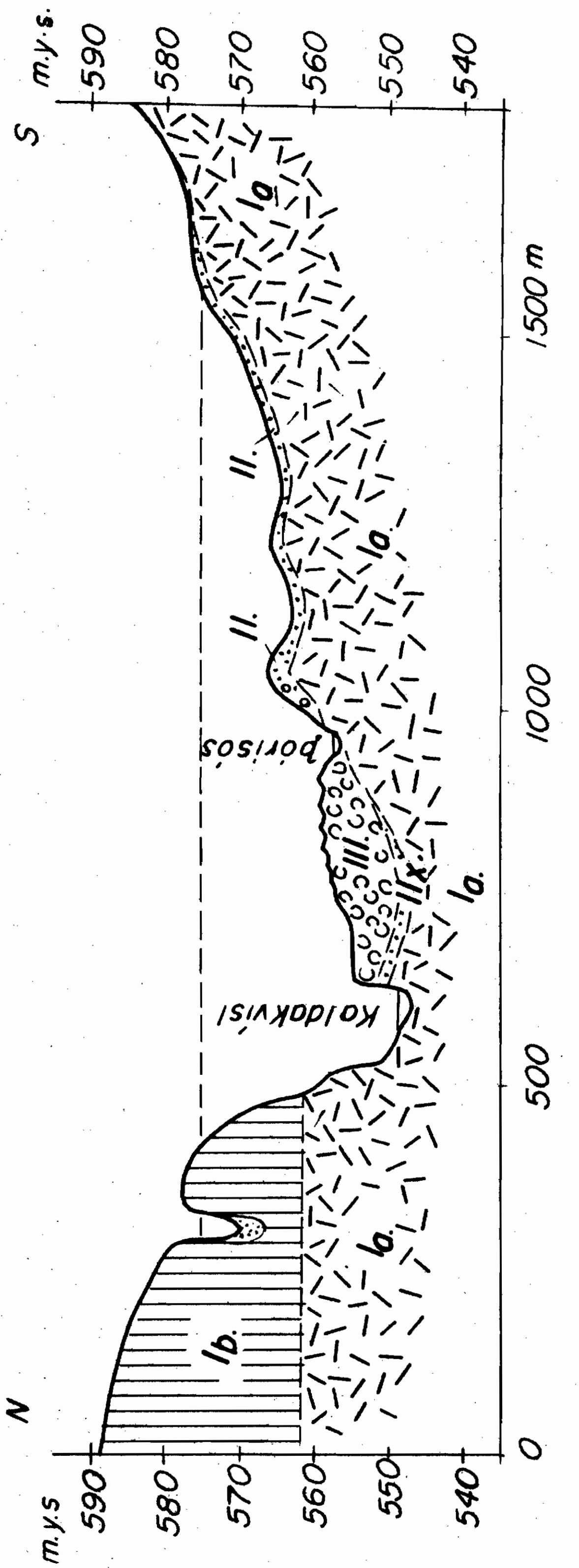
Ia Móberg; Ib Blágrýti; II. Mest jökulruðningur; X vatnsamt fastara lag; III. Hraun; A–F borholur.

FIG. 5

LOWER DAM SITE ON THE KALDAKVÍSL AND THE ÞÓRISÓS

m.y.s	=	metres above sea level
I_a	=	Palagonite bedrock
I_b	=	Basalt bedrock
II	=	Mostly moraine
III	=	Lava
X	=	Loose beds under the lava

5. MYND.	RAFORKUMÁLASTJÓRI NEÐRA STÍFLUSTÆÐI Á KÖLDUKVÍSL OG ÞÓRISÓSI.	jan.'59. G.Kj / P.J. TNR. 173 B 277 FNR. 4168.



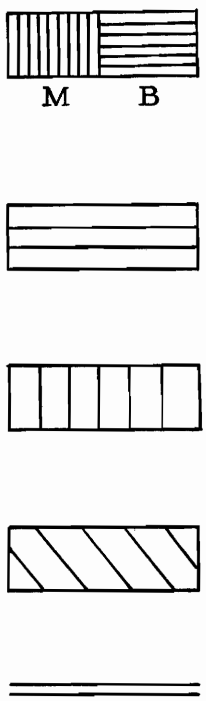
I. Berggrunnur, a móberg, b blágrýti; II. Mest jökulruðningur, x laus jarðlög undir hrauni.

FIG. 6

DRAINING TUNNEL

FROM LAKE ÞÓRISVATN

Routes A and B



Exposed bedrock
M = Palagonite rock; B = Basalt

Basalt bedrock, in most places covered

Palagonite bedrock, in most places covered

Thick moraine

Proposed tunnel routes

6. MYND.	RAFORKUMÁLASTJÓRI FRAMRÆSLUJARÐGÖNG ÚR ÞÓRISVATNI, A OG B. 1:20000.	jan.'59 G.Kj./P.J. Tnr. 174 B – 277 FNR. 4169

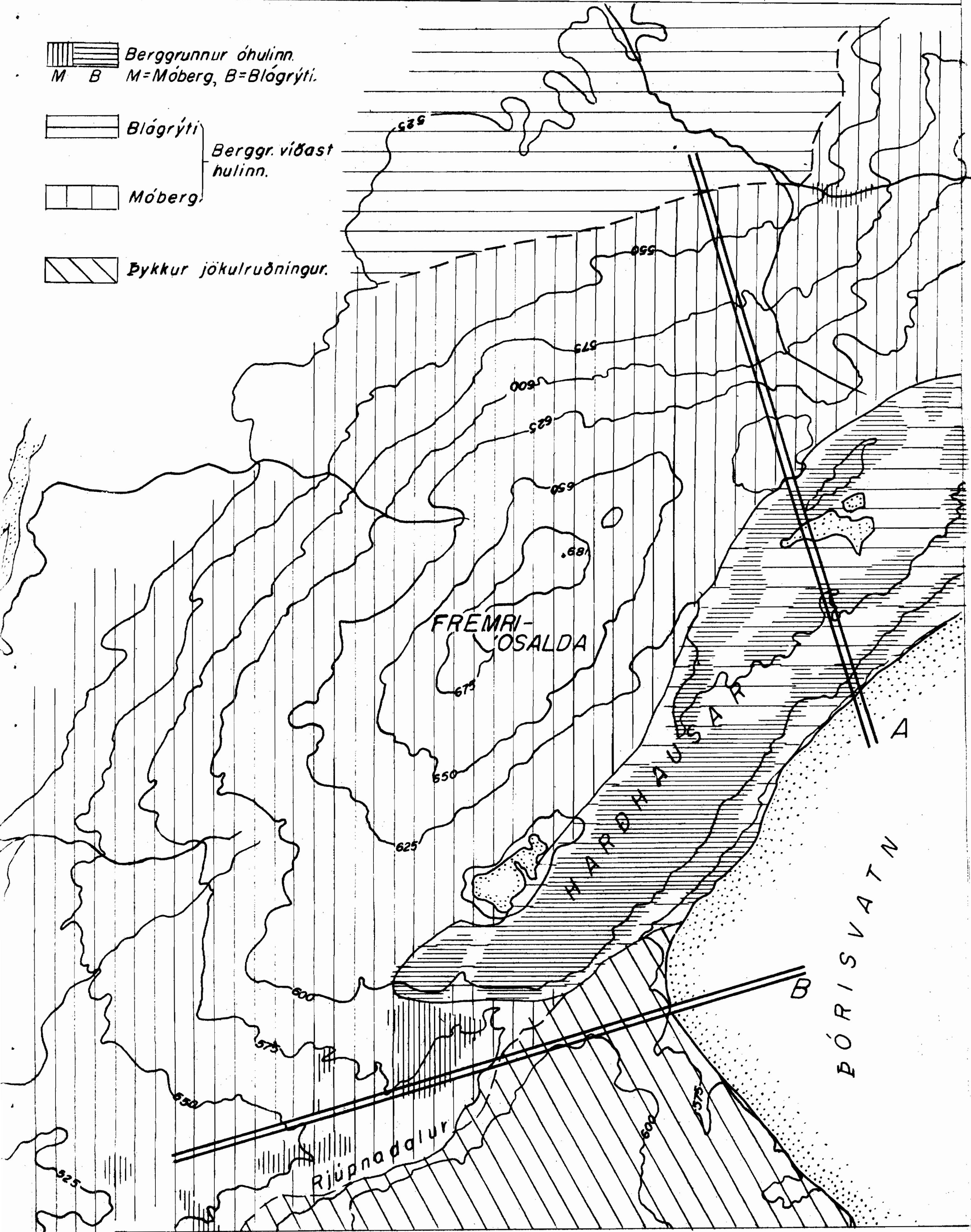


FIG. 7 (top)

DRAINING TUNNEL THROUGH THE FREMRI-ÓSALDA

(Route A on Fig. 6)

m.y.s	=	metres above sea level
I	=	Palagonite rock
II	=	Harðhausar basalt
III	=	Younger basalt beds
IV	=	Moraine and scree

FIG. 8 (bottom)

DRAINING TUNNEL THROUGH THE RJÚPNADALUR

(Route B on Fig. 7)

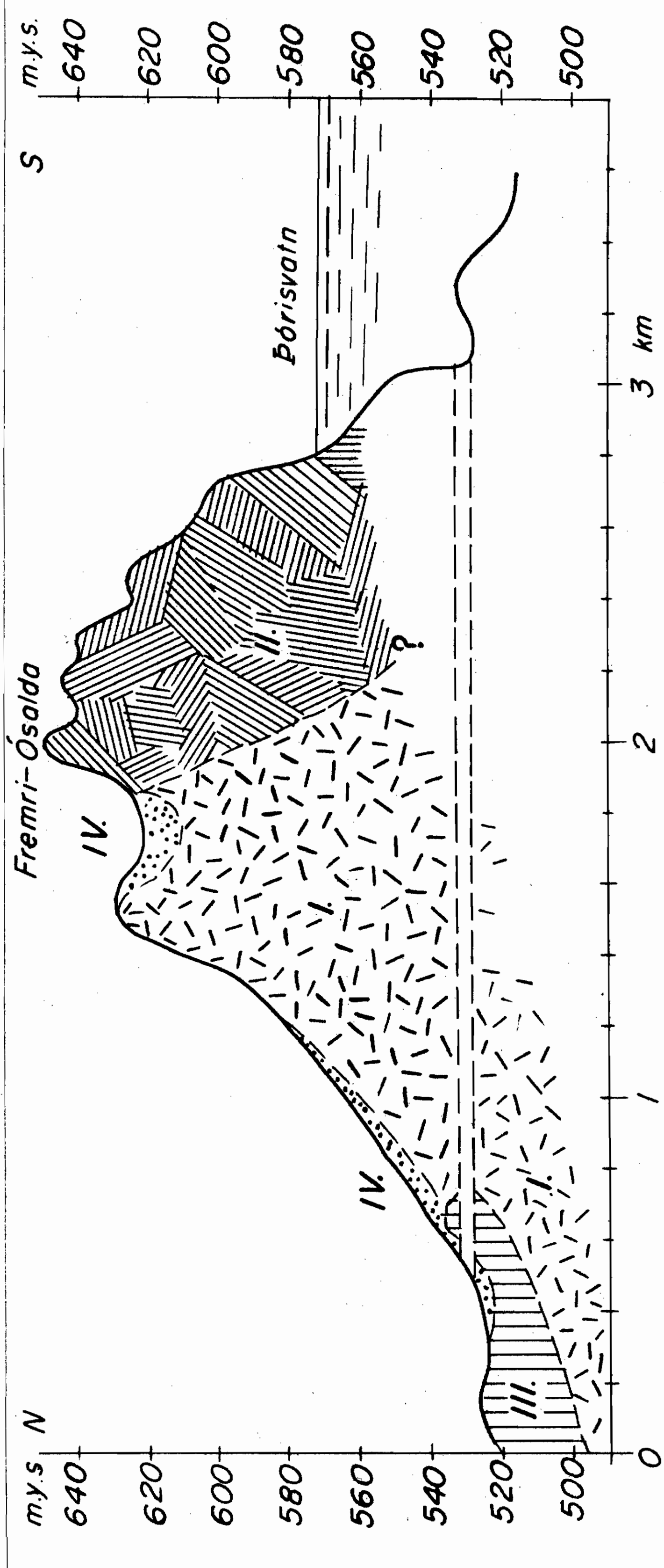
m.y.s	=	metres above sea level
V	=	West
A	=	East
I	=	Palagonite rock
II	=	Moraine

7–8 MYND.

RAFORKUMÁLASTJÓRI

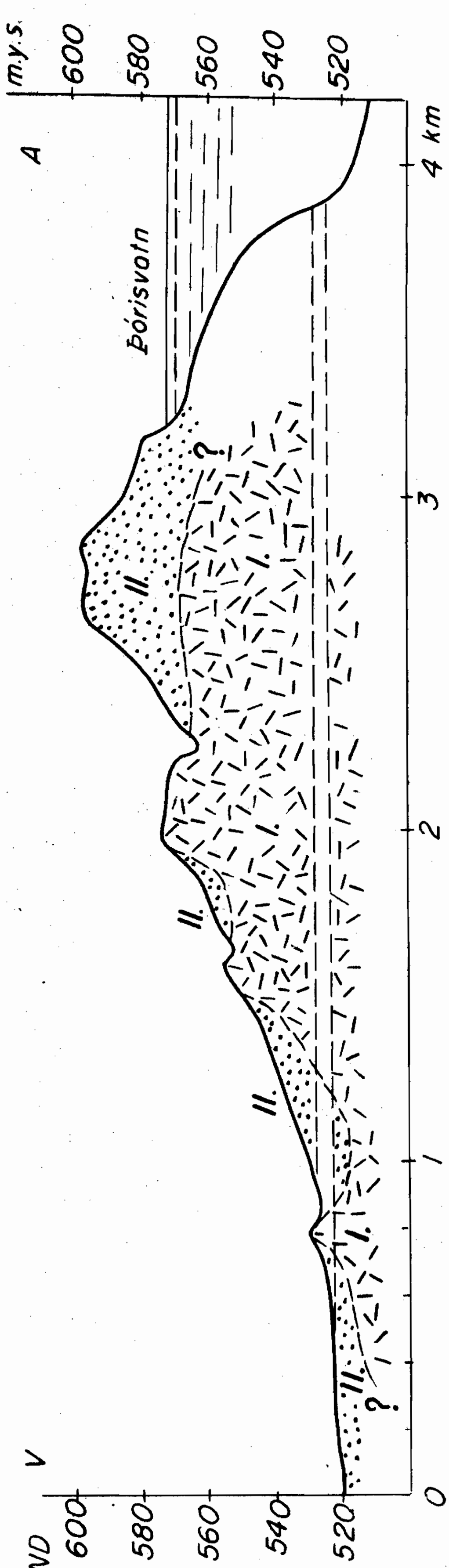
FRAMRÆSLUGÖNG GEGNUM ÓSÖLDUR.
FRAMRÆSLUGÖNG Í RJÚPNADAL.

jan.'59 G.Kj./P.J.	
TNR.	175
B –	277
FNR	4170



I. Móberg; II. Blágrýti í Harðhausum; III. Yngri basaltlög; IV. Jökulruðningur og skriða.

7. MYND



I. Móberg; II. Jökulruðningur.

8. MYND

FIG. 9

GEOLOGICAL MAP
OF THE ÞÓRISTUNGUR

Scale: 1 : 20 000

M B — Exposed bedrock
M = Palagonite rock; B = Basalt

The Þóristungur basalt, mostly covered

The Palagonite series, mostly covered

Pillow lava and jointed basalt
within the Palagonite series

Thick loose beds, mostly moraine

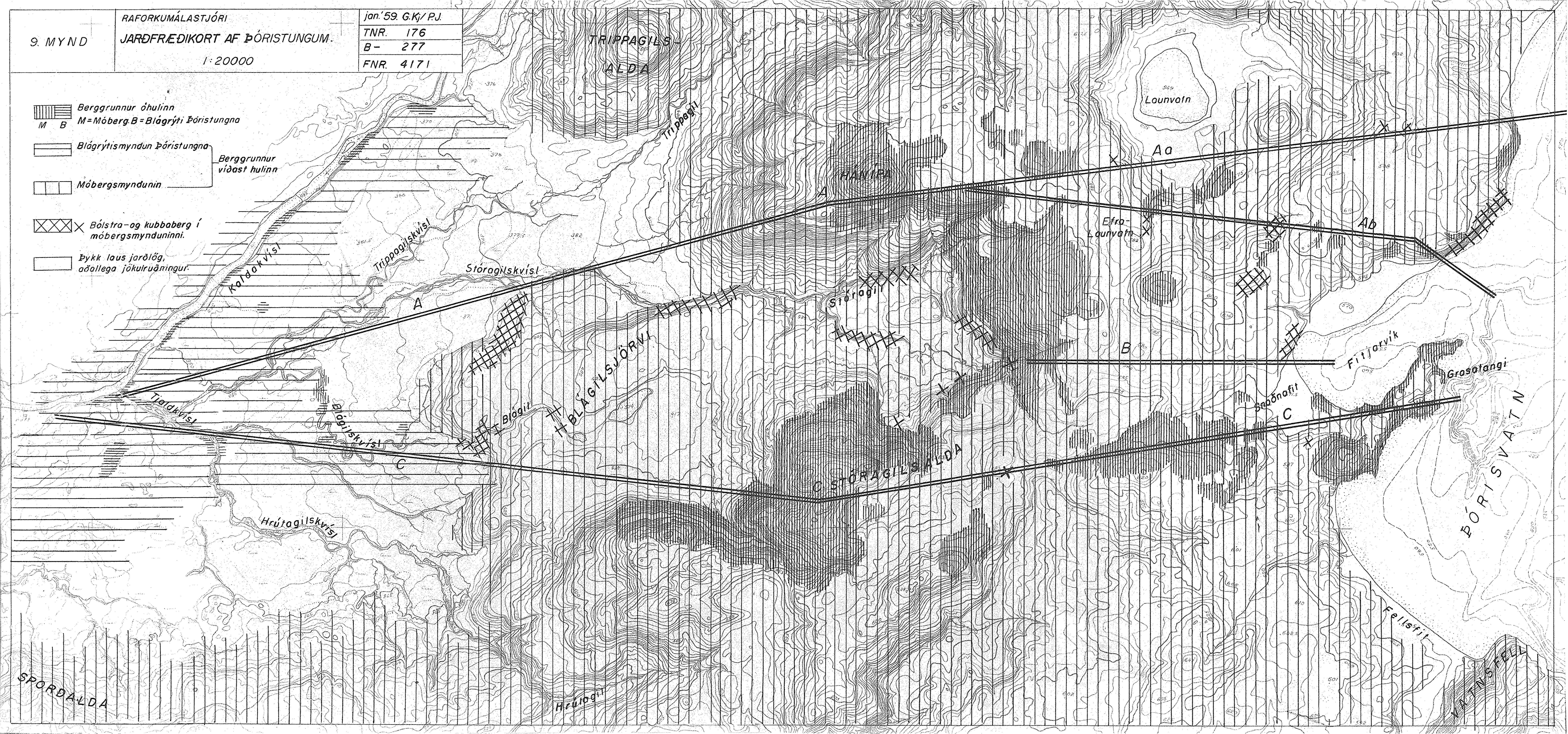

9. MYND
RAFORKUMÁLASTJÓRI
JARÐFRÆÐIKORT AF ÞÓRISTUNGUM.
1:20000
jan.'59. G.Kj/ P.J.
TNR. 176
B- 277
FNR. 4171
Berggrunnur óhulinn
M=Móberg. B=Blágrýti Þóristungna
M B
Blágrýtismyndun Þóristungna
Berggrunnur víðast hulinn
Móbergsmyndunin
Bólstra- og kubbaberg í móbergsmynduninni.
Þykk laus jarðlög, aðallega jökulruðningur.
TRIPPAGILS-ALDA
Launvatn
Efra-Launvatn
HÁNÍPA
Trippagil
Trippagilskvísl
Stóragilskvísl
Kaldakvísl
Stóragil
BLÁGILSJÖRNI
Blágil
Blágilskvísl
Tjaldkvísl
STÓRAGILSALDA
Hrútagilskvísl
Hrútagil
Fitjarvík
Sandafit
Grasatangi
ÞÓRISVATN
Fellsfit
VATNSFELL
SPORÐALDA
A
Aa
Ab
B
C

FIG. 10

TUNNEL BENEATH THE HÁNÍPA

(Tunnel Route Aa)

m.y.s	=	metres above sea level
I	=	The Þóristungur basalt formation
II	=	Pillowy and jointed basalt with upward increasing amount of palagonite rock
III	=	Palagonite rock intrusions with downward decreasing admixture of basalt rock
IV	=	Loose or poorly indurated beds, mostly moraine

10. MYND.	RAFORKUMÁLASTJÓRI JARÐGÖNG UNDIR HÁNÍPU (LEIÐ Aa)	jan. '59. G.Kj / P.J. TNR. 177 B – 277 FNR 4172

FIG. 11

TUNNEL BENEATH THE STÓRAGILSALDA

(Tunnel Route C)

m.y.s	=	metres above sea level
I	=	The Þóristungur basalt formation
II	=	Pillowy and jointed basalt with upward increasing amount of palagonite rock
III	=	Palagonite rock. Basalt with downward decreasing admixture of basalt rock
IV	=	Loose or poorly indurated beds, mostly moraine

II. MYND.	RAFORKUMÁLASTJÓRI JARÐGÖNG UNDIR STÓRAGILSÖLDU (LEIÐ C)	jan.'59. GKþ/PJ. TNR. 178 B - 277 FNR. 4173

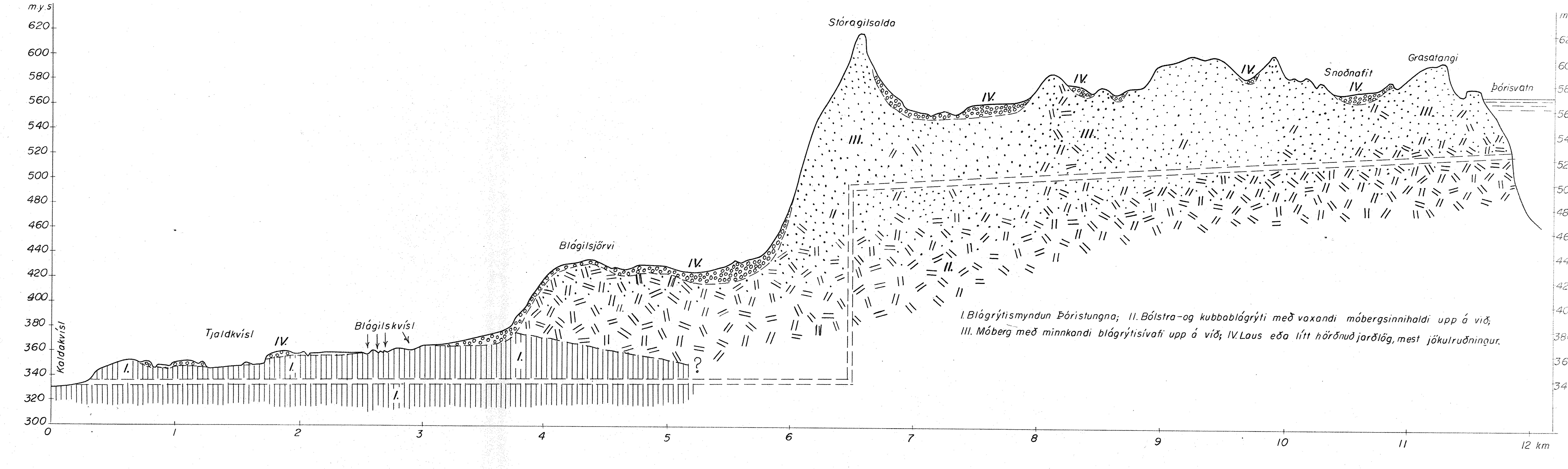


FIG. 12 (top)

DAM SITE ON THE ÞJÓRSÁ AND THE TUNGNAÁ AT SULTARTANGI

m.y.s	=	metres above sea level
NV	=	North-west
SA	=	South-east
I	=	The Hreppar series, mostly basalt
II	=	The Palagonite series
III	=	Moraine
IV	=	Þjórsá lava
V	=	Hekla lava
VI	=	Loose sand and scree

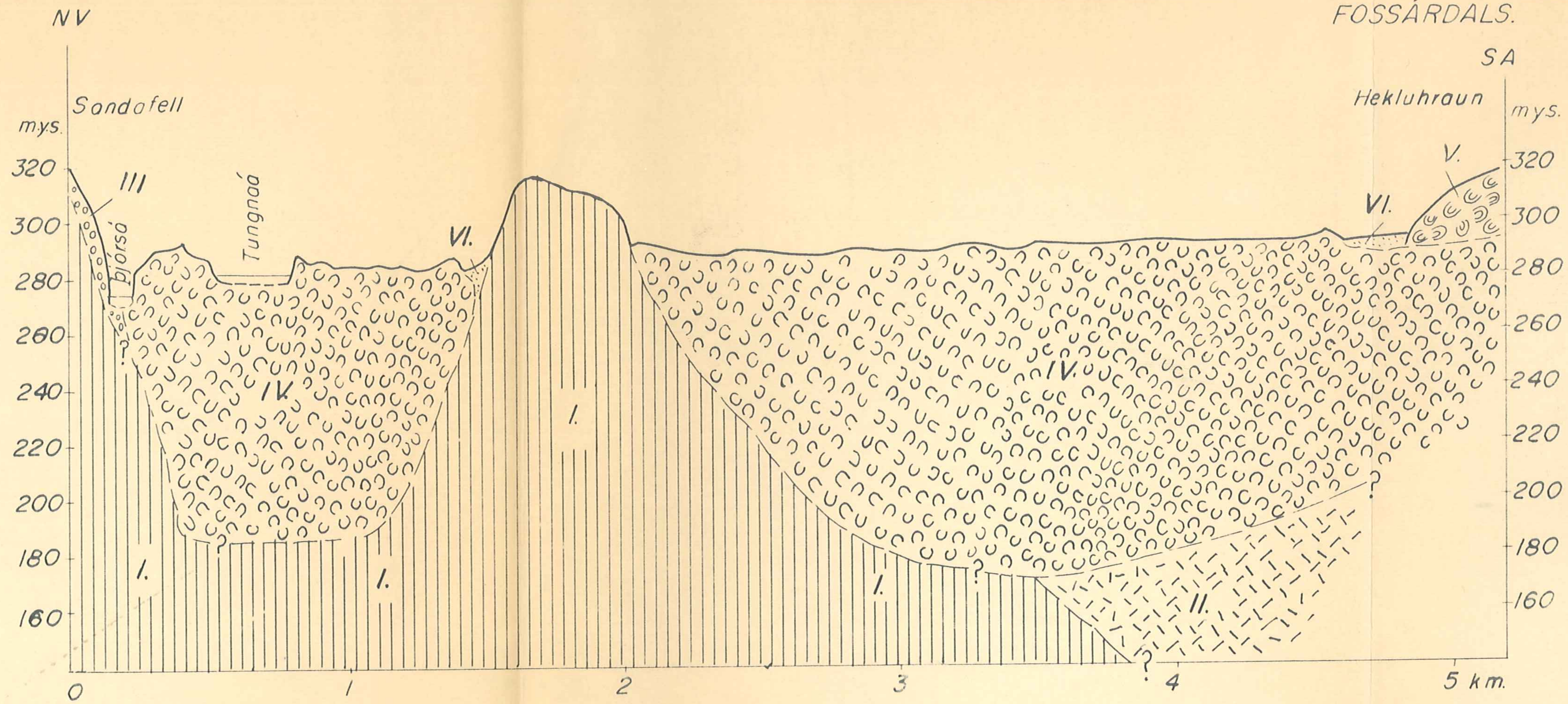
FIG. 13 (bottom)

TUNNEL FROM SULTARTANGI TO THE FOSSÁRDALUR VALLEY

m.y.s	=	metres above sea level
V	=	West
A	=	East
I	=	Rhyolite breccia
II	=	Palagonite breccia
III	=	Basalt
IV	=	Moraine and other loose beds
V	=	Þjórsá lava
jarðgöng	=	tunnel (other names are place names)

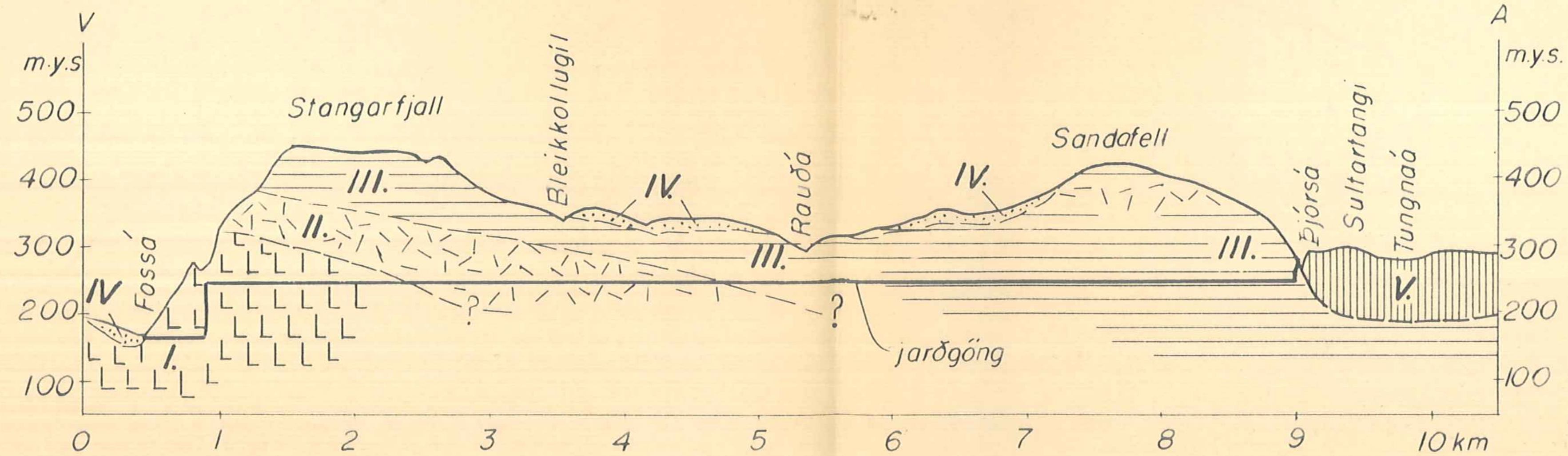
12.-13. MYND.	RAFORKUMÁLASTJÓRI STÍFLUSTÆÐI Á ÞJÓRSÁ OG TUNGNAÁ UM SULTARTANGA. JARÐGÖNG FRÁ SULTARTANGA TIL FOSSÁRDALS.	jan.'59 G.Kj / PJ TNR 179 B – 277 FNR. 4174

12. MYND



I. Hreppamyndunin, mest blágrýti; II. Móbergsmyndunin; III. Jökulruðningur; IV. Þjórsárhraun; V. Hekluhraun; VI. Laus sandur og skriða.

13. MYND



I. Líparítbreksía; II. Móbergsbreksía; III. Blágrýti; IV. Jökulruðningur og önnur laus jarðlög; V. Þjórsárhraun.

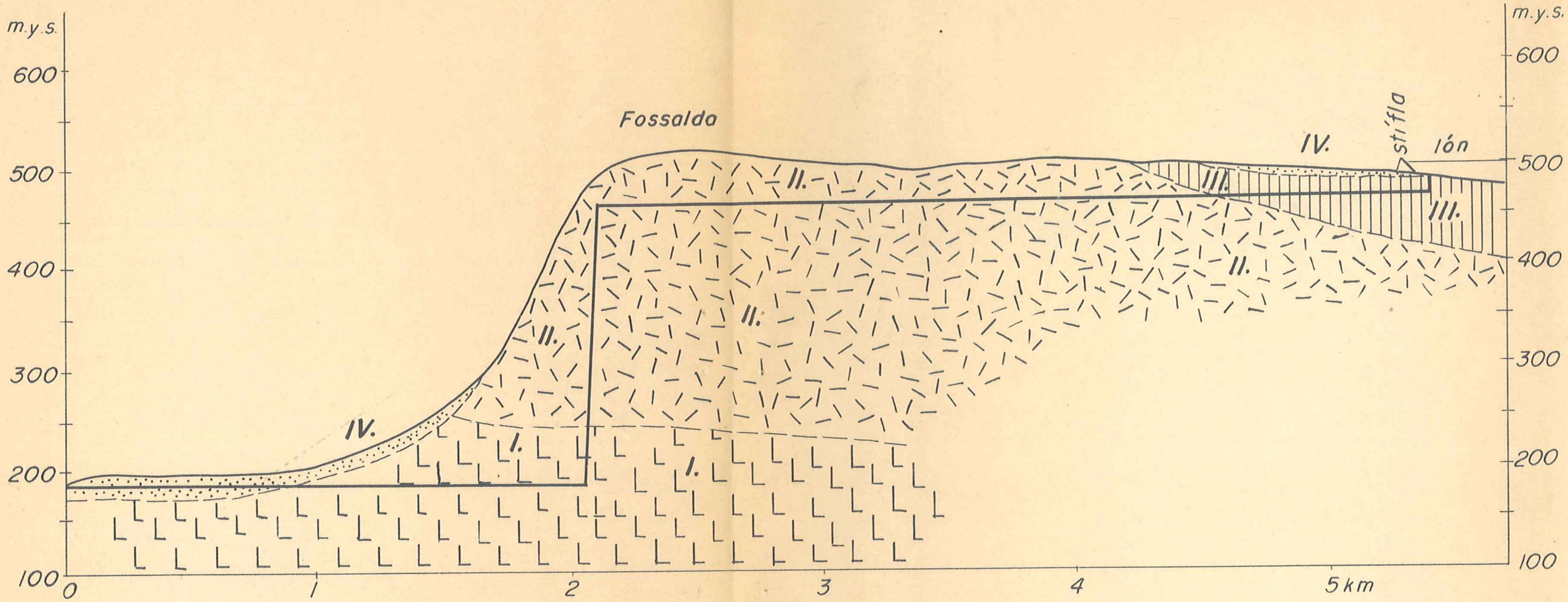
FIG. 14

TUNNEL THROUGH THE FOSSALDA

m.y.s	=	metres above sea level
I	=	Rhyolite
II	=	Clastic rock with intercalated basalt
III	=	Basalt beds
IV	=	Loose beds (moraine,scree, river gravel)
Stífla	=	Dam
Lón	=	Reservoir

(Other names are place names)

14. MYND.	RAFORKUMÁLASTJÓRI JARÐGÖNG GEGNUM FOSSÖLDU.	jan.'59 G.Kj./P.J. TNR. 180 B- 277 FNR. 4175



I. Líparít; II. Molaberg með blágrýtisívafi; III. Blágrýtislög; IV. Laus jarðlög (jökulruðningur, skriða, eyrar).

FIG. 15

TUNNEL FROM RIVER STÓRA-LAXÁ TO

THE FOSSÖLDUR

m.y.s	=	metres above sea level
I	=	Palagonite rock
II	=	Basalt
III	=	Loose sedimentary layers
b	=	Faults

15. MYND.	RAFORKUMÁLASTJÓRI JARÐGÖNG FRÁ STÓRU-LAXÁ TIL FOSSÖLDUVERS.	jan.'59. G.Kj / P.J. TNR. 181 B- 277 FNR. 4176

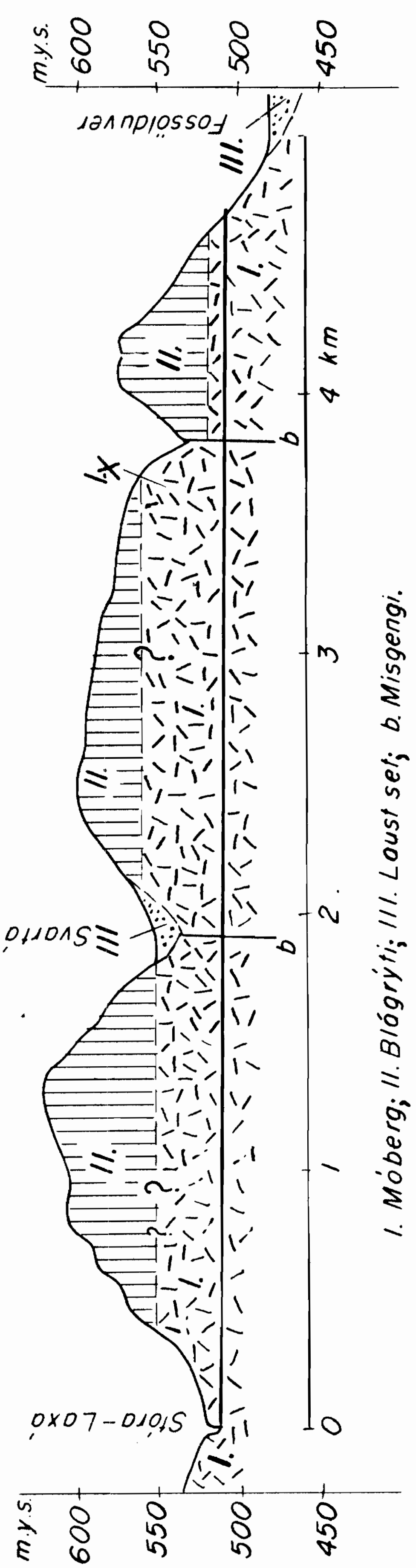
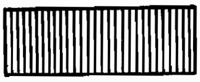
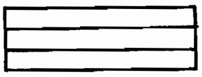
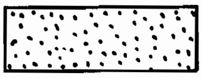
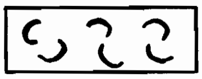
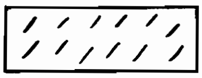
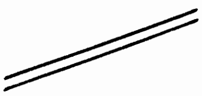


FIG. 16

GEOLOGICAL MAP SHOWING THE BEDROCK OF THE HVÍTÁRVATN AREA

Scale: 1 : 100 000

	The Breccia formation
	The Grey Basalt formation
	Bedrock totally covered (mostly with moraine)
	Lava
	Delta
	Proposed water conduits (tunnel or canals)
	Proposed dam
a - a	Line of cross-section through Mt. Bláfell shown on Fig. 20
gígur	cràter (other names are place names)
Numbers	See text

16. MYND	RAFORKUMÁLASTJÓRI BERGGRUNNSKORT. Bláfell og Hvítárvatn.	jan.'59. GKj / PJ. TNR. 441 B - 274 FNR. 6735

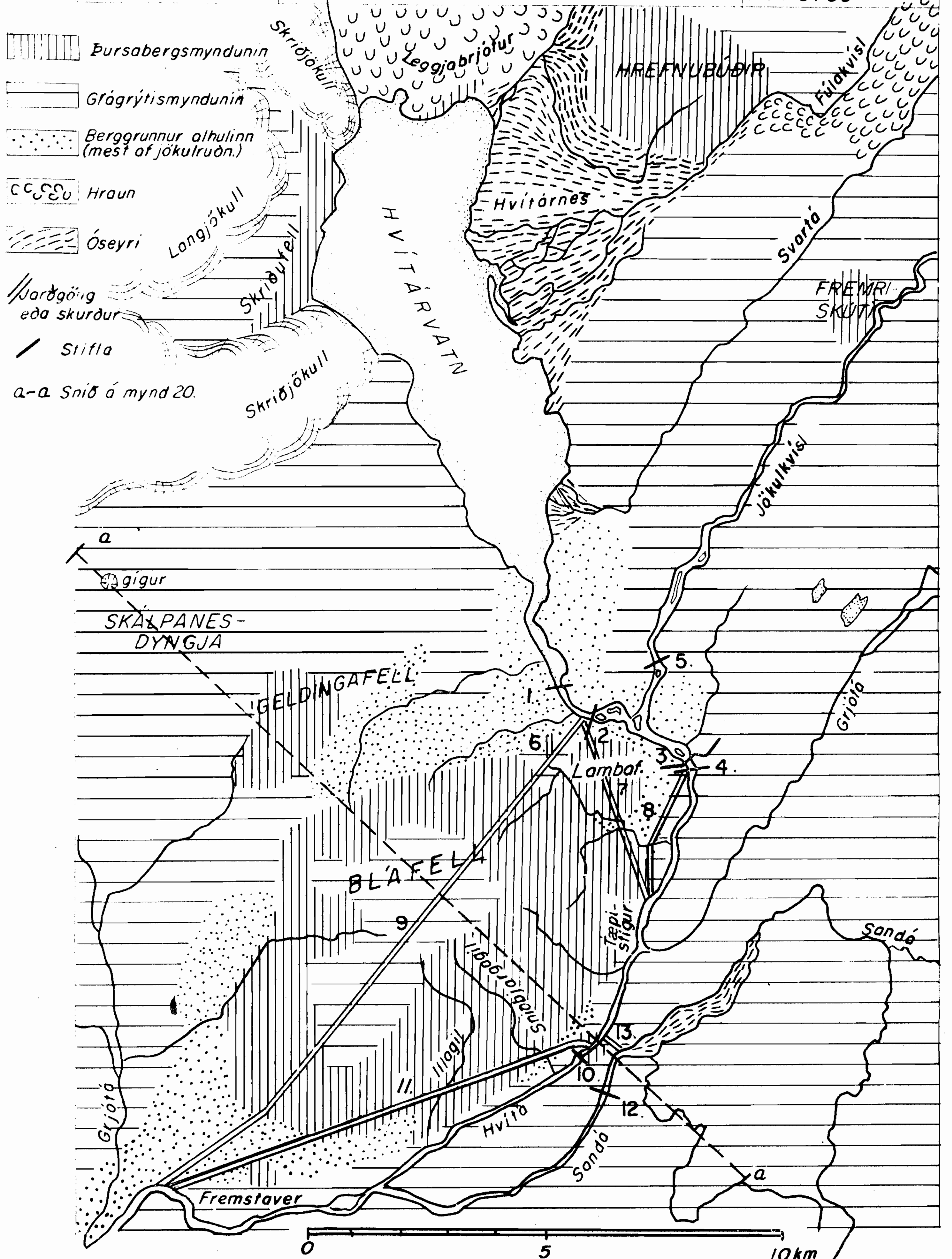


FIG. 17 (top)

DAM SITE No 2, ON RIVER HVÍTÁ

FIG. 18 (middle)

DAM SITE No 3, ON RIVER HVÍTÁ

FIG. 19 (bottom)

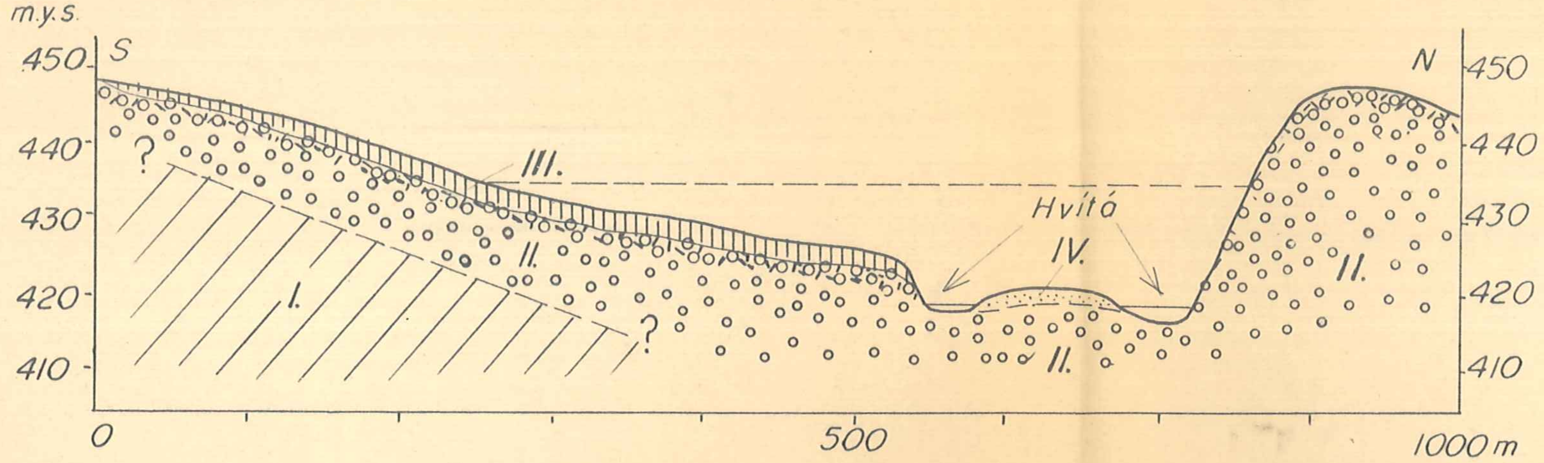
DAM SITE No 5, ON RIVER JÖKULFALL

Legend (to all three figures) :

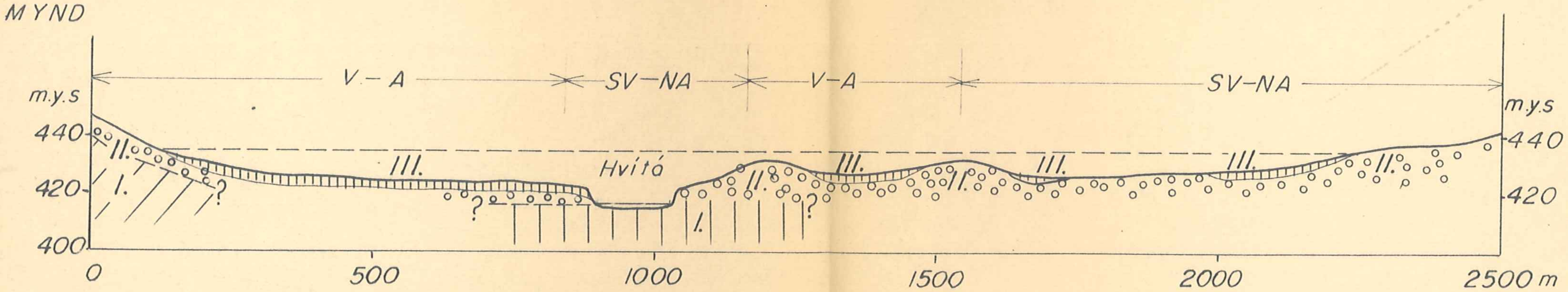
m.y.s	=	metres above sea level
S	=	South
N	=	North
V	=	West
A	=	East
SV	=	South-west
NA	=	North-east
I	=	Bedrock ( Basalt
		 Palagonite rock)
II	=	Moraine (a weathered surface layer is shown seperately in Fig. 17 and 19)
III	=	Soil
IV	=	River gravel
lækur	=	brook, other names are place names

17. 18 og 19. MYND.	RAFORKUMÁLASTJÓRI STÍFLUSTÆÐI 2, Hvítá. —"— 3, " —"— 5, Jökulkvísl.	jan.'59. GKj/PJ TNR. 442 B- 274 FRN 6736

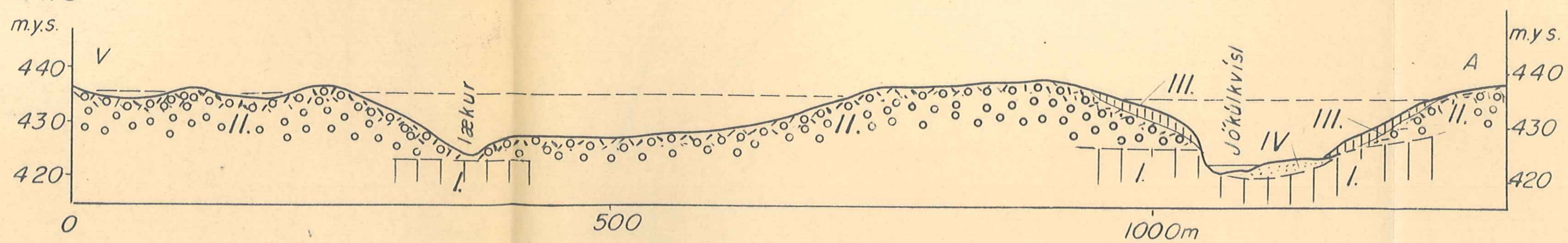
17. MYND.



18. MYND



19. MYND



Skýring við 17.18.og 19.MYND:

I. Berggrunnur, skástrikað móberg, lóðrétt strikað basalt. II. Jökulruðningur, (veðrað yfirborðslag merkt sérstaklega á 17. og 19. mynd.)

III. Jarðvegur. IV. Eyri.

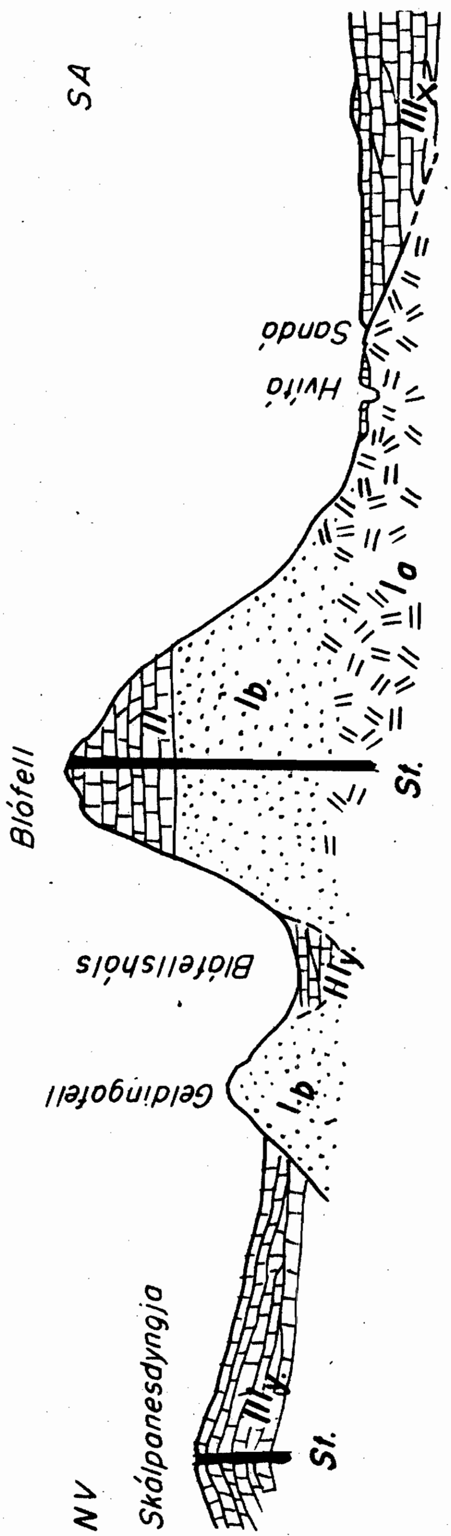
FIG. 20

A SCHEMATIC SECTION THROUGH Mt. BLÁFELL

(along line aa on Fig. 16)

NV	=	North-west
SA	=	South-east
I	=	The Breccia formation
		a: Jointed basalt predominating
		b: Palagonite rock predominating
II	=	Grey basalt in the top of Mt. Bláfell
III	=	The Grey Basalt formation
		x: Crypto-crystalline basalt predominating
		y: Skálpanes grey basalt
St	=	Volcanic neck or dyke

20. MYND	RAFORKUMÁLASTJÓRI SKEMATÍSKT SNIÐ GEGNUM BLÁFELL (a–a á 16 Md)	jan. '59. GKj / PJ TNR. 443 B – 274 FNR. 6737



I. Þursabergsmyndunin, a. mest kubbaberg, b mest móberg; II. Grágrýtiskollur á Bláfelli.

III. Grágrýtismyndunin, x mest blágrýti, y Skálpanesgrágrýti. St. Bergstandur eða gangur.

FIG. 21

A CROSS SECTION OF THE HVÍTÁ CANYON

AB. 200 m DOWNSTREAM FROM DAM SITE 10

m.y.s = metres above sea level

NV = North-west

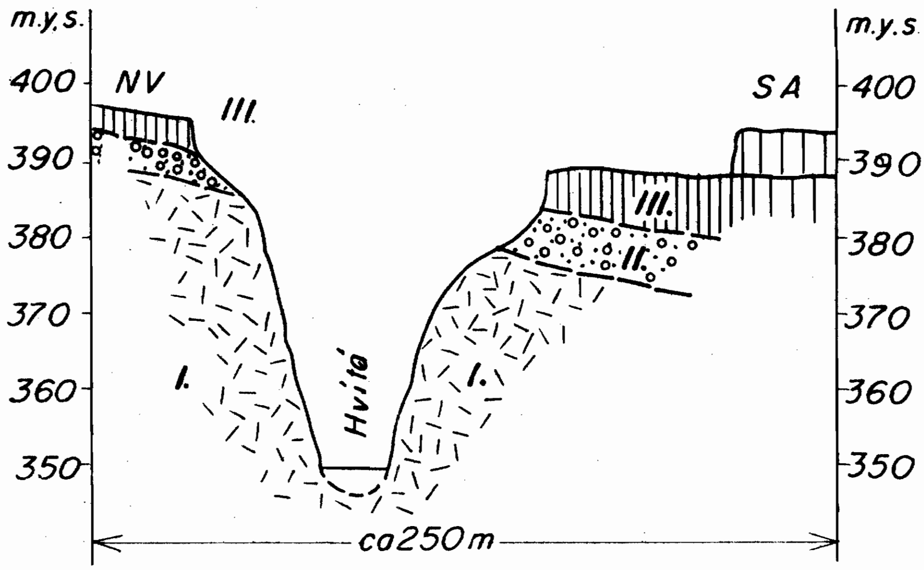
SA = South-east

I = Pillowy basalt

II = Sandstone and conglomerates

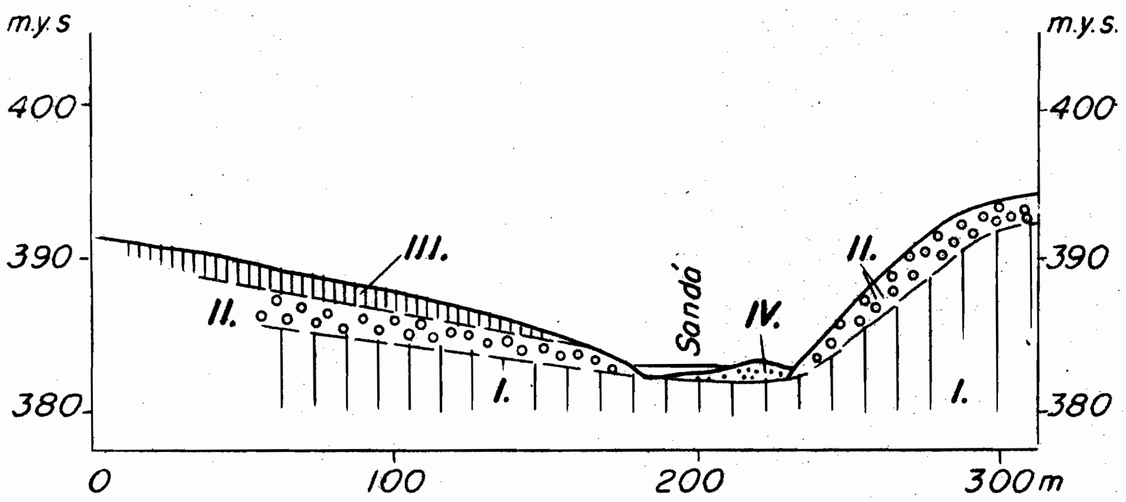
III = Basalt beds

21. MYND	RAFORKUMÁLASTJÓRI SNIÐ AF GLJÚFRI HVÍTÁR UM 200 m NEÐAN VIÐ STÍFLUSTÆÐI 10.	jan. '59. GKj / PJ TNR 444 B - 274 FNR. 6738



I. Bólstra- og kubbablágrýti; II. Vóluberg og sandsteinn, III. Blágrýtislög.

21. MYND a	RAFORKUMÁLASTJÓRI STÍFLUSTÆÐI Á SANDÁ	jan.'59. GKj/PJ TNR. 445 B – 274 FNR 6739



I. Blágrýti; II. Jökulruðningur; III. Jarðvegur; IV. Eyri

FIG. 21a

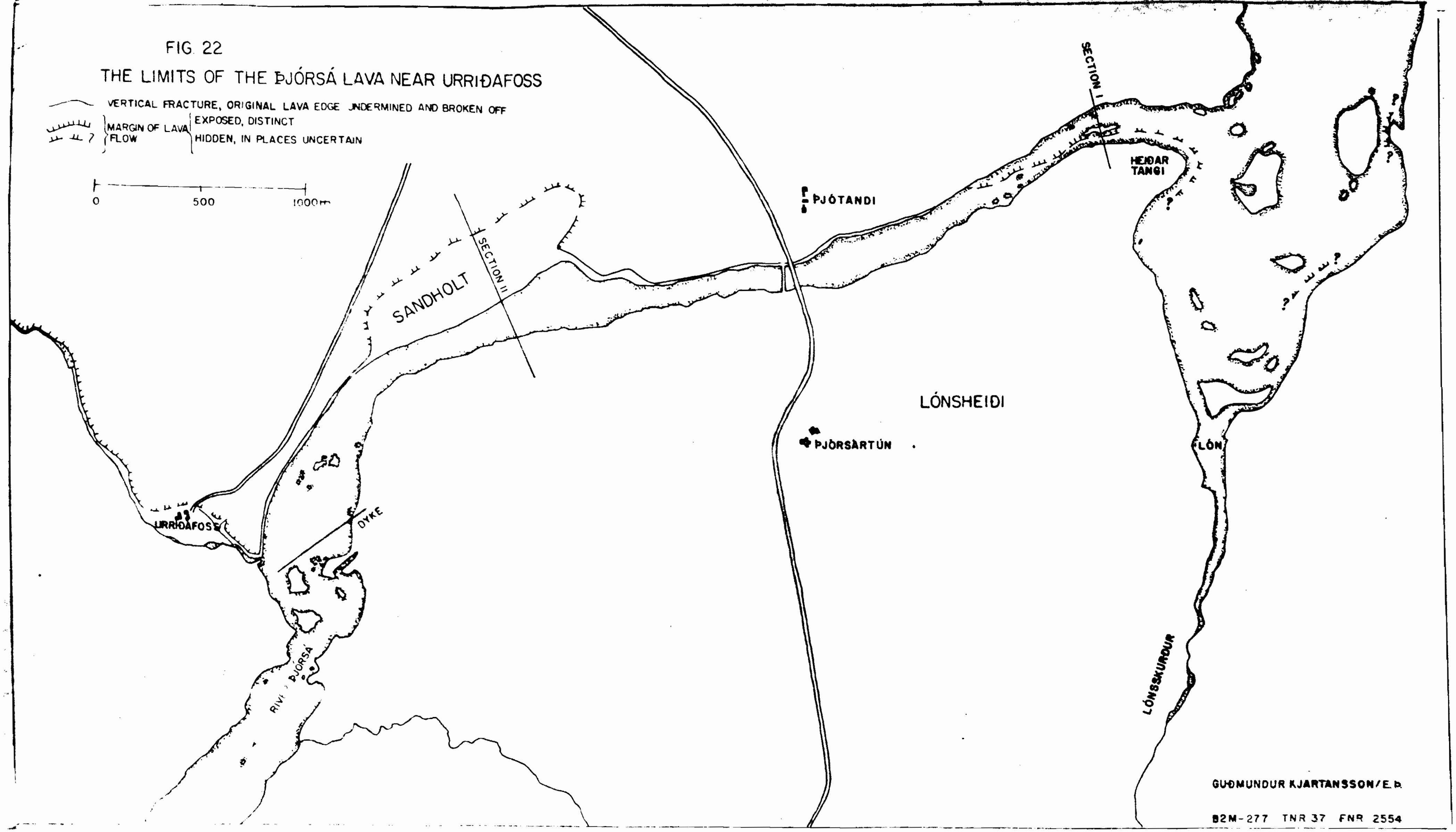
DAM SITE ON RIVER SANDÁ

m.y.s. meters above sea level

I Basalt
II Meraine
III Soil
IV River gravel

FIG. 22

THE LIMITS OF THE ÞJÓRSÁ LAVA NEAR URRIÐAFOSS



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B2M-277 TNR 37 FNR 2554

FIG. 23

WESTERN BANK OF THE ÞJÓRSÁ GORGE BETWEEN URRIÐAFOSS AND ÞJÓTANDI.

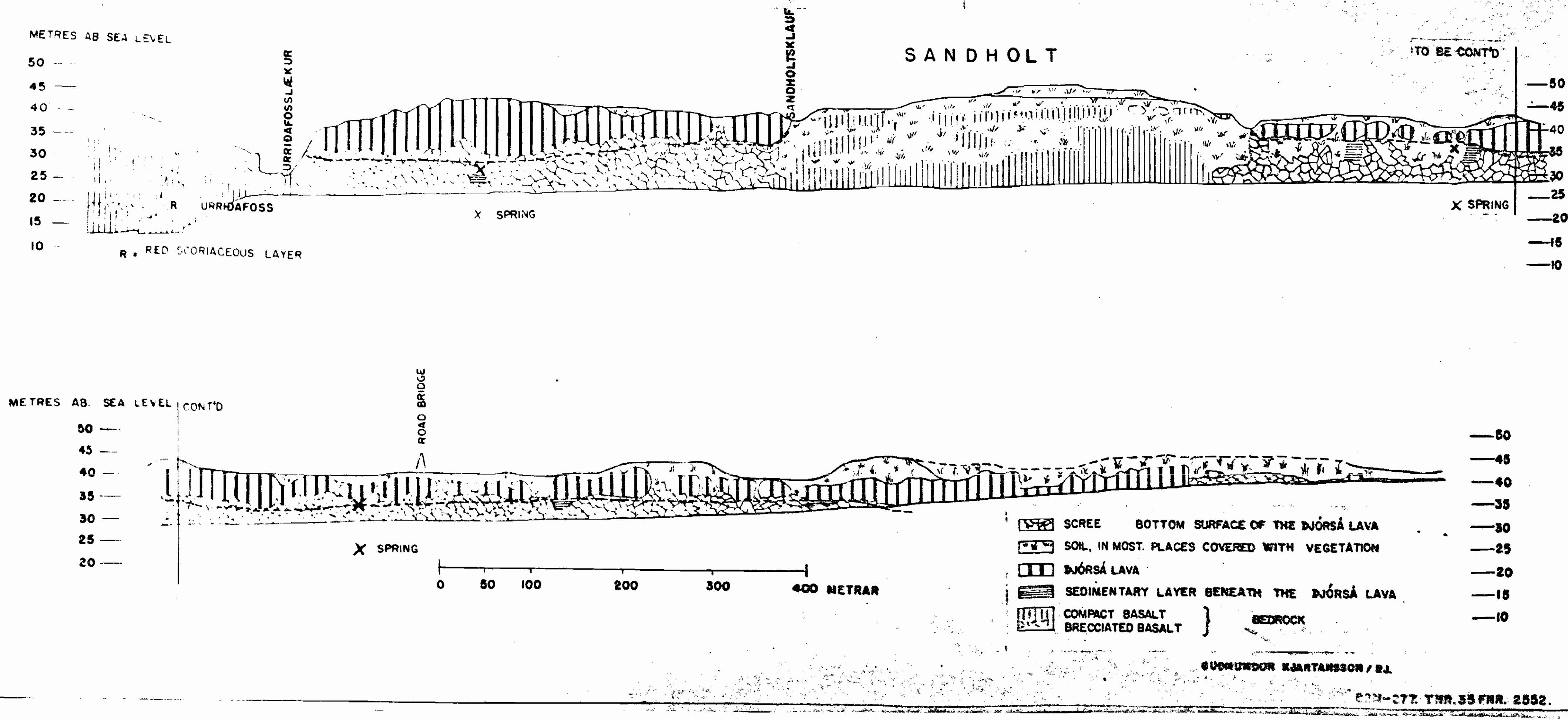


FIG. 24

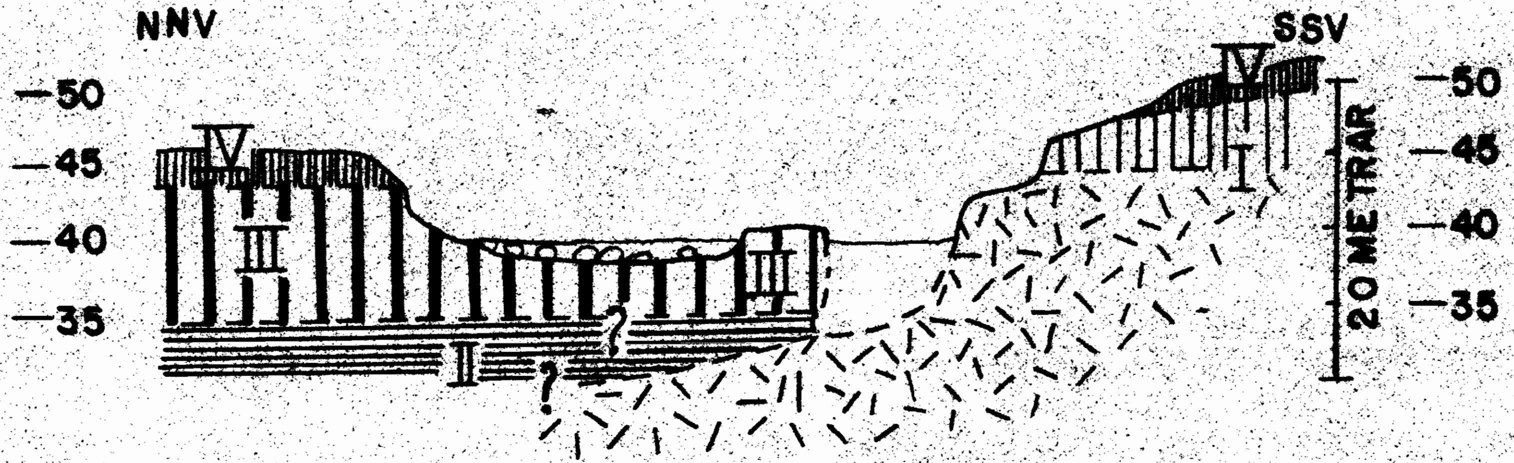
SECTION I THE GORGE TO THE NORTH OF HEIÐARTANGI

NNV	=	NNW
SSV	=	SSW
I	=	The bedrock. The uppermost parts consist of basalt, the lower ones of breccia
II	=	Sedimentary layer beneath lava
III	=	Þjórsá lava
IV	=	Humus

Fnr. 2553

24. MYND

SNEIÐ I. GLJÚFRIÐ NORÐAN HEIÐARTANGA



IV MOLD
III ÞJÓRSÁRHRAUN
II SET UNDIR HRAUNI
I BERGGRUNNUR, EFST BLÁGRÝTI, NEÐAR BREKSÍA

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FIG. 25

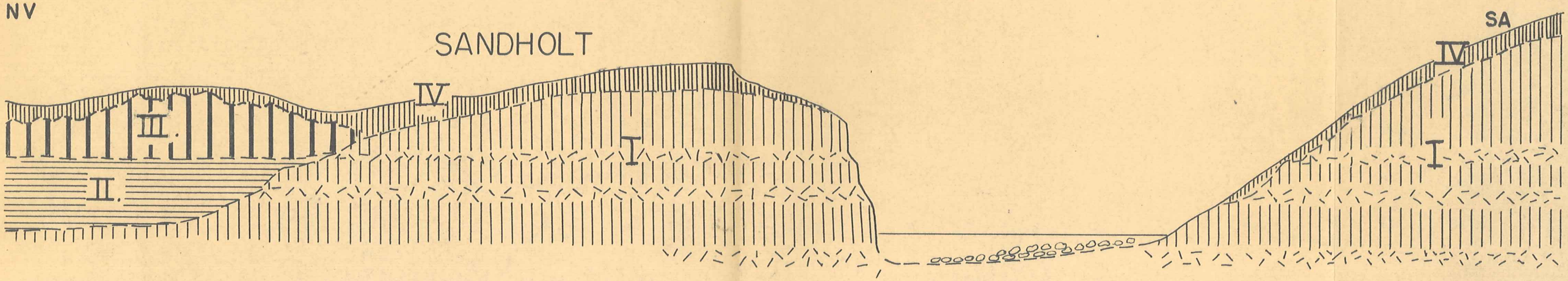
SECTION II AT SANDHOLT

NV	=	NW
SA	=	SE
I	=	Basalt bedrock with brecciated layers
II	=	Sedimentary layer beneath lava
III	=	Þjórsá lava
IV	=	Soil

Scale as on Section I

25. MYND.

SNEIÐ II. UM SANDHOLT



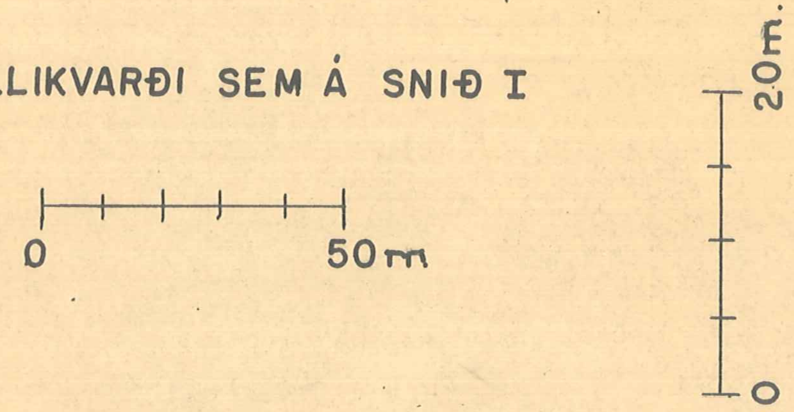
IV JARÐVEGUR

III ÞJÓRSÁRHRAUN

II SET UNDIR HRAUNI

I BERGGRUNNUR ÚR BLÁGRÝTI MEÐ BREKSÍU-
KENNDUM LÖGUM.

MÆLIKVARÐI SEM Á SNIÐ I



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