PROJECT PLANNING REPORT VOLUME II

DETTIFOSS PROJECT

GEOLOGY

THE STATE ELECTRICITY AUTHORITY

March 1963

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PREFACE

This report is a companion report to the Dettifoss Project Planning Report, Volume I by Harza Engineering Company International. The report forms the basis for the geology in Chapter IV in Volume I, supplements it with geological details and is therefore printed as Volume II of the Project Planning Report.

The report presents the geology of the area around Dettifoss in Jökulsá á Fjöllum. It is engineering geology pertaining to hydro electric development of the Jökulsá á Fjöllum Basin. The report is mainly a summary of a more general report with the title "Some Geological Problems involved in the Hydro Electric Development of the Jökulsá á Fjöllum, Iceland;" written for the State Electricity Authority by Dr. S. Thorarinsson in the year 1959. The summary is done by our geologist Mr. H. Tomasson who added results from investigations posterior to the general report.

The report discusses Geomorphology, and General Geology of the Area, the Storage Area south of Selfoss, the Geology of the Dettifoss Area and Further Investigations.

Reykjavík, March 1963.

Jakob Gíslason

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CHAPTER I

INTRODUCTION

This report describes the geology of the area around Dettifoss in Jökulsá á Fjöllum with special attention to a proposed power plant in the river at that site and a storage dam.

The river Jökulsá á Fjöllum (henceforth referred to as "the Jökulsá") is situated in the eastern part of Northern Iceland. It originates in the glacier Vatnajökull and flows towards north in a broad arch to Axarfjördur. It is the second longest river in Iceland, 206 km, only Thjórsá being longer. Dettifoss, the highest waterfall in the river, is 48 km from its mouth in Axarfjördur. Nearest towns are Húsavík 100 km and Akureyri 171 km from Dettifoss. The nearest habitation is to the southwest at Mývatn, to the north in Kelduhverfi and the south-east at Grímsstaðir, all at 30-40 km distance.

CHAPTER II

GEOGRAPHY (GEOMORPHOLOGY)

Volcanism

The drainage area of the Jökulsá is a highplateau gently sloping towards the river from both sides. The basin of the river slopes gently towards north. At the rim of the basin and inside are separate mountains or mountain ridges rising steeply from the highplateau and at the headwaters is the glacier Vatnajökull superimposed on the continuation of this highplateau towards south. The elevation of the southern part of the highplateau is 700-800 m but 200-300 at its northern end near Axarfjördur. From the highplateau the separate mountains rise up to 1000 m above the surroundings.

The highplateau itself is built up by Pleistocene to Recent volcanicity, mainly lava flows. The mountains are:

1) Table mountains, the highest and steepest mountains in the area. They are built up by subglacial central-eruptions and have a socle of tuff breccias and pillow lavas but they are capped by subaerial lava flows formed when the mountains had protruded through the ice cover.

2) Ridges, viz. long serrated rows of peaks, usually steep but much lower than the table mountains. They are the result of subglacial linear eruptions and consist of tuff breccias and pillow lavas.

3) Postglacial volcanoes, formed by central eruptions both of effusive and explosive character, i. e. shield volcanoes and explosion craters. Many linear eruptions have also occurred in postglacial time but they have mainly created small landforms such as crater rows and fissures. More complex landforms are also found inside the area. Most remarkable is Dyngjufjöll, a composite volcanic massif with a big caldera, Askja. Dyngjufjöll is still active. The last eruption occurred in Oct. 1961.

Erosion

The course of the river is affected by the tectonic lines in the basin. In its southern part they run NNE-SSW, in the middle part N-S and in the northernmost part then bending towards NNW. These tectonic lines also guide the volcanic fissures and consequently also the ridges and crater rows. The river follows the lowest part of the basin between two zones of Pleistocene volcanic activity which has built up the water divides. On the inner part of the highplateau the river is not eroding but is rather depositing and filling up depressions in the bedrock. But near the margin it has cut a canyon in the bedrock. This canyon "Jökulsárgljúfur" stretches between Selfoss and the place where the river leaves its gorge a short distance N of Vestara-Land and flows out to the sandur plain of Axarfjördur-Kelduhverfi. The total length of this "canyon" is 30 km. With its many beautiful rock formations, mainly of columnar lava, such as Hljóðaklettar and Vígaberg, and with its mighty falls of brownish glacier water contrasting with the clear bluish water in the many springs issuing from the slopes, and with its sheltered spots of luxuriant vegetation (Hólmatungur, Forvöð) Jökulsárgljúfur presents some of nature's most magnificent scenery in Iceland.

Only a part of Jökulsárgljúfur is a canyon in the strict sense. Morphologically we can distinguish between three main parts.

a) The northernmost part (11,5 km), is late postglacial mainly eroded during the last 2500 years. There are also many other "fossil" riverbeds which the river has had previous to the present one. Most famous is Åsbyrgi where the river had a 100 m high vertical waterfall some 2500 years ago. In the lower part of Jökulsárgljúfur there are now no real waterfalls, only a rather steep and even gradient the whole way through.

b) The middle part (9,0 km long) is more or less U-shaped valley with boulder and gravel terraces at different heights. It is obviously formed at least partly by glacier erosion but the present bed of the river on its bottom is in some places cut down in bedrock forming a second canyon. Near the upper end of this section are two waterfalls i.e. Réttarfoss and Vígabergsfoss.

c) The southernmost part (9,5 km long) is formed through backward erosion of a series waterfalls. This is the deepest part of the canyon and the waterfalls Hafragilsfoss (27 m high), Dettifoss (44 m high) and Selfoss (11 m high) are situated here. The part of the canyon S of the Sveinar crater-row is in all probability younger than the formation of this crater-row and thus evidently of postglacial age and hardly older than about 8 000 years. As to the middle part of Jökulsárgljúfur its U-shaped profile is obviously due to glacier erosion. The authors present opinion - not yet sufficiently founded - is that a broad U-shaped valley, open towards N, existed here at the end of the last but one glaciation (Riss or Iowan). During the Riss-Würm (Sangamon) Interglacial lavaflows, mainly from W, filled up the northern part of that valley and partly filled the bottom of its southern part and covered the moraines left there by the Riss-ice. Some of these flows may have come from fissures E of the present valley. South of Selfoss is one rapid but southwards from there the river has very flat gradient for more than 100 km. The Dettifoss power plant will utilize the head of the three last waterfalls and a storage will be created on the flat area upstream (south) of Selfoss.

CHAPTER III

GEOLOGY

The geology will be treated first generally, and then with special attention to a storage area south of Selfoss and finally the Dettifoss area, in which the structures will be situated.

General

The drainage area of Jökulsá á Fjöllum is on the whole situated within the young volcanic (Pleistocene and Postglacial) belt that extends from coast to coast from northernmost Melrakkaslétta to Eyjafjöll. We find here mainly 3 types of rock:

A. Interglacial dolerites.

B. Subglacially formed palagonite tuffs and breccias.

C. Postglacial basalt-lava flows.

Interglacial Rocks

Where postglacial lava has not been poured out the bedrock of the Jökulsá area between the tuff ridges consists mainly of dolerite lava flows. So does for instance the river bed of Jökulsá between Hrossaborg and Axarfjörður. Most of the dolerita lava flows visible in the area belong certainly to the Last Interglacial (Riss-Würm or Sangamon) that according to most geologists lasted from ab. 180 000 to ab. 120 000 years before the present, but which according to some recent theories, is considerably younger (150 000 - 80 000). Only in the Jökulsá Canyon one finds lava beds that may belong to the last but one Interglacial (Mindel-Riss or Yarmouth). The sources of the dolerite beds are, at least partly, interglacial shield volcanoes such as Grjótháls W of Dettifoss, but some of the flows may be flows from fissures. The dolerites at Jökulsá are on the whole a little more fine grained than the Reykjavík dolerite. Intercalated between the dolerite beds are sedimentary layers of different origin, such as tephra layers, wind- and water transported material and rock weathered in situ. The lithification of these sediments is on the whole little advanced and thus their permeability is rather high.

Subglacial Volcanic Rocks

During the Last Glacial (Würm or Wisconsin) that lasted from ab. 120 000 to ab. 20 000 years before the present (acc. to some recent theories from ab. 80 000 - ab. 12 000), the volcanic activity of the Last Interglacial continued, but because of the influence of the covering inland ice this activity produced other type of products i. e. the pillow lava, palagonite breccias and tuffs of the ridges and table mountains.

When studying the postglacial linear eruptions in Iceland e. g. in the Mývatn area, we find that one and the same fissure very seldom pours out lava more than once. This does not always mean that a long fissure was formed in its entire length in a single eruption, only that each part of the fissure has erupted only once (Hekla is the most famous exception). The same seems to have been the case with at least most of the subglacial fissure eruptions. Many of the subglacial ridges, such as Austari-Skógarmannafjöll, and the cone row between Möðrudalur and Víðidalur, are in the author's opinion monogenetic. Other ridges, such as Námafjall, are clearly built up by eruptions from two or more fissures running parallel and near each other. It is likely that they did not erupt at the same time and each of them only once.

The socles of the table mountains are built up mainly in the same way as the tuff ridges, but according to an explanation first suggested by G. Kjartansson (1943) as an alternative hypothesis to Recks tectonic theory, and later detailed independently by Mathews (1947) and van Bemmelen and Rutten (1955), the lava flows that cap the tuff socles were formed when the socles had been built up so high that the lava eruptions were no longer subglacial or subaquatic but subaerial. For details of this explanation, which the authors fully accept in principle, although not in all details as presented by van Bemmelen-Rutten, it is sufficient to refer to the comprehensive work: "Table mountains in Northern Iceland" (Leiden 1955). The table mountains are thus mainly constructive and not tectonic as assumed by Reck, Nielsen and many other geologists. They are the result of central eruptions and their uniform chemical composition suggests that they are not the result of mixed central eruptions and thus do not correspond to postglacially active volcanoes such as Öræfajökull and Snæfellsjökull, that presumably are fed by more or less isolated magma pockets. They are most likely directly corresponding to the postglacial shield volcanoes such as Trölladyngja and Kollótta dyngja, and are, like the tuff ridges and the postglacial crater rows, fed by a rather deep lying, uniform basalt magma. Their height corresponds roughly to that of the postglacial shield volcanoes and has an upper limit above which the magma table could not be raised. The explanation why the ridges did not reach a comparable height is simply the above mentioned fact that each fissure erupted only once.

Postglacial Rocks

The volcanic activity that built up the table mountains and tuff breccia ridges of the Ódáðahraun area during the Würm Glacial has continued without interruption into the postglacial time. One proof of this are the Dalfjall-Námafjall ridges. There it is really difficult to state where the subglacial activity ends and the postglacial one begins. And the postglacial building up of shield volcanoes is, as said before, a direct continuation of the activity that built up the table mountains. The postglacial fissures and shield volcanoes have both produced extensive lava flows within the area in question. Tephrochronological studies show, however, that the shield volcanoes activity ceased at least 3 000 years before the present while the youngest lava fissure, Nýjuborgir in Sveinagjá, erupted in 1785. The postglacial lava flows will be further dealt with in later chapters.

Besides the lava producing volcanoes, explosion volcanoes or volcanoes of Hverfjall type are found between Mývatn and Jökulsá. The youngest of these volcanoes is undoubtedly Hverfjall that has been proved to be younger than the light tephra layer H_3[1)] and thus hardly more than 2 500 years old.

1) In a previous paper, "Laxárgljúfur and Laxárhraun," Thorarinsson has dealt with the light rhyolitic tephra layers that occur in soil profiles in N and NE Iceland and illustrated how useful they are for geological datings. It is sufficient to refer to this paper, adding that since that paper was published three of the prehistoric Hekla layers, i. e. H_3 H_4 and H_5 have been dated with the C^{14} method.

The age of H_5 (dated by the Carbon-14 Dating Laboratory in Copenhagen) is

	6320 ± 190 years
	6510 ± 250 "
Av.	6410 ± 170 years

The age of H_4 (dated by the same laboratory) is

	4000 ± 150 years
	3650 ± 150 "
Av.	3830 ± 120 years

To the age of these layers should be added 200 years as a correction because of the s. c. Suers effect.

The age of H_3 (dated by the Geochronometric Laboratory in Yale) is 2712 ± 130 years. A new dating, by the Stockholm Geochronometric Laboratory gave the age 2820 ± 70.

Lúdent is considerably older than H5 and probably very early postglacial. The same is the case with Hrossaborg.

T. Einarsson was the first one to express the opinion that this volcano has been overridden and eroded by the inland ice. Thorarinsson has in his paper on Laxárgljúfur expressed the opinion that Hrossaborg was formed ruring the Alleröd Time (ab. 12 000 - ab. 10 800 before the present). On closer study he has found that its E and W flanks have also been eroded by rivers, the beds of which are clearly visible on aerial photos. It is most likely that these rivers were meltwater rivers from the receding inland ice.

Postglacial Sediments

The late glacial and postglacial sediments that cover the bedrock of the area dealt with in this paper are mainly glacial and glacifluvial. Along Jökulsá, especially on its E side, the ground moraine or glacial (till) drift has been washed away, but the main part of the Mývatn-Jökulsá area that is not covered by postglacial lava has a rather thick cover of glacial drift that certainly is to be found also beneath the postglacial lava flows. On the whole the drift is rich in big angular blocks. This seems to be typical for drift on dolerite (cf. the Reykjavík area). Typical glacial drift of this type may be seen on both sides of the Grímsstaðir-Reykjahlíð road W of the Jökulsá bridge. Presumably the lava flows further west rest on the same type of drift.

Between Lake Eilífsvatn and the Dettifoss area extends a broad belt of irregular terminal moraines and glaciofluvial deposits indicating a stagnation of the inland ice retreat. In the paper on Laxárgljúfur and Laxárhraun the author showed that during the Alleröd Period (ab. 12 000 - ab. 10 800 before the present) the inland ice receded from the Mývatn area and accordingly also from the plains between Mývatn and Jökulsá. During the following period, the cold Second Dryas Period, lasting from ab. 10 800 to ab. 10 000 before the present, the ice advanced again and became stationary for hundreds of years, and during this stage of stagnation which the author has named the Hólkot Stage the above mentioned deposits were formed. They belong to the same stage as the terminal moraines and kames running obliquely across Reykjadalur between Breiðamýri and Laugar, and the system of moraines and sandur plains between Reykjahlíð and Hlíðarfjall.

In a recent paper, Pollenanalytische Untersuchungen zur spät- und Postglazialen Klimageschichte Islands. Köln, 1961, Th. Einarsson ventures the opinion that these moraines are about 15 000 years old.

At the end of the Second Dryas Period the climate became rather suddenly warmer and the icefront began receding again and then seems to have dammed up a lake in the triangle between Hágöng, Eilífur and Grjótháls. At its maximum this lake may have covered a considerable area SE of the present Eilífsvatn i.e. the present Grænalág, including the basin of the present lake. There are, however, no signs of it having had an outlet towards NNW, between Eilífur and Hrútafjöll, but the bed of such an outlet might now be covered by post-glacial lava. Presumably the lake had its outlet towards E, between the ice margin and Grjóthåls.

The Grænalág Esker

An interesting remnant of this lake is an esker (Swedish "rullstensås") SE of Eilífsvatn (cf. Exhibit 1). This is by far the longest esker known in Iceland, where eskers on the whole are rare. The esker SE of Eilífsvatn (Sandhryggur) runs from a point about 1.2 km SE of the lake towards SE through Grænalág and the graben between Vestari Brekka and Austari Brekka and is at least 5 km in length. In the graben between Austari Brekka and Vestari Brekka it reaches its max. relative height, about 15 m, and is there more than 20 m broad at the base, its crest covered by head-size blocks and coarse gravel. Further NW-wards the esker is sinuous in a typical way and the material on its surface is a rather fine gravel with coarse sand beneath. Presumably its inner structure is that of an ordinary esker. A considerably smaller esker, Grjóthryggur, is situated a short distance W of the Sveinar graben, (cf. Exhibit 1). This esker is possibly an engorged esker (Swedish "slukås"). According to measurements by S. Björnsson civil engineer, VEFRA, the volume of gravel and sand in the Grænalág esker is about 300.000 m^3, that of the Grjóthryggur esker about 90.000 m^3. The most common mode of origin of eskers is in tunnels at the base of a nearly stagnant glacier. Usually these tunnels are parallel to the latest direction of the glacier flow. In these tunnels meltwater streams flowed under hydrostatic pressure and emerged into water at the glacier margin, depositing their load of sand and gravel outside the tunnel. Presumably the downstream parts of the eskers were built first and they were then gradually extended in the upstream direction. The Grænalág esker was probably formed when the inland ice receded to the S from its position during the Hólkot Stage. A tunnel river then emerged in the above mentioned ice dammed lake. As already mentioned a belt of moraines and glaciofluvial deposits stretches from Eilífsvatn eastwards towards Dettifoss. It is possible that suitable material for concrete filling may be found within this belt, besides in the eskers. The surface layer of the moraines near Dettifoss is rich in big blocks. Further study will reveal the type of the moraine, whether it is clayish, sandy etc. It gives the impression of being on the whole hardened and rather difficult to work. Besides the moraine the land is often covered with a loessial soil a meter or so thick. On extensive areas the loessial soil has blown away during the last centuries mainly because of too heavy grazing of sheep. This process is still going on at a fast rate.

Storage Area south of Selfoss

The Geology of the Water-Divide Area N of Skógarmannafjöll

One of the questions, and one of the most serious, that have arisen in connection with the planned harnessing of Jökulsá and forming of a great storage lake S of a dam near Selfoss is: How high can the level of that storage lake be raised without risk of the water escaping to the Mývatn area over the water divide between Jökulsá and Laxá where this divide is at its lowest? According to the topographical maps available the surface divide runs from Vestari Skógarmannafjöll towards NNE, following the Kræðuborgir crater row. The height figures on the water divide area differ on the Danish Geodetic Institute maps and the more recent U. S. Army Map Service maps, being considerably lower on the American maps, but to find out which figures are more correct is a geodetic problem beyond the scope of this paper. If there were no risk of leakage in the divide area question of the highest possible storage lake level would be merely a topographical one. But actually the divide area is covered by postglacial lava in a zone reaching about 7 km northwards from Skógarmannafjöll. It was therefore considered necessary to study this area geologically. The question that must be answered is:

How thick is the postglacial lava in the water divide area.? This again leads to the question. Is the area covered by a single lava flow or by many flows superimposed on one another? The types of lava and the age of the flows are also of importance when discussing the risk of leakage.

The geological map of this area which accompanies this report is topographically based on the U.S. A.M.S. maps (sheets 6023 I - 6023 IV, Scale 1:50 000). The geology is based on the authors field studies, and the study of aerial photos.
The geological history of the area is typical for most of the Mývatn-Jökulsá area. A brief outline of this history is therefore called for here.

Interglacial rocks are dolerites covered by glacial drift, the thickness of which has not been measured but seems to be the normal one for the Mývatn-Jökulsá Area. The glacial drift covered dolerite is in all probability found under the postglacial lava cover on the plain and the drift may be somewhat thicker in the lowest part of the divide area than in the higher areas where it is now visible. The palagonitic areas date back to the Last (Würm) Glacial. Here we have one typical table mountain, Búrfell, with lava cover and a circular summit crater. Short E of Búrfell is a long system of tuff ridges, Vestari Skógarmannafjöll, the topography of which indicates that they are composite, i.e. built up by two parallel running fissures.

Besides the above mentioned tuff ridges, the palagonite tuff protrudes through the dolerite lavas in a few small exposures. One such is visible S of the auto road between Austari Brekka and the Sveinar graben.

The oldest postglacial lava flows in the mapped area are found SE of Austari Brekka. The author has not studied this area sufficiently to be able to discern between the individual flows that may be found there. Presumably the oldest flow is from the Rauðuborgir crater row, that belongs to the Randarhólar-Sveinar system and is thus in all probability more than 6 000 years old. But at least the SE part of the lava area E of the Sveinagjá lava is younger than the Rauðuborgir lava and comes either from Ketildyngja or some volcano further towards the SE. All these flows are mainly helluhraun (pahoe-hoe). How far westwards beneath the Kræðuborgir lava this flow does extend cannot be decided by field observations only. We do not know with certainty the location of the sublava water divide. Presumably this water divide was not at all marked, as the terrain is so flat. The author's guess is that this divide is to be found between Kræðuborgir and Rauðuborgir and that the Rauðuborgir lava does not extend much further west than to this divide. But this lava flow is not the only one that may be expected underneath the Kræðuborgir lava (Búrfellshraun). From the shieldvolcano Ketildyngja enormous lavaflows have been poured out, the most extensive one being the flow a branch of which covers the area W of Búrfell. This lavaflow has been dealt with in Thorarinssons paper "Laxárgljúfur and Laxárhraun" and is called Older Laxárhraun (Older Laxá lava). Another branch of this lava has flowed towards NW, down Seljahjallagil and spread over the Mývatn area and then flowed northwards through Laxárdalur and Aðaldalur to Skjálfandi. This flow is definitely considerably older than H_3 but a little younger than H_4. Its age is thus about 3 500 years. A broad stream of this lava has flowed towards N between Hvannfell and Búrfell. We do not know how far northwards this stream extends but it is certain that it does nowhere emerge from underneath the margin of Búrfellshraun, which rather points against it having spread over a big area now covered by Búrfellshraun. The older Laxá lava is mainly helluhraun. Judging from the tephra layers in its soil cover the oldest lava that has flowed northwards between Austari and Vestari Skógarmannafjöll is also a branch of the same flow. It may possibly have joined the stream between Búrfell and Hvannfell somewhere N of Vestari Skógarmannafjöll, but in the author's opinion it more likely did not.

Later two lava flows have followed the same valley between the two Skógarmannafjöll. The sources of these flows are Taglabunga and (or) Skuggadyngja, two parasite domes on the north flank of Ketildyngja. Both these flows are thin and their extension underneath Búrfellshraun is in all probability very limited.

The extensive lava field Búrfellshraun has its source in the crater row Kræðuborgir, situated within a graben system that is a continuation towards S of the graben between Vestari Brekka and Austari Brekka and continues southwards through Vestari Skógarmannafjöll. Some of the craters are very big and the crater row has poured out a very great amount of lava. The eastern part of the flow (E of the crater row) is helluhraun, very even, so that it is rather easy to drive a jeep over it. The margin towards the east is diffuse. The lava increases in thickness towards the crater row. E of the two southernmost of the main craters, big areas have collapsed and are surrounded by vertical walls, 5-7 m high. The lowest height figures on the American maps of this area refer to the bottom of these collapsed areas. Farther SE are small sinkholes up to 8 m deep. On the continuation towards N of the fault line that runs along Vestari Skógarmannafjöll are some features that look like craters on the aerial photos and are shown as such on the map Exhibit 1.

The author does not think that any lava was emitted from these craters and is not even certain if these features should be interpreted as craters. W of the Kræðuborgir crater row the Búrfell lava has a much more uneven surface than E of the row. Between Fálkaklettur and Kræðuborgir it is, however, mainly helluhraun although split by many rifts, further westwards it gradually becomes more and more block lava (apalhraun). Búrfellshraun is certainly younger than H_3 and certainly prehistoric. A comparison between soil profiles on this lava and on Younger Laxárhraun - the age of which is very near 2 000 years according to Carbon^{14} datings - indicates that these two extensive lava flows are of about the same age. Consequently <u>the age of Búrfells hraun is not far from 2 000 years.</u>

The youngest lava flow on the mapped area is the Sveinagjá lava flow or Nýjahraun from 1875. This flow is interesting as being the only flow of this area the formation of which has been described by eye witnesses. The author refers to Th. Thoroddsens compilation of these descriptions in "Die Geschichte der isländischen Vulkane," pp. 230-240. The contemporary descriptions are more thoroughly related in Ó. Jónsson: "Ódáðahraun II," pp. 246 ff. These descriptions prove i.a. that the eruption fissure gradually increased in length during the eruption. The crater row B on the map on Exhibit 1 started erupting on Febr. 18th, the northernmost crater row (A) on March 19th and the craters C on April 4th. It is also of interest to note that the

Sveinagjá eruption coincided with an eruption in Askja 45 km farther south and during the same eruption smoke was emitted from the fissures in Gjástykki. Thus a zone about 100 km in length was activated at the same time.

Let us again turn to the cardinal question from the engineering point of view: How thick is the lava cover of the water divide area and how permeable. As to the first part of this question we state that at least three big lava flows may have reached that zone. On Exhibit 1 is a tentative schematic E-W section through the water divide area, but it must be stressed that we do not know the location of the water divide area and probably the divide is rather diffuse and may really be a rather broad zone. The thickness of the lava in the critical part of the water divide area, viz. the lowest part of that area, above which leakage could be expected, can be tentatively estimated at 15+ 5 m, and this is of course only a very rough guess.

It is really impossible to tell how much water would leak through the lava and be drained to Mývatn if the storage level was raised above the sublava water divide. Nowhere in the lava covered area is the ground water level visible, not even in the deepest sinkholes, and no springs are found at the W margin of Búrfellshraun, as that margin rests on lava that also lets water through.

In the author's opinion it is possible that the leakage through the lava from a storage area E of the water divide to the Mývatn area might not prove serious, even if the storage lake level were raised let us say 5-10 m above the sub lava water divide. The experience from the Laxá Canyon rather supports this possibility. But at the same time it must be stressed that <u>there is a risk</u> that the leakage might prove serious. How great that risk is the author simply cannot tell.

The northern-most part of the lava cover N of Skógarmannafjöll is probably rather thin. The line along which the lava would have to be tightened by grouting in case of serious leakage is hardly more than 3.5 km in length and may even prove shorter.

Diastrophism and Tectonic Features

One of the most striking features of the northern part of the Ódáðahraun area (including the Mývatn area) and its continuation towards N is the very great number of N-S running faults, fissures and graben strips.

On the map on Exhibit 1 has been drawn the main systems of grabens in the Mývatn-Jökulsá area, E of the water divide. These are: The Austari Brekka - Vestari Brekka graben or Kræðuborgir graben, the Sveinar graben, Sveinagjá graben and Fjallagjá graben. West of this graben system is one big system of faults and grabens that runs from the Mývatn area over Leirhnúkur and Gjástykki to Kelduhverfi.

Characteristic for these grabens is the small width in relation to the length of the graben system. Fissures and fault lines with a distance of few hundred metres may run parallel tens of kilometres. The vertical displacement seldom exceeds 20 m and is usually 5-15 m. The Sveinar graben is at least 30 km in length but its average width is only 0.6 km and the vertical displacement 2-30 m. The Austari Brekka - Vestari Brekka graben is 1.5-2.0 km wide. Within the main faults that outline a graben the down-faulted area is often split up by many parallel rifts. These are not shown on the map. Between the grabens, one also finds long rifts without displacement running parallel to the grabens. One such rift is W of the Sveinar graben. Some grabens are partly limited by step faults.

The Age Relation Between Grabens and Crater Rows

When studying the map on Exhibit 1 we find that each of the graben systems contains one and more crater rows. Within the Kræðuborgir graben are the big Kræðuborgir crater row and farther N, SE of Grænavatn, the tiny Grænalág crater row. Within the Sveinar graben is (partly) the Sveinar-Kvensöðull crater row, probably the longest one in Iceland, and the Rauðuborgir crater row. Within the Sveinagjá graben system are the Nýjahraun craters of 1875 and the miniature crater row E of Dettifoss. Also in the Fjallagjá graben there are craters.

When trying to find the age of the grabens it is of importance to study the time relation between them and the lava flows produced by the crater rows within them as the age of these lava flows can often be roughly determined - in some cases even quite exactly - by means of tephrochronology or in other ways, for instance by C^{14} dating, where the lava has flowed over vegetation-covered ground.

The Randarhólar-Kvensöðull crater row E of Jökulsá, which is a direct continuation of the crater row on the W side, does not follow the Sveinar graben but has a more easterly direction, or towards NNE. It seems probable that the Sveinar graben existed before the fissure eruption started and that the eruption started in the fissure E of Jökulsá. That fissure was then gradually prolonged towards SSW until it met the graben, from whence it changed direction and followed the graben towards S. The graben so to speak captured the eruption fissure. But we have also a clear evidence of the graben having deepened considerably after the beginning of the fissure eruption as, both E of Hafragil and S of the jeep track that crosses the graben farther south, transversal sections of the graben are of the c-type. This deepening was in all probability connected with the eruption. E of Jökulsá, at Randarhólar, the author has measured soil profiles on the lava produced by the crater row. This lava is so much older than H_4 that its minimum age is hardly less than 6 000 years and it may be a lot older. Thus it seems most likely that the fault lines of the Sveinar graben-system have not been active for at least 6 000 years.

As to the age of the Kræðuborgir graben system it is, at least partly, older than the lava field Búrfellshraun (outpoured from Kræðuborgir), that is more than 2 000 years old, but this graben system is also, at least partly, younger than the above mentioned Grænalág esker, as the fault lines have affected the esker after its formation. Consequently this graben-system was partly formed later than 10 000 years and earlier than 2 000 years before the present.

Nothing can as yet be said with certainty about the age of the Fjallagjá graben system, but in the authors opinion it is likely that it is, like Hrossaborg, early postglacial. Hrossaborg is, however, not situated within this graben, but just E of it. The youngest diastrophism in the area between Mývatn and Jökulsá is connected with the 1875 eruption of Sveinagjá. We do not know of any other dislocations E of Námafjall-Hágöng in historical time, and as far as we know the dislocations connected with the Sveinagjá eruption did not affect any other graben system. The small craters E of Selfoss are probably in the same graben system as Sveinagjá but these craters are probably old.

The Risk of Leakage through the Pleistocene Bedrock from the Storage Area S of Selfoss

In a previous chapter the risk of leakage from this area towards W through the postglacial lava beds has been discussed. But the planning of a great storage area S of a dam at Selfoss also involves the problem of leakage through the Pleistocene bedrock. As previously mentioned this bedrock consists mainly of interglacial dolerite beds, separated by sedimentary layers. Much of the storage area is without a permanent surface drainage. The only lake within the area, Eilífs-vatn, is without a permanent outlet drainage. Only during the main snow melting period in the spring is it drained through an outlet towards E, but rivulets, especially from the Hágöng massif, flow permanently into the lake. Consequently the lake must have some drainage through the bedrock. When the author visited this lake on Aug. 23rd 1957 the water level was 1.65 m below the highest level it had reached the previous spring. A study of the hydrography of this lake, including measurements of the discharge of the rivulets feeding it and the changes in the height of its water level, is highly desirable, as it might increase our scanty knowledge of the permeability of the bedrock of the storage area.

When trying to estimate the possibility of leakage from the planned storage area S of Selfoss a special attention should be paid to the springs in the Jökulsá canyon that possibly or probably are partly fed by water from the storage area. On the map on Exhibit 1 the location of some of these springs is shown schematically by arrows. We find that these springs are mainly limited to two areas. The southernmost one is in the close vicinity of Hafragilsfoss and a short distance downward from that waterfall. The main aquifer is here a sedimentary layer (unit G). At least two springs (both of them roughly estimated less than 20 l/sec) issue from this layer in the E wall of the canyon opposite the mouth of Hafragil. On the W side there are at least four springs, they are, on the whole, larger than on the E side; none of them however has discharge exceeding 50 l/sec

(This is a very rough guess as the author has only studied them at a great distance through fieldglasses).

The main spring area in the Jökulsá canyon is in the vicinity of Vígabergsfoss, in Hólmatungur, on the W side of the river. There small springfed rivers are found. Considerable springfed brooks are also found on the E side of the river, near Vígabergsfoss.

It seems obvious that the springs in the Hafragilsfoss and Vígabergsfoss areas are connected with the fault-graben-fissure systems that have been described in a previous chapter. The springs at Hafragilsfoss are connected with the Sveinar system, and the Hólmatungur springs mainly with the Kræðuborgir graben system. It may be added that from underneath the lava flows in the W part of Kelduhverfi issue many springs that are connected with a big fault and graben system W of the water divide between Jökulsá and Laxá viz. the Gjástykki-Leirhnúkur system.

In the author's opinion we may draw the conclusion that the dolerite bedrock obviously lets some water through, on the whole probably more than the palagonite bed rock; that the main aquifers are the contacts of the doleritic lava beds and the sedimentary layers between some of these beds and that the subterranean course of the drained water is directed by the N-S running fault lines and the feeder dykes of the crater rows. We may assume that the feeder dykes are more or less impervious to water and thus form an obstacle to subsurface drainage towards W and E. Therefore, any considerable leakage from the Selfoss storage area towards W to the Mývatn area beneath the postglacial lava is not to be expected, whereas the risk of leakage through the bedrock towards N must be taken seriously into consideration. Whether Eilífsvatn is drained towards W to the Gjástykki system or towards E to the Kræðuborgir system cannot be told with certainty but it is more likely that it is drained towards E, and that water should thus issue in Hólmatungur. What must be done as soon as possible is to measure the discharge of all the main springs in the Hafragilsfoss and Vígabergsfoss areas and also their temperature. When knowing the total discharge of the springs in each area and knowing roughly the precipitation (it is desirable to put up a rain sampler within the storage area) it might be possible to calculate roughly how much of the water of this springs can be accounted for by precipitation in the areas N of the planned storage area, and whether or not one has to reckon with some part of it coming from the storage area.

The question whether the Grænalåg and Eilífsvatn basin should be closed off because of the risk for leakage through Grjóthåls to the Hólmatungur springs cannot be answered now. For that purpose it is necessary to investigate the groundwater in the basin and its relation to the variations in flow of the Hólmatungur springs. Even if we could state with any probability that some of the water of these springs comes from the planned storage area (some of the springwater in the Hafragilsfoss area certainly does) it will of course be very difficult to estimate how much the leakage would increase after the formation of a storage lake. Almost certainly it will increase, but personally I doubt that it will increase very much. It may also be regarded as pretty certain that the initial leakage after the formation of the storage lake will gradually decrease because of tightening of the leakage channels by the sediment in the glacial water, but how fast this decrease will take place the authors dares not estimate.

The geology of the Dettifoss area

In the following the riverbed and canyon of Jökulså from about one km above Selfoss to just below Hafragilsfoss and a belt about 2 km broad on each side of the river is called the Dettifoss area.

As already mentioned the bedrock in this area is composed of dolerite lava beds with intercalated sedimentary layers. The dolerite layers are almost horizontal and have a tendency to solidify into a coarse vertical columnar structure which facilitates the formation of vertical canyon walls.

The canyon of Jökulså between Selfoss and Hafragilsfoss has mainly been eroded in Postglacial Time. Details of the history of the canyon will not be entered into here, but attention should be drawn to how much influenced by the diastrophism the erosion has been. Before finding its present bed that is directed by the tectonic N-S lines, as evident when studying the present Dettifoss and Selfoss, the river has followed several other parallel lines of weakness and formed such features as Hafragil, that follows the W limit of the Sveinar graben, and the shorter canyon midway between Hafragil and Dettifoss. In early Postglacial Time and at a time when the river carried more water than now, because of the melting of the receding inland ice, it has washed away most of the originally thick cover of glacial drift and other moraines on both sides of the river, especially on the E side, and left the moraine undisturbed only on the highest ridges. Such ridges are e. g. found along the E side of the Sveinar graben W of Dettifoss, and there the moraine-cover seems to be 6-10 m thick in places. The moraine-cover has about that thickness in the graben W of these ridges. In the northernmost part of it, near Hafragil, this moraine has been washed away before the lava was poured out, but farther south the moraine layer is covered by the lava. A notable event in the postglacial history of the Dettifoss area was the eruption of the Sveinar-Kvensöðull fissure that crosses the present Jökulsá canyon just N of Hafragilsfoss and from there continues in NNE direction on the E side of the canyon. The crater row is shown in its entire length on the map in Exhibit 1. The lava has flowed from the fissure at various places but nowhere in big volume, and as far as can be seen this lava is everywhere pahoehoe and the lava beds are thin. The extension of the lava flow is also shown approximately on the map in Exhibit 1 and a part of it more detailed on the map in Exhibit 2, but especially E of the canyon the mapping of the lava is far from accurate. As will be seen on the map in Exhibit 2 lava does not cover entirely the bottom of the graben S of Hafragil. A small apron of this lava, which has originated in the fissure W of the present canyon is now found E of the river about 400 m N of Dettifoss. Certainly the canyon did not exist W of that apron when it was poured out, and probably it did not at that time extend as far south as the place where the fissure crosses the canyon, at least it must then have been much narrower at that place than now, otherwise we can not explain the craters situated on the very rim of the canyon on both sides. The erosion of the river since the fissure erupted, has - on the E side of the canyon - exposed the feeder channel of the crater row down to the water level of the river. From ab. 20 m beneath the bottom of the crater and downwards the channel is filled by a ab. 6 m thick dyke of dense columnar basalt (horizontal columns). Upwards the channel widens and there we have the columnar basalt of rosette structure gradually emerging into slaggy lava and higher up to scoriæ.

It is obvious that in the Dettifoss area the Sveinar graben has deepened considerably since the lava from the fissure was consolidated, as the lava is cut through by faults showing vertical displacements of some metres. Probably this happened near the end of the eruption or shortly after.

The tiny crater row on the E side of Jökulsâ E of Selfoss, has previously been mentioned. The lava is of helluhraun type and has formed a very thin sheet.

As to the age of these two lava flows we only know that the minimum age of the lava from the Sveinar fissure E of Jökulsâ is hardly less than 6 000 years, and it may well be several thousand years older. Probably the lava E of Selfoss is also very old.

The Dettifoss Dolerite

Unit A. Some of the highest ridges between the river and the auto road on the E side are capped by this layer. It also covers a considerable part of the area W of the cataracts S of Selfoss and forms the bottom of the old riverbed found there. Still other layers (A_o) are superimposed on this layer beneath the moraine cover of the ridges bordering the E side of the Sveinar graben. Unit A consists of a rather fine grained basalt that does not show any pronounced tendency to jointing or columnar structure. It rests directly on unit B without any sediment between.

Unit B is a massively jointed gray basalt extending from about elevation 340-318 m. The columns are up to nearly 3 m across and frequently they are 2 m across. The surface exposure of this layer is characteristically light gray in colour. Its contact with the underlying unit C is very tight and nowhere where the author has been able to look at that contact has any sediment or a scoriaceous contact been found. On the whole the layer is very uniform and dense but because of the above mentioned columnar structure and a horizontal jointing it has not been resistant to stream erosion. This erosion has plucked out many large blocks which are evenly spread over the present surface exposure. Unit B forms the rapids of the river about 0. 5 km upstream from Selfoss.

Unit C extends from about elevation 318 to 307 m. It forms the waterfall Selfoss and the floor of the abandoned river bed between Hafragil and the canyon N of Dettifoss. This unit is easy to identify as it is rich in small felspar phenocrysts (diam. 2-5 mm). In its uppermost part it is vesicular and its surface looks so fresh, that when the author first saw it exposed he took it for postglacial lava. Clearly it has been covered by Unit B before any weathering or erosion had changed its surface. It rests unconformably on Unit D and its thickness thus varies from place to place. It thins out towards N and the author has not observed it N of Hafragil. It is massively jointed vertically and has also a tendency to horizontal jointing in the middle. It seems to be very resistant to erosion.

Unit D is a sedimentary or sedentary layer that varies much both in thickness and structure. Where it is thickest, about 6 m, due W and E of Dettifoss it is a breccia of angular blocks, that are not scoriaceous. They are up to more than 0. 5 m in diam. and the layer is without any stratification and poorly cemented. Maybe it is formed by weathering, mainly frost weathering, in situ. NW and E of Dettifoss it is seem to be capped by a 20 cm thick layer of black volcanic sand. The undercutting and collapse of Unit C has formed Selfoss.

Units E and F extend from about elevation 302 to 255 m. Together these units form Dettifoss because of the undercutting of unit G, E and F are of about the same thickness (E somewhat thicker) and consist of gray columnar dolerite. Unit E has in some places one indistinct interflow contact and Unit F has a distinct one. Between E and F are in some places lenses of intercalated breccia up to about 1 m thick.

Unit G is a sedimentary layer. It extends from about elevation 255 to 245 metres at Dettifoss but as it rests on an eroded dolerite layer it varies in thickness. N of Dettifoss it consists of stratified material, mainly coarse sand and fine gravel, but the uppermost part is coarse gravel. Like Unit D it is weakly cemented and seems to be very permeable and to be the main aquifer in this part of the canyon. Small springs issue from it S of Hafragilsfoss and bigger ones N of that waterfall.

Units H extends from about elevation 245 to 230 m. It is a rather compact dolerite layer without a conspicuous tendency to columnar jointing. It is in close contact with Unit I.

Unit I forms Hafragilsfoss and extends from about elevation 230 to 205 metres. It is a columnar dolerite of very much the same type as Unit F and shows also one distinct interflow contact.

The contact zone between Unit I and the underlying unit, which is probably a breccia, is obviously pervious and feeds considerable springs on both sides of the river.

The results from drilling

The drilling very well verified the stratigraphy obtained from the outcrops in the Jökulsá canyon already described. The main difference was that unit C was thinning out at the powerhouse site but unit D thickened considerably. The drilling also showed that in the Sveinar graben the dolerite A_o was thickening in that direction and consists of more than one bed. As to the vertical displacement of the Sveinar graben, the drillings hitherto carried out are not decisive. Yet they indicate that 15 m is a minimum value for the displacement. The possibility of an unconformity between layer A and layer A_o cannot be quite ruled out.

The ground water is usually perched and the sedimentary layers and the middle part of thick basalt beds seem to hold up ground water. The permanent ground water is very low, close, to elevation 300 m, at the power house site but probably still lower in the graben area. At Hafragil the ground water is at elevation 250 m where the highest springs issue. The hydraulic gradient in the ground water is between 1 and 2%.

The permeability is rather high for most units, but most permeable are contacts between lava flows. The glacial drift layer has a rather low permeability and the clastic layer D seems-rather unexpectedly to be less permeable than the basalt and dolerites. The same may be the case with the lower lying clastic layers but this has not been tested as they have not yet been drilled through. It seems likely that the faultlines have their highest permeability where they go through the lava beds and that they are less permeable where they go through the sedimentary layers as these layers have resettled in the fault fissures. This explains the occurrence of springlines in fault lines and above the sedimentary horizons.

The present surface is also generally covered with sediments, the moraine, which act in the same way as the older sedimentary beds. It could be clearly seen from the cores of the holes drilled through the fault lines in the Sveinar graben that moraine from above was partly filling the fault zone.

The permeability of the reservoir area is generally that of the moraine although at some places it may be much higher where the faults are open. The open faults are probably of limited extension and it may be possible to localize them and tighten them previous to damming.

The drilling did not penetrate the 3 lowest units of the Dettifoss Dolerite and therefore there is some uncertainty as to whether these units reach all the way to the powerhouse. But as all other units have been found in the drillhole it is very likely that the three lowest units are present also there. The Power House will be located mainly in units H and I which are excellent gray basalts and the bottom might be in the sedimentary layer J which is probably breccia but with unknown engineering characteristics. If all the head topographically favorable is developed the tailrace tunnel should be mainly in the sedimentary layer J but it is probable that by sacrificing some m of head as is now proposed in the planning report it can be uplifted to the above lying basalt bed. But it is of utmost importance for this project to get knowledge of the characteristics, thickness and distribution of this sedimentary layer J inside the project area. This can only be done with further drilling.

CHAPTER IV

FURTHER INVESTIGATION

Further geological investigation necessary for this project has already been mentioned in connection with each subject. But further discussion and a review of it will be made here.

For the powerhouse area and tailrace tunnel it is necessary to drill some holes to determine the location of the sedimentary unit J and its characteristics. Some holes might also be necessary in the Sveinar graben to determine the dislocation there and also to reach the permanent ground water table. A drilling through the feeder dyke of the Sveinar crater row is desirable.

Other investigation would mostly be in order to determine the ground water conditions in the entire reservoir area and at the critical water divide areas. In this connection it is necessary to try to determine the influence the faults have on the ground water by drilling both close to the faults and also between faults. These drillings are not necessary done with core drill and it may prove more economical to use churn drill because of the difficulty in obtaining drill water as there is no surface run off in substantial parts of the area.

A closer study of the sedimentary layers where they crop out N of Hafragilsfoss and in Hólmatungur. This involves both field study and sampling for grain size analysis of their cementing material and other laboratory studies.

Measurements of the discharge of the springs in Hólmatungur and near Hafragil on both sides of the river is necessary. The total discharge should then be compared with the size of the drainage area supposed to be drained by these with springs and the variations in the flow should be compared to the variations of the ground water level. This might give sufficient data to estimate the overall permeability of the reservoir area.

Finally it is necessary to localize probable areas of high vertical permeability, mainly open faults or faults filled only with big blocks. The extension of the glacial drift cover on the southern slope of Grjóthàls should also be mapped because where the dolerite is bare the vertical permeability may be rather high.

Appendix

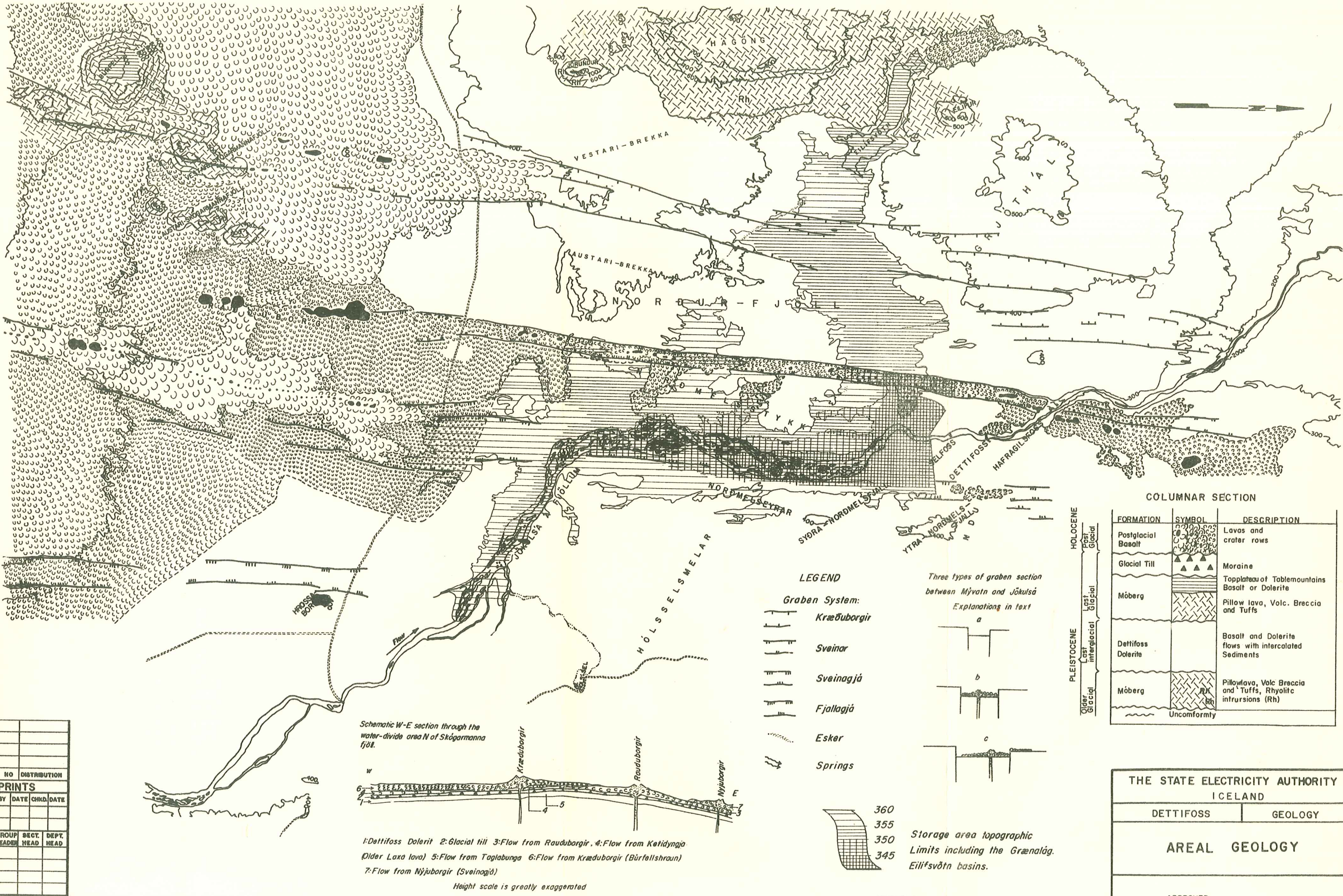
After the printing of this report, layer J was studied, where it outcrops below Hafragilsfoss. This study was made possible as a narrow passage was discovered, leading down to the bench below the waterfall.

Layer J is an interbed; its character is the same as that of the other interbeds in the Dettifoss dolerite, for example D and G.

Its thickness varies from one meter to three meters. If rests on a dark dense basalt, close-jointed and fractured, and therefore easily eroded. The basalt layer K reaches four metres above waterlevel (approximate elevation 204 m) at Hafragilsfoss, but is below waterlevel (approximate elevation 200 m) at the proposed tunnel outlet. This difference in elevation is caused by a displacement in the Sveinar Graben; the west wall of this graben is found between Hafragilsfoss and the proposed tunnel outlet.

This western wall consists here of a number of small step faults.

EXHIBIT I



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DETTIFOSS	GEOLOGY

AREAL GEOLOGY

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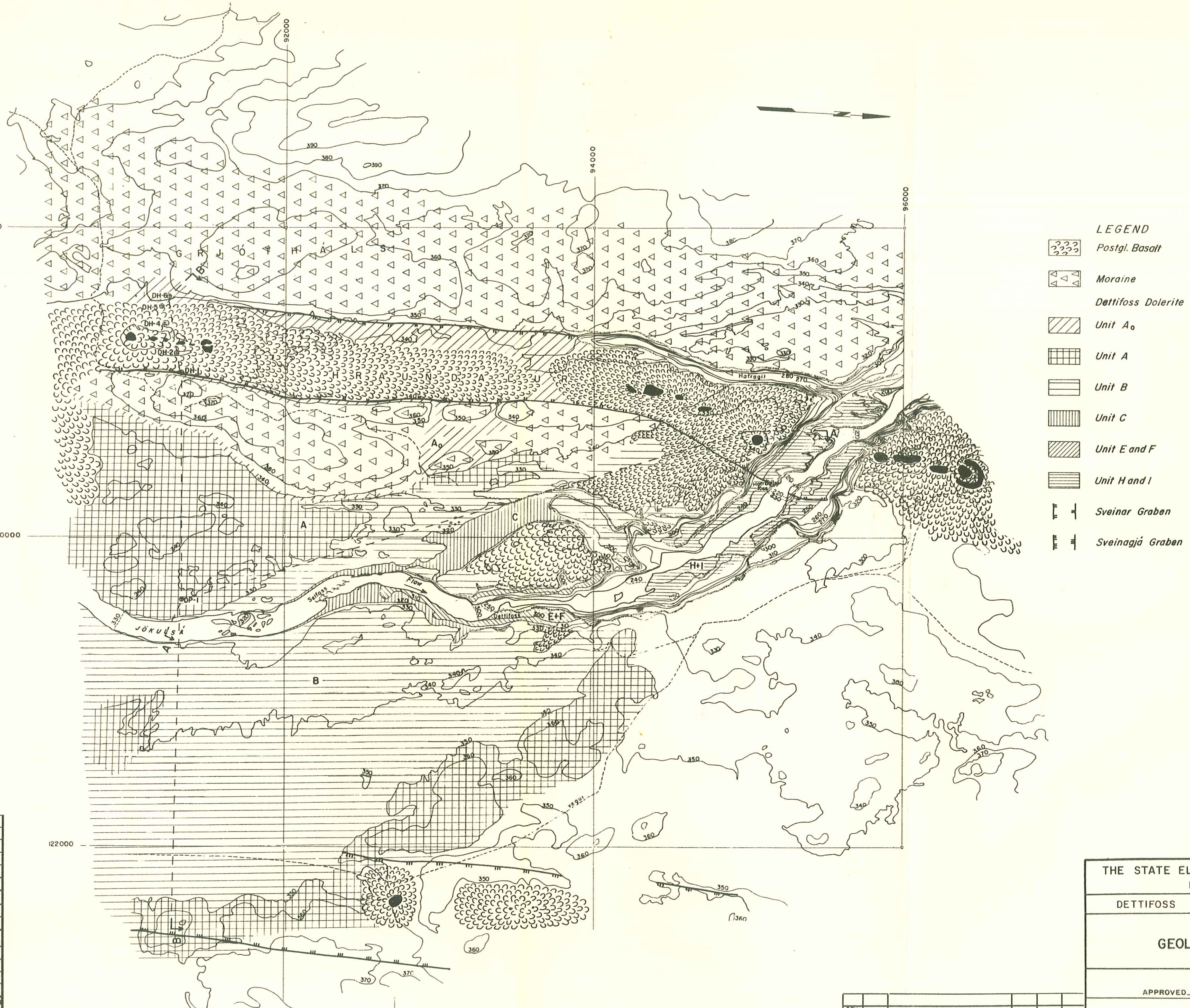
ELECT.			
PLAN.			
STAFF			CH.ENGR.

EXHIBIT 2



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GEOLOGIC MAP

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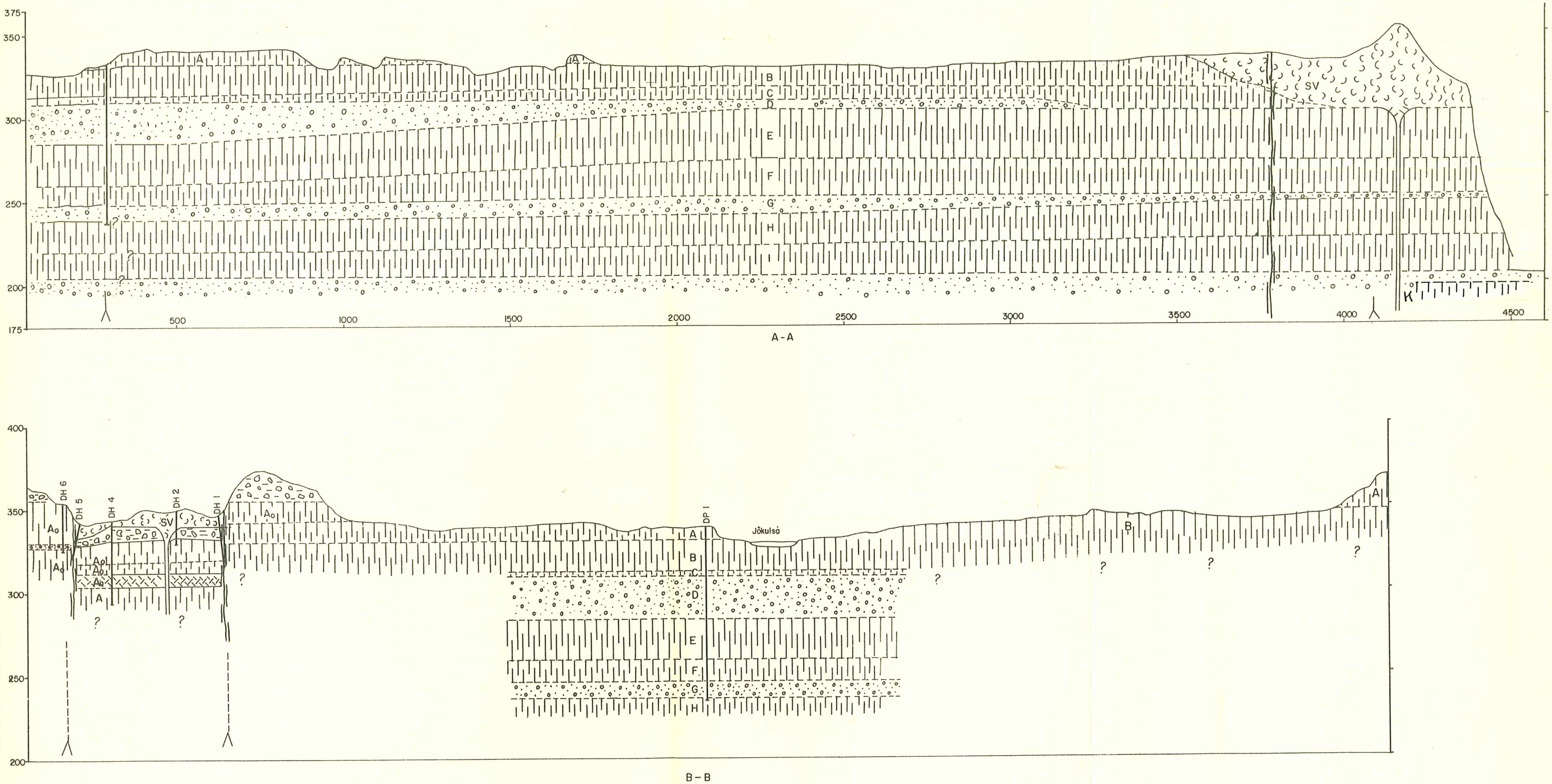
EXHIBIT 3



Scale 0 250 500 Meters

LEGEND

- Postglacial Basalts (The Sveinar flow)
- Moraine
- Dettifoss Dolerit and Basalt
- Volcanic Breccia
- Sedimentary Breccia or Conglomerate
- The Sveinar graben

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GEOLOGIC SECTIONS

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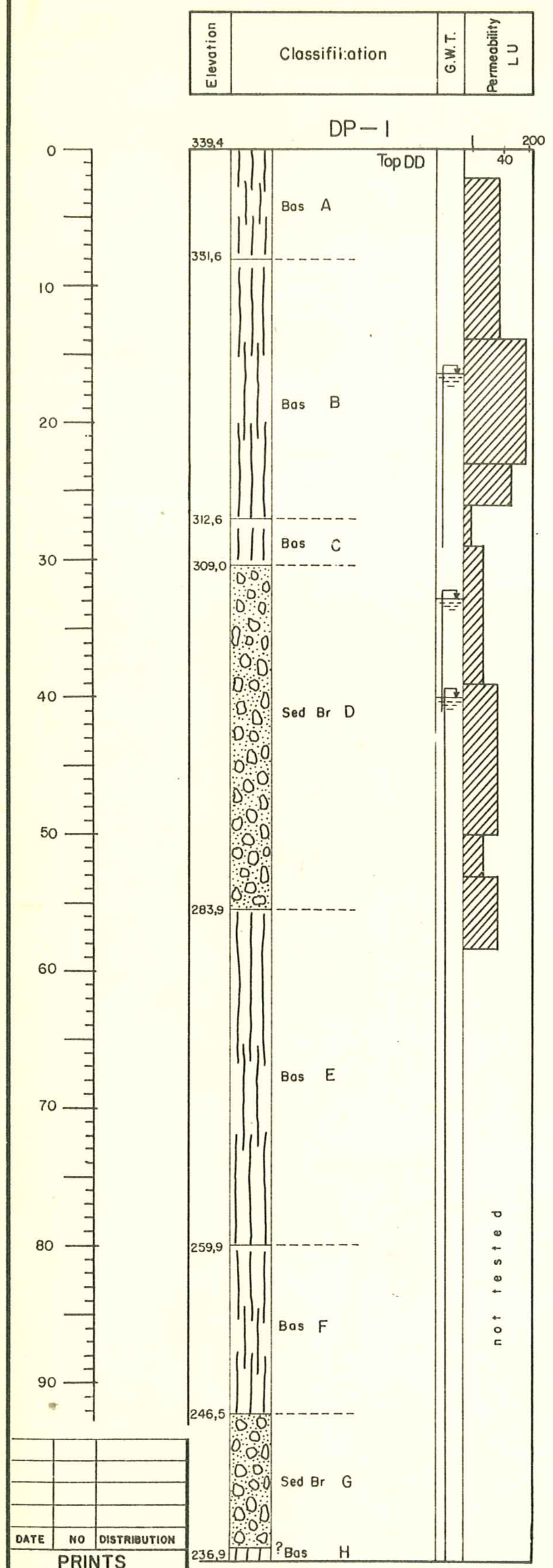
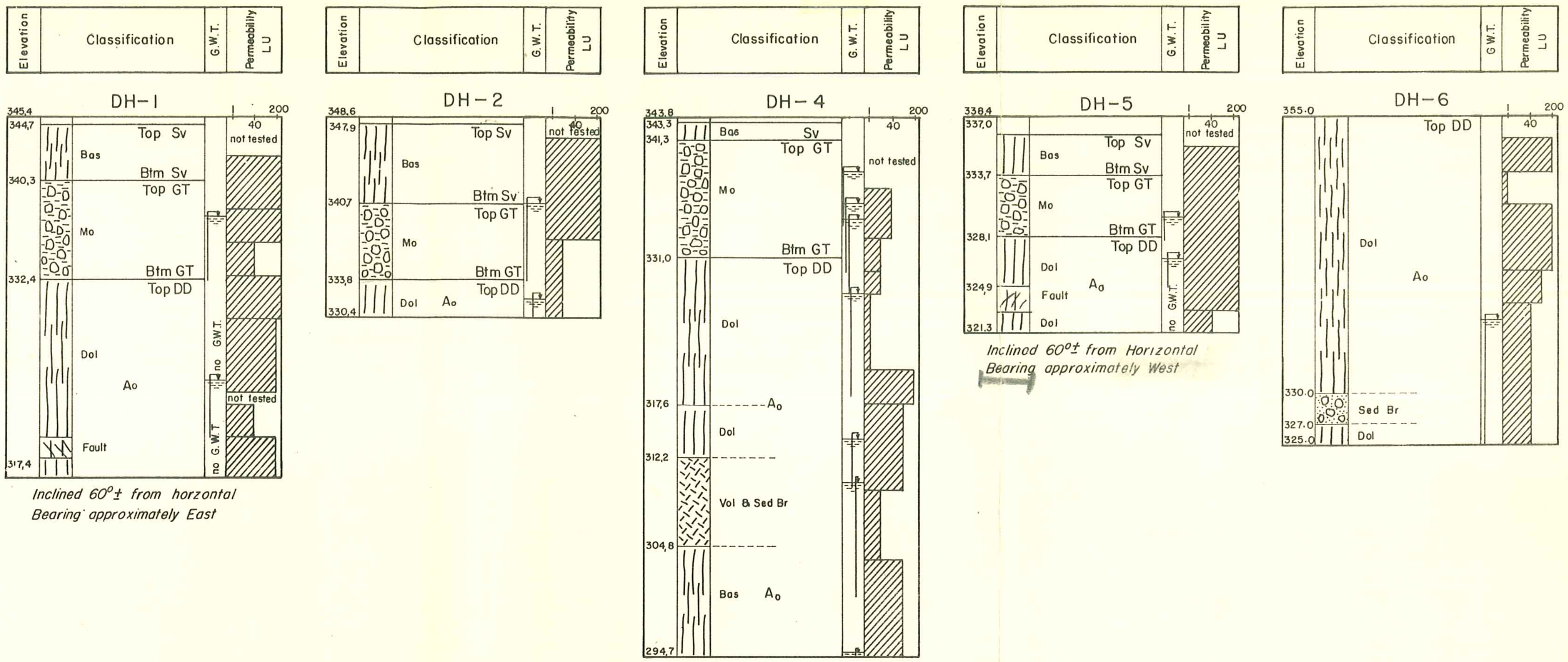
EXHIBIT 4





LEGEND

COLUMNAR SECTION

Age		FORMATION	SYM	MEMBER SYMBOL	THICKNESS m	DESCRIPTION
Holocene	Post Glacial	Sveinar	Sv	Sv	2 - 7	Feeder dike craters, basalt flow
Würm	Glacial	Glacial Till	GT	GT	5 - 11	Moraine (Boulder clay)
Pleistocene	Riss - Würm Last Interglacial	Dettifoss Dolerite	DD	Ao	>30	Dolerite beds with clastic interbeds
				A	8 - 10	Basalt fine grained (Andesitic)
				B	19 - 22	Basalt fine grained
				C	3 - 11	Basalt porphyritic
					4 - 25	Sedimentary Breccia
				E	24 - 30	Basalt medium grained
				F	12 - 26	
					9 - 10	Sedimentary Breccia
					15	Basalt
					25	
				J		Sedimentary Breccia

Notes:

1. Sv corresponds to Postglacial basalts (PB) shown on Exhibit 9, Dettifoss Project Planning Report. PB is a group desingation while Sv is a formation designation and refers to basalt originating in the Sveinar graben.
2. A_O corresponds to Units A_O, A_1, A_2, and A corresponds to Unit A_3 of the Planning Report.

MATERIAL

OVERBURDEN

Unclassified

SEDIMENTARY

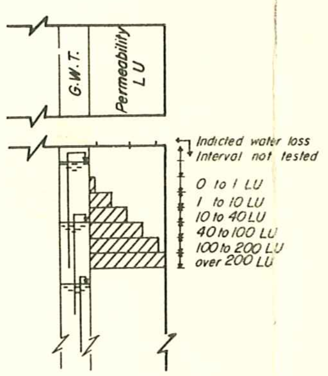
Breccia - Coarse to fine (Sed Br)

Boulder clay (Moraine) (Mo)

IGNEOUS

Basalt, Dolerite or Andesite (Bas) (Dol) (And)

(Palagonite) Volcanic breccia and tuff (Vol Br) (Tuff)



PERMEABILITY AND GWT EXPLANATION

NOTE: Ground water levels are shown by the arrows. Base of the arrows indicate the hole depth when water level changed. Successive levels are shown from left to right in the same sequence as observed during drilling. If no change in level was observed the arrow reaches to hole bottom.

ABBREVIATIONS

And - andesite
Bas - basalt
Dol - dolerite
Mo - boulder clay - moraine
Sed Br - breccia
Vol Br - volcanic breccia
G.W.T. - ground water table
B.T.M. - bottom
LU - lugeon unit

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DETTIFOSS PROJECT — GEOLOGY

GRAPHIC CORE LOGS
SHEET 1 of 1

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