í hillu
117

RESTRICTED

ORKUSTOFNUN
MÁLASAFN
442.1 /Bjarn

ENGINEERING GEOLOGY
of the
HVITA and THJORSA BASINS,
ICELAND

by

Allen H. Nicol
United Nations Special Fund

October 1965

This report has not been cleared with the Office of Special Fund Operations, Department of Economic and Social Affairs, of the United Nations, which does not therefore necessarily share the views expressed.

CONTENTS

	Page
Introduction	1
General Information	2
Engineering Geology	3
Basin Dam Site Investigations - Hvita Basin	6
Selfoss	6
Ora	7
Hestvatn	7
Dynjandi	8
Efstidalur	8
Thjorsa-Hvita (Diversion Canal)	8
Faxi	9
Haukholt	9
Tungufell	10
Burfellsmyrar	10
Blafellsholmi	11
Sandartunga	11
Aboti	12
Hvitarvatn	12
Basin Dam Site Investigations - Thjorsa Basin	13
Urridafoss	13
Hvita-Thjorsa (Diversion Canal)	14
Budafoss	14
Skard	15
Haifoss-Fossa	15
Sultartangi	16
Gljufurleitarfoss	17
Dynkur	18
Hvanngiljafoss	19
Nordlingalda	20
Budarhals	20
Kaldakvisl (Diversion)	21
Thorisvatn (Area)	22
Thorisvatn (Tunnel Site)	23
Hrauneyjafoss	23
Tungnaarkrokur	24
Bjallar	25
Storisjor	26
Langisjor	26
Conclusions	27
Recommendations	28
Supplementary Notes	30

FIGURES

1. Index Map
2. Engineering Geology Map
3. Engineering Geology Table, Sheets 1 and 2
4. Tungufell Map and Cross Section
5. Burfellsmyrar, Map and Cross Section
6. Aboti, " " " "
7. Urridafoss, " " " "
8. Hvita Diversion, " " " "
9. Skard, " " " "
10. Sultartangi " " " "
11. Dynkur, Kaldakvisl, Thorisvatn (3 sheets)
12. Hrauneyjafoss, Map and Cross Section
13. Tungnaarkrokur, " " " "

ENGINEERING GEOLOGY INVESTIGATIONS AND STUDIES
in the
HVITA AND THJORSA RIVER BASINS, ICELAND

Introduction

1. This section describes and interprets geologic features and conditions in relation to engineering aspects of the Hvita and Thjorsa Basins. It provides general information on geologic history, physiographic features, and geologic formations of Iceland as a basis for understanding geologic conditions and their engineering implications where hydraulic development projects are planned.

2. Field investigations were initiated under the United Nations Special Fund for these engineering geology studies on 1 June 1965. A total of 33 project sites for dams, diversion canals and tunnels are described here. They were visited in the field mainly by 4-wheel drive vehicle but some were reached only by foot over difficult terrain, and some by helicopter. This part of the assignment dominated the programme and continued into September, 1965, during which period observations were concentrated on geologic conditions at each site significant to hydroelectric development; these included an evaluation of foundation conditions, bearing capacity, permeability, excavation and tunneling conditions, and construction material availability.

3. In Iceland much basic geologic work has been done and published geologic maps are available at 1:250,000 for the entire island. Data on engineering properties of the mapped formations is, however, unavailable or unpublished. In order to show distribution of the main formations in the Hvita and Thjorsa Basins a special-purpose map was compiled and is accompanied by two tables with generalized descriptions of significant engineering characteristics. The engineering geology map and tables accompany this report. This presentation may be helpful for preliminary and general planning purposes in the Hvita and Thjorsa Basins, but it is not intended to supplant detailed investigations at specific sites.

4. The final part of this report contains a description of observed geologic conditions, engineering considerations and problems at each site in the two basins. All sites in both basins are shown on the engineering geology map. Larger scale geologic maps and detailed cross sections are included for several sites. Conclusions from the field observations were strengthened and expanded by subsurface data at some sites where preliminary work was done. Wherever possible to do so, the observed and inferred data pertain to topographic conditions, channel conditions, structural and engineering character of the bedrock, foundation conditions and bearing capacity, leakage and underseepage, overburden and excavation conditions, groundwater and perched tables, tunneling conditions and problems including bridge-action period, hazards, leakage and inflows, abrasive action, need for support and lining, feasibility of using rock bolts, construction material availability and suitability, conditions affecting height and type of dam, and conclusions and recommendations.

General Information

5. Iceland is situated in the North Atlantic Ocean at the intersection of the Mid-Atlantic and the Brito-Arctic Ridges. Both ridges were formed during the early and middle Tertiary Period by volcanic activity, and at the present time the Mid-Atlantic Ridge is an active seismic zone with frequent volcanism. The Mid-Atlantic Ridge is considered to cross Iceland from the southwest at the Reykjanes peninsula to the northeast at the Melrakkasletta peninsula, and forms a zone which coincides with the present belt of volcanism.

6. Iceland is therefore made up of volcanic products which are mainly of basaltic composition. In eastern and western Iceland the older basalt lavas are of Tertiary age, but in and along the volcanic belt the volcanic rocks are of Pleistocene to Recent age and consist of tuff, breccia and pillow lava formed by eruptions under glacier ice, and of subaerial lava flows during the interglacial periods. Ash falls, pumice, lapilli and other explosive volcanic ejecta mantled the surface of many lava flows during interglacial periods and in recent time.

7. Since the last glaciation some 10,000 to 15,000 years ago, the volcanic belt in Iceland is confined to two main zones which are connected in central Iceland by craters on the flanks of the glacier, Hofsjokull. The western zone is approximately 20 to 30 kilometers wide and extends from Reykjanes in the south to the north side of the glacier Langjokull, and the eruption fissures have a northeast-southwest trend. The other volcanic zone is approximately 30 to 50 kilometers wide and extends from the Vestmannaeyjar Islands off the south coast to Melrakkasletta in the north; the eruption fissures trend mainly northeast-southwest except for a north-south trend at Mt. Askja. Some lava flows in these volcanic zones have flowed along valleys and river courses for 100 kilometers or more from their vents.

8. Land forms and physiographic features in the Tertiary basalts of western and eastern Iceland are mainly the result of erosion of plateau basalt which has generally taken place along the structural trend of the present day volcanic fissures. Land forms in the Pleistocene are more complex due to volcanism having taken place partly under glacial ice, which covered most of Iceland several times during that time. The land forms of subglacial volcanism are long narrow ridges consisting of tuff, breccia, and pillow lava (Moberg) which have formed by fissure eruptions under the ice, and steep-sided table mountains having the lower part composed of subglacial Moberg and with surface lava flows that forced their way upward through the ice. Some Moberg ridges have a relief of several hundred meters and table mountains commonly 500 to 1,000 meters or more. During interglacial periods lava flows have filled some depressions between ridges, or flowed near the flanks of the table mountains. Present drainage patterns are conspicuously parallel in many areas since the rivers are confined to depressions between the Moberg ridges, many of which have been partly occupied by lava flows during interglacial periods.

9. The Hvita and Thjorsa River Basins are underlain by Pleistocene formations. The highest elevations are found in the glaciers that border the basins and that reach to 2,000 meters. The main glaciers are Vatnajokull, Hofsjokull, and Langjokull. Vatnajokull is the largest glacier in Iceland, having an area of 8,400 square kilometers, whereas the others are approximately 1,000 square kilometers. Glaciers cover most land areas in Iceland above an elevation of 1,000 meters, and some occur at lower elevations.

10. The main stem of the Thjorsa River is fed by melt waters from Hofsjokull and the principal tributaries, the Tungnaa and Kalkakvisl, are fed by Vatnajokull. Langjokull feeds the main stem of the Hvita River and some of its tributaries. Glaciers occupy approximately 15.9% of the drainage area of the Thjorsa, and 11.3% of the Hvita Basins.

11. In addition to the glaciers, other physiographic features of the basins are the northeast-southwest trend of volcanic fissures and Moberg ridges with the highest elevations southwest of the glaciers. The highland southwest of Hofsjokull is the divide between the Thjorsa and Hvita Basins. The Hvita River and its main tributaries flow through a broad valley with low relief between the tributaries. The Thjorsa River flows in a much narrower valley, and also its tributary, the Kaldakvisl; the other main tributary, the Tungnaa, in its upper reaches flows between narrow ridges, and in the central section it has cut through the ridges and flows in narrow gorges. In the lowlands both the Thjorsa and Hvita Rivers flow in shallow channels which have been radically shifted by volcanic activity in postglacial time.

12. Other physiographic features in the Hvita and Thjorsa Basins are the result of the shifting of the volcanic zones, of erosion and deposition by ice and water, and of fluctuations in sea level. During the Pleistocene, the volcanic zones have shifted from the central part of the basins toward the margins; the glaciers advanced and retreated several times, causing rapid erosion and the deposition of thick layers of coarse-grained sediments. Changes in sea level during the Pleistocene caused shoreline erosion during low stands and deposition during higher stands of the sea. Changes in sea level before the last ice age are not yet known. At the end of the last glaciation, some 8,000 to 9,000 years ago, it is known, however, that the sea level was more than 100 meters higher than at present. During that time thick layers of sand, silt and clay were deposited in the lowlands.

ENGINEERING GEOLOGY

13. Although volcanism is primarily responsible for the present land mass of Iceland, it is evident that glaciation also has played a very important part. The products formed by these geologic processes cover the Hvita and Thjorsa basins and now occur in a wide variety of earth and rock materials. On the basis of geological and engineering characteristics, those having certain similarities have been combined into categories or units which are shown on the engineering geology map. Thus, the wide variety of earth and rock materials in both basins are reduced to eleven different types or map units.

14. Basalt lava is by far the most widespread rock type in both basins, and it is represented in the mapped area by three distinct units, Nos. 3, 8, and 9. Unit No. 3 is Thjorsa lava, which has formed after the last period of glaciation. Units 8 and 9 are older Pleistocene basalts, distinguished from each other not only by age relationships, but more significantly on the basis of joint conditions. The older basalt of Unit 9 usually has joints and fissures filled or cemented which renders the rock masses firmer and less permeable than is the case with Units 3 and 8. From an engineering standpoint, therefore, the basalt of Unit 9 is considered superior to the other two types for tunneling and other construction.

15. Basalt lava flows normally have beneath their crust, two distinct structural zones. The upper zone, or entablature, commonly shows closely spaced prisms or columns of rock tilted at various angles from the horizontal. The lower zone, or colonnade, usually shows well developed vertical rock columns that are ofter larger in width, ranging up to 1 meter or more. The thickness of each zone varies with respect to composition and fluidity of the lava, and from flow to flow, with no apparent relationship between them. Rock prisms in the entablature and colonade structure can be broken along parting planes perpendicular to their long dimension. In colonnade structure where joints are loose, as is the case in the Thjorsa lava of Unit 3, there is little or no bond between individual columns; separation therefore occurs along these horizontal planes of weakness, and the unsupported blocks drop from the column. Where vertical joints are partly or wholly filled (Units 8 and 9), the frictional resistance to downward slippage may prevent detachment for indefinite periods.

16. Some lava flows show an irregular joint pattern forming roughly shaped cubical blocks in an unsymmetrical arrangement. The interlocking arrangement of the individual blocks in this case results in stronger conditions for excavations and tunneling. This condition is found in some parts of Unit 10.

17. Certain flows, particularly in some andesites, have a very well developed horizontal parting which is closely spaced. This results in a platy structure, whereby slabs and plates of rock from 1 centimeter to many centimeters in thickness are readily detached from each other. This condition is common in Unit 10, and presents unstable conditions in excavations and tunneling.

18. Pillow lavas are structurally different from all other types. They resemble stacks of pillows of various sizes, having a lava interior and an outer shell of palagonite. They range in size from less than 1 meter up to a few meters. The spaces between them are filled by tuff or other materials. Jointing and fracturing is closely spaced. They occur imtimately associated with tuff and breccia of subglacial origin, and are common components of the Moberg, Units 5 and 6.

19. Another extensive rock type in the two basins is the Moberg, represented by map units 5 and 6. Both units consist essentially of volcanic tuff and breccia, with pillow lava. They are distinguished from each other by a higher degree of cementation and firmness that is commonly found in Unit 6, and by their age relationships. Unit 6, being geologically the older of the two, has undergone more alteration of the glassy palagonite component. Where alteration is advanced, the products that occupy greater volume have filled many minute cracks, seams, and voids, which render the mass more compact and less permeable. Alteration of palagonite may not necessarily be the only cause of this condition, but the end result is the same. It is difficult in many cases to distinguish these units, and within each one well cemented beds may grade into friable zones. For this reason, both units are to be regarded with suspicion for tunneling, and both have doubtful suitability for construction. Further data on their engineering characteristics will be found in the tables that accompany the engineering geology map.

20. Ground moraine and morainal deposits also cover extensive areas, but are not shown on the map. Their thickness varies throughout the basins, and ranges from a few meters to a few tens of meters. At the surface, a thin layer of gravel and pebbles is common from which the fines have been removed by wind or water. The color is usually gray, and the constituent particles are basaltic in composition. A zone of loose, mixed gravel, cobbles and fine granular materials extends to about 1 meter in depth, beneath which a very compact and rock-like condition is found in some deposits. Cobbles, large boulders and erratics up to several meters in size are strewn at random on the surface and occur within the heterogeneous deposits. The compact character beneath the surface may not always be present, but this condition appears to be fairly extensive, and the degree of compaction may be so great that blasting is required for excavation. On exposure, some of the rock-like material is known to soften and break down to an unconsolidated condition. Morainal deposits may be useful for impervious core material, and eskers could supply aggregates for concrete, but extensive investigation in all cases would be required to determine suitability and volume available.

21. Loess and organic soils cover parts of the basins, especially at the lower elevations, but are less common in the highlands. The loess is a brown, loose silty or fine sandy soil developed on or associated with aeolian deposits. It is commonly about 1 meter in thickness, but may reach several meters in some areas. It has a very low unit weight, and is easily eroded by wind and water if the surface vegetation is disturbed. Organic soils consist of dark gray peat-like accumulations with silt and fine sand that reach several meters in thickness in some parts of the lowlands. They often occupy depressions and underlie the marshes and swamps where water table is high and drainage is very poor. Loess and organic soils are very unstable materials that require removal at sites where important projects are planned. They are not shown on the engineering geology map.

22. All map units are described in the tables and their engineering properties are given. The data are derived from surficial studies mainly and the inferred conditions may not always apply at depth

where the properties and types of rocks change from those found at the surface. However, it is believed that the geologic map and tables will help to surmise the engineering characteristics of not only project sites but also the areas adjacent to them for tunnels, canals, power plants, spillways and appurtenant structures. These data are concerned primarily with conditions affecting excavations, foundations, tunneling and construction materials. They are, by necessity, very brief and generalized. But from them it can be seen that in a very general way the best conditions for tunneling will be found in Units 3, 6 and 9, and that the weak ground will be found in parts of Units 4, 5, 7, 10, and all of 11. Earth excavation conditions dominate in Units 1, 2 and 4, whereas rock excavation will apply in most of Units 3, 6, 7, 8, 9 and 10; part earth and part rock excavation will occur in Units 4, 5 and 11. From a standpoint of support, the best foundation conditions can be expected in Units 3, 6, 8, 9 and 10. Rock bolts are believed suitable for tunnels driven in parts of 3, 6, 8, 9 and 10. Units 1 and 2 are highly permeable, and permeable zones will be found in parts of 3, 4, 5, 8 and 10. Other conditions and characteristics of engineering importance are given in the tables.

BASIN DAM SITE INVESTIGATIONS

23. The results of geological investigations made at 14 sites in the Hvita and 19 sites in the Thjorsa Basins are presented here in some detail. Each site is named and numbered under the basin in which it occurs, and all sites are shown on the engineering geology map. Where limited time, adverse weather, overburden or other adverse circumstances restricted the observations at some sites, it can be assumed that the generalized engineering characteristics as presented in the tables can be used to supplement the field observations. Detailed geologic maps and cross sections are included for 4 sites in the Hvita and 8 sites in the Thjorsa Basins. Much useful subsurface data came from borings at 9 sites in the Hvita and 6 sites in the Thjorsa areas.

Hvita basin

Selfoss dam site

24. Topographic conditions appear favorable for a low dam of 8 to 10 meters in height. The right bank bedrock is part Moberg breccia, Unit 6, and part tillite, both of which are hard and firm. The tillite is perhaps more porous than the Moberg, but the foundation conditions appear good for a concrete or an embankment type of dam. Rapids occur in the Thjorsa River along this section, and part of the channel section is probably underlain by tillite and breccia. Thjorsa lava, Unit 3, forms the left bank and is well exposed with negligible overburden. Jointing is indistinct in the tillite and the beds have an apparent dip of 8 to 10 degrees downstream. Jointing in the breccia is wide and irregular, ranging up to 2 meters apart, with most joints striking at an oblique angle across the river. An axis at this location would probably be in tillite at the right abutment, and firm Thjorsa basalt at the left abutment. Of the three types of rock, the basalt would probably be the most permeable, and the tillite the least, although visually the breccia and tillite

both appear to be fairly water-tight. Excavation of the rock at both banks will require drilling and blasting. Of the three types of rock, the lava at the left bank has the best quality for shell material and could also be used for riprap and aggregate. No subsurface exploration has been made here. In the event this site is considered for construction, it will be necessary to make at least two borings in the channel section to locate the contact between the lava and the tillite and to evaluate leakage in the contact zone, and one or two borings in each abutment. Further investigations will also be necessary for core material, fine aggregate and other construction materials. The site area is inhabited and is easily accessible by highway.

Ora dam site

25. The bedrock along both banks is gray basalt, Unit 9, which is well exposed in blocky, irregular columns, but is not of typical colonnade structure. It is hard, fresh and firm, and lacks the platy or slabby condition which is commonly found in this map unit in some areas. Rock of this character should provide excellent conditions for the foundation of any type of dam, and would be suitable for rock shell and aggregate. The topographic situation is also favorable here for the construction of a low dam. Both abutments and the foundation in the channel section would rest in the sound basalt, with negligible overburden stripping required. A diversion tunnel or canal and the power plant would also encounter similar rock conditions. A tongue of Thjorsa lava, Unit 3, occurs a few hundred meters downstream of the tentative axis, but all structures would be in the basalt of Unit 9. No subsurface work has been made here, but in view of the geologic conditions it would appear that very limited work would be required. Exploration would be needed, however, for core material, fine aggregate, and other construction materials. Further data generally applicable to the rock conditions at this site will be found in the tables accompanying the engineering geology map for Units 3 and 9, if desired. The site is located in a sparsely inhabited and inaccessible area.

Hestvatn dam site

26. The high right bank here is Moberg breccia, Unit 5, whereas the low left bank is Thjorsa lava, Unit 3. The contact occurs near the right bank in a deep channel. Both rock types are suitable for the foundation of the proposed low dike of only a few meters height that would impound water to be diverted by canal into Lake Hestvatn. The canal would be dug in Recent Alluvium, Unit 1, which is overlain in places by soil and bog overburden. A line of Borra soundings have found the overburden averages about 4 meters in thickness. The five borings made at this site indicate the lava is at least 40 meters thick, and that a fairly thick layer of talus occurs in the central part of the river channel. Curtain grouting may therefore be required in the talus zone and also in the contact zone to minimize leakage, but further investigation is advisable to evaluate this requirement. Studies would also be necessary to determine the suitability of the alluvium for aggregates and embankment. The basalt is considerred suitable for rock shell, but the breccia has questionable suitability. The site area is sparsely inhabited and inaccessible.

Dynjandi dam site

27. This site is located on the Bruara River, a tributary to the Hvita. Gray basalt of Unit 9 forms both banks for the main dam. It is a hard, massive rock, occurring in at least two flows, the upper one being moderately vesicular in the surface 1 or 2 meters. Overburden soil is less than 3 meters. A small knob of Moberg tuff, Unit 6, occurs at the left bank, which is believed to be an erosion remnant before deposition of finiglacial beds of Unit 4 in the adjacent areas. Topographic conditions here would require construction of a dike at the right bank where the foundation would rest on the compact finiglacial beds. The foundation for the main dam will rest on basalt, and conditions appear to be entirely satisfactory as borne out by surface observations and three completed borings. Only a low dam could be constructed here due to topographic limitations. The basalt, tuff, and finiglacial beds should be suitable materials for dam construction. The basalt would unquestionably be the best rock for shell, riprap and aggregate, whereas the finiglacial deposits might supply core material. The tuff appears to be doubtfully suitable for construction, but requires further study. Other data pertaining to the expected properties of the units in the site are will be found in the engineering geology tables. This site is located in a very sparsely inhabited area and is inaccessible.

Efstidalur dam site

28. This site is located on the Bruara River and appears favorable for the construction of a low dam of any type. Gray basalt of Unit 8 forms both banks and the river flows on basalt bedrock. At the surface the joints are fairly close and irregular; the surface rock is very hard and firm and does not show a slab-like condition. The indications are that it would, during excavation, break into more or less irregular-shaped blocks of various sizes. Overburden on the slopes is thick, but there is no overburden in the channel section. The water in the Bruara is crystal clear, since much of its flow emanates from a series of springs along both upstream banks. Five borings made in the vicinity of the site indicate the basalt bedrock to be about 40 meters thick and to consist of a series of closely jointed flows, some of which are vesicular. They are underlain by breccia and other Moberg beds of Unit 6. Although foundation support is excellent, there may be a possibility of serious leakage in and along the contacts between some of the lava flows, or even within certain flows. The Bruara carries so little sediment that sealing may not have occurred in the geologic past. The construction material situation in the vicinity appears very good but exploration is required to prove volume and suitability of the nearby morainal and fluvioglacial materials. The basalt would be useful for rock shell, coarse aggregate, and riprap. This site is inaccessible and is located in a very sparsely inhabited area.

Thjorsa - Hvita Diversion Canal

29. One plan being considered is diversion of the Thjorsa River into the Hvita River by means of a canal which would follow along an old course of the Thjorsa. The present channel of the Thjorsa is higher and was much higher in past geologic time. The former channel is

underlain by sediments of Unit 1 consisting of mixed gravel, sand and clay and ranging to 50 meters or more in thickness. The ground water table is high throughout much of the canal alignment, so that the problem of leakage is unimportant. Canal banks in material of this character will require fairly flat excavation slopes and possibly riprap to attain stability.

Faxi dam site

30. This site is located on the Tungufljot River, tributary to the Hvita. Moberg tuff, breccia and pillow lava of Unit 6 form both banks. The pillow lava predominates and is highly fractured and irregularly jointed into small masses ranging from a few centimeters to less than one-half meter in size. A lava flow of Unit 9 occurs beyomd the abutment zone of the right bank, exposing well developed colonnade structure. The conditions here appear good with respect to foundation support for a dam of any kind, but topography will permit only a fairly low dam to be constructed. No adverse problems are envisioned; exploration, if made later, should consider the permeability of the fractured pillow lava, however. The canal in connection with the proposed project will be through finiglacial beds of Unit 4. No exploration has been made at this site. Additional data for the respective map units will be found in the engineering geology tables. The site area is sparsely inhabited and inaccessible.

Haukholt dam site

31. Topographically and geologically this site appears to be well suited for a moderately high dam. At the left bank a thick layer of massive, fine-grained andesite of Unit 10 is overlain and underlain by thinner layers of partly vesicular basalt of Unit 9. An interbed of breccia at the base of the andesite pinches and swells from less than 1 meter to 2 or 3 meters in thickness. This breccia interbed appears to be friable and highly permeable. At the right bank a small-sized colonnade basalt is exposed in the steep canyon wall; it may be a single flow of Unit 9, since no interbed was observed. For this reason it appears that right bank conditions are somewhat better than the left bank, but no adverse conditions were observed that might seriously affect construction. There has been no exploration thus far at this site. However, the geological and topographical conditions appear worthy of study for concrete dam construction. The foundation beds appear capable of sustaining the heavy design loadings for buttress dam construction but exploration will be necessary by borings to evaluate permeability and strength. Time did not permit a reconnaissance of the area for construction materials. The andesite and basalt layers, however, should be satisfactory to make coarse aggregate, rock shell, and riprap. Fine aggregate and other materials will require geologic reconnaissance and exploration. The site area is difficult of access and is sparsely inhabited.

Tungufell dam site

32. The Hvita River flows in a fairly deep gorge in this section. At the left bank a few meters of moraine covers a layer of blocky basalt, Unit 9, which is 10 or more meters thick and which is in turn underlain by colonnade basalt near the base. The right bank is underlain by basalt, also Unit 9, but the geological conditions are more complex. A fault may lie in part of the outer right abutment zone, or there is a possibility that what appears to be a fault may be the margin of another basalt flow. This could not be resolved by surface field evidence within the period of observation. The foundation support is unquestionably good for a dam of any kind at this site. A fairly high dam would be topographically possible. No adverse geologic conditions are believed to occur here which would cause serious construction difficulties but further study will be required, especially at the right bank, to understand the apparent complexities. One boring has been made in the vicinity of the site along the left bank. Water pressure tests showed the basalt to be fairly permeable, but a few thin sedimentary interbeds to be of highly impermeable character. A transverse geologic cross section is prepared to depict the probable subsurface conditions. It is evident, however, that a considerable amount of subsurface exploration work will be necessary at this site and along the proposed tunnel alignment to provide a basis for preliminary design studies.

Burfellsmyrar dam site

33. The Hvita River flows here through a deep, narrow gorge in pillow lava, Unit 6. The rock is closely jointed but appears fresh, hard, and almost black in color with small white feldspar phenocrysts. The conditions here appear feasible for concrete dam construction. It is possible that arch dam construction might be considered, but extensive investigation would be required to verify this assumption. Although the dam would be of moderate height, the condition of the pillow lava, which contains much glassy palagonite, may have an unfavorable modulus of elasticity for arch construction. No in-place testing data in this connection are available in Iceland. The straight and narrow portion of the gorge appears to follow along the strike of a fault, and some minor faults are believed to trend obliquely to the main fault. To what extent faulting may adversely affect the foundation conditions is at present undetermined; this situation is one which requires further consideration and investigation. One boring along the left bank showed 140 meters of mainly pillow lava with a compact tillite interbed. Water-pressure testing showed a fairly high permeability in the upper 25 meters of pillow lava, below which very tight and almost impermeable conditions were found. Several additional borings would be required here at both banks and in the channel section to determine the suitability for concrete dam construction, and to assess the conditions in the fault zones. A generalized geologic cross section is prepared to depict probable conditions, but it may require modifications after additional subsurface data are available. The site can be reached by 4-wheel drive vehicle, but the area is uninhabited.

Blafellsholmi dam site

34. This site is located on the Hvita River a short distance below the confluence with the Sanda River. Blocky gray basalt of Unit 9 is exposed in the upper part of the banks and is underlain by several meters of sedimentary beds consisting of conglomerate above, grading into sandstone in the lower beds, all of which belong to Unit 7. The sedimentary beds are underlain by a massive, blocky basalt which extends to the bottom of the gorge. The sedimentary beds appear to be nearly horizontal but in places they have a very gentle downstream dip; the beds pinch and swell within short lateral distances and range from 1 meter to several meters in thickness and some show prominent cross-bedding. A fault may lie parallel to the direction of stream flow, which could explain the rapid erosion and downcutting that has taken place. The low falls here are cut into the sedimentary beds which are more easily eroded than the overlying or underlying basalt layers. Topographic limitations would permit only a low dam to be constructed here. Foundation conditions appear favorable for concrete or embankment type. The sedimentary interbeds are well indurated and appear impervious. Only minor leakage or underseepage might occur in the basalt, mainly along joints, or in the contact zones between the upper and lower basalt layers. Overburden stripping here would be negligible. Abundant rock is available for shell material but no suitable supply of core material was observed in the immediate vicinity with the exception of some ground moraine and loess; these are worthy of further investigation. All rock here will require blasting for excavation. Tunnels in the basalt should stand well with little or no support; some weak zones may occur in the sedimentary beds, however, that would require support and lining for protection against abrasion. Two borings were made in the nearby vicinity which showed the basalt and sedimentary beds to be quite impervious. Limited additional exploration would be required here, mainly in connection with construction materials. The area is difficult of access and is uninhabited. Two inclined borings, one at each bank, to intersect beneath the channel section would be helpful to locate the possible fault zone and evaluate conditions.

Sandartunga dam site

35. This site is located on the Sanda River which is tributary to the Hvita. The river flows in a fairly narrow gorge with steep walls which expose 2 meters of overburden, 4 to 5 meters of small blocky colonnade basalt (Unit 9) which is partly vesicular in the upper part. The basalt is underlain by 3 to 4 meters of very firmly cemented conglomerate having cobbles up to 10 centimeters in size, and some thin sandstone lenses; the basalt and conglomerate are nearly horizontal in attitude. Columnar basalt is exposed beneath the conglomerate in the channel and along both banks at river level. Rapids have formed in the gorge and the river flows on the conglomerate in the upstream section and on columnar basalt at some point downstream. Seepage was found at the contact of the upper basalt with the conglomerate, indicating the tight and relatively impervious character of the conglomerate. The geological conditions here appear favorable for the construction of a concrete or rockfill dam. There should be little if any problem of foundation support,

although it would be prefereable for a concrete dam to rest on the stronger basalt in the downstream section. All rock will require blasting for removal. The conglomerate beds should be the most impermeable. In tunneling, all beds should stand well without support; some seepage can be expected from the surface or from small perched water tables, but no excessive inflows are expected during tunnel operations. All rock could be used for shell material but the basalt is preferable and could also be used for aggregate and riprap; core and other materials require further study. One boring was made downstream at some distance from this site but the findings generally confirm the relatively impervious conditions. Additional borings would be required along the axis to provide detailed subsurface data for preliminary design. The area is difficult of access and uninhabited.

Aboti dam site

36. The Hvita River flows here in a fairly wide channel on basalt bedrock of Unit 9. At the left bank this rock is gray, hard and firm with joints spaced from ½ to ⅓ meter apart, and some of which appear to strike perpendicular to the direction of stream flow. The left bank is partly capped by ground moraine of unknown but probably shallow thickness. At the right bank one boring was made which showed 1 meter of overburden underlain by 53 meters of dense basalt having a few thin conglomerate interbeds, which in turn was underlain by 107 meters of Moberg tuff and breccia (Unit 6) to the bottom of the boring. A small island in the river also exposes basalt of a similar appearance to that seen at the left bank. The right bank was not visited. From a geological standpoint the foundation conditions at this site appear entirely satisfactory for the construction of a low concrete or embankment dam. On the basis of surficial geologic conditions here and the single boring, an extensive subsurface investigation does not seem necessary to appraise this site. Only a limited amount of further work, possibly by five additional borings, with pressure testing, should be adequate to evaluate foundation suitability and permeability; two of these borings should be made at the left bank, one more at the right bank, and two in the channel section. Excavation will require blasting and the rock can be used for rock shell, riprap, and for aggregate after crushing. Further prospecting will be necessary for core and other materials in the vicinity. Rock tunneling conditions should be satisfactory in rock of this character and little or no support should be needed except in occasional weak zones within the interbeds where support and lining will probably be required. Tunnel spoil from basalt excavation should be quite useful for rock shell. The site area is difficult of access and uninhabited.

Hvitarvatn dam site

37. The site is located near Lake Hvitarvatn, adjacent to the road bridge across the Hvita River. A long embankment is proposed here to impound the Hvita near its source from the lake. Fifteen core-borings have been made along a tentative axis. Both banks are covered by ground moraine and some loess. The borings show the moraine ranges from 1 to 24 meters in thickness and is hard and

firm within 1 or 2 meters below the surface. Where thickness is adequate it should provide satisfactory foundation support for a low fill type dam but its water-softening behavoir should be very thoroughly understood. The underlying basalt bedrock of Unit 8 is exposed in only one or two places, but on the basis of the borings and these exposures it appears to be somewhat micro-vuggy but very hard and tough, and closely jointed. Two or more flows may underlie the area; the sequence and other geological conditions are somewhat complex and unclear. However, wherever thickness of moraine is adequate the foundation would rest upon it but shallow sections would require stripping to bedrock basalt. The moraine and basalt require drilling and blasting for removal. Both types should be reasonably water-tight. Rock shell material can be obtained in the vicinity but no deposits were examined within the immediate site area. Limited amounts of aggregates and possibly fine-granular material could be obtained from the riverbed nearby, but the best possibility for both coarse and fine aggregates would be from the eskers that are known to occur within reasonable distance. The morainal material might be considered for impervious core but testing would be required for corroboration. Accessibility to the site is reasonably good but the area is uninhabited.

Thjorsa basin

Urridafoss dam site

38. The area examined is a section along the Thjorsa River stretching for about 1 kilometer downstream from the highway bridge. The river flows here in a deep and fairly narrow gorge with steep banks, and rapids are developed along its course. Geological conditions in general appear quite favorable for rock fill or concrete dam construction. The entire left bank exposes Pleistocene basalt of Unit 9 which is quite hard and dense, with fairly wide joint spacings. The right bank is mainly Thjorsa basalt of Unit 3 except a prominent area of Unit 9 approximately 150 meters wide and 350 meters long, around which the younger Thjorsa basalt has flowed. The Thjorsa basalt is fractured and vesicular in the upper part, but the underlying colonnade layer is firm and dense rock with loose, open joints, closely spaced. In comparison with left bank conditions in Unit 9, the basalt of Unit 3 appears highly permeable and excessive leakage may occur with an increase in hydraulic gradient unless the foundations are tightened and sealed. For this reason a preferred axis location is in the section where the tighter and denser rock of Unit 9 is exposed along both banks and will be the foundation rock for both abutments. The bearing capacity of both types of basalt, however, is entirely adequate for any type of dam. Overburden thickness in the channel is not known but should not be excessive. Excavation of the rock at both banks requires blasting. At the right bank, in the Thjorsa basalt of Unit 3, the rather close jointing and general condition would designate the rock as "blocky and seamy" for tunneling, requiring support and lining; overbreak could be high unless blasting is carefully controlled. At the left bank, in the more massive rock with widely spaced jointing, a tunnel designation of "moderately jointed" would apply; bridge-action period would be very long to infinite; very limited if any support would be required, and overbreak should be no problem if blasting is carefully controlled. The tunnel

method could be "full-face" or "heading and bench," and no hazards are expected, such as excessive inflows, horizontal pressures, high temperatures or harmful gases. Basalt of both types is suitable for rockfill material, riprap and coarse aggregate if crushed, but the left bank basalt of Unit 9 appears to have the best quality. The construction material situation with respect to impervious core and filter materials, as well as aggregates for concrete, will require further study. Shoreline deposits in the downstream areas may be promising sources. The siting of an axis in this section of the Thjorsa River was not undertaken, but one could be easily located. Other tentative axis locations are possible upstream of the highway bridge and further downstream. The advantages appear greater in the section described here (where rock of Unit 9 forms both banks) with more favorable rock conditions and because upstream axes would increase the tunnel length, and downstream sites would provide less head. These possibilities have been investigated by others and are described in reports for the State Electricity Authority, but no exploration work has been done. The rock at the left bank would provide the best conditions for a diversion or an intake tunnel. Subsurface investigation is required to determine possible leakage and the method and extent of foundation treatment. The site area is easily accessible and sparsely populated. A detailed geologic map and cross sections accompany this report.

Hvita - Thjorsa diversion canal

39. Geologic conditions at the Hestvatn dam site on the Hvita River are previously described in this report. That project would require a canal to divert into the Thjorsa River. The canal will cut through two different Thjorsa lava flows of Unit 3, ranging from 10 to 40 meters in thickness, the thickest being near the Hvita River. Both flows are underlain by older basalt of Unit 9, with a few meters of finiglacial sediments of Unit 4. Overburden averages 2 to 3 meters but is 6 to 8 meters in the section between flows. Excavation in the lava bedrock will require blasting, but the overburden can be easily removed by power equipment. Canal banks in overburden will require fairly flat excavation slopes and possibly riprap, but very steep to nearly vertical slopes in the lava bedrock should be stable. A detailed geologic map and cross section accompany this report, and further details applicable to bedrock characteristics are given in the engineering geology tables.

Budafoss dam site

40. A dense but closely jointed and fractured flow of Thjorsa lava, Unit 3, is exposed along both banks at this site. The blocky and scoriaceous surface layer common to other areas has been eroded here during past geologic time. The thickness of the lava flow is undetermined since no subsurface work has been done. The flow may be relatively thin, and is underlain by older basalt of Unit 9; the contact zone between these two lavas may be highly permeable. From a standpoint of foundation support, the conditions look satisfactory for any type of dam, but permeability may be high and can cause serious leakage unless special cut-off grouting or other foundation treatment is given. An axis could be reasonably well located here upstream of the falls, which mark the terminal of the lava flow.

Ground moraine covers part of the right bank section below the falls, but would not lie within the construction zone. No other geologic conditions were observed which might pose serious construction difficulties, except the possibility of leakage. A subsurface exploration program will be required, and an intensive investigation will be necessary to locate suitable construction materials. The site is difficult of access in a sparsely inhabited area.

Skard dam site

41. The left bank exposes a smooth surface of jointed and fractured Thjorsa lava of Unit 3 from which the scoriaceous upper crust has been eroded. The right bank is underlain by Early Pleistocene Basalt of Unit 9. Finiglacial beds of Unit 4 are wedged between Unit 3 and Unit 9. The river flows entirely on the Thjorsa lava, since the contact with the older basalt occurs at the water's edge along the right bank. The river here has a fairly steep gradient and rapids have developed. Both banks have gentle slopes and overburden is very thin. The geologic aspects here are similar to those at the Budafoss site. There is no question about adequate bearing capacity of the bedrock for any type of dam, but permeability may be high and leakage could be serious not only in the lave of Unit 3 but also in the underlying finiglacial beds. No studies have been made at this site. Detailed subsurface investigation will be required to determine thickness and permeability of the bedrock and the method and extent of foundation treatment. The construction material situation also requires thorough exploration. This site is located in an inaccessible and uninhabited area. A detailed geologic map and cross sections accompany this report.

Haifoss-Fossa

42. Three tentative sites are located on the Fossa River upstream of the waterfall, Haifoss. The upper and middle sites are considered unfavorable due to very thick overburden. The lower site, at an elevation of 470 meters, is considered suitable for a low dam; the overburden there is thin, firm andesite forms both abutments, and is exposed in the channel. An axis could be readily sited in this section. No exploration work has been done up to the present. A low dam at the lower site would provide storage in a large basin north of the falls, which was occupied by a lake in past geologic time. There is reason to believe this depression, therefore, is underlain by sediments that should be quite impervious. The falls (Haifoss) are cut in sedimentary beds of Unit 7, with two basalt layers of Unit 9 at the top. The sedimentary beds are exposed in the gorge along the base of the falls. In the downstream area from the falls, rhyolite of Unit 11 forms both banks. Much of this rock is pale gray to nearly white, very soft, and easily crumbled by hand. This condition is due to hydrothermal alteration, and the result is a very weak, soft and rotten rock. About 1.5 kilometers below the falls a complex network of dark dikes pierces the weathered rhyolite zone. These dikes range from a few centimeters to 1 meter or more in thickness; they pinch and swell and cut through the rhyolite body at various angles, some being criss-crossed with one another. They provide some stability and greater erosion resistance to the otherwise weak rhyolite mass into which they have been injected. Along the right bank several old

landslides can be seen in a section of the rhyolite belt which lies beyond the range of the dike zone. Palagonite tuff and breccia beds occur still further downstream of the dike belt. Mt. Fossalda is west of Haifoss and southwest of the dam site areas. It is made up principally of gray andesite of Unit 10, capped in places by ground moraine, and with some Moberg beds of Unit 6 cropping out toward the south. Mt. Fossalda is believed to be underlain by several different andesite flows, with interbeds of uncertain thickness and character. These interbeds, however, may be of doubtful permeability, whereas, the massive andesite should be moderately tight and firm. Two types of andesite were observed on the surface; one is very slabby and platy and separates on weathering into plates from 5 to 20 centimeters in thickness, and the other type occurs in fairly large cubical shapes and blocks up to 1 meter in size. Both types are hard and fresh and gray in color. In the event any site on the Fossa upstream of the falls should prove of future interest, a head of 250 meters or possibly more might be developed. The flow of the Fossa, however, is considered too small to have economic justification. However, water might be diverted from the Stora-Laxa by means of a long tunnel. At the lower site, a small auxiliary dam or dike would be necessary west of the site to prevent by-passing the main dam. An intake tunnel would probably encounter firm andesite in the north, but toward the south or southwest it would encounter altered rhyolite. A tunnel in andesite should stand well without support, but the decomposed rhyolite, even if injected by firm dikes, would require support and reinforced concrete lining, and rock bolts would be ineffective. The cliffs and landslide areas in the decomposed rhyolite area will present hazards and very difficult conditions for penstock construction. Foundation conditions for a power plant at about 225 meters elevation should be good. The site areas described are uninhabited and access is very difficult. A wide variety of potential construction materials occur in this area, but exploration is necessary to evaluate suitability.

Sultartangi dam site

43. A low dam is proposed near the mouth of the Tungnaa River to divert its waters south into the Thjorsa River. Subsurface conditions along the left bank have not been sufficiently explored by means of borings to make a reliable interpretation and no work has yet been done at the right bank. It is evident, however, that on the basis of the limited work done, an extensive boring program will be necessary before valid conclusions can be made. The few borings in the vicinity of the axis establish the fact that the left bank is underlain by Thjorsa lava of Unit 3, and that it consits of several flows separated by permeable interbeds of loose sand and pumiceous gravel. These interbeds pinch out and become generally thinner toward the northeast, and they range from 8 to 2 meters in thickness. It would therefore appear, at the left bank, that an axis location for a dam of any kind would be more favorably located as far as possible upstream toward the confluence in order to avert possible serious leakage. Firm and tight basalt of Unit 9 forms most of the right bank area, but near the confluence it is overlain by questionably stable and probably permeable sedimentary beds of Unit 7. Although some conglomerate of Unit 7 is firm and water-tight, the sandstone beds are soft and may be

fairly permeable. Conditions at the right bank will also require investigation if the abutment of the dam will rest in the sedimentary beds of Unit 7. Favorable foundation conditions for the right bank abutment occur in the tight and firm basalt of Unit 9 downstream beyond the contact with the sedimentary beds. Borro soundings along the canal alignment at the left bank show overburden sand and pumiceous gravel to range from less than 1 meter to over 10 meters in thickness. Flat slopes, possibly lining and riprap will be required along the canal banks. The basalt rock of Unit 3 and Unit 9 could be processed to provide rockfill shell, coarse aggregate and filter material; further investigation will be required to locate suitable deposits of fine aggregate and impervious core. The area is fairly easy of access but is uninhabited. Detailed geologic map and cross sections are prepared for this site and are included in this report.

Gljufurleitarfoss dam site

44. In this stretch of the Thjorsa River there is a deep, steep-walled gorge with waterfalls developed by downcutting into a thick series of sedimentary beds of Unit 7 and some basalt beds of Unit 9. At the top of the falls the sedimentary beds are overlain by a few meters of colonnade basalt and underlain by a few meters of blocky basalt. The lower, blocky basalt at the base of the falls is in turn underlain by more sedimentary beds along the water's edge. Thus, a complex sequence occurs here consisting of basalt flows and interbedded sediments, but with the sediments predominating. Some brown Moberg breccia of Unit 6 also occurs further downstream. The basalts are by far the firmest and most durable types in the sequence exposed in the gorge. Although sedimentary beds predominate in the gorge, basalt predominates in the abutment slopes above the gorge. Several glacial terraces have been scoured in the basalt along both banks. Glacial striae on the denuded rock indicate past ice movement was more or less parallel with present stream flow. Overburden brown silt and fine sand of wind-blown origin is quite deep in places along the left abutment slope, possibly as much as 6 to 8 meters, but distribution is uneven and sporadic. Similar conditions are surmised along the right bank. At the falls, a tributary stream entering the main channel from the right bank is deeply entrenched, leaving a narrow, steep-sided spur. The spur appears too narrow to be utilized as part of the foundation and is composed of sedimentary beds, so a tentative axis might be better located at least 500 meters or more upstream of the falls. An axis could be sited in this upstream section for a dam of low to moderate height. In the terraces above the gorge two types of basalt are exposed. One is very platy and separates into thin slabs up to 10 centimeters thick, and the other variety occurs in irregular-jointed blocks some of which reach 1 meter in width. Colonnade basalt also occurs but is less common. All varieties of basalt are hard and fresh and require blasting for removal. The cubical and colonnade varieties would be suitable for rock shell, riprap and crushed coarse aggregate. Fine aggregate and impervious core material will require prospecting, but a wide variety of materials are presumed to occur in the vicinity. Tunneling conditions in the vicinity of this site are believed to be closely comparable with those described in the following section for the Dynkur dam site. The foundation situation in the gorge at

Gljufurleitarfoss, where the bulk of the foundation would rest, requires careful study. No drilling work has yet been done. There is a question whether some of the sedimentary beds have adequate bearing capacity to support a heavy concrete structure, and the abutment conditions in the gorge do not appear favorable for arch dam construction. Leakage may also be a problem. Underseepage could occur along the contact zones between basalt flows, and within some sedimentary beds, and certain beds may be susceptible of piping. A valid understanding of these conditions calls for an intensive subsurface investigation. Extensive scaling and stripping of overburden will be necessary along both banks if the crest of the dam will be higher than the rim of the gorge. The site area is inaccessible and uninhabited.

Dynkur dam site

45. Basalt of Unit 9 is well exposed along both banks between the falls and a small island located about 2.5 kilometers upstream. The island exposes horizontal colonnade basalt which resembles a pile of cord wood, having prisms or columns averaging about 25 centimeters in width. At the left bank, opposite the downstream tip of this island, basalt is exposed in a small outcrop of tilted colonnade basalt in which the individual columns are much wider. About 200 meters downstream from the island, glacial conglomerate of Unit 7 is exposed; it is hard and firm with cobbles up to 5 or 7 centimeters in size, joints are widely spaced, bedding is indistinct, and the rock appears to be tight and impervious. Overhang was seen in a scoured-out area near the water's edge. Three and possibly four separate basalt flows of Unit 9 are believed to underlie the site area from the island to a point downstream near the upper falls. These flows have somewhat different characteristics and appearance. The flow at the island is probably an earlier one which may have flowed over an irregular surface which caused the tilted jointing. Later flows do not show tilted joint columns. Further downstream near the second falls the basalt shows vertical colonnade structure with some cubical joint blocks, and at the right bank three distinct basalt flows are exposed. Horizontal sedimentary beds occur between the middle and lower flows. At the left bank basalt has platy, horizontal jointing with plates about 10 centimeters thick and with joints up to 1 meter apart. Between the middle and lower falls, the sedimentary interbeds , also a part of Unit 9, are exposed along both banks. At the left bank these consist of fairly firm conglomerate, fine-grained dark sandstone, and brown sandstone. The brown beds are friable, weakly cemented, and easily eroded. In this section the river flows in a very narrow and deep gorge, where downcutting is vigorous in the relatively weaker beds. Within this site area, a tentative axis for a dam near the tip of the island appears to be favorable for any type of dam. The foundation support in the basalt rock forming the abutments and channel section would be adequate to support a heavy concrete structure. Although the banks are very steep to nearly vertical along the margins of the river, further away from the river both banks have fairly gentle slopes. This topographic condition would necessitate a long crest length if a very high dam is proposed. The advantage of this site lies in the potentially high head that could be developed, amounting to 100 meters or more within a distance

of 1 kilometer between the island and the middle falls. The island would lend itself useful for diversion during construction. The underground conditions for tunneling appear to be good in the predominant basalt; less favorable conditions would apply in the weak sedimentary beds, especially the brown sandstone, and possibly in the contact zones between basalt flows. The basalt of Unit 9 could be given a tunnel designation of "moderately blocky and seamy," whereas the sedimentary beds would be "stratified" and vertical walls within the sandstones would require support. Bridge-action period would be shortest for the sedimentary beds, and longest for the massive basalt. Excessive overbreak might best be minimized by maintaining a short length of unsupported roof during mining, and by installing support soon after each round is fired. The "full-face" mining method could be used in most rock types, but some very soft sedimentary beds might require the "top-heading and bench" method to improve conditions. Light to moderate inflows can be expected in local areas along both banks. Lining would be required in the sedimentary beds. Rock bolts could be used in the basalt wherever necessary. Little can be stated about underseepage in the foundation and abutments since no exploration work has been done. It seems logical to assume with the prominent joint system and the presence of contact zones and sedimentary interbeds that seepage can occur. Although the geological aspects here appear much more favorable than at Gljufurleitarfoss dam site, a complete understanding of the subsurface conditions and problems will require extensive study by borings and pressure testing. A wide variety of construction materials may be available within a reasonable distance, but this will also require investigation. The site area is uninhabited and inaccessible. A highly generalized geologic cross section is prepared to depict the probable conditions between the Dynkur and Gljufurleitarfoss sites.

Hvanngiljafoss dam site

46. This site is located on the Thjorsa River approximately 1 kilometer upstream of the falls. A thick ground moraine covers the right bank, from which our field observations were made. The very steep bank there is underlain by a firm, well cemented conglomerate and some very weak and friable sedimentary beds, all of which belong to Unit 7. The contact between the fine-grained sedimentary beds and the underlying conglomerate is irregular and undulating, but generally horizontal. The river flows in this section on the conglomerate. A short distance upstream the river has developed rapids, probably due to active downcutting of the overlying weaker beds. Still further upstream the river is wide and the low banks are covered by moraine. There is no question that the conglomerate would make a satisfactory foundation for a concrete or other type of dam along this section but the weaker overlying beds would require strengthening. The conglomerate is so hard and firm that blasting would be required for excavation and tunnels would probably stand well without support but would require lining. It should also prove a useful shell material for rock fill construction, but it is not considered suitable for aggregate. An axis could be easily located along this stretch of the Thjorsa, and the overburden thickness of moraine and soft beds as well as the subsurface conditions could be readily evaluated by means of a few borings. The area is inaccessible and uninhabited.

Nordlingalda dam site

47. Both banks at this site are capped by moraine containing soft sandstone lenses. A basalt layer and volcanic breccia lie beneath the moraine. Both belong to Unit 8. The basalt and the breccia are underlain by conglomerate of Unit 7. The river is flowing on conglomerate. The breccia bed appears to be the least stable and subject to scour and abrasion, and it is permeable. The river is downcutting this bed, and rapids have formed. The conglomerate is very tight and firm and compares with the same bed which occurs downstream at the Hvanngiljafoss site, previously described. Considerable seepage occurs at the contact of the breccia with the conglomerate, and a promenent spring was observed in the contact zone; other springs are reported nearby. It is evident that the breccia is an aquifer and very permeable and that special foundation treatment will be required. From a standpoint of foundation support, all beds except the soft sandstone lenses and possibly the upper few meters of moraine, should be satisfactory for a concrete or rockfill dam. Borings are required to determine whether the moraine and interbedded soft sandstone become firmer with depth, and their thickness. All three types will require blasting for removal. The conglomerate will provide the best tunneling conditions, with a long bridge-action period and low overbreak. Expected overbreak may be greatest in the closely jointed basalt. Lining will very likely be required in all three types. Water table conditions are not known, but perched tables undoubtedly occur which could cause moderate inflows, especially at the contact of the breccia with the conglomerate. Nearby exposures of basalt and conglomerate would be useful for rock shell and riprap; the moraine might be considered for impervious core material but suitability requires testing. Core, filter material and fine aggregate for concrete require further exploration. This site is exceedingly difficult of access and would require considerable road construction. The area is completely uninhabited.

Budarhals dam site

48. This site is located approximately 1.5 kilometers upstream from the cable bridge, or 7.5 kilometers above the confluence with the Thjorsa, on the Tungnaa River. A low rockfill dam is proposed here. The left bank is underlain by a young flow of Thjorsa basalt, Unit 3, whereas the right bank is composed of pillow lava of Unit 6 and an older basalt of Unit 9, which is very dense and shows columnar jointing in the lower part. A ground moraine reaches as much as 5 meters in some places but varies with the undulating surface of the underlying bedrock; and also at the right bank the colonnade basalt becomes inclined in an upstream direction. Further upstream the colonnade basalt is overlain by blocky, irregularly jointed basalt of the entablature type. There is no overburden at the left bank, but the upper 1 or 2 meters of clinker and scoriaceous lava are underlain by progressively firmer rock with depth. The bedrock basalt along both banks could be given a tunnel classification of "moderately jointed" although the joint pattern in the left bank basalt is more irregular and indistinct. Near the axis at the left bank a

large slump block along a vertical joint exposes the wall rock and it was found to be very dense and massive in comparison with the surface 1 or 2 meters of blocky clinker and aa lava. At one place in this slump block the wall has considerable overhang, attesting to a long bridge-action period with low overbreak. The ability of the basalt along both banks to stand on nearly vertical slopes further suggests a long bridge-action period. The rock at both banks definitely require explosives in excavation and the "full-face" mining method could be used in rock of this character. Expected rock loads on a tunnel roof would probably be higher in the columnar basalt and pillow lava of the right bank than in the more massive rock at the left bank; only limited support would be required in the few weaker sections but lining and/or gunnite would seem prudent to minimize leakage. No tunnel hazards are envisioned but moderate local inflows might be encountered from perched tables in the overlying moraine at the right bank. Foundation conditions and bearing capacity are well suited for a dam of any type at this site, but the possibility of leakage at the left bank requires investigation. Also, the thickness and engineering properties of the moraine in the right bank need subsurface investigation. Basalt rock of both banks would make suitable material for shell, riprap, and coarse aggregate after processing. The right bank moraine might be suitable for impervious core, but this possibility needs to be established by further study, together with prospecting for filter materials and fine aggregate. A side-channel spillway could be easily excavated along the left bank for the low dam proposed here. The area is difficult of access and uninhabited.

Kaldakvisl diversion

49. A brief reconnaissance was made along a section of the Kaldakvisl River, which is a tributary to the Tungnaa. Although the site for the dam was not reliably located, geological conditions were observed for a considerable distance where the river flows in a deep and narrow gorge cut into Moberg tuff and breccia of either Unit 5 or 6, and jointed basalt of Unit 8. In many places the Moberg stands on nearly vertical slopes but is easily scoured and eroded. A tunnel is proposed to divert the waters of the Kaldakvisl into the Thjorsa River. The alignment would very likely pierce the Moberg of Unit 6 for the greater part of its length, with some basalt of Unit 8 at the Kaldakvisl end and a short section in older and firmer basalt of Unit 9 at the Thjorsa end. Tunneling conditions in Unit 6 are considered much better than in Unit 5. In this particular area, however, the probability seems great that some soft and weak Moberg beds of a type characteristic of Unit 5 may be encountered along the tunnel line, but the firmer type should predominate. Since the location of the soft zones is unpredictable, the prepared cross section shows the alignment to be in Unit 6. It will be necessary to study this area in further detail in order to estimate the relative amount of weak ground that may be encountered. Further generalizations on tunneling conditions for the respective rock units will be found in the engineering geology tables accompanying this report.

Thorisvatn area

50. Four dam sites were briefly examined in the vicinity of Lake Thorisvatn. Two are located on the Thorisos River, which is a short outlet river from Lake Thorisvatn which contributes its waters to the Kaldakvisl River, and two sites are located on the Kaldakvisl. At the lower site on the Thorisos River the right bank is underlain by Thjorsa scoriaceous basalt, Unit 3, grading into massive basalt at the water's edge. The left bank is capped by ground moraine, underlain by platy andesite of Unit 10 near the water's edge. Both banks are very low. A dam approximately 25 meters high is proposed here to bridge both the Kaldakvisl and the Thorisos, and to do so would necessitate a very long dam of at least 2 kilometers in length. At the upper Thorisos site, near the highway bridge, conditions are similar to those at the lower site except that moraine caps both banks. The Thjorsa lava of Unit 3 is exposed a short distance beyond the moraine at the right bank at the water's edge. The left bank is completely concealed by moraine but the bedrock is believed to be massive andesite. At the lower site on the Kaldakvisl River, the right bank is capped by ground moraine, beneath which is a thin lava flow, possibly of andesite, Unit 10, which in turn is underlain by a few meters of bouldery tillite. These beds rest on palagonite breccia of Unit 6 and extend to river level. The left bank is Thjorsa lava, Unit 3, of the characteristic type with scoria in the upper part, grading into more dense rock beneath. The long, low dam proposed here would have considerable part of its foundation on the Thjorsa lava. The clinker and scoria forming the upper part would require stripping to firm rock; this operation could be accomplished by bulldozer. The underlying basalt would provide an excellent foundation for any size or type of dam, but permeability will be high. A few springs issue at the left bank from what appears to be a contact between two Thjorsa flows. The assumption may be made that underseepage and leakage would soon be sealed by sediment carried by the river, but this assumption requires confirmation. Piping would seem to be a very remote possibility. Foundation treatment by grouting may be both difficult and expensive. The tillite and palagonite breccia on the right bank should prove to be fairly water-tight. At the upper site on the Kaldakvisl, very fine-grained gray andesite of Unit 10 forms both banks. It is very hard and fresh, but it splits or cleaves into very thin plates, some ranging from 1 or 2 centimeters to 10 or 15 centimeters in thickness. Vertical joints are fairly wide in spacing. This horizontal platy structure is very pronounced at the left bank. A low dike of 10 meters height is envisioned here, and from a geological viewpoint it appears to be a very favorable site for any type of construction. The horizontal seams in the rock may permit leakage and seepage, but would probably seal in time with silt from the river; this assumption seems logical but is unproven. Otherwise, foundation treatment by grouting, if required, may be difficult and expensive. There appear to be two andesite flows above river level, but the rock character is similar in both. A tunnel classification for both flows would be "very blocky and seamy." Abundant rock is available in the vicinity for shell, riprap, and coarse aggregate, but other construction materials deposits require investigation.

Thorisvatn tunnel site

51. The tunnel alignment is tentatively located at the northwest edge of Lake Thorisvatn. This area is underlain by Moberg tuff and breccia of Unit 6, and by very platy andesite of Unit 10. Field observation indicates that the Moberg beds have been partly eroded in past geologic time, leaving a highly undulating surface with high hills and low depressions, which was then covered by andesitic flows and possibly injected with andesite. A tunnel in this area connecting the west part of the lake with the Kaldakvisl River will very probably pierce either or both of these two main types of bedrock. The platy andesite, if it is like that exposed in the area, will require support and lining; it is very blocky and extremely seamy, resembling thin-bedded shale or sandstone. The bridge-action period would probably be very short, so that light charges should be used during blasting, followed by rapid back-packing to minimize overbreak. The tuff and breccia beds of Unit 6 resemble those seen in other exposures, with the exception of having some surfaces that have become hardened on exposure, leaving a softer rock core behind this outer "case-hardened" skin. It cannot be assumed that this surface-hardening condition would necessarily apply to all of the Moberg beds, but in this particular area there seems a strong possibility that a much softer quality of rock would be encountered during tunneling operations. In such a case, vertical walls would require support, and lining, to minimize scour and leakage. A portal on the northwest side of the lake will encounter a layer of sand and cobbles many meters thick, underlain by fairly firm Moberg breccia, but the upper 1 or 2 meters of rock may be soft and weathered. Portal for a tunnel along the southwest and south side of the lake will most likely encounter a much thicker layer of sand and cobbles, possibly up to 10 meters or more in some sections along the shore, and will be underlain by a weakly cemented, crumbly type of Moberg tuff-breccia (Unit 5), gray in color, which disintegrates on exposure and is easily eroded. These conditions lead to the conclusion that far better tunnel conditions will be found toward the northwest part of the lake in preference to the southwest and south parts, but in either case, tunneling will be difficult and expensive. Geological mapping and subsurface exploration may prove helpful to estimate the relative amount of weak ground that will be encountered. A generalized geologic map and cross section of the area accompanies this report.

Hrauneyjafoss dam site

52. This site is located on the upper reaches of the Tungnaa River. About 100 meters below the falls on the left bank Thjorsa lava of Unit 3 is exposed, and the right bank is made up of Moberg, Unit 5, consisting mainly of pillow lava. The pillows are not too distinctive and are small, but the structure is similar to that seen at other Iceland exposures; they are irregularly jointed, very closely spaced, and blocky. Although the canyon wall stands on a nearly vertical slope, there is evidence of sliding, slumping and raveling that formed small talus accumulations. The tuff and breccia of the Moberg here is believed younger geologically than at other areas, and is dark gray in color. Unit 5 also con-

tains interbedded glacial sands and gravels and other very fine-grained intercalations, most of which appear compact. The right bank of the river is capped in places by ground moraine reaching a few meters in thickness. At the left bank the Thjorsa lava of Unit 3 has an exposed thickness of about 10 meters, underlain by gray moraine or tillite. It appears similar in characteristics to that seen at the downstream gaging station, where a bluff of Thjorsa lava extends for over 400 meters along the river and exposes in the upper part 1 to 3 meters of scoriaceous clinker, 2 to 3 meters of highly vesicular but fairly massive basalt, grading sharply into 7 or 8 meters of very dense, non-vesicular basalt with plagioclase phenocrysts, with curvilinear joints spaced from 1 to 2 meters apart, and with no horizontal parting. The conditions here at Hrauneyjafoss are very similar, but with some development of colonnade structure, and with Moberg tuff and breccia underlying the colonnade. Foundation conditions here appear to be favorable for rockfill construction, but the possibility of leakage from the reservoir through the Thjorsa beds may require a grout curtain. All rock at this site will require drilling and blasting for rapid and efficient excavation. Moderately light charges should be used in the pillow lava to avoid excessive fragmentation and to lessen overbreak. The Thjorsa lava may be regarded as "blocky and seamy" and the pillow lava as "very blocky and seamy," by tunnel classification, and vertical rock walls may require some support. Rocks such as these could be tunneled by the "full-face" method. Bridge-action period will be much shorter in the pillow lava, due to its irregular and closely jointed condition, than would be expected in the Thjorsa lava, and excessive overbreak can best be reduced by shortening the length of the unsupported roof and installing roof support as soon as possible. Rock bolts may not be useful in blocky rock of this character and probably also may be ineffective in much of the breccia and sedimentary beds of the Moberg. Bolts may be useful, however, in the mose massive Thjorsa which would provide better anchorage, but fairly long bolts may be required. The contact zone with the Moberg tuff-breccia may be highly permeable. The Moberg tuff-breccia of Unit 5 at the right bank and the underlying beds are considered weak tunnel ground. This unit may contain many structurally weak zones and tunnel alignments may break into overlying weak superficial materials. All tunnel sections will probably require lining and locally strong support during the construction period. Construction materials are available at this site, with the exception of fine aggregate and impervious core. The Thjorsa lava would be the most suitable by processing to produce shell, coarse aggregate and riprap. The morainal materials may have possibilities for core but visually they appear quite high in sand and gravel sizes, and too indurated to be suitable. Further investigation in this regard will be required. A geologic map and cross section is prepared for this site.

Tungnaarkrokur dam site

53. This site is also located on the upper Tungnaa, above the Hrauneyjafoss site, and the river here flows in a deep and narrow gorge. The wall rock at the right bank is Moberg pillow lava and

tuff-breccia of Unit 5; the pillows are small in size and closely and irregularly jointed. Patches of ground moraine cap the right bank. Several large cavities are scoured out in the tuff-breccia near water level. The river flows here on tuff-breccia. The walls are very steep to nearly vertical. At the left bank there are three or more separate flows of Thjorsa lava, Unit 3, with thin interbeds. The flows consist of strong, firm basalt, with some well developed colonnade structure with columns as much as ½ meter in diameter. Several springs with copious flows of water issue from the contact of the lower basalt layer and the underlying Moberg tuff-breccia. It is not determined if the spring openings in this highly permeable contact zone, and also the interbeds, may be connected with the groundwater table south of the gorge. If so, the problem of leakage with respect to an axis location in the gorge would appear to be serious. An axis location upstream of the gorge, however, would lessen the problem, but might not eliminate it. A great part of the reservoir will occupy an ancient lake bottom in which the possibility of leakage is remote. An impermeable blanket on the Thjorsa lava between the upstream toe of the dam and the edge of the lake deposits seems advisable to prevent excessive leakage. Foundation support and other geologic conditions, as well as the topographic situation, appear to be favorable for the construction of a rockfill dam at this location in the area upstream of the deep gorge. Arch dam construction might be considered in the gorge, but detailed investigations and studies are imperative to verify this possibility. The strength of the pillow lava and the tuff-breccia at the right abutment to withstand the thrust of an arch is a matter which would require considerable detailed investigation, preferably by in-place testing for shearing strength and modulus of elasticity. Concrete buttressing, grouting, or other means of strengthening the abutment support might have to be employed for arch construction. Rockfill construction in the section upstream of the gorge would alleviate the problem. Tunnel designation for the Thjorsa lavas here can be considered "blocky and seamy," and the pillow lava as "very blocky and seamy." The expected tunneling conditions are believed to be similar to those described for the Hrauneyjafoss site. The Moberg tuff-breccia would probably be classified as "weak, stratified," and similar tunneling characteristics may be assumed as given in the tables accompanying this report. The construction material situation here will require extensive investigation. A large gravel bar downstream of the gorge may supply aggregates for concrete and possibly filter material. Some fine aggregate may be obtained along the shorelines of the ancient lake upstream of the site, and it may be possible to locate suitable core material at higher strandline elevations. The clay exposed along the river edge is considered too "fat" and plastic to be useful, but might be used for blanket material. Prospecting is essential at higher elevations where layers of fine granular materials of suitable composition for core material may occur. The Thjorsa lava, by processing, should be suitable for shell and riprap. The tuff-breccia is considered doubtfully suitable for construction. This area is inaccessible and uninhabited. A geologic map and cross sections accompany this report.

Bjallar dam site

54. Moberg tuff-breccia of Unit 5 is exposed in a high hill along the left bank at this site. It appears typical of exposures seen elsewhere and is brown, friable, thick-bedded, and has widely spaced joints. An assumed tunnel designation for this rock would be "soft, stratified." No pillow lava was noted. The topographic condition here would require an unusually long axis for a dam, probably more than $1\frac{1}{2}$ kilometers in length. From the left bank the right bank can be seen to be composed also of Moberg tuff-breccia, but the right bank was not visited. A tentative axis here would be located upstream of the falls. Between the left and right banks the wide expanse is covered by a Thjorsa lava flow of Unit 3, having the characteristic surface features of scoriaceous blocky masses with local mounds and blisters, and some smooth pahoehoe areas. The bulk of the foundation would, therefore, rest on Thjorsa lava. The foundation conditions appear suitable for rockfill or embankment type construction, but the long axis with the major part of the foundation on highly permeable Thjorsa lava would impose a grouting requirement or other means of sealing to prevent leakage, and this could be an expensive undertaking.

Storisjor dam site

55. This site is located on the upper Tungnaa at the confluence of the Lonakvisl, and the river is flowing in a fairly narrow and constricted section. An extensive storage area could be developed in the upstream portion of the Tungnaa if a dam were constructed here. Massive Moberg tuff-breccia of Unit 5 forms the bedrock of both banks, with some thin moraine at the left bank. Topographic conditions and geologic conditions appear entirely suitable here for the construction of a rockfill dam of moderate height; a high dam would necessitate a very long crest length. The Moberg here is mainly a dense type of volcanic tuff containing small fragments of basalt and is interlaced with a complex network of basalt injections. Although the rock is dense, it appears to be more friable than in other exposures, possibly because it is younger geologically and the alteration process in the palagonite has not proceeded to the point where the voids in the rock are filled by weathered products. It therefore seems that tunnels in rock of this character will require reinforced concrete lining and full support during construction. Bedding or stratification is indistinct and joints are widely spaced. Most of this rock appears fairly permeable, but some zones in it may be better cemented and could have a lower order of permeability. This site appears to be worthy of further study, but thus far no exploration work has been done. The site area is inaccessible and uninhabited; it was visited by helicopter and time limitations did not permit a more detailed evaluation of ground conditions.

Langisjor dam site

56. This site is located on the Utfall River which discharges from the northeast part of Lake Langisjor through a narrow gorge. Lake

Langisjor receives its glacial melt water from the southwest part of Vatnajokull, the largest glacier in Iceland. A dam at this location in the narrow gorge would serve the purpose of checking the outflow from the lake, thereby raising its level. It could, in essence, be considered a regulating dam. The gorge is only about 35 meters wide. Moberg breccia with pillow lava, Unit 5, is exposed in the walls of the gorge and in the vicinity along the lake shore. The upper slopes of both banks are covered by talus and scree of Moberg materials, some of which appear to be quite thick at the right bank and would require stripping to prevent sliding. The breccia beds are compact and contain small inclusions of finely vesicular basalt. The pillows of the pillow lava are of fairly small size and because of these conditions it might be presumed the foundation beds will have a much higher permeability than normal for Moberg materials. Diversion during construction of a dam in the gorge would be a relatively simple procedure by driving a tunnel through the narrow ridge along the left bank, or it could be done by a cut. In the event building of a dam here would raise the level of Lake Langisjor to some point higher than its source at the glacier edge, it may result in some overflow toward the east side of the glacier and from there into a braided network of streams which flow from the glacier edge toward the southwest. Tunneling anywhere along the south and west sides of the lake will encounter Moberg tuff-breccia and pillow lava of Unit 5, and both types are considered permeable. Tunneling in the tuff-breccia would probably require reinforced concrete lining throughout and adequate support during the construction stage; grouting and rock bolts might not be effective. The pillow lava will be somewhat better ground but will require lining and probably support in fissured zones. The construction material situation here appears to be critical in that tuff-breccia and pillow lava are the predominant bedrock types in the area and both have doubtful suitability for construction purposes. Although the pillow lava might be processed for rockfill and aggregate. it is so closely interlayered with tuff-breccia that it might be difficult or even impossible to economically recover. A thorough geologic reconnaissance will be required in the vicinity to locate core material and other deposits for construction but it appears that they may be located at a considerable distance from the project area. This site is completely inaccessible and the area is uninhabited; it was reached by helicopter during this investigation.

CONCLUSIONS

57. Geological conditions in the Hvita and Thjorsa Basins are considered generally quite favorable for dam construction.

58. The basalt lava bedrock which predominates at many sites is relatively fresh and non-weathered. Arctic climate has had very slight chemical effect upon the young geologic formations. Surface exposures show splitting and spalling by freezing and thawing, but this condition does not extend very deep. Hardness and toughness of the basalt bedrock are therefore unimpaired for engineering work.

59. Faulting, folding, and other structural deformation is of minor importance in the Hvita and Thjorsa Basins. Most of the stratified rocks, and the lava flows, are very gently dipping or nearly horizontal in attitude. This condition makes possible a greater horizontal projection of boring and other subsurface data than would otherwise be the case.

60. Foundation support at most sites appears very favorable. Nearly all bedrock types have an entirely adequate bearing capacity to support the heavy design loadings that may be placed upon them, and subsidence seems a remote possibility. The exceptions where foundation conditions appear doubtful in this respect are discussed in the report.

61. Although foundation support is adequate, underseepage can take place in the highly permeable interbeds and contact zones between the lava flows. Reservoir leakage is also a possibility at a few sites. The complex sequence of events which have brought one lava flow upon another, intermingled with glacial deposits, all of which pinch out or terminate at unknown points beneath the surface makes investigation by borings imperative.

62. Permeability investigations are highly important at all sites. Leakage and seepage problems are probably not too severe for solution, but the necessity for extensive grouting or other treatment will add greatly to the project cost. Natural sealing will take place by deposition of sediments carried by the rivers to reduce leakage and seepage, and in some cases this may be completely effective in a relatively short time. To what extent this process will be effective in other cases, such as open-work-gravel interbeds, requires further study.

63. Rock of excellent quality is available at most sites for shell material, riprap, and coarse aggregate, if crushed and processed. The situation appears unfavorable at many sites with regard to deposits of impervious core material and fine aggregate within a reasonable haulage distance. An intensive exploration program, similar to that conducted at Burfell, will be required at the majority of sites in both basins.

64. Some sources of concrete aggregates in Iceland carry mineral constituents that are reactive with high-alkali cement. The possibility of concrete disintegration resulting from this reaction can be averted by precise field and laboratory investigation, and adopting whatever corrective procedures may be required.

RECOMMENDATIONS

65. Geological mapping and subsurface investigation should be continued at all sites where construction is definitely planned. This work should be done by or under the guidance and direction of the engineering geologist.

66. Water-pressure testing should be conducted in the borings at all contact zones, interbeds, and sections of no core recovery, in order to evaluate permeability, leakage and seepage conditions, and grouting requirements.

67. Some hydroelectric projects proposed in the Hvita and Thjorsa Basins will involve considerable tunneling. Since very little is known by actual experience with tunnel conditions and problems in Iceland as a basis for cost estimates, it is recommended that exploratory adits and tunnels be driven at sites where project planning designates a critical need for such basic data.

68. An intensive exploration for construction materials should be made in the early stages of development work. Experimental studies should be made of crushing characteristics, fragmentation, and of suitability of the various materials for the desired use. Some attention should be given to the possibility of producing coarse and fine aggregates and filter material by crushing and processing the bedrock at the site.

69. An investigation should be made of morainal and similar deposits to determine their suitability for impervious core material. This investigation should consider the method of excavation required, the workability of the material and ease or difficulty of placing it in the core zone, and permeability.

70. Rock-mechanics testing is recommended, especially for shear and modulus of elasticity, at sites where topographic conditions are favorable but where abutment rocks are composed of doubtful types.

71. Alkali-aggregate reaction investigations should be started in an early stage of the work in order to have the results available for final design and construction.

72. During future underground construction, especially tunnels, every effort should be made to carefully log and map the various rock types encountered, to describe the conditions and problems, and to correlate with rock-mechanics and boring data.

73. The Engineering Geology Map and Tables presented in this report should be expanded and extended as additional data become available, in order to provide some basic data for preliminary planning of future projects in other areas of Iceland.

SUPPLEMENTARY NOTES

Inspection Trip to Burfell Dam Site

A short reconnaissance of the site was made on 3 June, 1965, with Messrs. Tomasson and Sigurdsson of the State Electricity Authority, and Mr. Stig Angelin of the United Nations Special Fund. The purpose of the trip was to observe geological conditions and problems, and the character of the various construction materials proposed for use in the construction of the rock-fill dam.

Geologic conditions at this site have proven to be more complex than at first envisioned, but the extensive subsurface exploration work completed thus far is thorough and well justified for a project of such importance and magnitude. The Burfell area is perhaps the first example of its kind in Iceland where such intensive subsurface investigations of a large area have been made. It can be expected that some future projects in other parts of Iceland may, to some extent, encounter complex geologic conditions that will require a proportionate amount of subsurface work.

It is proposed to use moraine for impervious core, basalt from the canal excavation for shell, and massive basalt for crushed aggregate. Representative deposits of each type were field inspected. All appear suitable for their proposed uses, and have been carefully sampled and tested.

Regarding the moraine, a long exploration adit was driven which encountered a compact, dark gray silty sand with 4 to 5 percent of clay and some gravel and cobbles. Some of it in the natural state is hard and firm and requires blasting, but on exposure it breaks down and becomes very soft. During construction, it may be necessary to allow a sufficient time after excavation to expose the material and permit it to soften. Otherwise, it might have the character of rock and would not serve well the purpose for impermeable core material.

Whatever rock deposit from which aggregate will finally be produced by crushing justifies a thorough study to verify potential reactivity with high-alkali cement. It is well known that certain minerals such as opal and others of volcanic origin can cause concrete deterioration by chemical reaction within the concrete mass when used with cements having a high content of Na_2O and K_2O. These deleterious mineral types occur in Iceland. Thorough testing is justified, preferably by the standard expansion-bar procedure of the ASTM. This method generally takes much longer, but is considered more reliable than the rapid chemical methods.

The character and size of blocks obtainable from canal excavation for shell material will best be known only during construction. The borings that have been made may not supply useful data on fragmentation as affected by joint pattern and spacing. It would seem prudent, therefore, to use careful control during blasting in the canal to avoid excessive shattering of the rock.

Bjarnalaekur Pond is now a dry lake bed that will be used for pondage from the intake canal before the water enters the approach canal to the power intake and pressure tunnel. The reason this lake is now dry is attributed to filling by many meters of pumice and lapilli from Mt. Hekla, and the present pumice cover is about 10 meters above the old lake level. Because the pumiceous materials are commonly highly vesicular and spongy a certain percentage will float for long periods and will eventually migrate to the power intake and pressure tunnel. If this process continues for a long period of time, the removal of the floating particles could deepen and increase the storage capacity of the pond.

Andakill Dam and Power Plant

Evidence of alkali-aggregate reaction was observed here. The characteristic map-cracking pattern is pronounced in many sections, with gel formation, but no pop-outs were seen. Exposed areas subject to scour in the spillway are severely abraded and other areas have deteriorated by freezing and thawing. The local aggregate that was used shows thin films and veinings of opal and mixtures of opal and chalcedony. Conditions since construction in 1948 do not, on the whole, appear too severe but considerable maintenance and patching has been necessary.

Gonguskardsa Power Plant

No evidence of alkali-aggregate reaction was found at the power plant and outlet works. The dam was not visited.

Skeidsfoss Dam

Attention was first called to leakage in slide material at the right bank of this concrete-buttress dam, in 1947 or 1948. In 1964 there was presumed to be an increased amount. During this long interval, it might be presumed that piping could have occurred, if the slide materials were susceptible to piping. During this inspection on 9 June 1965 the leakage water was quite clear. The slide material through which the water is leaking consists of angular and blocky fragments of basalt of various sizes, mixed with fines. Leakage probably occurs along channels where the fines have been leached. Leakage measurements will be resumed again and will be continued over a period of time to observe if an increase continues, or if the water becomes cloudy. After a sufficient period, if the observations indicate little change in the amount of leakage and the water remains clear, it might be assumed that conditions have come to equilibrium. Unless detailed subsurface work is done by borings to locate the main path or paths of percolation, a procedure which at present does not appear justified, it seems extremely doubtful if the slide material could be successfully grouted. Bentonite might be used as a retardant on the upstream side where leakage originates. No evidence of alkali-aggregate reaction was observed at the concrete dam and power plant.

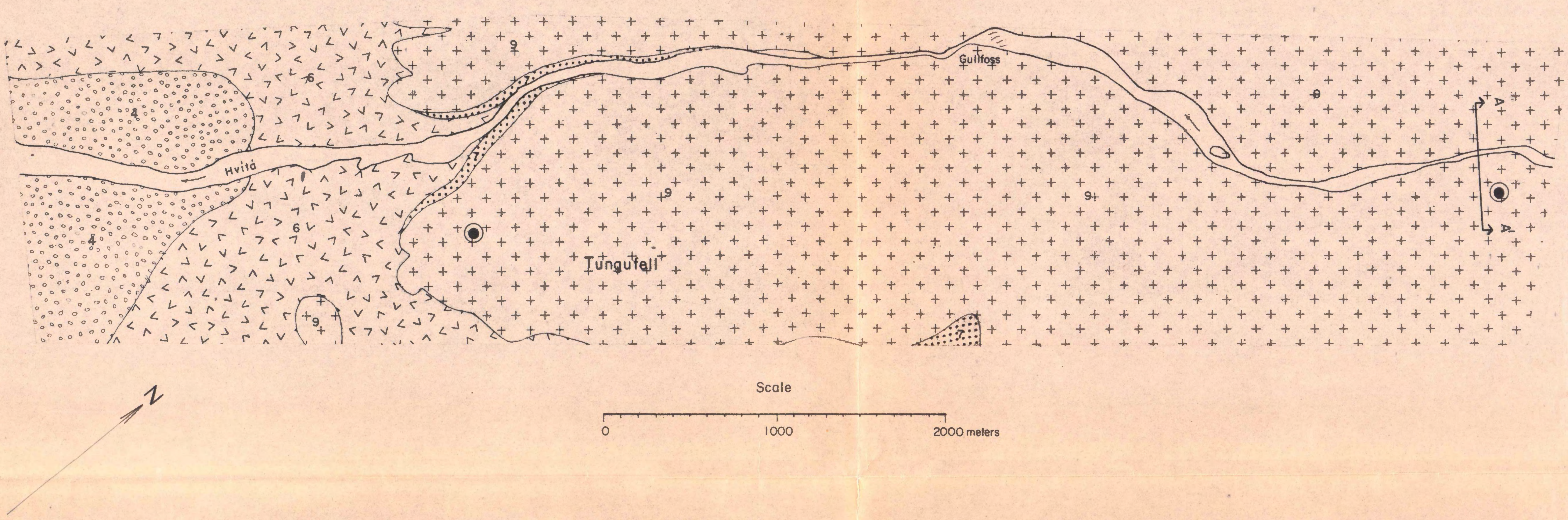
Laxa (Upper) Dam Site

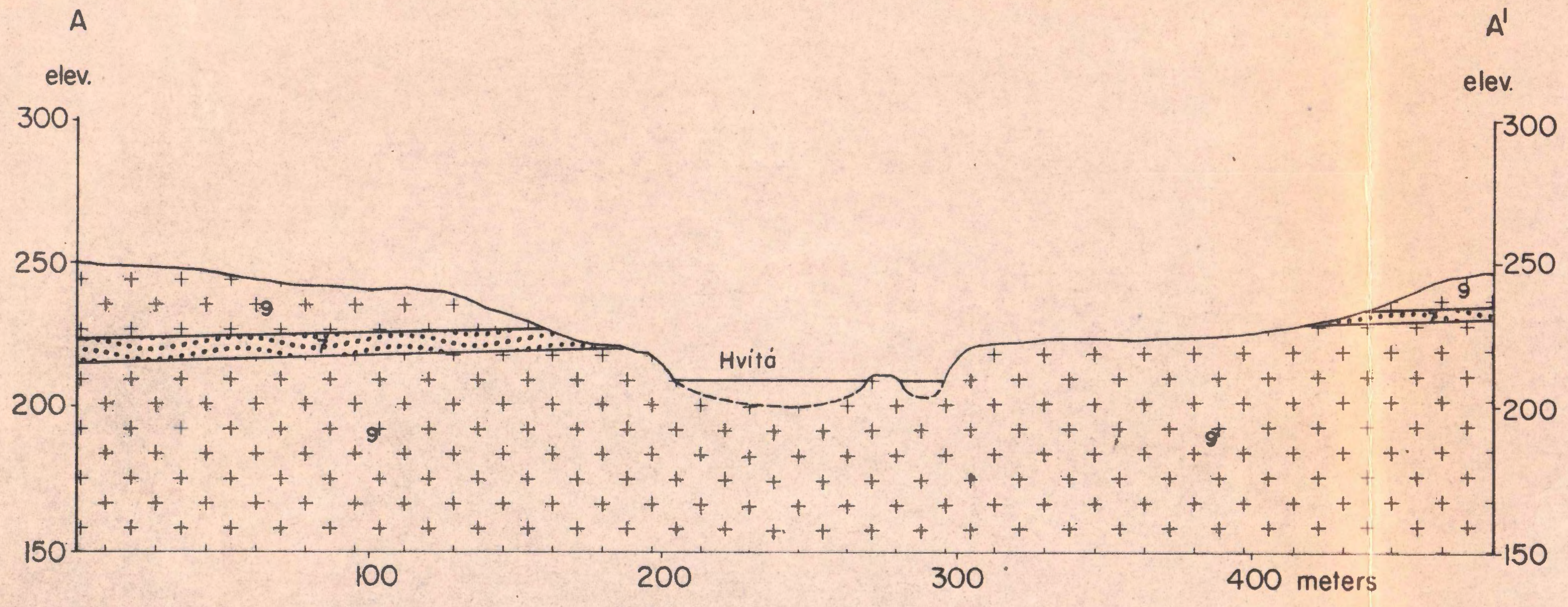
The proposed site looks excellent from a geological standpoint for any type of dam. A rockfill type is being considered. Firm basalt forms both abutments and the channel section. Either bank could be used for tunnel diversion and intake works. The rock appears excellent for shell material. Local sand and gravel for aggregates are available near the site. Samples of moraine and volcanic ash were taken for testing to determine their suitability for impervious core materials. Excavation was made by a power-driven backhoe to a depth of about 1 meter; below this depth the moraine became too hard to be removed. In this area the moraine is dark gray and consists of silt and sand with some cobbles and a high content of small gravel; it appears to be permeable. The volcanic ash, on the other hand, is brown and very fine-grained, with a low unit weight. It was easily dug by shovel. Blending of these two materials will be undertaken in the laboratory.

Dettifoss Dam Site

Two large waterfalls occur in this section of the Jokulsa River, which is one of the very large rivers of Northern Iceland. The upper waterfalls, Selfoss, was not visited, so observations were confined to the left bank of the lower or Dettifoss area. A large rockfill dam is and has been under consideration in view of the tremendous power potential that could be developed. Basalt of the cube-jointed and colonnade types are well exposed along both banks in the gorge. The rock is hard and firm, but it has wide, open joints and some shows a horizontal, platy character. It would be excellent for rock shell material and riprap. The firm rock exposed at Dettifoss is reported to extend upstream to the upper falls at Selfoss; in such a case, the foundation support can be considered excellent. A long dike would be required at the left bank to prevent impounded reservoir water from overflowing into an old channel of the river. This dike would also rest on hard, firm basalt. Diversion and spillway would probably require a tunnel since a suitable side-channel spillway location may not be topographically practical. There was insufficient time to explore for construction materials; morainal deposits are known to occur in the area and might be considered for core material. The Jokulsa River carries a high amount of sediment, based on its appearance, and there can be some question regarding rapid siltation impairing the life of the reservoir if a dam is constructed in the area. Construction would be expensive in view of the great length of dike required along the left bank to prevent overflow. Otherwise, conditions appear good for any type of dam. The Dettifoss site is worthy of further study in view of the power potential.

-0-0-0-0-0-0-0-0-0-





LEGEND

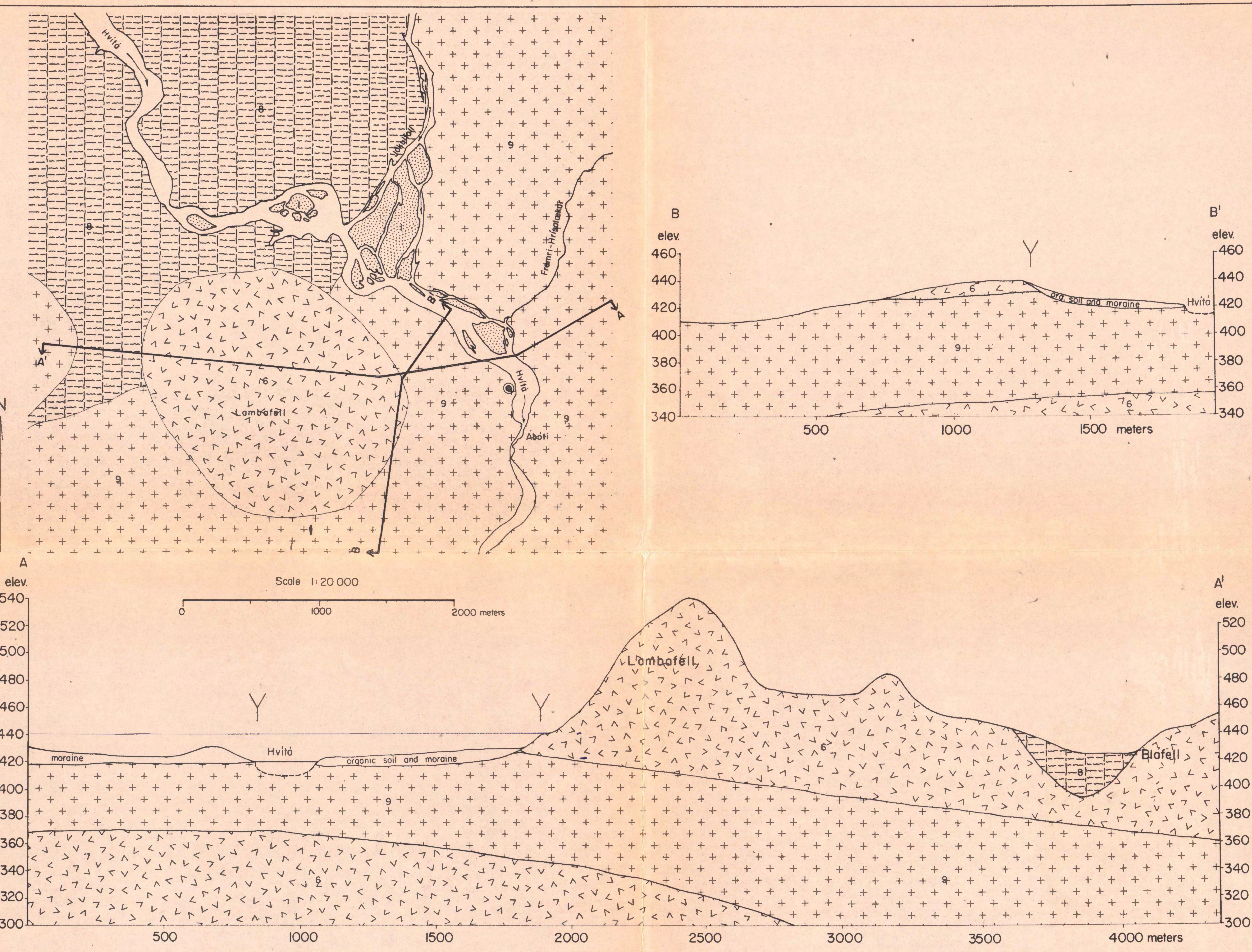
LOCATION OF CROSS SECTION

◉ APPROXIMATE LOCATION OF DRILLHOLES

FOR EXPLANATION OF MAP UNITS SEE FIG. 2

H-9 TUNGUFELL GEOLOGIC MAP AND CROSS SECTION
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND, REYKJAVIK, ICELAND

Fig.4



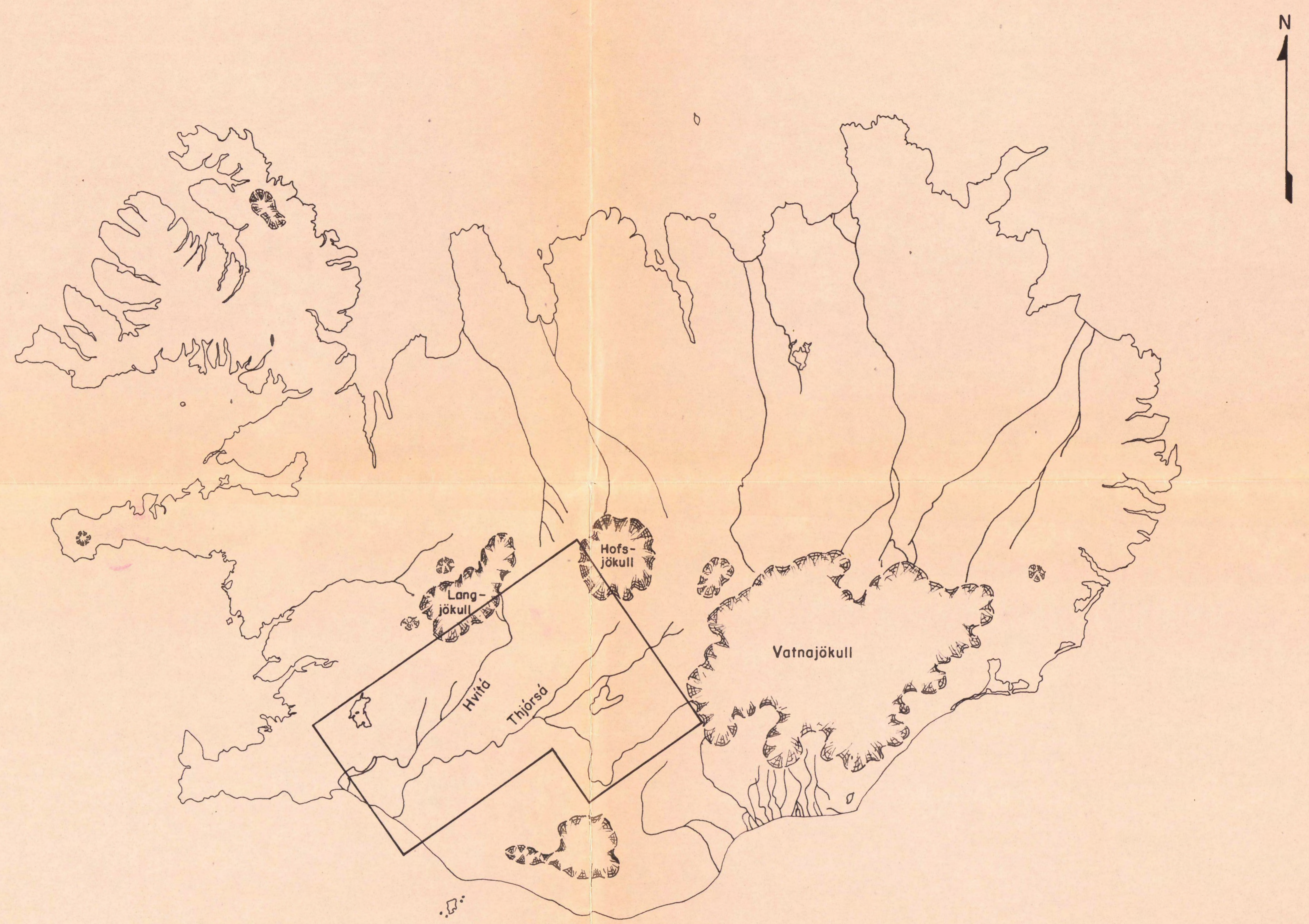
LEGEND

- SECTION TURNS
- LOCATION OF CROSS SECTIONS
- ◉ APPROXIMATE LOCATION OF DRILLHOLE

FOR EXPLANATION OF MAP UNITS SEE FIG. 2

H-13 ÁBÓTI GEOLOGIC MAP AND CROSS SECTIONS
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND REYKJAVIK, ICELAND

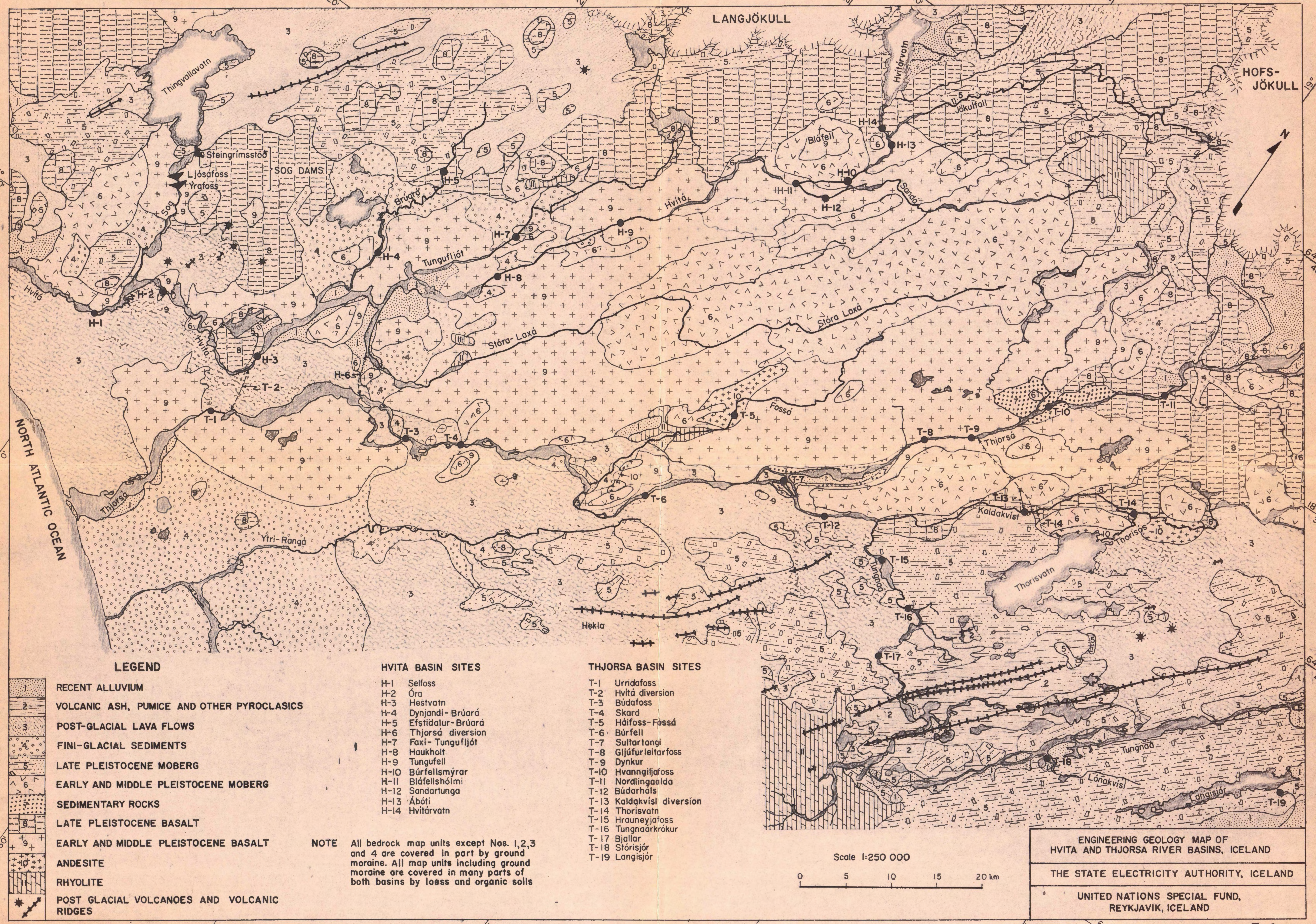
Fig.6



KEY MAP

THE STATE ELECTRICITY AUTHORITY, ICELAND

UNITED NATIONS SPECIAL FUND.
REYKJAVIK, ICELAND



LANGJÖKULL
HOFS-JÖKULL
Thingvallavatn
Steingrimsstöð
Ljósafoss
Írafoss
SOG DAMS
Sog
Hvítá
Brúará
Tungufljót
Stóra-Laxá
Stóra Laxá
Fossá
Thjorsá
Sandá
Jökulfall
Hvítárvatn
Bláfell
Kaldakvísl
Thorisós
Thorisvatn
Tungnaá
Lónakvísl
Langisjór
Ytri-Rangá
Hekla
NORTH ATLANTIC OCEAN
N
LEGEND
RECENT ALLUVIUM
VOLCANIC ASH, PUMICE AND OTHER PYROCLASICS
POST-GLACIAL LAVA FLOWS
FINI-GLACIAL SEDIMENTS
LATE PLEISTOCENE MOBERG
EARLY AND MIDDLE PLEISTOCENE MOBERG
SEDIMENTARY ROCKS
LATE PLEISTOCENE BASALT
EARLY AND MIDDLE PLEISTOCENE BASALT
ANDESITE
RHYOLITE
POST GLACIAL VOLCANOES AND VOLCANIC RIDGES
HVITA BASIN SITES
H-1 Selfoss
H-2 Óra
H-3 Hestvatn
H-4 Dynjandi-Brúará
H-5 Efstidalur-Brúará
H-6 Thjorsá diversion
H-7 Faxi-Tungufljót
H-8 Haukholt
H-9 Tungufell
H-10 Búrfellsmýrar
H-11 Bláfellshólmi
H-12 Sandartunga
H-13 Ábóti
H-14 Hvítárvatn
THJORSA BASIN SITES
T-1 Urridafoss
T-2 Hvítá diversion
T-3 Búdafoss
T-4 Skard
T-5 Háifoss-Fossá
T-6 Búrfell
T-7 Sultartangi
T-8 Gljúfurleitarfoss
T-9 Dynkur
T-10 Hvanngiljafoss
T-11 Nordlingaalda
T-12 Búdarháls
T-13 Kaldakvísl diversion
T-14 Thorisvatn
T-15 Hrauneyjafoss
T-16 Tungnaárkrókur
T-17 Bjallar
T-18 Stórisjór
T-19 Langisjór
NOTE All bedrock map units except Nos. 1,2,3 and 4 are covered in part by ground moraine. All map units including ground moraine are covered in many parts of both basins by loess and organic soils
Scale 1:250 000
0 5 10 15 20 km
ENGINEERING GEOLOGY MAP OF HVITA AND THJORSA RIVER BASINS, ICELAND
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND, REYKJAVIK, ICELAND

Fig 2

ENGINEERING GEOLOGY TABLE

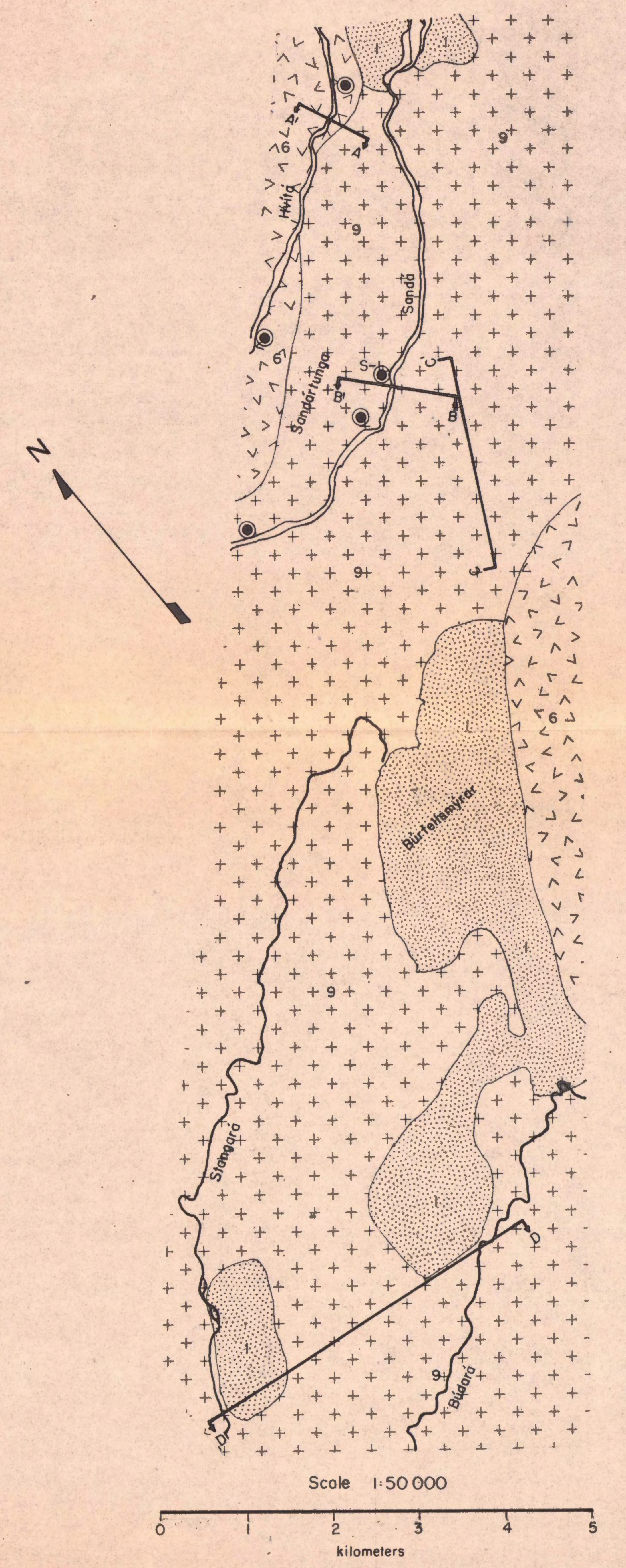
To Accompany Engineering Geology Map of Thjórsá and Hvítá Basins, Iceland

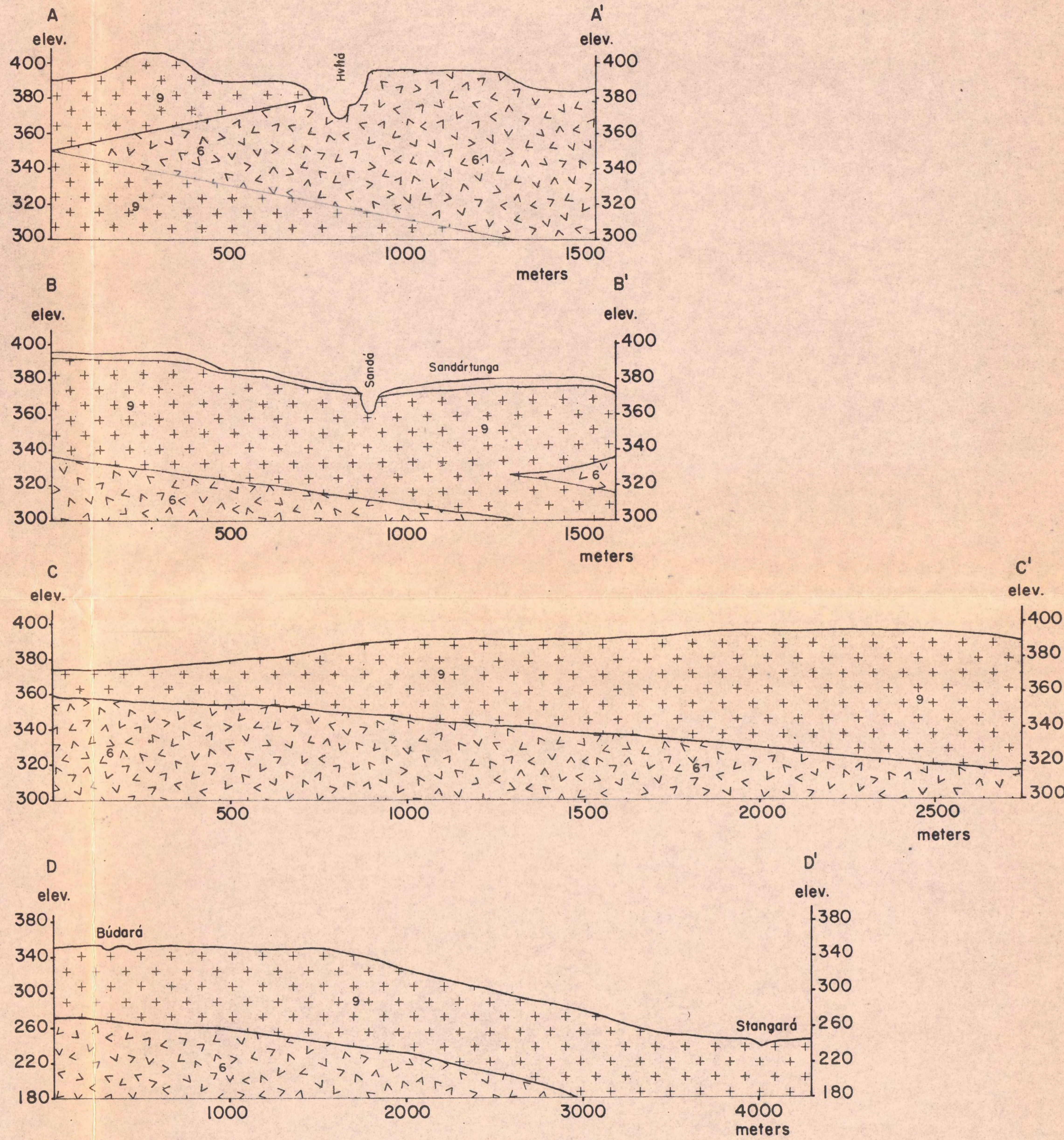
UNIT	NAME	DESCRIPTION	EXCAVATION CONDITIONS	FOUNDATION CONDITIONS	TUNNELING	CONSTRUCTION MATERIAL SUITABILITY
1	RECENT ALLUVIUM Chiefly river and lake sands, some fine gravel	River and lake deposits in the Thjorsa and Hvita Basins have a wide range in gradation. Lake deposits are fine sand and silt, some small gravel. Lower reaches of Thjorsa and Hvita carry gravel but sand predominates in banks and floodplains; in highlands both flow on bedrock or shallow overburden with cobbles and boulders locally. Tributary streams with steep gradients have coarse gravel and cobbles; many flow on bedrock or shallow overburden with mixed sand and gravel in banks. Gravels consist mainly of hard basalt, some palagonite, with minor andesite, white and red rhyolite. Some larger gravels and cobbles are vesicular; most particles are sub-rounded. Sand grains are usually sharp and angular, consisting mainly of volcanic glass fragments.	Earth excavation; all deposits can be easily excavated by hand tools and power equipment above the water table. Thickness of most deposits varies from less than 4 to more than 20 meters in a few areas. Excavation slopes of 1 : 1 may be required for stability. Canals require lining to prevent slumping, scour and leakage.	Fair to good foundation support for light structures, but probably poor for heavy design loadings on fine-grained alluvial sand; stripping to firm bedrock would normally be preferred where deposits have shallow thickness. Safeguards are required against erosion and possible flooding in some areas.	Alluvial deposits in this map unit are not considered here for tunneling at the main projects proposed in the Thjorsa and Hvita Basins on account of their relatively shallow thickness. Portals of tunnels, however, if driven would require full support and lining, and most operations would be below water table.	Most sand and gravel deposits along the Thjorsa and Hvita Rivers appear poorly graded for coarse and fine aggregates for Portland Cement concrete, and require processing or blending with crushed stone for satisfactory gradation. Gravel is lacking in many deposits and sand is commonly deficient in both coarse and fine sizes. Nearly all sands contain reactive minerals; unless corrective measures are taken, serious disintegration of concrete may result by reaction of these minerals with high-alkali cements.
2	VOLCANIC ASH, PUMICE AND OTHER PYROCLASTICS loose, uncemented	Volcanic ash predominates; usually brown, and containing pumice fragments, lapilli and other ejecta blown from explosive eruptions of Mt. Hekla; consists of minute glassy fragments and dust, forming layered deposits up to tens of meters thick near vents. Pumice and other fragmental ejecta of coarser size form uncemented beds or sheets of varying thickness up to 10 or more meters; color creamy white or light gray, some brick red or black, with individual fragments up to 30 centimeters but most less than 2 or 3 centimeters in size; fragments are extremely cellular, frothy, and will float; distribution is sporadic; many deposits are common in old glacial lake beds and depressions.	Earth excavation; easily removed by hand tools and power equipment. Excavation slope stability varies with compaction, from nearly vertical in some ash deposits to 1 : 1 or less, in loose pumice. Most materials are highly permeable, with rapid downward percolation; deposits in lake beds and depressions favor development of underlying perched water tables.	Most beds have low bearing capacity and are easily eroded. They would probably provide inadequate support for heavy design loadings and, in most cases, will require stripping to firm bedrock. Drainage is good, but erosion protection will be required in all cases. Canals in this unit will require lining.	It is unlikely that tunnels would encounter sufficient thickness of this unit in the project areas, but if driven, they would require support and lining. Heavy inflows may be encountered in rock units beneath some thick pumice accumulations in large depressions, where perched water tables are likely to occur.	The materials in this unit are considered unsuitable for engineering construction except possibly for manufacture of concrete block.
3	POST-GLACIAL LAVA FLOWS Mainly basalt, some andesite, with open joints, fractures and cavities	Very extensive unit in lower Thjorsa and Tungnaa area. Comprises several lava flows each ranging from a few to 20 or more meters of dark gray basalt with small white feldspar phenocrysts. Flows are congealed tabular bodies with dissimilar characteristics and thicknesses, with younger flows overlying some earlier flows. A boring in this unit will pierce one flow and possibly seven recognized flows, and will be underlain by either one of Map Units 4 to 11 and by morainal deposits. Interbeds between flows vary in composition; many are highly permeable; thickness ranges from less than 1 meter to several meters. A surface crust on most flows consists of rough, jagged blocks and loose fragments of scoriaceous, froth-like rock, becoming more massive and less vesicular at depth and grading to dense, fine-grained rock. Columnar jointing is well developed in the massive underlying rock, commonly forming five or six-sided columns usually less than 1 meter wide with horizontal parting. Joints and partings are commonly open and unfilled.	Rock excavation, requiring drilling and blasting, except the surface of scoria and slag which can usually be removed by bulldozer. The underlying massive beds require blasting, and occasional mushroom-shaped masses of vitrified rock at the surface may require blasting. Surface irregularities, cavities and depressions are filled with wind-blown or water-borne sand. Excavations will stand on very steep to nearly vertical slopes.	Except in the surface 2 or 3 meters of slag and clinker, foundation support of the underlying massive rock is excellent for all heavy structures. Some interbeds with high permeability may permit excessive underseepage. Open joints in massive basalt also permit leakage and seepage. Borings and pressure-testing are imperative at all sites to evaluate subsurface conditions.	Rock-tunneling conditions prevail; rock designation is moderately blocky and seamy. Vertical walls may require permanent support, but little or no side pressure is expected. No hazards are anticipated; light to moderate surface seepage common, with strong inflows in some interbeds. Full-face mining method should be suitable in solid rock; heading-and-bench, or top-heading mining may be more practical in some thick interbeds. Vertical joint conditions can induce downward slippage. Bridge-action period variable but limited; for closely jointed rock possibly less than one excavation cycle, *requiring roof* support close to working face; in severe conditions, careful backpacking and wedging soon after detonation will minimize overbreak.	Massive bedrock underlying surface clinker is excellent for most construction use. Quarries could be easily developed, but borings are essential to determine thickness and characteristics of individual flows. Jointing conditions will govern size of blocks obtainable for riprap; light riprap is normally obtainable, but joint spacing is too close in some flows to obtain suitable heavy riprap or cyclopean riprap. Excellent source of rock shell material and of crushed coarse aggregate.
4	FINI-GLACIAL SEDIMENTS (Glacial river and lake deposits) -silt, sand and gravel, friable to firm and compact	This unit is a complex sequence of horizontally stratified beds and lenses composed of mixed clay, silt, sand and gravel, having an over-all thickness ranging from a few meters to several tens of meters. In the Thjorsa delta the beds are mainly friable, loose sands with some pea gravels, many of which show pronounced cross-bedding. In the Hvita areas the beds are more compact and fine-grained, mainly silt and clay. Lake deposits in the highlands are also very fine-grained and compact, and some eskers occur there containing mixed sand and gravel.	Mainly earth excavation, but some firm beds may require blasting to facilitate rapid removal. Nearly vertical slopes should be stable for short periods in shallow excavations but slumping will eventually occur so that 1 : 1 slopes may be required for stability. Canals will require lining in these easily scoured and eroded materials.	Fair to poor foundation support. Some beds may be compressible. Bearing capacity is probably inadequate to sustain heavy design loadings such as power plants or equivalent structures; stripping to firm bedrock is advisable wherever possible. All foundations need protection against erosion and undermining. Unsatisfactory foundation for high concrete dams; some firm beds of adequate thickness may be suitable for rock fill or embankment dams and dikes. Permeability is high in coarse-grained beds, and very low in some compact, fine-grained layers. Conditions in most beds are probably unsuitable for grouting.	Earth tunneling conditions predominate, but some firm beds may require blasting. Bridge-action period varies from extremely short in loose, saturated sands to longer in compact lake sediments. Unsupported roof sections may not stand long. Operations can encounter strong inflows through coarse-grained beds; squeezing and swelling ground may be found in some lake deposits. Mining method depends on character of ground. Portals require full support and protection against erosion. Lining will be essential in nearly all tunnel sections. Rock bolts are impractical in materials of this character.	Construction materials may be available within this unit, but exploration, sampling and testing are required to evaluate them. Some deposits in the Thjorsa delta may be suitable for fine aggregate, blending sand and filter materials. The fine-grained deposits in the Hvita area and in some lake beds may provide materials for impervious core. Lava flows cover much of this unit and many beds can only be observed in canyon walls; some may be encountered during tunnel operations. Eskers in highland areas might supply coarse and fine aggregates for concrete but their location and suitability need investigation.
5	LATE PLEISTOCENE MOBERG Volcanic tuff, breccia and pillow lava, friable and poorly cemented	This unit consists of three rock types closely associated in origen but having dissimilar properties. The principal types are volcanic tuff, volcanic breccia, and pillow lava (basalt). Tuff and breccia are stratified and grade into one another; color usually brown but sometimes gray; individual beds range from a few centimeters to several meters in thickness. Pillow lava is basalt with a structure resembling pillows or sacks of various sizes resting upon one another, with spaces filled by palagonite. Most tuff and breccia beds are porous, weakly cemented and friable, and pillows can often be broken along open seams and fractures into small blocks. Soft sand lenses are also found. This unit is distinguishable from Unit No. 6 mainly by poor cementation, higher permeability and abundant soft sand lenses.	Part earth and part rock excavation. Some tuff and breccia beds can be removed by bulldozers and power tools, whereas other beds require blasting. Blasting normally required in pillow lava except where pillows are small, badly shattered, and poorly cemented. Nearly vertical excavation walls may remain stable in flat-lying tuff and breccia beds but sliding and slumping can occur where beds are steeply inclined. In pillow lavas walls may stand on steep slopes but will slack and ravel forming thick talus.	Poor to fair in tuff and breccia; weak beds and zones are sporadic and unpredictable. Confined compressive strength probably adequate in most cases for heavy design loadings except soft sand lenses. Permeability is moderate to high. Pressure foundation grouting may strengthen badly fissured tuff and breccia and seal joints and fractures in pillow lava. Pillow lava provides good foundation support, but permeability may be high. Many sites are suitable for embankment dams, but conditions for concrete dams require detailed subsurface exploration.	Mixed rock and earth tunneling conditions. Bridge-action period may range from a few hours to many days or even weeks, depending upon structural conditions and rock character. Heavy roof pressures can cause high overbreak unless unsupported sections are quickly supported after detonation. Vertical walls in some soft beds may require permanent support; lateral pressure is anticipated where steeply dipping beds occur and in defective rock zones. Occasional heavy inflows and caving ground conditions can be anticipated. Mining method will vary with type of ground, but full-face may be suitable under favorable conditions; less favorable ground may require top-heading or heading-and-bench methods. Tunnels require lining and portals require full support and erosion protection.	Tuff and breccia beds are doubtfully suitable for rock shell, and are too friable for aggregate; some pillow lava, however, should be suitable for both purposes. Rock of better quality is usually available within reasonable distances of many sites, and would be preferred to most materials in this unit.

ENGINEERING GEOLOGY TABLE

To Accompany Engineering Geology Map of Thjórsá and Hvítá Basins, Iceland

UNIT	NAME	DESCRIPTION	EXCAVATION CONDITIONS	FOUNDATION CONDITIONS	TUNNELING	CONSTRUCTION MATERIAL SUITABILITY
6	EARLY AND MIDDLE PLEISTOCENE MOBERG Volcanic tuff, breccia and pillow lava, firm and compact.	In composition and appearance this unit is very similar to Unit No. 5, and consists of volcanic tuff, volcanic breccia, and pillow lava, with minor sand lenses. The engineering properties, however, are more favorable. Tuff and breccia beds are usually well cemented, strong and compact. In the pillow lavas, joints and seams are partly or completely filled with palagonite or other materials which welds them into stronger rock. Sand lenses are less abundant, and permeability is much lower than in Unit No. 5.	Rock excavation; blasting is required to remove all beds except minor sand lenses. Nearly vertical walls will remain stable in flat-lying tuff and breccia beds and pillow lava, but sliding may occur in some steeply dipping beds.	Conditions are very good for all structures and bearing capacity is excellent for heavy loadings. Permeability is generally low. Foundation and curtain grouting are probably unnecessary. Geologic conditions are favorable for embankment and concrete dams.	Rock tunneling; designation for tuff-breccia beds is 'hard, stratified' and 'moderately blocky and seamy' for pillow lavas. Bridge-action period is long; overbreak may be low except in inclined beds. Light support may be required for some tuff-breccia beds but no side pressure is expected. Full-face mining method can be used. Rock bolts may be useful in slabby zones if encountered. Inflows may be light to moderate at contacts with other rock units but no hazardous conditions are anticipated.	Of the three rock types in this unit, the pillow lava has the best quality for shell material and riprap, and crushed aggregate for concrete. The tuff and breccia may be suitable for shell material, but suitability for aggregate is questionable. Sampling and testing will be required to evaluate all materials in relation to rock of superior properties adjacent to project areas.
7	SEDIMENTARY ROCKS Mainly sandstone and conglomerate, friable to firmly cemented.	This map unit is not extensive and is limited mainly to some areas on the upper Thjorsa River. It consists mainly of conglomerate and sandstone beds having a total thickness of several tens of meters. The conglomerate is hard and firm, with cobbles up to 10 or more centimeters in size; joint spacing is wide and bedding is indistinct. The sandstone is usually fine-grained, friable, and is easily eroded. The contact between the sandstone and conglomerate is undulating, but generally horizontal.	Rock excavation; blasting will be required for most beds, and all of the well cemented conglomerate.	The conglomerate beds would provide an excellent foundation for all structures, but conditions are far less favorable in some beds of weakly cemented sandstone of questionable durability. Most conglomerate appears fairly tight and impervious, whereas certain weak sandstone may be highly permeable. Subsurface exploration is imperative in this unit to evaluate conditions.	Rock tunneling conditions will apply to nearly all beds in this unit. Bridge-action period will be very long in conglomerate, but short and variable in sandstone. Vertical walls in the softer grades of sandstone may require support and overbreak may be high. The full-face mining method should be suitable for both rock types. All tunnels in sandstone will require lining, and portals need erosion protection.	The conglomerate should be suitable for rock shell, but most of the sandstone is too friable for construction use. Rock deposits of better quality can be located within reasonable distances of many sites.
8	LATE PLEISTOCENE BASALT Open joints, partly filled by clay mainly.	The predominant rock is a gray basalt which occurs in many flows, and having a total thickness of a few hundred meters. Compact volcanic breccia is also present, and sedimentary beds are sandwiched between various basalt flows and are not commonly exposed. The basalt has a fairly close and irregular joint system, and will break into more or less cubical shapes; the joints are usually open and unfilled. Some sedimentary beds are poorly cemented, highly permeable and easily eroded; all beds are flat-lying.	Rock excavation; blasting is required in nearly all cases, except possibly some of the very soft sedimentary interbeds.	Excellent support in basalt and breccia, but conditions are less favorable in the sedimentary interbeds. Although confined compressive strength may be adequate, some interbeds are highly permeable and easily eroded, so that a possibility of piping may occur.	Rock tunneling is required. Bridge-action period will vary greatly with rock conditions but will probably be shortest in very blocky basalt due to loose joints and seams. Strong inflows can be expected at contact of basalt with some sedimentary interbeds. The full-face mining method should be suitable in this unit. Lining will be required in most sections. Rock bolts might prove useful in basalt, but would not be effective in the sedimentary beds.	Basalt is by far the best rock in the unit. It can be easily quarried, and fragmentation should be high. It could be used for rock shell, light riprap, and coarse aggregate when crushed. The other rock types within the unit have doubtful suitability for most heavy construction.
9	EARLY AND MIDDLE PLEISTOCENE BASALT Joints usually filled with secondary minerals and clay.	Basalt is the predominant rock in this unit, which consists of several flows having a total thickness of several hundred meters. In comparison with Unit 8, the basalt has many joints and seams filled by secondary minerals and clay, and therefore much lower permeability. Breccia beds and sedimentary beds also occur between some flows. Colonnade and entablature structures are quite common, and in this respect resembles the lava of Unit 3. Some of the sedimentary beds are friable, permeable and easily eroded.	Rock excavation is required. Excavation walls will stand on very steep to nearly vertical slopes.	This unit provides generally excellent foundation conditions for all types of structures. As is the case in Unit 8, however, some interbeds are permeable and easily eroded, and might cause piping.	Rock tunneling conditions prevail; bridge-action period will be fairly long in basalt due to cemented conditions in joints and seams. Inflows can be expected at contacts with sedimentary interbeds. Full-face mining method should be satisfactory. Rock bolts could be used, if necessary, in basalt, but would probably not be satisfactory in the sedimentary materials.	The basalt rock of this unit would make satisfactory shell material, riprap, and coarse aggregate after crushing. The sedimentary beds have doubtful suitability.
10	ANDESITE Hard and tough, commonly platy with scoriaceous zones between flows	Massive, gray, fine-grained, hard and tough andesite, having open vertical joints ranging from 20 centimeters to fairly wide spacings. Often shows a pronounced horizontal parting which develops a very platy condition and breakage into thin slabs from 2 to 20 centimeters thick. Also shows colonnade structure and cubical jointing (kuppaberg) which permits breakage into blocks up to 1 meter in size. Andesite flows are often concealed between vesicular basalt lava flows of Unit 9, and cannot be shown on the geological map; the distribution of this unit may therefore be more extensive than indicated. It may also be underlain by some friable and permeable breccia of Unit 6. Scoriaceous zones and interbeds are very common and are probably highly permeable.	Rock excavation entirely; blasting is required for removal, but light explosives will minimize high shattering of platy varieties. Open joints and horizontal seams prevent stability on very steep slopes, and much breakage and talus will accumulate at toe of slopes.	Excellent foundation support for structures of all kinds. Seams, joints and parting planes may, however, cause high permeability. Scoriaceous zones and interbeds also may be highly permeable. Curtain grouting or other treatment may be required to minimize leakage and underseepage. Borings are required to determine thickness of flows and rock character in all cases.	Rock tunneling conditions; designation of platy rock is 'very blocky and seamy,' whereas, colonnade and cubical types may be considered as 'moderately blocky and seamy.' The very platy varieties will require support and lining; they will have a short bridge-action period and light explosives during full-face mining will tend to minimize overbreak. Strong inflows and much surface seepage can be expected in rock of this character. Rock bolts could be used in the cubical-jointed rock but may not be effective in the very platy varieties.	The colonnade and kuppaberg varieties of andesite will be useful for rock shell, riprap, and for coarse aggregate when crushed. The platy varieties, however, are probably unsuitable except for flagstone.
11	RHYOLITE Usually soft, highly decomposed with some hard, fresh zones and veins.	This volcanic rock unit is not very extensive in the Thjorsa and Hvita Basins. It is usually pale gray to nearly white, very soft and easily crumbled, which is largely the result of hydrothermal alteration. Some zones of severely altered rock have clay-like properties. Weathered zones may be locally pierced by a complex network of hard, dark-colored dikes up to 1 meter in thickness, which impart somewhat greater stability to the weak and rotten rhyolite mass. Landslides are common and most of the altered rock is easily eroded.	Mixed earth and rock excavation; most of the highly altered rhyolite can be removed by power equipment, but the density of fresh and hard dikes may necessitate blasting in some zones. Most of this material does not stand well on very steep slopes and will slump and ravel badly. Deep excavation walls will require shoring to prevent caving.	Poor to unsatisfactory conditions. Bearing capacity is generally low to sustain heavy design loadings. Some zones may contain compressible clay-like materials. Foundation or curtain grouting probably ineffective in most cases. Permeability is low except in some fractured dikes and intrusions.	Earth tunneling mainly, except in dike zones where explosives will facilitate removal. Considerable side pressures can be expected in zones where squeezing or swelling rock occurs. Bridge-action period may vary from several hours to several days; length of unsupported roof sections must be regulated carefully. Inflows can be common in fractured dikes and in platy varieties. Rock bolts would not be effective in most of this unit. Support and lining are required, and portals need erosion protection.	Some of the weathered rhyolite within this unit might be considered for impervious core material but the sporadic and unpredictable character of the rock, ranging from platy, crumbly types to clay-like masses within relatively short distances would make recovery difficult. Similar conditions would apply to recovery for embankment material. Detailed subsurface exploration would be necessary to block out suitable deposits of adequate size.





LEGEND

LOCATION OF CROSS SECTIONS

APPROXIMATE LOCATION OF DRILLHOLES

FOR EXPLANATION OF MAP UNITS SEE FIG. 2

H-10 BURFELLSMYRAR
GEOLOGIC MAP AND CROSS SECTIONS

THE STATE ELECTRICITY AUTHORITY, ICELAND

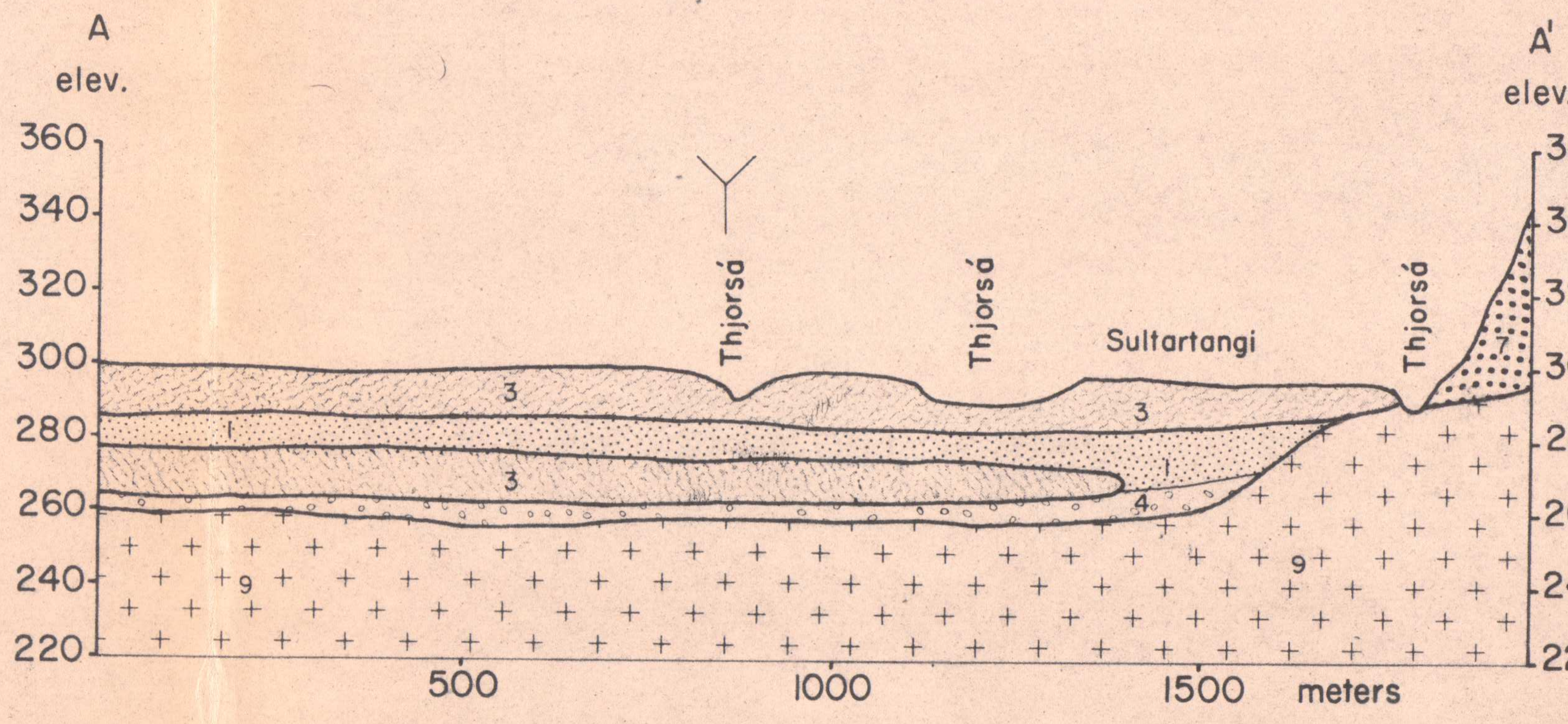
UNITED NATIONS SPECIAL FUND,
REYKJAVIK, ICELAND

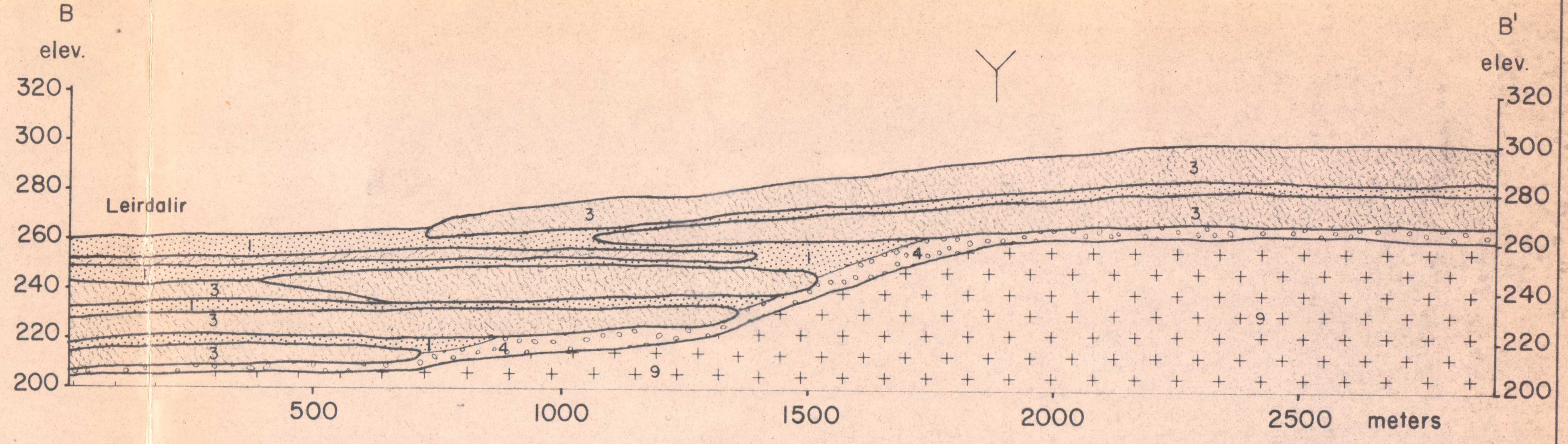
Fig. 5

Scale 1:50 000

0 1 2 3 4 5

kilometers





LEGEND

SECTION TURNS

LOCATION OF CROSS SECTIONS

APPROXIMATE LOCATION OF DRILLHOLES

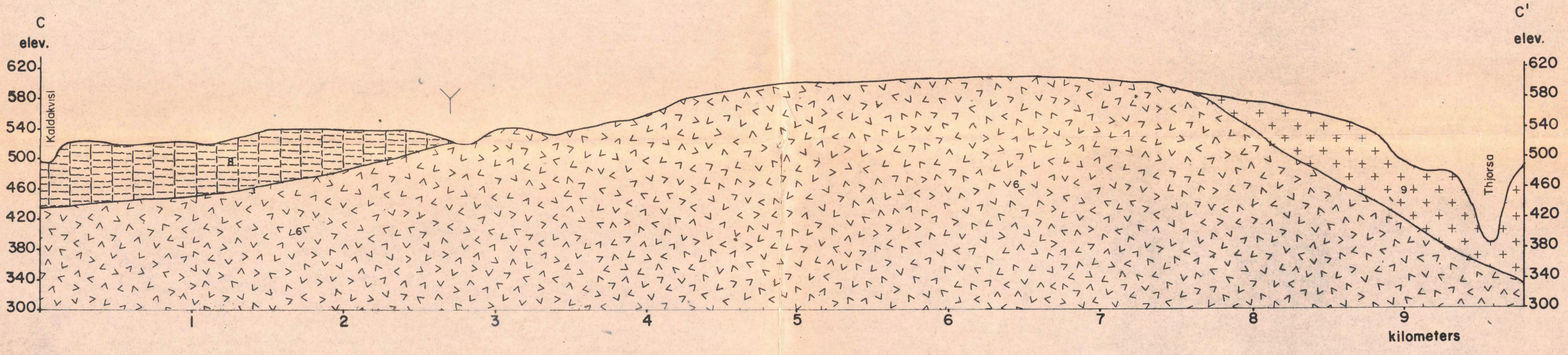
FOR EXPLANANATION OF MAP UNITS SEE FIG 2

T-7 SULTARTANGI
GEOLOGIC MAP AND CROSS SECTIONS

THE STATE ELECTRICITY AUTHORITY, ICELAND

UNITED NATIONS SPECIAL FUND, REYKJAVIK, ICELAND

Fig 10



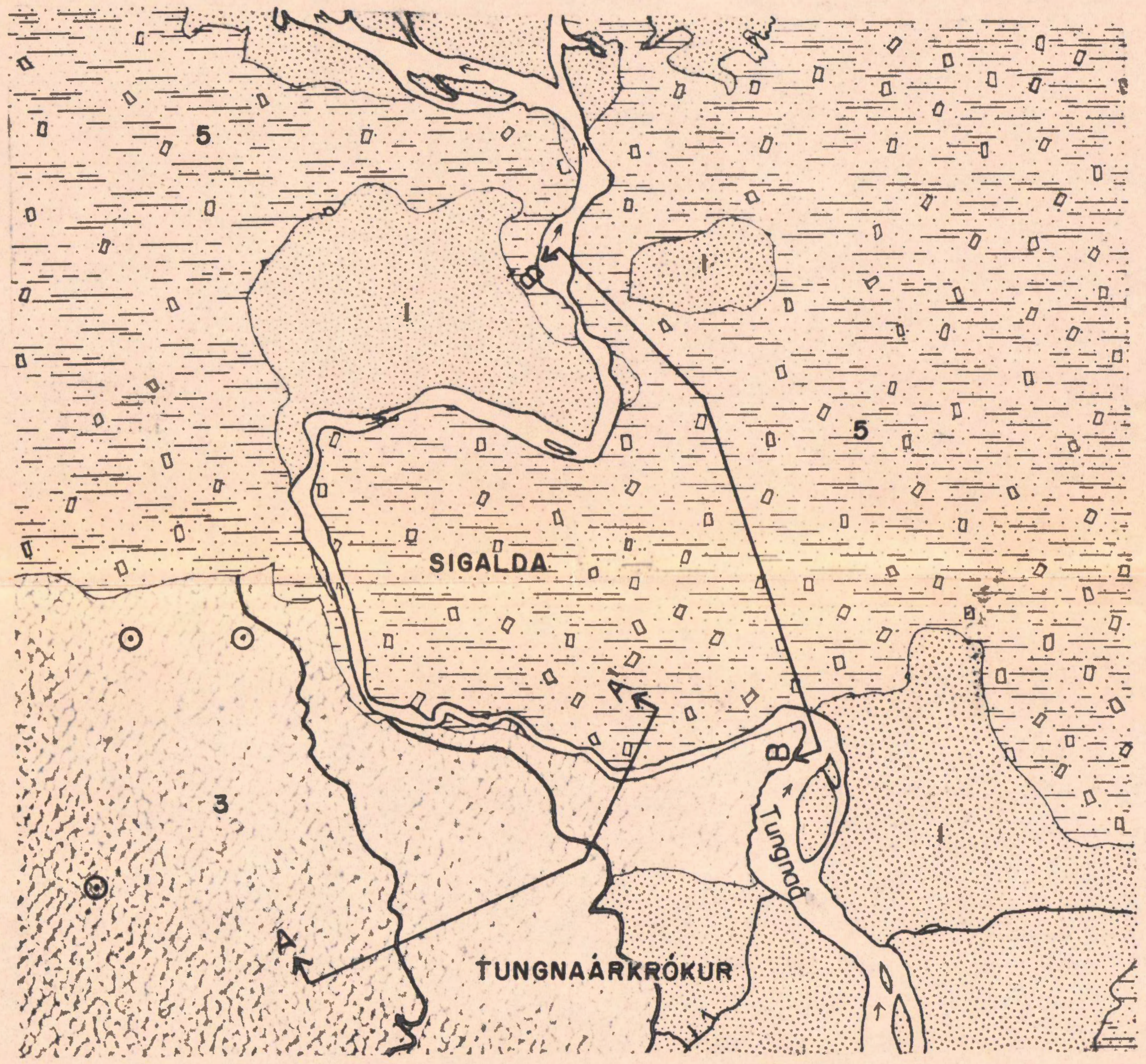
LEGEND

SECTION TURNS

LOCATION OF CROSS SECTION IS SHOWN ON FIG. 11 SHEET 3

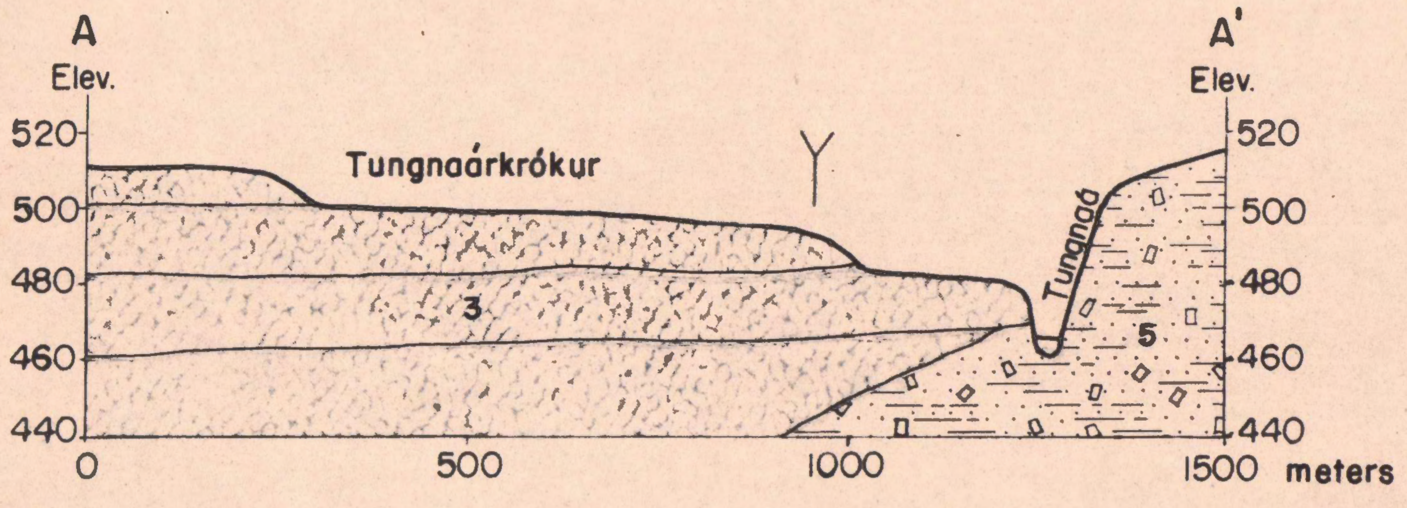
FOR EXPLANATION OF MAP UNITS SEE FIG. 2

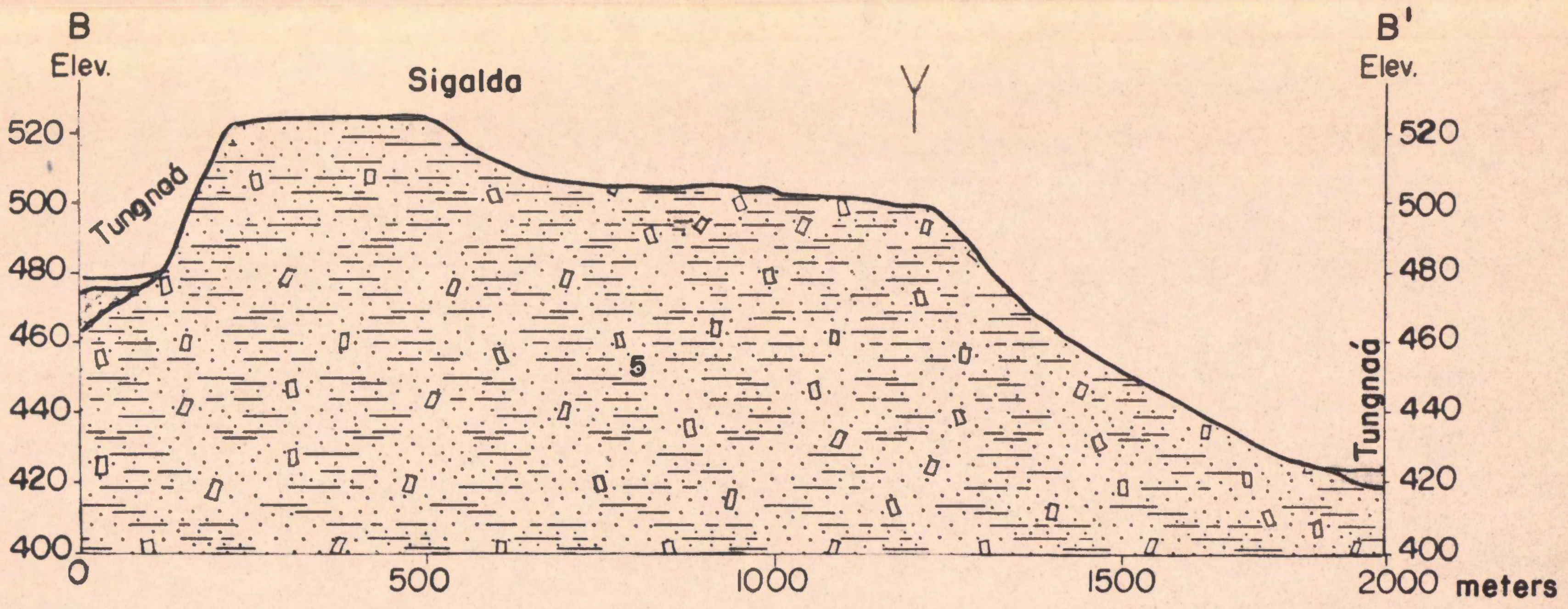
T-13 KALDAKVISL DIVERSION CROSS SECTION
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND, REYKJAVIK, ICELAND



Scale 1:20000

0 1000 2000 meters





LEGEND

SECTION TURN

LOCATION OF CROSS SECTIONS

APPROXIMATE LOCATION OF DRILLHOLES

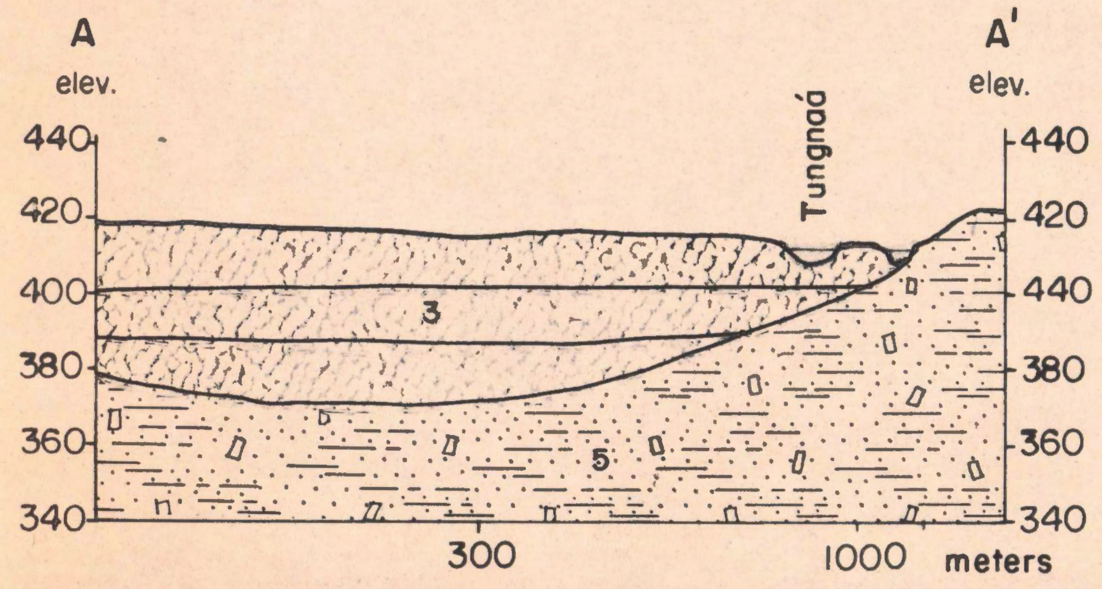
FOR EXPLANATION OF MAP UNITS, SEE FIG 2

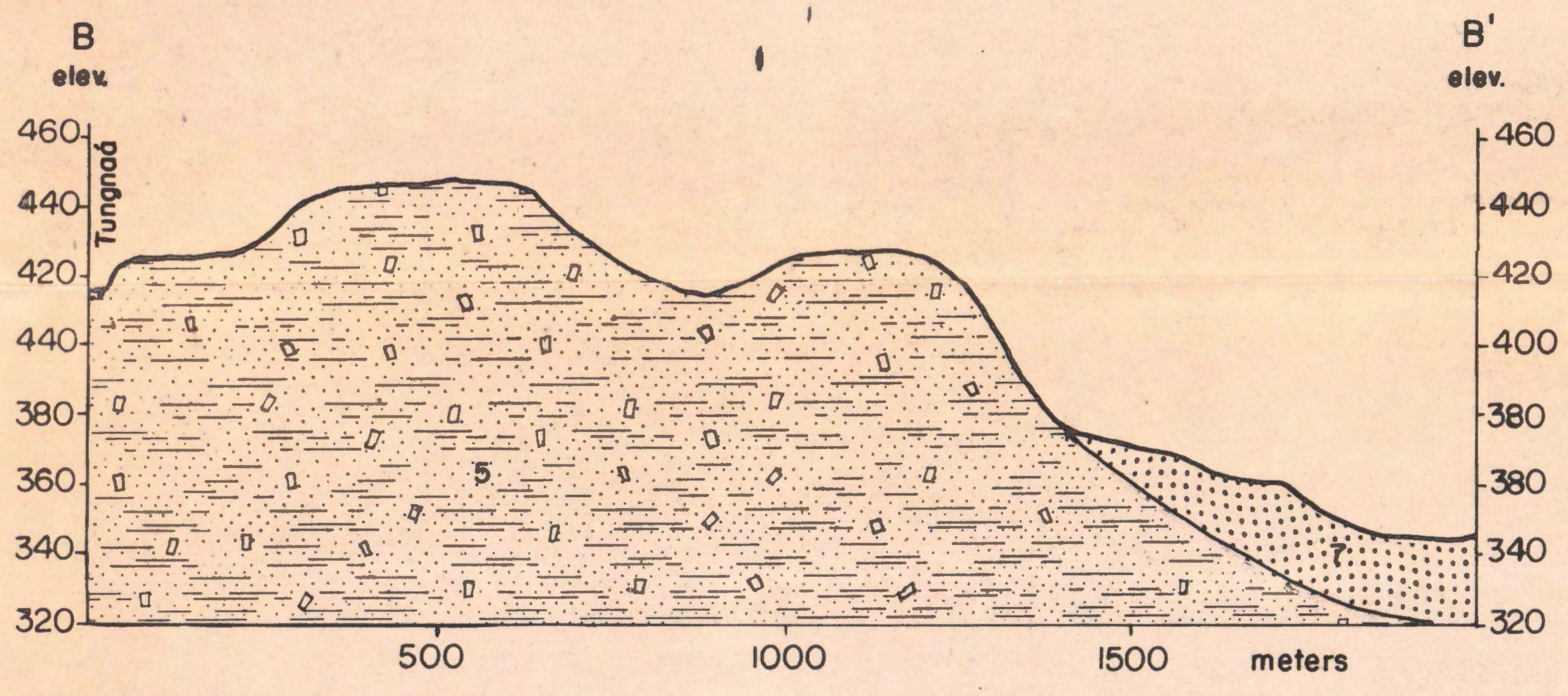
T-16 TUNGNAÁRKRÓKUR GEOLOGIC MAP AND CROSS SECTIONS
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND, REYKJAVIK, ICELAND

Fig 13

Scale 1:20000

0 1000 2000 meters





LEGEND

LOCATION OF CROSS SECTIONS

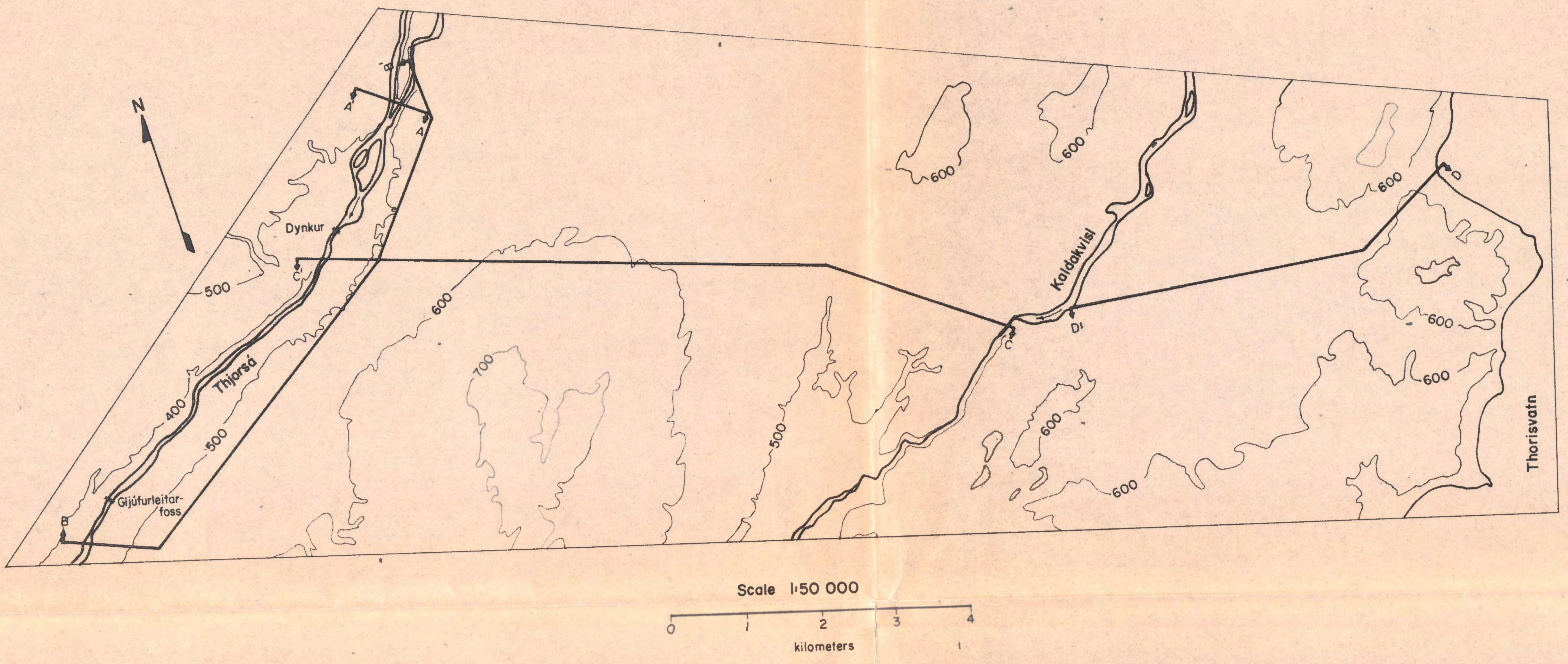
APPROXIMATE LOCATION OF DRILLHOLE

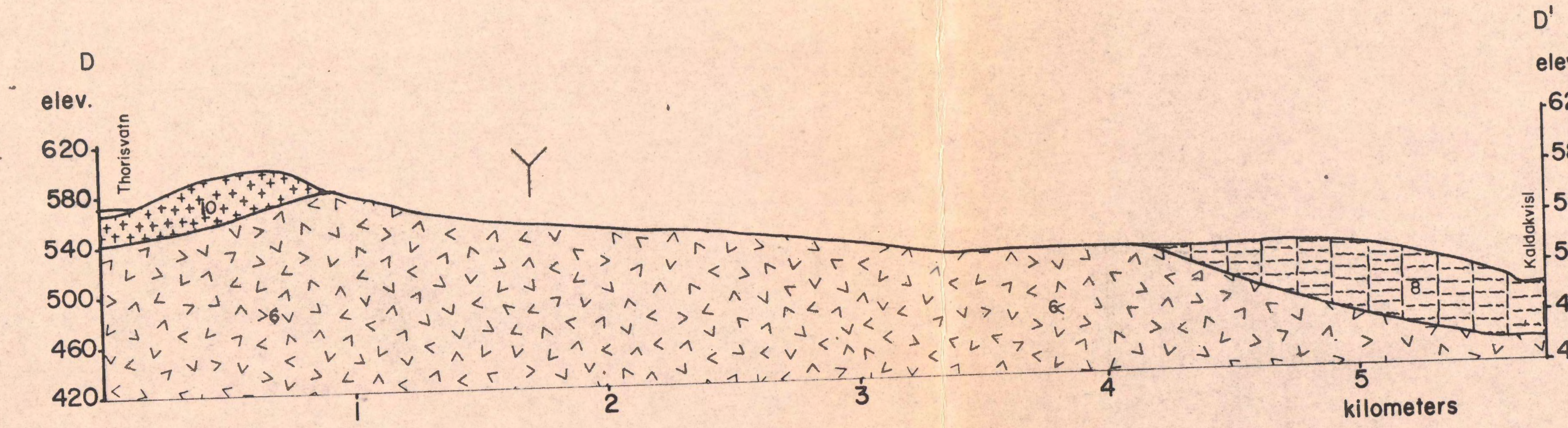
FOR EXPLANATION OF MAP UNITS, SEE FIG 2

T-15 HRAUNEYJARFOSS
GEOLOGIC MAP AND CROSS SECTIONS

THE STATE ELECTRICITY AUTHORITY, ICELAND

UNITED NATIONS SPECIAL FUND
REYKJAVIK, ICELAND





LEGEND

SECTION TURNS

LOCATION OF CROSS SECTION

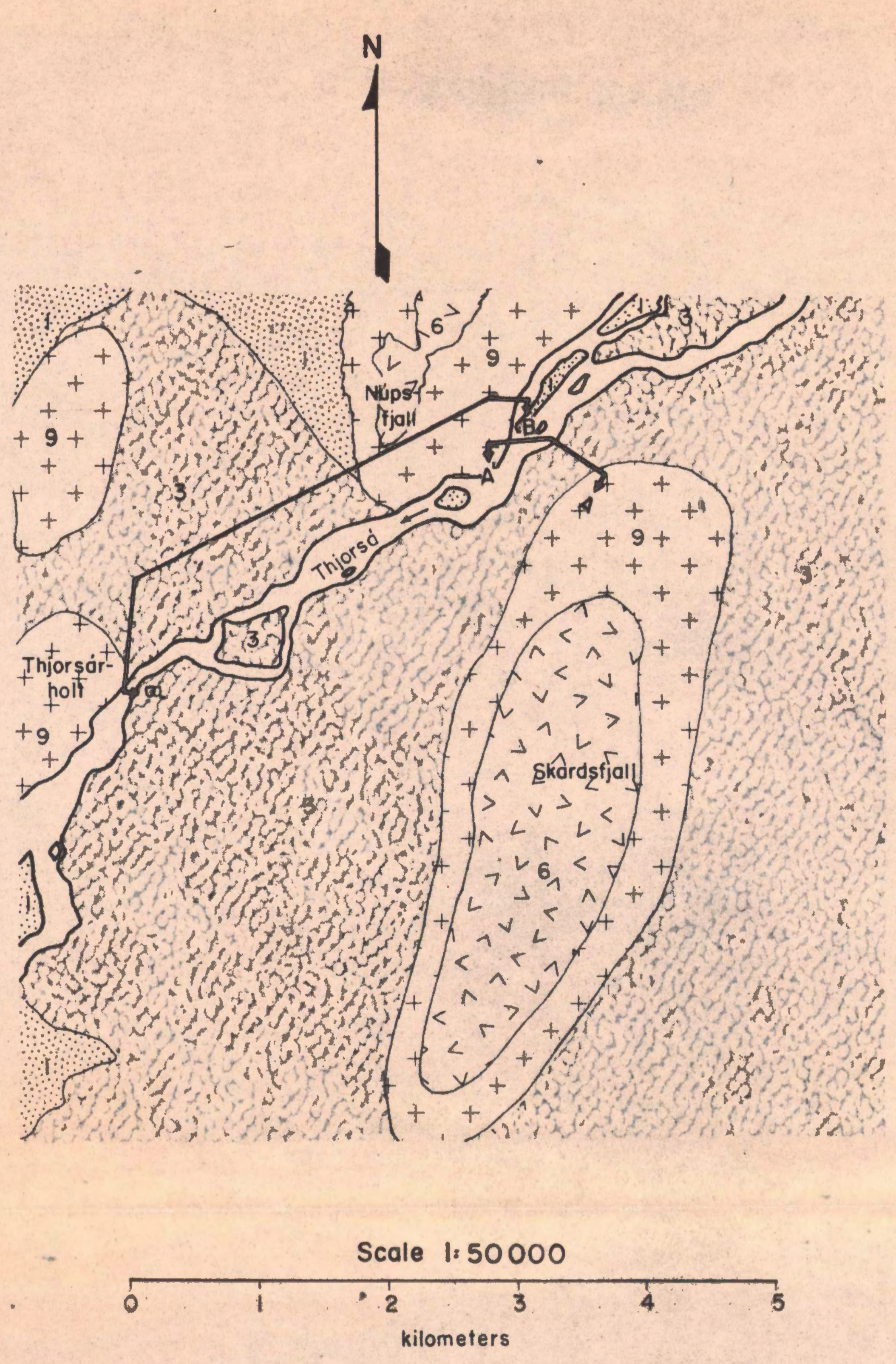
FOR EXPLANATION OF MAP UNITS SEE FIG. 2

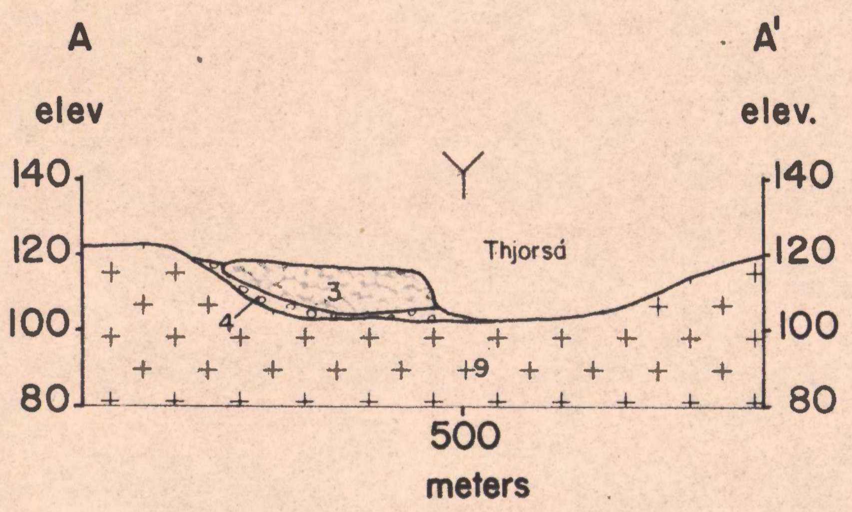
T-14 THORISVATN TUNNEL SITE
CROSS SECTION

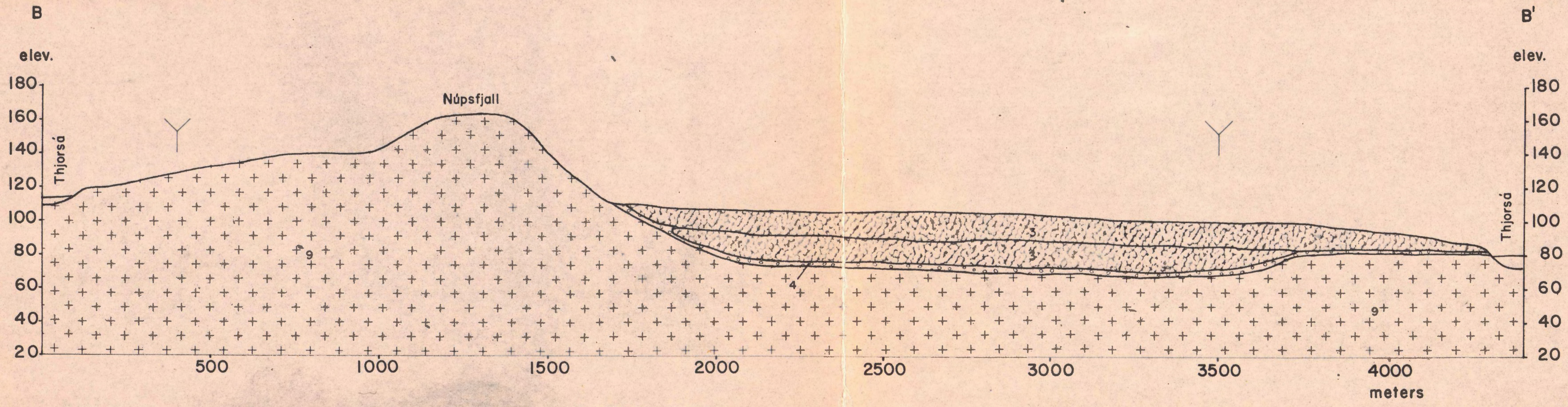
THE STATE ELECTRICITY AUTHORITY, ICELAND

UNITED NATIONS SPECIAL FUND,
REYKJAVIK, ICELAND

Fig. 11 Sheet 3 of 3







LEGEND

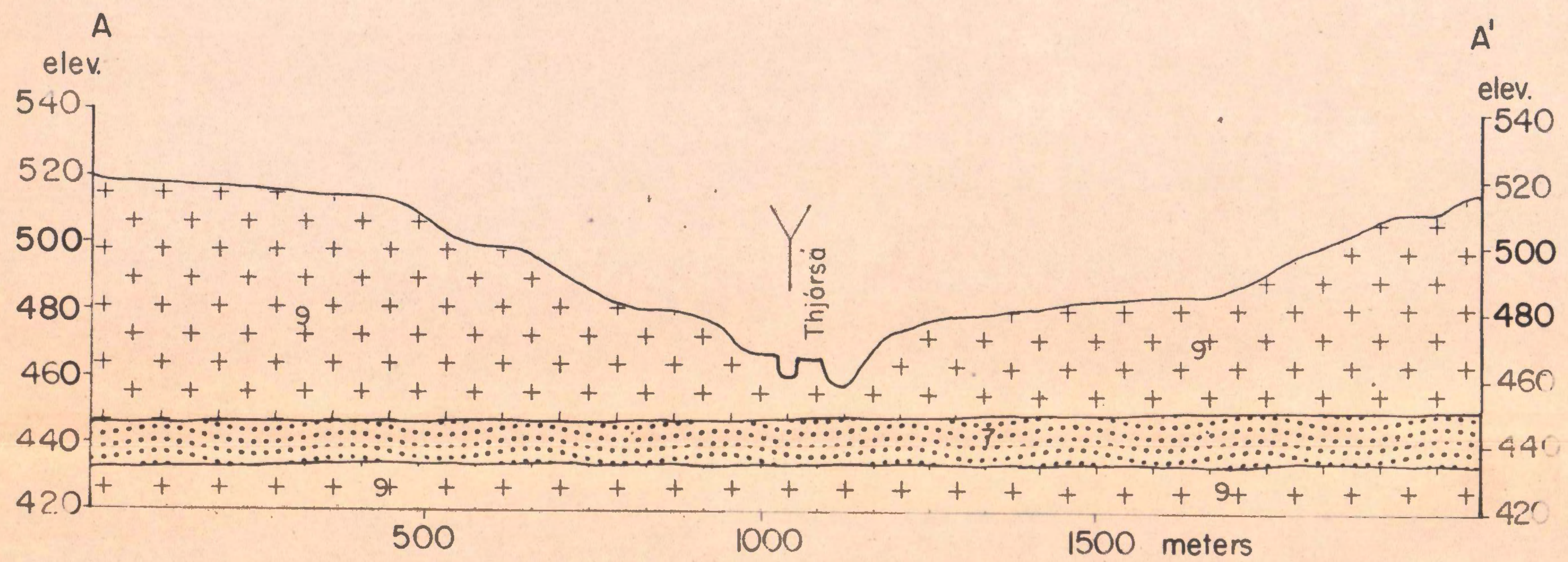
Y SECTION TURNS

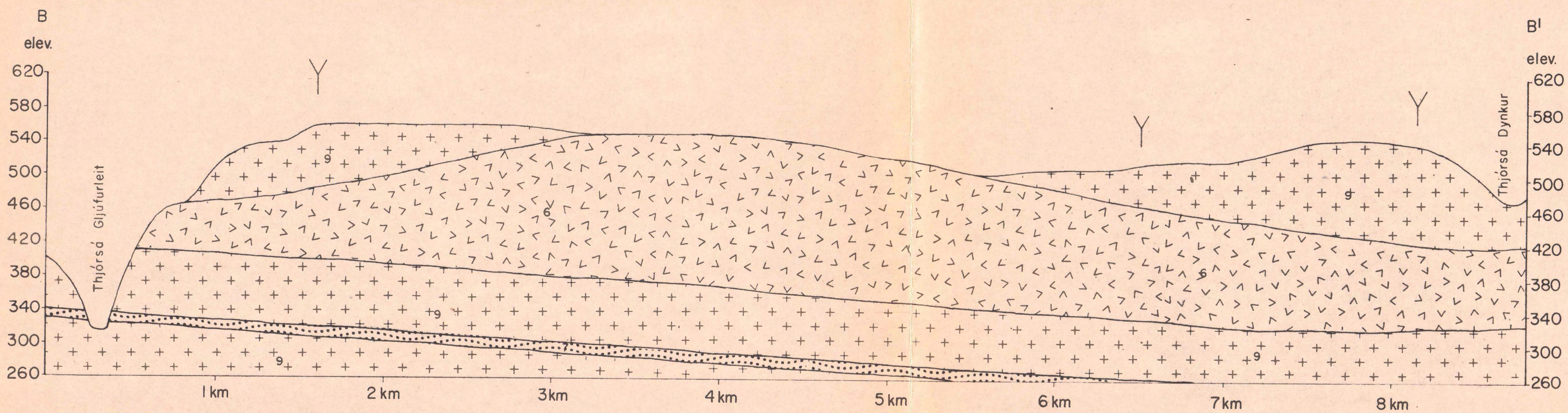
LOCATION OF CROSS SECTIONS.

FOR EXPLANATION OF MAP UNITS, SEE FIG 2

T-4 SKARD GEOLGIC MAP AND CROSS SECTIONS
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND, REYKJAVIK, ICELAND

Fig 9





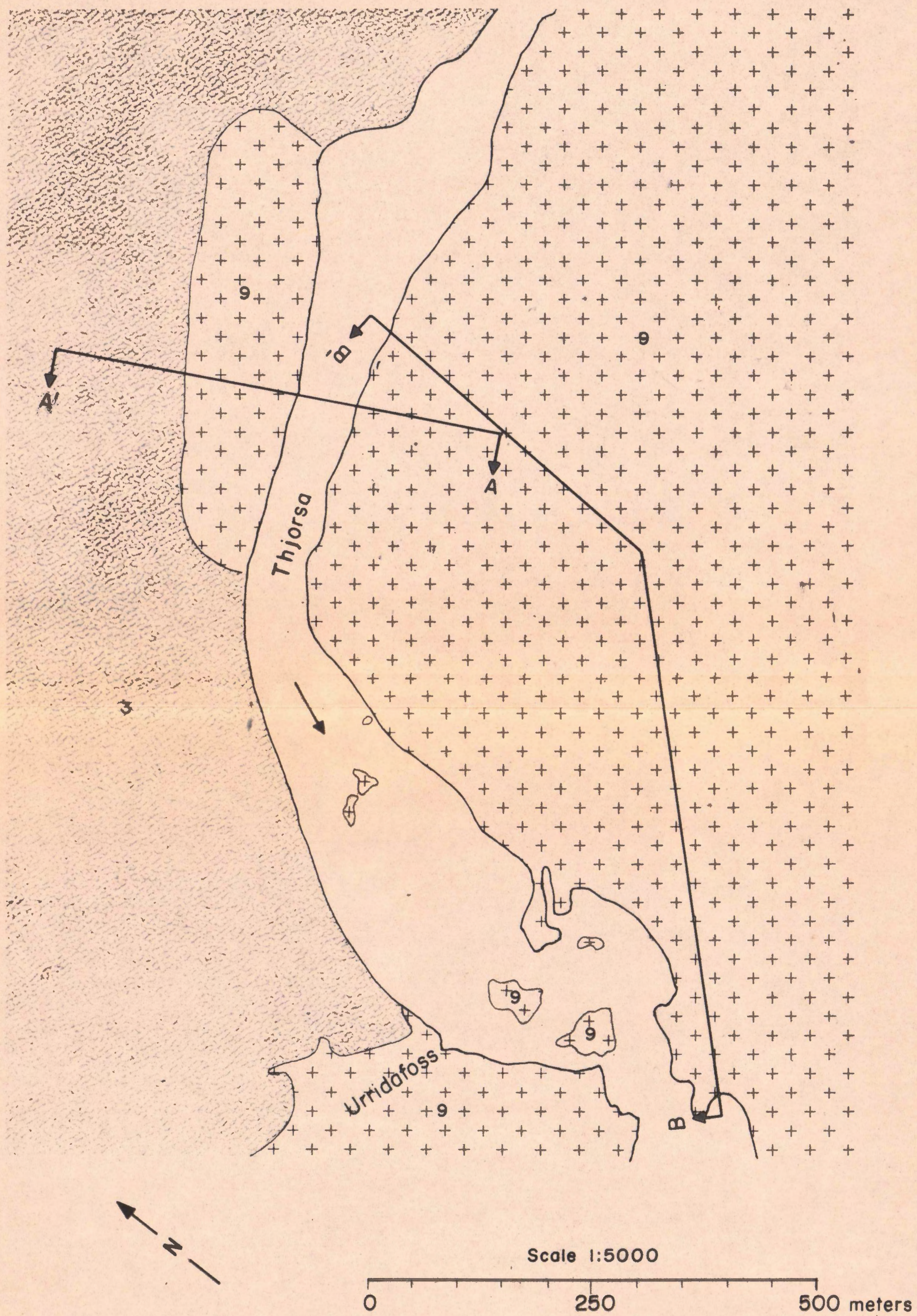
LEGEND

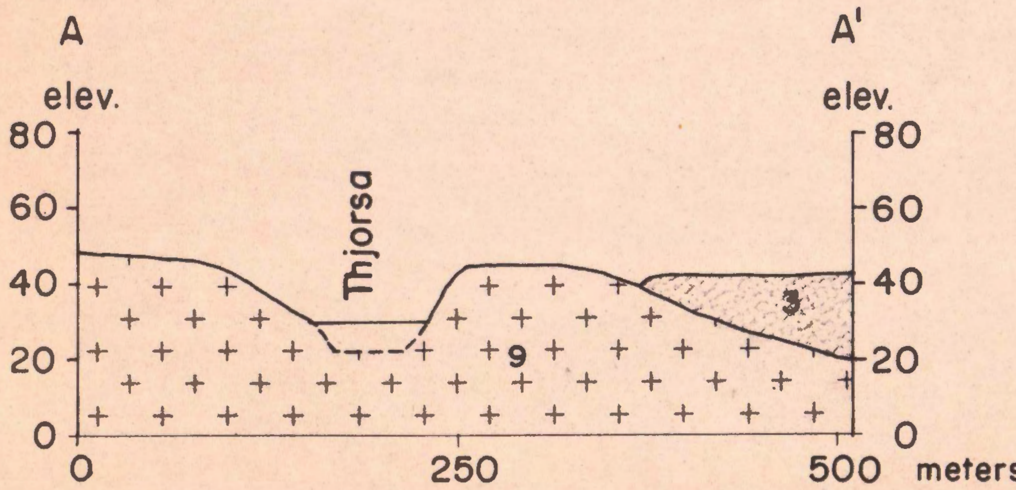
Y SECTION TURNS

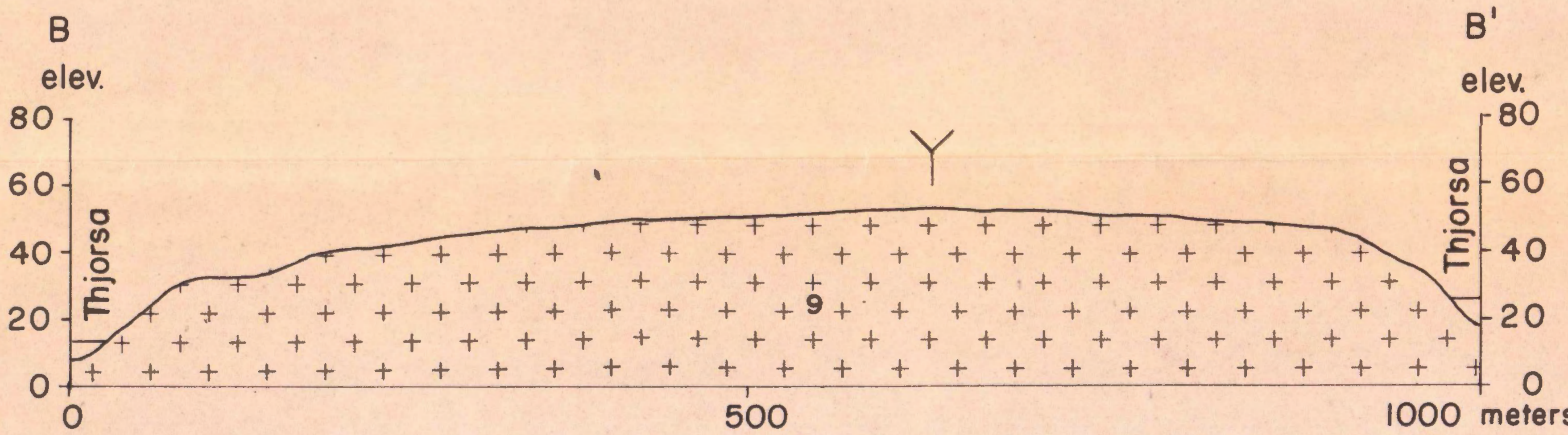
LOCATION OF CROSS SECTIONS IS SHOWN ON FIG. 11 SHEET 3

FOR EXPLANATION OF MAP UNITS SEE FIG. 2

T-9 DYNKUR CROSS SECTIONS
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND, REYKJAVIK, ICELAND







LEGEND

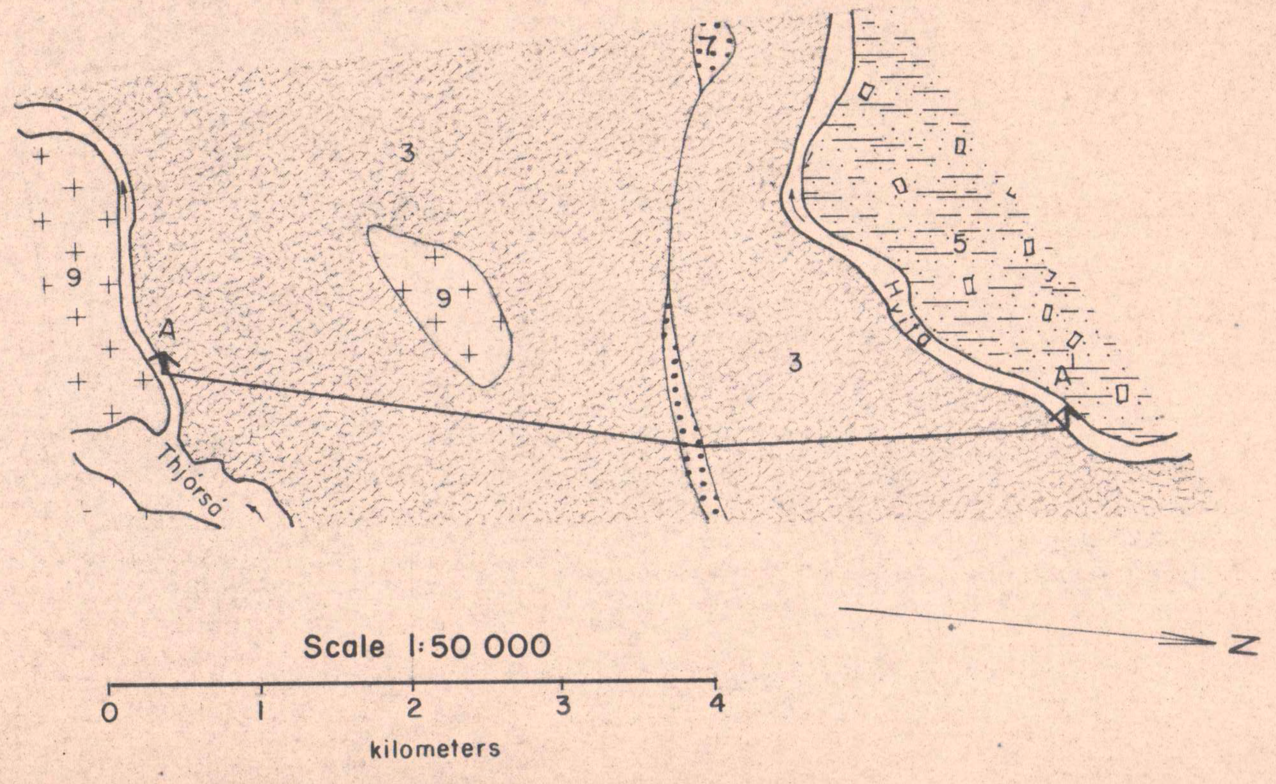
SECTION TURN

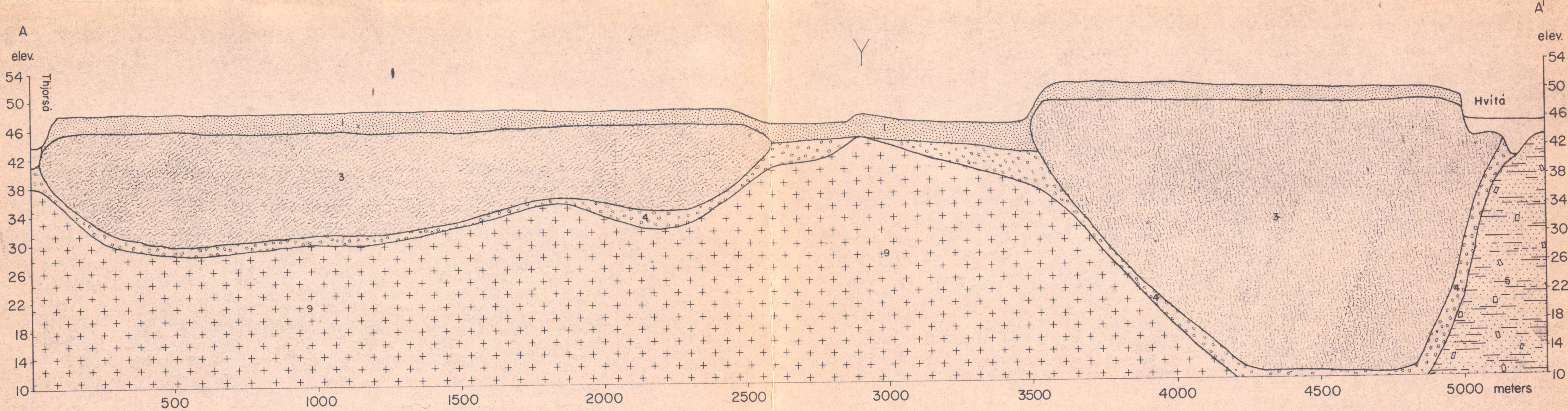
LOCATION OF CROSS SECTIONS

FOR EXPLANATION OF MAP UNITS, SEE FIG 2

T-I URRIDAFOSS GEOLOGIC MAP AND CROSS SECTIONS
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND, REYKJAVÍK, ICELAND

Fig 7





LEGEND

Y SECTION TURNS

LOCATION OF CROSS SECTION

FOR EXPLANATION OF MAP UNITS, SEE FIG 2

T-2 HVITA DIVERSION GEOLOGIC MAP AND CROSS SECTION
THE STATE ELECTRICITY AUTHORITY, ICELAND
UNITED NATIONS SPECIAL FUND, REYKJAVIK, ICELAND

Fig 8