THE MARINE GEOLOGY OF EYJAFJÖRDUR, NORTH ICELAND: SEDIMENTOLOGICAL, PETROGRAPHICAL AND STRATIGRAPHICAL STUDIES.

by

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Declaration

I declare that all the work presented in this thesis is my own, except when stated otherwise, and that the thesis has been composed by myself.

Til Edda og Svanhildur

ABSTRACT

This study deals with a stratigraphical and sedimentological work on a fjord sediment, Eyjafjördur in northern Iceland. The lower stratigraphy was studied in seismic reflection profiles while the uppermost metres were examined with cores and grab samples.

Topographically, the marginal shelf area of Eyjafjördur extends over a relatively large proportion of the fjord area covering a similar area to the deeper part of thefjord. Rock bars which are characteristically at the sea entrance, do not exist. In this respect the configuration of the fjord differs from most of fjords studied.

The sediments are on average 150 - 180 m thick along the Eyjafjördur basin, reaching the maximum thickness of 200 m. In this sediment infill 24 - 25 stratigraphical units have been identified, comprising 13 stages of glacier advance and 11 of retreat. The top unit represents the Recent time sedimentation, on average 15 - 20 m thick and the unit immediately below is correlated with the Búdi stage (10.000 - 11.000 B.P.). Other sediment units have not been dated or correlated, except the till material covering the rock basin which is considered to be from the maximum of the Weichselian glaciation.

The three ca. 9 metres long piston cores studied were dated back to 3.000 - 4.000 B.P. using the acid tephra layers from the volcano Hekla and the magnetic susceptibility for a cross-correlation.

For the Holocene time period, the sedimentation rate in Eyjafjördur is esimated 1.8 - 2.0 mm/y or on average

17 - 20 m. For the same time period, the denudation rate within the drainage area of Eyjafjördur is calculated 0.11 - 0.15 mm/y.

Studies of the petrographic classification suggest that a part of the finest sediment fraction is wind transported from other areas into Eyjafjördur, causing anomalously high sedimentation rate. No 'foreign' grains were identified.

The grain size distribution reflects in general the pattern of sedimentation which is to be expected in a fjord environment, i.e. sand texture predominates in the deltas and along the coasts, but in the deeper water the mud texture predominates.

The clay minerals found in the fjord's sediments are predominantly derived from the Eyjafjördur drainage area.

The carbonate content is very low (<1%) presumably due to a high sedimentation rate. The organic carbon content is relatively high, but varies with the mean grain size.

The environmental and climatic changes studied in soil profiles around Iceland only appear in the core profiles as an increase in the sedimentation rate and as a minor increase in the mean grain size distribution and this can be related to the settlement time in Iceland (i.e. after ca. 1.100 B.P.).

No turbitides were identified in the cores.

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Chapter 1. INTRODUCTION

1.1 Objects of study

For the past decade, a systematic survey of the nature of sediments on the continental shelf has been made. However no detailed marine geological work has been undertaken in the associated fjords. The aim of this study is to carry out seismic survey and sedimentological work in Eyjafjördur in order to describe the sediment structure and the history of the sedimentation and the physical and mineralogical character of its sediments. Some emphasis will be made to assess the effect that changes in climate and environment have on the sediment composition, especially in respect of change in erosional patterns.

1.2 Location

Eyjafjördur is situated in the middle of Northern Iceland immediately south of the Arctic Circle and of longitude approximately 18°30'W (Figure 1.1). The fjord bisects a peninsula, which can be described as a 1000 - 1500 m high plateau, heavily dissected by valleys which are directed to the north. The peninsula, located between Skjálfandi on the east and Skagafjördur on the west, has no name but will here be called the Eyjafjördur area. The western part of this area is one of the highest mountain ranges in Iceland and accordingly bears the name Tröllaskagi (The

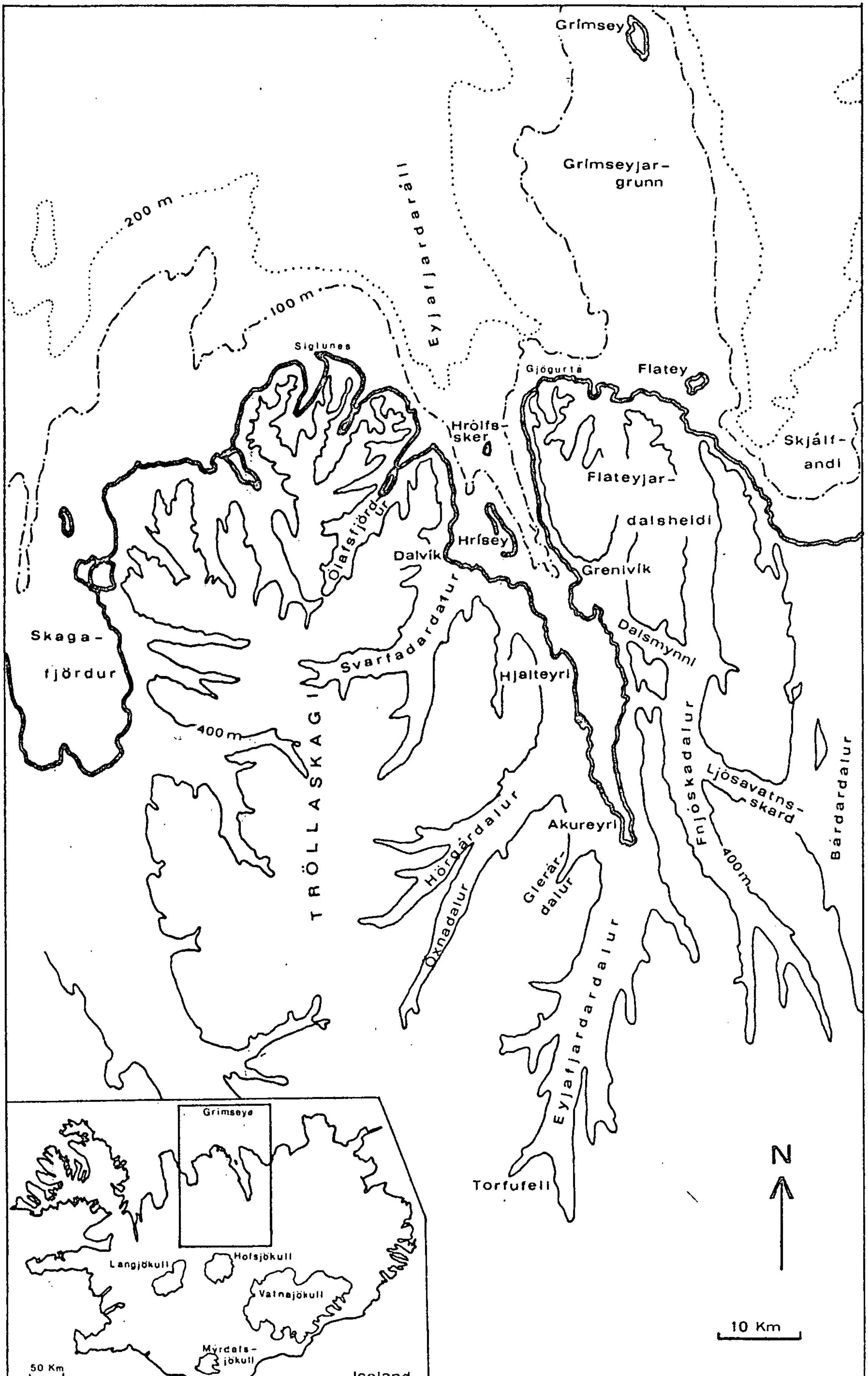


Figure 1.1. Central North Iceland, with names of the most important localities mentioned in the text.

peninsula of the trolls).

Fjords have been commonly described as an estuary (Cameron and Pritchard, 1963) or more recently as a local environment (Selley, 1970; Pettijohn, 1975) that is isolated from the continental shelf. For Eyjafjördur, such definitions apply only to the inner part of the fjord (Fig. 1.1) an area barred to the north by a prominent sill or threshold. What is characteristic for Eyjafjördur, as far as the fjord setting and hydrography is concerned, is that the transitional zone, combining the fjord type environment and the open sea, extends over all the outer part of the fjord.

1.3 Previous marine geological work in Iceland

In Iceland like many other northerly countries fjord-landscape is a characteristic morphological feature. As early as 1867 it was recognized (cf. Helland, 1882) that the fjords of Iceland had been sculptured by glacial erosion. Amund Helland (1881/1882) also pointed out that their bathymetrical features are those of glacial fjords, but to what extent these fjords had been excavated by the glaciers is difficult to estimate.

In the beginning of the century a fruitful discussion took place about the formation of the fjords and bays in Iceland after the Danish hydrographic survey published a new bathymetric data from the continental shelf around Iceland (Thoroddsen, 1901, 1902; Nansen, 1904; Pjeturss.

1905).

Meaningful descriptions of the sediments off Iceland are few. In 1941 Einarsson publish the first sediment distribution map of the continental shelf with a short discussion of the provenance of the sediments. This latter study was based on grab samples taken from a small area in SW-Iceland. Complimenting this work Danish navigational charts, for the shelf all around Iceland, also show incidental notations of sediment type. Some twenty years later Hartsock (1960) discussed the sediment distribution on the SE-Iceland shelf. This work was based entirely on data from this Danish navigational charts.

Several reports on the Icelandic sea-floor sediments appear in Russian publication in the 1960's. For example, Gorshkova (1960a,b, 1964) made a geochemical and mineralogical study of sediments from the Norwegian Sea, and sedimentological study of the sediments off north eastern and eastern Iceland was made by Vinogradova (1964). A few sediment samples, taken during a Russian expedition off the western half of Iceland have been described by Avilov, 1965. Some aspects of marine geology in the vicinity of Iceland have been discussed by Kotenev (1968), including sediments and sea-floor morphology.

The U.S. Naval Oceanographic Office (1965) published an oceanographic atlas of sediment distribution in the North Atlantic, which includes some information on the variation in sediment type around Iceland.

In the early 1960's Tr. Einarsson (1962, 1963) reinterpretated some of these maps and charts, and attempted to assess the geological history of the Icelandic shelf and a tectonic history of Iceland. In 1974 a marine geological department was opened at the Marine Research Institute and is programmed to study the sediments of the continental shelf. Also this year the first major sedimentological study is carried out on the Icelancic continental shelf (Thors, 1974).

1.4 Terminology

The term fjördur (Icelandic), fjord (Danish and Norwegian), Föhrde (German) and firth (Scottish) are linguistically all variants of the same word (Hansen, 1971). All refer simply to a marine inlet whose length is greater than its with. Geomorphologically, the term fjord has traditionally come to be applied to the partially submerged glacial troughs of mountain-backed coastlands (Embleton and King, 1975). In referring to the fjords, the term 'head' is used for the inland end, where there is usually a major river bringing in fresh water, and the term 'mouth' for the seaward end. These terms will be applied to Eyjafjördur. Eyjafjördur is also divided into the inner and the outer part i.e. approximately south and north of Hjalteyri (Fig. 1.1) where there is a minor sill (Fig. 2.8).

Chapter 2 GEOLOGY AND PHYSIOGRAPHY

2.1 Geology

a) General setting of Iceland.

Iceland lies at the intersection of the Mid-Atlantic Ridge and the Wyville-Thomson Ridge, a seismically inactive transverse ridge crossing most of the north-eastern branch of the North Atlantic between East Greenland and the Faroe Islands. Productivity of volcanic material has been anomalously high on this part of the mid oceanic ridge system (Vogt, 1971).

The Mid-Atlantic Ridge transects Iceland from SW to NE in a rather well-defined axial rifting zones, characterized by extensional tectonic features such as open fissures, graben structures and crater rows (Jakobsson, 1972). Active volcanoes and earthquakes are also signs of the plate boundaries in Iceland where active plate growth is taking place. For the last few million years the mean half rate of spreading has been assumed 1 cm/y on the Reykjanes and the Kolbeinsey Ridge (Vine, 1966).

Present position of the neovolcanic zones indicates that the oldest exposed rocks in Iceland should occur in three main areas: 1) in the furthest north-west, 2) middle of North Iceland and 3) in east Iceland. K/Ar dating supports this contention. Rocks 13 m.y. old have been measured from the east (Ross and Musset, 1976) and 14 m.y. from the north-west (Albertsson and Einarsson, 1982), but from the middle of North Iceland the age is slightly lower or about 11 m.y. old (Saemundsson et al., 1980).

The greatest part of the stratigraphical pile is of volcanic rocks, mostly basalts. Chronostratigraphical information presented by Th. Einarsson (1973a) and based on floral and faunal changes, paleomagnetic reversal patterns and changes in proportion of subglacial-subaerial lavas show that the volcanic rock series can be divided into three major formations: 1) Tertiary Plateau Basalt Formation (TBF, > 3 m.y), 2) Grey Basalt Formation (GBF, 3 - 0.7 m.y.) and 3) Palagonite Formation (PGF, 0.7 m.y.). These three formations make up most the bedrock (Figure 2.1) with a fourth formation, named here Late Weichselian-Holocene Formation, comprising sediments including tills and recent lava flows.

b) Geology of the Eyjafjördur area.

1. The basement.

The bedrock of Eyjafjördur and its drainage area is mostly of Tertiary age (Figure 2.1 and 2.2). Until recently the geology of the area was known only in outline. The first geological maps showing regional dips of the area were published by Tr. Einarsson (1960, 1965). Recent work supplementing Einarsson's map shows that the Eyjafjördur area only gradually changes in dip from south-west to south and south-east (Saemundsson et al., 1980).

The oldest rocks are found at the entrance of Eyjafjördur, and the rocks become progressively younger toward

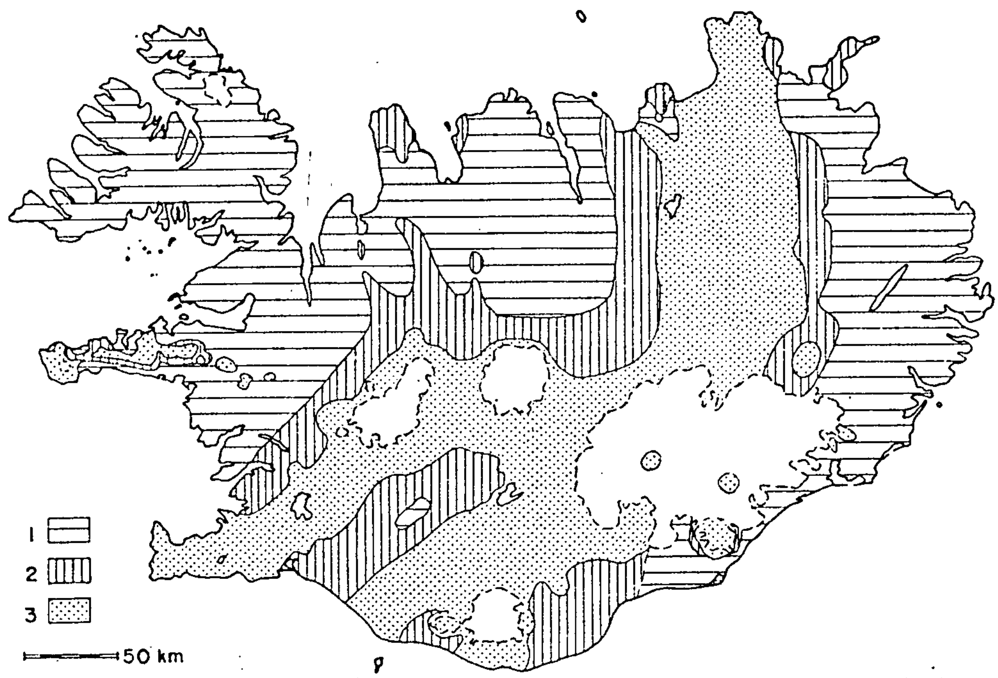


Figure 2.1. Geological map of Iceland. The three major geological formations are: 1) Tertiary Plateau Basalt, 2) Grey Basalt and 3) Palagonite. From Th. Einarsson, 1978.

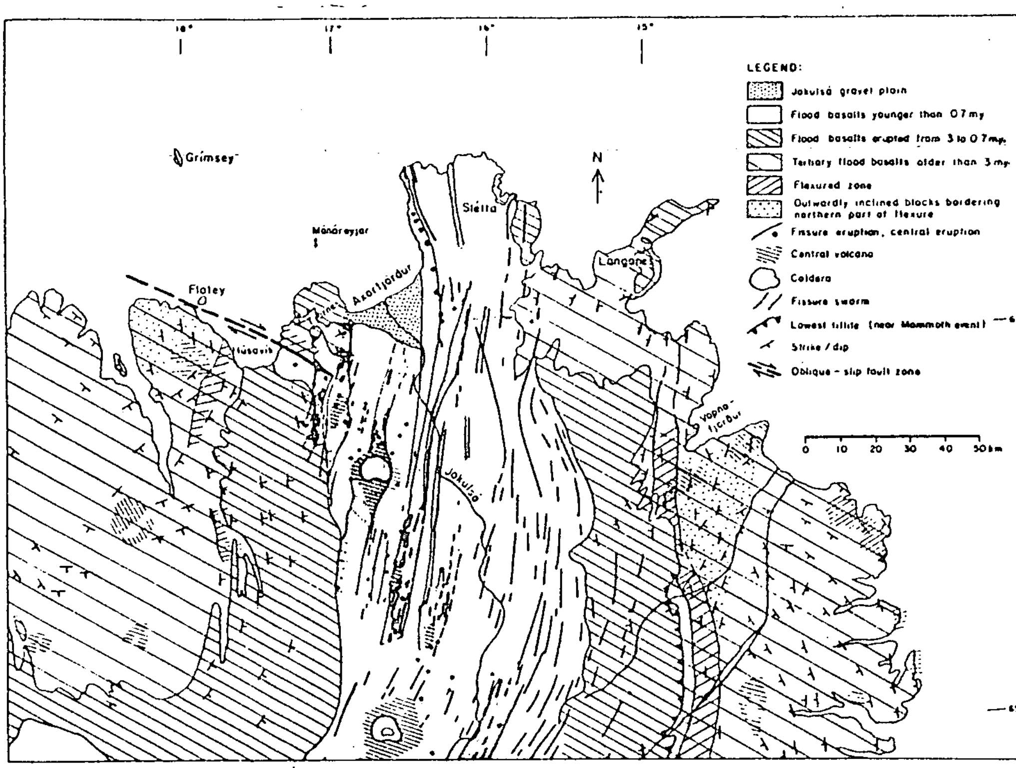


Figure 2.2. Tectonic setting of northeastern Iceland. From Saemundsson, 1974.

the south-west and south. The dips of the lavas are usually very gentle (2^{o}- 10^{o}) but tend to be steepest in the valley bottoms, but decrease upwards such that at the top of the plateau ($>$1100 m) they are barely discernible. The age of the lava pile ranges from more than 11 m.y. in the north (Saemundsson et al., 1980) to 6 m.y. in the south (Aronson and Saemundsson, 1975).

Three central volcanoes are known to be buried in the lava pile, one at Öxnadalur - Glerárdalur which is well inside the Eyjafjördur drainage area, and two others which occur near its margins in the north-east, at Flateyjardalur, and to the south-west, Torfufell, (Figure 1.1 and 2.2) (Björnsson and Saemundsson, 1975). None of these has been mapped.

Recent mapping of the lava pile west of Eyjafjördur, in the Tröllaskagi region north of Öxnadalur, shows almost no evidence of central volcanoes during its growth, which is somewhat exceptional when compared with other areas in Iceland. The lava flows are here on average 13 - 15 m thick with minor amounts of interbedded sediment and thin acid tuffs, which indicates that the lavas extend over great areas and were extruded onto a surface of low topographic gradient (Saemundsson et al., 1980).

In this 5 km thick lava pile the dominant lava type is of fine-grained tholeiite constituting about 60% of their total thickness. The remainder (40%) is composed of olivine tholeiites and lavas comprising much porphyritic plagioclase. Interbedded tuffs and sediment constitute about 7.5% of the thickness of the section (Saemundsson et al., 1980).

The proportion of sediment in this area of Iceland is slightly less than that found in eastern and western Iceland, where sediments constitute some 10% to 15% of the lava pile (Walker, 1959; McDougall et al., 1977).

The lavas have been mineralized and altered on a regional scale. In the deeply cut valley landscape a flat lying sequence of zeolite mineral zones are seen (Figure 2.3). These zones represent fossil isotherm surfaces caused by low grade burial metamorphism (Walker, 1959). The zeolite zones reach their highest level in the north, and decline slightly southward from there. The lava pile has by erosion been cut to expose the chabazite-thomsonite and analcime zone and these extend downwards into the mesolite-scolesite zone (Figure 2.3) (Pálmason et al., 1979). A more intense alteration can be seen in local hydrothermal aureoles associated with fossil central volcanoes inside the Eyjafjördur area. The inner aureoles may bear chlorite, epidote, calcite, quartz, launomtite, garnet and occasionally pyroxenes and amphiboles (Jóhannesson, 1975).

Zone of faulting and seismic activity has been described off Mid-Northern Iceland (Sykes, 1967). This zone named The Tjörnes Fracture Zone, connects the southern end of the submarine Kolbeinsey Ridge and the volcanic zone in north-east Iceland. According to Saemundsson (1974), this zone has been operative for the last 4 m.y.

On the Figure 2.4 are shown the epicenters for earthquakes in North Iceland larger than M 6.0 on Richter scale that have been reported since 1700. Inside Eyjafjördur and the surrounding area only earthquakes of low magnitudes have

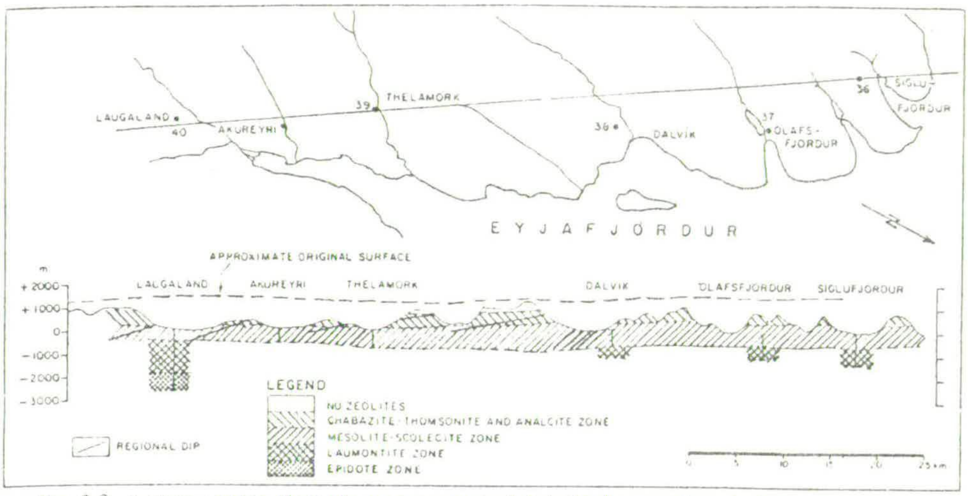


Fig. 2.3. A cross section along the western coast of Eyjafjördur, northern Iceland, showing the subsurface extension of the alteration zones. The original surface of the lava pile is indicated in the figure. From Palmason et al., 1979.

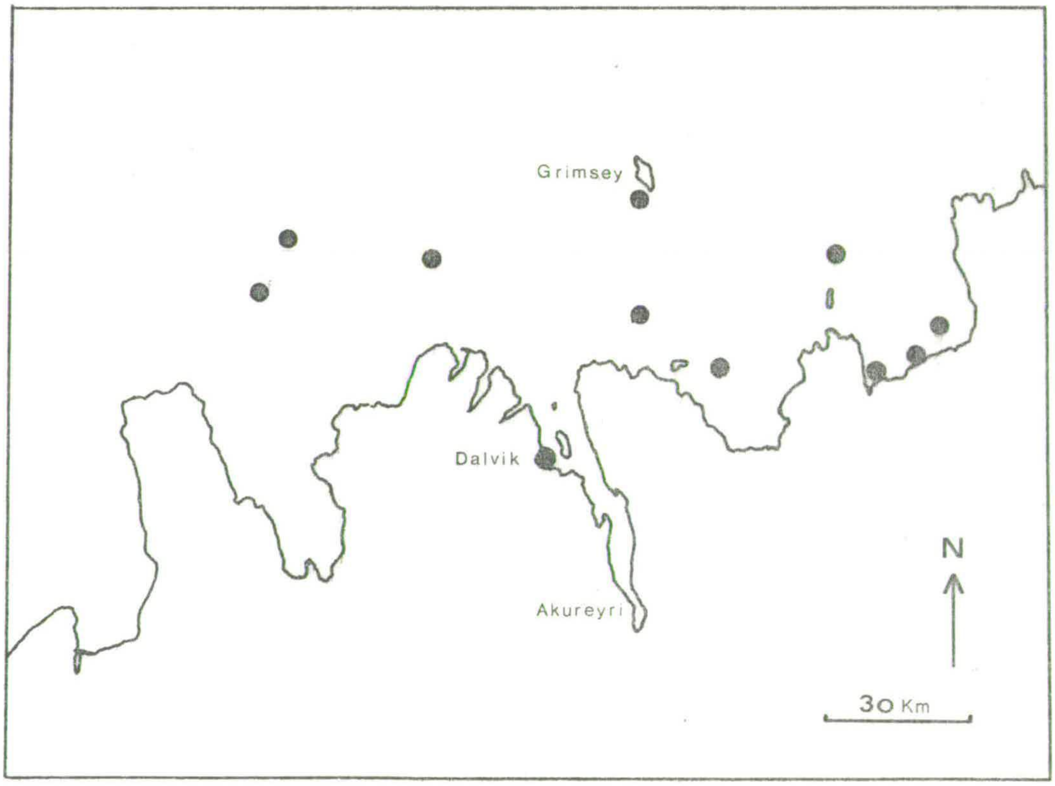


Figure 2.4. Epicentre of earthquakes in North Iceland at the magnitude M=6 on Richter scale since 1700 A.D. From Th. Einarsson, 1978.

been recorded except 1934, but an earthquake of the magnitude 6.25 caused an extensive damage in the village of Dalvík (Figure 1.1 and 2.4) (Thorarinsson, 1937a).

2. Late Weichselian - Holocene deposits.

Studies of glacial and postglacial deposits in Eyjafjördur extended back to the beginning of the century (Thoroddsen, 1905-06, 1908-11, 1913-15). Early work in the Eyjafjördur area is concentrated on local formations especially in Eyjafjördur (Eyjafjardardalur) and Fnjóskadalur (Figure 1.1). Topographically Fnjóskadalur can be described as a semitributary valley of Eyjajfördur through Dalsmynni suggesting a two distinct areas. However, recent studies have revealed that during the Late Weichselian time these areas were closely related and must be equally discussed.

As early as in the beginning of the century it was stated by Thoroddsen (1905-06, 1908-11, 1913-15) that during the maximum extent of the glaciation (the Weichselian) all of the North Iceland, except the highest mountains in the coastal regions, was ice covered. Similar conclusions were later reached by Thorarinsson (1937b), Hospers (1954), Tr. Einarsson (1959), Th. Einarsson (1961, 1967, 1968, 1973a,b, 1978), Milanovsky (1979) and Norddahl (1983). The distribution of flora also supports the existence of nunataks and suggests that a part of the Icelandic flora survived the last glaciation (Steindórsson, 1962).

During the retreat of the glacier from the coastal areas Fnjóskadalur bacame ice-free earlier than the surrounding valleys forming an ice-lake in Fnjóskadalur (Thoroddsen, 1905-06, 1908-11, 1913-15; Pjeturss, 1910; Hospers, 1954; Áskelsson, 1956; Tr. Einarsson, 1959; Th. Einarsson, 1967, 1968, 1973b,1978; Milanovsky, 1979; Norddahl, 1979, 1981, 1982, 1983). At first it was suggested that the ice-lake in Fnjóskadalur was dammed by a glacier in Dalsmynni (Pjeturss, 1910), but later Tr. Einarsson (1959) stated that the ice-lake was formed as active glacier-tongues from the main glaciers in Eyjafjördur and Bárdardalur to the east protrudes into Dalsmynni and Ljósavatnsskard, respectively (Figure 2.5). Similar opinion was reached by Th. Einarsson (1967, 1968, 1973b,1978) but he also suggested that the blockage of Dalsmynni and Ljósavatnsskard was due to a readvance of the glaciers in Eyjafjördur and Bárdardalur.

It was already pointed out by Thoroddsen 1905-06 that two ice-lakes were formed in Fnjóskadalur and later studies have concluded that several lakes were formed in the valley (Tr. Einarsson, 1959; Milanovsky, 1979, Norddahl, 1981, 1982, 1983). The idea was put forward by Tr. Einarsson (1959) that the ice-lake strandline recognized in Fnjóskadalur could be analoguous to the raised postglacial shorelines in Eyjafjördur having similar rising trend towards the south (Tr. Einarsson, 1966). This suggestion, that the ice-lake strandlines are of rising altitude towards the south, has now been proved correct (Norddahl, 1977, 1981, 1982, 1983). By studying the raised postglacial beaches in North Iceland

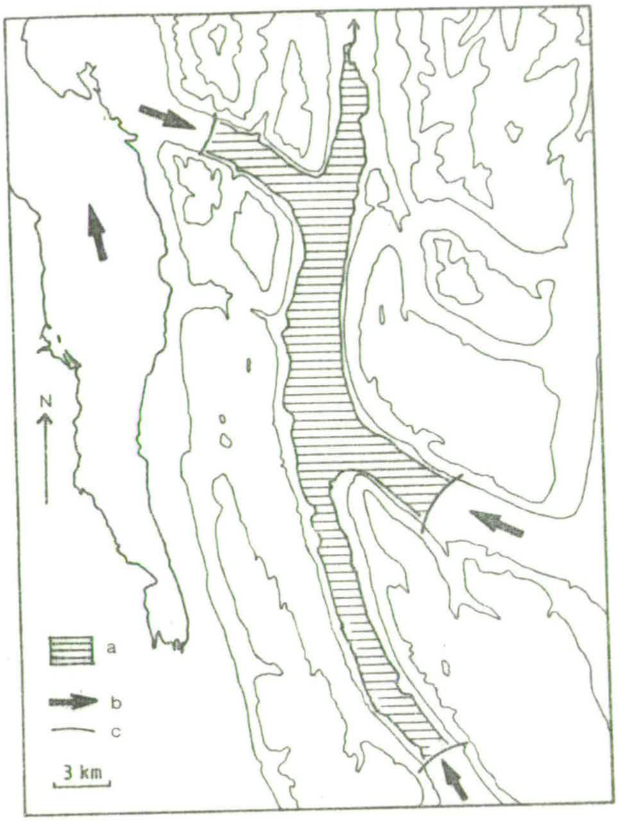


Figure 2.5. The last ice-lake phase in Fnjóskadalur (ca. 12.300 B.P.). a) ice-lake, b) main ice-streams, c) glacier termini. From Norddahl, 1983.

it should be possible to estimate the glacioisostatic depression of the land during the formation of various ice-lake stradlines in Fnjóskadalur together with the rate of the postglacial isostatic recovering, which started about 18.000 B.P. and was completed about 7.000 B.P. (Tr. Einarsson, 1966).

In Eyjafjördur the shorlines reaches their highest level just north of Akureyri, 26 m above the present sea level (Hallsdóttir, 1973) declining to the north along the fjord (Tr. Einarsson, 1959; Hjartarson, 1973), with gradient of about 0.40 m/km. Age of this event is correlated to the age of the highest shorelines in Iceland dated to be the Alleröd age (11.000 - 12.000 B.P.)(Kjartansson et al., 1964; Th. Einarsson, 1968, 1973b).

In a detail study of Late Pleistocene sediments in Fnjóskadalur, Norddahl (1981, 1983) has been able to calculate the strandline gradient for four of the nine lake phases recognized in the valley. Taking these strandlines as four periods of uplift it was considered feasible to look at the strandline gradients as a function of time. For calculating the uplift durations the Eyjafjördur shoreline gradient must be introduced as a reference and using the minimum age of 11.000 B.P. for this event Norddahl (1983) estimated the minimum ages for these four ice-lakes in Fnjóskadalur as:

12.300 $\frac{0}{100}$ B.P. Belgsá stage

17.000 $\frac{100}{300}$ B.P. Fornhólar stage

20.800	$\frac{500}{1000}$	B.P.	Orustuhóll stage
23.900	$\frac{1300}{2500}$	B.P.	Melar stage

Also four ice-lake phases have been recognized described older than the above phases, but they have not been dated.

Several people have studied the maximum extent of the glaciation in Eyjafjördur and the surrounding areas during the Weichselian time. The first attempt to estimate the northward extent of the glaciers in North Iceland is made by Tr. Einarsson (1959) and his conclusion is that the Grímseyjargrunn and the island of Grímsey were never overridden by glaciers suggesting an ice free continental shelf. However, glacial striae have been found on the island of Grímsey indicating that the glaciers in North Iceland had reached much further north than concluded by Tr. Einarsson (Th. Einarsson, 1967; Hoppe, 1968). The extension of ice beyond the present coast is not known in detail, but the position of the glacier's terminus has been described both from the North-west and from the South-west Iceland, drawn as a moraine ridge along the continental shelf margin at 200-250 m depth below present sea level supposing the maximum extent of the Weichselian glaciation in that areas (Ólafsdóttir, 1975; Haflidason, 1979).

The Weichselian maximum glaciation in Iceland has hitherto been assumed to have occurred about 18.000 B.P. (Tr. Einarsson, 1966; Th. Einarsson, 1973b) but this assumption is contradicted by Norddahl (1983) proposing the minimum age of the Melar stage about 23.900 B.P. and of the Grímsey stage referred as the maximum glaciation in North Iceland somewhat older.

Studies of the southward retreat of the glaciation in Eyjafjördur has in nearly all cases been combined with the ice-lake formation in Fnjóskadalur (Tr. Einarsson, 1959; Th. Einarsson, 1967, 1968, 1973b,1978; Hallsdóttir, 1973; Hjartarson, 1973; Milanovsky, 1979; Norddahl, 1981, 1982, 1983).

An attempt was made by Tr. Einarsson (1959) to estimate the position of the glacier in Eyjafjördur by reconstructing the maximum glaciation limit to the present topography. Using the elevation of the upper limit of the glaciation it is suggested that near Akureyri is it of 1050 m altitude and near the mouth of the fjord it is of 400 - 500 m altitude. A Similar conclusion is reached from a detailed study of Glerárdalur near Akureyri where the altitude of the surface of the glacier is estimated about 800 m (Hallsdóttir, 1973). According to Th. Einarsson (1967, 1968, 1973b,1978) the glacier has extended far out into the inlet of Eyjafjördur during the formation of ice-lake in Fnjóskadalur. Hjartarson (1973) concluded that the glacier terminated approximately across Hrísey and Milanovsky (1979) suggested that the glacier terminated about 3 km south of Hrísey. Concordant with this is the study of Norddahl (1982) estimating the northward extent of the glacier in Eyjafjördur, based on altitudes and gradients of lateral features in the Fnjóskadalur area and general longitudinal profiles of glaciers, to terminate just south of Hrísey.

Generally the results suggest that sufficient is to position the glacier terminus just south of Hrísey for creating a glacier tongue large enough for blocking Dalsmynni and damming up an ice-lake in Fnjóskadalur.

To date these events described above stratigraphical position and correlations with other areas have most frequently been used as no absolute dating of the Weichselian events is available from the Eyjafjördur area. Apart from the age of the Weichselian maximum glaciation in North Iceland previously descussed Th. Einarsson (1967, 1968, 1973,a,b, 1978) referred the ice-lake formation in Fnjóskadalur to a Late Weichselian event, but he also attempted to a more precise age estimate of it by correlating its formation with the Álftanes stage readvance, which has been dated C^{14} to be about 12.300 B.P. (Ashwell, 1967; Th. Einarsson, 1967, 1968, 1973b, 1978, 1979).

More recently Norddahl (1981, 1983) has been able to correlate the youngest ice-lake formed in Fnjóskadalur (Figure 2.5) with the Álftanes stage on the basis of strandline gradient and the age of the maximum transgression which followed the retreat of the Álftanes stage glaciers dated about 11.000 B.P. (Th. Einarsson, 1964, 1968, 1973a, 1973b, 1978).

In Eyjafjördur geological studies have not been able to determine more than two readvance stages, the Álftanes and the Búdi stages, since the maximum of the Weichselian glaciation. However, studies of the Fnjóskadalur environmental phases have revealed at least eighteen different stages of advance and retreat in this area and strandlines from nine ice-lake phases have been recognized. The emptying of each of these ice-lakes seems to have occurred through Dalsmynni into Eyjafjördur due to a retreat of the glacier in Eyjafjördur and its glacier-tongue in Dalsmynni (Norddahl, 1981, 1982, 1983). The repeated appearances and disappearances of ice-lakes in Fnjóskadalur is also reflected in repeated advance and retreat of the Eyjafjördur glacier. The exact position of the terminus of the glacier-tongue in Eyjafjördur is not known, but taking the terminus of the glacier-tongues known from Fnjóskadalur into consideration and the size of the ice-lakes it is suggested that during all the nine ice-lake phases extending from 12.300 B.P. (Figure 2.5) to more than 23.900 B.P. (Norddahl, 1983) the Eyjafjördur glacier-tongues generally terminated in the outer part of the fjord and only occasionally extended out of the fjord.

Following the retreat of the glaciation in the end of the Álftanes stage and the maximum transgression about 11.000 B.P. the readvance of the inland ice formed moraines dated by C^{14} to 10.000 - 11.000 B.P. (Th. Einarsson, 1964) also correlated with the Salpausselkä-Raerne stage in Fennoscandia (Thorarinsson, 1951, 1960). In the Eyjafjördur area the inland ice is estimated only to have reached the southern part of Eyjafjördur during the Búdi stage terminating 35 km south of the head of the fjord at Hólar (Th. Einarsson, 1967, 1973b). Similarly the number of terminal moraines described in the tributary valleys of Eyjafjördur and formed by local valley glaciers are also correlated with the Búdi stage (Th. Einarsson, 1967, 1968, 1973b, 1978; Hallsdóttir, 1973; Hjartarson, 1973; Nordahl, 1979, 1981, 1983).

2.2 Denudation and erosion rate

The basalt plateau between Skagafjördur and Skjálfandi is of Upper Tertiary age. During its development, the climate was warm and moist, similar to that measured on the eastern coast of North America today, but signs of flora deterioration from warm temperate to temperate has been recorded from this period (Símonarson, 1979).

Physical weathering at first was insignificant except for areas close to the central volcanoes allowing for the formation of an extensive lava plain with thin units of interbeded sediments. Most rain soaked into the porous lava and has drained off in the form of spring-fed rivers (Th. Einarsson, 1968).

Growth and burial of the lava pile allowed for some degree of mineral alteration to zeolites. The degree of alteration increases downwards and some low grade burial metamorphism is noted in the deeply cut fjordlandscape.

The structural position of zeolite zones indicate that the landscape was flat with little relief by the time volcanic activity has ended in the Eyjafjördur area. This alteration by remineralization of the lavas caused the run-off pattern to change from spring-fed rivers to direct run-off rivers, developing a dendric drainage pattern. Erosion increases markedly and following a rapid deterioration of the climate about 3.0 m.y. ago (Mc.Dougall et al., 1966; Saemunds., 1974; Kristjánsson et al., 1980) glaciers are introduced as the main geomorphological component with the development of tillites.

During the first one million year of glaciation the tillite seems to have been formed mainly in topographic high areas, but at 2 million years there is for the first time evidence of a regional glaciation (Albertsson, 1978; Eiríksson, 1979). Stratigraphical studies in Iceland reveal at least 10 glaciations, probably more, during the Pleistocene (Th. Einarsson, 1973b). In the Eyjafjördur area such deposits have only been described from the last glaciation and during the Holocene.

To estimate the denudation ant the erosion rate of the Eyjafjördur area (Figure 2.6) knowledge of the main topographic features as they appear today and the stratigraphic history of the pile have to be known. Remains of the ectensive volcanic plateau are still visible even where the overall lowering of the original surface is 200 - 500 m. At sea level erosion has been estimated to be 1200 - 1500 m (Figure 2.6 and 2.7). Erosion on this scale has been measured in western Iceland, where 800 - 1000 meters deep valleys have been carved out in less than 1.8 m.y. (Saemundsson, 1979) and even in less than 1.0 m.y (Saemundsson, 1979) on the Snaefellsnes Peninsula (Th. Einarsson, 1967). However, in the Eyjafjördur area the plateau basalt seems to be somewhat more resistant, probably because its lack of lithologic variation.

The extent of the study area (Figure 2.6) is in general limited to the Tertiary Plateau Basalt formation (see Figure 2.1 and 2.2), the topographic high area between Skjálfandi and Skagafjördur (Figure 1.1) and the 50-100 m depth contours

Figure 2.6. Topographical map of the Eyjafjördur area. Location of the transverse profiles illustrated in Figure 2.7 is shown.

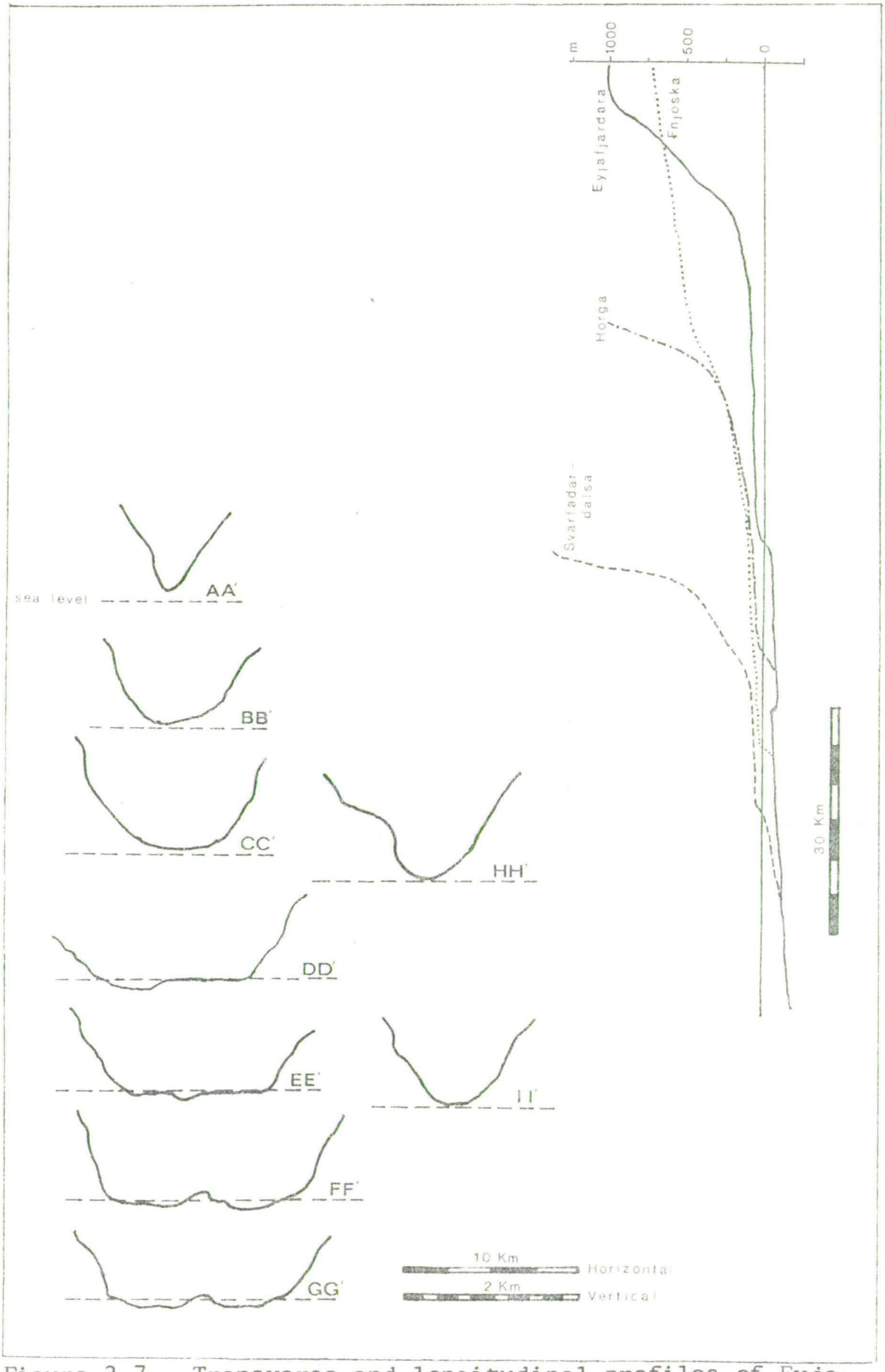


Figure 2.7. Transverse and longitudinal profiles of Eyjafjördur and the main tributary valleys.

to the north. The original upper surface of this plateau is estimated using the zones of alteration described for this area in Figure 2.3.

In the Eyjafjördur area it is assumed that the main erosion ~~rate event~~ has lasted about 3 m.y. However, evidence of a regional glaciation is for the first time reported at 2 m.y. as discussed above and the erosion rate is also calculated for this event. The denudation and erosion rate for the area outlined in Figure 2.6 is:

a) for areas of an average height of 1500 m above sea level	0.29 mm/y over 3 m.y.	0.39 mm/y " 2 m.y.
b) for areas of an average height of 1600 m above sea level	0.32 mm/y over 3 m.y.	0.44 mm/y " 2 m.y.

Thus on average the denudation rate is about 0.3 - 0.4 mm/y. For comparison denudation rates of other areas in Iceland have been estimated using sediment load transport as it appears today (Tómasson, 1976).

Table 2.1

Region	Rates of denudation mm/year
Vatnajökull	3.2
Mýrdalsjökull	4.5
Hofsjökull	0.9
Langjökull	0.4
Other glaciers	0.3
Unglaciated areas	0.1

after Tómasson (1976).

2.3 Bathymetry

The shape of Eyjafjördur is long and narrow. At its mouth the width is about 12 to 15 km, but decreases to 2.5 km near the head of the fjord, 60 km inland (Figure 1.1). The approximate area ~~size~~ of the fjord ~~area~~ is 480 km^2.

Near the mouth of Eyjafjördur two islands, Hrísey and Hrólfssker, divide the main fjord into two parallel fjords, Eyjafjördur and Svarfadardalur, which coalesce at the mouth. Two other valleys, Ólafsfjördur and Hédinsfjördur, eroded down to sea level, also open obliquely into the main fjord near the mouth.

The bathymetry of the fjord is shown in Figure 2.8. Essentially it is a shallow fjord and for the most part its depth is $<$100 m, however towards the mouth the fjord deepens to 150 m and at the mouth depths can exceed 200 m. A major feature is the presence of a minor sill of 70 m depth across the fjord north-east of Hjalteyri. Another major bathymetric feature is the bisection of the fjord due to the islands Hrísey/Hrólfssker. The fjord west of the islands has the same character as described above for the main fjord, except no sill is recorded. This bifurcation of Eyjafjördur disappears at its mouth, and is traceable 160 km northwards as a single groove in the sea floor, down to 500 m depth.

Six profiles based on echosounding showing the variation in cross section of Eyjafjördur have been drawn (Figure 2.8). These show a fairly gradual slope of the side walls, in the shallower parts of the fjord. In all the profiles the bottom of the fjord is flat and probably represents sedimentary infill.

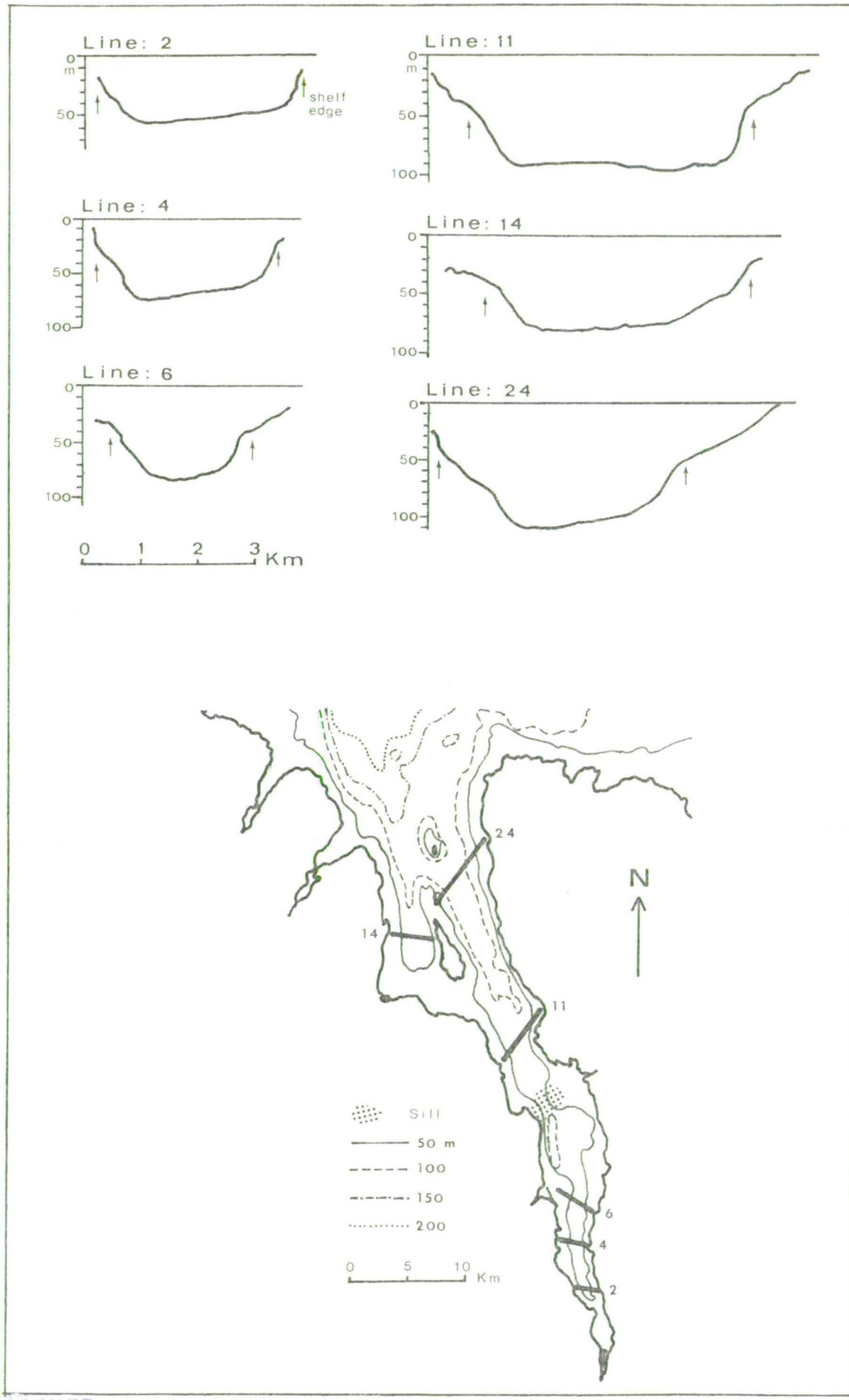


Figure 2.8. Bathymetrical chart of Eyjafjördur

The sill in the middle of the fjord conveniently divides the fjord into an inner and outer part. Also, in the inner part bathymetric features show a basin to exist the deep middle part of the fjord and a marginal shelf of 20 - 40 m depth that can be followed arount the fjord (Figure 2.8).

2.4 Climate and hydrology

The climate in Iceland can be described as cold temperate and maritime. The average temperature for the warmest summer month is about 11°C on the south coast and about 9°C on the north coast. The average temperature for the coldest winter month is -1°C to -2°C on these respective coasts.

The paths of the atmospheric depressions crossing the North Atlantic usually lie close to Iceland. The country is therefore in an area of high cyclonic activity situated on the border of cold polar air masses and warm air masses of sub-tropical origin. The climate of Iceland is also affected by the confluence of warm and cold oecanic currents, namely, a branch of the Gulf Stream and the polar East Greenland Current. The East Greenland Current sometimes carries Arctic drift ice towards the Icelandic coast and strongly affects both air-temperature and precipitation. The precipitation is very unevenly distributed, which is to be expected in mountainous country, Figure 2.9 (Eythorsson and Sigtryggsson, 1971).

In the Eyjafjördur district (Tröllaskagi), with high ground and high precipitation, about 115 cirque and valley glaciers of the Alpine type are found; the total area covered by ice is approximately 40 km^2 (0.5% of the total drainage area). Only a few of the glaciers cover more than 1 km^2. The orographic snowline lies at 1200-1400 m, but is down to 900 - 1000 m on the valley glaciers (Björnsson, 1979).

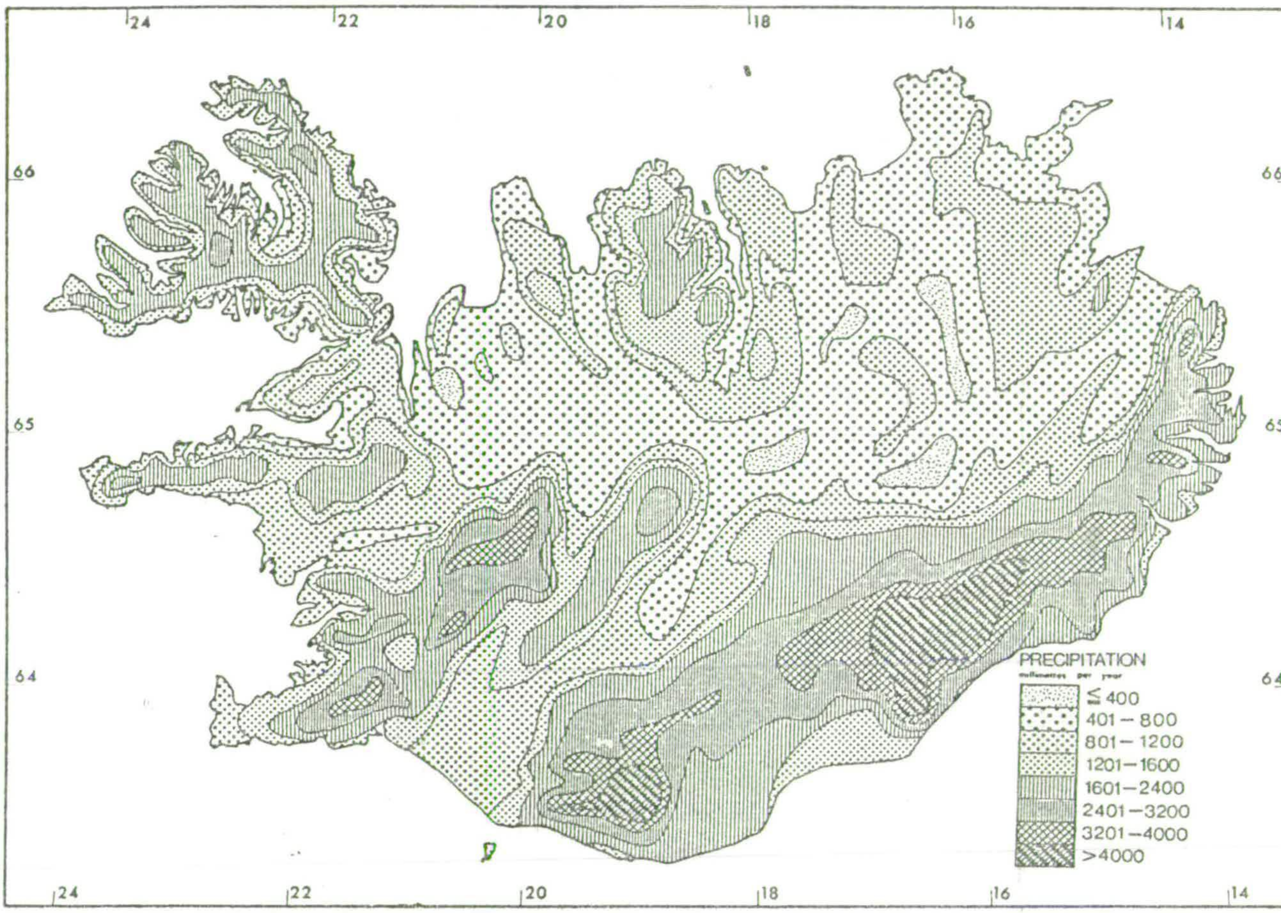


Figure 2.9. Distribution of precipitation. Average for 1931 - 1960. From Eythorsson and Sigtryggsson, 1971.

The drainage area for the whole of Eyjafjördur is 4700 km^2. Into the inner part of Eyjafjördur three main rivers discharge, all by direct run-off. They are Fnjóská, Eyjafjardará and Hörgá with catchment areas of 1310 km^2, 1300 km^2 and 653 km^2 respectively (Figure 2.10). In the latter however there is some glacier discharge from two or three small rivers.

In the outer part of Eyjafjördur the main discharge has been from the Svarfadardalsá (460 km^2); this river is a mixture of direct run-off rivers and rivers from cirques and small valley glaciers (Figure 2.10).

The sediment has not been trapped in lakes or dams on the way to sea, but is carried directly into the fjord by the rivers. The only exception is in Ólafsjördur, the fjord that opens into Eyjafjördur at its entrance, where the rivers first accumulate into a lake before entering the sea (Figure 1.1 and 2.10).

There are few direct run-off measurements available from the Eyjafjördur drainage area and these have been "spot" rather than continous measurements. The average discharge is known to be approximately 15 - 40 m^3/sec for the main rivers (approximately 40 l/sec km^2), but can be 7 - 8 times that in floods (Rist, 1956; Tómasson <u>et al</u>., 1973, Pálsson, per. commun.). There is however one exception to this. Continous gauging has been made on the river Kolka, on the west side of Tröllaskagi, which can be regarded as characteristic for most of the rivers in the Eyjafjördur area (Pálsson, pers. commun.). The mean monthly run-off and precipitation has been drawn up for

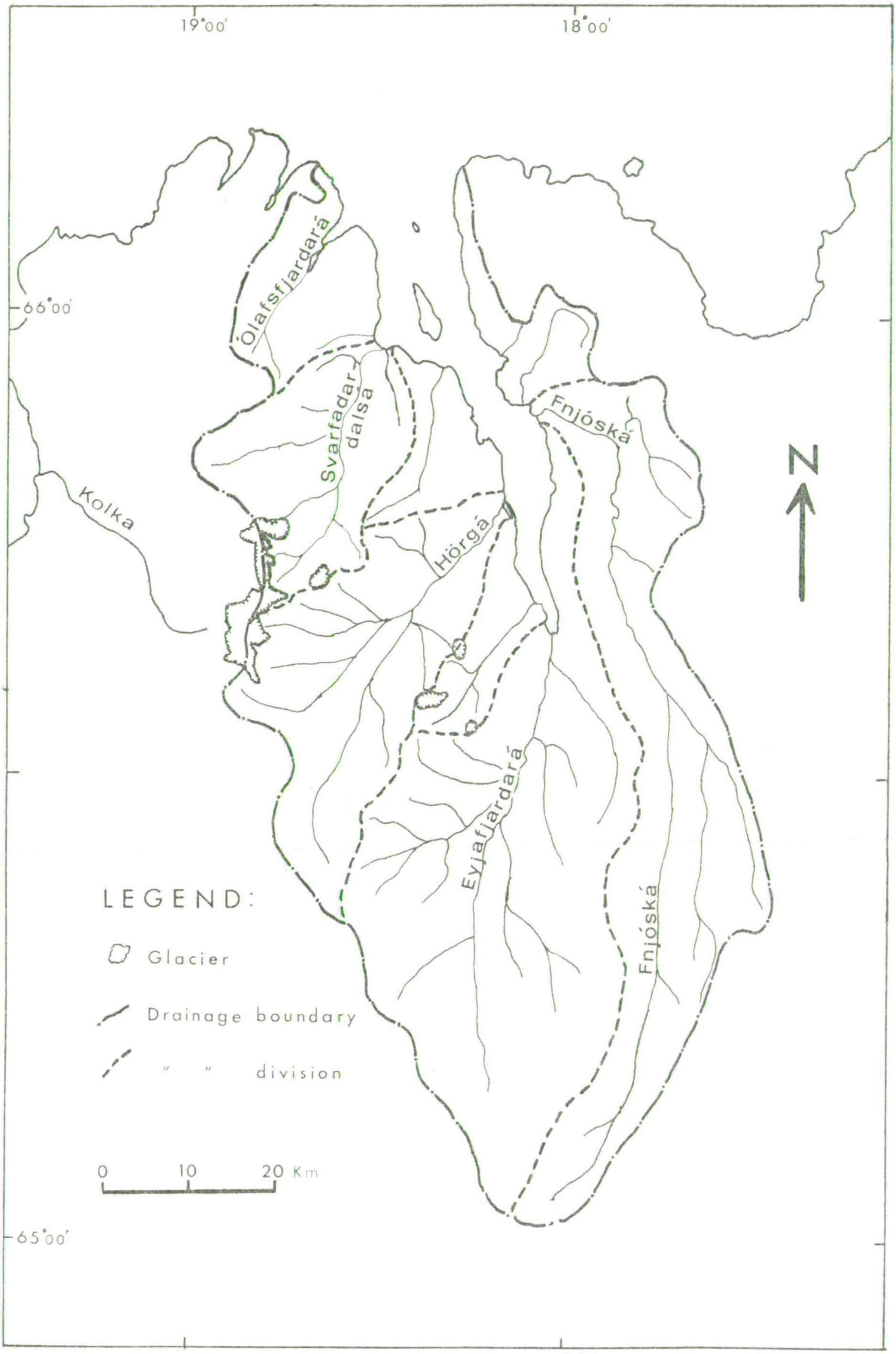


Figure 2.10. The drainage area of Eyjafjördur and the main rivers.

this river during the period January 1978 to December 1980 (Figure 2.11). This graph can be described as characteristic both for the precipitation pattern as well as the direct run-off pattern. In spite of a great fluctuation in the precipitation an annual cycle of three peaks can be discerned. There are two major peaks, one in late spring early summer and an other in the autumn and a small peak in late winter.

The seasonal fluctuation in rivers run-off shows a certain degree a similarity to that of the precipitation. However, there is just one well defined peak, instead of three, due to high mountain regions and frost and snow effects. Direct run-off from high mountain rivers in the Eyjafjördur area, appear to have their high-water flood in June instead of April - May as is found in the lowlands. Also, the flood peak in rivers from high mountain regions is much smoother than the flood peak from lowland rivers (Rist, 1956). In late summer the run-off decreases considerably, but may often increase again in autumn owing to increased precipitation. When the winter sets in, the run-off decreases again and diminishes steadily during the frost period.

It is well known that input of freshwater in a coastal area can affect the surface salinity (cf. Helland - Hansen and Nansen, 1909) and in fjords it is probably the most important factor that affects the water properties. This means it is controlled by two main components, direct rainfall drainage into the rivers and the fjord, and precipitation stored in the form of winter snow in the mountains

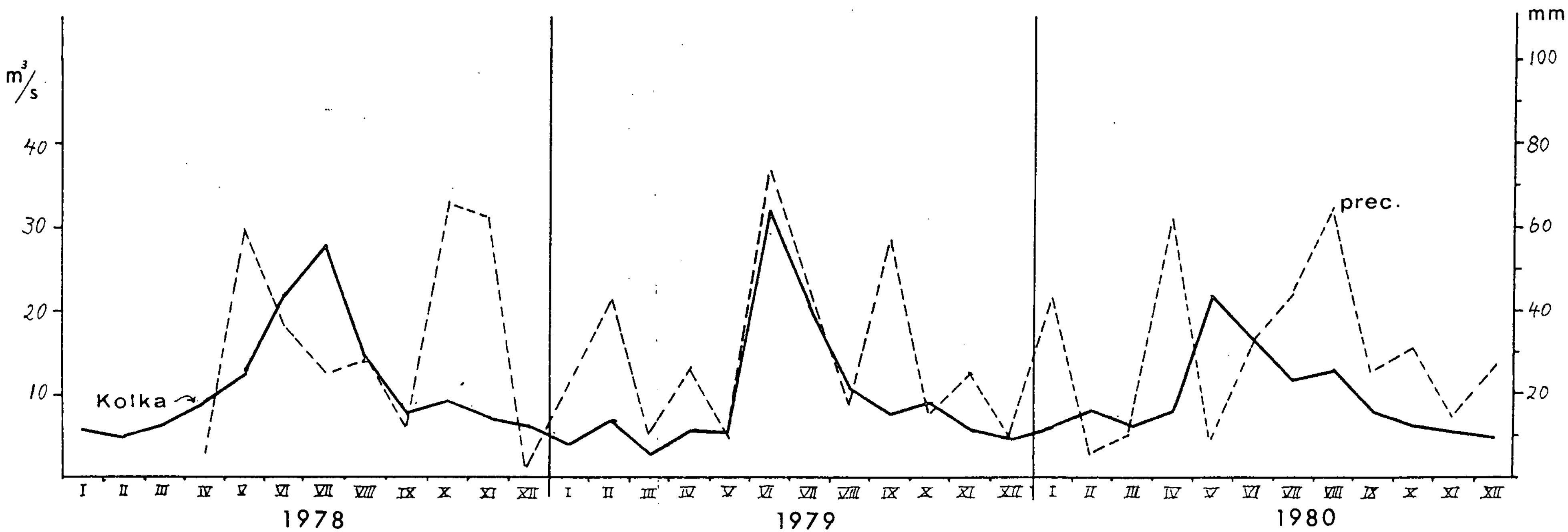


Figure 2.11. Variations in precipitation and run-off from the river Kolka from January 1978 to December 1980 (see location Figure 2.10).

which melts during a short period in the summer causing floods in the rivers.

The thickness of a layer of water spread over the whole fjord area could also indicate the freshwater input. Where the average annual run-off for the drainage area is estimated as 4o l/s km^2 the freshwater input to the fjord is calculated to form a ~12 mm thick layer in Eyjafjördur. Comparison with Alaska fjords indicates that Eyjafjördur is a high run-off fjord (Pickard and Stanton, 1980).

2.5 Hydrography

a) Water masses.

It is possible to distinguish between three primary water masses in the region north of Iceland. The character of each of them is shown in Table 2.2.

Table 2.2

	T°C	S ‰
Atlantic Water	>4.0	>35.00
Polar Water	<0.0	<34.50
Arctic Bottom Water	<0.0	~ 34.92

(Based on Stefánsson, 1962)

Two secondary water masses, formed by dilution or intermixing from the primary water masses, can be considered here. They are Arctic Water and Coastal Water.

Temperature and salinity is variable, because mixing is constantly taking place.

The Arctic Water denotes the mixed waters occupying the surface layers in the central part of the region between Iceland, Greenland and Jan Mayen. This water consists mainly of an intermixture of Polar Water coming originally from the Norwegian Current.

The Coastal Water may naturally be of a very variable composition, consisting of Atlantic Water and/or Arctic Water diluted by fresh water from the land (Stefánsson, 1962).

b) Circulation.

The general water circulation on the Icelandic continental shelf is clockwise along the coast. From the south the Irminger current brings more or less warm Atlantic influx along the western and northern coast of the island and from the north the East Icelandic Current brings cold water eastward along the coast (Figure 2.12). These two current systems are the dominating factors in the circulation around Iceland.

In the North Icelandic Coastal area the influx from west appears as a moderately strong current with maximum velocities near the slope of the coastal shelf, but this influx can fail from year to year. More inshore, however, the current is of lower velocity and more irregular and the current direction seems to be determined largely by the bottom configuration. It appears, for example from the density distribution, that the current in the shelf area

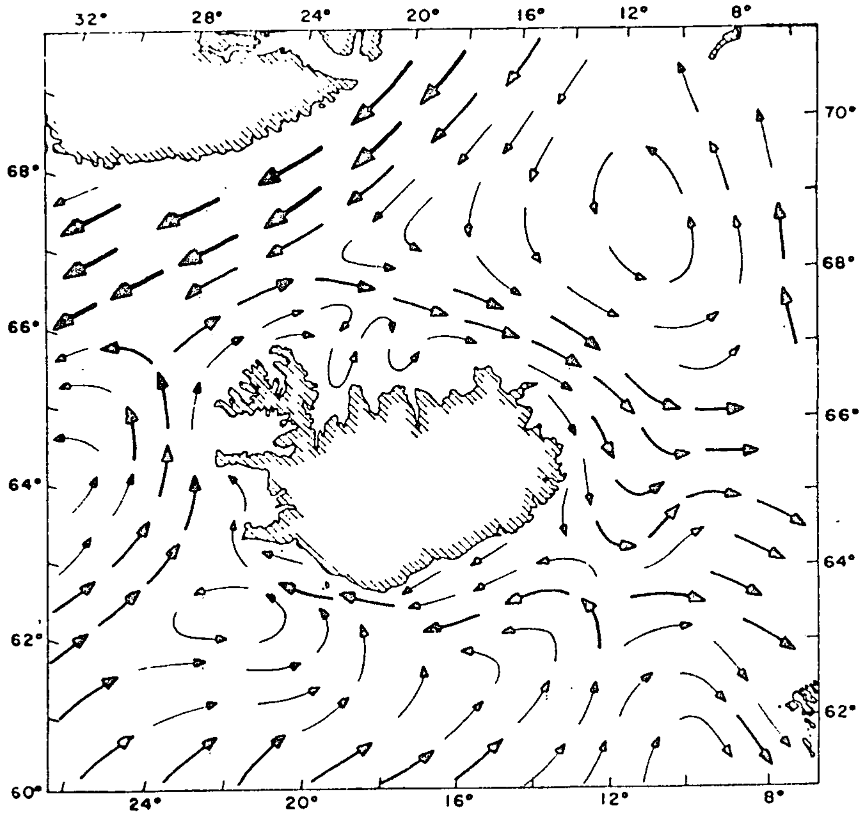


Figure 2.12. Surface currents in the sea aound Iceland. From Stefánsson, 1961.

north of Iceland, due to the bottom configuration, has a southward component along the west side of the Eyjafjardaráll and a northward component along the east side. The mean velocity of the coastal current is estimated to be about 7 cm/sec (Stefánsson, 1962).

c) Fjord hydrography.

Some of the first continous measurements made of temperature and salinity in an Icelandic fjord were carried out, by the Marine Research Institute, Reykjavík, in the inner part of Eyjafjördur in 1959/1960 (Figure 2.13 A). They lasted for 14 months and during that time 8 hydrographic sections were taken (Figure 2.14 and 2.15).

In these hydrographic sections the marked change with seasons is quite clear, especially in the surface layers. In summer when the water is stratified the light Coastal Water is limited to a thin surface layer above the thermocline, and it spreads out in the fjord. In October and November the winter convection has started and the water is turned over. When the water column has been homogenized it must contain Coastal Water from the summer which will reduce its salinity. In February and March this water has been carried away from the area, and the Coastal Water now does not extend as far out into the fjord as in summer. Besides, the run-off from land has by now been reduced because of freezing (Figure 2.14 and 2.15).

In addition to the profiles from 1959/1960, which were limited to the inner part of the fjord, further temperature-

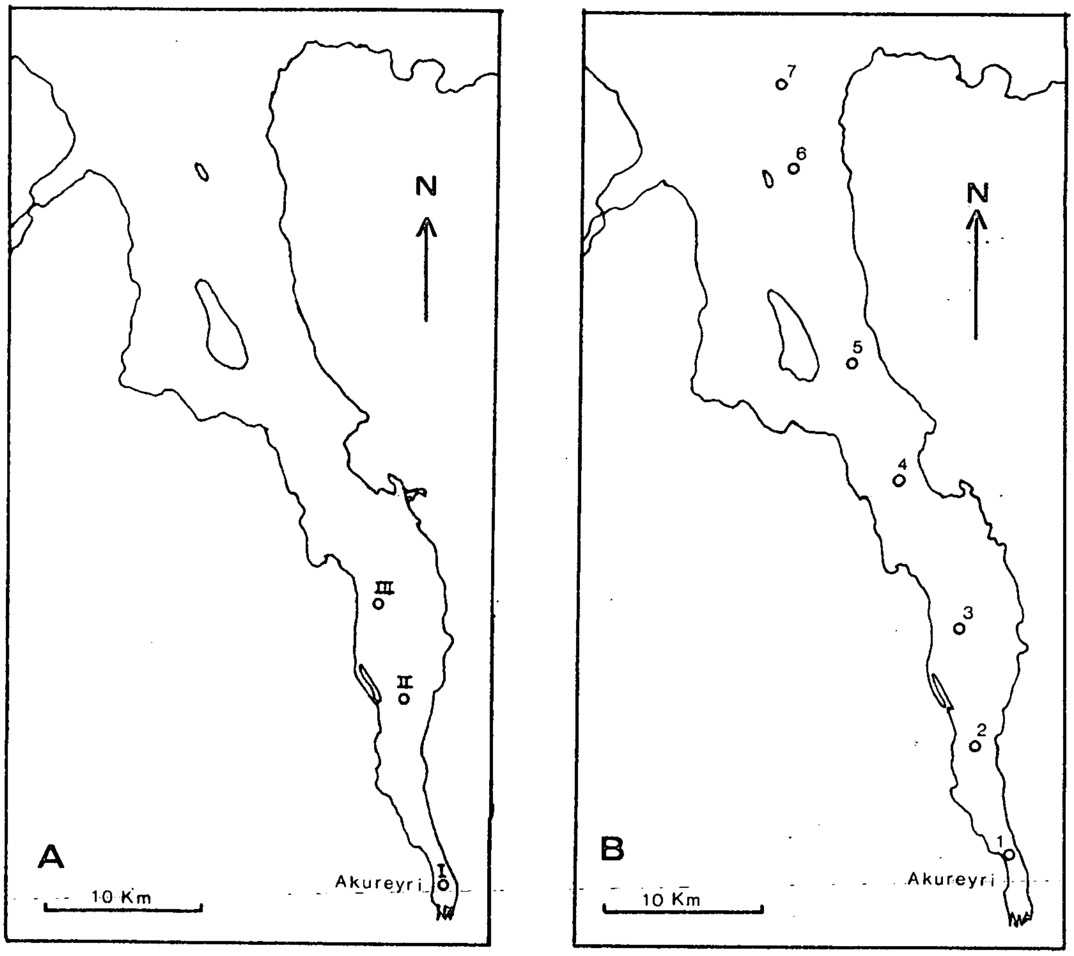


Figure 2.13. Location of hydrographic sections in Eyjafjördur. A. Section taken 1959-1960. B. section taken 1974-1977.

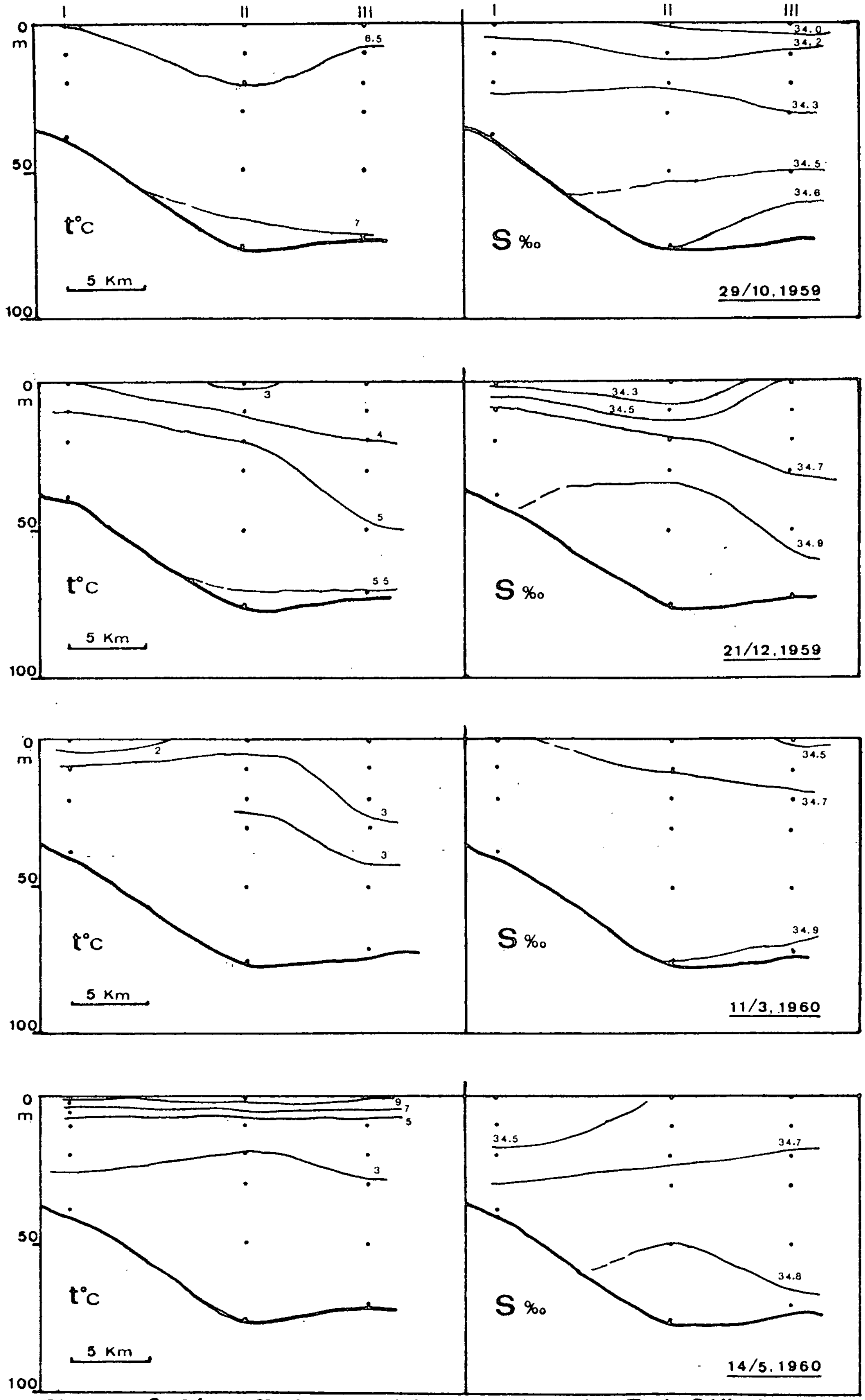


Figure 2.14. Hydrographic section in Eyjafjördur 1959-1960.

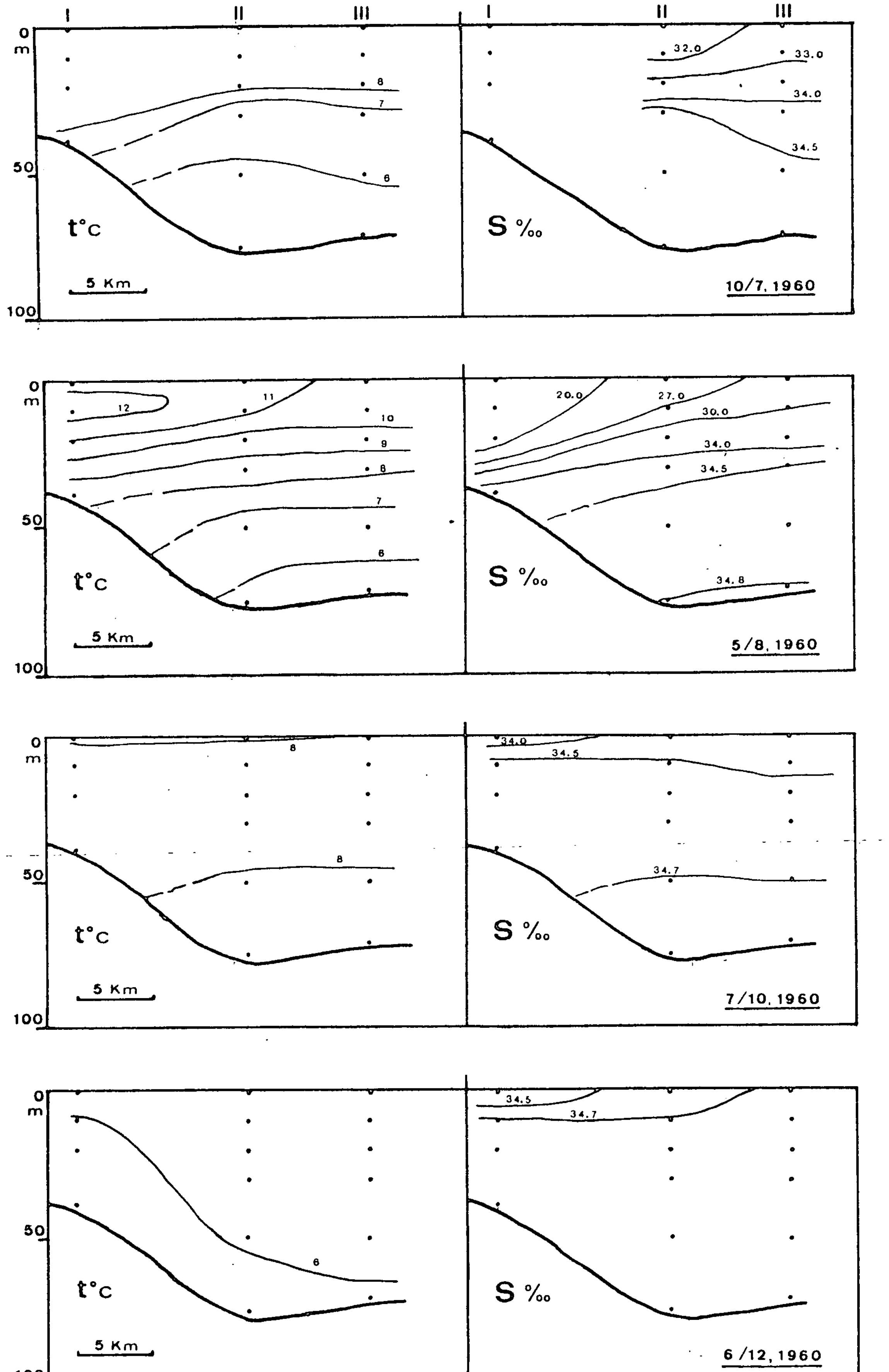


Figure 2.15. Hydrographic section in Eyjafjördur 1960.

salinity measurements were carried out in 1974 to 1977 by the Marine Res. Inst. at seven stations for different seasons (Figures 2.12 B, 2.16, 2.17). These sections show basically the same cycle as described above, but in the 1974/1977 sections the Coastal Water is perhaps more near the mouth dominant, having the 34.7‰ as its highest salinity.

Stefánsson (1981) has pointed out that difference in surface salinity in Eyjafjördur in late May 1974 compared with June 1976 can be matched with meteorological data, where the precipitation for June 1976 is more than twice that measured for late May 1974. As has been mentioned in a previous chapter (chapter 2.3) it is also important to take the snow melting into account, especially at this time of the year.

In a high run-off fjord, as is Eyjafjördur, stratification is a characteristic feature as can be seen in the T-S sections. Taking the 1974/1976 sections as an example a well-defined surface layer of approximately 5 m thick and with a market halocline below is seen as a characteristic for the inner part of the fjord. Toward the mouth the surface layer becomes less defined following decreasing stability and increasing vertical mixing. The longitudinal differences of the salinities show a typical estuarine profile, where the steep gradient in the inner part reflects high freshwater inflow. The same characteristics have been described by Pickard and Stanton (1980), for high run-off fjords on the Pacific coast.

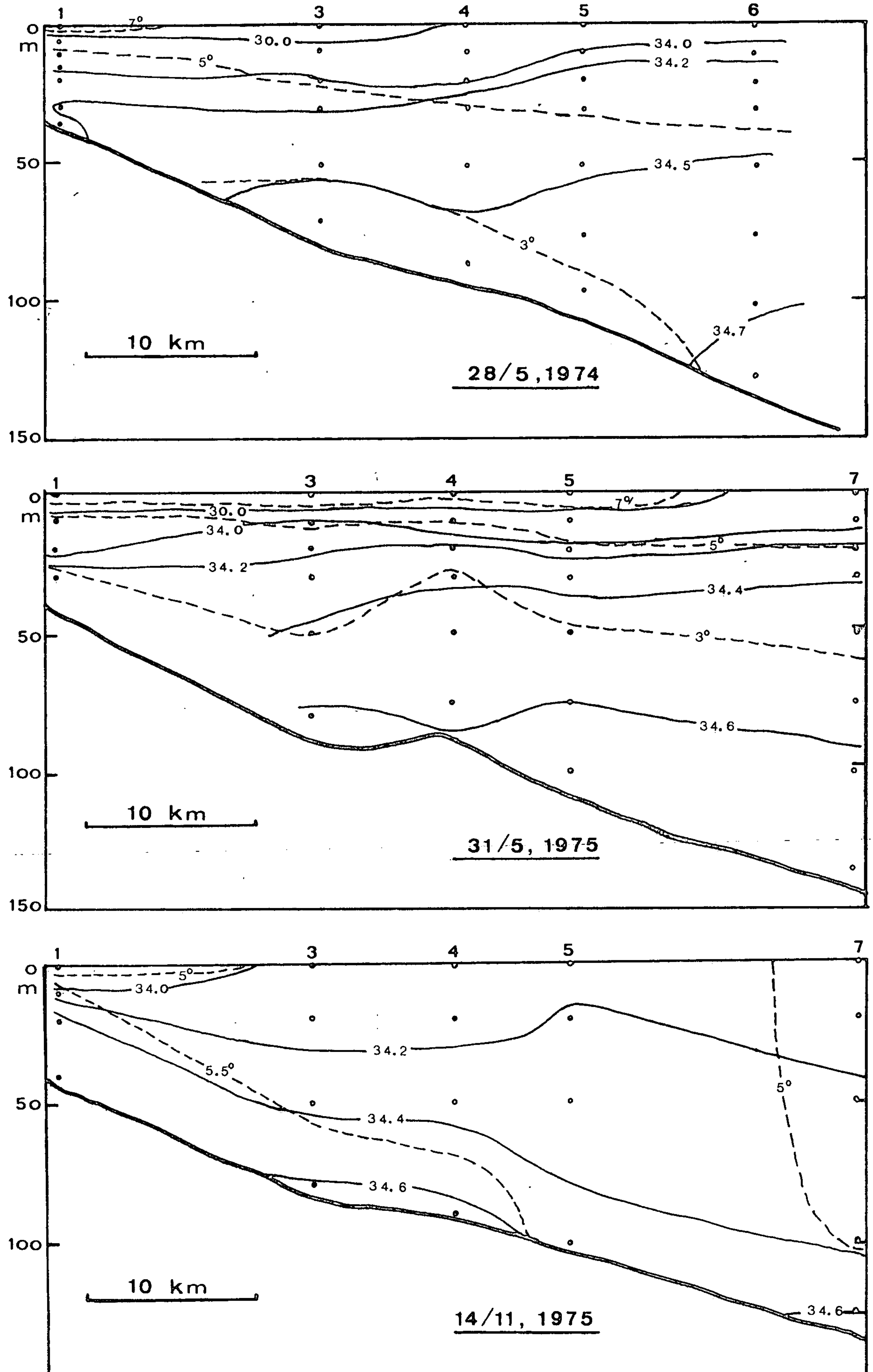


Figure 2.16. Hydrographic section in Eyjafjördur 1974-1975.

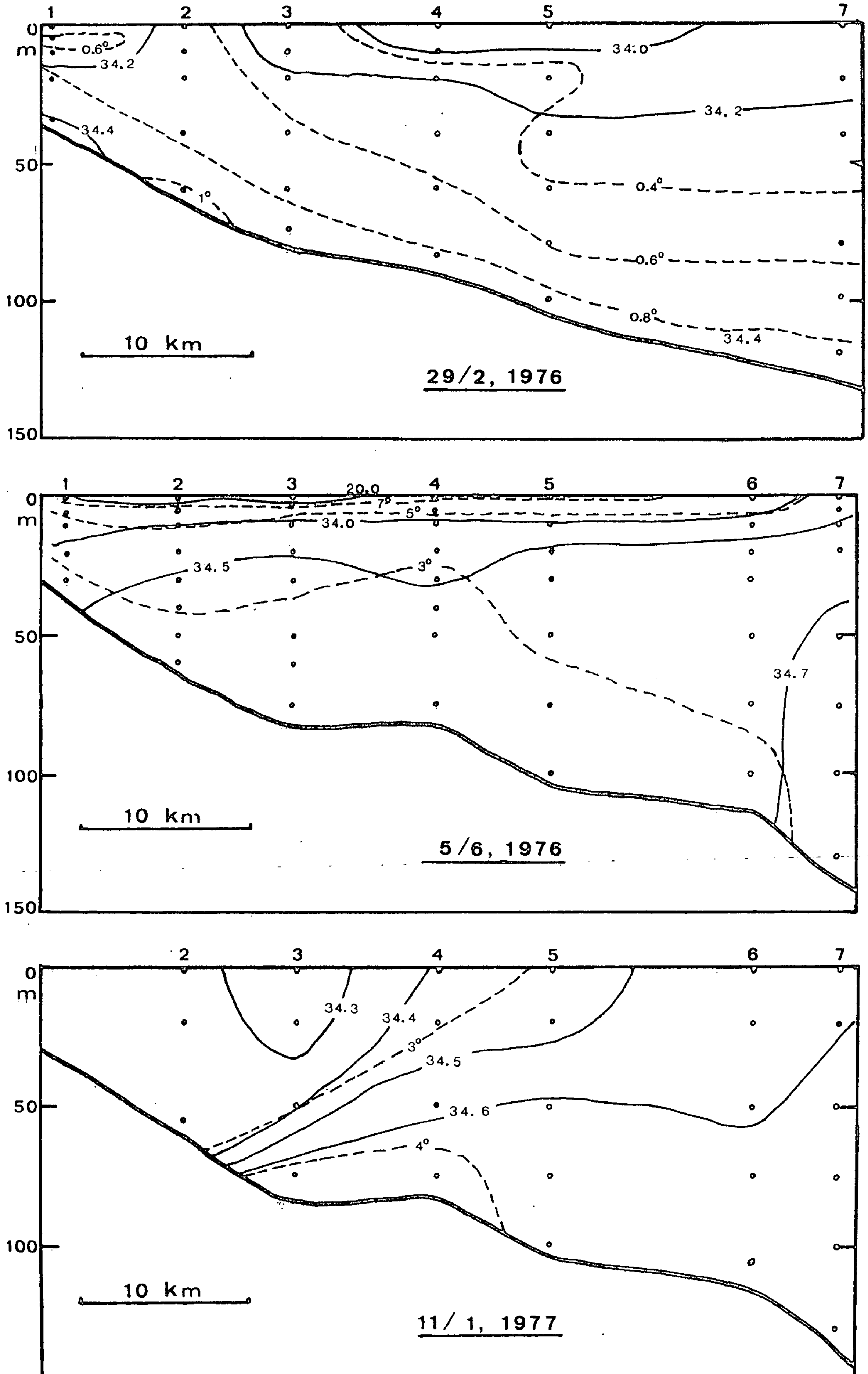


Figure 2.17. Hydrographic section in Eyjafjördur 1976-1977.

d) Fjord circulation.

A common circulation pattern in a fjord with estuarine characters is a so called two layer system i.e. an upper fresh or lower salinity layer flowing seaward and a dense layer of saline water below flowing inward (Pickard and Stanton, 1980).

Direct current measurements were carried out in the summer 1973 and 1974 on a section across Eyjafjördur, where the fjord is at its narrowest part, just off Akureyri (Figure 2.18) (Malmberg 1978). Consecutive observations were made at various depths over three days, and a continuous recording at location A during the period of one month and at location B during the period of two months. In general three current layers were observed on this section (Figure 2.18): 1) a thin surface layer with a steady outflow both during flood and ebb tides and, 2) an inflowing intermediate layer also both during the flood and ebb tides and 3) an in/out - flowing bottom layer where the main direction is obviously affected by the bottom topography. The mean velocity of this current was measured about 3 cm/sec to the south, with maximum velocities up to 40 cm/sec in the inflow during the flood tide (Malmberg, 1978). The intermediate layer has not been explained adequately, but can possibly be related to the outlet to some of the rivers in the outer part of the fjord (Malmberg, 1978). It could also be explained as a compensatory undercurrent to the surface outflow.

In the sea around Iceland the tides are semi-diurnal with a marked diurnal inequality. The mean spring range for

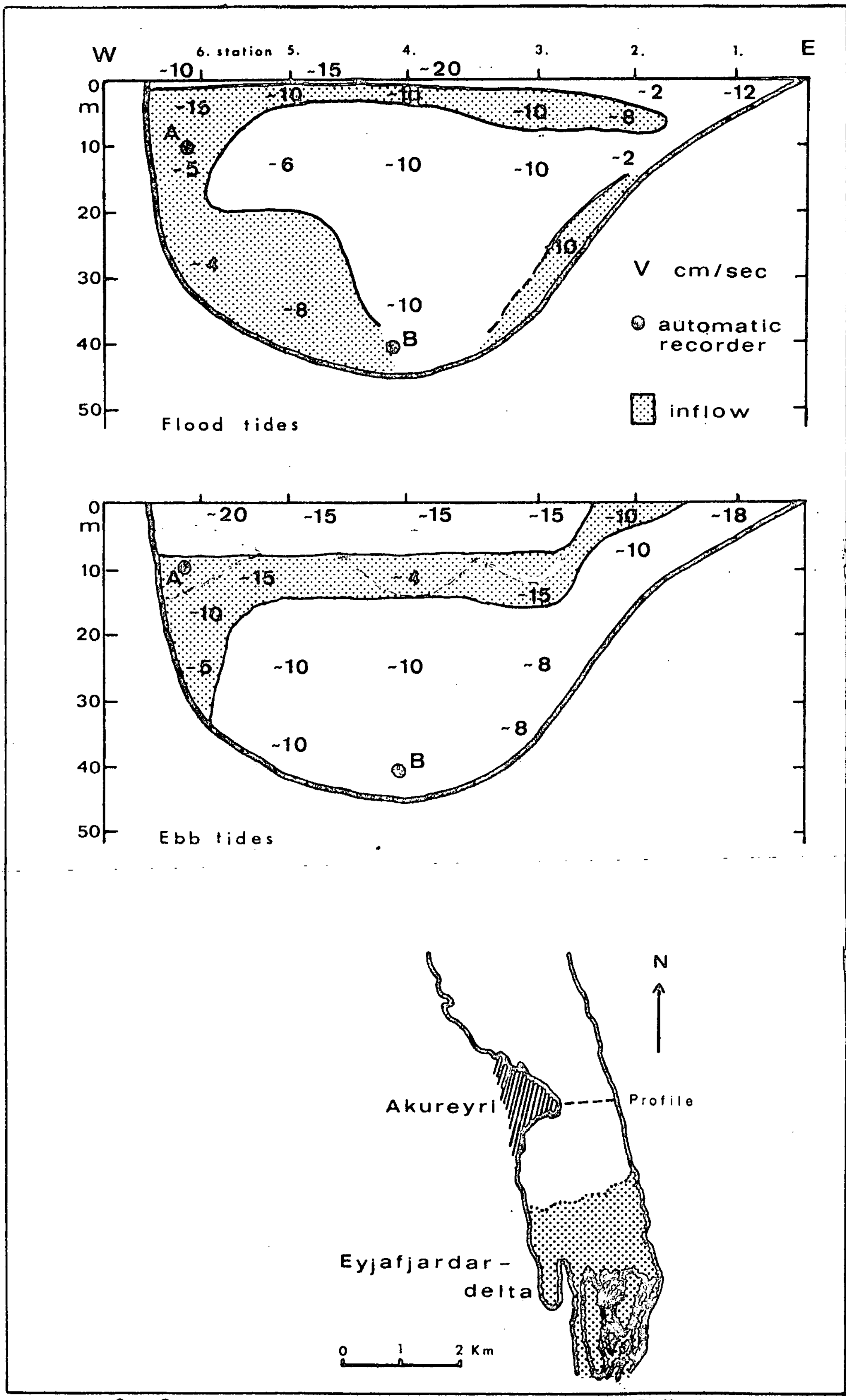


Figure 2.18. Velocity profile across Eyjafjördur off Akureyri. From Malmberg, 1978.

Eyjafjördur is given as 1.3 m and the mean neap range as 0.6 m (Icel. Hydrgr. Service). The times of high and low water and the range of tide are basically the same at the head as at the mouth of Eyjafjördur and according to Pickard and Rodgers (1959) tidal currents are observed at all depths in fjords.

e) Waves.

In Eyjafjördur wave energy can also be described as an important factor in the sedimentation. The coastline is long compared with the size of the fjord and most of the coast is dominated by cliff-walls, except where the rivers flow into the fjord. In a long and narrow fjord like this the effect of waves varies according to where inside the fjord it is taking place. For example, in the outer part the coast is exposed to relatively high energy swells and storm waves from the open sea, while the coastline in the inner part is moulded by low energy waves, originating within the area and which are restricted to the fetch conditions of the inner part.

Chapter 3. METHODS OF STUDY.

3.0 Introduction.

Field work has been carried out both on land and at sea where the main emphasis was of an examination of the sediment of the fjord. Four cruises to the area, between 1978 and 1980, were undertaken in collaboration with Dr. Kjartan Thors at the Marine Research Institute, Reykjavík. During the first cruise (D-12-78, October 1978) on r/s 'Dröfn' a preliminary survey of the fjord was made from the collection of grab samples and boomer seismic- and bathymetric profiles. During the second cruise (A-12-79, October 1979) on r/s 'Árni Fridriksson', sparker seismic profiles were taken and on the third cruise (A-15-79, November 1979) on the same research vessel all the cores were taken and a few sparker profiles. The last cruise (D-3-80, February 1980) on r/s 'Dröfn' completed the seismic survey grid (Figure 3.1).

3.1 Sampling.

a) On land.

The sampling on land was in two parts and undertaken in 1979 and 1980. Firstly, emphasis was laid on getting a good range of samples from the white ash bands in soil from the

Eyjafjördur area and a complete coverage of at least one soil profile. Secondly, samples were taken from rivers, deltas and the lava pile.

b) At sea.

Twenty three Shipek grab samples were taken in the fjord's basin and on the shelf around the fjord. These were stored in polythene jars and brought back to Edinburgh for analysis. These samples were chosen to assess the variation in the character of surface marine sediment in the research area. In addition fifteen piston and three gravity cores were collected from the fjord. In spite of a considerable effort to take cores from the slope and the shelf only one gravity was collected from this area.

The corer used was a modified Kullenberg corer, which could be used either as a piston or a gravity corer (see Appendix C). The piston cores were on average 8.4 meters; the greatest length being 9.4 meters. The gravity cores were generally 1.3 meters in length.

Core material collected in a plastic liner were cut into suitable lengths, their ends sealed, and stored vertically in a cool place until they were landed. On land all the cores were cut lengthwise into two halves with an electro-osmosis butcher knife which leaves the sediment surface smooth and undisturbed for detailed descriptions (Chmelik, 1967; Bouma, 1969). Each half was then pakced in two plastic tubes and heat sealed. As most of the samples did not show any obvious structure such as laminations or colour changes it was thought possible that some of the sediments were disturbed during coring. For many of the cores, this was not so.

Radiography facilities, however, were made available at The National Hospital in Reykjavík. Owing to the thickness of the samples (up to 2.5 cm) and that the film used was of medical instead of industrial type, some of the finer details of sedimentary structure were obscured. The results of x-rays clearly shows that all the gravity cores were undisturbed. For the piston cores all showed an undisturbed sediment in the upper one meter or so. However at depth most showed some occasional disturbance and only two showed completely undisturbed sediment for their entire length.

3.2 Seismic survey.

For the seismic profiling both boomer and the sparker sources were used; the former gave high resolution but limited penetration and the latter comparatively good resolution and high penetration. Details of the equipment used are given in Appendix B.

Because no tape recorder was available pre-selection had to be made on the frequency range recorded. For the Boomer system with a pulse energy of 1000 joules (ws), 300 - 550 Hz were selected, but in the sparker system with a pulse energy of 6000 joules, 24 - 650 Hz were recorded.

The total length of the continous seismic profiling was 390 km, comprising 158 km of boomer tracks and 232 km of sparker tracks (Figure 3.1).

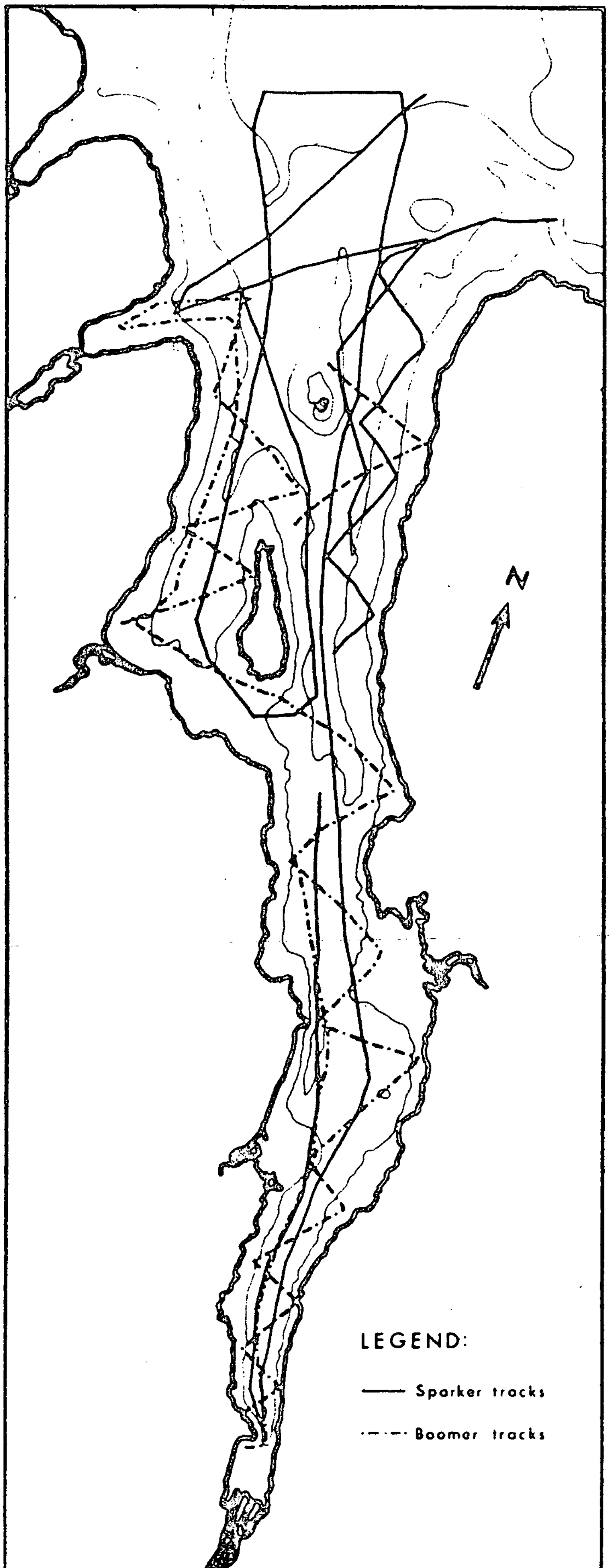


Figure 3.1. Boomer and Sparker tracks in Eyjafjördur. Depth contours with 50 m intervals.

Chapter 4. SEISMIC SURVEY

4.1 Introduction

A seismic survey on a wide variety of fjord systems has been carried out both in the northern and the southern hemisphere. Most of this work can be described either as a reconnaissance or as a local industrial survey, usually published is mimeographed reports. An exception, however, is the studies of Holtedahl (1975) and Boulton et al., (1981).

The purpose of this chapter is to give a detail description of the sediment distribution in an Icelandic fjord, Eyjafjördur, and to relate it to geological studies on land.

The Eyjafjördur area comprises a highly glaciated landscape, forming a dendritic network of troughs and fjords. The glacial erosion has been concentrated in troughs forming a landscape of selective linear erosion (Figures 2.6 and 2.7). The largest of the troughs is the Eyjafjardardalur-Eyjafjördur and Svarfadardalur the submarine parts of which are presently being studied.

The seismic studies enabled the recognition of the shape of the troughs basin as well as providing information to the structure and thickness of the sediment infilling.

In the interpretation of the seismic records, a distinction is made between three main seismic textures:

1) A major acoustic reflector, which commonly gives strong hyperbolic reflectors from its surface, interpreted as the surface of bedrock. In the Eyja-

fjördur area the bedrock is usually partly and sometimes entirely covered with till.

2) This texture also gives a strong surface reflection, usually with numerous hyperbolic reflectors, but lacks internal coherency which partly results from a compaction and deformation of sediment layers (rugged surface) and partly from reflections from cobbles and boulders set within a finer matrix. In this study this type of seismic texture is referred to as a morainic structure. Usually it is relatively easy to distinguish between seismic texture 1 and 2 because of the strength of the bedrock surface reflector.

3) A seismic texture comprising a 'horizontally' layered structure which is believed to record relatively homogeneous sediments. In the present study usually referred to as a proglacial sediment.

4.2 Presentation and limitation of the seismic measurements.

In measuring the sediment thickness and structure of the sediment infilling only seismic reflection technique has been employed. To fulfill the aims of the study the seismic profiling had to give a good coverage of the fjord (Figure 3.1). Firstly, to make possible a relatively accurate figuring of the sediment distribution in the fjord and the depth to the basement. Secondly, to give a representative picture of the sediment structure in various parts of the fjord.

In measuring the sediment thickness and the sediment structures in the deeper parts of the fjord Sparker equipment was used. Boomer records were also used to assess the upper few metres of the sediment in the deeper parts of the fjord and for estimating the sediment thickness where it is thin. This is because the shock waves created by the Boomer and Sparker system provide a different vertical resolution in the sediment. For the Boomer system the pulse length is approximately 2 - 4 ms and the frequency band filtered onto the seismic recorder 300 - 550 Hz. The resolution is 2 - 6 metres. In the Sparker system the pulse length is approximately 5 - 10 ms and the frequency interval filtered on the recorder is 24 - 650 Hz. The vertical resolution is therefore estimated 8 - 12 m.

Because no refraction measurements have been carried out in the fjord the velocity in the sediment is estimated with reference to available refraction measurements from another Icelandic fjord (Thors, 1978). In a quite comparable sedimentation environment the results are:

a) unconsolidated to weakly/moderately consolidated sediment	1.5 - 1.7 m/s
b) till material	2.0 - 2.5 m/s
c) basement - basalt lavas	4.0 - 4.5 m/s

Also, measurements available from Norwegian fjords show quite similar results, but each sediment type does show a slightly greater range (Sandvik, 1976, 1977).

The fact that neither tape recording nor digital processing of the reflection data was possible, due to the equipment used, it was only possible in few cases to identify the real surface of the basement. With a fixed filter band during the recording and only one hydrophone to pick up the signals from reflecting layers, the profiles, especially the deep ones, are often dominated by multiple reflections and other noise. In such cases only those sediments above acoustic basement could be assessed.

During the Boomer measurements much of the undesired ground motion originated from the ship's propeller, tended to dominate over all other signals. These difficulties were solved by alternately engaging and disengaging the propeller during the cruise.

The results of the seismic survey are displayed on a time-related rather than a depth-related scale. The reason for this is twofold. Firstly, direct velocity determinations of the Eyjafjördur sediments have not been carried out and secondly, due to the form of the seismic data i.e.

no digital processing was possible it was impracticable to calculate all the seismic profiles in light of a velocity-depth model. The scale used during the processing is in milliseconds (ms) for two-way time travel. In general terms 10 milliseconds two-way time travel corresponds to about 7.5 metres measured in a sea water, but 10 - 12 metres measured in a till material. The increase of velocity with depth has not been allowed for in this generalization.

The maps expressed for the sediment distribution are entirely based on the seismic reflection profiling except in the innermost part of the fjord where the penetration was limited to the top few metres of the sediment. Very useful information came from a borehole located in the Eyjafjardará delta (Figure 4.1). The borehole exceeded 110 m depth and did not reach bedrock (Jónsson, pers. information).

4.3 The shape of the fjord

A. Depth to the basement

The geomorphological feature of the fjord's bottom as evidenced by the position of the basement is outlined in Figure 4.1 As described in chapter 4.2 the depth sometimes can only be measured down to the acoustic basement. Extensive studies on land show that the basement of glaciated valleys in the Eyjafjördur area is most frequently covered with till, usually not a very thick formation (T. Einarsson, 1959; Hjartarson, 1973; Norddahl, 1983). Seismic record irregularities above the basement often show an uneven surface

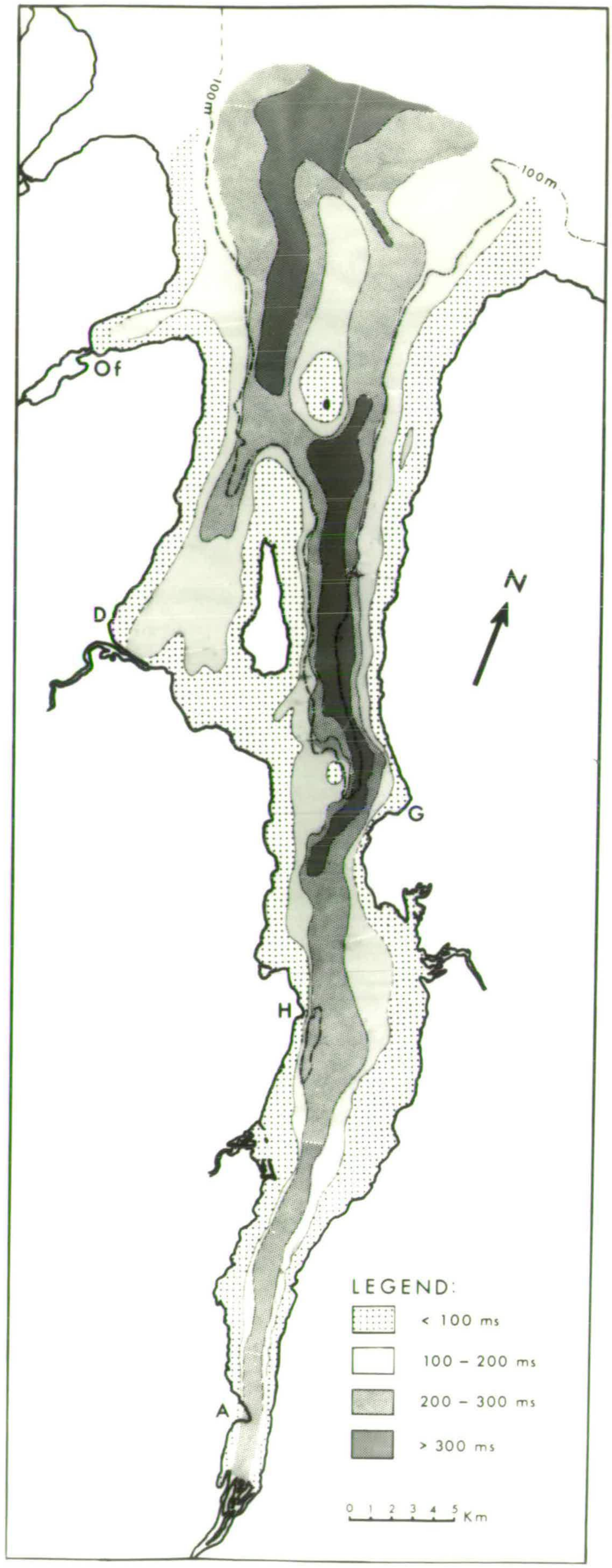


Figure 4.1. Depth in milliseconds to the acoustic basement of Eyjafjördur (time related scale).

of till deposit confirming this interpretation (Figure 4.5).

The main features of the map (Figure 4.1) drawn with 100 ms isobath lines can be outlined in the following paragraphs:

- a shelf of about 1 - 2 km width and approximately 100 ms (70-80 metres) depth can be followed around the fjord and the islands.
- a trench of 1 - 2 km width runs along the middle of the fjord, the deepest part exceeding a depth of 350 - 400 ms (ca 320-360 m) east of Hrísey.
- along this trench the topography is relatively smooth forming only a minor sill on either side of Hrólfssker.
- the division of the fjord into two parallel fjords on either side of Hrísey-Hrólfssker, as indicated on the bathymetric charts (Figure 2.8), is further confirmed.
- the depth configuration as well as the seismic records indicate that the erosion along Eyjafjördur is more directed to the west, through the strait south of Hrólfssker.
- the division of Eyjafjördur into two parallel fjords is not evident in the outermost part of the fjord.

B. Morphology

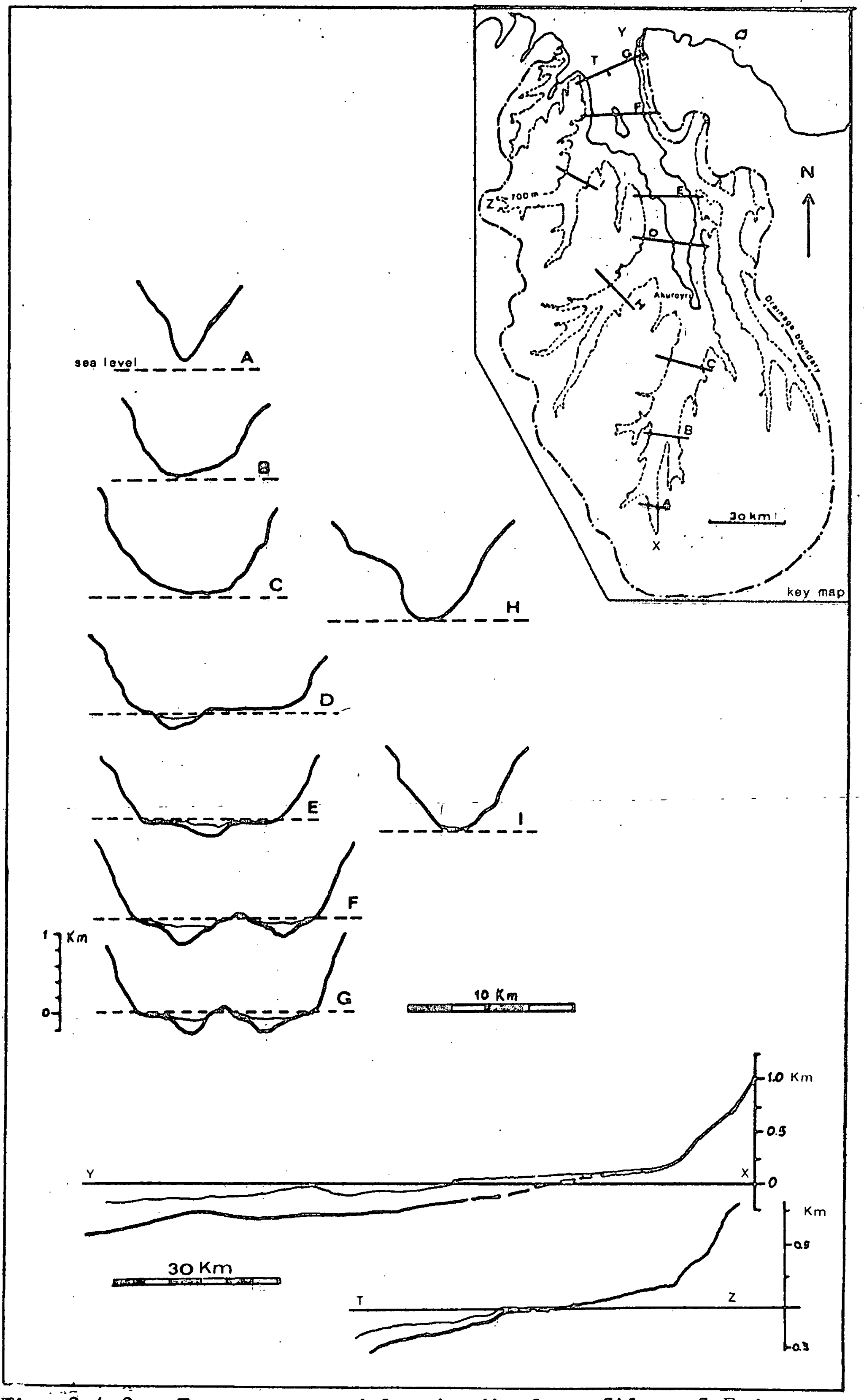
The shape of the fjord's bottom as expressed on the map in Figure 4.1 is used for drawing both cross and longitudinal profiles of the research area. By studying these profiles the features characteristic of glaciated valleys can be more easily figured out and analysed and the structure in the sediment infill more easily recognized and understood.

<u>The cross-profiles</u> of Eyjafjördur/Eyjafjardardalur, outlined in Figure 4.2 are drawn equidistantly along the valley. Also, two profiles from adjacent valley systems are expressed.

The profiles outlined from the inner part of Eyja-fjardardalur (Section A to C, Figure 4.2) show a typical evolution of a glaciated valley. The innermost section indicates a V-shaped form, a narrow valley floor with a sloping side walls, but northwards sections show a gradual change to a symmetrical U-shape form with a considerably over-deepened side walls and a relatively broad valley floor. The formation of the U-shaped cross-profile is achieved by the widening of the valley from a V-shaped form without over-deepening. This glacial parabolic or U-shaped form of the valley floor is the most striking characteristics of a well-developed glaciated valley (Embleton and King, 1975).

Further to the north the valley has deepened down to the sea level and the tributary valley shown in Section H has coalesced with the main valley causing an asymmetrical structure of the fjord where the cross-profile is a truncated U-shaped form (Section D). Here one can recognize two erosion levels i.e one related to the main valley where the erosion has extended below sea level and the other where the erosion level is still above sea level in continuation of the tribuatry valley (Section H).

Between sections D and E the intervening divides have



Figur2 4.2. Transverse and longitudinal profiles of Eyjafjördur and Svarfadardalur down to the acoustic basement.

progressively diminished and disappeared in section E, where the valley has again reached its symmetrical form. The shape of the cross-profile has the same truncated U-form as described in section D.

In the two outermost sections (F and G) the cross-profile topography bocomes enlarged due to intersection of a sub-parallel valley system (Section I). Northwards two troughs of a nearly equal size have been eroded in parallel.

With the enlargement in width of the fjord the intervening divide becomes progressively less evident and is non-existent at the fjord's mouth.

<u>The longitudinal-profile</u> (Figure 4.2) along with the cross-profiles shows likeness to characteristic sections of glaciated valleys. The most striking features of the form are the existence of the basins and steps. These are, to a large extent, associated with the presence of tributary hanging valleys and truncated spurs that can be recorded along the valley sides.

In Eyjafjördur area a longitudinal-profile has been drawn of the acoustic bottom both for the Eyjafjördur valley and for the Svarfadardalur valley (Figure 4.2). What is characteristic for these profiles is that the typical basin form is not recognized on land in the form of lakes and these profiles show evenly sloped trough basins from the 'trough head' along the valley and continously out of the fjord. What separates the Eyjafjördur longitudinal profile from those classified as typical river valleys is the existence of a minor sill in the outer part of the fjord and the steep sides of the tributary valleys where they coalesce with the main valley.

The relatively good precision achieved by the seismic profiling makes many of the deviations of irregularities from the ideal glacial parabolic or U-shape important in the interpretation of sediment infill.

4.4 Sediment distribution

A. Thickness.

A map of the sediment thickness is presented in Figure 4.3. This map is based on the same data as expressed in the depth to the acoustic basement map (Figure 4.1) and the scale used is the same i.e. milliseconds. The isobath lines are drawn with 20 ms or 40 ms interval instead of 100 ms on the basement map. As an example 20 ms are approximately 16 - 18 metres.

The results presented seem to be in harmony with those described from previous maps published from the fjord i.e. the bathymetric map and the basement map (Figures 2.8 and 4.1). The main features of sediment thicknesses are outlined below.

They are:

a) A shelf of about 1 - 2 km width with sediment cover of less than 20 ms can be followed around the fjord and the islands. What is indicated on the basement map and is further strengthened on this map is that Svarfadardalur is divided into two parallel parts between Dalvík

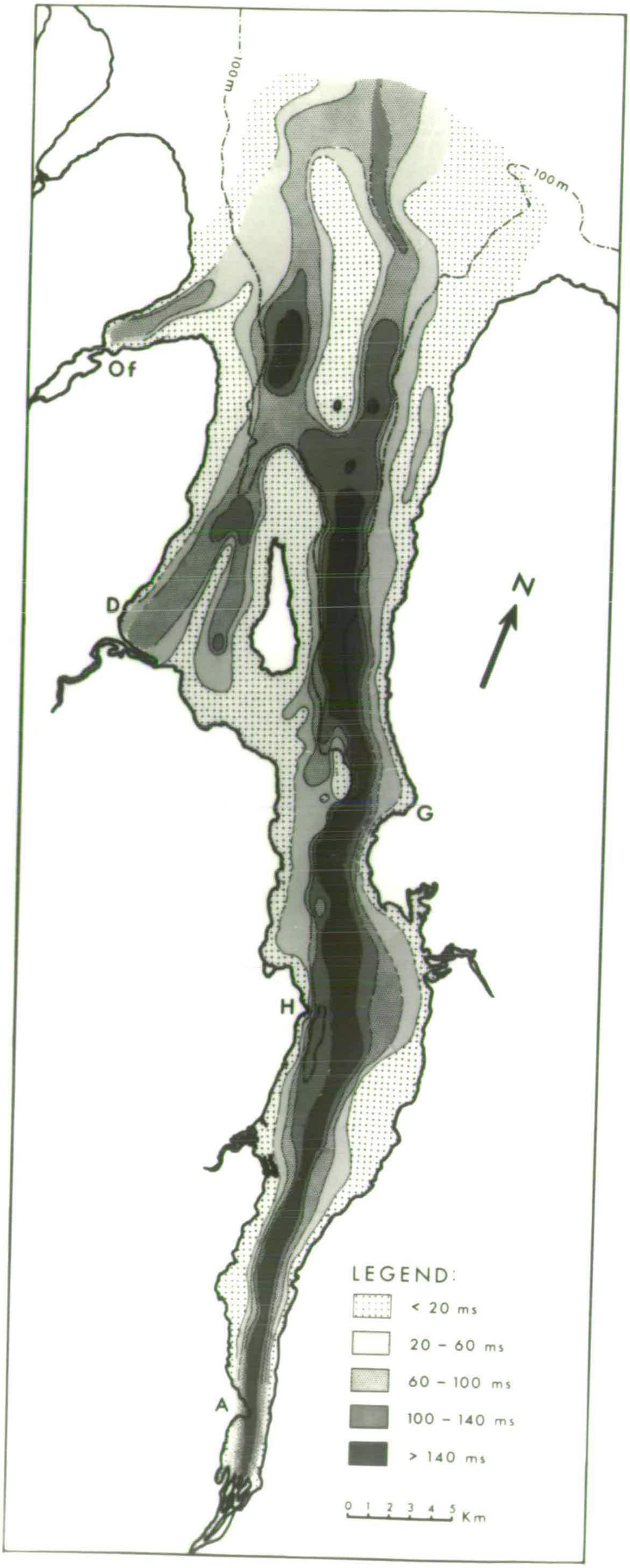


Figure 4.3. Sediment thickness of Eyjafjördur. Scale in milliseconds.

and Hrísey. Also, irregularities indicated in the middle of Eyjafjördur, west of Grenivík are further emphazised.

b) Along middle of Eyjafjördur and Svarfadardalur a trench of about 1 - 3 km width is situated filled with a relatively thick formation of sediment. In the main fjord the sediment is more than 100 ms thick along most of the fjord, but in Svarfadardalur this sediment thickness has a patchy distribution. The greatest thickness recorded amounts to about 250 ms to the south-east of Hrísey. On the map (Figure 4.3) the deepest isobath line is for convenience drawn with 140 ms, but on limited areas east of Hrísey the sediment exceeds 200 ms thickness.

c) A relatively thin sedimentary deposit covers the outer part of the research area north of Hrólfssker; where a significant sediment thickness is measured it is concentrated to a narrow part of the fjord.

It is noticeable that the shelf area extends over a relatively large proportion of the fjord area, covering a similar area to the deeper part of the fjord. In this respect the configuration of the fjord differs from most of the fjords studied (Holtdahl, 1967, 1975; Embleton and King, 1975).

B. Sediment accumulation.

A typical model of the sediment distribution in a fjord environment can be described as 'a basin of rock partly filled with relatively unstratified (seismically) "horizontal" layers, accumulated after and during the retreat of the glacier from the fjord. The rock basin is commonly covered with till material and the threshold near the mouth, and -where present- individual sills within the fjord's basin, are usually covered with or constructed of till-deposit. The steep-sided walls are normally covered with thinner layers of sediments' (Holtedahl, 1965, 1975; Embleton and King, 1975; Sugden and John, 1976).

Where a glacier has undertaken a repeated cycle of retreat/readvance in a fjord environment (during the Late Weichselian-Holocene time) a modelling of the sediment distribution is more difficult. Crary (1966), in his study of a present-time glacier, revealed that the floating ice is in a close contact with the bottom sediment, and that the mechanism by which the floating ice erodes the bottom material appeared to be completely different from that of a grounded ice. However, the processes of a glacial deposition in either sea- or fresh water have this far been inadequately studied, and thus little is known in detail (Sugden and John, 1976).

The seismic profiles from the Eyjafjördur area are used to interpret the sediment types in the fjords. Three longitudinal profiles, along Eyjafjördur, Svarfadardalur and Ólafsfjördur have been assessed for this purpose (Figure 4.4).

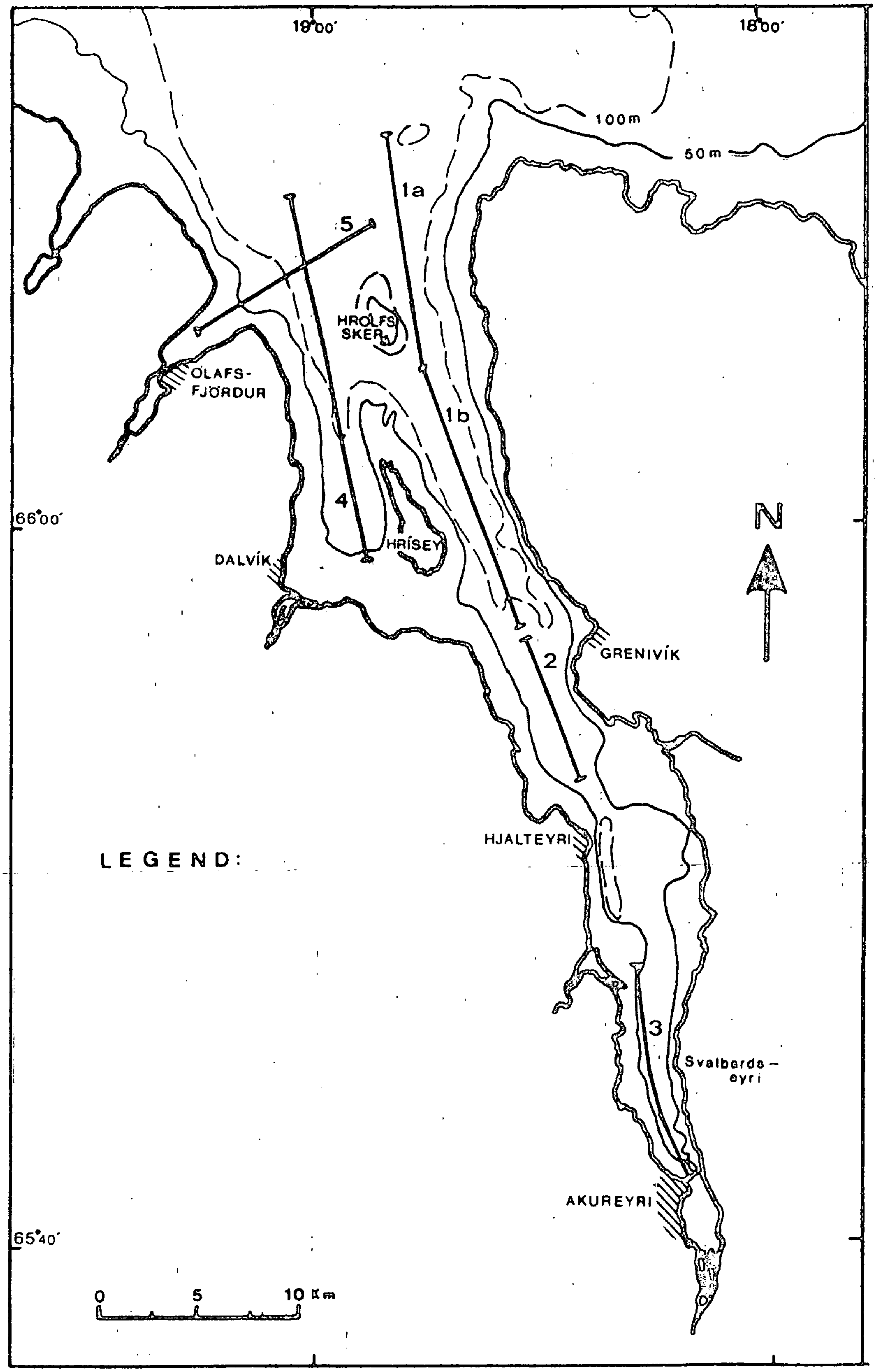


Figure 4.4. Location of the seismic profiles.

In the case Eyjafjördur, the profile is divided into three sections (see below). Several seismic profiles, of various length, are available for interpretation, but for convenience only the most representative ones are described for each fjord.

While the quality of the siesmic data available from the Eyjafjördur area is good for a detailed study of the sediment accumulation and its structure, it is unfortunate that the only material available to interpret the seismic reflections consists of core samples taken from the uppermost few metres of the sediment. This obviously limits a detailed interpretation of the sediment infill. However, several reflectors are seen in these profiles (Figure 4.5 and 4.9) showing characteristics that allow sediment tracing over a considerable distance. These will be described for the three profiles.

Eyjafjördur: the Eyjafjördur profile (the main fjord) ~~is divided into three sections (Figure 4.4)~~.

The first section (1) is for cenvenience divided into two subsections, section 1 a and 1 b. Section 1 a extends from the mouth of the fjord and south to Hrólfssker, about 7 nautical miles (13 km). Section 1 b is about 6 - 7 miles long a continuation of section 1 a and extends to approximately one nautical mile south of Hrísey.

Section two (2) extends over about 4 - 5 nautical miles (ca 7.5 - 9 km) from a place south-west of Grenivík to Hjalteyri.

Section three (3) is situated in the inner part of the fjord, from the Hörgá delta and into Akureyri, about 5 nautical miles.

In total 22 sedimentary units are discussed in this profile and these will be described stratigraphically, the oldest unit being discussed first.

The unstratified ca. 30 ms thick rugged deposit covering the top of the basement in section 1 is interpreted as a till deposit. It is suggested that this is the oldest sediment unit in Eyjafjördur possibly forming an end moraine feature, Unit 1 in the outer part of the fjord, between Stations 265 and 267 (Figure 4.5 a,b).

Unit 2, which can be distinguished at Stations 257-259, is interpreted as proglacial sediments deposited during the retreat of the glacier responsible for the accumulation of the end moraine feature of Unit 1 (Figure 4.5 a,c).

Unit 3 is the sediment associated with the topographic high area between Stations 264, 5 and 267 and is interpreted as an end moraine structure. To the north it is represented by horizontal layering. It covers the irregular basement in the outer part of the fjord and at its moraine has assimilated much of the underlying Unit 1 during readvance (Figure 4.5 a,b).

Unit 4 has been deposited following the retreat of the glacier to the south, interpreted as a proglacial sedimentary assemblage (Figure 4.5 a,b).

In Unit 5 an event of glacier readvance is again reported forming a ca 50 ms thick topographic feature in the sediments and horizontal layers to the north, approximately north to Hrólfssker at Station 262.5 (Figure 4.5 a,b).

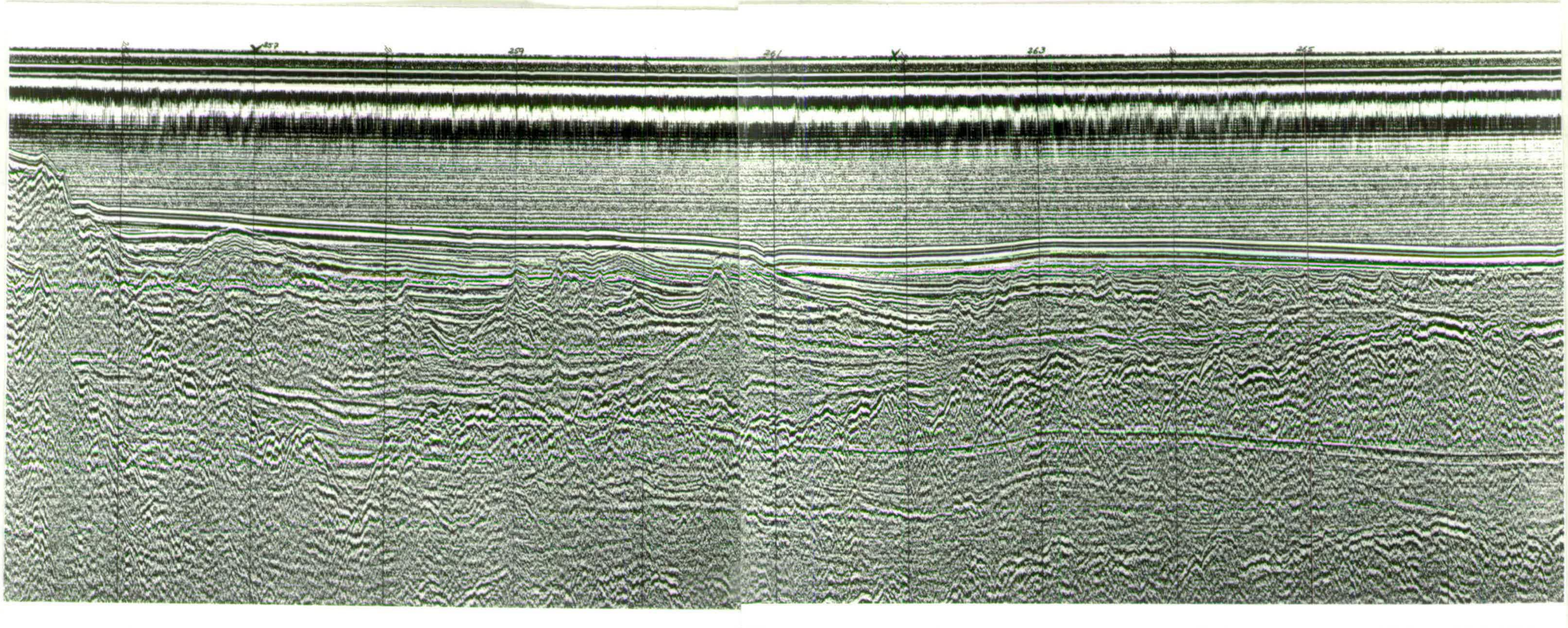


Figure 4.5a. Eyjafjördur profile. The seismic graph of sections 1a and 1b.

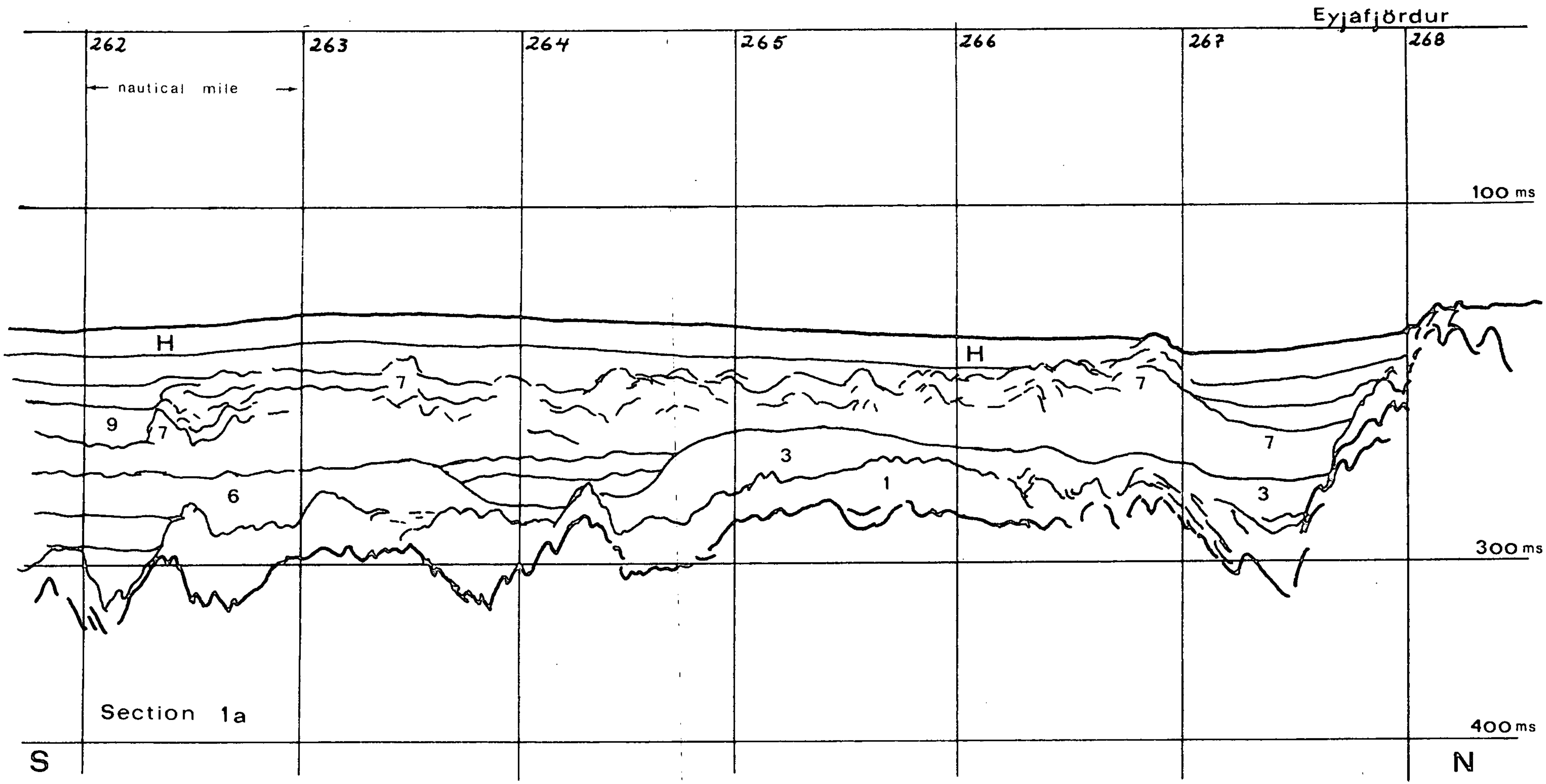


Figure 4.5b. Eyjafjördur profile. Interpretation chart of section 1a.

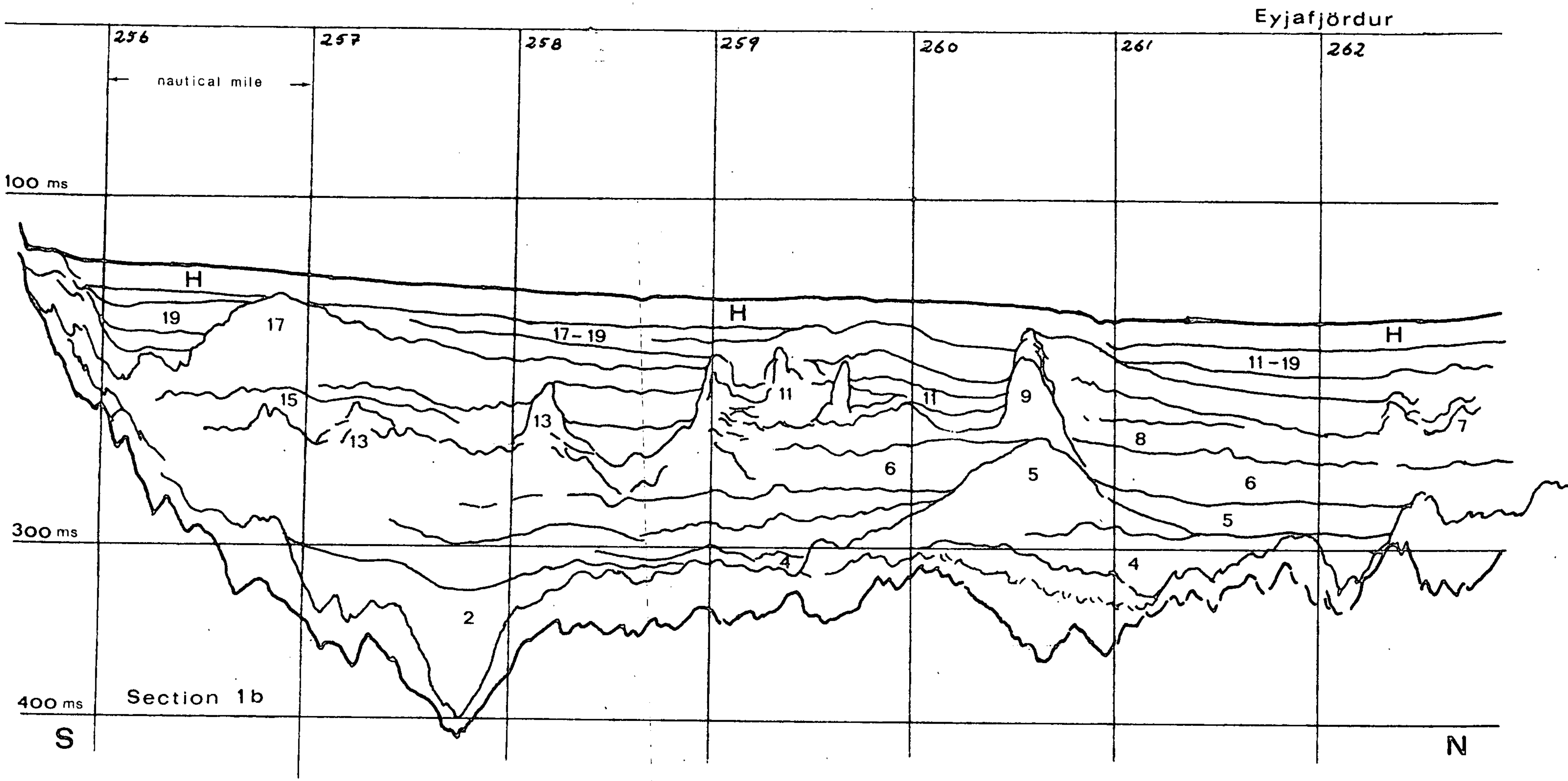


Figure 4.5c. Eyjafjördur profile. Interpretation chart of section 1b.

In Unit 6 proglacial sediment of ca 30 ms thickness covers most of the irregular structures left on the fjord's bottom by the retreat of the glacier.

Unit 7 (ca 40 ms) is the irregular sediment structure, seen between Stations 262.5 and 268 where it protrudes trough the later sediments. Here it is interpreted as a composite end moraine (Figure 4.5 a,b).

Unit 8 is interpreted as a proglacial sediment following the retreat of the glacier from Station 262.5. At this station the sediments of Unit 7 have formed a barrier, near Hrólfssker, for the sediment flow northwards possibly turning the main sediment flow through the trench separating Hrísey and Hrólfssker west of Station 262.

Probably the most dominating feature of section 1 is the end moraine structure at Station 260,5. This sediment unit, numbered Unit 9, is situated right above the end moraine structure of Unit 5. Here sediment layers have been rolled or puckered into a 60 milliseconds thick formation, while to the north of the moraine contemporary sedimentation is horizontal. Similar to Unit 8 most of horizontal sediment layers of Unit 9 is probably deposited along the trench south of Hrólfssker and should be detectable north of Svarfadardalur fjord (Section 4, Figure 4.4).

The sediment Unit 10 is considered to be integrated in the prominent sediment structure of Unit 11. Similar to Unit 9 sediment Unit 11 is made of a large scale puckering causing a 50-- 60 milliseconds vertical profile with a complicated end moraine structure some 1 to 1.5 nautical miles (2 - 2.5 km) in width suggesting some minor oscillation in the position of the glacier snout. It is noticeable that immediately beneath these morainic features a few horizontally layered sediments of considerable thickness are measured. These are interpreted to belong to the proglacial sediment Unit 6, but thrust effects from the readvance of the glacier both related to Units 7 and 9 and partly to Unit 11 seem only to affect the topmost sediment layers of this unit (Figure 4.5 a,e).

A similar cycle of sedimentation follows in Unit 13. The sediment layers of Unit 12 formed during the retreat of the glacier from Unit 11 must be mixed into the puckered formation of Unit 13, interpreted as an end morainic formation.

To the south the sediments in section 1 b are interrupted by a topographic high area of rock or highly consolidated material. The sedimentation between sections 1 and 2 has taken place in a very narrow and restricted trench near the east coast of the fjord (Figure 4.1) but the grid of continous seismic profiling of Eyjafjördur failed to cover this sedimentation area. For this reason it is unfortunate that good stratigraphic correlation cannot be made between sections 1 and 2 (Figures 4.5 and 4.6).

The horizontal layers covering Unit 13 are interpreted as a proglacial sediment formation from the end moraine formation in section 2, numbered Unit 15. Basically numbering of units in section 2 do not bear a time relationship with those in section 1 although it is thought that units in section 2 post-date those of section 1. However, the sediment layers of Unit 15 in section 1 b are of the same or similar topographic level as the sediments of Unit 15 in section 2, and as the distance of these two well defined stratigrpahic horizon is only about 2 nautical miles (Figure 4.4) an attempt is made to correlate these sediment units across sections 1 b and 2.

The lowermost part of the sediment layers in Unit 15, Station 257 can possibly include sediments from Unit 14.

Unit 17 is an approcimately 50 milliseconds thick end moraine complex situated right above the end moraine structure of Unit 13, at Stations 256,5 - 258. Unit 17 is the youngest of the morainic features seen in section 1 and is more similar to the terminal moraines of Units 3 and 5 than Units 7, 9, 11 and 13.

The sediment layers of Units 16 and 18 related to the retreat of the glacier from the end moraine structures of Units 15 and 17, respectively can not be identified in the seismic profiles with any certainity.

The horizontal layers of Unit 19, at Station 256, section 1 b are correlated with Unit 19 in section 2 as part of the proglacial sediments of the end moraine at Stations 223 - 226. This interpretation is based on that both these sediment units are from the same topographic level.

In section 1 also a thin sediment levels out most of the irregular structures of the youngest terminal moraines described in the section. These sediment layers are built

Figure 4.6a. Eyjafjördur profile. The seismic graph of section 2.

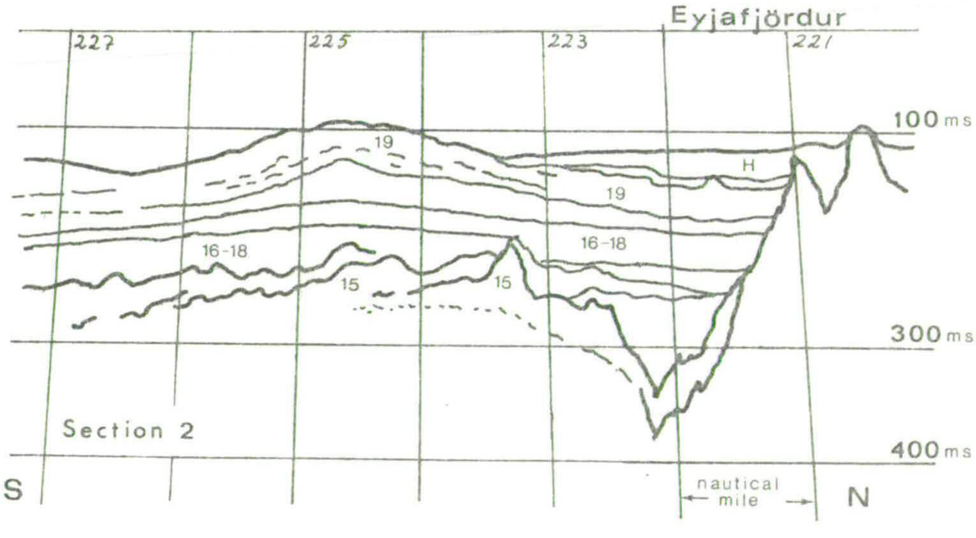


Figure 4.6b. Eyjafjördur profile. Interpretation chart of section 2.

up of sediments from Units 11 - 19 (Figure 4.5 a,b,c).

The top sediment unit, named here Unit H is predominantly of Holocene age exceeding only about 20 milliseconds thickness in the outer part of the fjord.

In section 2, 6 sediment units are discussed (Figure 4.6). As discussed above numbering of units in section 2 does not bear an exact time relationship with those in section 1 although the same numbering system is used. However, for convenience an attempted correlation is introduced for these sections.

Right above the acoustic basement a folded sediment structure, labelled Unit 15, is interpreted as a terminal moraine correlated with the horizontal layers of Unit 15 in section 1 b.

The terminal moraine structure seen in Unit 19 is probably the largest one recognized in the fjord. It affects the distribution of the modern sediment in that its upper structrue forms a minor sill in the fjord and traps sediments on its inner side. Sediment deposited north of this morainic feature may therefore predominantly be older or a contemporanaeous formation, but later sediments were largely trapped behind the end moraine. The thickness of Unit 19 is over 100 milliseconds. The 'horizontal' layers deposited in close continuity with this terminal moraine are seen to the north through much of section 2 and are correlated with the 'horizontal' layers of Unit 19 in section 1 b, Station 256 and the thin sediment layers north of Station 257 (Figure 4.5 b,c).

Units 16 - 18 are recognized between the terminal moraines of Units 15 and 19 but can not be distinguished further in the seismic profiles.

Sediment layers of Unit H are recognized in the top sediment formation of section 2, of approximately 15 to 20 milliseconds thickness to the north of Station 224 (Figure 4.6). The sediment layers inside the sill i.e. south of Station 226.5 all post-date the sediments in Unit 19, but the thickness of the sediments in Unit H can not be determined from the seismic profiles, where part of the sediment is related to at least one readvance stage recognized to the south of this sill, considered as the last readvance stage of the Late Weichselian time (Th. Einarsson, 1967, 1973 a,b).

In section 3, located in the inner part of the fjord, (Figures 4.4 and 4.7), an irregular structure dominates most of the section. Seismic profiles parallel to this section clearly show that this feature is restricted to the western half of the fjord. Due to a lack of penetration in the innermost part of the fjord it can only be stated that the top metres of this pyramidal structure are covered with sediments. Right above this feature 'horizontal' sediment layers have suffered some push effects probably related to movements of a glacier ice. This pyramidal structure, numbered as Unit 21 will according to the seismic profiles only be referred to as a minor advance or movement of the glacier snout.

The topmost horizontal sediment layers of section 3 exceed 20 - 40 milliseconds in thickness and are inter-

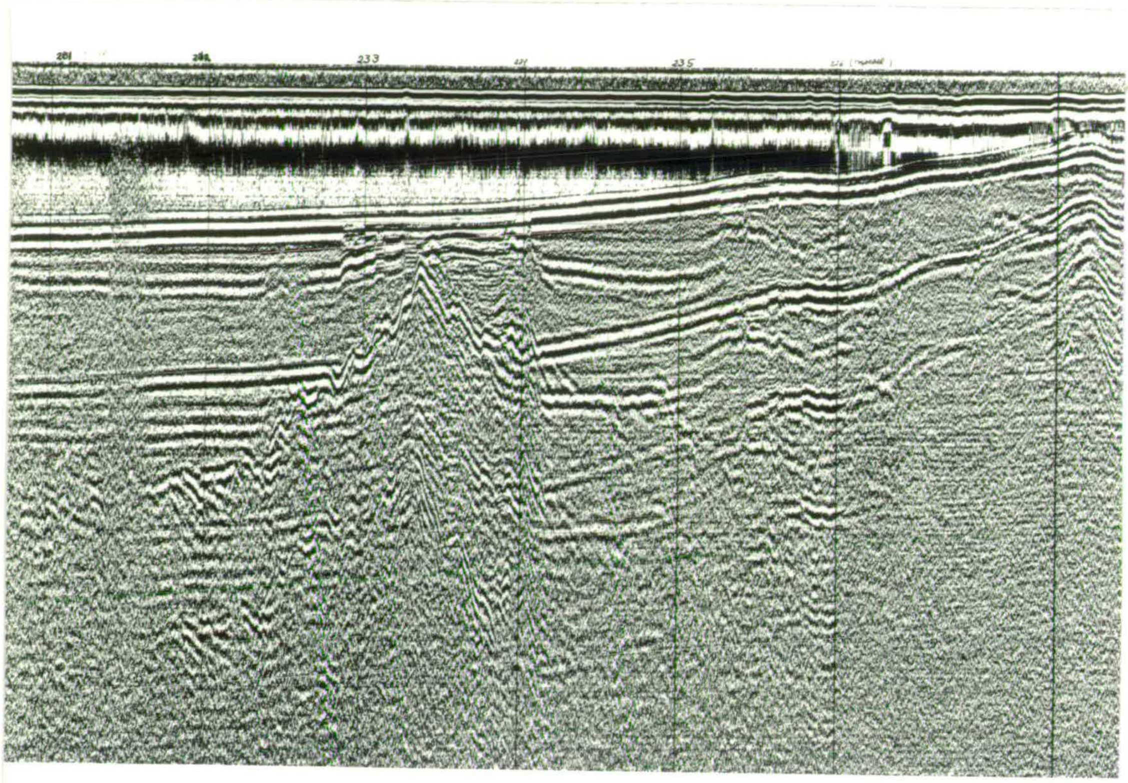


Figure 4.7a. Eyjafjördur profile. The seismic graph of section 3.

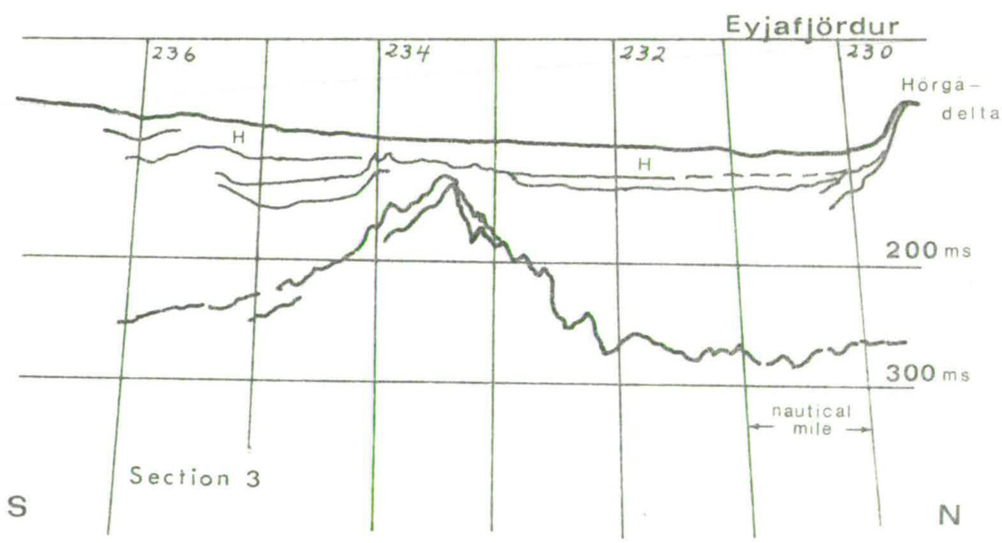


Figure 4.7b. Eyjafjördur profile. Interpretation chart of section 3.

preted as sediment accumulated since the glacier retreated from the fjord, labelled as Unit H.

Svarfadardalur: the profile studied extends over a distance of approximately 10 nautical miles located from one mile north of the fjord's head and north to the 200 metre depth contour (Figures 4.4 and 4.8). The stratigraphic units described here are independently numbered from those in Eyjafjördur. The till material situated on the top of the basement is in the same way as in Eyjafjördur profile excluded in this discussion.

The oldest distinguishable stratigraphic unit, numbered Unit 1-S in section 4, smoothes out much of the uneven basement along the section. Unit 1-S has been determined between Stations 278.5 - 280.5 and Stations 281.5 - 283.5 (Figure 4.8).

The overlying Unit 2-S is of a variable thickness. For example south of Station 281.5 the Unit does exceed 30 - 35 ms thickness smoothing out much of the irregular structures both in Unit 1-S and of the acoustic basement. Northwards, to Station 278 it thickens considerably exceeding 120 ms at Station 281. The weak folding of the sediment layers at Station 281 can possibly be related to a readvance stage of the (Svarfadardalur) glacier; a contemporary structure to Unit 2-S, but is interpreted here to be due to ice movements related to the above sediments in Unit 3-S.

Unit 3-S is identified to extend between Stations 278 - 282 and has been interpreted to form a weak terminal mo-

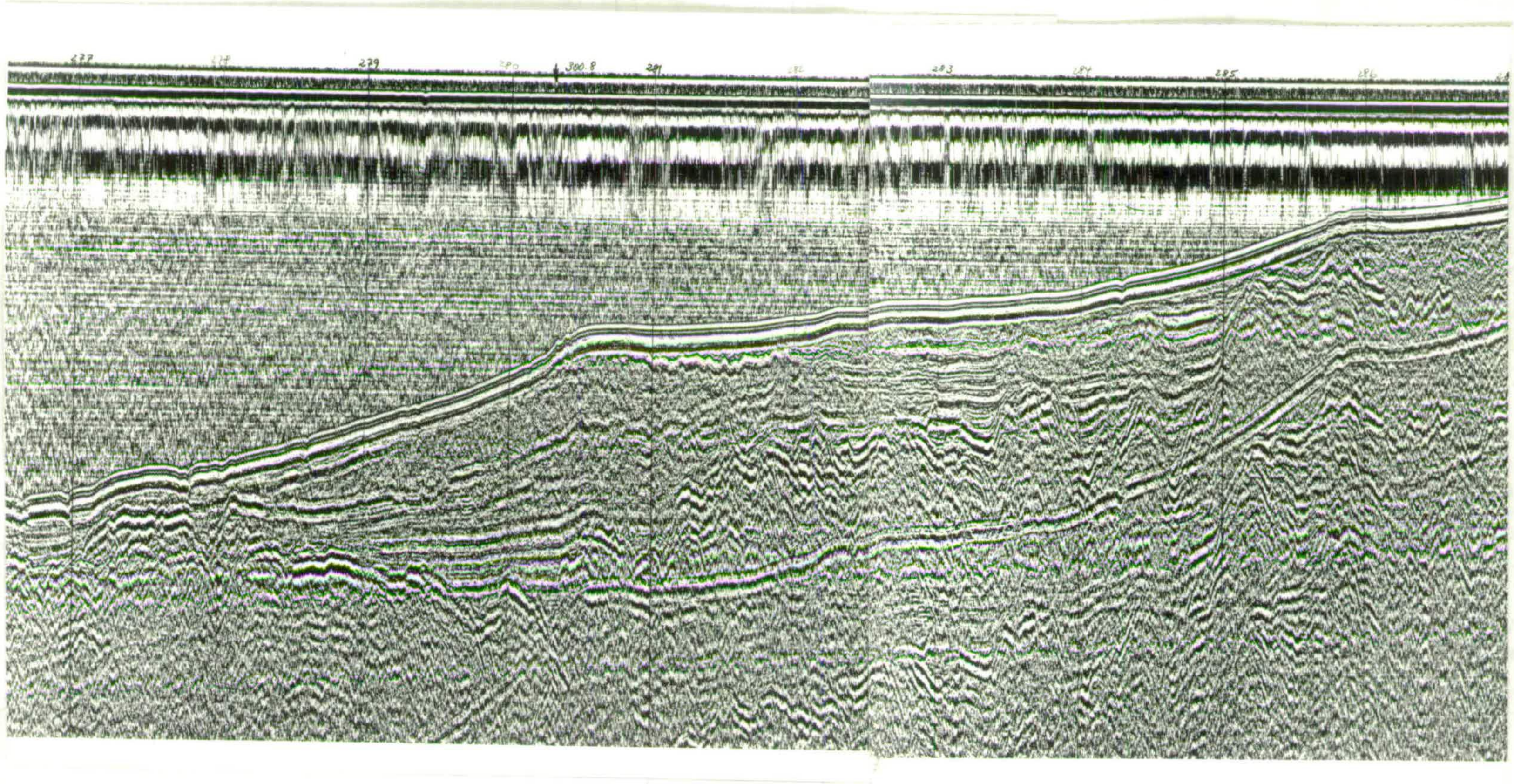


Figure 4.8a. Svarfadardalur profile. The seismic graph of section 4.

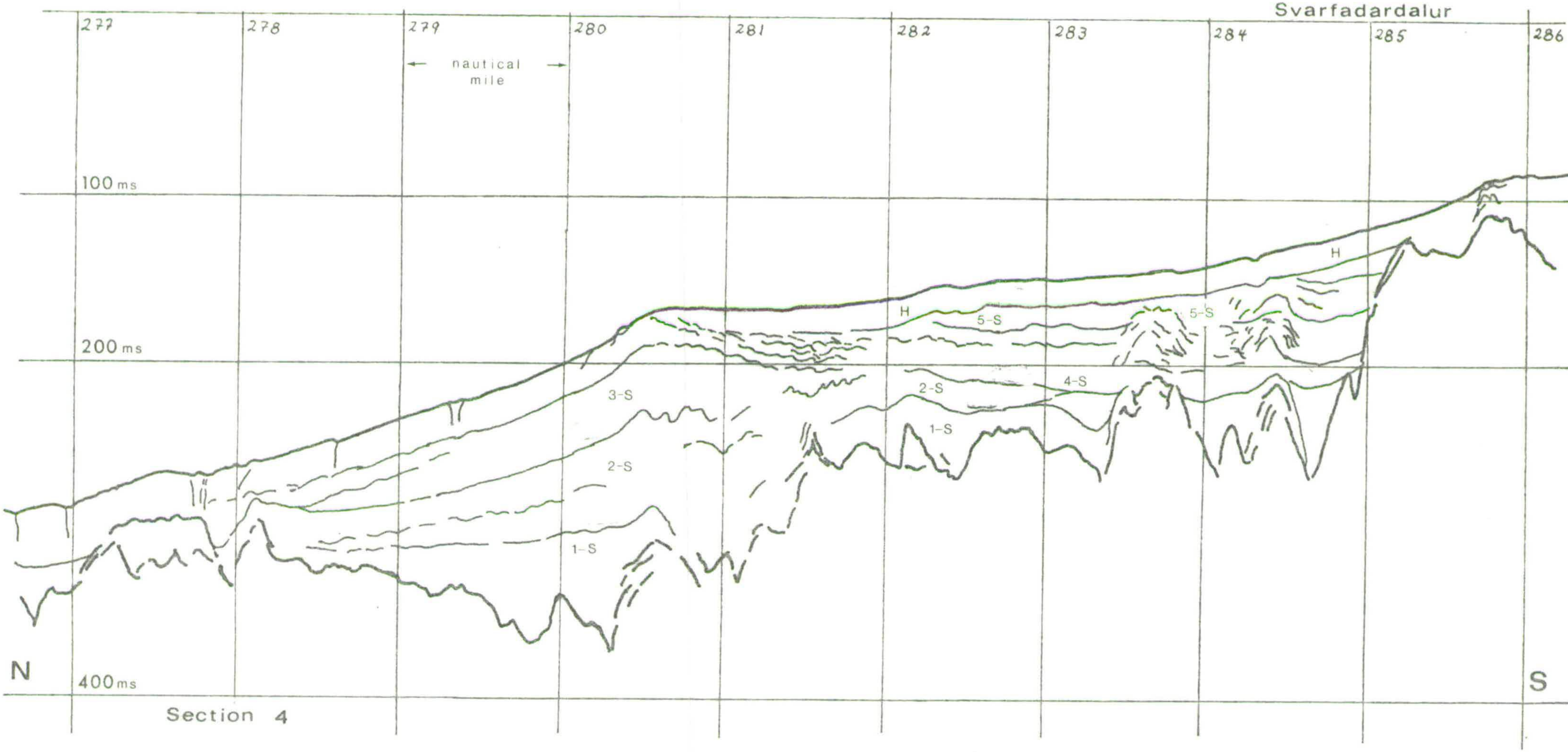


Figure 4.8b. Svarfadardalur profile. Interpretation chart of section 4.

raine at Station 281. This feature is probably the initial stage of development of the 'bathymetric edge' structure that has clearly been formed by a continous sedimentation at Station 280.5.

Unit 4-S is a thin 'horizontal' layer covering more or less all the previous units. In the south i.e. south of Station 283 the unit thins out and is not easily identified; possibly it merges into Unit 2-S. To the north the unit increases slightly in thickness to this 'edge' structure at Station 280.5, and then gradually decreases to a thin sediment cover. As in Unit 3-S the sediments are weakly folded near this 'edge' structure but are undisturbed away from this location.

Unit 5-S is thickest to the south of the 'edge' structure, (at Station 280.5) forming structures that are related to a glacier readvance. Two phases of irregular structures are recognized within this sediment unit. Around Station 281 some weakly folded sediment layers are visible in the lowermost part of the unit. At the 'edge' (Station 280.5) some of these folded sediments protrude through a smooth sediment cover and may represent a 'down at heel' profile, a feature characteristic in most glacier troughs (Sugden and John, 1976). In the Svarfadardalur profile this feature is interpreted as related to an end moraine feature.

The upper part of Unit 5-S at Station 284 consists of two irregular structures, each 30 - 50 ms thick. Both are continuations of topographic highs rising from the basement. Apparently, the sediment layers immediatly above these topographic highs (Stations 283.7 and 284.5) may have been relatively stable, while the sediment layers above the troughs features (at Stations 283.4, 284 and 284.7) may have been unstable (collapsed). These effects of compaction are also seen in the deeper sediment layers at Stations 283 - 285 where the sediment reflector, originally 'horizontal', has after compaction, formed a drape-like structure over the topographic highs at Stations 283.7 and 284.5.

The topmost sediment cover of section 4 comprises about 20 - 30 ms of 'horizontal' sediment layers deposited during the last stages of the glacial time and during Holocene.

Correlation between the stratigraphic units in the Svarfadardalur profile with the units in the Eyjafjördur profile is difficult, partly due to the lack of continous seismic profiles between the fjords. If only the prominent reflectors in Svarfadardalur are considered there is some indication that Unit 2-S in Svarfadardalur is time equivalent to Unit 8 and Unit 4-S time equivalent to Unit 9 in Eyjafjördur.

<u>Ólafsfjördur:</u> The stratigraphical units here are numbered independently of those in the profiles of Svarfadardalur and Eyjafjördur described above. Topographically the Ólafsfjördur is considerably shallower than Svarfadardalur and essentially represents a hanging valley. The sediment cover between these fjords is thin and sediment layers

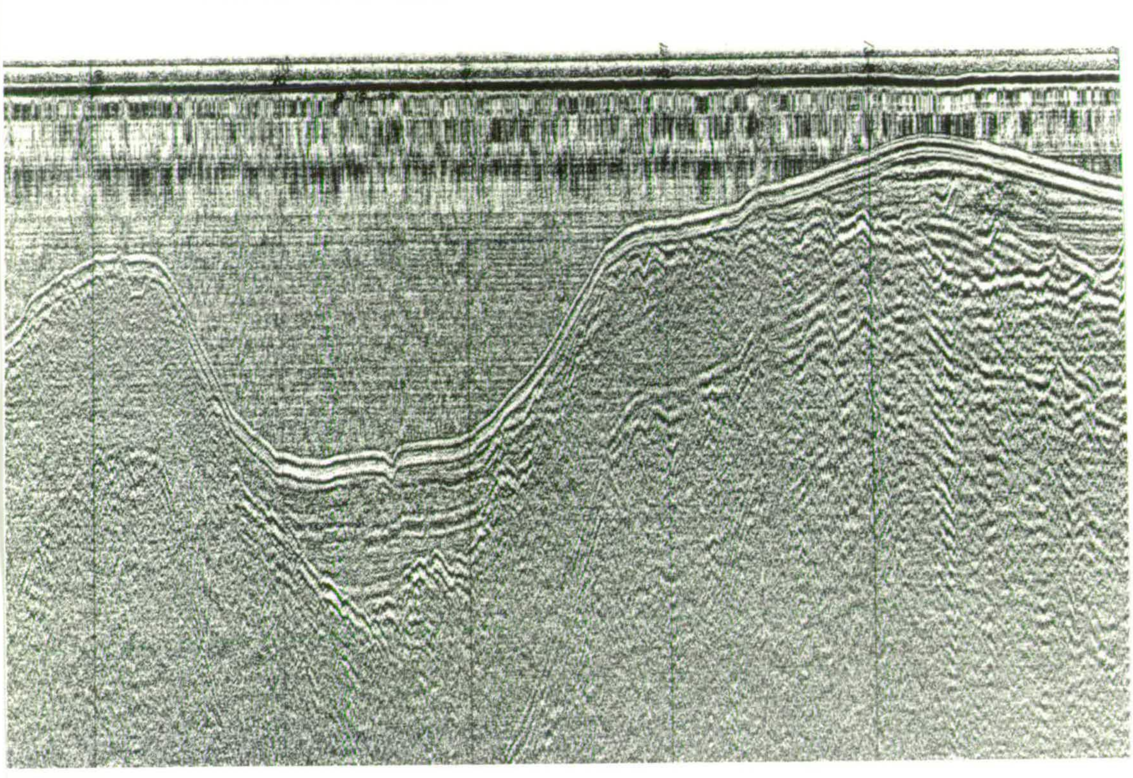


Figure 4.9a. Ólafsfjördur profile. The seismic graph of section 5.

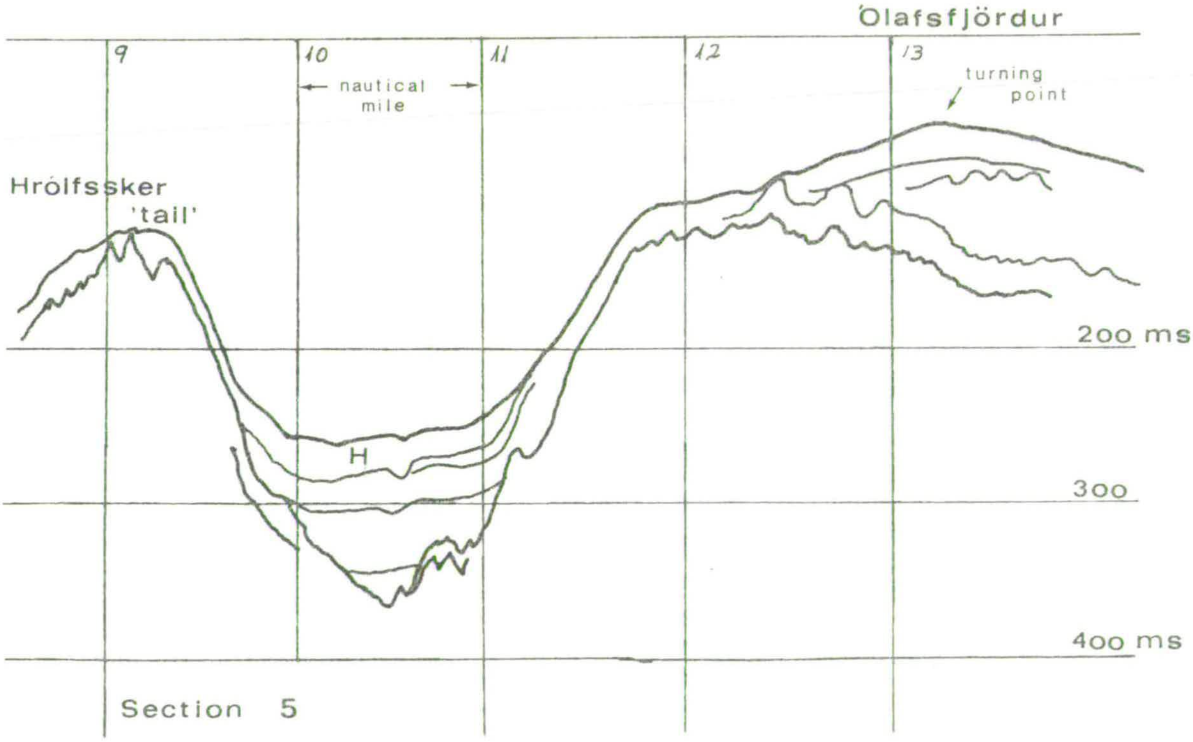


Figure 4.9b. Ólafsfjördur profile. Interpretation chart of section 5.

characteristic of the Svarfadardalur profile cannot be traced to Ólafsfjördur (Figures 4.4 and 4.9). The length of the profile within the fjord itself is only 1 to 1.5 nautical miles (Figures 4.4 and 4.9).

Three stratigraphic units are identified. Unit 1-Ó is dominated by a puckered sediment structure interpreted as a terminal moraine situated at the edge of this hanging valley (Figure 4.9). The quality of the seismic profiles is insufficient to distinguish between morainic deposit and the basement morphology, but does indicate a sediment thickness of at least a couple of metres.

In Unit 2-Ó sediments show horizontal layering in its lower part which partly fills the basin inside the end moraine. Its upper part is a dipping structure of a deltaic character.

Unit H forms the top 10-15 ms or so of infill sediment deposited during the last stages of glacial time and in Recent time.

C. Pathways of the sediment flow.

A study of the sediment structure in transverse profiles (Figure 4.9) reveals that submarine channels are an important feature in the sediments, especially the Holocene sediment. By drawing the channel positions on a bathymetric map the chain characteristics of these features have been outlined (Figure 4.10).

Most the sediment deposited into the Eyjafjördur area seems to be related to a few well defined deltas with

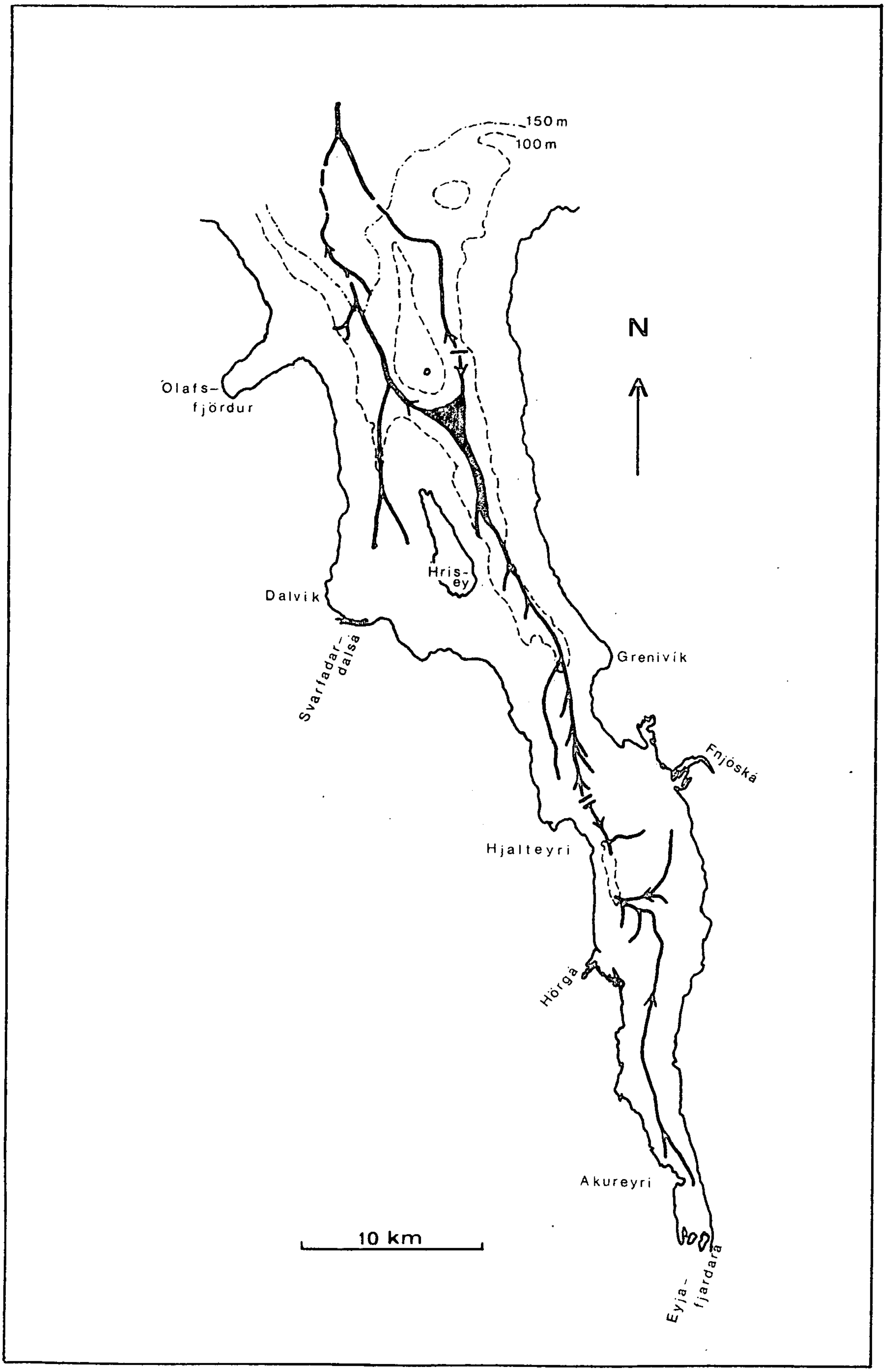


Figure 4.10. Pathways of the submarine sediment flow in Eyjafjördur.

a secondary source coming from the sides of the fjord. The shape and disposition of the channels shows this unequal sediment distribution within the basin. They occupy the lowest point on the fjord's bottom and where there is a significant steepening of gradient the channels are seen as a groove without an attendant rim which is typical in the case of turbidity current flows (Blatt <u>et al.</u>, 1972).

The most general feature of these channels is their dendritic pattern with major channels orientated parallel to the axis of the fjord (Figures 4.9 and 4.10). Minor tributary channels join the main channels. This pattern is consistent with that of the adjacent river system. Annual flood in the rivers probably causes erosion in the submarine channels as well as an increase of sedimentation.

In the same way as is seen on land, the topographic divides dictate the pathway of sediment movement and deposition. For example in the inner part of the fjord the shallow sill just north of Hjalteyri (Unit 19, Figure 4.6) divides the fjord into two independent areas of deposition. Presumably all of the coarser grained deposit (i.e. approximately ≥ medium silt size) from the Eyjafjardará, Glerá and the Hörgá drainage areas and much of the coarser grained deposit from Fnjóská is trapped in the inner part of the fjord (Figures 2.10 and 4.10).

In the outer part of the fjord the main channel for sediment movement is located on the east side of the basin, east of Hrísey, but cuts across to the west along the trench seen to the south of Hrólfssker. West of Hrólfssker the main channel of Eyjafjördur and the Svarfadardalur sediment channel merge into one deep channel (Figure 4.9). The area east and north of Hrólfssker does not show as obvious channel structure as recorded to the south and east, suggesting a less active sedimentation area.

4.5 Summary

The attempt to position the major sediment units especially terminal moraines into a chronostratigraphical order, has shown a consideral lateral movement of the ice margin with time (Figure 4.11). Assessment of the different locations of the moraines within the different sediment units, particularly within Eyjafjördur, is shown in Figure 4.12.

It is realised that geological and geomorphological land studies adjacent to the fjord are unreliable as a basis for understanding the stratigraphy of the sediment in the fjord. For much of the Pleistocene the Eyjafjördur glacier extended into the present day fjord. During that time, especially during the maximum period of the last major glaciation, it eroded the landscape down to its deepest level (Figure 4.2) and the volume and thickness of the Eyjafjördur glacier must have been at its greatest, and produced extreme erosion effects. The seismic profiles clearly indicate that subsequent oscillations of retreat and readvance of the ice causing erosion and deformation

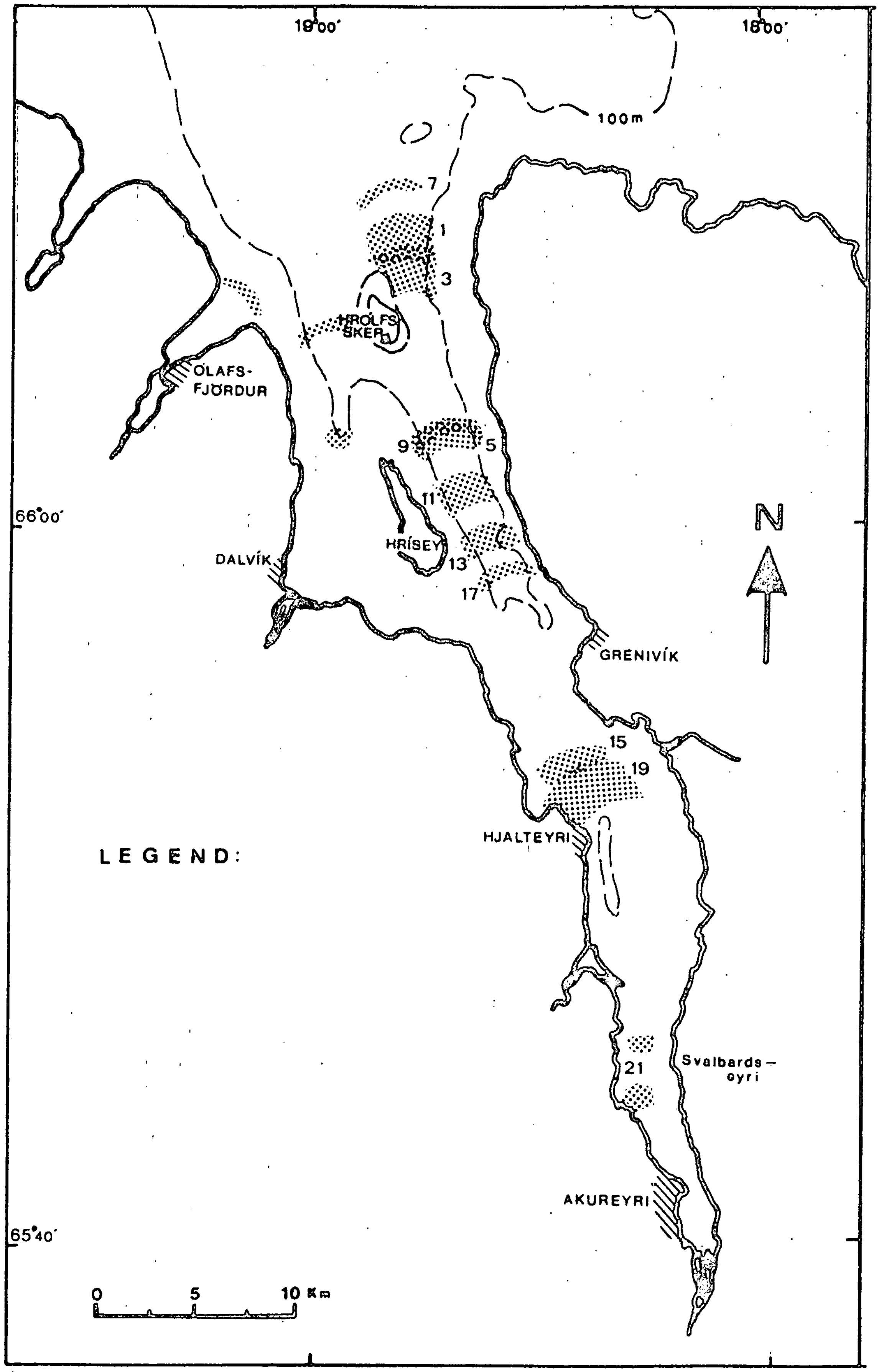


Figure 4.11. Location of the end moraine features identified in Eyjafjördur.

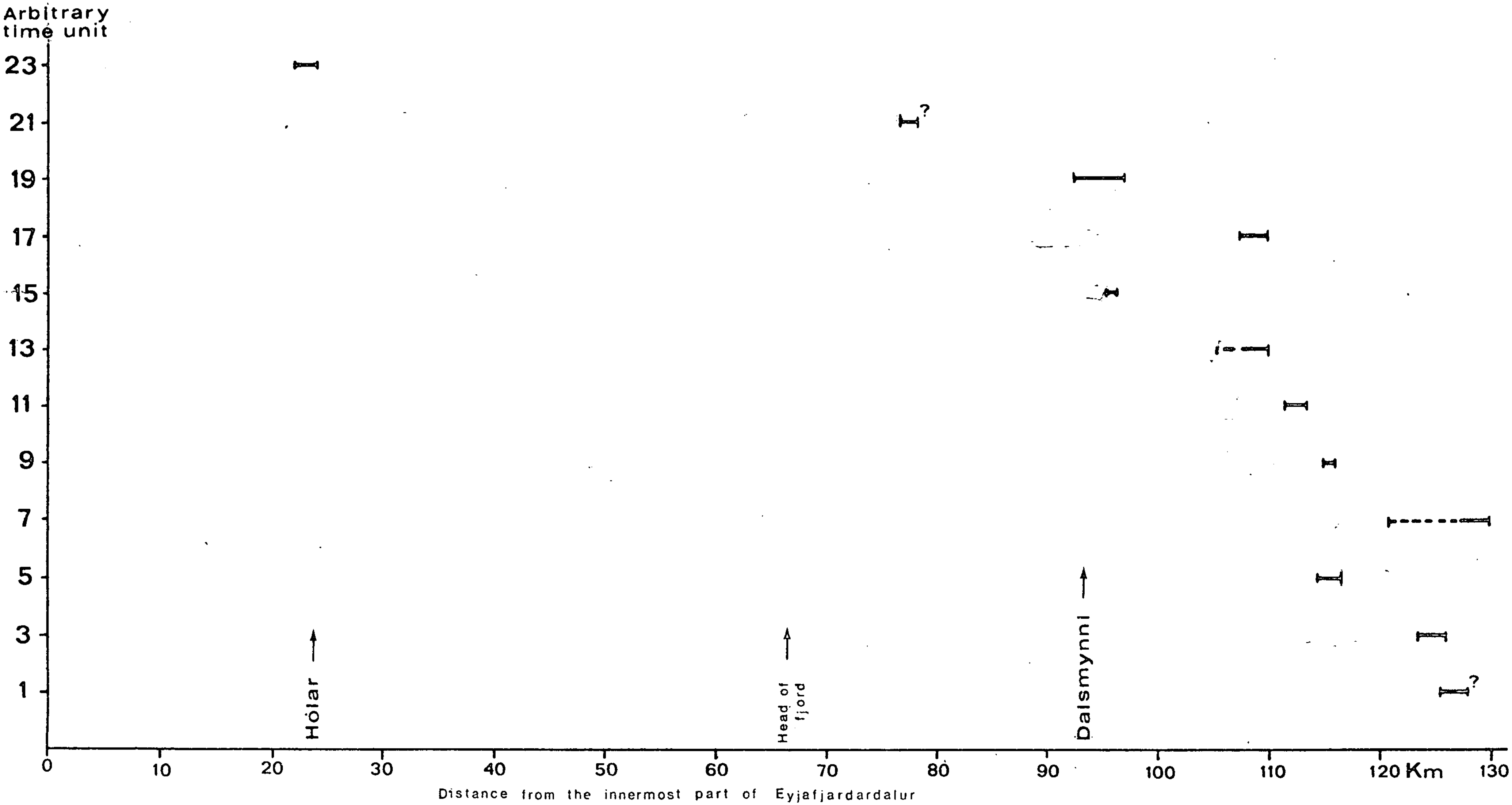


Figure 4.12. Arbitrary time unit scale for the readvance stages in Eyjafjördur.

only affected the upper layers of sediment.

Two stages of late readvances have been dated in Iceland, the Álftanes-stage 12.000 - 12.500 B.P. (Older Dryas) and the Búdi-stage 10.000 - 11.00 B.P. (Younger Dryas) after the ice had retreated rapidly up to the highland during the Alleröd interstadial. It has been suggested that these periods of readvance stages could be studied in Eyjafjördur-Eyjafjardardalur land area (Th. Einarsson, 1967, 1968, 1973a,b, 1978).

A well defined terminal moraine in the innermost part of Eyjafjardardalur, approximately 100 km from the mouth of the fjord at Hólar (Figure 4.11) has been identified with the Búdi stadial (Th. Einarsson, 1973a,b, 1978), although confirmatory dating of the moraine has not been made. However no direct indication of moraines relating to the Álftanes-stage has been noted on land, although some evidence of their existence is afforded by the blocking of the Dalsmynni valley by the Eyjafjördur glacier, causing an ice dammed lake, in Fnjóskadalur during this time (Th. Einarsson, 1967, 1968, 1973 a, 1978; Nordahl, 1982, 1983).

Repeated appearances and disappearances of ice-lakes in Fnjóskadalur up to ten times extending from 12.300 B.P. to more than 23.900 B.P. is according to Norddahl (1983) also reflected in repeated advance and retreat of the Eyjafjördur glacier. Results suggest that it is sufficient ~~is~~ to position the glacier terminus 1 - 2 km north of Grenivík for blocking Dalsmynni and damming up an ice-lake in Fnjóskadalur.

Studies of the seismic profiles form the fjord area indicate that the existing views on ice movement is grossly oversimplified as generally the sediment structure is identified either as a sediment unit of a glacier readvance or of a glacier retreat. Up to 10 - 12 readvance stages have been distinguished by the presence of terminal moraines (Figure 4.11). As an example at least 7 readvance stages stratigraphically younger than the maximum glaciation period are identified in the seismic profiles north of Dalsmynni. To a certain extent this is confirmed by the ice-lake studies in Fnjóskadalur, but emptying of each of these nine ice-lake phases recognized seems to have occurred through Dalsmynni into Eyjafjördur. Until borehole information and sediment dating is available the Eyjafjördur readvance stages cannot with certainity be correlated with the Álftanes and the Búdi stadials or the Fnjóskadalur ice-lake phases.

In general the sediment accumulated into the fjord can be divided into two sedimentation phases, where the lower part of the sediment profile is related to the maximum glaciation to the Late Weichselian time period but the upper 15 - 30 ms to the end of the Late Weichselian period and Holocene.

Chapter 5. CORRELATION - DATING AND SEDIMENTATION RATE

5.1 Introduction

Various dating methods have been introduced for use in postglacial geology, like varves, tree-rings, pollen, tephra layers, radio-carbon (C^{14}) and now recently magnetic measurements. Post-glacial materials in Iceland have been dated by most of these methods among which tephrochronology has proved to be highly successful. In the latter instance the method has been used mostly on soils but only very occasionally on lake sediments.

One of the main objectives of this work is to establish some chronological record of the source material of the fjord as well as in the upper sediments of the fjord. There is a need to establish some correlation between the types and age of soils in the adjacent land area and the fjord sediment.

The samples of the fjord sediments were taken from 9 m length of piston cores (Figure 5.1 and 5.2). Three of these were examined, encompassing both the inner and outer basin of the fjord. Commonly when core samples are taken from within a relatively small area some correlation of lithology is usually seen. However, this was not noted in Eyjafjördur and the only changes seen result from the presence of white-yellow tephra layers (Figure 5.3).

Comparative dating using tephra layers and magnetic measurements have been attempted for these three cores. The findings of these will be considered in turn and compared to

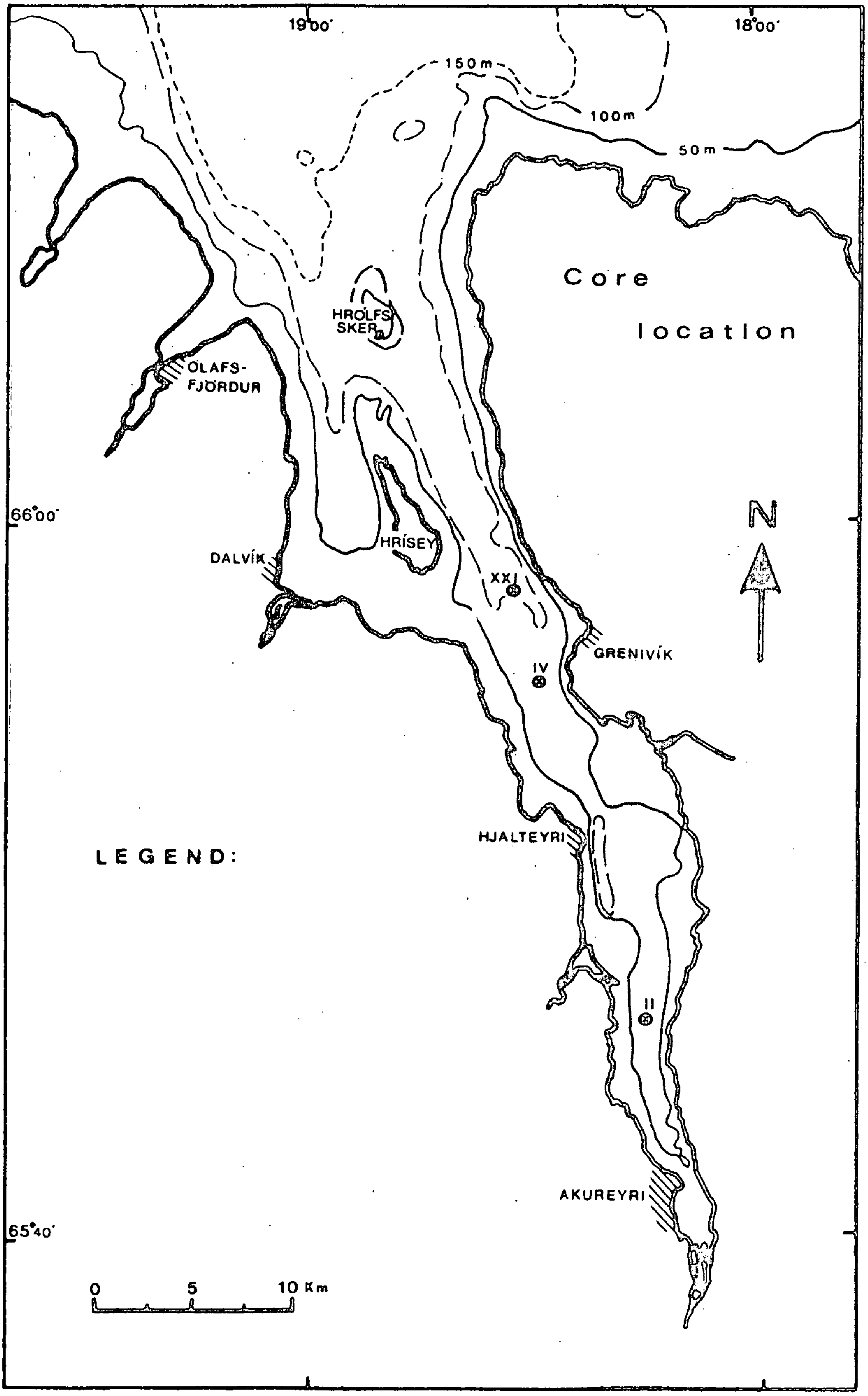


Figure 5.1. Location of Cores II, IV and XXI.

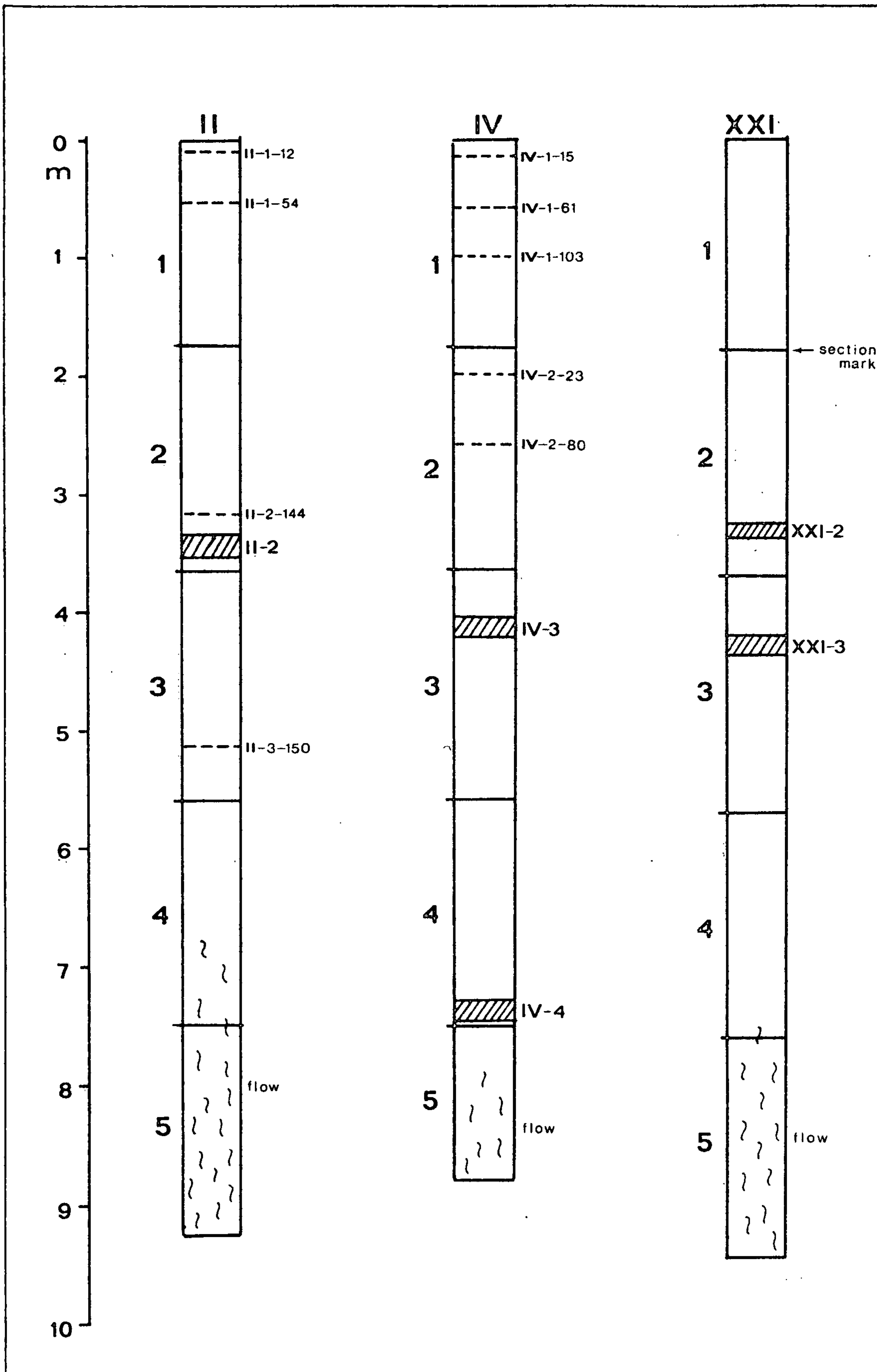


Figure 5.2. Core sections and sample number of the acid and basaltic tephra layers.

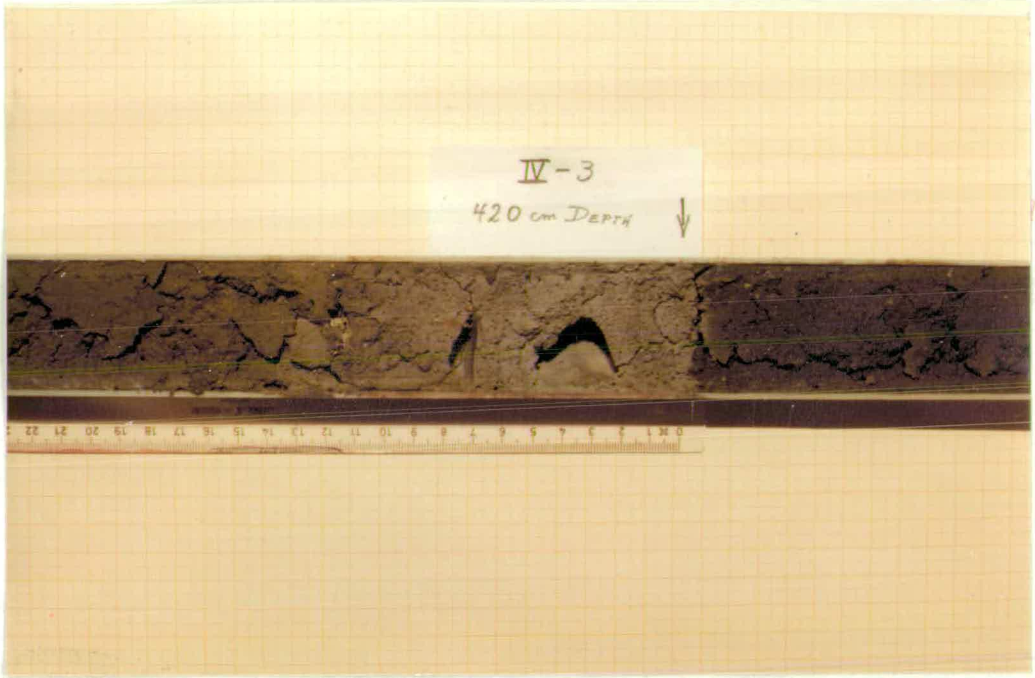


Figure 5.3. The acid tephra layer IV-3
at 420 cm depth in Core IV.

chronological records known on land. Also, a great effort was put on establishing a palynological record of the fjord sediment, but without a benefit, where the pollen concentration was found to be very low.

5.2 Tephrochronology

5.2.1 Distribution of tephra

The establishment of tephrochronology in Iceland (Thorarinsson, 1944) is made possible by the fact that the country is one of the few highly active volcanic areas in the world where formation of both peat soil and loesial soil is unusually rapid. As a consequence, tephra layers of only a few years difference in age can usually be separated in soil profiles.

Tephra layers deposited in Iceland in historical time (< 1.100 B.P.) have often been identified, and dated with accuracy through written records, in a few cases even to the exact day of the tephra fall (Thorarinsson, 1958, 1967, 1975). The oldest eruptions mentioned in Icelandic records occurred during the settlement time 870 - 930 A.D. (Thorarinsson, 1979).

Pre-historic layers or tephra layers not mentioned in written records can be exactly dated by C^{14} dating of peat soil immediately above and beneath them or from other exactly dated tephra layers using the rate of sedimentation (rate of soil thickness), pollenanalysis and archaeology (Thorarinsson, 1979, 1981).

The word tephra, from the Greek τέφρας, meaning 'ash' was introduced 1944 by Thorarinsson, as a collective term for all pyroclasts (i.e. all the solid fragmental matter ejected by all types of volcanoes, and covers all rock compositions from basic to acid). Later, a re-defination by Thorarinsson (1974) describes the term 'tephra', as a collective term for all airborne pyroclasts, including both air-fall and pyroclastic flow material.

The tephra may include a wide range of different sized fragments divided for example into ash ($<$ 2.00 mm), lapilli (2.00 - 64.0 mm) and blocks and bombs ($>$ 64.0 mm) (Fisher, 1961). Due to its long distance from an active volcano we are predominantly dealing with ash size fragments in the Eyjafjördur area.

Postglacial volcanic activity is confined to four well defined zones (Jakobsson, 1972), transecting Iceland from south-west to north-east, as described in chapter 2 (Figure 2. 1). Recent studies suggest that the active zones are made up of about 29 volcanic systems and nearly all develop as distinct rock suites which are petrographically and chemically distinguishable from each other (Jakobsson, 1979a).

The location of Eyjafjördur outside these active zones means that only tephra outfalls of a large areal distribution are likely to be seen in the soils and sediment profiles.

Twelve tephra layers, already mapped and dated throughout Iceland, are known to have been distributed over the study area (Figure 5.8). Four of these are acidic being white-greyish yellow in colour and there are potentially good markers especially on land, even when quite thin.

These acid layers are produced by Hekla (situated about 200 km SSW of Eyjafjördur) deposited both in historical and pre-historical time. The youngest, H_1, is from the 1104 A.D. eruption (Thorarinsson, 1943, 1967), the others i.e. H_3, H_4 and H_5 are all prehistoric.[x)] The respective ages for H_3, H_4 and H_5 are 29000 y.B.P., 45000 y.B.P. and 7000 y.B.P. (Larsen and Thorarinsson, 1977) based on numerous datings of the tephra layers both C^{14} dates and thickness measurements.

According to isopach maps of the H_3 and H_4 tephras a significant thickness, 5-10 cm is expected in the fjord area, but on the other hand the H_1 and H_5 tephra layers are very thin, less than 1 cm. In this study of the soil profiles taken around the fjord (Figure 5.4) the H_3 and H_4 layers are, as expected, thick and easily recognized (Figure 5.5 and 5.6), but the H_1 and H_5 tephra layers are so thin that they cannot always be noticed in some profiles (Figure 5.5).

In addition eight basaltic tephras are also known to be distributed around Eyjafjördur originating from three volcanic systems in southern and southeastern Iceland (Figure 5.7). Three of these were erupted from the Hekla volcanic system, dated 1300 A.D., 1636 A.D. and 1766 A.D. (Figure 5.8) (Thorarinsson, 1967). The Katla volcanic system produced two layers: one dated 1000 A.D. (Thorarinsson, 1967, 1975). The other layer is dated as 1721 A.D. (Figure 5.8) (Thorarinsson, 1967; Larsen, pers. information). Two further layers have eminated from the Veidivötn-Dyngjuháls (Dyngjujökull) volcanic

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x) H_2 was once thought to be younger than H_3, but later it was found to be between H_3 and H_4 and renamed as the Selsund pumice. The volume much less than of the other four acid Hekla layers (Larsen and Thorarinsson, 1977).

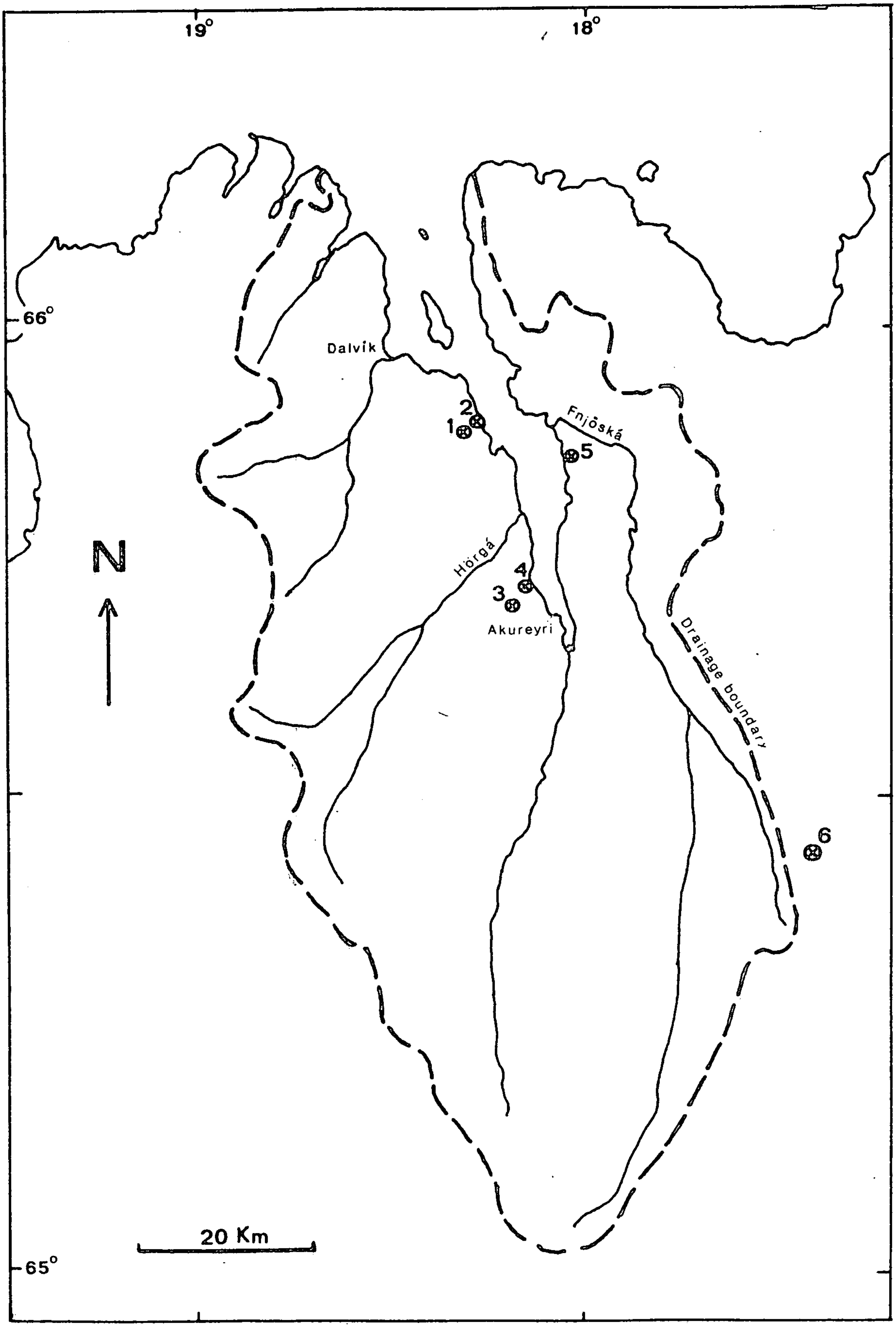


Figure 5.4. Location of soil profiles, illustrated in Figure 5.5.

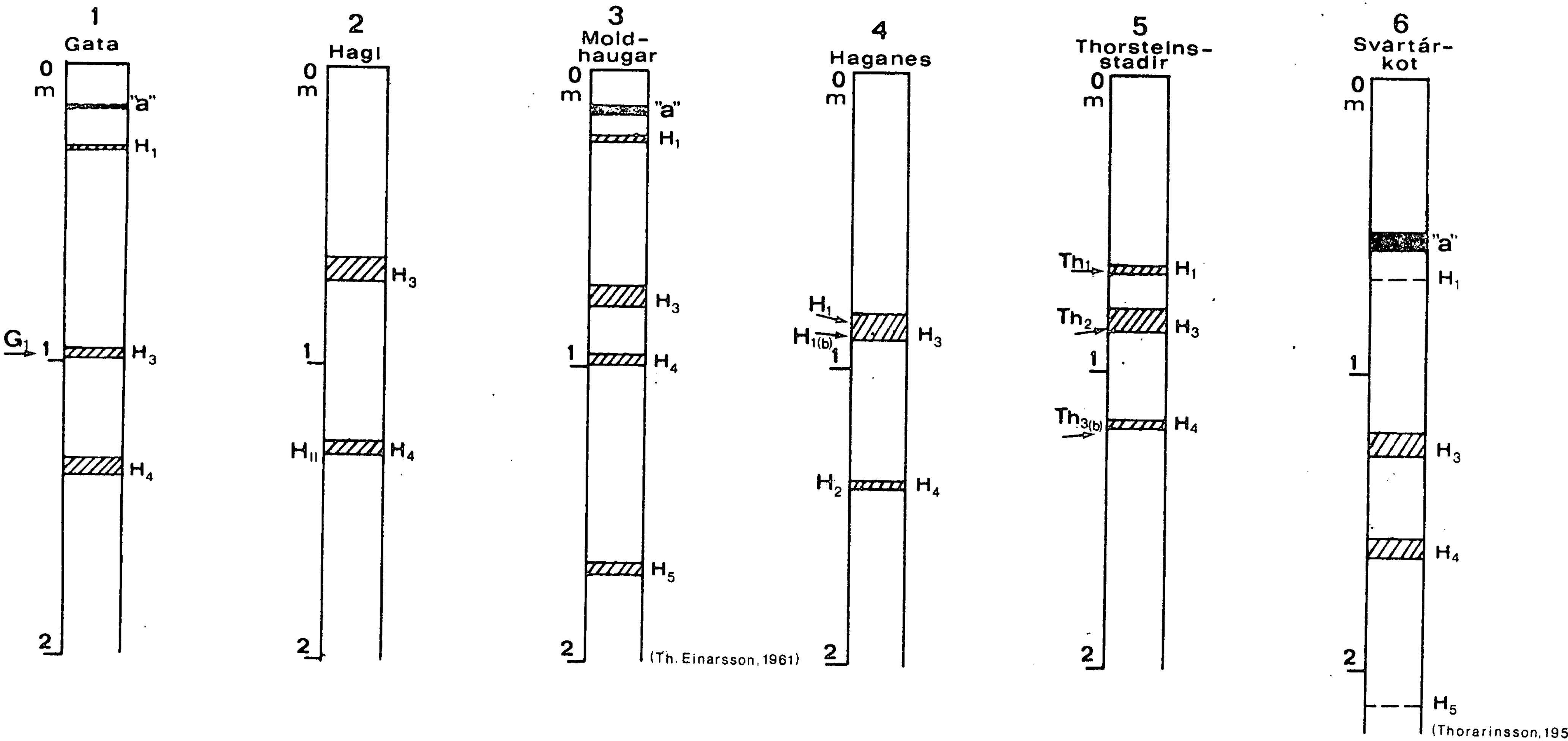


Figure 5.5. Soil profiles from the Eyjafjördur area. Their location is shown in Figure 5.4.

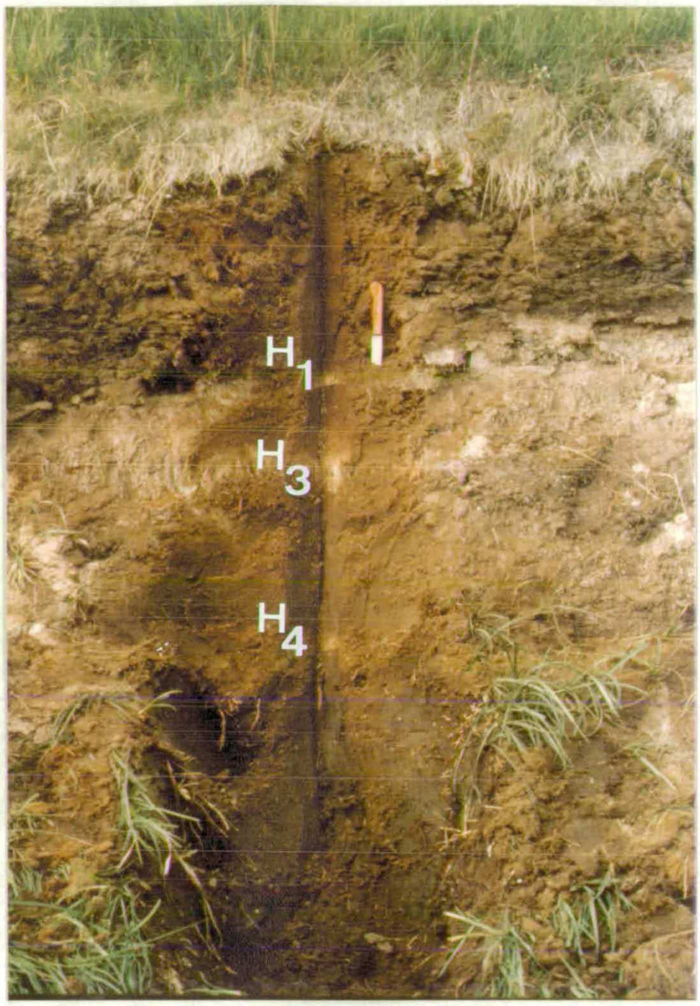


Figure 5.6. The soil profile at Thorsteinsstadir. See also Figures 5.4 and 5.5. (The handle of the knife is 12 cm long).

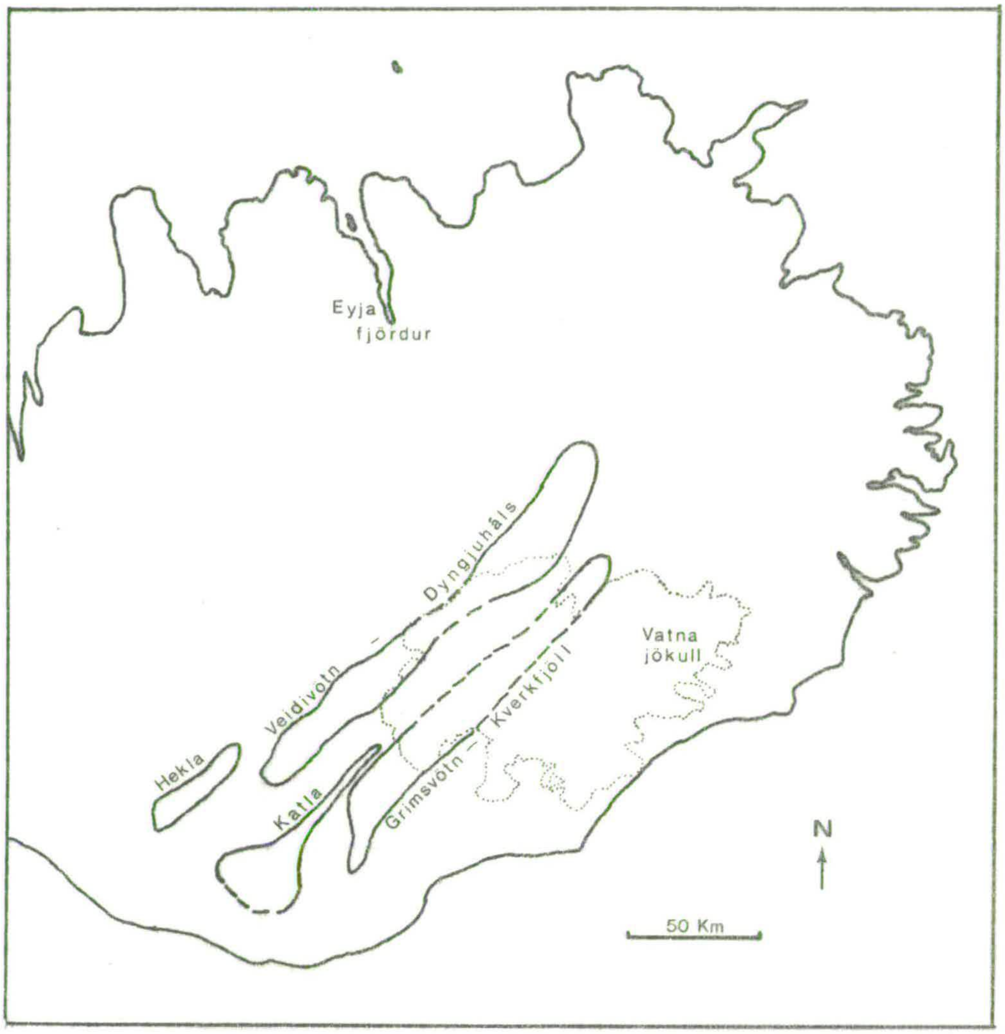


Figure 5.7. Location of the volcanic systems in Iceland known to have distributed tephra into the Eyjafjördur area. Based on Jakobsson, 1979b and Larsen, 1982.

system; one labelled layer "a" dates from 1477 (Thorarinsson, 1958; Larsen, 1982) and is the thickest basaltic layer to be found in soils in northeastern Iceland (Benjaminsson, 1981). The other layer is dated as 1717-1729 A.D. (Figure 5.8) (Thorarinsson, 1950; Larsen, 1978, 1982). An isopach map has not been published of this layer, but its distribution is known to have been over the northeastern part of Iceland (Larsen, pers. information).

A further basaltic tephra known to be distributed all over the country originates from the southern part of the Veidivötn Dyngjuháls (Dyngjujökull) volcanic system (Larsen, 1978, personal communication). This layer has been named the Settlement Layer (V11a+b) and is dated as 850-930 A.D. from historical records and pollen analysis (Figure 5.8) (Thorarinsson, 1944, 1967; Th. Einarsson, 1962). A study of the aerosol fall-out preserved in ice cores from Greenland indicates that this ashfall probably occurred in 898 A.D. (Hammer et al., 1980; Larsen, 1982).

In the soil profiles studied only one of the eight basaltic tephra layers known to have been distributed into the Eyjafjördur area has been distinguished, i.e. tephra layer "a" (Figure 5.5).

5.2.2 Characterization of tephra

The characterization of tephra layers has been made using several types of observations. Thorarinsson (1944) emphasised their character from colour, grain size distribution, thickness, areal distribution, stratigraphy, lithic

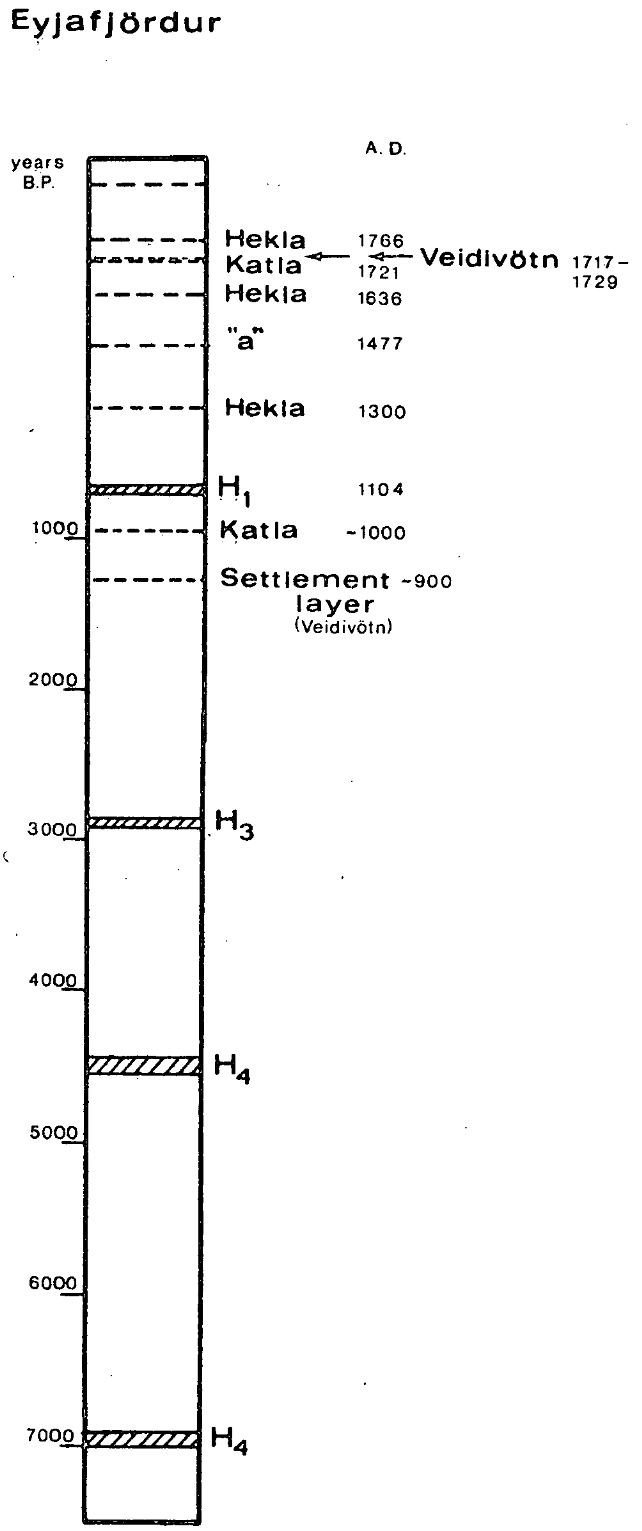


Figure 5.8. The 'ideal' tephrochronological profile of Eyjafjördur showing all known tephra layers distributed into the area.

content and refractive indices of mineral constituent and glass.

Usually these provide a reliable control for identification and correlation in regions near the source vents, and to some extent for distal tephras, especially those deposited in historical times (Thorarinsson, 1961). More recently studies of their physico-chemical characters have defined them more accurately and has allowed them to be interpreted from petrological reasons.

Inspection of the definite sedimentary horizons in the marine cores from Eyjafjördur clearly indicate that those field characteristics described for identifying soil tephras are insufficient for the recognition of particular ash layers. For example the acid tephra layers from Hekla do not show colour differences in the sediment cores.

The value of refractive indices as a tool for correlation is not always reliable due to possible fractionation of mineral grains during their transport. More importantly the products from Hekla change in composition during an eruption, where they become more silica rich with time (Thorarinsson, 1967; Larsen and Thorarinsson, 1977).

The refractive index of acid glasses in the near vicinity of Hekla clearly shows that the index for the H_1 and H_3 layers is the same, n=1.504, but for H_4 and H_5 the index is slightly lower, n=1.498 and n=1.496, respectively (Tómasson, 1967). Devitrification can have some effect on older glasses but Tómasson (1967) believes that post-glacial glasses are unaffected by alteration.

The refractive index in the acid tephra glasses of Eyja-

Table 5.1

Soil samples

Number	Profile	Hekla tephra	Refractive index
Th_1	Thorsteinsstadir	H_1	n=1.504
Th_2	" "	H_3	n=1.504
$Th_{3(base)}$	" "	H_4	n=1.496
H_1	Haganes	H_3	n=1.505
$H_{1(base)}$	" "	H_3	n=1.503
G_1	Gata	H_3	n=1.502 - 1.503

see location in Figure 5.5

Core samples

Number	Depth	Refractive index
II-2	350 cm	n=1.504
IV-3	410 cm	n=1.504
IV-4	735 cm	n=1.500 - 1.504
XXI-2	330 cm	n=1.504
XXI-3	430 cm	n=1.500 - 1.504

see location in Figure 5.2

fjördur, both in soils and the cores, are outlined in Table 5.1.

In the soil samples, with the exeption of horizon $Th_{3(base)}$, represent either H_1 or H_3 tephra layers. From field parameters $Th_{3(base)}$ is identified with the H_4 tephra. These values are similar to those found in tephras in the near vicinity of Hekla.

In the marine cores the refractive indices show small inter variations between samples and by themselves cannot be correlated with a particular acid tephra layers. For a more precise correlation to be made using refractive indices alone far more measurements would have to be made. However, owing to the similar values of refractive indices in the glasses of the H_1 and H_3 events and the H_4 and H_5 events, such a programme of measurements would probably be unprofitable. The results discribed from the cores are nevertheless reliable enough to confirm that they have close affinity with those in the soils.

In general the chemical composition of volcanic glasses have been shown to be the most appropriate method in recognizing particular tephras. However, bulk tephra analyses are not always useful in this respect, because of mineralogical and hence compositional fractionation during their transport. In order to overcome this difficulty Sigvaldason (1974) has conducted analyses on the acid tephra layers of Hekla using only separated fractions of glasses and minerals. The analysis were performed on X-ray fluoresence spectrometry. The results are reported in Table 5.2.

In this study the composition of volcanic glasses have been determined using an electron microprobe technique, where the analytical precision ($\pm$ 1%) allows minor variations in composition to be observed. Analysing individual grains of glass rather than a bulk sample relieves the problems of mineral fractionation during atmospheric transport and contamination effects of extraneous materials particularly within thin tephra layers in marine sediment cores.

5.2.3 Results

a) Acid tephra layers

In this study more emphasis has been placed on the composition of the acidic rather than the basaltic glasses and minerals. The samples selected were prepared as described in Appendix D and analysed both in Edinburgh and in the University of Rhode Island (by Prof. H. Sigurdsson). Using two instruments for analysing certain tephra layers an opportunity has been made both for an intercorrelation of data and for comparing the tephra layers taken in the near vicinity of Hekla (Sigurdsson, 1982) with those from more distal Eyjafjördur district.

Though the glasses of each volcanic system appear to have a distinctive petrology as discussed above they tend to be petrographically similar and thus not easily recognized (e.g. Hekla) unless resorting to analysing the composition of the glass itself. The chemical analyses outlined in Tables 5.2 and 5.3 are from samples taken in the near vicinity

TABLE 5.2

Sample	H_1	H_{3a}	H_{3b}	H_{3c}	H_4	H_5
SiO_2	69.72	70.00	65.23	64.54	73.91	73.76
Al_2O_3	15.87	14.66	14.98	14.93	12.59	12.90
TiO_2	0.16	0.19	0.36	0.58	0.10	0.16
Fe_2O_3	0.35	0.47	0.86	1.94	0.26	0.47
FeO	2.76	2.61	4.72	5.81	1.52	1.60
MnO	0.10	0.11	0.17	0.20	0.09	0.09
MgO	0.23	0.00	0.36	1.16	0.00	0.17
CaO	2.81	2.55	3.46	4.15	1.29	1.69
Na_2O	4.41	4.76	4.66	4.25	4.80	4.52
K_2O	2.38	2.38	2.00	1.74	2.83	2.67
P_2O_5	0.07	0.01	0.12	0.21	0.01	0.01
H_2O	1.81	2.44	2.71	0.76	2.56	2.58
Total	100.67	100.18	99.63	100.37	99.96	100.62

(From Sigvaldason, 1974)

H_1: Collected 10 Km north of Hekla

H_3: 3a 10 cm from the bottom
3b 100 cm from the bottom
3c 190 cm from the bottom
} 10 km north of Hekla

H_4, H_5 } Collected 16 km NW of Hekla

TABLE 5. 3

Sample number	H_1 (10)	H_3 (10)	H_4 (12)	H_{4base} (10)	H_5 (16)
SiO_2	72.56	72.49	74.30	74.37	74.80
σ	(.80)	(.85)	(.61)	(.60)	(.53)
Al_2O_3	14.05	14.13	13.09	12.97	12.62
σ	(.19)	(.23)	(.24)	(.20)	(.16)
TiO_2	0.21	0.20	0.12	0.12	0.12
σ	(.04)	(.05)	(.03)	(.03)	(.03)
FeO	3.04	2.88	1.58	1.60	1.37
σ	(.24)	(.15)	(.10)	(.12)	(.11)
MnO	0.15	0.13	0.14	0.14	0.12
σ	(.03)	(.04)	(.03)	(.04)	(.03)
MgO	0.10	0.10			
σ	(.02)	(.04)			
CaO	1.96	1.97	1.33	1.28	1.29
σ	(.12)	(.16)	(.07)	(.10)	(.14)
Na_2O	5.39	5.48	4.89	4.73	4.54
σ	(.10)	(.15)	(.18)	(.22)	(.22)
K_2O	2.80	2.56	2.60	2.59	2.53
σ	(.22)	(.10)	(.25)	(.16)	(.28)
Total	100.26	99.94	98.05	97.80	97.39

(From Sigurdsson, 1982)

Samples collected about 12 km NW of Hekla of Hekla (Sigvaldason, 1974 ; Sigurdsson, 1982). Table 5.2 shows tha X-ray fluoresence analyses of bulk samples of different tephras. Analyses of P_2O_5 and H_2O are also expressed as determined by gravimetric analyses and iron is shown as Fe_2O_3 and FeO.

Published information on SiO_2, Al_2O_3, FeO^x, CaO and K_2O values show the most variation. The tephra layers of H_4 and H_5 on one hand and H_1 and H_3 on the other are easily distinguishable on grounds of variable major oxide compositions (Sigvaldason, 1974) and this is confirmed by glass samples of these layers analysed by electron microprobe and shown in Table 5.3

A difficulty arises in differentiating between H_1 and H_{3a} or H_4 and H_5 (Table 5.2) using the major elements, however. As for example measured by microprobe (Table 5.3) H_4 is higher in Al_2O_3 and FeO than H_5, which conflicts with the X-ray fluoresence analysis of bulk sample (Table 5.2) where the contents of these elements in the samples are reversed. Measurements of the minor elements of those acid tephras described in Table 5.2 (Sigvaldason, 1974) did not show any well defined differences in content. This example emphasizes only the importance of stratigraphical control in identifying these layers.

Results of the major element analysis from the Eyjafjördur area are presented in Appendix G and H and summarized in Tables 5.4 and 5.5 Table 5.5 shows data of soil and marine laid tephra glasses analysed in Edinburgh. The samples selected were taken from the same horizons as the samples measured for the refractive index, Table 5.1 except for the

Table 5.4

Sample	SiO_2	AlO_3	TiO_2	FeO	MnO	MgO	CaO	Na_2O/Na loss	K_2O/K loss	Total/plus Loss
HAGANES 1 (Soil glasses)										
3	69.94	13.52	.30	3.22	.13	.10	2.02	4.10/	2.41/	95.75/
σ	61	.47	.02	.42	.05		.28	.14/	.10/	1.49/
HAGANES 1 (base)										
4	68.19	13.14	.24	2.90			1.99	3.80/	2.35/	92.70/
σ	.91	.44	.06	.08			.10	.03/	.10/	1.22/
THORSTEINSSTADIR 1										
3	70.50	13.63	.24	2.97			1.94	3.89/	2.46/	95.74/
σ	.69	.10	.03	.07			.03	.12/	.06/	.67/
2	64.95	13.21	.41	4.60	.18		2.62	3.71/	2.06/	91.95/
σ	.60	.26	.08	.99	.05		.40	.08/	.11/	1.18/
THORSTEINSSTADIR 2										
2	69.26	13.23	.27	2.97			1.84	3.95/	2.46/	94.12/
σ	1.39	.17	.10	.15			.07	.05/	.13/	1.87/
2	63.78	14.01	.37	5.45	.17	.31	3.16	3.96/	1.93/	93.20/
σ	.38	.05	.01	.02	.01	.07	.07	.09/	.04/	.35/
THORSTEINSSTADIR 3 (base)										
4	71.97	12.51	.17	1.89			1.32	4.22/	2.75/	94.89/
σ	1.47	.17	.05	.09			.04	.15/	.07/	1.89/
CORE: 11-2										
4	69.01	13.35	.26	3.93			2.22	4.02/	2.33/	95.46/
σ	1.21	.68	.07	.93			.20	.19/	.13/	1.02/
CORE: IV - 3										
2	69.96	13.77	.25	3.27			2.24	4.30/	2.37/	96.32/
σ	1.56	.19	.02	.39			.19	.14/	.19/	.63/
1	63.70	14.15	.60	6.35	.22	.55	3.58	3.91/	1.79/	94.85/
CORE: IV - 4										
4	63.33	14.22	.62	6.87	.21	.54	3.83	4.05/	1.84/	95.46/
σ	1.20	.27	.15	1.29	.01	.24	.53	.04/	.14/	1.28/
CORE: XXI - 2										
3	68.98	13.02	.21	3.03			1.93	4.03/	2.37/	93.60/
σ	1.25	.27	.05	.14			.06	.08/	.07/	1.58/
CORE: XXI - 3										
2	63.60	14.04	.51	6.02	.17	.39	3.46	3.88/	1.90/	93.99/
σ	.16	.68	.18	1.44	.00	.34	.78	.12/	.05/	3.33/

Table 5.5

Sample	SiO_2	Al_2O_3	TiO_2	FeO^+	MnO	MgO	CaO	Na_2O/Na Loss	K_2O/K Loss	Total/plus Loss
Haganes 1										
26	71.60	13.95	.18	2.76	.09	.04	1.85	1.99/	2.51/	94.97/
σ	.81	.22	.05	.20	.06	.03	.16	.23/	.15/	1.06/
Haganes 2										
27	74.08	13.02	.07	1.73	.07	.00	1.22	2.08/	2.67/	94.93/
σ	.59	.25	.03	.16	.04	.00	.14	.16/	.23/	.80/
Gata 1										
8	72.13	14.22	.21	3.04	.13	.07	2.13	2.19/	2.52/	96.64/
σ	.68	.20	.05	.13	.05	.02	.09	.17/	.11/	.90/
5	74.68	13.17	.07	1.95	.12	.00	1.33	2.05/	2.63/	96.01
σ	.93	.28	.01	.08	.02	.00	.13	.30/	.28/	.60
3	71.60	13.68	.32	3.83	.17	.14	1.30	2.34/	3.37/	96.74/
σ	.33	.27	.06	.40	.03	.00	.02	.13/	.17/	.73/
HAGI II										
5	73.91	13.19	.11	1.73	.07	.00	1.25	2.52/	2.59/	94.97/
σ	.81	.16	.03	.18	.03	.00	.00	.33/	.26/	1.15/
THORSTEINSSTADIR 2										
8	71.57	14.11	.18	2.95	.16	.07	2.04	1.89/	2.62/	95.60/
σ	.73	.28	.05	.21	.04	.04	.19	.19/	.14/	1.08/
2	68.73	15.21	.47	5.78	.23	.31	3.24	2.06/	2.15/	98.16/
σ	.13	.07	.04	.06	.01	.03	.16	.11/	.21/	.28/
Core: II-2										
3	71.10	14.39	.18	2.95	.09	.02	2.01	2.01/	2.69/	95.44/
σ	1.20	.28	.06	.03	.05	.02	.08	.82/	.42/	2.42/
2	66.92	14.85	.43	5.76	.23	.27	3.48	2.02/	2.12/	96.06/
σ	.54	.13	.04	.31	.04	.04	.12	.19/	.01/	.27/
1	67.26	16.59	.37	5.12	.24	.20	2.42	1.86/	2.37/	96.43/
Core: IV-3										
4	71.20	14.13	.19	3.14	.07	.05	2.03	1.76/	2.46/	95.02/
σ	1.28	.36	.04	.55	.03	.05	.20	.36/	.16/	1.57/
5	68.21	15.02	.40	5.18	.18	.23	3.09	1.86/	2.24/	96.40/
σ	.95	.16	.06	.19	.04	.02	.23	.42/	.13/	.82/

Table 5.5

Sample	SiO_2	Al_2C_3	TiO_2	FeO^+	MnO	MgO	CaO	Na_2O/Na loss	K_2O/K loss	Total/plus loss
Core: IV-4										
2	72.44	14.66	.17	3.07	.05	.02	1.92	1.51/	2.65/	96.49/
σ	.44	.03	.00	.15	.05	.01	.18	.27/	.02/	.46/
1	67.19	15.54	.54	6.32	.20	.46	3.44	1.95/	2.33/	97.96/
4	65.03	15.57	.78	7.24	.24	.62	4.46	2.78/	1.98/	98.69/
σ	.51	.28	.01	.40	.07	.12	.12	1.00/	.29/	.91/
2	62.66	15.20	.88	9.04	.25	.88	4.52	2.26/	2.19/	97.85/
σ	.21	.27	.12	1.11	.04	.01	.33	.08/	.11/	.57/
Core: IV-5										
4	71.18	14.29	.21	3.11	.10	.04	2.22	1.96/	2.87/	95.95/
σ	.88	.43	.06	.10	.03	.03	.13	.32/	.19/	.89/
1	69.39	15.14	.27	4.18	.10	.07	2.95	1.16/	2.79/	96.06/
1	66.86	15.26	.45	5.49	.19	.27	3.11	1.79/	2.54/	95.96/
Core: XXI-2										
3	71.31	15.00	.17	2.95	.08	.00	2.11	1.70/	2.61/	95.93/
σ	.85	.79	.03	.03	.02	.00	.09	.12/	.19/	1.17/
1	68.60	15.45	.30	5.05	.16	.19	3.38	1.30/	2.11/	96.55/
1	66.24	14.98	.54	5.80	.20	.33	3.68	2.10/	2.27/	96.13/
1	64.68	15.51	.82	6.45	.25	.70	4.67	2.40/	1.83/	97.31/
1	63.77	15.33	.75	7.33	.16	.68	4.41	2.23/	2.29/	96.94/
Core: XXI-3										
1	71.53	14.04	.18	2.85	.12	.01	2.15	1.76/	2.88/	95.52/
1	69.73	16.69	.14	1.64	.04	.48	3.18	3.57/	2.46/	97.93/
1	68.95	14.74	.26	3.77	.09	.10	2.76	1.70/	2.52/	94.88/
3	67.00	15.53	.45	5.73	.16	.35	3.84	1.87/	2.38/	97.33/
σ	1.85	.49	.18	.94	.04	.18	.42	.12/	.20/	1.91/
1	64.89	16.08	.82	5.45	.17	.60	5.20	4.69/	1.14/	99.04/
4	64.42	15.52	.76	7.55	.22	.75	4.61	1.96/	2.04/	97.82/
σ	.18	.17	.03	.12	.06	.08	.13	.28/	.17/	.91/
3	62.05	15.76	.80	8.33	.24	.88	4.91	2.24/	1.88/	97.09/
σ	1.52	.32	.06	.30	.03	.08	.14	.33/	.22/	1.98/

soil sample G_1 (Gata) (see Figure 5.2 and 5.5 for location). Four of the soil samples i.e. Haganes 1; Haganes $1_{(base)}$; Thorsteinsstadir 1 and Thorsteinsstadir 2 have been identified on field characters either as H_1 or as H_3 tephra layer, but one soil sample Thorsteinsstadir $3_{(base)}$ is identified as tephra layer H_4. The chemical analyses presented in Table 5.4 also reflect this difference in that the four samples identified as H_1 of H_3 tephra layer do all show similar values for the major elements, but for the H_4 tephra sample, Thorsteinsstadir $3_{(base)}$ an increase in SiO_2 and decrease in Al_2O_3 and FeO^x is analysed as expected compared with reference samples in Table 5.3.

Results of major element analyses of the acid tephra layers in Cores II, IV and XXI do all show relatively low values of SiO_2. The upper acid glass horizon of Cores IV and XXI (samples IV-3 and XXI-2) and sample II-2 from Core II do show a SiO_2 content of 69% value identical to the H_1 or H_3 tephra layers identified in the soil profiles, when analyses of the lower acid glass horizon of Cores IV and XXI (samples IV-4 and XXI-3) do show a SiO_2 content of 63.5% a value quite comparable with the soil samples Thorsteinsstadir 1 and 2 (Table 5.4) also identified as tephra layer H_1 and tephra layer H_3 (Figure 5.5).

Table 5.5 shows data of soil and marine glasses analysed at the University of Rhode Island. Five samples were selected from the soil profiles described in Figure 5.5, i.e. Haganes 1, Gata 1 and Thorsteinsstadir 2 identified on field characters either as tephra layer H_1 or H_3 whereas samples Haganes 2 and Hagi II have been identified as tephra layer H_4.

Results of the chemical analyses also confirm this division where the data of soil samples Haganes 1, Gata 1 and Thorsteinsstadir 2 are almost identical to the reference samples for tephra layers H_1 and H_3 (Table 5.3). Similarly analyses of soil samples Haganes 2 and Hagi II are matched with the reference samples in Table 5.3 for tephra layers H_4 and H_5.

The same tephra layers on the marine sediments analysed in Edinburgh (Table 5.4) and the chemical analyses (Table 5.5) are more or less identical for all the core samples and comparing that either with the soil samples described above or the reference samples in Table 5.3 show a definite relation to H_1 - H_3 tephra layers.

For a further comparsion the chemical analysis from Edinburgh and Rhode Island are listed both for the soil and the core samples in Tables 5.6 and 5.7. Analyses undertaken at Edinburgh are on average 3% lower than analyses at the University of Rhode Island. The reason for this is not known, but may partly be related to the high vesicularity of the acid grains and partly to the mounting technique (see also Appendix D).

In conclusion the results above show that the acid tephra horizons in the core sediments can clearly be matched with either the H_1 tephra layer of the H_3 tephra layer. Finally, stratigraphically samples IV-3 and XXI-2 are tephra layer H_1 and samples IV-4 and XXI-3 tephra layer H_3 (Figure 5.9).

Table 5.6

Sample aver	Hekla-1 (10)	Hekla-3 (10)	Hekla-4 (12)	Hekla-4 Base (10)	Hekla-5 (16)	Haganes 1a (15)*	Haganes 1 (11)*	Haganes 1a (4)▽	Haganes 1 (3)▽	Haganes 2 (27)*
SiO_2	72.56	72.49	74.30	74.37	74.80	71.61	71.59	68.19	69.94	74.08
Al_2O_3	14.05	14.13	13.09	12.97	12.62	13.97	13.93	13.14	13.52	13.02
TiO_2	0.21	0.20	0.12	0.12	0.12	0.18	0.18	0.24	0.30	0.07
FeO	3.04	2.88	1.58	1.60	1.37	2.79	2.73	2.90	3.22	1.73
MnO	0.15	0.13	0.14	0.14	0.12	0.09	0.09		0.13	0.07
MgO	0.10	0.10				0.04	0.04		0.10	
CaO	1.96	1.97	1.33	1.28	1.29	1.86	1.84	1.99	2.02	1.22
Na_2O	5.39	5.48	4.89	4.73	4.54	1.98	2.00	3.80	4.10	2.08
K_2O	2.80	2.56	2.60	2.59	2.53	2.56	2.46	2.35	2.41	2.67
Total	100.26	99.94	98.05	97.80	97.39	95.09	94.80	92.70	95.75	94.93

(From Table 5.3)

* From Table 5.4
▽ From Table 5.5

Sample aver	Thorsteinsstaðir 1 (3)▽	Thorsteinsstaðir 1 (2)▽	Thorsteinsstaðir 2 (8)*	Thorsteinsstaðir 2 (2)*	Thorsteinsstaðir 2 (2)▽	Thorsteinsstaðir 2 (2)▽	Thorsteinsstaðir 3a (4)▽	Gata 1 (5)*	Gata 1 (8)*	Hagi (5)*
SiO_2	70.50	64.95	71.57	68.73	69.26	63.78	71.97	74.68	72.13	73.91
Al_2O_3	13.63	13.21	14.11	15.21	13.23	14.01	12.51	13.17	14.22	13.19
TiO_2	0.24	0.41	0.18	0.47	0.27	0.37	0.17	0.07	0.21	0.11
FeO	2.97	4.60	2.95	5.78	2.97	5.45	1.89	1.95	3.04	1.73
MnO		0.18	0.16	0.23		0.17		0.12	0.13	0.07
MgO			0.07	0.31		0.31			0.07	
CaO	1.94	2.62	2.04	3.24	1.84	3.16	1.32	1.33	2.13	1.25
Na_2O	3.89	3.71	1.89	2.06	3.95	3.96	4.22	2.05	2.19	2.52
K_2O	2.46	2.06	2.62	2.15	2.46	1.93	2.75	2.63	2.52	2.59
Total	95.74	91.95	95.60	98.16	94.12	93.20	94.89	96.01	96.64	94.97

Table 5.7

Sample aver.	Core: II-2 (3)*	Core: II-2 (2)*	Core: II-2 (1)*	Core: II-2 (4)▽	Core: IV-3 (4)*	Core: IV-3 (5)*	Core: IV-3 (2)▽	Core: IV-3 (1)▽	Core: IV-4 (4)▽
SiO_2	71.10	66.92	67.26	69.01	71.20	68.21	69.96	63.70	63.33
Al_2O_3	14.39	14.85	16.59	13.35	14.13	15.02	13.77	14.15	14.22
TiO_2	.18	.43	.37	.26	.19	.40	.25	.60	.62
FeO	2.95	5.76	5.12	3.93	3.14	5.18	3.27	6.35	6.87
MnO	0.09	0.23	0.24		.07	.18		.22	.21
MgO	0.02	0.27	0.20		.05	.23		.55	.54
CaO	2.01	3.48	2.42	2.22	2.03	3.09	2.24	3.58	3.83
Na_2O	2.01	2.02	1.86	4.02	1.76	1.86	4.30	3.91	4.05
K_2O	2.69	2.12	2.37	2.33	2.46	2.24	2.37	1.79	1.84
Total	95.44	96.06	96.43	95.46	95.02	96.40	96.32	94.85	95.46

Sample aver	Core: IV-4 (2)*	Core: IV-4 (1)*	Core: IV-4 (4)*	Core: IV-4 (2)*	Core: IV-5 (4)*	Core: IV-5 (1)*	Core: IV-5 (1)*	Core: XX1-2 (3)*	Core: XXI-2 (1)*	Core: XX1-2 (1)*
SiO_2	72.44	67.19	65.03	62.66	71.18	69.39	66.86	71.31	68.60	66.24
Al_2O_3	14.66	15.54	15.57	15.20	14.29	15.14	15.26	15.00	15.45	14.98
TiO_2	.17	.54	.78	.88	.21	.27	.45	.17	.30	.54
FeO^+	3.07	6.32	7.24	9.04	3.11	4.18	5.49	2.95	5.05	5.80
MnO	.05	.20	.24	.25	.10	.10	.19	.08	.16	.20
MgO	.02	.46	.62	.88	.04	.07	.27		.19	.33
CaO	1.92	3.44	4.46	4.52	2.22	2.95	3.11	2.11	3.38	3.68
Na_2O	1.51	1.95	2.78	2.26	1.96	1.16	1.79	1.70	1.30	2.10
K_2O	2.65	2.33	1.98	2.19	2.87	2.79	2.54	2.61	2.11	2.27
Total	96.49	97.96	98.69	97.85	95.95	96.06	95.96	95.93	96.55	96.13

* From Table 5.4
▽ From Table 5.5

Table 5.7 (cont.)

Sample aver.	Core: XXI-2 (1)*	Core: XXI-2 (1)*	Core: XXI-2 (3)▽	Core: XXI-3 (1)*	Core: XXI-3 (1)*	Core: XXI-3 (1)*	Core: XXI-3 (3)*	Core: XXI-3 (1)*	Core: XXI-3 (4)*	Core: XXI-3 (3)*	Core: XXI-3 (2)▽
SiO_2	64.68	63.77	68.98	71.53	69.73	68.95	67.00	64.89	64.42	62.05	63.60
Al_2O_3	15.51	15.33	13.02	14.04	16.69	14.74	15.53	16.08	15.52	15.76	14.04
TiO_2	.82	.75	.21	.18	.14	.26	.45	.82	.76	.80	.51
FeO	6.45	7.33	3.03	2.85	1.64	3.77	5.73	5.45	7.55	8.33	6.02
MnO	.25	.16		.12	.04	.09	.16	.17	.22	.24	.17
MgO	.70	.68		.01	.48	.10	.35	.60	.75	.88	.39
CaO	4.67	4.41	1.93	2.15	3.18	2.76	3.84	5.20	4.61	4.91	3.46
Na_2O	2.40	2.23	4.03	1.76	3.57	1.70	1.87	4.69	1.96	2.24	3.88
K_2O	1.83	2.29	2.37	2.88	2.46	2.52	2.38	1.14	2.04	1.88	1.90
Total	97.31	96.94	93.60	95.52	97.93	94.88	97.33	99.04	97.82	97.09	93.99

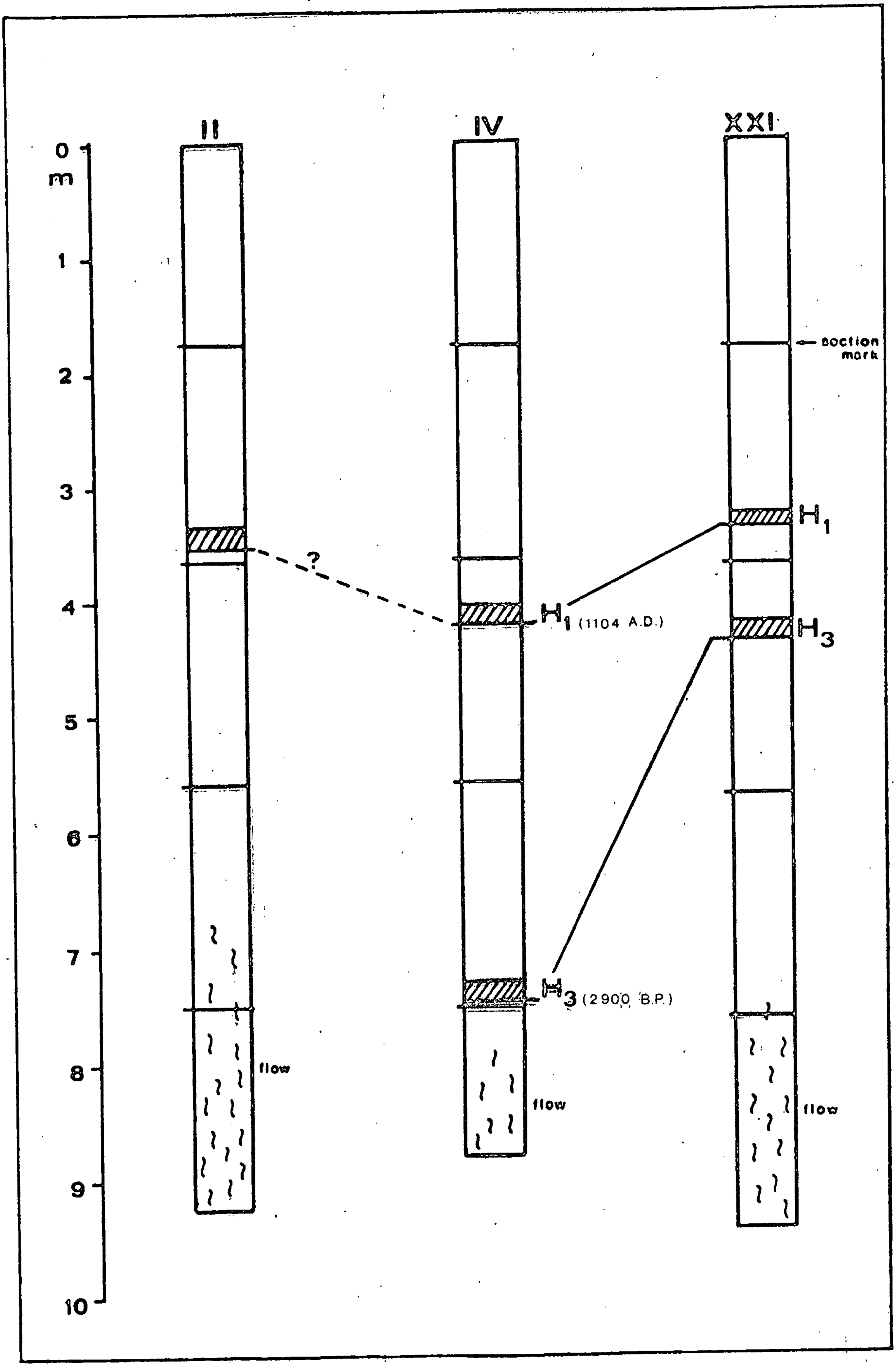


Figure 5.9. Chronostratigraphy of Cores IV, XXI and II.

b) Basaltic tephra layers

A number of thin ($\leq$ 1-1.5 cm) basaltic tephra samples were examined in the cores. Only samples from Core II and Core IV were distinguishable and their chemical analyses are presented in Appendix J and summerized in Table 5.8.

As mentioned in chapter 5.2.1 no basaltic tephra layer has been sampled from the soil profiles around the fjord, primarily because the products from basaltic volcanism do in general not change significantly in composition during an eruption and the basalt composition should therefore be more or less representative for the materials collected within the volcanic systems known to have distributed tephra into the Eyjafjördur area (Figure 5.8).

The geochemical trends of the basaltic tephras are illustrated as plots of K_2O against TiO_2 (wt%) and FeO^x against TiO_2 (Figure 5.10 and 5.11). On the K_2O - TiO_2 diagram the average values and compositional ranges (filled circles and bars) of postglacial basalts from four volcanic systems in the south and the southeast part of Iceland (Figure 5.7) (Jakobsson,1979b; Larsen, 1981) are shown, and these can be compared with the composition of the tephra layers in the cores (Figure 5.10). Similarly the TiO_2 - FeO^x diagram illustrates the compositional ranges (loops) from four volcanic systems, located in Figure 5.7 and these can be compared with the basaltic tephras in the cores (Figure 5.11).

The resultant diagrams show that the tephra layers can be matched to particular volcanic systems i.e. the Katla, the Veidivötn-Dyngjuháls (Dyngjujökull) and the Grímsvötn-Kverk-

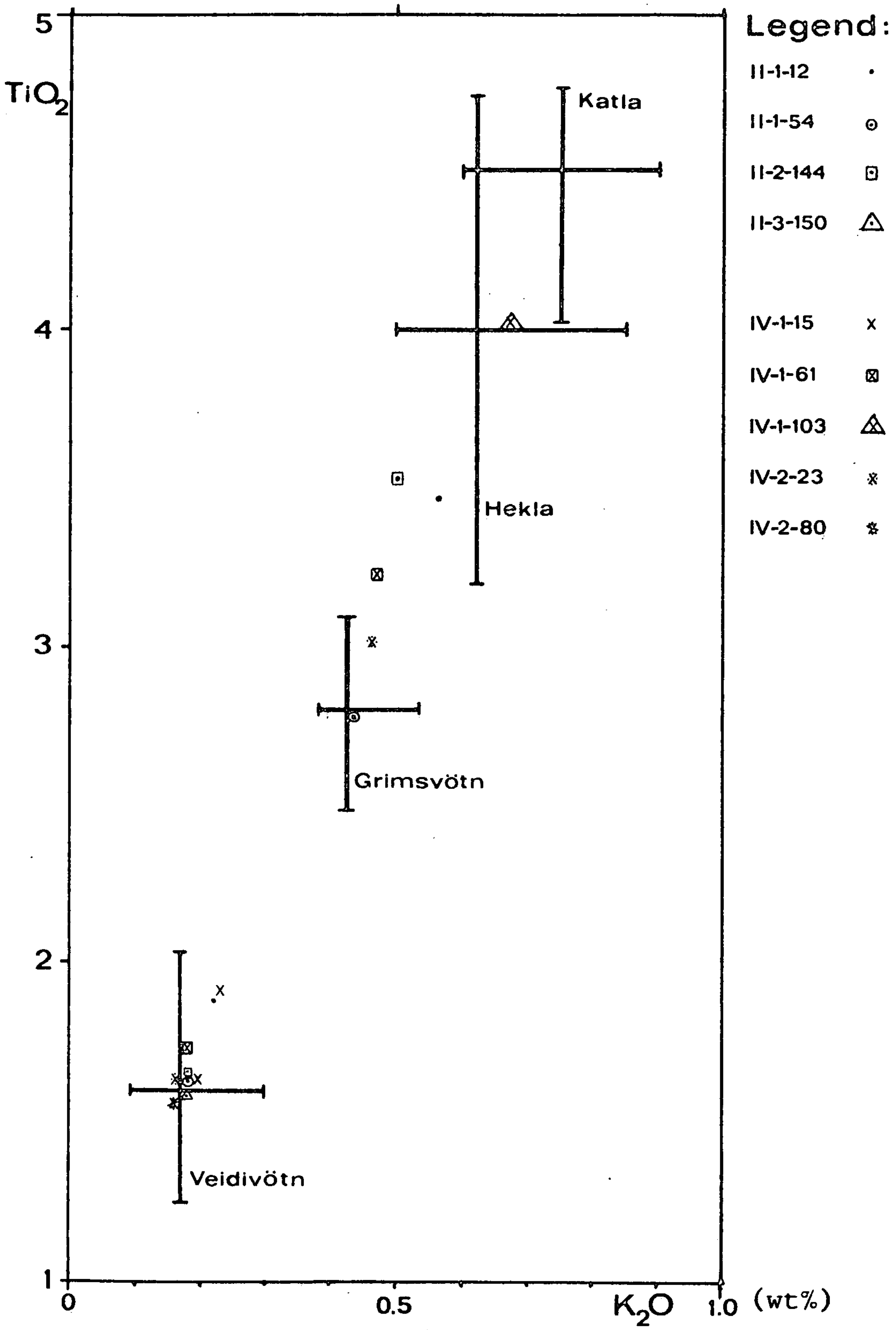


Figure 5.10. TiO_2 - K_2O diagram of the basaltic tephra samples. Their location is shown in Figure 5.2. The average value and range -bars- of these elements is based on Jakobsson, 1979b.

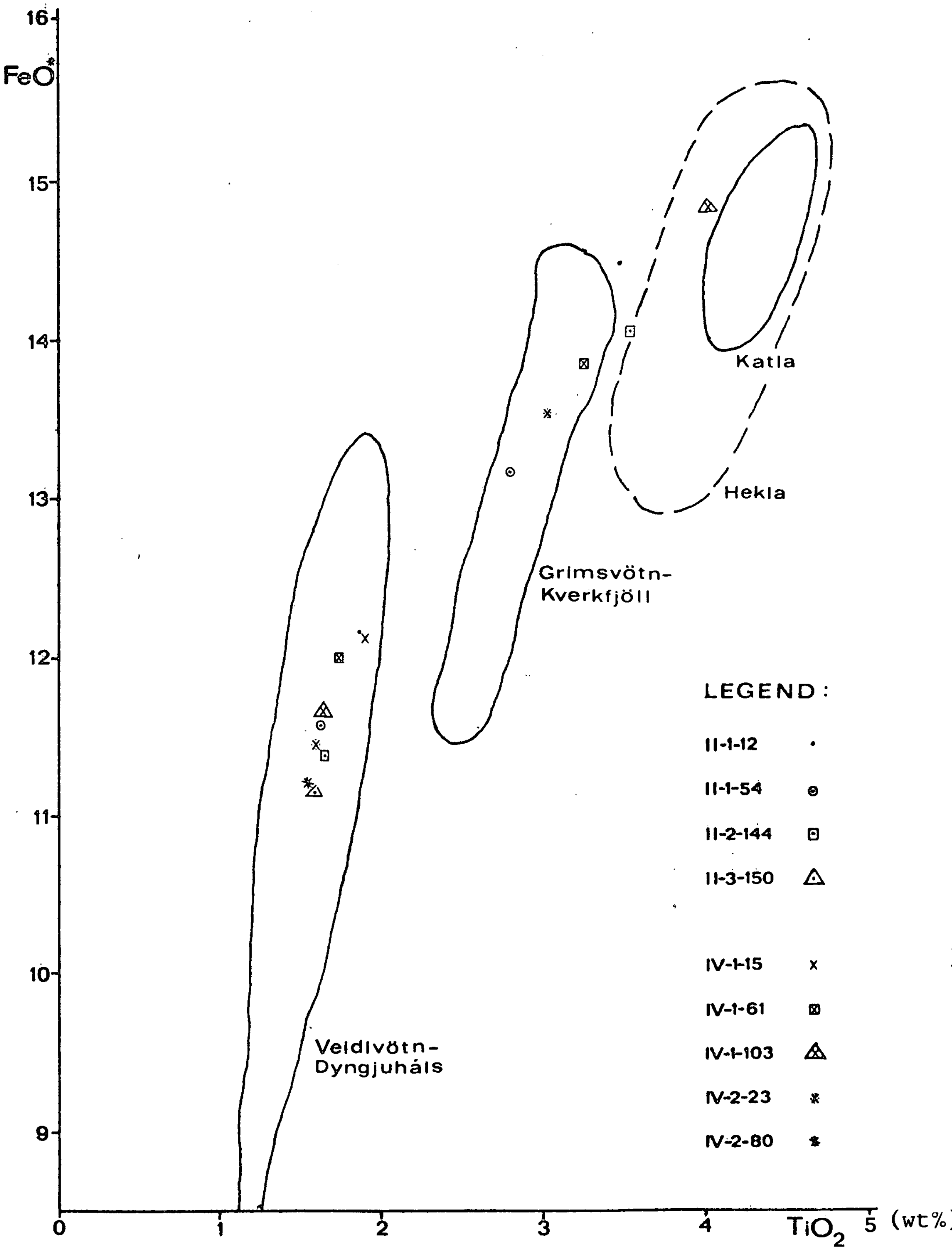


Figure 5.11. FeO^x - TiO_2 diagram of the basaltic tephra samples. Their location is shown in Figure 5.2. The loops are based on data from Jakobsson, 1979b and Larsen, 1982.

fjöll volcanic systems which appear to have well defined and different geochemical trends (Figure 5.10).

In Core II the data presented, for three of the four samples analysed in the core i.e. samples II-1-12, II-1-54 and II-2-144, appears to be associated with two volcanic systems (Table 5.8). Basaltic glass grains in all the four samples are matched with the Veidivötn-Dyngjuháls (Dyngjujökull) volcanic system, but basaltic glass grains from samples II-1-12, II-1-54 and II-2-144 are also matched with the Grímsvötn-Kverkfjöll volcanic system (Figure 5.10 and 5.11).

Similarly in Core IV three of five samples analysed i.e. samples IV-1-61, IV-1-103 and IV-2-23 appear to be associated with two volcanic systems (Table 5.8). Basaltic glass grains in all the five samples are matched with the Veidivötn-Dyngjuháls (Dyngjujökull) volcanic system. In samples IV-1-61 and IV-2-23 basaltic glass grains are also compared with the Grímsvötn-Kverkfjöll volcanic system and basaltic grains from sample IV-1-103 with the Katla volcanic system (Figure 5.10 and 5.11).

In distinguishing conclusively between the last two systems and the Hekla volcanic system the composition of Al_2O_3 in the tephras have to be taken into account, but none of the basaltic glass grains analysed did show the characteristic values assigned to that.

Results of the basaltic glass grains identified in the cores are summerized in Table 5.9.

Table 5.8

Sample	SiO_2	Al_2O_3	TiO_2	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
Core: II-1-12											
5	49.68	13.46	1.88	12.15	.22	6.87	11.92	2.14	.22		98.54
σ	.35	.18	.22	.31	.02	.20	.39	.08	.04		.77
2	48.31	12.85	3.47	14.49	.22	5.06	9.76	2.83	.56	.39	98.03
σ	1.59	.47	1.30	.28	.02	.32	.17	.25	.18	.27	.03
Core: II-1-54											
3	49.72	12.91	2.78	13.18	.19	5.54	10.31	2.59	.43	.22	97.74
σ	.72	.14	.24	.26	.03	.24	.41	.22	.08		.52
3	49.26	13.54	1.62	11.57	.18	7.22	12.19	2.15	.18		97.98
σ	.26	.30	.29	.83	.02	.73	.96	.34	.06		.46
Core: II-2-144											
3	48.99	13.56	1.65	11.39	.19	7.29	12.34	1.96	.18	S .19	97.88
σ	.39	.13	.14	.58	.06	.57	.67	.26	.02	.02	.21
2	47.53	12.62	3.53	14.07	.27	5.43	10.40	2.77	.50	S .28 .23	97.72
σ	1.91	.57	.73	.05	.01	.40	.58	.39	.15	.09 .06	1.49
Core: II-3-150											
4	49.26	13.69	1.59	11.14	.19	7.23	12.09	2.07	.18	S .21 .19	97.55
σ	1.00	.31	.17	.68	.44	.70	.76	.28	.07	S .05	.28
Core: IV-1-15											
5	49.64	13.39	1.91	12.13	.21	6.84	11.49	2.20	.23	S .24	98.30
σ	.61	.22	.23	.44	.05	.15	.37	.25	.03	.05	.22
Core: IV-1-61											
5	49.32	13.51	1.74	12.01	.19	6.98	11.90	2.18	.18	S .25 .16	98.28
σ	.45	.36	.22	.83	.04	.48	.44	.17	.06	S .04	.42
1	49.38	12.77	3.23	13.87	.21	5.01	9.50	2.75	.47	S .39	97.57
Core: IV-1-103											
4	50.12	13.91	1.64	11.66	.19	7.41	12.44	2.02	.19		99.56
σ	.13	.34	.24	.64	.02	.27	.60	.27	.06		.06
5	48.07	12.67	4.02	14.85	.22	4.90	9.63	2.98	.67	.31	98.33
σ	.69	.31	.63	.86	.06	.10	.15	.28	.25	.12	.23
Core: IV-2-23											
3	49.88	13.71	1.62	11.45	.24	7.34	12.22	2.19	.17		98.82
σ	.26	.11	.18	.31	.06	.29	.38	.04	.04		.19
2	48.75	13.43	3.02	13.53	.13	5.84	10.58	2.81	.46		98.56
σ	1.87	.16	.93	.15	.14	.24	.63	.20	.06		.49
Core: IV-2-80											
5	49.85	13.83	1.56	11.20	.18	7.39	12.31	2.07	.17		98.65
σ	.20	.18	.18	.61	.03	.32	.70	.28	.05		.21

Table 5.9

CORE: II		CORE: IV	
Sample	Volcanic system	Sample	Volcanic system
II-1-12	Veidivötn-Dyngjuh. Grímsvötn-Kverkfj.	IV-1-15	Veidivötn-Dyngjuháls
II-1-54	Veidivötn-Dyngjuh. Grímsvötn-Kverkfj.	IV-1-61	Veidivötn-Dyngjuháls Grímsvötn-Kverkfjöll
II-2-144	Veidivötn-Dyngjuh. Grímsvötn-Kverkfj.	IV-1-103	Veidivötn-Dyngjuháls Katla
II-3-150	Veidivötn-Dyngjuh.	IV-2-23	Veidivötn-Dyngjuháls Grímsvötn-Kverkfjöll
		IV-2-80	Veidivötn-Dyngjuháls

Stratigraphically no obvious linkage is recorded between the core samples, Tabel 5.9 and the tephrochronological profile established for the Eyjafjördur area (Figure 5.8). For example no basaltic glass grains from the Hekla volcanic system are identified. On the contrary basaltic glass from the Grímsvötn-Kverkfjöll volcanic system is identified in the core samples; tephras not known to have been distributed into the Eyjafjördur area. However, one of the core samples can possibly be matched with tephra layers recorded in the Eyjafjördur profile. This is sample IV-1-103 of basaltic glass from the Veidivötn-Dyngjuháls and Katla volcanic systems as expected in a horizon matched with the Veidivötn 1717-1729 and Katla 1721 tephra layers in Figure 5.7. This suggestion can not be confirmed by correlation with other core samples.

In conclusion the results on the composition of the basaltic tephras are such that they are not sufficiently comprehensive to be used for accurate dating.

5.3 Magnetic measurements

Magnetic measurements have recently been introduced to improve the correlation and the dating technique of the Recent sediment (Mackereth, 1971; Thompson, 1973; Thompson <u>et al</u>., 1975). Particularly, the magnetic measurements have been found useful for reconnaissance work because of their rapidity and flexibility, as this type of dating/correlation can be carried out while the sediment core still remains undisturbed within its liner tube.

In the pioneer work of Mackereth (1971) the oscillations observed in the declination do show an excellent agreement between the "magnetic" age and the C^{14} age which indicate fluctuation of constant frequency. Such measurements could provide a time scale based on the behaviour of the Earth's field. More detail studies of the remanent magnetization confirmed that the changes measured in direction of the magnetization of the sediments is reflected by the secular variation of the geomagnetic field (Creer <u>et al</u>., 1972; Molyneaux <u>et al</u>., 1972; Creer <u>et al</u>., 1976; Thompson, 1977).

For an absolute dating the oscillations recorded in the declination must be matched with a master geomagnetic secular variation curve. The same master curve will be used here as constructed for Britain. It is essentially a combination of three types of master curves. 1) the most recent secular changes have been recorded at magnetic observatories since A.D. 1576. 2) the observatory record has been extended back to A.D. 1000 by archeomagnetic studies. 3) before A.D. 1000 paleomagnetic records have been dated by palynological changes and C^{14} age determinations (Thompson et al., 1980).

One of the most necessary conditions for a reliable magnetic dating is for the sediment to be sufficiently well magnetised. The paleomagnetic intensity serves as an indicator of the magnetic strength of the sediment. This is a function of the proportion and type of magnetic grains carrying the magnetic remanence as well as the past strength of the geomagnetic field. In relation to the intensity factor the reliability of the magnetic declination parameter can be decided.

The most easily obtained and probably the most sensitive parameter for correlation between cores is the magnetic susceptibility. The apparent susceptibility of the core is proportional to the quantity of magnetic minerals present and therefore tha variations the susceptibility are due to changes in concentration of the magnetic minerals. Such measurements usually show a large amplitude variation which is easily resolved in the profiles. These amplitude variations are independent from the geomagnetic field changes.

There is a wide variaty of methods available for measuring the magnetic susceptibility, but the simplest and probably the most reliable one is to use a weak alternating field bridge (Mooney, 1952). Until recently susceptibility measurements on the sediment material were mainly carried out on individual soil samples (Mullins, 1977), but in 1973 Molyneux and Thompson constructed a susceptibility bridge to use on whole cores of sediment.

5.3.1 Previous studies

Nearly all magnetic or magnetostratigraphical studies on sediment material have so far been concentrated either on lake sediment or peat deposits. In the present study only fjord sediments are considered. However, in order to make a sensible interpretation on their magnetic variability, it is important to compare these with profiles of magnetic measurements from Icelandic lakes. Fortunately magneto-stratigraphical studies on a number of six meter long cores were carried out on Icelandic lake sediments in 1979 and preliminary results have already been described by Beamer (1980). These are used as a reference when interpreting the fjord sediments as well as the secular variations seen in some British lake sediments especially from Loch Lomond and Lake Windermere (Creer et al., 1972; Thompson, 1977; Turner and Thompson, 1979).

Information on sediments from lake Svínavatn (Beamer, 1980) was found to serve as a good reference for the Eyja-fjördur sediments because of its close proximity (less than 100 km west of the fjord) and also due to the similar geology as within the Eyjafjördur drainage area.

5.3.2 Sampling and analytical procedure

For the magnetic measurements subsamples were taken continously down the cores following the method of Thompson (1979). Small retangular plastic boxes of approximately 10 ml volume were used. Each box sealed after sampling to avoid drying of the material, as fresh samples are preferred for natural directional data where distortion during drying may affect the direction of natural remanance.

Every subsample was placed in a fluxgate spinner magnetometer for measuring the natural remanent magnetization (NRM) directions and intensities (Appendix E). The stability of the remanence is tested by subjecting the samples into a stepwise partial alternating field demagnetization where the direction and intensity of the remanent magnetization is measured after each step.

The samples selected for demagnetization from the cores did not show much difference from the NRM direction in the upper 2-3 meters, but this difference seems to increase downwards. Similar tendency was noticed in the intensity. In studies by Creer et al., (1972) and Turner and Thompson (1979) it is indicated that selected samples taken from a core profile are in a good agreement with the detailed analyses carried out on the cores.

All the subsamples were measured on a low-field susceptibility bridge (Appendix E) where each analysis was carried out within a second.

5.3.3 Results

The results of the palaeomagnetic directional analysis and the magnetic susceptibility analysis are described graphically in Figure 5.12 and 5.13. The two cores analysed (Core: XXI and IV) are presented separately and the two acid tephra layers identified from Hekla i.e. H_1 (1104 A.D.) and H_3 (2900 B.P.) both used as a reference horizon. These zones were found to be important when the magnetic measurements were carried out.

The strength of magnetic intensity is high in these cores compared with those in lake and peat profiles (Creer et al., 1976; Turner and Thompson, 1979; Beamer, 1980). Generally such high intensities are important for estimating a reliable directional analysis as the paleomagnetic intensity is a function of the proportion and type of magnetic grains carrying the magnetic remanence as well as the past strength of the geomagnetic field. For example the intensity strength in the Eyjafjördur cores is on average 250-450 mAm^{-1} in the upper 3 to 4 meters i.e. above the upper tephra layer in each core (H_1), but only 100-200 mAm^{-1} on average below this layer (Figure 5.12 and 5.13). The continous decrease measured both in the intensity and in the susceptibility immediately above the upper tephra layer is related to the mixing of the acid tephra with the sediment. It appears that minerals containing magnetic elements are very few in the acid layers.

Interpretation of such intensity variations is complicated due to effects eminating from variations in the geomagnetic field strength and from the grain size distribution of the sediment, but a comparsion with materials measused within the core tube than for single sample measurements traces of the palaeomagnetic directional analysis as well as of the susceptibility tend to be smoother (Turner and Thompson, 1979).

The high intensity strength measured in both cores has probably prevented scatter effects related to unreliable analyses as is common in cores with low intensity. However, some scatter effects are measured in both cores especially above the H_1 acid tephra layer, e.g. Core XXI (EY-1) (Figure 5.12).

In contrast the declination variations are not well defined. To identify some of the major cycles as seen in Figure 5.12 and 5.13 and match them with the master declination curve or curves constructed from the Icelandic lakes studies is difficult. In fact the declination curves for the two Eyjafjördur cores cannot easily be matched. Similarly the inclination variations in the cores are too weak to be matched with any master inclination curve.

Although the palaeomagnetic directional studies presented above do not provide a reliable basis for an absolute dating or a cross-correlation between the fjord's cores, the magnetic susceptibility variations seems to provide such a correlation.

The down-profile variation in the magnetic susceptibility (Figure 5.12 and 5.13) do show a sequence of high and low susceptibility values of a consistent order for both core sections. By plotting the highs and lows in the susceptibility with depth (labelled a-g) the variation pattern is

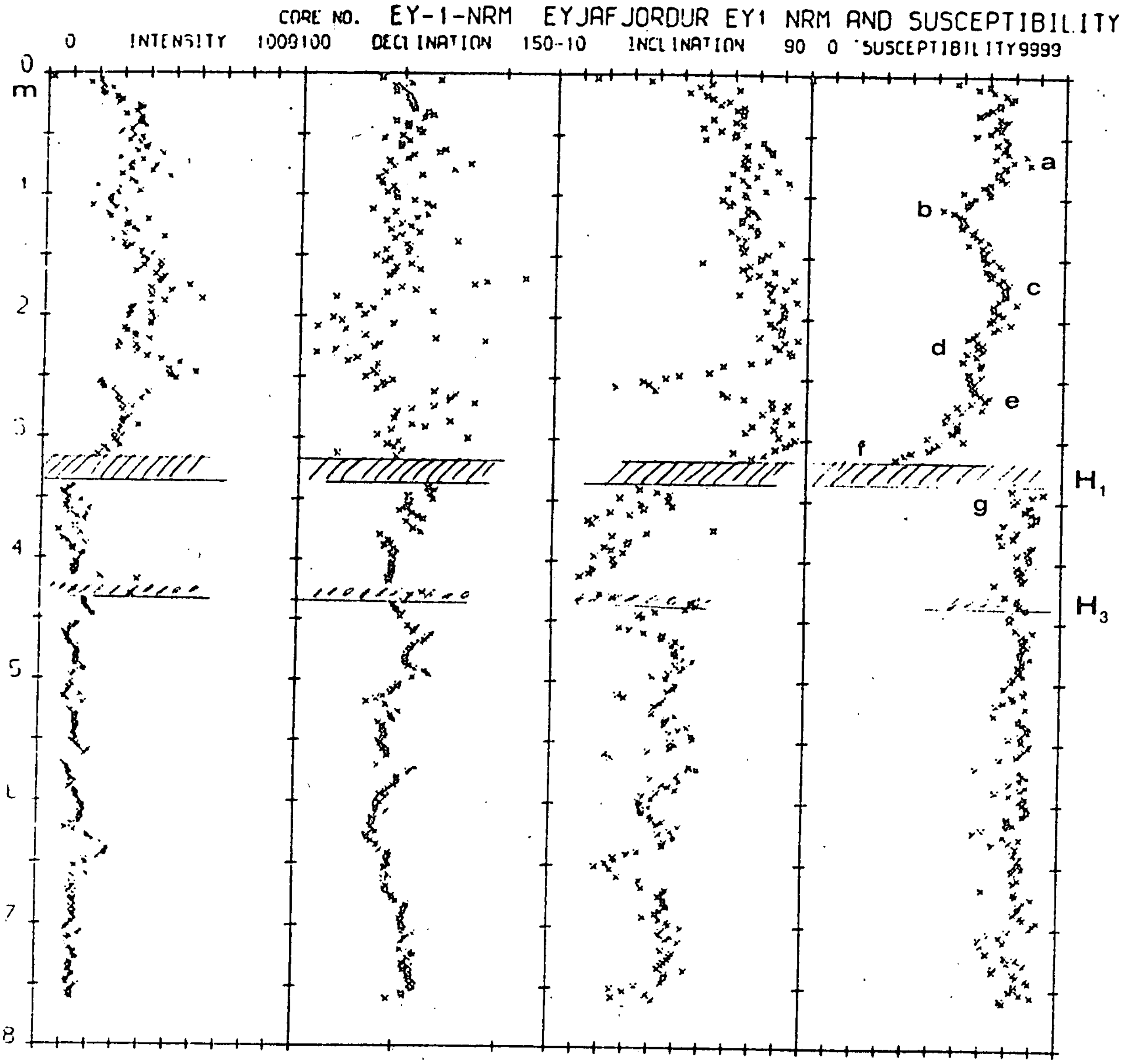


Figure 5.12. Magnetic directional measurements of Core XXI (EY-1).

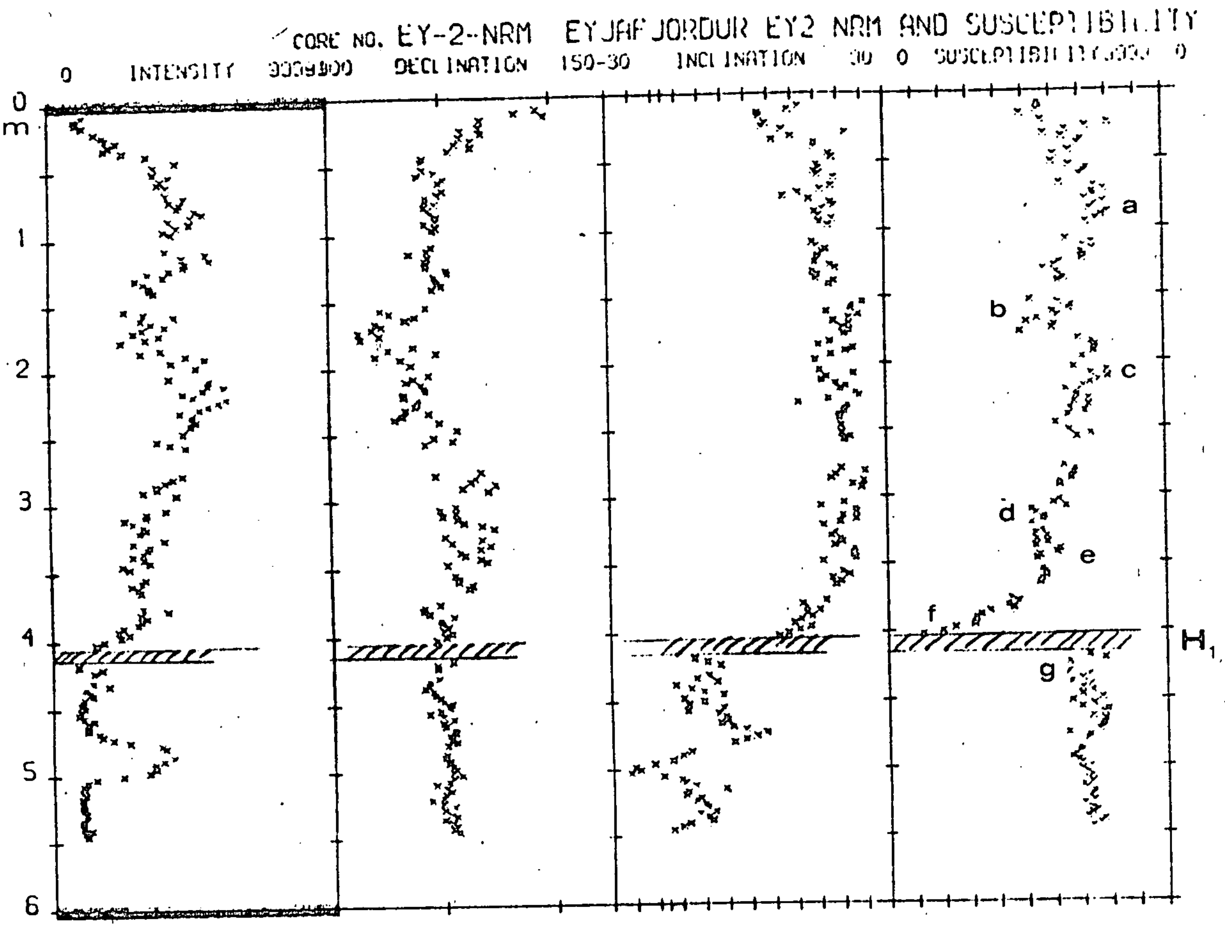


Figure 5.13. Magnetic directional measurements of Core IV (EY-2).

illustrated down each core. For example the low pattern b and the two highs a and c right above and below are well defined in Core XXI (EY-1). In Core IV (EY-2) this sequence is also well defined through a similar depth interval. Similarly in Core XXI (EY-1) sequence d, e and f immediately above the acid tephra layer H_1 is almost identical to that in Core IV (EY-2). Below tephra layer H_1 sequence g is recorded almost the same in both core sections. Only on the basis of susceptibility variations a (cross-) correlation can be carried out between these two cores analysed, but they are at ca. 5 km distance from each other.

The sedimentation rate is according to the H_1 acid tephra horizon estimated about 20% faster in Core IV compared with Core XXI. The magnetic susceptibility cross-correlation record confirms that, However, the sedimentation rate is not of steadily faster in Core IV than in Core XXI, but fluctuates with time, as is evident if the sequences of a, b, c and b, c, d, in Core XXI (EY-1) are compared with the same sequences in Core IV (EY-2).

5.4 Sedimentation rates

In the previous chapters the chronological record for the cores are discussed and the sedimentation rate calculations are based on these results. Table 5.10 summerizes these results.

Up to 25-30 cm are estimated to have been lost from the top during the coring process and this is taken into account in the calculation of the sedimentation rate.

The sedimentation rate in Core IV is on average 4.56 mm/y between the time markers H_1 (1104 A.D.) and the present time, but 4.85-4.90 mm/y if 25-30 cm are added to the top of the core.

For the same period in Core XXI the values are 3.65 mm/y and 3.94-3.99 mm/y if 25-30 cm are added to the top. Similar sedimentation rate is calculated for Core II giving 3.76 mm/y, but about 4.10 mm/y if 25-30 cm are added to the top.

In general the sedimentation rate is 3.94-4.88 mm/y from H_1 time marker to the present time in the fjord's basin.

For the time period H_1 (1104 A.D.) to H_3 (2900 B.P.) the sedimentation rate is calculated to be from 0.43 mm/y in Core XXI to 1.50 mm/y in Core IV. This great difference can not be explained sufficiently when only two cores are involved, but taking into account the short distance between the cores (ca. 5 km) it can not be excluded that some pause in the sedimentation or even some erosion had taken place and these could have affected the sedimentation rate in Core XXI at the same time as Core IV is undergoing a continous sedimentation.

The increase in sedimentation rate after the H_1 time marker is from 3.2 to 8.8 times that measured before the H_1 time marker. A similar ratio has been measured in soil samples taken in the northern part of Iceland from two different soil types (peat and silty soil), where the rate of thickening is measured approximately constant before the H_1 time marker and through the Holocene time (Thorarinsson, 1961; Th. Einarsson, 1963; Gudbergsson, 1975; Gudmundsson, 1978).

Studies of soil thickening or of climatic changes do not indicate that any significant increase/decrease has taken place in the erosion or the sedimentation rate during the Holocene time - before the H_1 time marker.

According to this approximation the average sedimentation rate in Core IV is estimated ca. 1.8 - 2.0 mm/y (17-20 meters/9-10.000 y) in Eyjafjördur during the Holocene. This is approximately the same value (20-30 milliseconds) as has been interpreted for Unit H (Holocene sedimentation) in the seismic profiles (chapter 4).

By comparing this sedimentation rate with studies from other nearshore environments, usually showing sedimentation rates of 0.4 - 1.0 mm/y (cf. Holtedahl, 1975; Aarseth et al., 1975; Pantin, 1978; Glasby, 1978) the conclusion is reached that the sedimentation rate in Eyjafjördur is very high.

An attempt is made to calculate the rate of denudation for the drainage area of Eyjafjördur according to the mean sedimentation rate of 1.8 - 2.0 mm/y. With aid of the seismic profiling the size of the fjord area showing this rate

Table 5.10

Time marker	Core: IV Ey-2		Core: XXI Ey-1		Core: II	
Present	400 cm/876 y	4.56 mm/y	320 cm/876 y	3.65 mm/y	330 cm/y	3.76 mm/y
	425 cm/876 y	4.85 mm/y	345 cm/876 y	3.94 mm/y	355 cm/y	4.05 mm/y
H_1	430 cm/876 y	4.90 mm/y	350 cm/876 y	3.99 mm/y	360 cm/y	4.10 mm/y
H_1	310 cm/2050	1.50 mm/y	90 cm/2050 y	0.44 mm/y		
H_3	305 cm/2050	1.49 mm/y	85 cm/2050 y	0.41 mm/y		

of sedimentation is considered to be about 320 - 350 km^2. Outside this area the sedimentation rate seems to be low, except in the deltas. Presuming that most of the material deposited into the fjord (the tephra layers are excluded) has originally been eroded from the drainage area (4.730 km^2) the rate of denudation is estimated 0.11 - 0.15 mm/y for the Holocene time period. For a comparsion the denudation rate in the Eyjafjördur area has been estimated 0.30 - 0.45 mm/y, on average, for the Pleistocene-Holocene time period (2 - 3 m.y.)(section 2.2) or 3 to 4 times faster than during Holocene, i.e. after the glaciers retreated from the Eyjafjördur area.

Chapter 6. SEDIMENT TEXTURE AND COMPOSITION

The aim of this chapter is to describe the texture and composition of Eyjafjördur sediments, their distribution within the fjord and variation with time in the core profiles.

Grab samples of surface sediments were taken from fjord basin and from the shallow water along the coast. The limited number of sampling stations reveals only general features rather than the details of sediment distribution. In addition, three of the most complete cores were selected for sediment analysis.

6.1 Grain size

6.1.1 Grain size analysis

To study the range of particle size in the sediment two principal methods were used. For the coarser fraction, i.e. sand and gravel, the grain size was measured directly by wet or dry sieving (Folk, 1968). For the silt and clay fraction the grain size was measured indirectly by two density sedimentation methods, the pipette and the falling drop methods (Galehouse, 1971a; Moum, 1965). Sieving and sedimentation methods are not strictly comparable in that sieving separates particles mainly on the basis of their volume and shape, whereas the sedimentation methods also take density and angularity of the grains into account (Schlee, 1966). Size measured by sieving is therefore somewhat different from size measured by sedimentation methods. The choice of methods was governed by their common usage and comparability of results.

As all the grab samples were unconsolidated no special treatment for disaggregation was needed, but the samples were washed to remove sea salt (Appendix F). The core samples were all weakly consolidated and were treated with a weak H_2O_2 solution (6%) (Appendix F) to aid initial disaggregation of the sediment.

No treatment was carried out to remove the carbonate and organic particles from the sediment before analysing the grain size as these biogenic fractions constitute only a minor proportion of most sediments (Section 6.2.3).

The scale used here for describing grain size is the phi schale introduced by Krumbein (1934), which is a modification of the size scale developed by Udden (1898) and Wentworth (1922). A sieve interval of 1 phi was chosen for all the samples, except for the coarse ones taken from the shelf where a 1/2-phi interval was used. The 1-phi spacing of the sieves is regarded by Folk (1966) as too inaccurate, especially in studying bimodality or subtleties of tails.

A comparison of the pipette and the falling drop methods revealed an inconsistency of 1/2 - 1 phi in the mean size of those samples where both methods were employed. The pipette method gives a coarser distribution than the falling drop method of about 13% on average (Table 6.1).

In an attempt to explain this inconsistency sub-samples were taken from some of the deeper stations for checking of the falling drop analytical procedure. The grain size values obtained from this analysis did show a very good agreement with previous results, on average a ± 3% deviation (Table 6.2), indicating that the difference between the falling drop and the pipette methods is inherent or caused by the analytical procedure.

The falling drop method employs a standard curve based on a solution of NaCl and distilled water. For a tolerable accuracy in this analytical procedure the density variation of the sediments must be kept within ± 0.05 - 0.10 g/cm^3. Three bulk density measurements on samples from the fjord sediments have been made on different parts of Core IV (S.Pálsson, personal communication). The first sample taken at 10 cm depth (IV-10 cm) shows a density of 2.929 g/cm^3. At 385 cm depth (sample taken 20 - 25 cm above the acid layer H_1) the bulk density is between 2.950 - 2.951 g/cm^3 and samples taken from the H_1 tephra layer (IV-420 cm, Figure 5.3) shows values between 2.430 and 2.437 g/cm^3.

All these density values differ significantly from that of the standard solution used in the falling drop analysis and this is probably responsible for the difference recorded in the grain size distribution between the falling drop and the pipette methods (Table 6.1). Theoretically a difference of ca. 0.25 g/cm^3 as illustrated for the 10 cm

Table 6.1

Station	Grav.	Sand	Silt	Clay	Mz	Sand	Silt	Clay	Mz
		Sieving - Pipette				Sieving-Falling drop(aver.)			
9	0.08	91.27	8.64		2.74				
11		43.75	53.95	2.31	4.16				
14		29.37	64.65	5.97	4.25				
19	0.34	74.61	25.05		3.59				
20		94.53	5.46		3.08				
3		12.0	78.8	9.2	5.47	5.1	72.4	22.4	6.55
7		9.9	80.4	9.7	5.65	3.6	74.0	22.4	6.72
12		17.5	75.6	6.9	5.14	10.6	85.8	3.6	5.93
13		9.2	83.0	7.8	5.28	7.3	79.5	13.2	5.88
18		9.5	81.6	8.9	5.62	7.2	82.6	10.1	6.17
21		18.9	75.4	5.7	5.03	12.8	79.1	8.0	5.54
16		39.0	56.3	4.7	4.60				

Table 6.2

Falling drop analysis

Station	Sand	Silt	Clay	Mz
3	4.6	72.7	22.7	6.52
3_1	5.7	72.1	22.2	6.58
7	3.6	74.0	22.4	6.72
12	10.6	85.8	3.6	5.93
13	6.4	84.5	9.1	5.96
13_1	8.3	74.1	17.6	5.73
18	8.1	85.1	6.8	6.11
18_1	6.4	80.1	13.5	6.23
21	13.6	84.2	2.2	5.47
21_1	12.0	74.1	13.9	5.62

and 385 cm depths means that all the falling drop grain size values are over-estimating the finer fractions. In contrast the acid tephra layer (IV-420 cm) as analysed tends to over-estimate the coarser fractions.

The results of the size fractionation were plotted as cumulative curves, both on probability paper and with arithmetic ordinates. The probability curves were then used to obtain statistical parameters. Arithmetic ordinates were used only to construct frequency curves, as described by Bush (1951).

The grain size distribution is of course open-ended, as no analytical technique used generates data for fractions finer than 10ϕ (i.e. 0.98 μ). In the case when samples do not reach 84th or 95th percentile, an extrapolation was made to 14 phi as recommended by Folk and Ward (1957).

The simplest representation of a grain size analysis is to plot the proportion of three constituents, usually gravel(2.00 mm), sand (0.0624 - 2.00 mm) and mud (silt and clay, less than 0.0625 mm) on a triangular diagram. The triangle may then be subdivided for classification purposes, for example in the way described by Folk (1954) (Figure 6.2).

<u>Mean grain size</u>. Graphic Mean (M_z) was defined by Folk and Ward as:

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

and will be used here as a measure of mean size.

Grain size mode. The mode or modes, of a size distribution may be obtained from the frequency curve, which in turn, is graphically derived from the arithmetic cumulative curve (Folk, 1968; Bush, 1951).

The great sieve interval used in the present study does not allow a precise determination of grain size modes. Nevertheless, an attempt was made to obtain estimates of modal sizes as discussed below.

Sorting. Inclusive Graphic Standard Deviation (σ_I) is is a measure of sorting, defined as:

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

(Folk and Ward, 1957)

Skewness and Kurtosis. Accurate measures of skewness and kurtosis depend on good data control (small sieve interval) and are omitted here.

6.1.2 Results

6.1.2.1 Grab samples

Texture. Figure 6.1 shows the grab sampling stations used for the grain size analysis. Broadly speaking, sand and gravel are found along the flanks of the fjord, whereas muds predominate in the deeps.

Figure 6.2 is based on data from both the pipette and

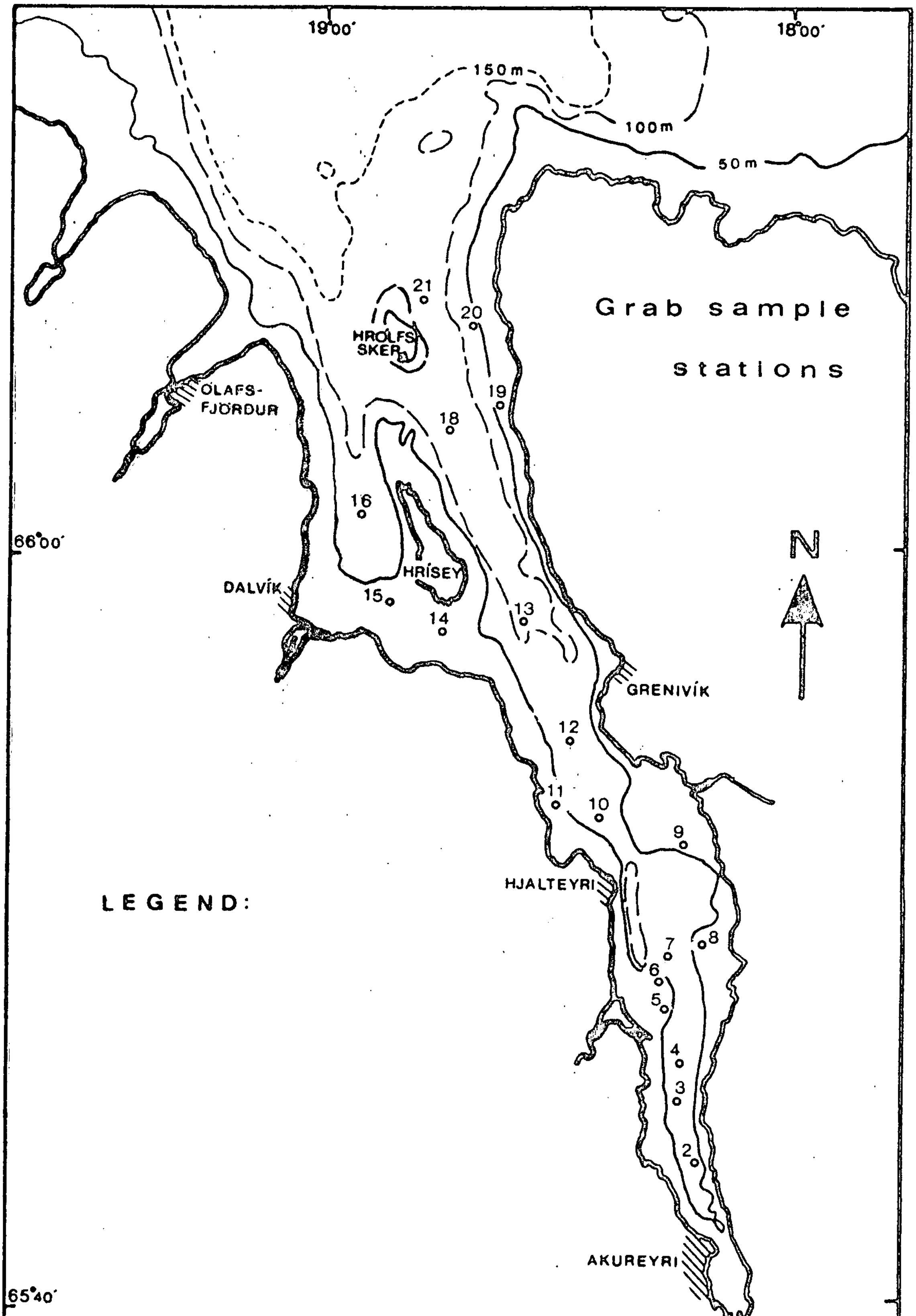


Figure 6.1. Location of grab samples, with station number.

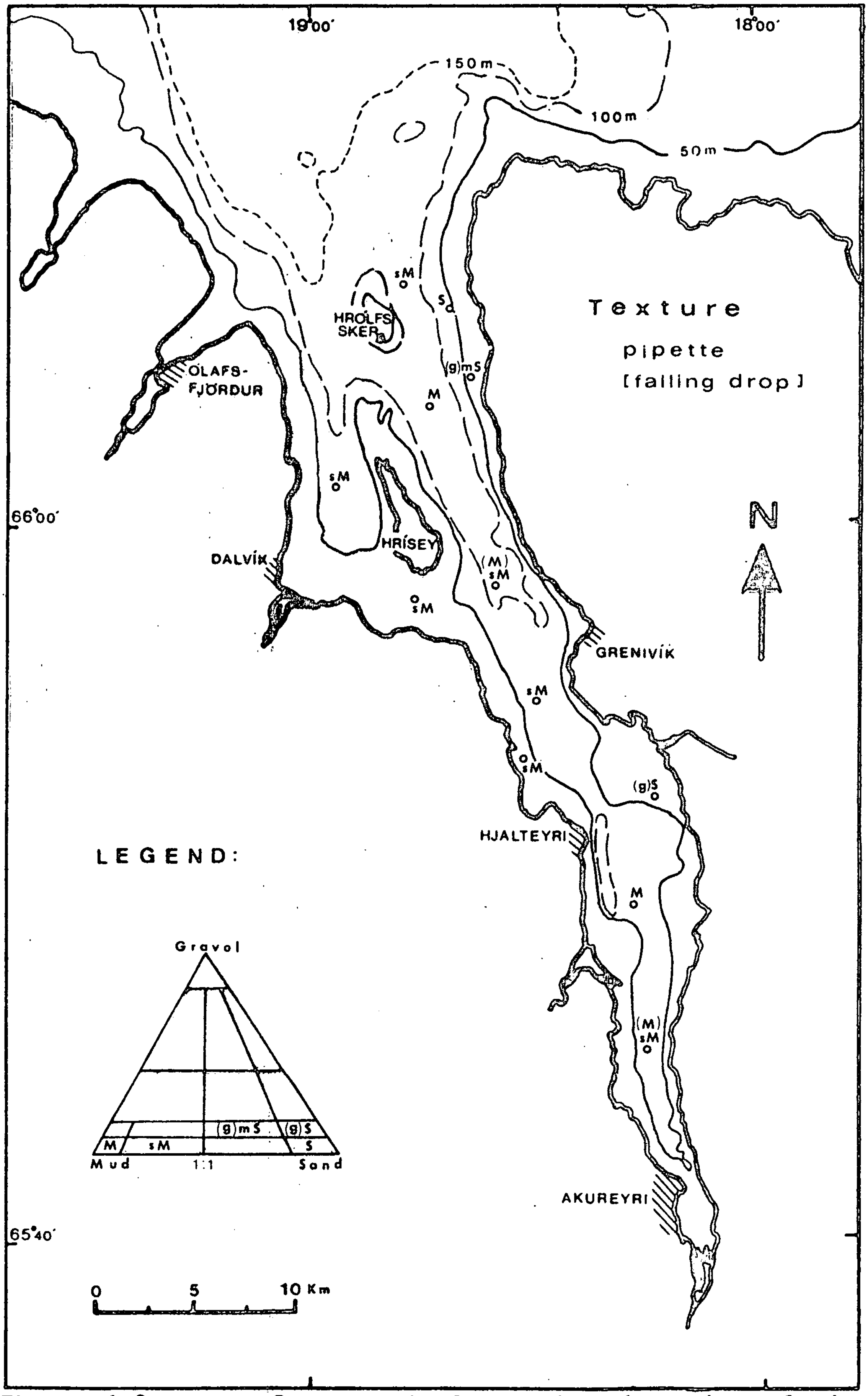


Figure 6.2. Map of textural classes based on the relative abundance of gravel, sand, and mud in samples. Horizontal lines of triangle at 0.01,5,30, and 80 % gravel. Ratio lines at 1:9, 1:1, and 9:1.

the falling drop techniques. The minor inconsistency between the results discussed above is recorded. The textural classes found at the deeper stations are mud and sandy mud. On the shelf around the fjord and on the Fnjóská delta the sediments are much richer in sand.

Mean grain size. Distribution of Graphic Mean is shown on Figures 6.3 and 6.4 where results from the pipette and falling drop methods are recorded separately. The mean size measured on the shallow stations ranges from 2.7ϕ to 4.3ϕ (fine sand to coarse silt). The 2.7ϕ value is related to a delta environment (Fnjóská) compared with values of 4.2ϕ taken in an accumulation-free zone opposite this delta in the fjord. In the outer part of the fjord two samples taken from the shallow part (shelf) ~~do~~ show values of 3.1ϕ and 3.6ϕ. It would seem that in this area the effects of river disharge is insignificant.

The pipette analysis (Figure 6.3) records a mean size range from 5.7ϕ to 5.0ϕ along the main fjord, but west of Hrísey it reaches the value of 4.6ϕ. The falling drop method (Figure 6.4) indicates a greater range of size values for the same sediments, i.e. from 6.7ϕ to 5.5ϕ.

Both methods show the mean grain size becoming coarser along the fjord towards its mouth and the finest sediments are seen in the inner part of the fjord, within the sill. However, two areas of very fine sediments can be outlined in the fjord's basin i.e. in the inner part of the fjord (5.5ϕ - 5.7ϕ, Figure 6.3 and 6.5ϕ - 6.7ϕ, Figure 6.4) and

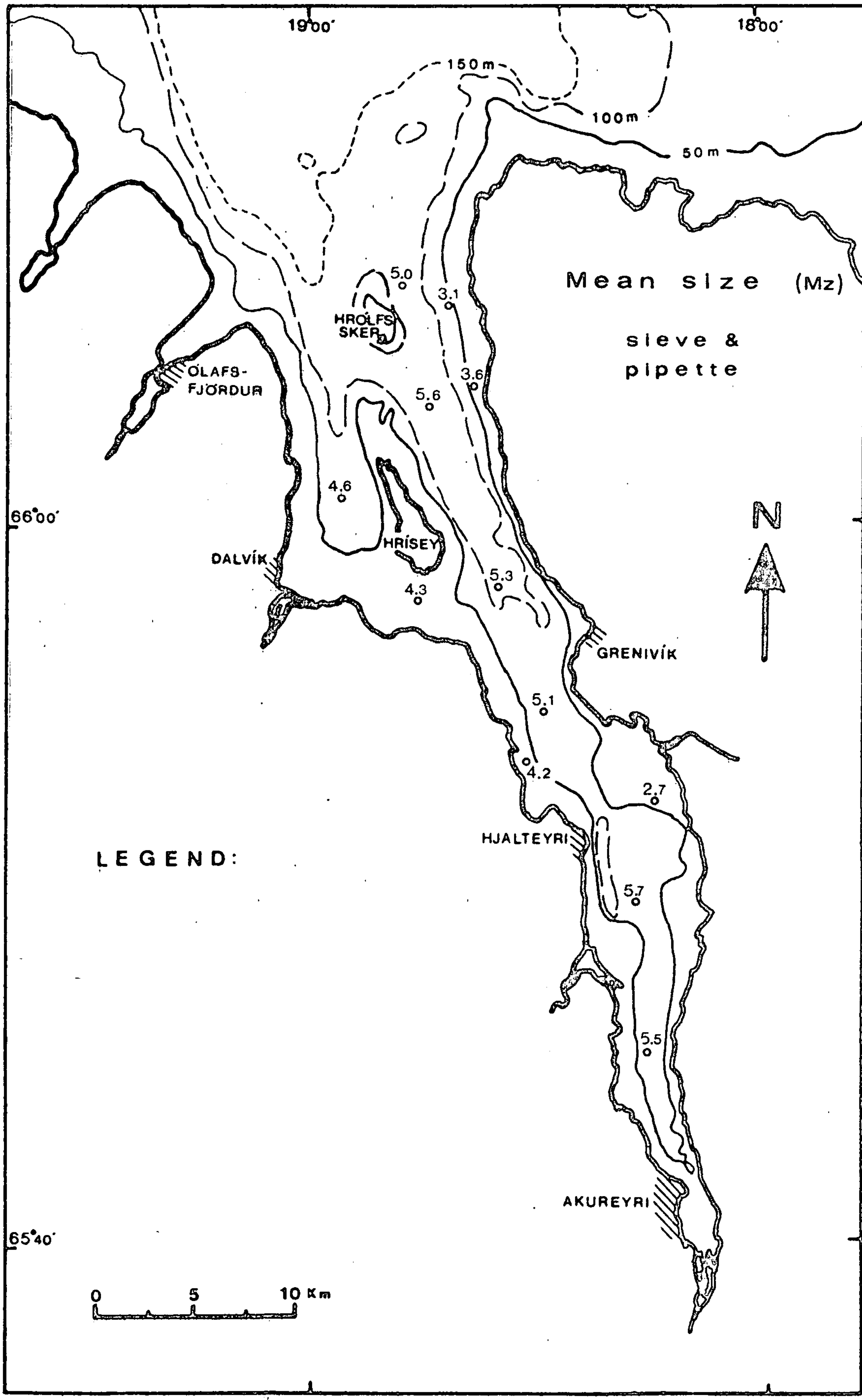


Figure 6.3. Distribution of mean grain size in the surface sediments -pipette and sieving-.

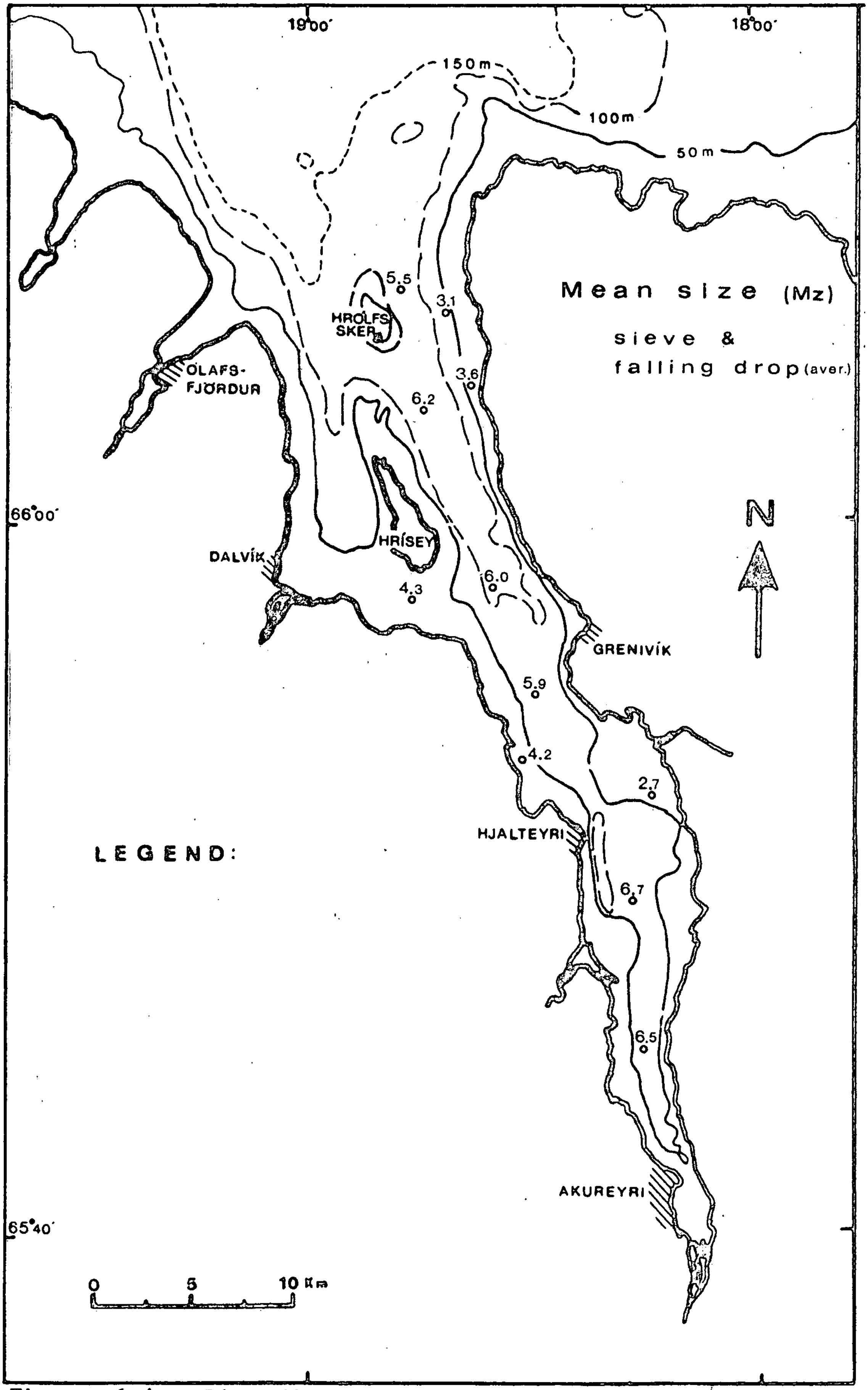


Figure 6.4. Distribution of the mean grain size in the surface sediments -falling drop and sieving-.

in the area east north-east of Hrísey (5.3ϕ - 5.6ϕ, Figure 6.3 and 5.9ϕ - 6.2ϕ, Figure 6.4). At the sill and immediately north of the sill the mean grain size is slightly greater (5.1ϕ, Figure 6.3 and 5.9ϕ, Figure 6.4). To the north of Hrólfssker the sediments are becoming coarser again showing the mean grain size value of 5.0ϕ (Figure 6.3) and 5.5ϕ (Figure 6.4).

<u>Grain size mode</u>. Two or three modes were found in the fine sediments of the fjord´s basin, but one or two in shallow stations at the periphery of this basin. As expected there is a small difference in the modal sizes obtained from the pipette and falling drop methods. The histogram of modal sizes (Figure 6.5) shows a population of fine to very fine sand and a spread of modes in the silt range.

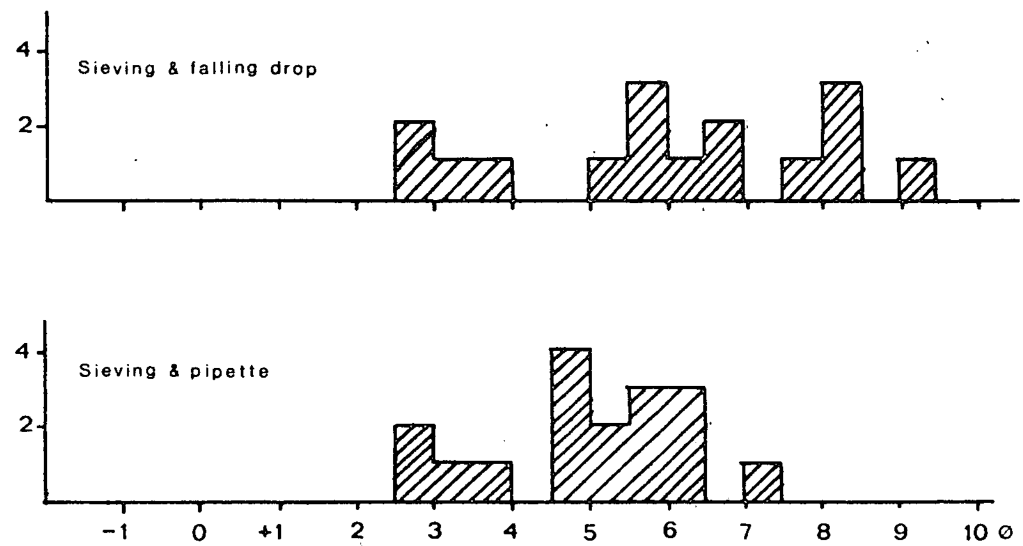


Figure 6.5. Frequency histograms of modal sizes in the surface sediments

Sorting. The results of the sorting parameters were identical for those samples analysed by both the pipette and the falling drop methods. Two main classes are recorded in the fjord, according to Folk and Ward's (1957) terminology. In the shallowest stations the sediments are moderately sorted (Station 20 has well sorted sediments) and at the deeper stations, in the fjord's basin, the sediments are poorly sorted (Figure 6.6).

A scatter diagram of Graphic Mean versus Inclusive Graphic Standard Deviation of the samples (Figure 6.7) illustrates this trend of better sorting in the coarser sediments. Folk and Ward (1957) have suggested that improved sorting is dependent on the mean size and assume this is due to bedload transport. This hypothesis is consistent with that seen in the fjord where sediments from the fjord's shelf (coastal margin) are more prone to bedload movement and hence there should be a better sorting of shallower sediment. Bedload transport of the shallow sediments may also explain the difference in modality of the sediments in the fjord.

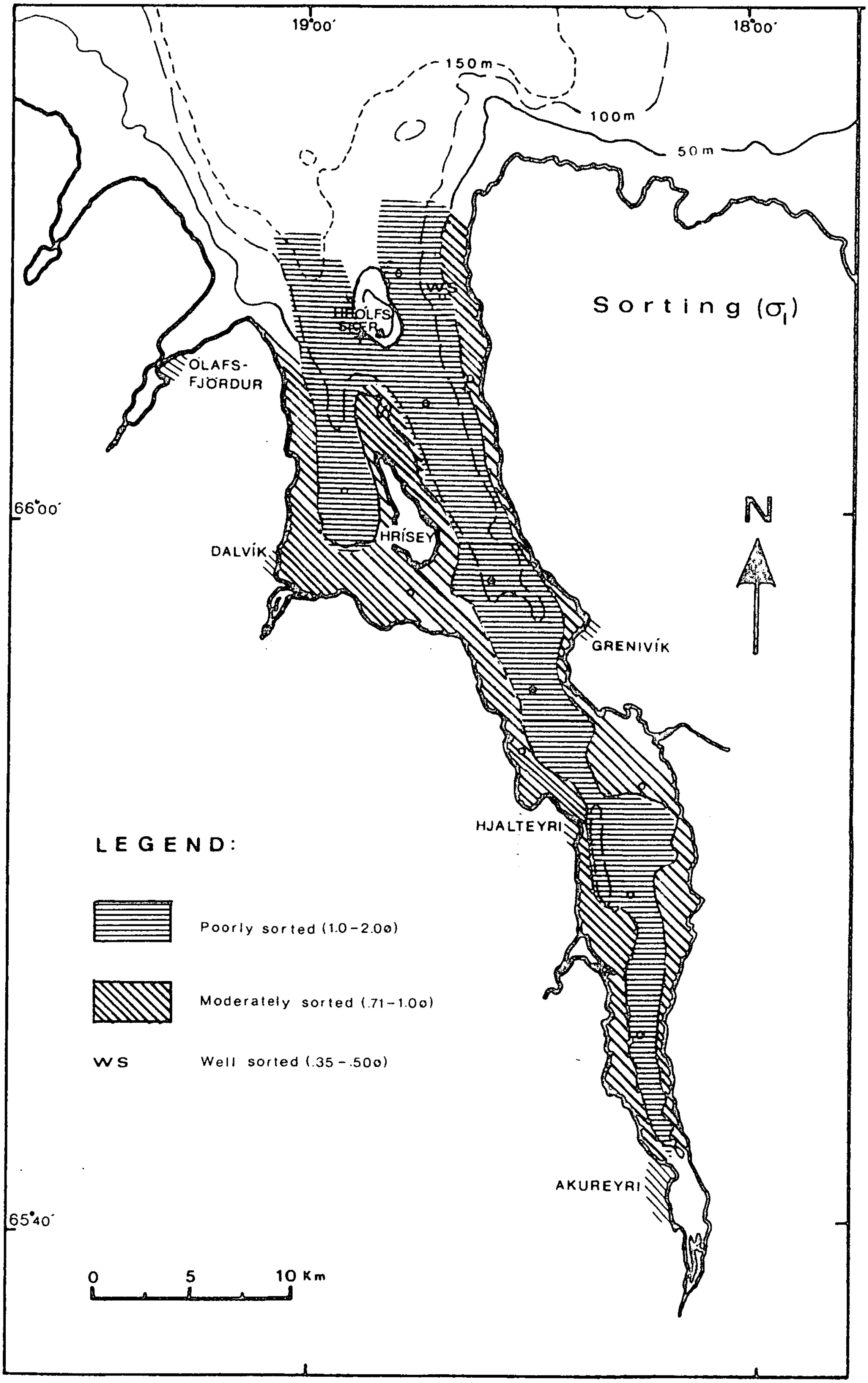


Figure 6.6. Surface sediments, sorting.

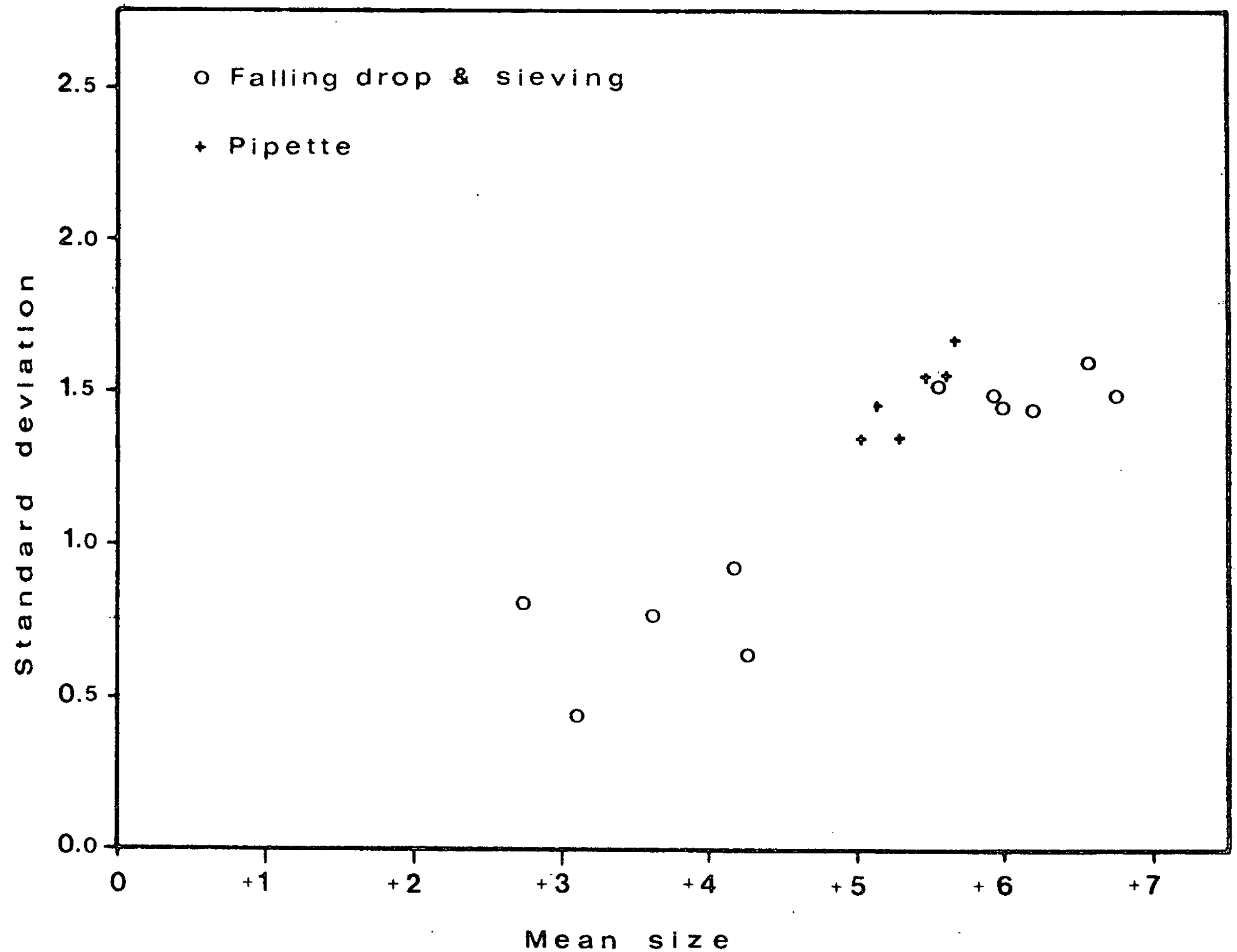


Figure 6.7. Surface sediments. Scatter diagram, mean size versus sorting.

6.1.2.2 Core samples

Grain size analyses were carried out on samples from five cores (Cores II, IV, XXI, VI and XII). Their locations are seen in Figure 6.8. The chronostratigraphy of Cores II, IV and XXI was discussed in Chapter 5. The samples from these cores are shown in Figure 6.9.

All the samples were analysed using the falling drop sedimentation method - and sieving. The analysis of each sample from Cores II, IV and XXI was replicated four to six times and showed a standard deviation of less than $\pm$ 1.5% for each size interval. In samples taken from Cores VI and XII duplicate grain size measurements showed somewhat poorer precision.

<u>Texture</u>. In the core sediments the most distinct textural classes is mud (M). Sandy mud (sM) makes up 3 samples in Core IV, 1 sample in Core VI and predominates in Core XII.

<u>Mean grain size</u>. Results of the mean grain size distribution are shown in Figure 6.10. Studying the top sample from each of the cores the highest phi value, 6.76ϕ is found in Core II (Figure 6.10) taken in the inner part of the fjord (Figure 6.8). From this locality towards the mouth of the fjord the phi values tend to decrease. For instance at Hrólfssker the mean grain size is 4.42ϕ in the core top sediment (Core XII). This trend of increasing grain size towards the fjord's mouth is further emphasized

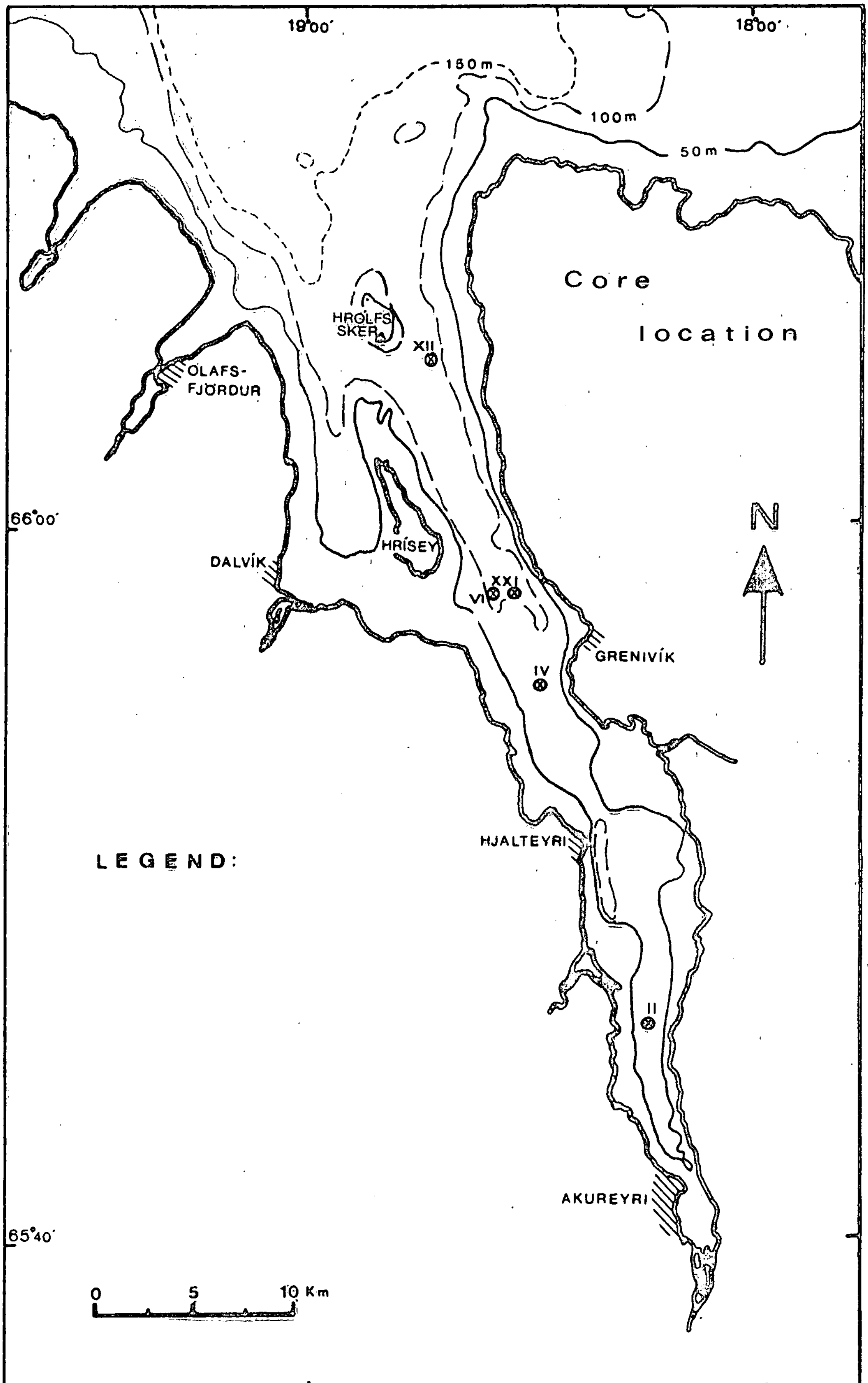


Figure 6.8. Location of cores.

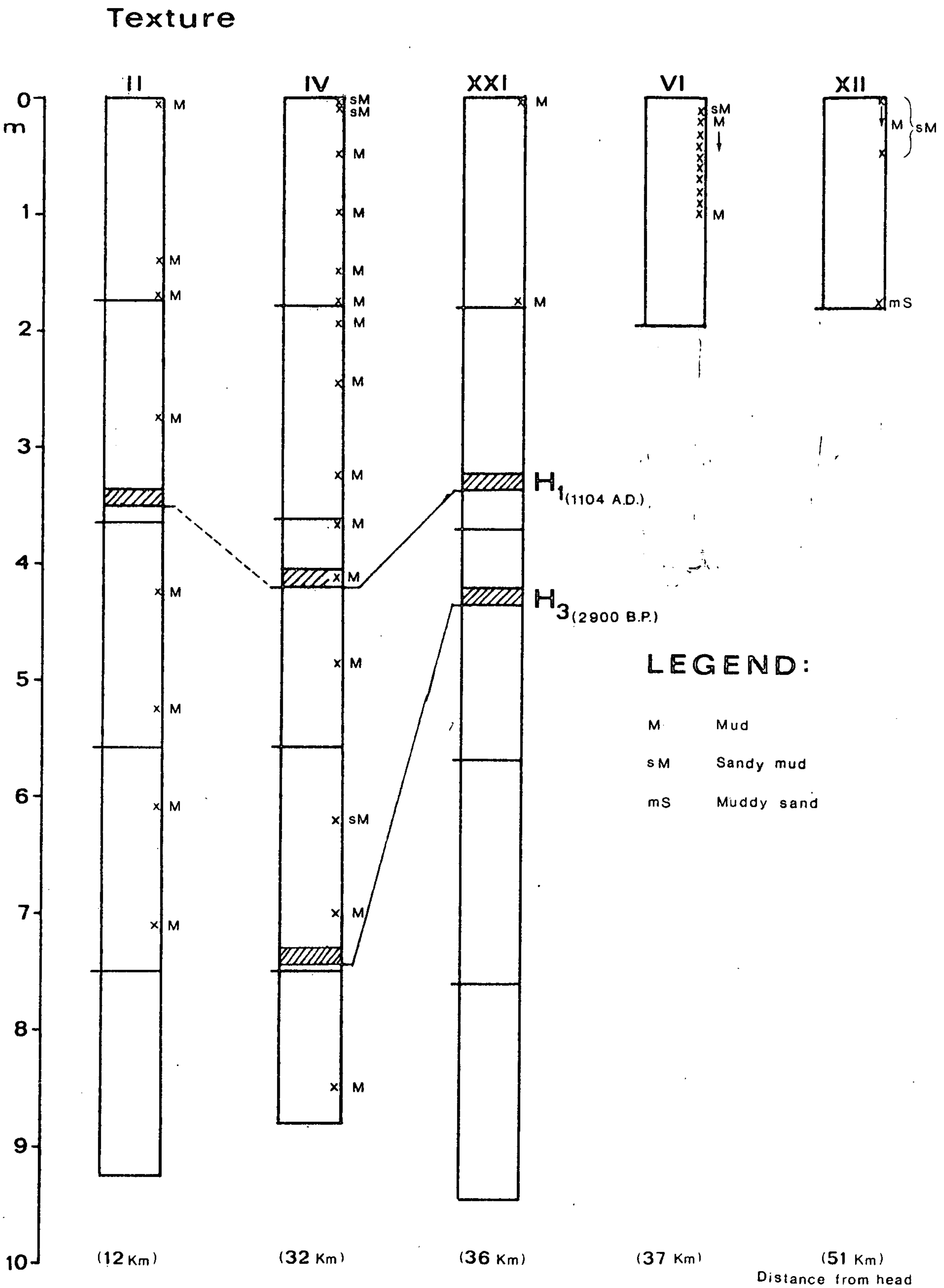


Figure 6.9. Distribution of the textural classes in the subsurface sediments. See also legend in Figure 6.2.

if the average grain size values for the top 2 - 4 metres in each core are taken into account. For Cores II, IV, XXI, VI and XII the average phi values are 6.92∅, 6.12∅, 5.97∅, 5.37∅ and 5.14∅ respectively. As discussed in section 6.1.2.1 a similar trend is recognized in the surface sediments along the fjord's basin (Figure 6.4).

A definite downward trend of decreasing grain size has been determined in the two cores sampled back to ca. 2.000 - 3.000 B.P. i.e. Cores II and IV. For example in Core II the average grain size value is 6.92∅ above the H_1 time marker, but 7.10∅ below; for Core IV the corresponding values are 6.12∅ and 6.36∅. For the same time period similar values of decreasing grain size versus depth have been recorded in soil profiles west of Eyjafjördur i.e. in Skagafjördur (Figure 1.1) (Gudbergsson, 1975).

One sample was selected from the H_1 tephra layer in Core IV. The mean size value of 6.92∅ is somewhat finer than the sediments above and below. The acid tephra layers from Hekla (i.e. H_1, H_3, H_4 and H_5) found in the Eyjafjördur region have all been transported by wind for at least 150 - 200 km (Figure 5.7) before settling either directly into the fjord or in the immediate drainage area. As can be expected the acid tephra layer is therefore measured somewhat finer than the surrounding terrestrial material.

Sorting. The core sediments show a deviation (σ_I) of approximately constant range, 1.4 - 2.0∅ (P) for most of the samples. An exception from this is the tephra layer H_1 with a value of 1.0∅ (moderately) and one sample from

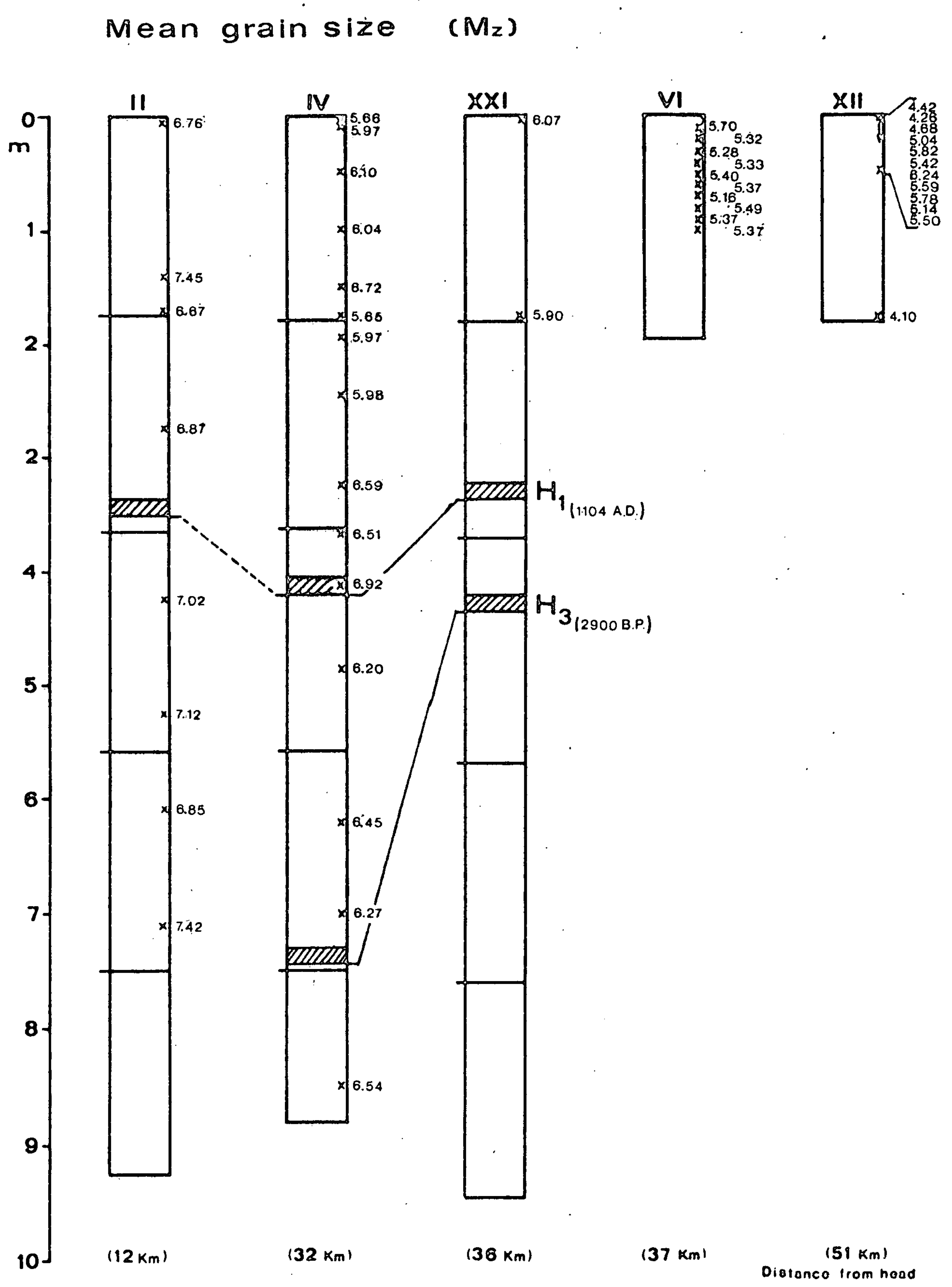


Figure 6.10. Distribution of the mean grain size in the subsurface sediments -falling drop and sieving-.

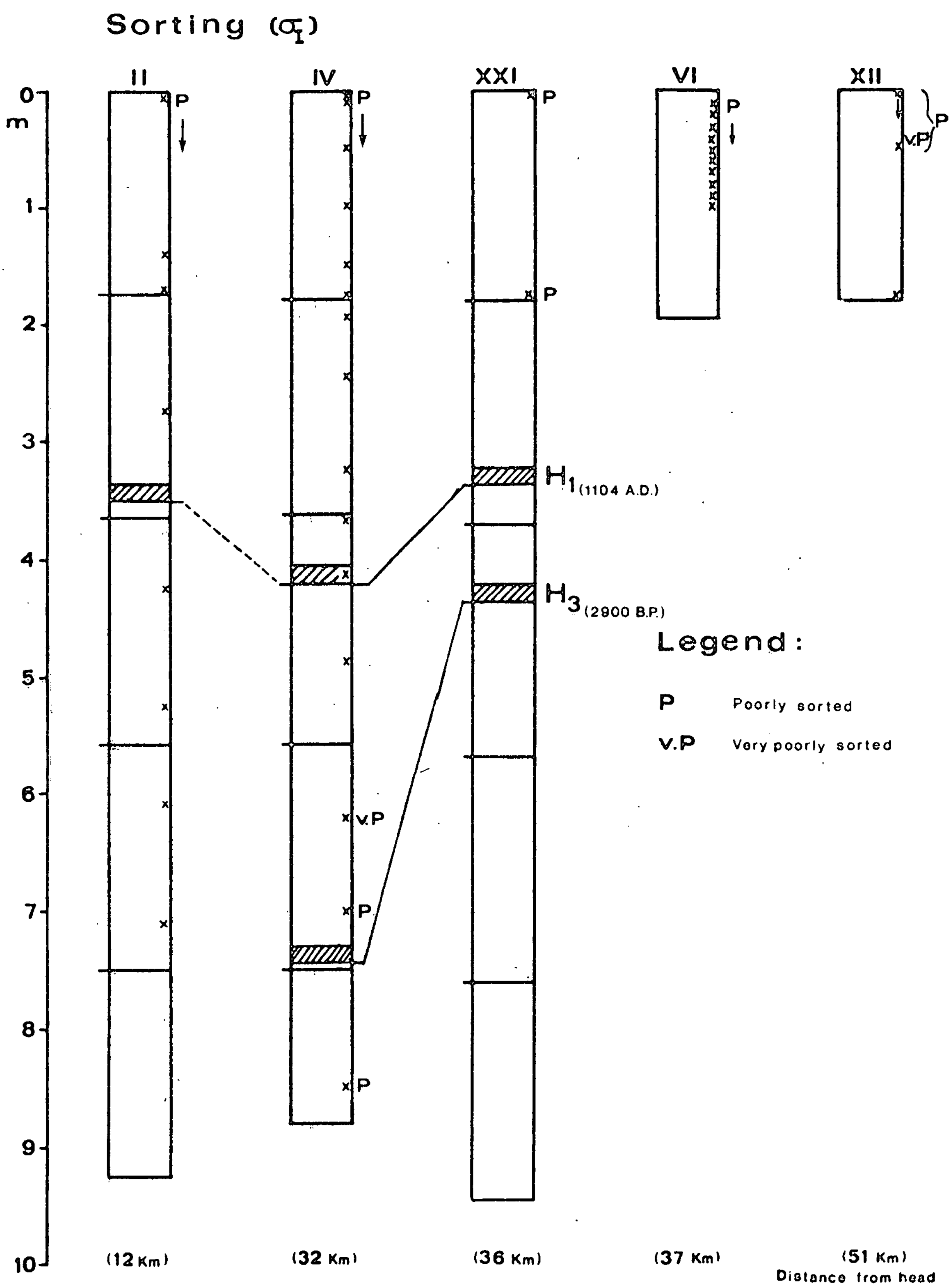


Figure 6.11. Subsurface sediments, sorting.

Core IV and Core XII with a value of 2.1ϕ (very poor). The results of sorting are presented in Figure 6.11 using the classification scale introduced by Folk and Ward (1957).

6.1.3 Discussion

The results of the grain size analyses in Eyjafjördur reflect in general the pattern of sedimentation expected in a fjord environment. In the shallow water along the coast and in the deltas the sand texture predominates with a mean grain size of fine sand to coarse silt but in the deeper or basin type water the mud texture predominates with a mean size of medium to fine silt.

The sediments transported by rivers are partly deposited in the deltas and are partly in suspension. Only a part of the coarse sediments is transported into the deeper parts of the fjord by turbidity currents (Figure 4.10). The finer fraction is in suspension and the particles settle out in floccules rather than as single grains. The sediments eroded from the coast around the fjord are deposited on the flanks and, partly transported along the coast and partly migrated into the deeper part of the fjord.

This kind of sediment distribution is shown in the distribution of mean grain size of the surface sediments but also in the modes and the sorting parameters. In the deep water the sediments are poorly sorted and polymodal originating, as they do, from concentrated floccules of fine grains, but on the flanks and in the deltas where current activity is higher the sediments are unimodal or bimodal and moderately to well sorted due to control exerted by currents on the sedimentation. Mud is an important constituent of the sediment at only ~~already at~~ 20 - 25 m depth, which gives an indication of the depth of current control.

In the core profiles the trend of decreasing grain size recorded versus depth/time is found consistent with grain size analyses carried out on soils west of Eyjafjördur for the same time period (Gudbergsson, 1975). These results are considered to reflect the increase in the sedimentation rate after the time of settlement (approximately above the H_1 time marker). This increase in the sedimentation rate has been related to the devastation of forests, soil destruction on big scale and partly to climate deterioration after the Settlement in Iceland (Thorarinsson, 1961).

The change measured in the grain size distribution seems to be gradual rather than subtle and no obvious sign of turbitites as could be expected in an area of seismic activity. Either the turbidites are confined to narrow channels in the area of core location and the cores taken outside these channels or the turbidites are so fine grained that they can not be recognized in the core profiles.

6.2 Sediment composition

Analyses of the mineralogy of the sand and clay fractions of the various sediments including soils are presented in the following sections. It is felt that although these grain size fractions represent only a small proportion of the sediments, silt being the major constituent, an assessment of their petrographic variability in different cores will provide evidence on the dispersal of sediments in the fjord.

6.2.1 Optical methods on sand size grains.

Sand size samples of different phi grades were grain mounted for examination in this section (Appendix F). An attempt made to classify the sediment from grain mount studies of the sand sized material is based on the line method of Galehouse (1971 b). The details of this method and the computations for estimating composition from the modal analysis of 900 grains of two different phi intervals 2ϕ - 3ϕ (.250 - .125 mm) and 3ϕ - 4ϕ (.125 - 063 mm) are outlined in Appendix F.

The mineralogy of sand sized grains of surface and subsurface marine sediments and soils was divided into several mineral classes. These are tabulated in Table 6.3. From their presence and relative abundance in marine sediments, river sediments and soils it was hoped to identify the major sources of mineral supply to these sediments.

Table 6.3

Non-Biogenic Fraction.

A.	Colourless-white to greyish-yellow glass (Acid) (n $\leq$ 1.55):	predominantly forming elongate pipe-like vesicles with thin walls; up to 80% of the grain may consist of crystals (phenocrysts).
B.	Brown glass (Basaltic) (n $>$ 1.55):	consist primarily of reddish-brown transparent fragments (sideromelane) usually with a trace of minerals; the vesicles are usually randomly spaced and the vesicles are spherical and only rarely stretched into elongate shapes. Not more than ca. 50 - 60% of the grain may be opaque and not more than ca. 80% may consists of crystals.
C.	Palagonite:	about 10 - 20% or more of the transparent fragment (sideromelane) is devitrified.
D.	Opaque (tachylite):	more than 50 - 60% of the grain is opaque (microlites), but not more than ca. 70% of crystals (pl).
E.	Basalt fragments:	mainly basalt fragments, but also grains that can not be categorized in classes B and D.

Table 6.3 (continue)

F.	Monocrystalline grains: (Crystals)	plagioclase, pyroxene, olivine, zeolites, quarts.
G.	Others:	granite, gneiss, micas etc.

(Based on Vilmundardóttir et al., 1979; Haflidason, 1979)

Biogenic Fraction.

H. Molluscs:

I. Foraminifera:

J. Echinoderma:

K. Siliceous organisms:

L. Others:

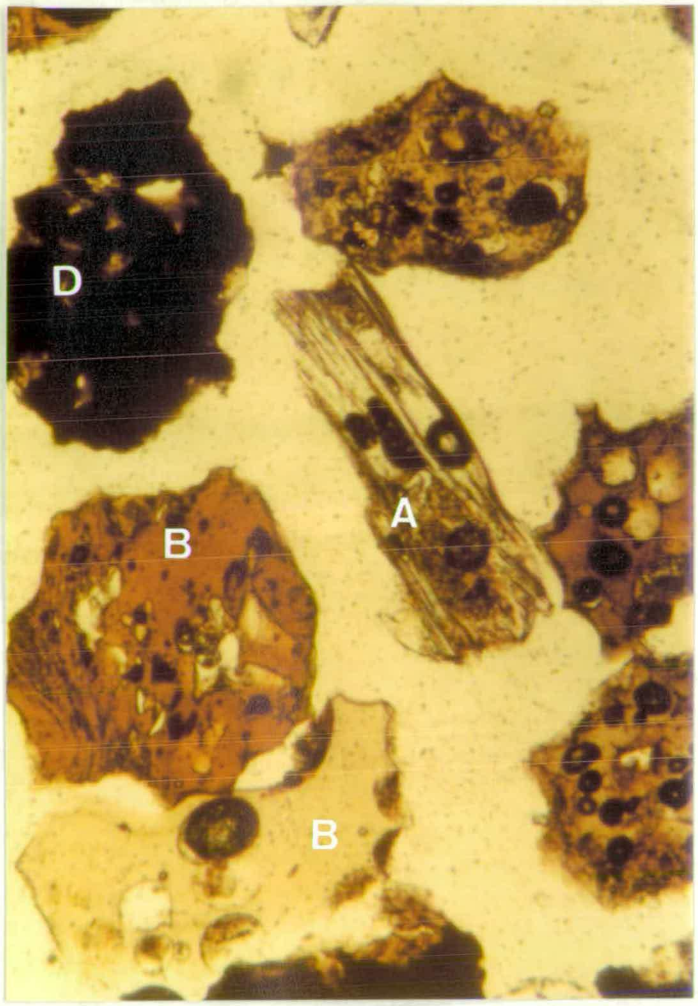


Plate 1 A.

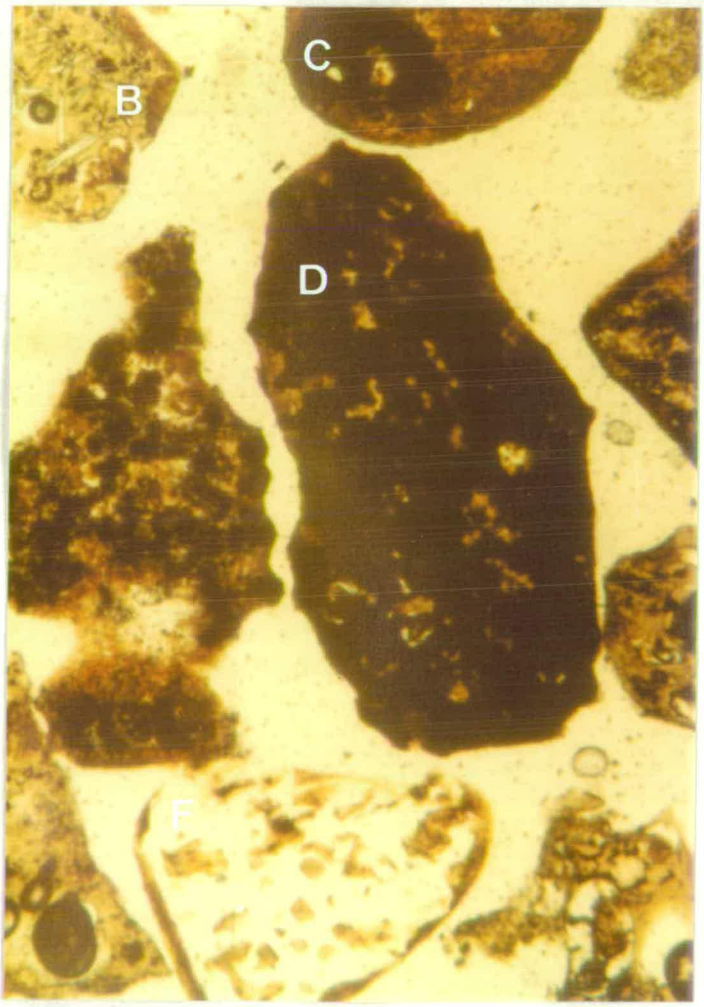


Plate 1 B.

It is usually difficult to distinguish between grains directly eroded into rivers and those introduced to the marine environment by wind action especially when they are derived from the same inorganic rock source. In the Eyjafjördur area, however, the bedrock is predominantly a fine grained crystalline basalt in contrast to much of the wind-derived sediment which can be traced to the Palagonite Formation sediment source to the south and south-east of the drainage basin. This material is composed mostly of altered basaltic glass.

6.2.2 Composition of the non-biogenic fraction

The petrographic classes described in Table 6.3 are of various origin and rock types.

The white (acid) glass grains are related to central volcanic activity. In Eyjafjördur these grains are predominantly of tephra origin from the active volcano Hekla and have been transported into the study area by wind.

The brown glass (basaltic) grains are also predominantly of tephra origin transported by winds into the Eyjafjördur area, especially from the south and south-east. Also, a few grains may derive from the thin sediment interbeds of the Tertiary Basalt Formation and from the Palagonite Formation (Figure 2.2), but a part of the Palagonite Formation is usually of 'fresh' glass fragments.

The basalt fragments derive from the Tertiary Basalt Formation. Fragments and lumps of basalt also occur in the Palagonite Formation, but as this Formation only covers the south-east margin of the drainage area, basalt fragments of this origin cannot be an important factor in the sediments of Eyjafjördur.

Opaque grains are predominantly related to the Tertiary Basalt Foramtion. Also, a few grains may have come from the Palagonite Formation or transported by wind into the study area as a minor constituent of the basaltic tephra layers.

Monocrystalline grains predominantly derive from the Tertiary Basalt Formation. Also, few grains can have been transported by wind into the area either as inclusions in the tephra glass grains or ,occasionally, as 'xenocrysts'.

Palagonite fragments mainly originate from the Palagonite Formation, but also from the thin sediment interbeds of the Tertiary Basalt Formation.

Because the white glass graine constitutes only a minor part of the sediments, 1 - 2%, they have been illustrated with the brown glasses on the histograms.

6.2.2.1 River sediments

Observations on river sediments taken from the subaerial deltas of Eyjafjardará, Hörgá and Fnjóská are presented in Figure 6.13. Only one size interval of the river sediments was analysed (0.125 - 0.250 mm).

There is a significant difference recorded between the rivers, presumably reflecting different drainage areas.

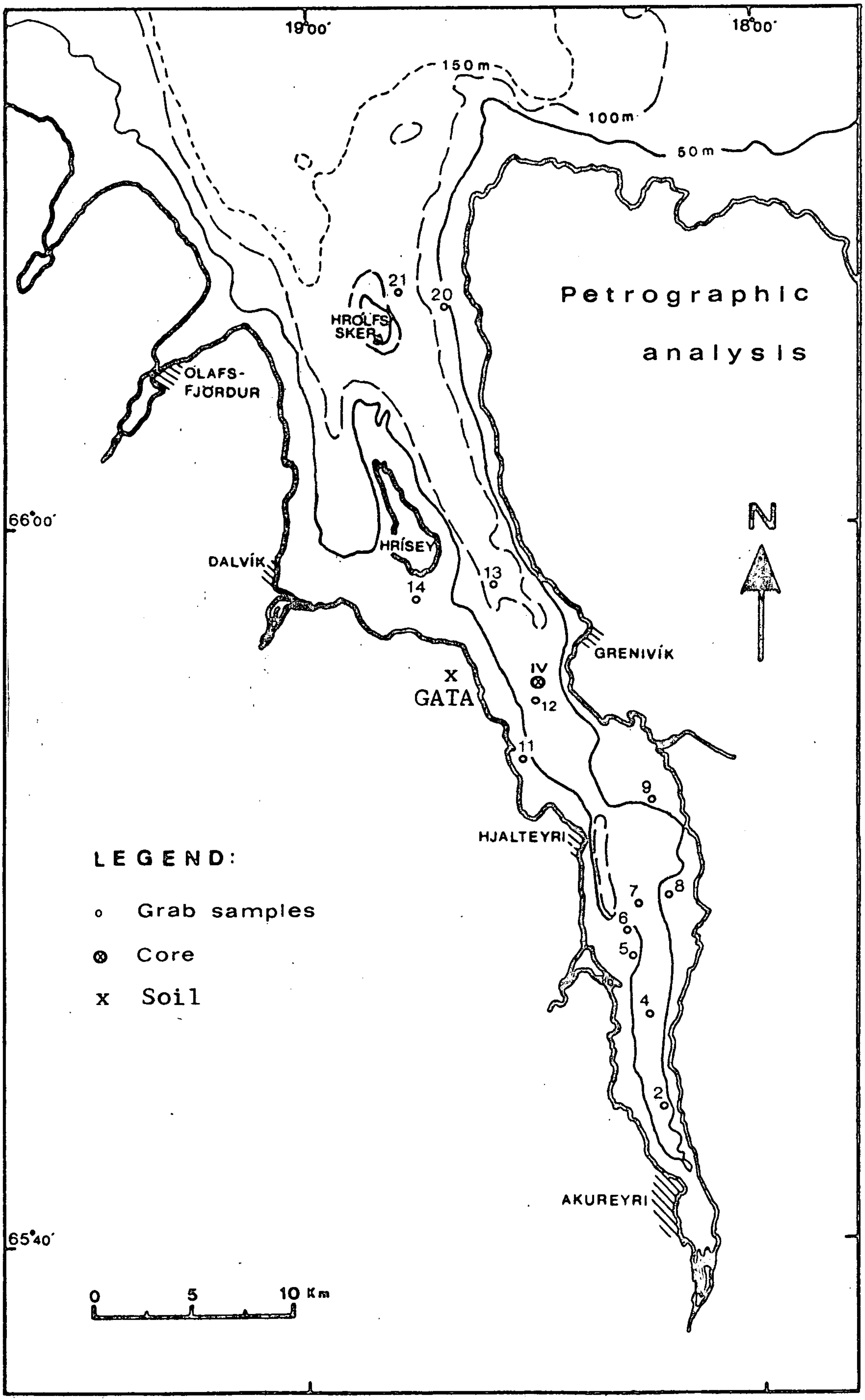


Figure 6.12. Location of petrographic samples

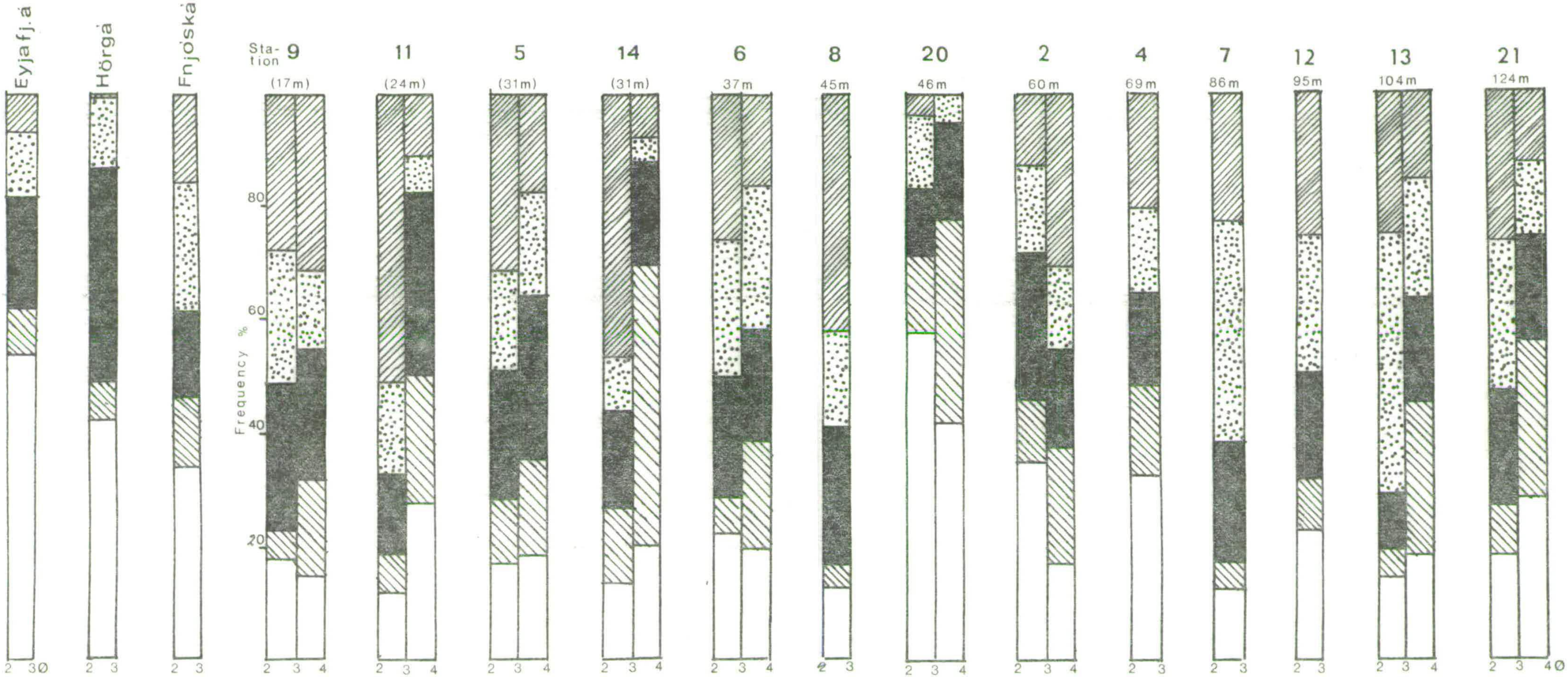
For example the rock basement of the Hörgá drainage area is of the Tertiary Basalt Formation, but in the Fnjóská drainage area the Palagonite Formation has also been mapped along the drainage area.

6.2.2.2 Grab samples

Studies were made on sediments from 13 grab stations both in the inner and the outer part of the fjord (Figure 6.12). Two grain size intervals were prepared (i.e. 0.125 - 0.250 and 0.063 - 0.125 mm) and the results are presented in a histogram (Figure 6.13). In four of the samples only the coarser fraction was prepared

The petrographic character is quite different within each grain size interval in the samples. A systematic increase can be recorded in the monocrystalline group with decreasing grain size presumably due to their original small size. Also the amount of palagonites is usually found less in the finer fraction of the surface sediments. In an attempt to study the petrographic variations in the surface sediments and to compare them with the rivers sediments the results of the petrographic classification are plotted on triangular diagrams (Figure 6.14). Only the 0.125 - 0.250 mm (2-3ϕ) size interval can be studied.

On the diagram in Figure 6.12a the highly vesicular and the most glass rich components are plotted. In comparing the river and the surface sediments a part of the material transported by the rivers seems to have been deposited in the deltas, where the brown and white glass



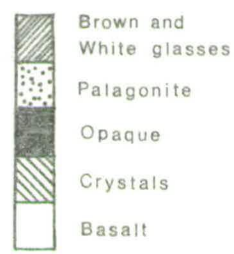


Figure 6.13. Histogram of the non-biogenic fraction in the river and surface sediments, petrographical analyses.

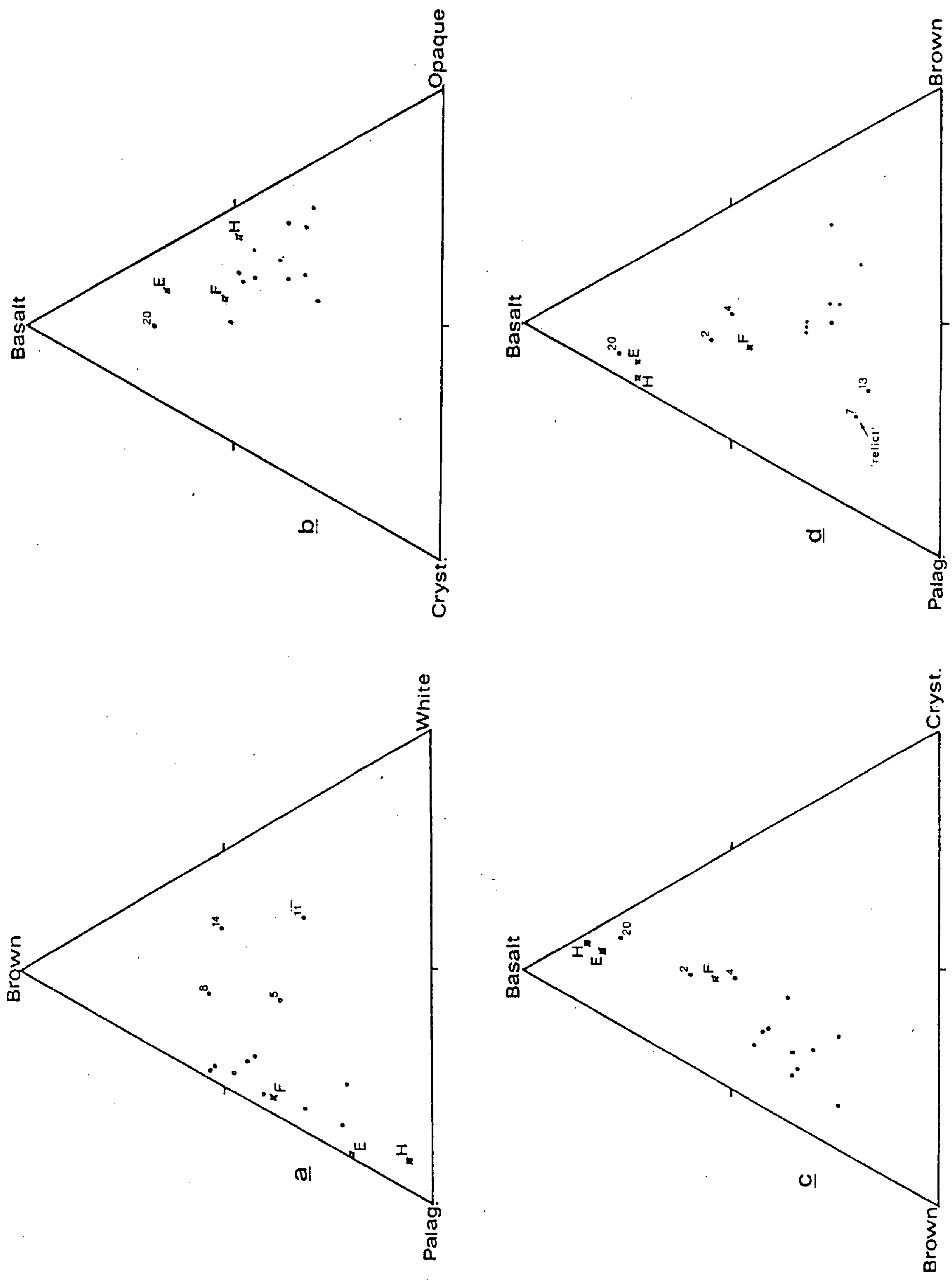


Figure 6.14. Triangular diagrams of the non-biogenic petrographical components in the river and surface sediments.

grains are more prominent in the surface sediments. Both the brown and white glass grains are highly vesicular and can for that reason, stay somewhat longer in suspension than grains free of vesicles. As an example, white glass grains are relatively abundant in the shallow water sediments at Stations 5, 8, 11 and 14 indicating a somewhat less mixing than recorded at the other stations. What can also cause difference between the river and the surface sediments is the fact that a relatively large part of the brown glasses and most of the white glass grains have been transported by wind into the drainage area and directly into the fjord.

The components with low glass ratio and almost free of vesicles are plotted in Figure 6.14b. It seems apparent from this diagram that the basalt/crystal ratio decreases from the deltas and into the surface sediments, i.e. the importance of crystals (mostly plagiclase) increases in relation to that of basalt fragments, suggesting more maturity, where rock fragments are generally more susceptible to abrasion than for example plagioclase or quartz. An exception from this trend is sample 20, taken on the flank in the outer part of the fjord. The basalt/crystal ratio is found somewhat higher than measured in the river sediments presumably related to a high wave-tidal current activity, but the sediments at this station were found to be well sorted.

In Figure 6.14c the basalt/crystal ratio is studied in comparison with the brown glass component. Firstly, if these three components have been transported predominantly by the rivers into the fjord it can be suggested that currents and transport within the deltas have broken down the brown glasses and the crystal component and/or the basalt and the crystal components are deposited in the deltas when the brown glass grains are transported into the fjord. This result could indicate that the basalt/crystal ratio is controlled by the amount of volcanic glass grains in the sediments. Secondly, if most of the brown glass grains ~~is~~ are transported by winds directly into the fjord this will cause a higher volcanic glass content in the fjord sediments. The most resistant part of the ash, i.e. the phenocrysts, will be deposited and bypassed by the glasses in an environment of sufficiently strong abrasion. This factor is not thought to be of any importance in the size interval studied (0.125 - 0.250 mm) as the phenocrysts (mostly plagioclase) are usually smaller. The increase recorded in the mineral content with decreasing grain size (e.g. 0.063 - 0.125 mm) can partly be related to this phenomenon.

The basalt, palagonite and the brown glass components are plotted in Figure 6.14d. The results indicate that the palagonite and the brown glass grains are breaking down in the deltas and are transported into the fjord, presumably due to their high vesicularity. Also, the surface sediments are in general found somewhat richer in brown glasses than palagonites, probably because of the effects of the wind transported glass grains. The sediments in sample 7 are considered to be partly 'relict'.

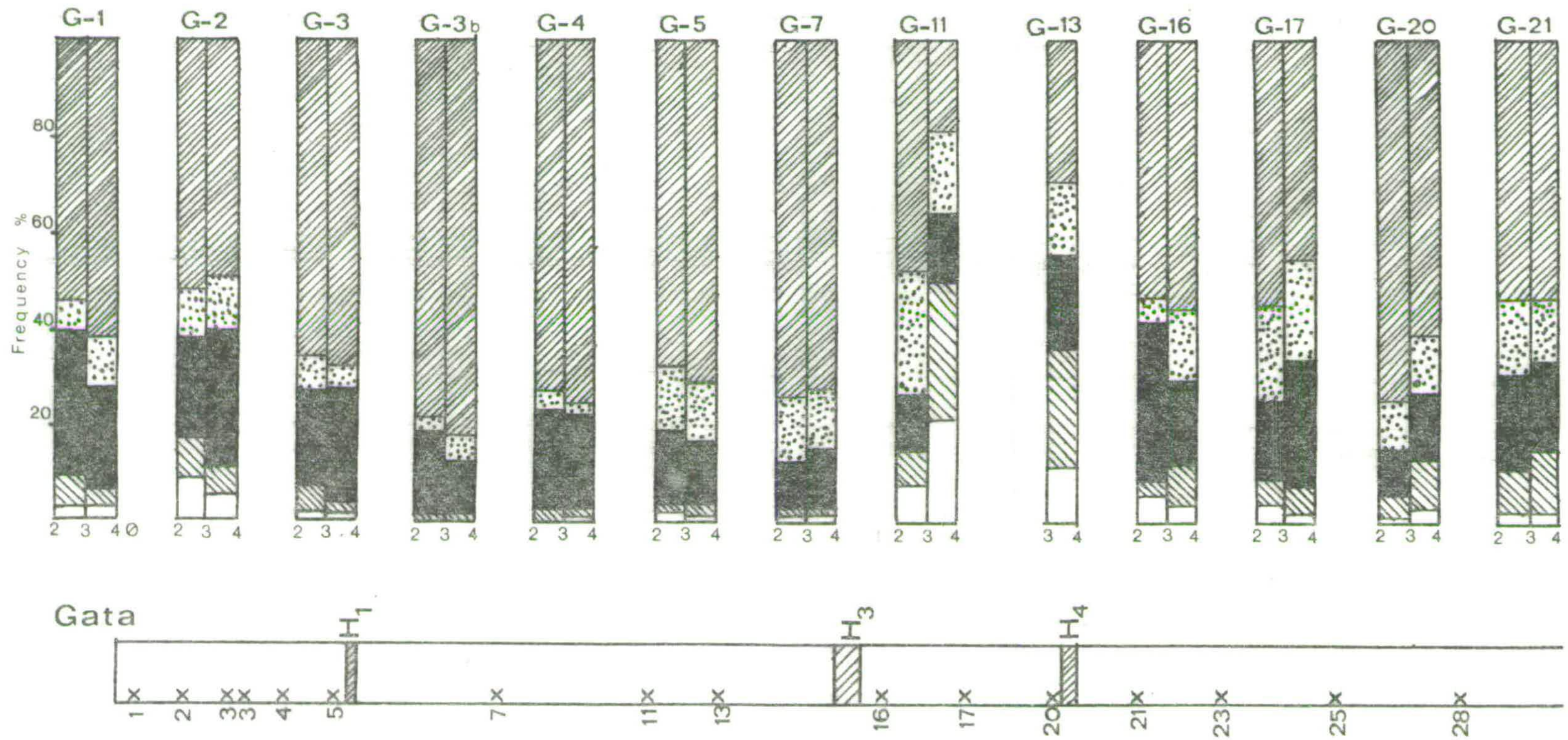
To sum up, some kind of fracionation seems to be taking place in the deltas. For example, the components of low vesicularity (basalt, crystal, opaqe) are predominant in the deltas whereas the components of high vesicularity (brown, white, palagonite) are more common in the surface sediments. Also, the volcanic glass components transported by wind into the study area are much more prominent in the surface sediments than in the river sediments.

According to these diagrams, it seems impossible to trace the primitive sediments of the rivers to any of the fjord stations studied. The surface sediments are well mixed and as the river sediments are found relatively homogenous, they cannot be distinguished in the surface sediments of the Eyjafjördur.

6.2.2.3 Soil samples

Observations on teh soil samples are based on only one profile at Gata farm on the western bank of Eyjafjördur (Figure 6.12). The chronostratigraphy has been established for this soil section (Chapter 5) which extends over a period of 7.000 years. 6 cm subsamples of the profile down to 175 cm depth were treated to remove organic matter using boiling sodium hypochlorite (NaClO) (McIntyre, 1977) and two grain size intervals (0.125 - 0.250 and 0.063 - 0.125 mm) were prepared as mounts in thin section.

The results of the petrographic analysis are presented on the histogram in Figure 6.15 reflecting variation in the petrographic character with time. In one part of the profile the non-biogenic fraction was found apparently low,



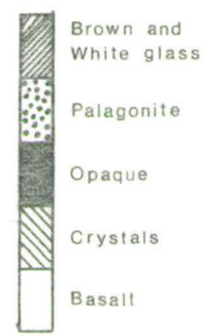


Figure 6.15. Histogram of the non-biogenic fraction in the soil profile Gata, petrographical analyses.

i.e. between the H_1 and the H_3 time markers and therefore each sample had to span a long time period (e.g. sample 7). In sample 13 only the finer fraction could be studied.

The biogenic/non-biogenic ratio was not measured, but was found to vary considerably within the profile. For example above the H_1 time marker this ratio is very low due to a significant increase in the destruction of the soil and vegetation cover in Iceland since the Settlement of the country (< 1.100 B.P.) (Thorarinsson, 1961). Below the H_1 (1104 A.D.) time marker this ratio is generally high, but seems to vary slightly in relation to climatic changes, whereas a close relationship is found between the soil formation and the changes in vegetation cover (Gudbergsson, 1975). These climatic changes have been correlated with periods of climatic changes recorded in Europe (Th. Einarsson, 1961, 1963). For example, during the period 1.100 - 2.500 B.P., approximately between the H_1 and the H_3 time markers, the climate was relatively cold and wet (subatlantic), but during the period 2.500 - 5.000 B.P., approximately between the H_3 and the H_4 time markers, the climate was relatively warm and dry (subboreal). In the soil profile of Gata (Figure 6.15) these periods of climatic changes are reflected in different rates of soil formation and a different biogenic/non-biogenic ratio.

In an attempt to understand this variation shown in the petrographic classification, the results were plotted on triangular diagrams (Figure 6.16). The same size interval is studied, as plotted in the diagrams which represent river and surface sediments (Figure 6.14).

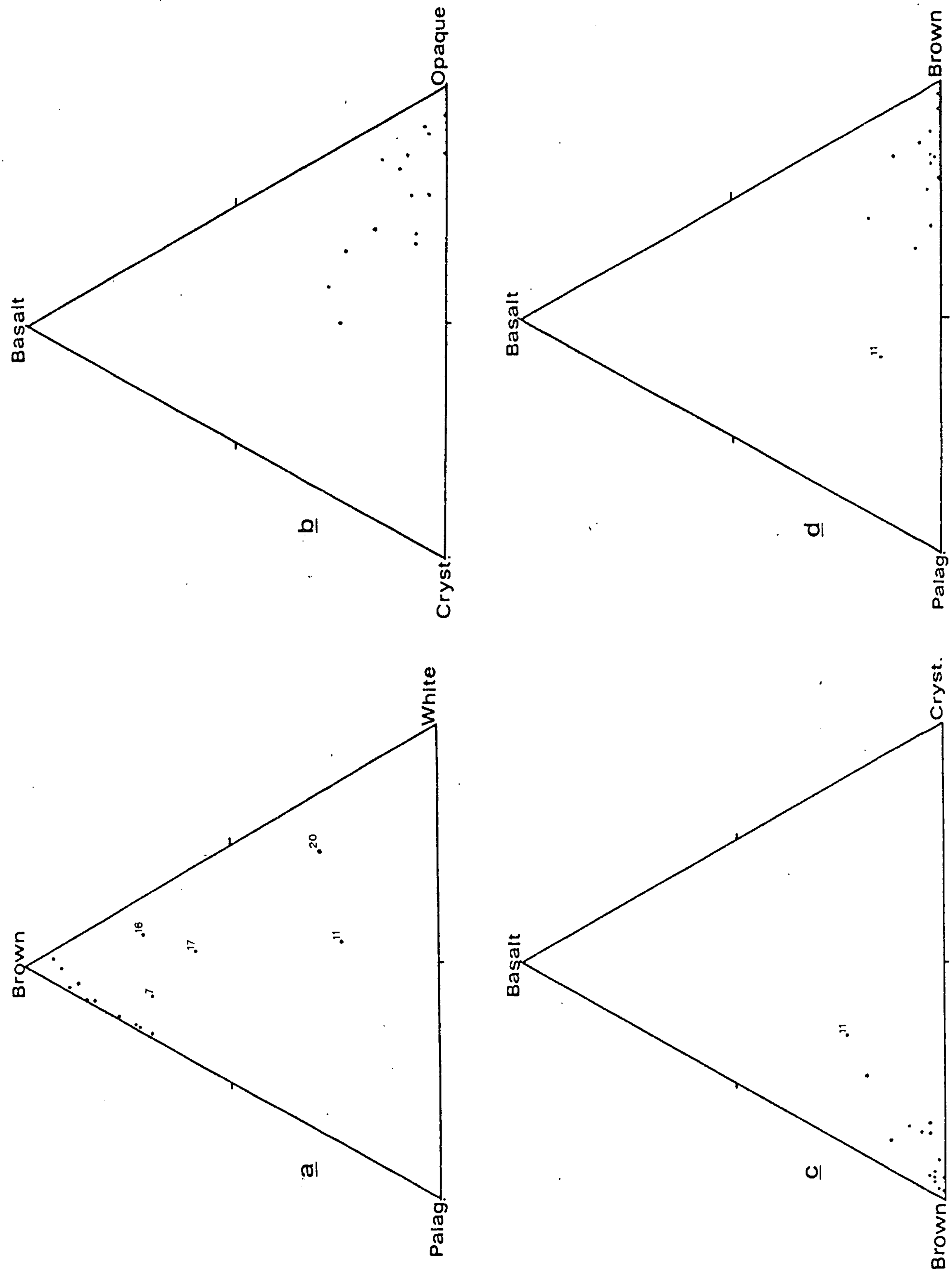


Figure 6.16. Trinagular diagrams of the non-biogenic petrographical components in the soil profile at Gata.

In Figure 6.16a the glass rich components are plotted. The soil samples are found mainly to be of brown glass; presumably tephra in origin. Only a few samples are rich in white glass grains (the acid tephra layers were not sampled for petrographic classification) i.e. samples taken either immediately above the thick acid layers of Hekla, H_3 and H_4 (e.g. sample 20) or in the profile above these layers where the biogenic/non-biogenic ratio is high (e.g. samples 11, 16 and 17).

The basalt, crystal and opaque components are plotted in Figure 6.16b. The opaque component is found to vary in the soil samples and the basalt/crystal ratio seems to be predominantly controlled by the volcanic glass content, as can be seen ~~studies~~ in Figure 6.16d. Most of the basalt and crystal grains are considered to have originated in the local environment, but wind transported into the study area. Similarly, the brown glasses are wind transported into the area. They are presumably of tephra origin from the Neovolcanic Zone located in the south and south-east of the Eyjafjördur drainage area. In comparsion with the basalt and crystal components, predominantly of local origin, the volcanic glass grains (i.e. brown and white glasses) are most striking in the soil sediments. This interpretation is further underlined in Figure 6.16d showing a great deal of palagonite and brown glass grains in comparison with the basalt fragments.

In general most of the soil sediments have been transported over a long distance before settling out and depositing in the study area. From the diagrams in Figure 6.16

no obvious petrographic variation can be outlined that correlates with the climatic or environmental changes described above. Presumably this high proportion of 'long distance' wind transported sediments recorded in the soil samples has masked out the petrographic variation which could have been identified in the soil profile.

6.2.2.4 Core samples

Observations on the petrographic variation of the subsurface sediments were made on Core IV, taken from the middle of the fjord, west of Grenivík (Figure 6.12). The chronostratigraphy for this core was described in section 5.2. The core, nearly 9 metres in length, represents 3.000 years of sedimentation. Nine samples for petrographical studies were selected from the core profile and thin sections for three size intervals prepared i.e. 0.250 - 0.500, 0.125 - 0.250 and 0.063 - 0.125 mm.

Results for all the three size intervals are plotted on the diagrams in Figure 6.17 and can be directly compared with the diagram of the peat soil described in Figure 6.15. For the marine sediment the biogenic components are excluded. Because grab sample station 12 is so close to this core profile (Figure 6.12) the petrographic study carried out on this grab sediment was regarded as representative for the top layer of the core.

The petrographic character of each size interval is quite different in the core samples. For example, a con-

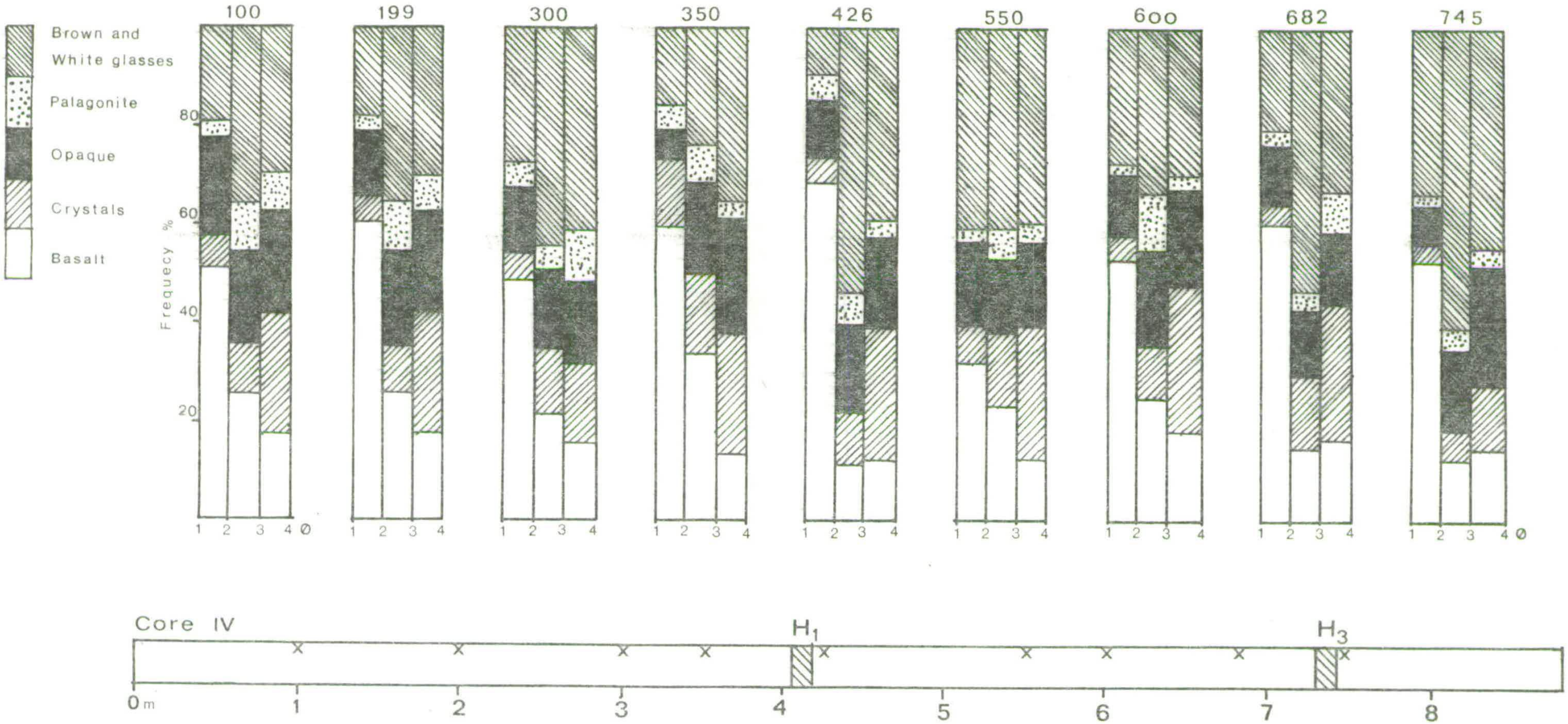


Figure 6.17. Histogram of the non-biogenic fraction of Core IV, petrographical analyses.

sistent increase is measured in the monomineralline group with decreasing grain size, presumably due to their original small size, but the amount of palagonites varies. The basalt content decreases with decreasing grain size, as can be expected with increasing abrasion.

In an attempt to analyse the petrographic variation in the subsurface sediments, the results, presented in Figure 6.17, are plotted on triangular diagrams in Figure 6.18.

The conclusion is, that in spite of 3.000 years of sedimentation the same trend is recorded between the river and the surface sediments, as discussed in section 6.2.2.2.

As discussed in section 4.4 (Figure 4.10) a part of the sediment deposited from the river Fnjóská is distributed into the outer part of the fjord by submarine sediment channels. The location of the main rivers would indicate that the Fnjóská sediment is probably predominant in the coarser part of the core sediments. However, the petrographic composition described above cannot confirm this, as the Fnjóská sediments have not been traced to any of the grab samples or to the core sediments of the fjord. A significant effect of mixing seems to be a dominant factor in the sedimentation of Eyjafjördur.

The only effect noticed in the core sediments, with increasing sedimentation rate, is that the brown glass content decreases (Figure 6.18a), presumably due to an increase in sediments originally derived from the drainage area.

To sum up, the relatively high proportion of volcanic

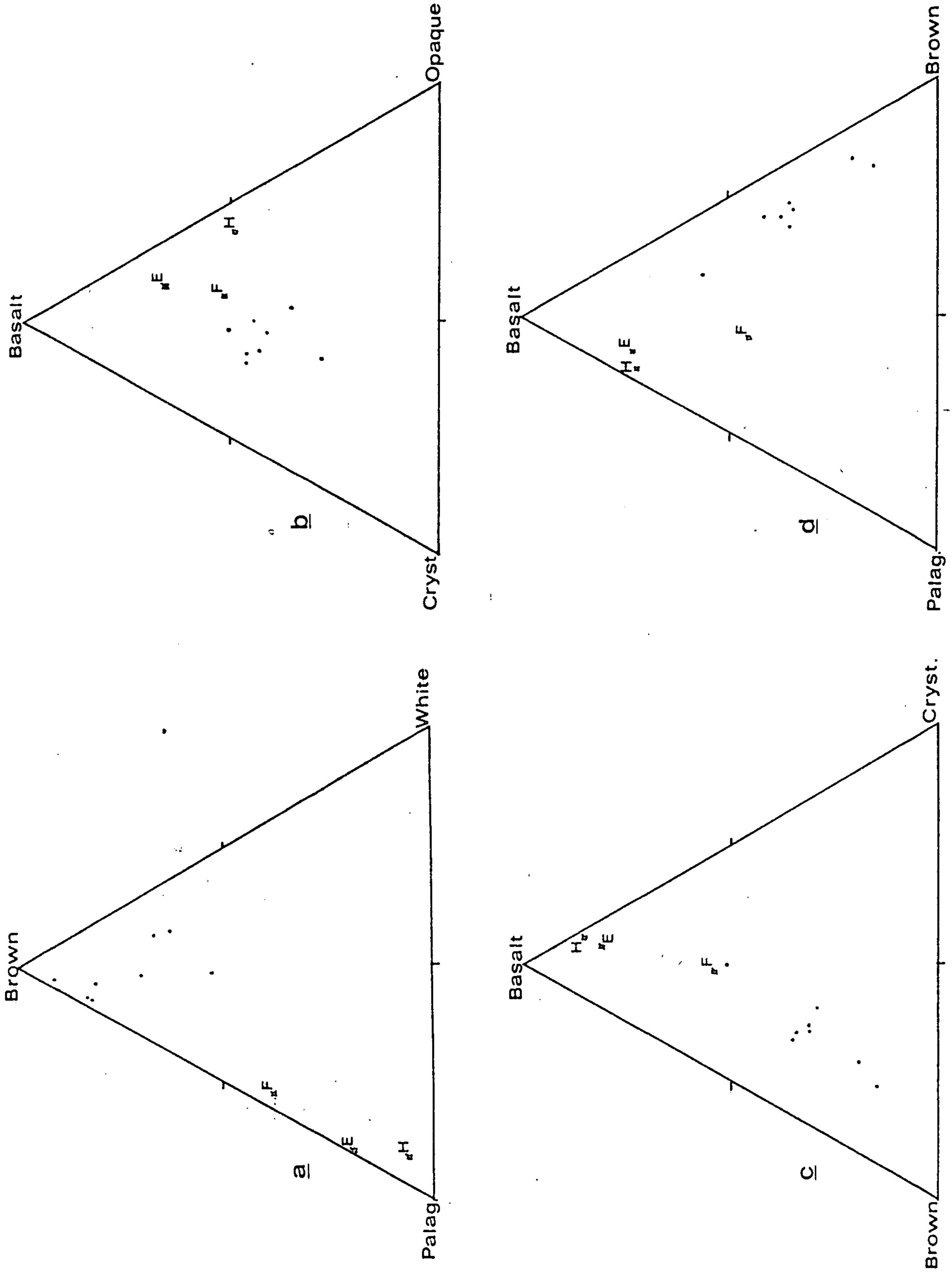


Figure 6.18. Triangular diagrams of the non-biogenic petrographical components in the rivers and Core IV.

glass grains (brown and white glasses) in the fjord's sediments indicate that wind transported sediments from other parts of the country are an important factor in the sedimentation. These sediments originally deposited into the drainage area or directly into the fjord seem to have been transported at a relatively constant rate into the area, at least during the last 3.000 years (Core IV). Therefore one cannot expect the petrographic classification to reflect the climatic or other environmental changes in the area.

6.2.3 Composition of biogenic fraction

6.2.3.1 Grab samples

The proportions of biogenic components are shown on the diagram in Figure 6.19. The biogenic fraction only constitutes 2 - 5% of the sediments with an exception of 14 and 17% in samples 7 and 21. Four shallow-water samples (Stations 5, 6, 9 and 20) contain no biogenic material.

Molluscs and forams are the dominant components of the biogenic fraction. Other components found are echinoderma and radiolaria. No grains or fragments of diatoms, worm tubes and fecal pellets were identified, but these are common in Icelandic shelf sediments (see e.g. Haflidason, 1979). No detrial carbonates were found.

The low proportion of biogenic material in the surface sediments can partly be related to effects of fresh and

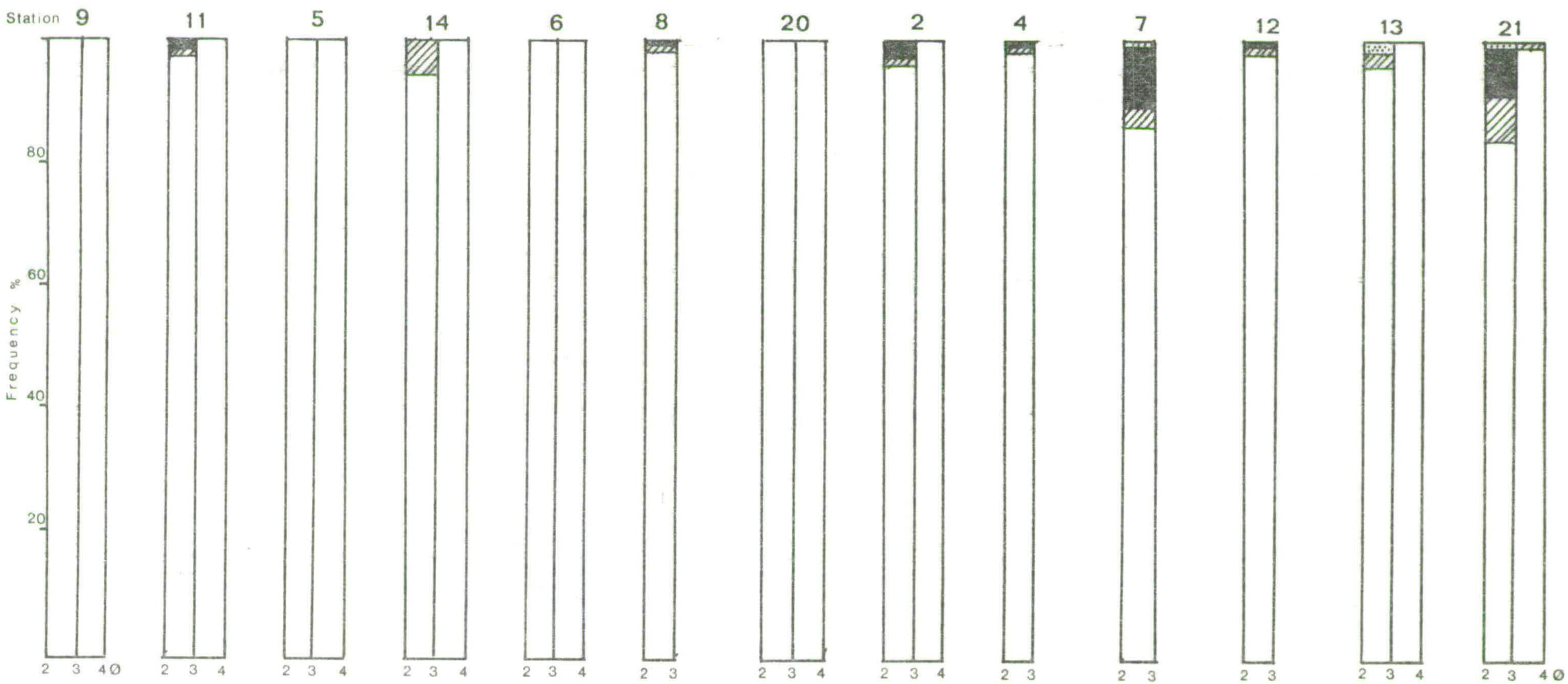
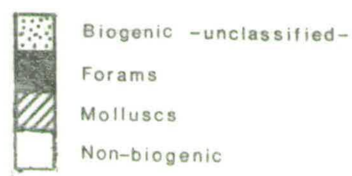


Figure 6.19. Histogram of the biogenic fraction in the surface sediments, petrographical analyses.



brackish waters. For example in samples taken from the delta environment of Hörgá and Fnjóská (Stations 5, 6 and 9), no biogenic material is identified. Also, a systematic study of the benthic fauna in the inner part of the fjord (< 20 m depth) showed that the number of species decreases steadily from the region of Hjalteyri to the head of the fjord. Lower salinity of the water in the inner part of the fjord is believed to be the main cause of this trend (Hauksson, 1979). Samples 8 and 11 (Figures 6.12 and 6.19) could reflect these brackish water effects.

In areas of high salinity i.e. the deeper parts of the fjord (Figures 2.14 - 2.17) sediments show a low degree of biogenic material, presumably because of a high rate of terrigenous sedimentation.

The highest biogenic content is found in samples 7 and 21 (Figures 6.12 and 6.19). In sample 7, most of the mollusc grains identified show signs of alteration/decomposition either in the form of ´iron´ staining or as borings. Although this sample is taken from relatively deep water, the biogenic components indicate a low sedimentation rate at this sampling site. As discussed in section 4.4 (Figure 4.10) the main transport path of the coarser grain sizes is confined to relatively well-defined submarine channels and as this sampling station is located at the fjord´s marginal ´slope´ a possilbe explanation for this low sedimentation rate or ´relict´ character is that the sample is taken from an inactive area or from the ´lee´ site of the submarine channels.

The relatively high biogenic content of sample 21 may also reflect a low sedimentation rate, but it could also be due to the transport of carbonate material from the shelf outside Eyjafjördur.

6.2.3.2 Core samples

Observations of the biogenic fraction in Core IV are presented on the diagram in Figure 6.2o. The biogenic content is measured in three size intervals (i.e. 0.250 - 0.500, 0.125 - 0.250 and 0.063 - 0.125 mm). Along with the surface sediments, molluscs and forams predominate. The amount varies slightly between the size fractions, but individual grain sizes only reach the amount of 8% and ca. 4% on average for all the size fractions.

The biogenic content is found relatively constant throughout the core and no obvious decrease is measured with increasing sedimentation rate i.e. after the settlement took place in Iceland (samples 100 - 426).

In the three deepest samples analysed in the core (600.682 and 745) a minor decrease is recorded in the biogenic content. However, this decrease is not found characteristic enough for correlating with any of the environmental changes described in section 5.2.2.3 or relating this with the effects of decomposition.

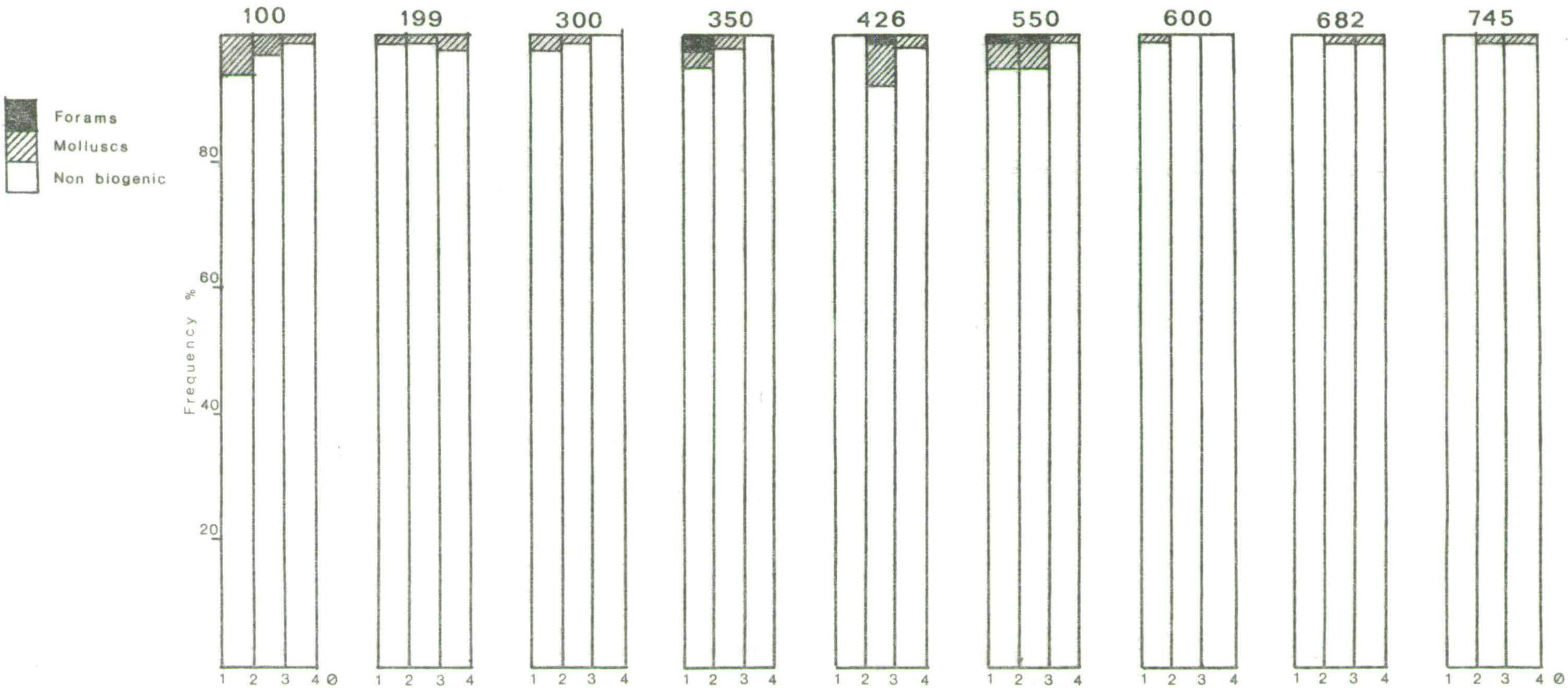


Figure 6.20. Histogram of the biogenic fraction in Core IV, petrographical analyses.

6.3 Mineralogy of the clay size fraction

6.3.1 Determination of clay minerals.

The clay minerals were determined using a Philips X-ray diffraction PW 1010. Details of instrumental conditions are presented in Appendix F. The 2 micron size fraction of each sediment sample was separated by grain settling and mounted on a ceramic tile by dispensing the clay minerals in water suspension onto it by a pipette. To avoid preferential settling of clay minerals with the highest specific density the tiles were placed on a hot-plate heated to 80°C to accelerate evaporation. In spite of repeated mounting the quantity of clay minerals in each sample was never sufficient to mask the diffraction spectrum (quartz, cristobalite and anorthite) of the tile.

To identify the clay minerals each sample was scanned three times, that is: 1) untreated, b) after glycolation and c) after heating to 600°C (see also Appendix F).

The mineral identification followed a procedure described by Kristmannsdóttir (1971, 1977), illustrated in Table 6.4. A minor exception was made in the identification of the chlorite mineral. Usually chlorite is identified by the 14 Å (001) and the 7 Å (002) peak, which are not affected by glycolation. Commonly in this study the large smectite (001) peak masked the 14 Å chlorite spacing, even in glycolated samples making the 7 Å peak the most diagnostic for chlorite.

Table 6.4

Mineral	d(001) in Å at 35% rel.moist.	d(001) in Å glycolated	d(001) in Å after heat-ing at 600°C
Smectice............	12.3-15.3	16.9-17.1	9.6-9.9
Mixed layer mineral of chlorite/smectite...	14.0-14.6	15.3-15.7	12.3-12.9
Chlorite			
1.................	14.0-14.6	14.0-14.6	13.9-14.0
Swelling chlorites			
2.................	14.0-14.6	15.0-15.5	13.9-14.0
3.................	14.0-14.6	15.0-15.5	none
4.................	14.0-14.6	16.5-17.0	13.9-14.0
5.................	14.0-14.6	16.5-17.0	none

(From Kristmannsdóttir, 1977)

6.3.2 Results

6.3.2.1 Samples from the drainage area

The samples taken from the drainage area were aimed to give answers to the following questions: a) which clays are present at the surface of the drainage area, b) what is their regional and local distribution, and c) how effective has chemical weathering been in the area, in particular as regards the most reactive of the sediments, the volcanic glass.

A wide range of samples were taken from the drainage area; covering the bedrock, soils, rivers and glaciolacustrine sediments (Table 6.5, Appendix K). Their locations are shown in Figure 6.21.

Bedrock. Four of the bedrock samples were taken from the bottom area of Eyjafjardardalur (Locations 3 and 4, Figure 6.21), an area of high dyke density (5 - 7%) (Björnsson et al., 1979). One sample is taken from an interbasaltic clastic bed (sediment and tuff) near Ólafsfjördur (Location 11, Figure 6.21) and one sample is taken from a rock slide within the fossil central volcano of Öxnadalur (Location 10, Figures 6.21 and 2.2). All the samples are taken from a lava pile of 6 - 10 m.y. (chapter 2.1).

Smectite clay minerals were identified in all the four samples from Eyjafjardardalur. The crystallinity seems good according to strong peak intensity (Table 6.5, Appendix K). The reflections measured in the samples from

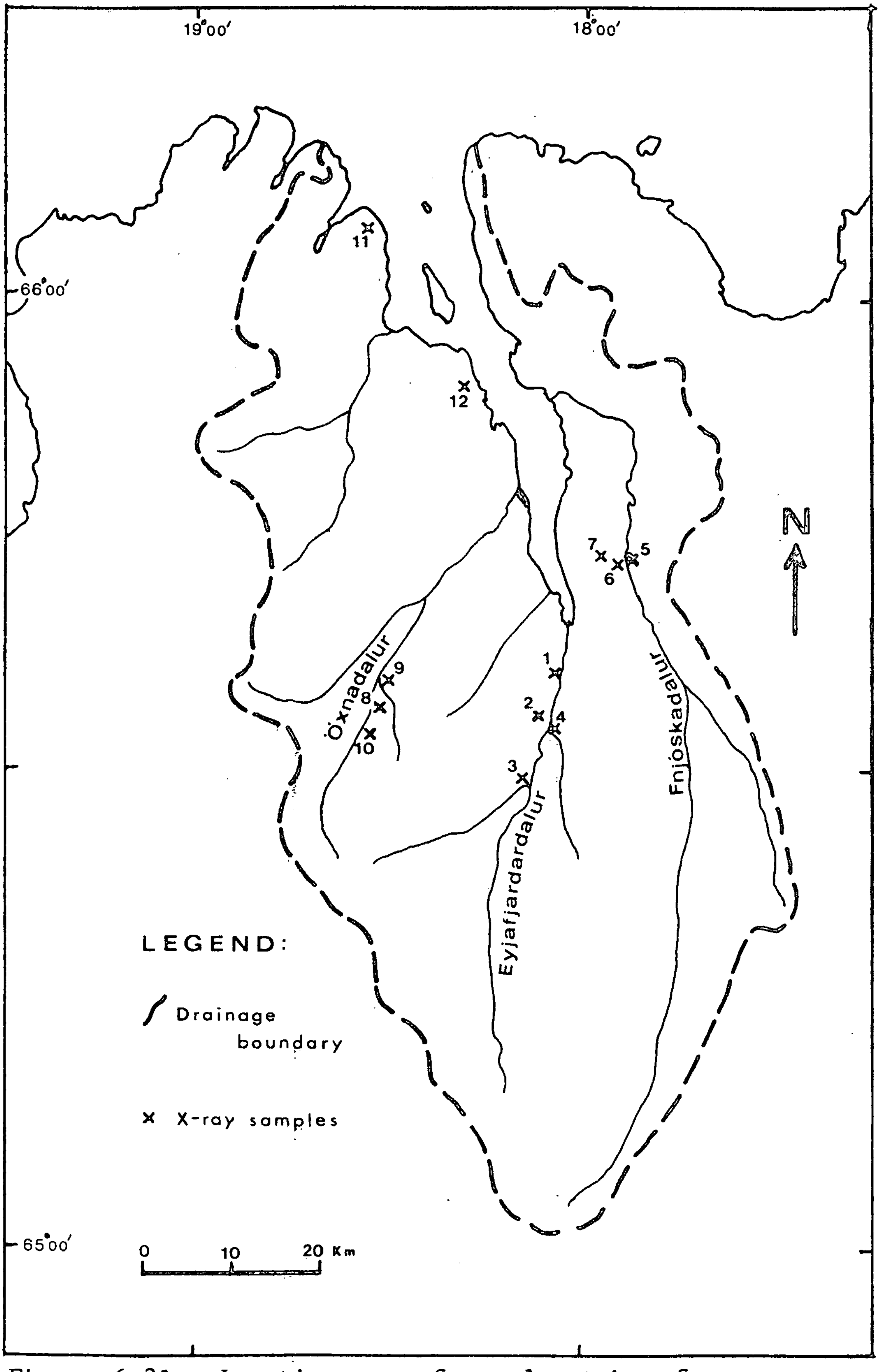


Figure 6.21. Location map of samples taken for x-ray analyses from the drainage area.

the clastic interbed are so weak that they have not been determined. In the sample from Öxnadalur the clay minerals are found to be of different type compared with the other samples i.e. chlorite (002) and mixed-layer and the crystallinity is much better developed than in samples from other parts of the study area (Table 6.5, Appendix K).

Rivers. Samples were taken from river Fnjóská 25 km from the estuary (Location 5, Figure 6.21), Eyjafjardará 6 km upstream (Location 1, Figure 6.21) and Hörgá 27 km upstreams (Location 9, Figure 6.21).

Smectite minerals are measured in all the river sediments, but the crystallinity is variable, weak in Eyjafjardará and relatively good in Fnjóská and Hörgá (Table 6.5, Appendix K). In river Hörgá chlorite minerals of a good crystallinity and illite minerals have also been identified.

Glaciolacustrine sediments. One sample of sand-silt was taken from a ca. 12.000 years old sediment pile (Norddahl, 1981) in Fnjóskadalur (Location 6, Figure 6.21). Smectite minerals have been identified in this sample, but the crystallinity seems to be very weak (Table 6.5, Appendix K).

Soils. Samples from four soil profiles were selected for clay mineral analyses. Judging from their position in relation to the acid tephra layers from Hekla (i.e. H_1, H_3, H_4 and H_5) the samples span a time interval from ca. 1.000 B.P. to more than 7.000 B.P.

Three samples (E:11, 12, 13) were taken from a soil profile at Hrafnagil, in Eyjafjardardalur (Location 2, Fig-

TABLE 6.5

X-ray samples from the Eyjafjördur drainage area.		Clay minerals
E 10:(1)	Muddy sand taken from Eyjafjardará, about 6 km up-streams from the estuary	Smectite (very weak)
E 11:(2)	Soil sample from Hrafnagil (farm) 30 - 36 cm depth	No clay minerals
E 12:(2)	" " " " " 80 - 86 " "	No clay minerals
E 13:(2)	" " " " " 108 -114 " "	No clay minerals
E 20:(3)	Sample taken from a thick weathered dyke (near the chilled margin) at Strjúgsá	Smectite (weak)
E 21:(3)	Basalt taken from the country rock at the same location	Smectite
E 23:(4)	Sample taken from a dyke (near the chilled margin) in Thverá, a tributary river of Eyjafjardará.	Smectite

TABLE 6.5 (cont.)

X-ray samples from the Eyjafjördur drainage area		Clay minerals
E 24:(4)	Basalt sample taken from the country rock at the same location as E 23	Smectite
E 30:(5)	Sand sample from Fnjóská, about 25 km from the estuary	Smectite
E 31:(6)	Sand-silt sample taken from an unconsolidated sediment pile in Fnhóskadalur - from Late Weichselian time	Smectite (very weak)
E 33:(7)	Acid ash layer from Hekla (H_3), taken from a soil profile in Fnjóskadalur.	Undefined weak reflection
E 40:(8)	Soil sample from Öxnadalur (near the farm Hraun) taken at 1 m depth, estimated age 3000-4000 B.P.	Mixed-Layer ? (very weak)

TABLE 6.5 (cont.)

X-ray samples from the Eyjafjördur drainage area		Clay minerals
E 41:(9)	Sand-gravel sample taken in Thverárdalsá in Öxnadalur	Smectite, Chlorite (002), Illite
E 42:(10)	Boulder sample taken from a rock slide in Öxnadalur within the Öxnadalur fossil central volcano	Mixe-Layer, Chlorite (002)
E 50:(11)	Sample from a Tertiary conglomerate sediment layer near Ólafsfjördur (approx. 10 m.y. old)	Very weak undefined reflection
G 10:(12)	Soil sample taken on the west coast of Eyjafjördur at GATA (near Hjalteyri) 54 - 60 cm depth, 1-2 th. B.P.	No clay minerals
G 30:(12)	" " " 174 - 180 " " 6-7 " "	No clay minerals
G 31:(12)	" " " 180 - 186 " " 6-7 " "	Very weak reflection, undefined.

ure 6.21). One sample (E-33) is taken from the H_3 (2.900 B.P.) acid tephra layer in a soil profile from Fnjóskadalur (Location 7). Also one sample (E:40) is taken from a soil profile in Öxnadalur (Location 8, Figure 6.21), estimated age 3.000 - 4.000 B.P. From the soil profile at Gata farm (Location 12, Figure 6.21) (same profile as described in section 6.2) three samples were selected G:10, 30, 31. One sample (G:10) is from ca. 1.000 B.P., but two are from 6.000 - 7.000 B.P.

As discussed in chapter 6.2.2 the non-biogenic fraction of the soils studied is very rich in volcanic glass shards suggesting that no significant difference should be found between the soil samples and samples taken directly from the tephra layers (e.g. the acid tephra layers from Hekla). Volcanic glass is very susceptible to alteration and by analysing soil samples from various environments spanning a time range of ca. 7.000 years it was expected then effects of chemical weathering in the formation of clay minerals could be studied.

The negative results of the x-ray diffraction analysis (Table 6.5, Appendix K) for the soil samples seem to indicate that the formation of clay minerals in Icelandic soils is a very slow process.

A similar conclusion has also been reached in a study by Tu (1960) from other parts of the country. Detailed studies of soil formation in western Iceland definitely show that alteration of volcanic glass shards in soils is extensive and has in some cases developed a microgranular structure. However, this alteration is not sufficient to form clay minerals (Gudmundsson, 1978).

In general clay minerals with a well defined crystallinity (a relatively strong peak intensity) have only been found in samples from the bedrock and in the rivers in the Eyjafjördur area. Two clay mineral populations can be distinguished. One population, consists of chlorite, smectite, mixed-layer and illite, and is related to areas of high temperature alteration (Kristmannsdóttir and Tómasson, 1974; Kristmannsdóttir, 1975). The other consists only of smectite and is predominantly related to areas of low temperature alteration (Kristmannsdóttir, 1977).

Samples of high alteration clay minerals are confined to the Öxnadalur area, an area of fossil central volcanic activity (Björnsson and Saemundsson, 1975). In connection with the central volcanoes, local areas of high temperature geothermal activity ($\gtrsim$ 200^{o}C at 1 km depth) create aureoles of high temperature alteration reaching to shallow levels (Jakobsson, 1979a). Two other fossil central volcanoes occur within the drainage area of Eyjafjördur creating cupolas of high temperature alteration on Flateyjardalsheidi and Torfufell (Chapter 2.1, Figures 1.1 and 2.2).

The samples from Eyjafjardardalur and rivers Fnjóská and Eyjafjardará, rich in smectite are taken in areas affected by low temperature alteration combined with low grade burial metamorphism (Björnsson and Saemundsson, 1975; Pálmason et al., 1979, Figure 2.3). This alteration can be described as regional and is found relatively extensively in the most deeply cut calleys (Pálmason et al., 1979).

The results described above can be summarized in two statements:

a) Two different clay mineral populations can be distinguished. Local areas of high temperature alteration produce a mixture of chlorite, smectite, mixed-layer and illite. These are superimposed on a regional pattern of low temperature alteration showing exclusively smectite minerals.

b) Chemical weathering during the Holocene seems to be incapable of forming clay minerals in Icelandic soils, at least on a regional scale.

6.3.2.2 Grab samples

The results of clay size analyses of grab samples are listed in Table 6.6 and their location is shown in Figure 6.22. Clay minerals are found in nearly all samples but their crystal intensity varies considerably. At Station 8 clay minerals appear absent. Two clay mineral types are observed; smectite which is characteristic of all stations and chlorite (002) which is observed only in the three northernmost stations. In general the smectite is poorly crystalline except at Station 5, taken in the Hörgá delta and at Stations 18 and 21, the two outermost stations in the fjord's basin, where the clay minerals are highly crystalline. Chlorite (002) is highly crystalline in these

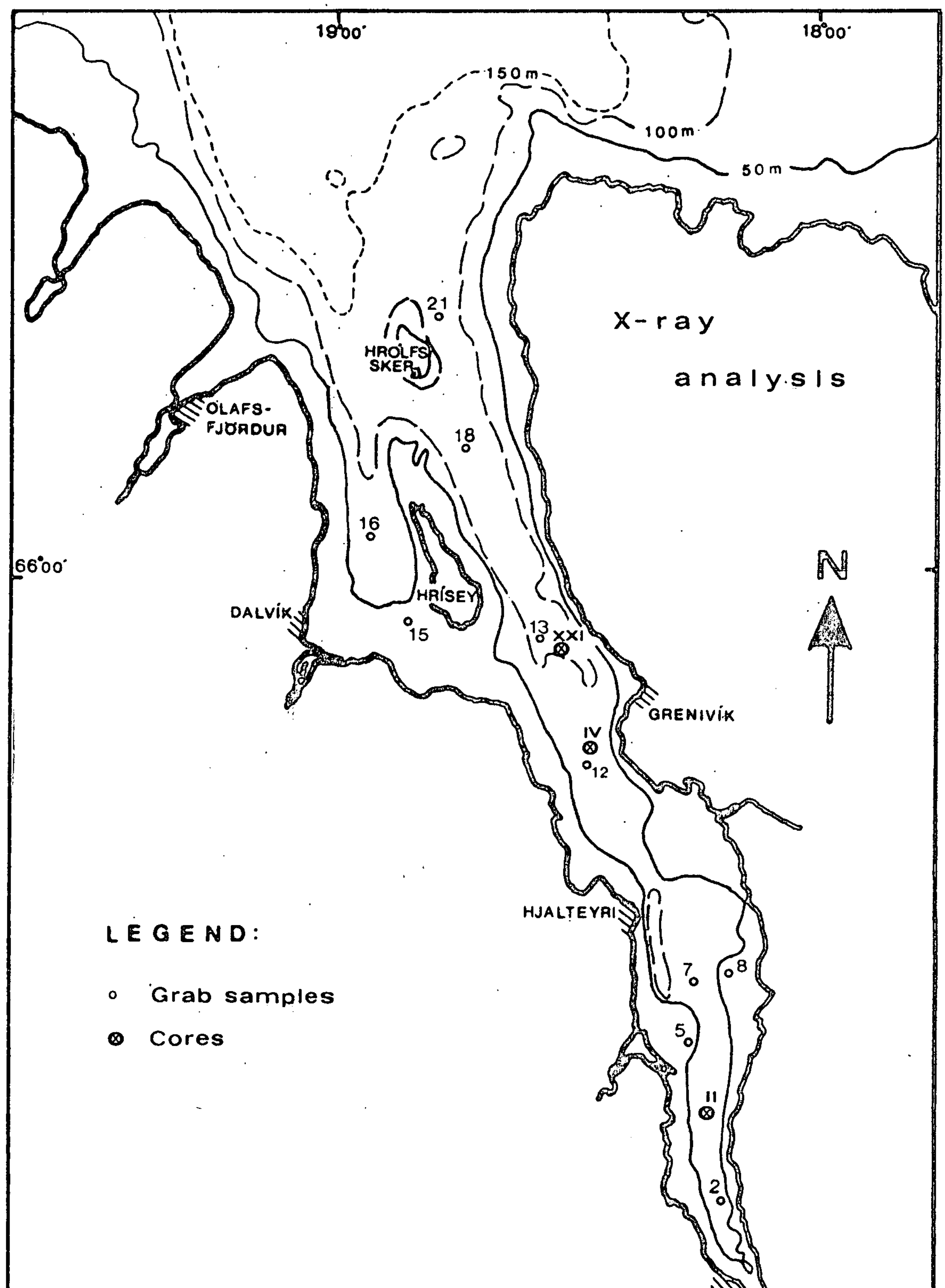


Figure 6.22. Location of grab samples and cores used for x-ray analyses.

TABLE 6.6

Grab sample station	Clay minerals
2	Smectite (weak)
5	Smectite
7	Smectite ? (very weak)
8	No clay minerals
12	Smectite (weak)
13	Smectite (weak)
15	Smectite (weak)
16	Smectite (weak), Chlorite (002) (weak)
18	Smectite, Chlorite (002)
21	Smectite, Chlorite (002)

latter two outermost stations, but is of a poor crystallinity at the station west of Hrísey (Station 16). The surface sediment samples analysed are too few for making any postulation from different areal distribution of the clay mineral types.

The relative quantity of clay minerals in the samples cannot be estimated from the x-ray diffractograms (Appendix K), when both the crystallinity is variable and the concentration low in some of the samples. However, what can be stated is that the clay minerals identified in the surface sediments are of the same type as have been determined in samples from the drainage area. Also the mineral type most frequently analysed in the surface sediments has also been described as quite common inside the drainage area.

The effects of ice rafting on the sediment composition in Eyjafjördur are considered insignificant. It is known from written records that drift ice and pack ice has occasionally filled the fjord in Historical time (ca. $H_{1(1104\ A.D.)}$) (Vilmundarson, 1969) and has probably carried 'foreign' material into the study area but this can only be a negligible amount compared with the amount of sediments accumulated from the drainage area. This has been partly confirmed in the petrographic study (Chapter 6.2) whereas no 'foreign' grains have been recognized in the sand size fraction.

6.3.2.3 Core samples

Samples for clay mineral analysis were taken from Cores II, IV and XXI (Figures 6.9 and 6.23).

From Core II nine samples for clay mineral analysis were selected with 50 - 100 cm interval (Figure 6.23). Results of the x-ray analysis are presented in Table 6.7. Diffractograms are illustrated in Appendix K. The smectite clay mineral is identified in all the samples from this core, but the crystallinity is slightly variable. For example in the top sample (1 - 0) the clay mineral is hardly identifiable compared with sample 3 - 160, at ca. 5 metres depth where the peak is of a strong intensity. In some of the samples there is also a sign of a contamination in the crystal structure, as for example in samples 1 - 140, 3 - 60 and 4 - 150 (see also Appendix K). This contamination has not been extensive enough to form a new mineral.

X-ray analyses were conducted on twelve samples from Core IV ranging from present time, top of the core, to ca. 3.000 B.P. at 8.5 m depth (Figure 6.23). Like in Core II smectite is identified in all the samples (Table 6.7) from this core and shows in general better crystallinity than in Core II (diffractograms are shown in Appendix K). Contamination of the smectite structure is not obvious. In at least 5 of the samples, chlorite (002) has also been recognized, i.e. in the top two samples (1 - 4, 1 - 50) and in samples 2 - 65, 2 - 140 and 3 - 0. In Core IV all the samples containing chlorite minerals are located above

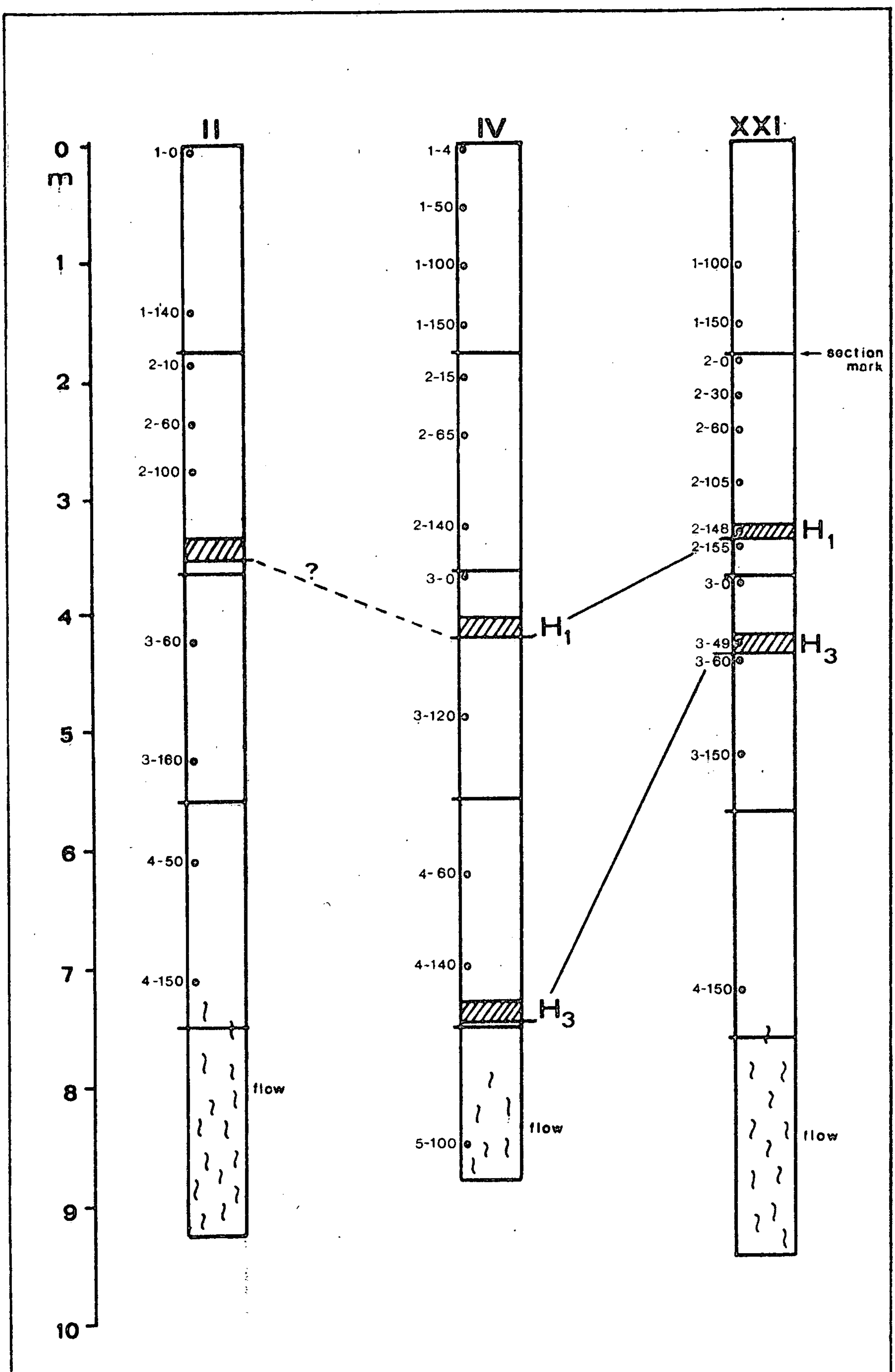


Figure 6.23. The sample numbers of the x-ray diffraction analyses taken in Cores II, IV and XXI.

Table 6.7

Depth in Core	Core II Clay minerals	Depth in core	Core IV Clay minerals	Depth in core	Core XXI Clay minerals
1-0	Smectite (weak)	1-4	Smectite; chlorite (002) (weak)	1-100	Smectite
1-140	Smectite; Illite?	1-50	Smectite; chlorite (002) (weak); Illite?	1-150	Smectite
2-10	Smectite	1-100	Smectite	2-0	Smectite (weak); Illite?
2-60	Smectite	1-150	Smectite	2-30	Smectite
2-100	Smectite	2-15	Smectite	2-60	Smectite
3-60	Smectite; Mixer-Layer	2-65	Smectite; chlorite (002)	2-105	Smectite
3-160	Smectite; chlorite (002) (weak); Illite?	2-140	Smectite; chlorite (002)	2-148	No clay minerals
4-50	Smectite	3-0	Smectite; Chlorite (002) (weak)	2-155	Smectite
4-150	Smectite	3-120	Smectite	3-0	Smectite
		4-60	Smectite	3-49	No clay minerals
		4-140	Smectite	3-60	Smectite
		5-100	Smectite	3-150	Smectite
				4-150	Smectite

see location of samples in Figure 6.23

the H_1 (1104 A.D.) tephra layer. No such pattern has been identified in Cores II and XXI. Therefore this chlorite occurence in Core IV can not definitely be related to any environmental changes like changes of the erosional pattern or climatic changes, but is much likely a matter of local effects.

In Core XXI thirteen samples were analysed. Pure smectite mineral is the most prominent clay type in the core samples (Table 6.7). Other crystal structures identified seem basically to be a smectite mineral showing a minor contamination, as for example in samples 2 - 60 and 3 - 0 (see Appendix K). In two samples, taken from the acid layers H_1 and H_3 (2 - 148 and 3 - 49), definitely no mineral structure is recorded. This result proves the absence of postdepositional clay mineral formation, even in the case of highly reactive material such as silicic glass shards that have been buried in the fjord sediments up to 2.900 years.

The results of the mineralogical study of the cores may be summarized in three statements:

a) Both crystal type and character (crystallinity) of the clay mineral identified is comparable to terrestrial material analysed from the drainage area (Chapter 6.3.2.1).

b) The variation recorded within each core may be explained by fluctuations in the accumulation process and/or crystallinity of the clay minerals. These variations cannot be correlated.

c) Neither environmental changes on a regional scale nor signs of postdepositional alteration have been identified in the cores.

6.3.3 Discussion.

It is a well known fact that the dominant process of weathering in the high latitude areas is physical rather than chemical. The clays in soils and Recent marine sediments of Arctic and Antarctic regions are for the most part primary minerals that have suffered a reduction to clay size by physical weathering (Kunze et al., 1968; Naidu et al., 1971; Wright, 1972).

In studies by Biscaye (1965) and Berry and Johns (1966) it is concluded that clay minerals in North Atlantic-Arctic Ocean sediments are derived primarily from terrestrial sources i.e. the surrounding continents and are transported to environments of deposition primarily by ice rafting and ocean currents. In these studies clay minerals are not expected to be derived from the Mid-Atlantic Ridge system.

From the data presented here from the Eyjafjördur area it is concluded that the clay minerals found in the fjord's sediments are predominantly derived from its drainage area. This is not considered to be a local phenomenon, because areas of clay mineral formation, similar to the Eyjafjördur drainage area, can be found in other parts of the country (Saemundsson, 1979). Therefore in marine areas of active sedimentation one should expect to find a measurable amount of clay minerals.

Compared with other terrestrial sources in the North Atlantic and Arctic regions the supply of sediments is relatively high from the Icelandic province. This suggests that clay minerals from the Icelandic province may also be detectable in the North Atlantic-Arctic Ocean sediments.

6.4 Carbonate and Organic carbon - chemical determination

Carbonate and organic carbon content were determined for both the surface and the subsurface sediments using standard analytical methods. For measuring the carbonate carbon the 'wet' carbonate method was employed, but for the organic carbon the high temperature combustion method (Appendix F).

Two or three subsamples were processed from each sample published. A relatively good reproducibility was measured. The confidence limit calculated for these analyses is outlined in Appendix F.

6.4.1 Carbonate carbon

6.4.1.1 Grab samples

Results of the chemical carbonate determinations from seven grab sample stations are shown in Figure 6.24. As can be expected from the results of the petrographic classification the carbonate content is low in the surface sediments. For example at Station 2 (Figure 6.12), north of Akureyri the biogenic material is measured 3% of the sand size fraction, but total carbonate analyses record 0.21%. Similar values are found on the shallow-water station (Station 11) north of Hjalteyri. At Station 7, west of Hjalteyri and at Station 21, north of Hrólfssker the biogenic material constitutes 14 and 16% of the sand size fraction, whereas the carbonate content is measured

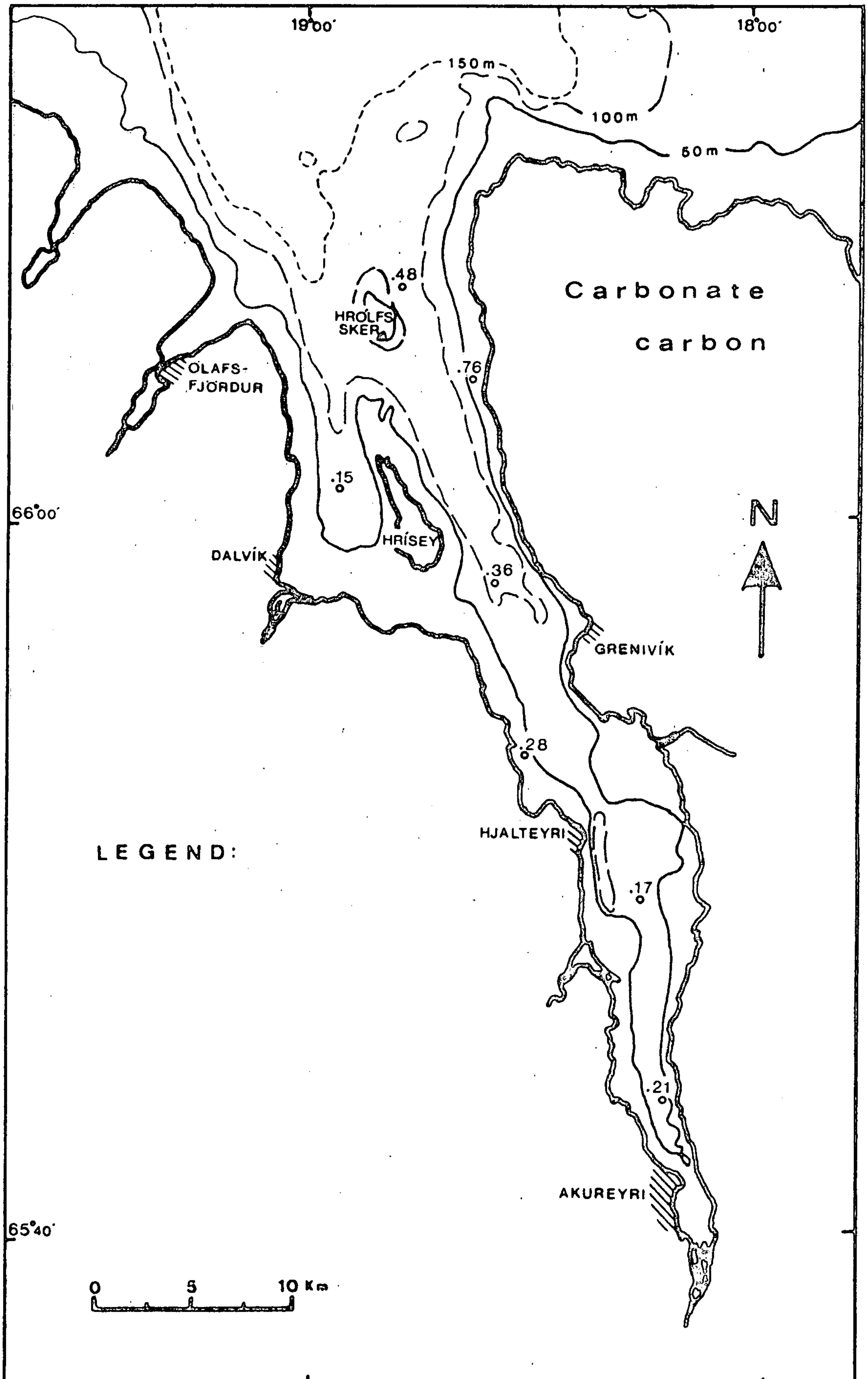


Figure 6.24. Distribution of carbonate carbon in the surface sediments.

only 0.17 and 0.48% on the bulk sample.

In general, lower carbonate values are found in the bulk sediments than recorded in the sand size fraction, suggesting that the predominant amount of the carbonate material has originally derived from the sand size or coarser fractions.

6.4.1.2 Core samples

Carbonate carbon analyses of the subsurface sediments were conducted on Cores II, IV and XXI. The results of these are illustrated in Figure 6.25. Petrographic classification has only been carried out on Core IV and the results indicate that the carbonate content could be low. For example, the biogenic material constitutes 1 to 8% of the sand size fraction compared with values of 0.05 - 0.49% for the total carbonate content. Similar to the surface sediments, the results of the bulk sediment analyses are found much lower than recorded with the petrographic classification suggesting that most of the carbonate fragments are originally derived from the sand size fraction or coarser materials. In the Core IV profile, the minor decrease recorded in the carbonate content below approximately the 6 metres depth interval seems to reflect similar variations measured in the biogenic fraction (Figure 6.20).

The carbonate content in Cores II and XXI is usually much lower than in Core IV and not consistent for the same time period. For example, above the H_1 time marker the

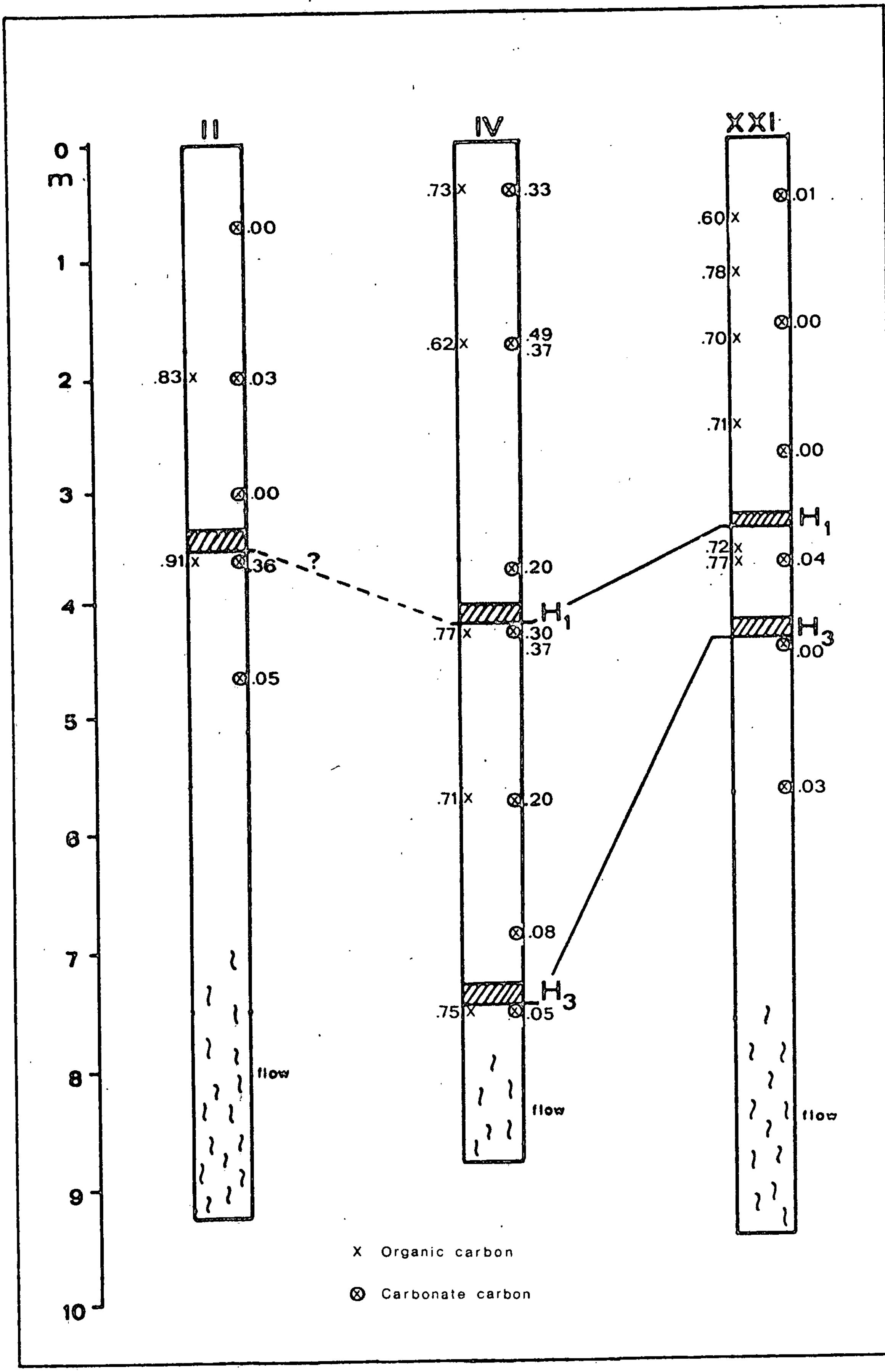


Figure 6.25. Distribution of the organic carbon and the carbonate carbon in the subsurface sediments.

carbonate content in Cores II and XXI is on average 0.01%, but 0.35% in Core IV.

In general the carbonate content is low in the cores and it fluctuates both in relation to depth/time and also between the core profiles, presumably because of a high and fluctuating sedimentation rate in this area.

It is found noticeable that no marked change is recorded in the carbonate content when crossing the zone of increasing sedimentation rate, at ca. 4.5 - 5.0 metres depth in Core IV. This zone reflects approximately the time of settlement in Iceland and the sedimentation rate has been found 2 to 3 times faster above this time boundary than below (section 5.4). This can possibly be related to the sedimentation environment where the ratio of biogenic and the non-biogenic material is approximately constant throughout the period of 3.000 years at least. Whereas the carbonate content is low in the sediments, decompositoin of the carbonates can be an important factor in the core sediments, and carbonate content in the deeper part of the cores can partly be related to a gradual increase in the decomposition down the cores.

6.4.2 Organic carbon

6.4.2.1 Grab samples

Determinations of organic carbon content were carried out on five grab samples from the surface sediments of Eyjafjördur. The results are shown in Figure 6.26.

The organic content of Eyjafjördur sediments is relatively high compared with the world-wide distribution of the organic carbon in marine sediments. Bezrukov et al. (1977) suggested that the relatively high organic content in sediments of the arctic shelf stems from the influx of chemically stable organic material from river deposits.

In a relatively closed sedimentation area, such as Eyjafjördur, deposition of organic matter from the drainage area must be an important factor. It is a well known phenomenon that during peak floods (Figure 2.11) in the rivers of the Eyjafjördur drainage area a considerable amount of soil material is carried into the fjord. In a few of the sediment samples, traces of soil matter have been identified.

It is impossible to reveal the type or identity of the indigenous organic compounds with the analytical method employed for measuring the organic carbon content. Therefore it cannot be estimated how large a proportion of the organic carbon measured is of soil (organic) matter accumulated into the fjord and how large a proportion can be related to the organic productivity in the sea.

By plotting the carbon content of the surface sedi-

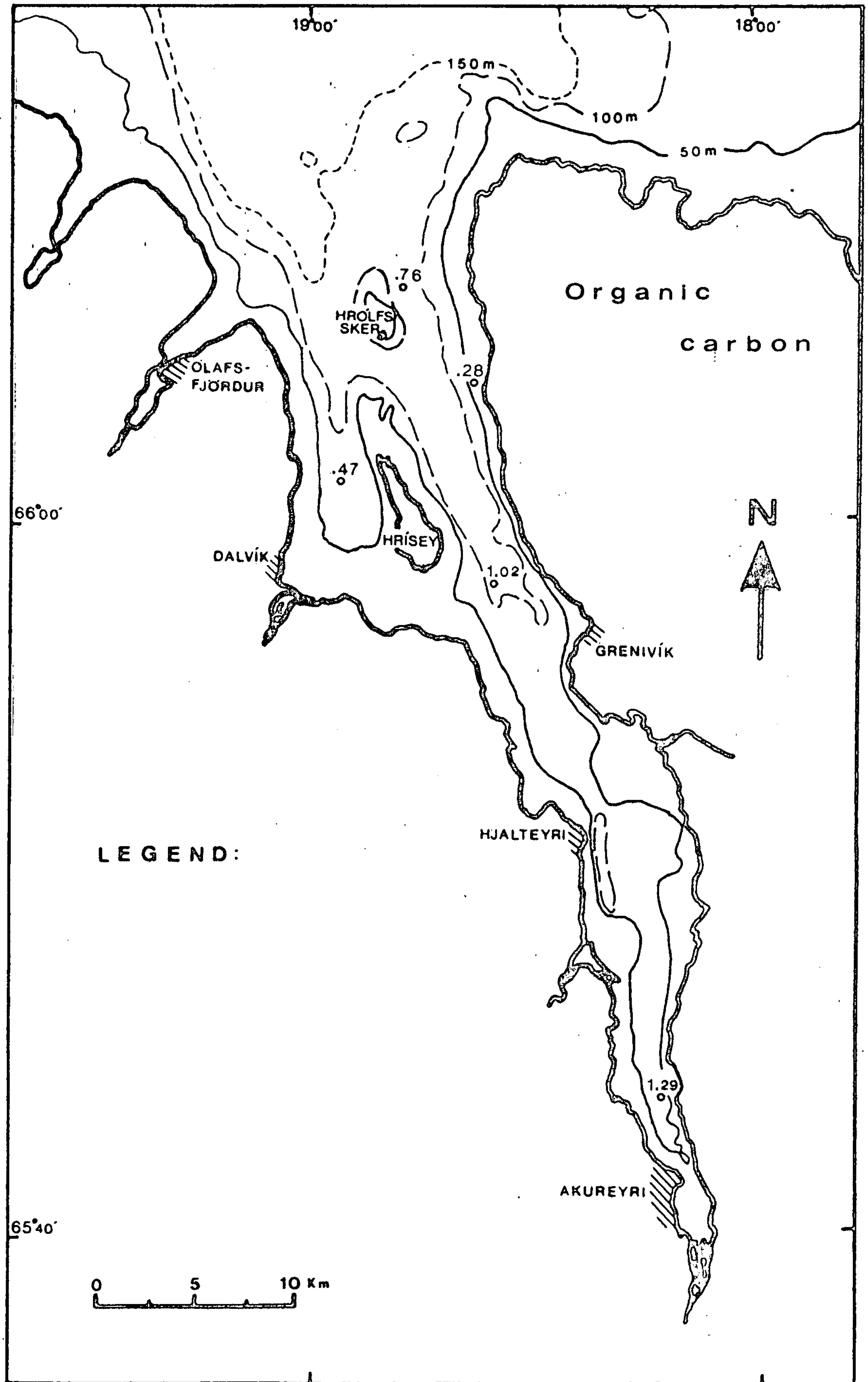


Figure 6.26. Distribution of organic carbon in the surface sediments.

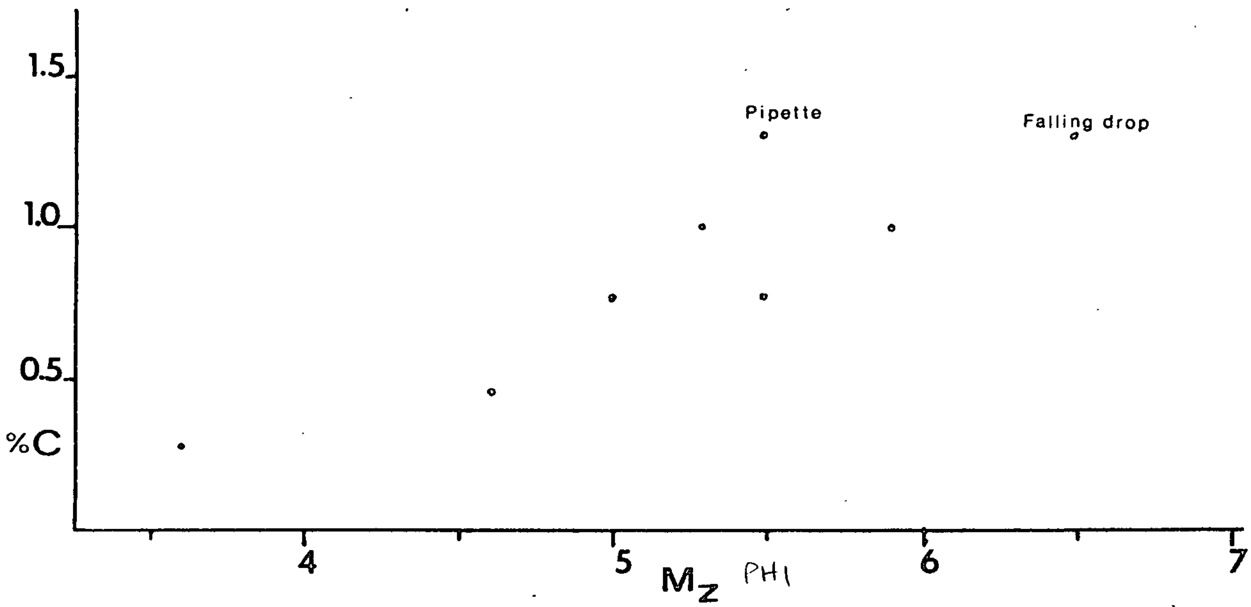


Figure 6.27. Carbon content plotted versus mean size for the surface sediments.

ments analysed versus mean grain size (Figure 6.27) a trend of increasing carbon content is illustrated with decreasing grain size. This relationship can at least partly be related to the fact that the finely particulate organic mateer can settle out of suspension only in areas attended by relatively low current velocities. Also, a part of this carbon content measured can be related to the organic carbon being somewhat more effectively preserved in the finer fractions than the coarse one.

6.4.2.2 Core samples

Analyses of organic carbon content were conducted on samples from the cores analysed for carbonate content. The results are illustrated in Figure 6.25.

Variation in the organic content versus depth is small in all the cores. For the period from H_1 (1104 A.D.) to Present time the organic content is the same in Cores IV and XXI, but slightly higher in Core II, presumably related to a slightly finer (lower) mean grain sizes recorded in Core II (Figure 6.10).

It is well known in the literature that a decline is recorded in the organic carbon content of marine sediments with increasing depth of burial due to the decomposition of organic material. In Eyjafjördur, however, the only tendency noticed is that the core material is on average 25 - 30% lower in organic carbon content that comparative surface sediments.

The difference recorded between the surface and the subsurface sediments can possibly be related to increasing supply of nutrient matter in Present time (pollution ?), causing a much higher organic productivity than before.

In the surface sediments a part of the organic content measured is from active organisms only living in the surface sediment and it is mostly unaffected by high sedimentation rate. After the death of these organisms a part of the organic tissue is decomposed, but a part is stable and buried in the sediments.

Decomposition of the organic compounds seems to be slow at least after burial. Also, this approximately constant organic content within each core can be related to increasing sedimentation rate in the upper part of the cores, compensating for somewhat higher decomposition in the lower part of the cores. Another reason for constant organic content is that most of the stable compounds are of a soil origin deposited into the fjord in approximately stable proportion to the inorganic matter and showing a slow decomposition. To understand this process the types of the sedimentary organic compounds and the source and the identity and the quantity have to be revealed.

Chapter 7. SUMMARY AND CONCLUSION

The Eyjafjördur study area is a highly glaciated landscape eroded into a Tertiary Basalt plateau, forming a dendritic network of troughs and fjords. Two of the largest trough features i.e. Eyjafjardardalur-Eyjafjördur and Svarfadardalur are eroded down to sea level and the submarine parts of these troughs are studied in seismic reflection profiles, surface bottom samples and cores. The shape of the troughs is the ideal glacial parabolic or U-shape form characteristic for glaciated valleys. No definite signs of tectonic or fluvially eroded subglacial trough forms are noticed in the seismic profiles.

Topographically, it was found noticeable that the marginal shelf area extends over a relatively large proportion of the fjord area covering a similar area to the deeper part of the fjord. Also, rock bars usually at or near the sea entrance (the fjord's mouth) and characteristic for fjord profiles do not exist. In this respect the configuration of the fjord differs form most of the fjords studied.

The greatest sediment thickness measured in the research area is ca 200 m recorded north and west of Grenivík, but on average the sediments are 150 - 180 m thick along the basin of Eyjafjördur. In this sediment infill, 24 - 25 stratigraphical units have been identified, comprising 13 stages of glacier advance and 11 of retreat. The top unit (Unit H) recorded is on average 15 - 20 m thick and has been identified as the ~~Recent~~ Holocene time deposit, and the sediments immediately below it are related to the youngest readvance stage found in the fjord, proposed to be the Búdi stage (10.000 - 11.000 B.P.) at Hólar, 35 km south of the fjord's head.

The till material covering the rock basin is considered to be from the maximum of the Weichselian glaciation. In North Iceland the Weichselian maximum glaciation has been proposed to be earlier than 18.000 - 23.900 B.P.

All other sediment units distinguished between the Búdi stage and the maximum Weichselian glaciation must be arbitrary time, related to these two stages whereas no dating has been carried out.

The position of the end moraine structures north of Dalsmynni reveals at least eight cycles of retreat/readvance of the Eyjafjördur glacier after the maximum of the Weichselian glaciation. At least some of these cycles, if not all, are in a time relation with the ice-lake phases recognized in Fnjóskadalur, east of Eyjafjördur, but a definite correlation cannot be carried out, due to a lack of marker horizon.

The three ca. 9 metres long piston cores studied were dated back to 3.000 - 4.000 B.P. using the acid tephra layers from Hekla, i.e. H_1 (1104 A.D.) and H_3 (2.900 B.P.) and the magnetic susceptibility for a cross-correlation. Using the acid tephra layers the sedimentation rate can be accurately calculated in the cores. Above the H_1 time marker (i.e. since the settlement of Iceland) the sedimentation rate is found to be 2 to 3 times faster than between the

H_1 - H_3 time markers (Core IV) and for all the Holocene time the sedimentation rate is estimated 1.8 - 2.0 mm/y or on average 17 - 20 m. For the same time period the denudation rate within the drainage area is calculated 0.11 - 0.15 mm/y or on average 3 to 4 times slower than calculated for the Quaternary time period in the Eyjafjördur area. This indicates that the sedimentation-denudation rate is relatively high during Holocene, espebecause no effect of glacial erosion is recorded.

From the studies of the petrographic classification it can be suggested that a part of the finest sediment fraction is wind transported from other parts of the country, especially from the Neovolcanic Zone, and into the drainage area of Eyjafjördur or directly into the fjord causing anomalously high sedimentation - denudation rate for the Eyjafjördur area. No 'foreign' grains were identified.

The grain size distribution of Eyjafjördur reflects in general the pattern of sedimentation expected in a fjord environment, i.e. sand texture predominates in the deltas and along the coasts, but in the deeper water the mud texture predominates.

The clay minerals found in the fjord's sediments are predominantly derived from the Eyjafjördur drainage area.

The biogenic fraction and the calcium carbonate content are found very low in the fjord presumably due to a high sedimentation rate. The organic carbon content is relatively high but varies with mean grain size.

The environmental (i.e. the settlement) and the climatic changes which have been studied in soil profiles around Iceland only appear in the core profiles as an increase in the sedimentation rate and as a minor increase in the mean grain size distribution related to the settlement time in Iceland (i.e.after ca. 1.100 B.P.). Other parameters studied like the petrographical, mineralogical and the chemical ones are not found characteristic enough to identify these environmental or climatic changes in the core sediments. Also it is possible that sediments, transported into the area by wind from other parts of the country, are of such quantity that all variations disappear.

No turbitides were identified in the cores as could be expected in this area of seismic activity.

REFERENCES

Aarseth, I.; K. Bjerkli; K.R. Björklund; D. Böe:, J.P. Holm:, T.J. Lorentzen-Styr; L.A. Myhre:, E.S. Ugland and J. Thiede, 1975. Late quaternary sediments from Korsfjorden, Western Norway. Sarsia, 58, 43 - 66.

Albertsson, K.J., 1978. Um aldur jardlaga á Tjörnesi. Náttúrufraedingurinn, 48, 1 - 8. (English summary).

Albertsson, K. and Einarsson, Th., 1982. Um aldur jardlaga efst á Breidadalsheidi. In Thorarinsdóttir, H.; Ó.H. Óskarsson; S. Steinthórsson and Th. Einarsson (eds.); Eldur er í nordri. 205 - 210, Sögufélagid, Reykjavík. (In Icelandic).

Anderson, J.V., 1963. An improved pretreatment for mineralogical analysis of samples containing organic matter. Clays and Clay Minerals. 10, 380 - 388.

Aronson, J., and K. Saemundsson, 1975. Relatively old basalts from structurally high areas in central Iceland. Earth Planet. Sci. Lett. 28, 83 - 97.

Ashwell, I.Y., 1967. Radiocarbon ages of shells in the glaciomarine deposits of western Iceland. Geogr. Journal, 1, 48 - 50.

Avilov, I.K., 1965. Section and bottom-dwelling sediments of the shelf and continental slope of the northwest Atlantic. Morskaya Geologiya 57, 173 - 234. (In Russian).

Áskelsson, J., 1956. Myndir úr jardfraedi Íslands V. Hálfsögd saga og varla thad úr Út-Fnjóskadal. Náttúrufraedingurinn 26, 97 - 99. (In Icelandic).

Beamer, A.J., 1980. The magnetostratigraphy of Iclelandic lake cores. B.S. Hon.dissertation, University of Edinburgh, 34 pp.

Benjaminsson, J., 1981. Tephra layer "a". In Shelf, S. and R.S.J. Sparks (eds.): Tephra Studies, 331 - 337. D. Reidel Publ. Comp., Dordrect.

Berry, R.W. and W.D. Johns, 1966. Mineralogy of the Clay-Sized Fractions of Some North Atlantic-Arctic Ocean Bottom Sediments. Bull. Geol. Soc. Am. 77, 183 - 196.

Bezrukov, P.L., Ye.M. Yemel'yanov, A.P. Lisitsyn and Ye.A. Romankevich. 1977. Organic Carbon in the Upper Sediment Layer of the World Ocean. Oceanology 17, 561 - 564.

Biscaye, P.E., 1965. Mineralogy and sedimentation of recent deep sea clay in the Atlantic Ocean and adjacent seas and oceans. Bull. geol. Soc. Am. 76, 803 - 832.

Björnsson, A., and K. Saemundsson, 1975. Jardhiti í nágrenni Akureyrar. National Energy Authority. JHD 7557, Reykjavík. 53 pp. (In Icelandic).

Björnsson, A., K. Saemundsson, S. Einarsson, F. Thorarinsson, S. Arnórsson, H. Kristmannsdóttir, Á. Gudmundsson, B. Steingrímsson, Th. Thorsteinsson, 1979. Hitaveita Akureyrar, Rannsókn jardhita í Eyjafirdi, áfangaskýrsla, ágúst 1978. National Energy Authority OS JHD 78027) 51, Reykjavík. 91 pp. (In Icelandic).

Björnsson, H., 1979. Glaciers in Iceland. Jökull 29, 74-80.

Blatt, H., G. Middleton, and R. Murray, 1972. Origin of Sedimentary Rocks. Prentice - Hall. New Jersey. 634 pp.

Boulton, G.S.; P.N. Chroston and J. Jarvis, 1981. A marine seismic study of late Quaternary sedimentation and inferred glacier fluctuations along western Inverness-shire, Scotland. Boreas 10, 39 - 51.

Bouma, A.H., 1969. Methods for the Study of Sedimentary Structures. Wiley Interscience, New York. 458 pp.

Brunton, G., 1955. Vapour pressure glycolation of oriental clay minerals. Am. Miner, 40, 124 - 126.

Bush, J., 1951. Derivation of a size-frequency curve from the cumulative curve. J. Sediment Petrol., 21 178 - 182.

Cameron, W.M. and D.W. Pritchard, 1963. Estuaries. In Hill, M.N. (ed.): The sea. 306 - 324. Interscience V. 2, New York.

Chmelik, F.B., 1967. Electro-osmosis core cutting. Marine Geol. 5, 321 - 325.

Crary, A.P., 1966. Mechanism for fjord formation indicated by studies of an ice covered inlet. Bull. Geol. Soc. Am. 77, 911 - 929.

Creer, K.M.; R. Thompson; L. Molyneux and F.J.H. Mackereth, 1972. Geomagnetic secular variation recorded in the stable magnetic remanence of recent sediments. Earth Planet Sci. Lett., 14, 115 - 127.

Creer, K.M.; T.W. Anderson and C.F.M. Lewis, 1976. Late Quaternary geomagnetic stratigraphy recorded in Lake Erie sediments. Earth Planet. Sci. Lett. 31, 37 - 47.

Douglas, L.A. and F. Fiessinger, 1971. Degradiation of clay minerals H_2O_2 treatments to oxidise organic matter. Clays and Clay Minerals 19, 67 - 68.

Einarsson, H., 1941. Survey of the benthonic animal communities of Faxa Bay, Iceland. Medd. Komm. for Danm. Fiskeri og Havunders. Ser. Fiskeri 11, 1 - 52.

Einarsson, Th., 1961. Pollenanalytische Untersuchungen zur spät- und postglazialen Klimageschichte Islands. Sonderveröff. Geol. Inst. Univ. Köln, 6, 1 - 52.

Einarsson, Th., 1962. Vitnisburður frjógreiningar um gróður, veðurfar og landnám á Íslandi. Saga, 3, 442 - 469. (In Icelandic).

Einarsson, Th., 1963. Pollen-analytical studies on the vegetation and climatic history of Iceland in Late and Post-Glacial times. In Löve, A. and D. Löve (eds.): North Atlantic Biota and their History, 355 - 365, Pergamon Press, Oxford.

Einarsson, Th., 1964. Aldursákvardanir á fornskeljum. Náttúrufrædingurinn. 34, 127 - 133. (English summary).

Einarsson, Th., 1966. Thaettir úr loftslagssögu Íslands. Vedrid, 11, 47 - 53. (In Icelandic).

Einarsson, Th., 1967. Zu der Ausdehnung der Weichsel - zeitlichen Vereisung Nordislands. Sonderveröff. Geol. Inst. Univ. Köln, 13, 167 - 173.

Einarsson, Th., 1968. Jardfraedi, saga bergs og lands. Mál og menning, Reykjavík, 335 pp. (In Icelandic).

Einarsson, Th., 1973a. Geology of Iceland. In Pitcher, M.G. (ed.): Arctic Geology. 171 - 175. Am. Assoc. Petrol. Geol. Mem., 19.

Einarsson, Th., 1973b. Jardfraedi. Heimskringla, Reykjavík. 254 pp. (In Icelandic).

Einarsson, Th., 1978. Jardfraedi. Mál og menning, Reykjavík. 240 pp. (In Icelandic).

Einarsson, Tr., 1959. Studies of the Pleistocene in Eyjafjördur. Sac. Sci. Islandica., 23, 1 - 62.

Einarsson, Tr., 1960. The Plateau Basalt areas in Iceland. In Thorarinsson, S. (ed.): On the Geology and Geophysics of Iceland. 5 - 20. Guide to Excursion No.A2. 21st Int. Geol. Congr. Reykjavík.

Einarsson, Tr., 1962. Nokkur drög að jarðsögu sjávarbotnsins kringum Ísland. Náttúrufraedingurinn, 32, 155 - 175. (English summary).

Einarsson, Tr., 1963. Firdir og flóar og fornar brotalamir. Tímarit verkfraedingafélags Íslands 3, 33 - 39. (English summary).

Einarsson, Tr., 1965. Remarks on the crustal structure in Iceland. Geophys. J. Roy. Astron. Soc., 10, 283 - 288.

Einarsson, Tr., 1966. Late and post- glacial rise in Iceland and sub-crustal viscosity. Jökull, 16, 157 - 166.

Eiríksson, J., 1979. The Breidavík Group on Tjörnes, North Iceland: Lithostratigraphy and late Cainozoic Glaciations. Ph. D.thesis, University of East Anglia, Norwich, 347 pp.

Embleton, C. and C.A.M. King, 1975. Glacial Geomorphology. Edward Arnold, London, 573 pp.

Eythorsson, J., and H. Sigtryggsson, 1971. The climate and weather of Iceland. The Zoology of Iceland. 1(3). 1 - 62.

Fisher, R.V., 1961. Proposed classification of volcaniclastic sediments and rocks. Bull. Geol. Soc. Am. 72, 1409 - 1414.

Folk, R.L., 1954. The distribution between grain size and mineral composition in sedimentary rock nomenclature. J. Geology, 62, 344 - 359.

Folk, R.L., 1966. A review of grain size parameters. Sedimentology 6, 73 - 93.

Folk, R.L., 1968. Petrology of sedimentary rocks. Hemphill Publishing Company, Austin, Texas, 170 pp.

Folk R.L. and W.C. Ward, 1957. Brazos River bar, a study in the significance of grain-size parameters. J. Sediment. Petrol., 27, 3 - 27.

Galehouse, J.S., 1969. Counting grain mounts: Number percentages vs. number frequency. J. Sediment. Petrol. 39., 812 - 815.

Galehouse, J.S., 1971a. Sedimentation Analysis. In Carver, R.E. (ed.): Procedures in Sedimentary Petrol. 69 - 95. Wiley Interscience. New York.

Galehouse, J.S., 1971b. Point Counting. In Carver, R.E. (ed.): Procedures in Sedimentary Petrology, 385 - 409. Wiley Interscience. New York.

Glasby, G.P., 1978. Sedimentation and Sediment Geochemistry of Caswell, Nancy and Milford Sounds. N.Z. Oceanogr. Institute Memoir 79, 19 - 37.

Gorshkova, T.I., 1960a. Sediments of the Norwegian Sea. Int. Geolog. Congr. XXI Sess. Rep. Soviet Geologists. 16 - 22.

Gorshkova, T.I., 1960b. Chemical composition of ground solution of the Norwegian Sea. Okeanologicheskie Issledovaniya, 2, 113 - 116. (In Russian).

Gorshkova, T.I., 1964. Bottom-dwelling sediments of the Norwegian Sea. Okeanologicheskie Issledovaniya, 13. 213 - 224. (In Russian).

Gudbergsson, G., 1975. Myndun móajardvegs í Skagafirdi. J. Agr. Res. Icel. 7, 20 - 45. (English summary).

Gudmundsson, T ., 1978. Pedological Studies of Icelandic Peat Soils. Ph.D. thesis, University of Aberdeen. 252 pp.

Haflidason, H., 1979. Laust set á landgrunninu suðaustan Íslands. B.S. Hon dissertation. University of Iceland, Reykjavík, 67 pp. (In Icelandic).

Hallsdóttir, M., 1973. Um ísaldarlok á Glerárdal og í nágrenni Akureyrar. B.S. dissertation, University of Iceland, Reykjavík. 39 pp. (In Icelandic).

Hammer, C.V., H.B. Clausen and W. Dansgaard, 1980. Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. Nature, 288, 230 - 235.

Hansen, K., 1971. Tunnel valleys in Denmark and northern Germany. Meddr. dansk geol. Foren. 20, 295 - 306.

Hartsock, J.K., 1960. Submarine topography and bottom sediments off the south-eastern coast of Iceland. International Geol. Congress, XXI Session, Part X, 7 - 15.

Hauksson, E., 1979. Könnun á botndýralífi í innanverðum Eyjafirði. Náttúrugripasafnið á Akureyri, 9, 1 - 19. (English summary).

Helland, A., 1882. On Islands Geologi. Geogr. Tidsskr. VI, 75 - 110.

Helland - Hansen, B. and F. Nansen, 1909. The Norwegian Sea. Norwegian Fishery and Marine Investigations, Report, 2, 390 pp.

Hjartarson, Á., 1973. Rof jarðlagastaflans milli Eyjafjardar and Skagafjardar og ísaldarmenjar við utanverdan Eyjafjörd. B.S. dissertation, University of Iceland, Reykjavík. 36 pp. (In Icelandic).

Holtedahl, H., 1965. Recent turbidites in the Hardangerfjord, Norway. Proc. 17th Symp. Colston Res. Soc. (Bristol)., 107 - 141.

Holtedahl, H., 1967. Notes on the formation of fjords and fjordvalleys. Geogr. Ann. 49. 188 - 203.

Holtedahl, H., 1975. The Geology of the Hardangerfjord, West Norway. Norges geol. under. 323, 1 - 87.

Hoppe, G., 1968. Grímsey and the maximum extent of the last glaciation of Iceland. Geogr. Ann., 50, 16 - 24.

Hospers., J. 1954. The geology of the country between Akureyri and Mývatn in northern Iceland. Geol. Mijnb. 16. 491 - 508.

Jakobsson, S.P., 1972. Chemistry and distribution pattern of Recent basaltic rocks in Iceland. Lithos. 5, 365 - 386.

Jakobsson, S.P., 1979a. Outline of the Petrology in Iceland. Jökull 29, 57 - 73.

Jakobsson, S.P., 1979b. Petrology of Recent basalts of the Eastern Volcanic Zone, Iceland. Acta Nat. Islandica, 26, 1 - 103.

Johannesson, H., 1975. Structure and petrochemistry of the Reykjadalur central volcano and the surrounding areas, Midwest Iceland. Ph. D. thesis. University of Durham, 273 pp.

Kjartansson, G., S. Thorarinsson and Th. Einarsson, 1964. C^{14} - aldursákvardanir á sýnishornum vardandi íslenzka kvarterjardfraedi. Náttúrufraedingurinn 34, 97 - 145. (English summary).

Kotenev, B.N., 1968. Marine geological studies in the vicinity of Iceland. Okeanologia Akad. Nauk SSSR, 6, 1049 - 1052. (In Russian).
English translation:
Oceanology 8, 826 - 829.

Kristjánsson, L., I.B. Fridleifsson, and N.D. Watkins, 1980. Stratigraphy and paleomagnetism of the Esja, Eyrarfjall and Akrafjall mountains, SW - Iceland. J. Geophys. 46. 31 - 42.

Kristmannsdóttir, H., 1971. Ákvördun á leirminarölum í bergi frá borholum á Reykjanesi. National Energy Authorogy, Reykjavík. 23 pp. (In Icelandic).

Kristmannsdóttir, H., 1975. Clay minerals formed by hydrothermal alteration of basaltic rocks in Icelandic Geothermal fields. GFF. The Transections of the Geological Society of Sweden. 97. 289 - 292.

Kristmannsdóttir, H., 1977. Types of Clay Minerals in Hydrothermal Altered Basaltic Rocks, Reykjanes, Iceland. Jökull, 26, 30 - 39.

Kristmannsdóttir, H. and J. Tómasson, 1974. Nesjavellir. Hydrothermal alteration in a high temperature area. Proceedings Int. Symp. on Water-Rock interaction, Praha.

Krumbein, W.C., 1934. Size frequency distributions of sediments. J. Sediment. Petrol. 4, 65 - 77.

Kunze, G.W., L.I. Knowles, and Y. Kitano, 1968. The distribution and mineralogy of clay minerals in the Taku Estuary of southeastern Alaska. Marine Geol. 6, 439 - 448.

Landnámabók, 1946. (manuscript from the 12th century A.D.). In Jonsson, G. (ed.): Íslendinga sögur I, 21 - 241, Reykjavík.

Larsen, G., 1978. Gjóskulög í nágrenni Kötlu. B.S. Hon. dessertation, University of Iceland. Reykjavík. 60 pp. (In Icelandic).

Larsen, 1982. Gjóskutímatal Jökuldals og nágrennis. (Tephrochronological history of Jökuldalur and vicinity). In Thorarinsdóttir H.; Ó. Óskarsson; S. Steinthorsson; Th. Einarsson (ds.): Eldur er í nordri, 51 - 66, Sögufélag, Reykjavík. (In Icelandic).

Larsen, G., 1981. Tephrochronology by microprobe glass analysis. In. Self S. and R.S.J. Sparks (eds.): Tephra Studies, 95 - 102, D. Reidel Publish. Company. Dordrecht.

Larsen G., and S. Thorarinsson, 1977. H_4 and Other Acid Hekla Tephra Layers. Jökull 27, 28 - 46.

Lavkulich, L.M. and J.H. Wiens, 1970. Comparsion of organic matter destruction by hydrogen peroxide and sodium hypochlorite and its effect on selected mineral constituents. Soil Sci. Soc. America Proc., 34, 755 - 758.

Mackereth, F.J.H., 1971. On the variation in direction of the horizontal component of remanent magnetisation in lake sediments. Earth Planet Sci. Lett., 12, 332 - 338.

Malmberg, S.A., 1978. Straummaelingar við Oddeyrartanga í Eyjafirdi. Náttúrugripasafnid á Akureyri 7, 1 - 11. (English summary).

McDougall, I. and H. Wensink, 1966. Paleomagnetism and geochronology of the Pliocene - Pleistocene lavas in Iceland. Earth Planet. Sci. Lett. 1, 232 - 236.

McDougall, I.; K. Saemundsson ; H. Jóhannesson; N.D. Watkins and L. Kristjánsson, 1977. Extension of the geomagnetic polarity time scale to 6.5 m.y.: K-Ar dating, geological and paleomagnetic study of a 3500 m lava succession in western Iceland. Bull. Geol. Soc. Am., 88, 1 - 15.

McIntyre, V.S., 1977. A manual for tephrochronology. Published by the author, Idaho Springs, Colorado, 167 pp.

Milanovsky, E.E., 1979. Iceland and mid-oceanic ridge, geomorphology, tectonics. Publishing House Nauka, Moscow. 211 pp. (In Russian). Published in English by: The National Research Council, Reykjavík, 1982.

Molyneux, L.; R. Thompson ; F.Oldfield and M.E., Mc-callan,1972. Rapid Measurement of the Remanent Magnetization of Long Cores of Sediment. Nature, 237, 42 - 43.

Mooney, H.M., 1952. Magnetic susceptibility measurements in Minnesots. Part 1: Technique of measurement. Geophys. 17, 531 - 543.

Moum, J., 1965. Falling drop used for grain-size analyses of fine grained materials. Sedimentology, 5. 343 - 347.

Mullins, C.E., 1977. Magnetic susceptibility of the soil and its significance in soil science - A review. J. Soil Sci. 28, 223 - 246.

Naidu, A.D., D.C. Burrel, and D.W. Hood, 1971. Clay mineral composition and geologic significance of some Beaufort Sea sediments. J.Sediment.Petrol. 41, 691-694.

Nansen, F., 1904. The bathymetrical features of the North Polar Seas, with a discussion of the continental shelves and previous oscillations of the shore line. Norwegian North Polar Exped., 1893 - 96. Sci. Research, 4, 1 - 232.

Norddahl, H., 1977. Strandlína jökullóns í Fnjóskadal. Unpublished report to the Icelandic Science Fund. Reykjavík. 16 pp.

Norddahl, H., 1979. The Last Glaciation in Flateyjardalur central North Iceland, a preliminary report. Lund University. Dept. Quat. Geol. Rep. 18. 24 pp.

Norddahl, H., 1981. A prediction of minimum age for the Weichselian maximum glaciation in North Iceland. Boreas, 10, 471 - 476.

Norddahl, H., 1982. Ljós vikurlög frá seinni hluta síðasta jökulskeids í Fnjóskadal. In Thorarinsdóttir, H., Ó. Óskarsson, S. Steinthórsson and Th. Einarsson (eds.): Eldur er í nordri, 167 - 175. Sögufélag, Reykjavík.

Norddahl, H., 1983. Late Quaternary Stratigraphy of Fnjóskadalur Central North Iceland, a study of sediments, ice-lake strandlines, glacial isostasy and ice-free areas. Lundqua Thesis 12, Lund, 78 pp.

Ólafsdóttir, Th., 1975. Jökulgardur á sjávarbotni út af Breidafirdi. Náttúrufraedingurinn 45, 31 - 36. (English summary).

Pantin, H.M., 1978. Quaternary sediments from the north-east Irish Sea: Isle of Man to Cumbria. Bull. Geol. Surv. Great Britain, 64, 1 - 35.

Pálmason, G.; S. Arnórsson; I.B. Fridleifsson; H. Kristmannsdóttir; K. Saemundsson; V. Stefánsson; B. Steingrímsson; J. Tómasson and L. Kristjánsson, 1979. The Iceland crust: Evidence from drillhole data on structure and processes. In Talwani, M., C.G. Harrison and D. Hayes. (eds.): Deep Drillory Results in the Atlantic Ocean: Ocean Crast. 43 - 65. Maurice Ewing Series 2.

Perez-Rodrigues, J.L. and M.J. Wilson, 1969. Effects of pre-treatment on a 14 Å swelling mineral. Clay minerals, 8, 39 - 46.

Pettijohn, F.J., 1975. Sedimentary Rocks. Harper and Rowt. New York. 628 pp.

Pickard, G.L. and A.M. Rogers, 1959. Current measurements in Knight Inlet, British Columbia. J.Fish. Res. Bd. Canada 16. 653 - 678.

Pickard, G.L. and B.R. Stanton, 1980. Pacific Fjords - A review of their Water Characteristics. In Freeland H.J., D.M. Farmer, and C.D. Levings (eds.): Fjord Oceanography, 1 - 51. Plenum Press. New York.

Pjeturss.,H., 1905. Om Islands Geologie. Medd. dansk geol. Foren 2 (11), 1 - 106.

Pjeturss.,H., 1910. Island. Handbuch der Regionalen Geologie, 4, No. 1, 1 - 22.

Rist, S., 1956. Icelandic Fresh Waters. The State Electricity Authority. Reykjavík. 127 pp.

Ross, J.G. and A.E. Musset, 1976. $^{40}Ar/^{39}Ar$ dates for spreading rates in eastern Iceland. Nature. 259, 36 - 38.

Saemundsson, K., 1974. Evolution of the axial rifting zone in Northern Iceland and the Tjörnes fracture zone. Bull. Geol. Soc. Am., 85, 495 - 504.

Saemundsson, K., 1979. Outline of the Geology of Iceland. Jökull, 29.

Saemundsson, K.; L. Kristjánsson; I. McDougall, and N.D. Watkins, 1980. K-Ar dating, geological and paleomagnetic study of a 5 km lava succession in northern Iceland. J.Geophys. Research, 85, 3628 - 3646.

Sandvik, K.O., 1976. Sand og Grus pa Sokkelen. Nor. Geol. Unders. Rapport 1335/2. 39 pp.

Sandvik, K.O., 1977. Sand og Grus pa Sokkelen. Nor. Geol. Unders. Rapport 1335/4. 13 pp.

Schlee, J., 1966. A modified Woods Hole rapid sediment analyzer. J. Sediment. Petrol., 36., 403 - 413.

Selley, R.C., 1970. Ancient Sedimentary Environment. Chapman and Hall, London. 237 pp.

Sigurdsson, H., 1982. Útbreidsla íslenskra gjóskulaga á botni Atlantshafs. In Thórarinsdóttir, H.; Ó. Óskarsson; S. Steinthórsson; Th. Einarsson. (eds.): Eldur er í nordri. 119 - 128, Sögufélag, Reykjavík. (In Icelandic).

Sigvaldason, G., 1974. The Petrology of Hekla and Origin of Silicic Rocks in Iceland. In Einarsson, T.; G. Kjartansson and S. Thorarinsson (eds.): The Eruption of Hekla 1947 - 1948. V.I. 1 - 44. Soc.Sci. Islandica, Reykjavík.

Símonarson, L., 1979. On climatic changes in Iceland, Jökull, 29, 44 - 46.

Stefánsson, U., 1961. Hafið. Almenna bókafélagið, Reykjavík, 293 pp. (In Icelandic).

Stefánsson, U., 1962. North Icelandic Waters. Rit Fiskideildar III, 3, 1 - 269.

Steindórsson, S. 1962. On the Age and Immigration of the Icelandic Flora. Soc. Sci. Islandica. Rit 35, 1 - 157.

Sugden, D.E. and B.S. John, 1976. Glaciers and Landscape - A Geomorphological Approach - . Edward Arnold, London, 376 pp.

Sykes, L.R., 1967. Mechanism of earthquakes and nature of faulting on the mid-ocean ridges. J. Geophys. Research, 72. 2131 - 2153.

Tarling, D.H., 1971. Principles and Applications of Palaeomagnetism. Chapmann and Hall, London, 164 pp.

Thompson, R., 1973. Palaeolimnology and palaeomagnetism. Nature 242, 182 - 184.

Thompson, R., 1977. Stratigraphic consequences of paleomagnetic studies of Pleistocene and Recent sediments. J. Geol. Soc. Lond., 133, 51 - 59.

Thompson, R., 1979. Palaeomagnetic correlation and dating. Mimeograph, University of Edinburgh. 21 pp.

Thompson, R.; R.W. Battarbee; P.E. O'Sullivan and F. Oldfield, 1975. Magnetic susceptibility of lake sediments. Limnol. Oceanogr. 20, 687 - 689.

Thompson, R.; J. Bloemendal; J.A. Dearing; F. Oldfield; T.A. Rummery; J.C. Stober and G.M. Turner, 1980. Environmental Applications of Magnetic Measurements. Science, 207, 481 - 486.

Thorarinsson, S., 1937a. Das Dalvik - Beben in Nordisland 2. Juni 1934. Geogr. Ann. 19A, 232 - 277.

Thorarinsson, S., 1937b. The Main Geological and Topographical Features of Iceland. Geogr. Ann. 19 A, 161 - 175.

Thorarinsson, S., 1943. Þjórsárdalur och dess förödelse. In Stenberger, M. (ed.): Forntida gårdar i Island. 9 - 52, Ejnar Munksgaard, Köbenhavn.

Thorarinsson, S., 1944., Tefrokronologiska studier på Island. Geogr. Ann. 26, 1 - 217.

Thorarinsson, S., 1950. Glacier outbursts in the river Jökulsá á Fjöllum. Náttúrufraedingurinn, 20, 113 - 133. (English summary).

Thorarinsson, S., 1951. Laxárgljúfur and Laxárhraun. A Tephrochronological Study. Geogr. Ann., 33, 1 - 80.

Thorarinsson, S., 1958. The Öraefajökull eruption of 1362. Acta Nat. Isl. II, 2, 1 - 100.

Thorarinsson, S., 1959. On the Geology and Geomorphology of Iceland. Geogr. Ann., 77, 135 - 169.

Thorarinsson, S., 1961. Uppblástur á Íslandi í ljósi öskulagarannsókna. Ársrit Skógraektarf. Ísl., 1961, 17 - 54. (English summary).

Thorarinsson, S., 1967. The eruptions of Hekla in historical times - A tephrochronological study -.. In Einarsson, T., G. Kjartansson and S. Thorarinsson, (eds.): The Eruption of Hekla 1947 - 1948, I, 1 - 170, Soc. Sci. Islandica, Reykjavík.

Thorarinsson, S., 1974. The Terms Tephra and Tephrochronology. In Westgate, J. and C.M. Gold (eds.): World Bibliography and Index of Quaternary Tephrochronology. 17 - 18. The University of Alberta.

Thorarinsson, S., 1975. Katla og annáll Kötlugosa. Árb. Ferðaf. Ísl. 1975, 124 - 149. (In Icelandic).

Thorarinsson, S., 1979. Tephrochronology and its application in Iceland, Jökull, 29, 33 - 36.

Thorarinsson, S., 1981. The application of tephrochronology in Iceland. In Shelf, S. and R.S.J. Sparks (eds): Tephra Studies. 109 - 134. D. Reidel Publ. Comp. Dordrect.

Thoroddsen, Th., 1901. Islandske Fjorde og Bugter. Geogr. Tidsskr. 16, 58 - 82.

Thoroddsen, Th., 1902. Thaettir úr jardfraedi Íslands. Andvari, 23, 127 - 176.

Thoroddsen, Th., 1906. Ísland. Grundriss der Geographie und Geologie. Petermanns Mitt., Ergänzungsh. 152 und 153. Justus Perthes, Gotha. 358 pp.

Thoroddsen, Th., 1908-11. Lýsing Íslands. Vol. 1 and 2, 365 pp. and 673 pp. Hid íslenska Bókmenntafélag, Copenhagen. (In Icelandic).

Thoroddsen, Th., 1913-15. Ferdabók, skýrslur um rannsóknir á Íslandi 1882 - 1889. Vol. 1 - 4, 380 pp., 293 pp., 360 pp., 356 pp. Hid íslenska fraedafélag, Copenhagen. (In Icelandic).

Thors, K., 1974. Sediments of the Westfirdir Shelf, NW - Iceland. Ph. D. thesis. University of Manchester. 167 pp.

Thors., K., 1978. Setthykktarmaelingar í Önundarfirdi í ágúst 1978. Marine Research Institute Spec Report. sept. 1978, 23 pp.

Tómasson, H., 1976. The sediment load of Icelandic rivers. Nordic Hydrological Conference. 1976, V-I-16, Reykjavík.

Tómasson, H.; S.Pálsson; S. Rist and G. Vigfússon, 1973. Skýrsla um aurbardarrannsóknir fram til 1970, 1. kafli. Natiolan Energy Authority, Reykjavík, 77 pp.(In Icel.).

Tómasson, J., 1967. Mineralogical and petrographical characteristics of Icelandic tephra. In Einarsson, Tr.; G. Kjartansson and S. Thorarinsson (eds.): The Eruption of Hekla 1947 - 1948 I, 172 - 183. Soc. Sci. Islandica, Reykjavík.

Tu, H.Y., 1960. Some mineralogical properties of Icelandic soils. In Jóhannsson, B. (ed.): The soils of Iceland. 124 - 138. University Research Institute, Dept. of Agriculture, Reykjavík.

Turner, G.M. and R. Thompson, 1979. Behaviour of the earth's magnetic field as recorded in the sediment of Loch Lomond. Earth Planet. Sci. Lett., 42, 412 - 426.

U.S. Naval Oceanographic Office, 1965. Oceanographic Atlas of the Norht Atlantic Ocean. Section V. Marine Geology Pub.no. 700.

Udden, J.A., 1898. Mechanical composition of wind deposits. Augustana Library Publ. 1, 1 - 69.

van Langeveld, A.D.; S.J. van der Gaast, and D. Eisma, 1978. A comparison of the effectiveness of eight methods for the removal of organic matter from clay. Clays and Clay Minerals. 26, 361 - 364.

van der Plas, L., and A.C. Tobi, 1965. A chart for judging the relatively of point counting results. Am. Jour. Sci., 263, 87 - 90.

Vilmundardóttir, E.G.; S. Pálsson and Á. Gudmundsson, 1979. Búdarhálsvirkjun, borhola St-15: Setgreining. National Energy Authority, OS 79025, Reykjavík. 63 pp. (In Icelandic).

Vilmundarson, Th., 1969. Heimildir um hafís á sídari öldum. In Einarsson, M. (ed.): Hafísinn. 313 - 332. Almenna bókafélagið, Reykjavík. (In Icelandic).

Vine, F.J., 1966. Spreading of the sea floor: new evidence: Science, 154, 1405 - 1415.

Vinogradova, P.S., 1964. Recent sediments in the Norwegian Sea. (In Russian). Papers of the N.M. Knipovich Scientific Research and Project Institute of Marine Fisheries and Oceanography (PINRO). No. 16, 111 - 132.

Vogt, P.R., 1971. Asthenosphere motion recorded by the ocean floor south of Iceland. Earth Planet. Sci. Lett. 13, 153 - 160.

Walker, G.P.L., 1959. Geology of the Reydarfjordur area, eastern Iceland. Quart. J.Geol. Soc. London. 114, 367 - 391.

Walker, G.P.L., and R. Croasdale, 1972. Characteristics of some Basaltic Pyroclastics. Bull. Volcanol. 35, 303 - 317.

Wenthworth, C.K., 1922. A scale of grade and class terms for clastic sediments. J.Geol., 30, 377 - 392.

Wright, P.L., 1972. The geochemistry of Recent Sediments of the Barents Sea. Ph. D. thesis. University of Edinburgh, 203 pp.

APPENDIX A

Historical notes

Somewhat more than 1100 years ago the peace of the island was broken. They came lika a thunder from the east and south, those seekers of land whom the world still calls Vikings. These Nordic voyagers had heard of the island of Thule[x)]. It is also well known that many Irish people claimed land in Iceland, and it was from Ireland that the first settler of Eyjafjördur district, Helgi the Lean, came.

The Book of Settlement (Landnámabók- from the 12th century) states: "Eyvind the Eastman had wed Rafarta, the daughter of Kjarval, king of Ireland, and settled there; he was a Viking. They had a son by the name of Helgi. He was given to a foster home in the Hebrides as a child, but when they came to see him two years later, he had been so starved that they did not recognize him. They then took him away and dubbed him Helgi the Lean.

When Helgi was a grown man he gained great respect. He married Thórunn Axblade, and they had many offsprings. Helgi the Lean went to Iceland with his wife and children. He believed in Christ, yet invoket Thor for voyages and manly deeds. When Helgi sighted Iceland, he sought guidence from Thor where to take land, and the oracle directed him to the north of the country. Helgi made land north of Hrísey and south of Svarfadardalur. He stayed at Hámundarstadir during the first winter; it was a very cold one. He saw that the

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x) Thule was first described about 300 B.C. by Pytheas, a Greek captain from Massalia (present-day Marseille), who located it as "six days sail from Britain".

land was much less snowy toward the head of the fjord, which they had named Eyjafjördur for the islands off the shore. During the summer Helgi explored the entire district and lighting a blaze by the mouth of every strean, claimed the whole of Eyjafjördur between Siglunes and Reynisnes (Gjögurtá)'.

APPENDIX B

Seismic equipments

Boomer and Sparker units. Both pieces of equipment are based on E.G. & G. system where the basic components are the same grouped in two main units, the transmitting and the receiving unit. In the Boomer system the components in the transmitting unit are power supply, trigger capacitor bank and Boomer transducer (Figure B1), but in the Sparker system it is power supply, trigger capacitor bank, capacitor bank and two Sparkarrays each with three electrodes (Figure B2). For the receiving unit the components are the same for both systems i.e. one hydrophone, pre-amplifier, filter and recorder.

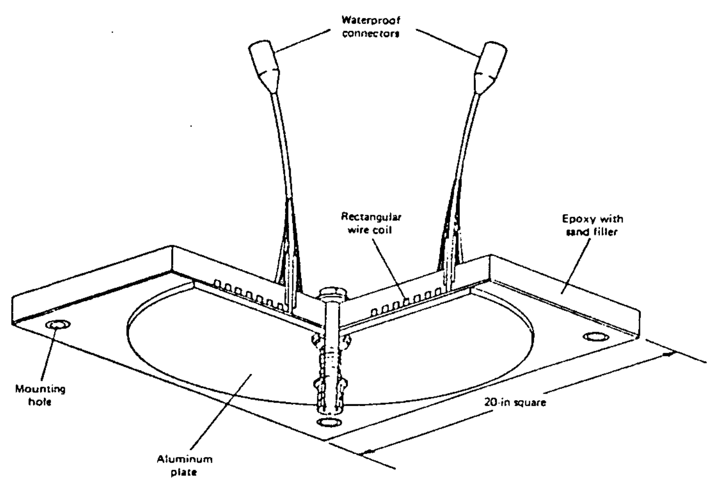


Figure B1.

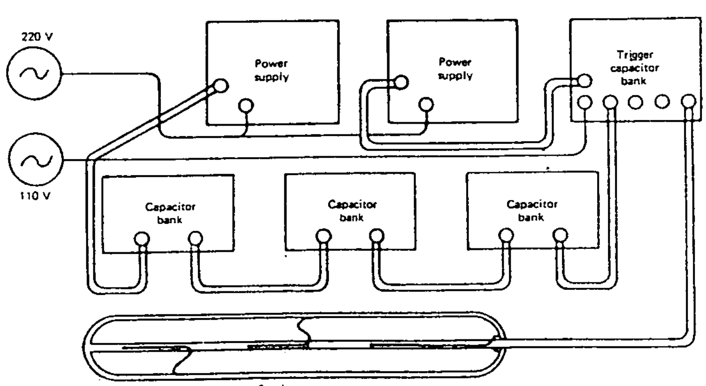
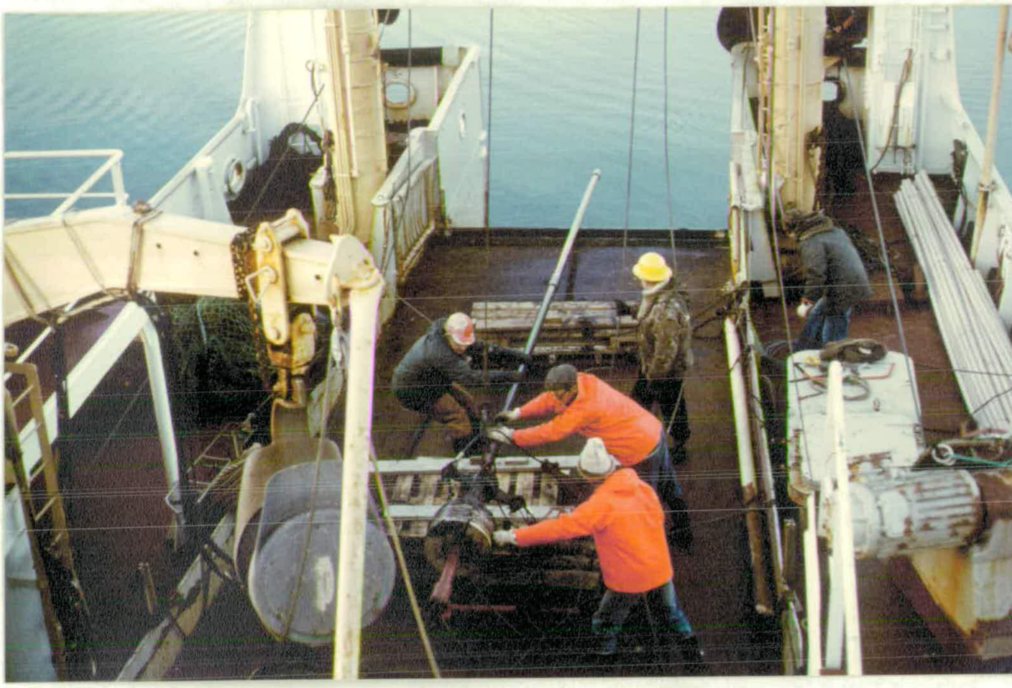
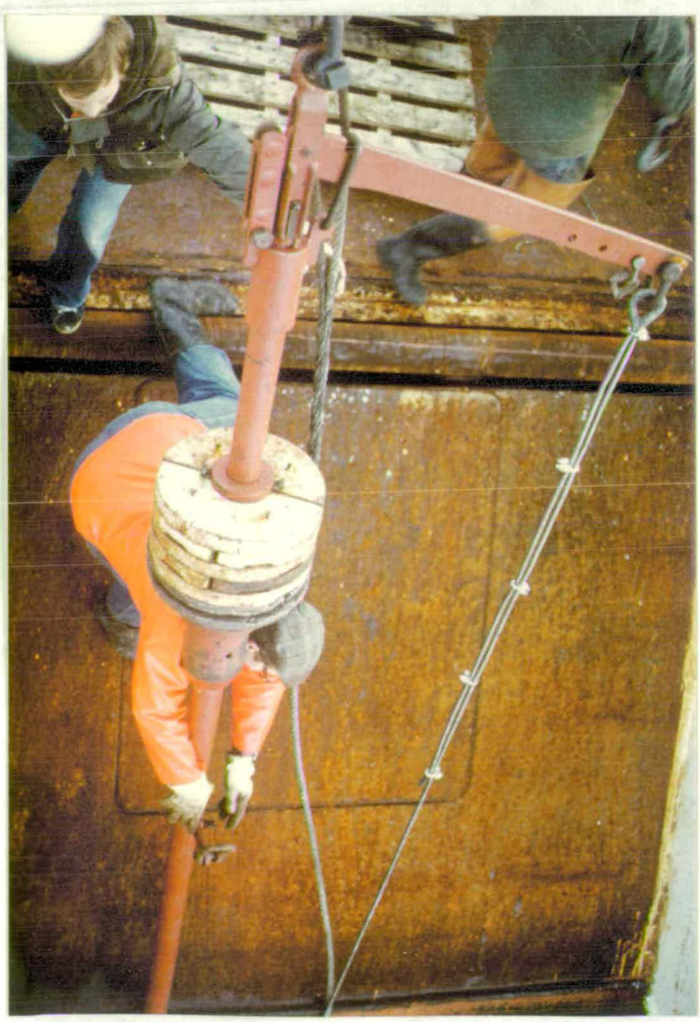


Figure B2.

APPENDIX C

Corer





APPENDIX D

Electron microprobe analysis

a) Preparation of samples.

A number of glass particles were removed from the tephra layers both from soil profiles around Eyjafjördur and from cores taken in the fjords basin.

For the soil samples all organic matter was removed according to Anderson (1963), with a solution of sodium hypochlorite (NaOCl). The method can be summerized as:

1. Immediately prior to use, adjust the solution to pH 9.5 with HCl. Use test paper or a spot test to determine pH.
2. To one part sample add four parts solution, stir.
3. Heat suspension 15 minutes in a boiling water bath. Let the solits settle and decant the liquid.
4. Repeat procedure three times if necessary to remove organic matter. Additional treatment will only dissolve inorganic constituents, referring to Lavkulich and Weins (1970).

Each sample is washed through a sieve of 63 microns and what gets through is stored, but what is left on the screen is washed into a beaker and a few drops of Calgon added for dispersal use. The samples are then dried at 60°C and during the drying process tha samples are occasionally put into an ultra-zonic bath for a few seconds. Mounting the samples on glass plates was proceeded by the technicians.

The preparation of the samples taken from the sediment cores is basically the same except in the removal of the organic matter. Each sample is treated with a 6% solution of H_2O_2 to oxidise the organic matter and for a weakly consolidated samples this method has also proved to be useful for the initial disaggregation (see also Appendix F).

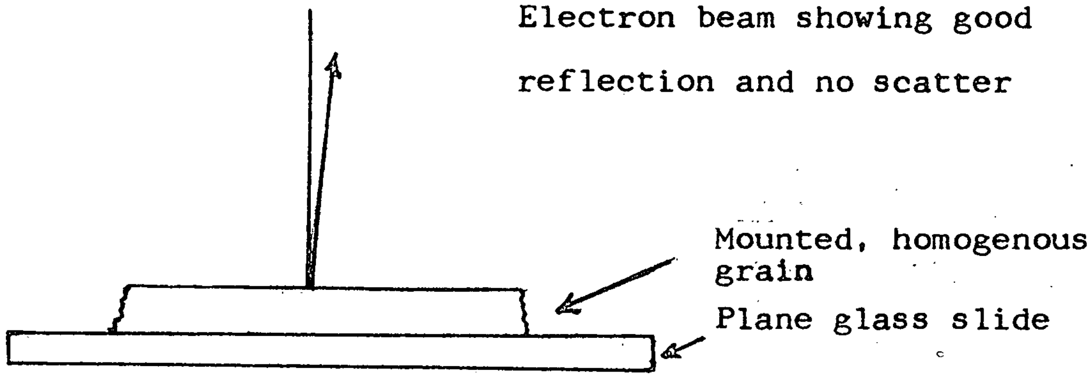
b) Problems in mounting and analysing.

Some difficulties arose in mounting and analysing of the acis (silicic) tephra layers from Hekla.

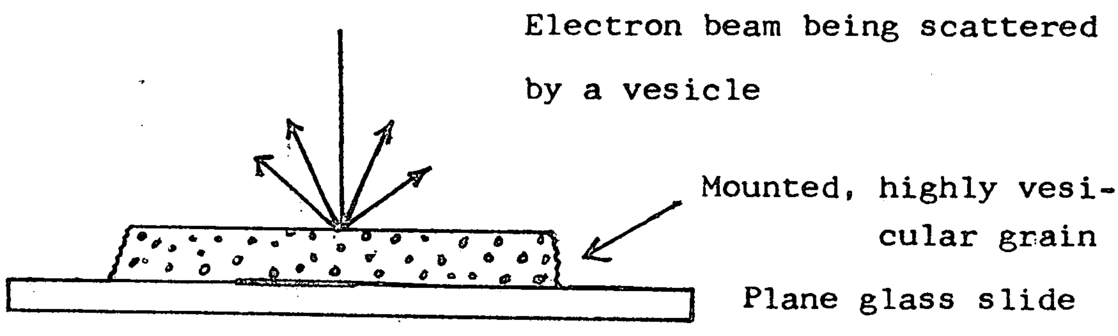
In a conventional thin-section prepared for electron microprobe analysis the grains mounted on a glass slide are well situated in the polished surface and they are also quite distingctive, forming a good analytical reflection for the electron beam -no scatter- (Figure A.1). Both crystals and basaltic tephra grains can easily be mounted in this way.

On the other hand are samples where the electron beam is scattered from the surface by highly vesicular grains (Figure A.2). The acid tephra grains are highly vesicular and in addition the walls between the vesicles are very thin. The bulk density is therefore low and the specific gravity is also less than the basaltic tephra grains ($\sim$ 0.5 g/cm^3 lower).

Some difficulties appeared in mounting of the acid grains due to its low density. In spite of that this problem was solved, but the grains were still more or less covered with the cement. Partly due to its shape (platy) and partly due to the hich vesicularity. As a result only a very few grains in each thin-section could be analysed in the Edinburgh samples with any reliability, but for some unknown reason the thin sections analysed in Rhode Island did give a much more reliable grain analysis (see Tables 5.4 and 5.5).



A.1. Diagram showing good electron beam reflection



A.2. Diagram showing poor electron beam reflection

c) The equipment.

Only the major elements were analysed using the energy dispersive technique. The Gun Potential was set at 20 KV and the Probe current at 6 nA. The beam was also difocused up to 20 microns to prevent destruction of the tephra grains.

APPENDIX E

Magnetic measurements

a) Fluxgate spinner magnteometer. A computerized slow speed spinner magnetometer was employed. This system uses the advantages of the spinner magnotometer combined in sensitive fluxgate and second harmonic detection devices. The specimen is rotated near the fluxgates at a speed of seven revolutions per second and the signal integrated over 128 revolutions. A complete measurements consisting of a total of 6 spins about 3 othogonal axes in both directions (less than 5 minutes including the time for computing the direction and intensity of the remanent magnetic vectors) (see also Tarling, 1971).

The use of the digital computer greatly reduces the time taken to measure the specimens and to calculate the direction and intensity of their magnetization, and it increases the accuracy of the measurements. According to Creer et al. (1972) this is achieved partly by the use of Fourier analysis by the accuracy to which all calculations are automatically carried out, partly by the allowance for magnetization of the rotational parts which is made by the program and partly by the use of linear as opposed to exponential integration.

b) Susceptibility bridge. This equipment consists of two ferrite rings with primary winding carrying an alternating current which produces an alternating magnetic field of up to 10 oersteds across gaps cut in the rings. A ferrite plug can be positioned to balance the two circuits so that a specimen placed within one of the gaps unbalances the circuit in secondary windings in proportion to its susceptibility.

The air-cored coil bridge system used produces weak alternating fields, of about 0.1 mT peak strength, and of a high frequency, ~10 kilohertz.

c) Electromagnet. Uniform fields of strength up to 1 T (10 kOe) is produced by conventional electromagnets with flat 5 cm diameter pole pieces.

The "saturation" isothermal remanence magnetization (SIRM) is measured on a sensitive magnetometer after placing the speciamen in a (d-c magnetic field) direct field of 10 kOe applied with an electromagnet at room temperature. Less than a minute is needed for both the magnetization and the remanence measurement.

Remanent coercivity, B_{cr} is the reverse d-c field required to reduce the SIRM to zero.

d) Demagnetization. Alternating magnetic field demagnetisation method is used. Passing an alternating current through a coil an alternating field is produced along its axis. The current is usually that of the public mains supply, alternating at either 50 or 60 Hz, which is controlled by a potential divider to avoid sudden steps in the current. The specimen is placed on the axis of the coil and the Earth's magnetic field cancelled (field free space) to reduce anhysteritic magnetisation. The mains supply does not have a pure wave form as possible; irregularities in the wave form result in an unidirectional field being produced along the axis of the coil so that the specimen can acquire an anhysteritic magnetisation.

APPENDIX F

Analytical methods

GRAIN SIZE:

a) Sieving. The sample size used for dry sieving is approximately 50 grams. To get rid of the sea salt in the sample it is washed into a beaker and stirred. When all the sediment has settled the clear water is decanted. The sample is now washed through a sieve of 63 microns and the fraction that gets through is dried and weighed. The coarse fraction left on the screen is dried and sieved through a bank of sieves. The screen selected for the sieving has a 1/2 phi interval on the Krumbein scale (1934), and each sample is shaken for 20 minutes on an Endecott Test Sieve Shaker. Every fraction is examined under binocular microscope and then weighed. In these samples the amount of aggregates was minimal so there was no need to sieve them again. The fine fraction that passed the 63 micron sieve was not subjected to further fractionation in the samples that were dry sieved: where the sedimentation method was used the coarse fraction was wet sieved.

b) Falling drop analyser. In the falling drop method the sample must be composed of only silt- and clay-size particles. Therefore 1-5 grams of material has to be washed through the 63 micron sieve. What is left on the screen is wet-sieved through a bank of sieves with 1 phi interval, and each fraction is then dried and weighed. The suspension left in the pan is centrifuged once to get rid of the sea salt. Because the principle of this method is based on Stokes law it is vital for the validity of the measurement that every single particle settles separately. To conduce that a dispersant is added. The sample is suspended in a known volume of water and then transferred into 30 ml settling tube. From the settling tube, kept in a water bath of constant heat, a subsample is taken by a micro-pipette at specific time interval and at known depth. A drop of known size is then ejected into a column of an organic liquid anisole ($C_6H_5OCH_3$) and the falling time over certain distance is measured with a stopwatch. The density of the drop is determined by comparing it with a calibration chart established by using drops of different sodium chlorite solutions with known densities. The particle concentration can then be calculated from the density measurements by using formula described by Moum (1965).

c) Pipette. In the pipette method the principle is the same as has been described in the falling drop method. The procedure of the sample is also the same through the first steps, except the size of the sample used is about 10 grams. After the sea salt has been removed some Calgon dispersant is added to the suspension and the sample put in a 1000 ml cylinder. The cylinder is then placed in a water bath with a constant temperature. During the measurement the sampling depth and withdrawal time will be known. After each withdrawal time the sample is drained into an evaporating dish. The dish is then dried and weighed and each grain size can be calculated.

d) Counting. Quantitative determination of each class mounted on the slides with the line method means counting all grains that intersect the cross-hair under the microscope along linear traverses and those lines equidistantly spaced over the slide (Galehouse, 1971b). By using the line method the number frequency is determined. Conventionally it means that it cannot be treated statistically in the same way as the number percentage because of a build-in bias. For example the number frequency is larger than the number percentage for larger grains and smaller than the number percentage for the smaller grains. Mounting only a limited size interval on the slide can minimize the descrepancy between number frequency and number percentage (Galehouse, 1969). Choosing 1 phi interval as was done in this research makes the statistics increasingly appropriate whereas the number frequency approaches the number percentage.

In each thin section approximately 900 grains are counted. The error estimated in percentage for each group at 95% confidence limit can be seen graphically or calculated from the formula

$$E = 2 \sqrt{\frac{P(100-P)}{N}}$$

where N is the total number of grains counted and P is the percentage of N of an individual group (van des Plas and Tobi, 1965).

B. MINEARALOGY:

a) Preparation of samples. All samples from the fjord prepared for clay mineralogical studies were treated with H_2O_2 to oxidise the organic matter. It may otherwise have caused a high background and prevented paralled orientation in the preparation of oriented mounts. In a weakly consolidated sample it has also proved to be useful in the inital disaggegation for size-separation. The effect of the peroxide treatment on the clay mineral structure has been discussed by Perez-Rodrigues and Wilson (1969) and by Douglas and Fiessinger(1971), who indicate that mild degradation of expandable clays can be encouraged by H_2O_2 treatment. The interlayer material of some 14 Å swelling minerals is removed by oxidation and H_2O_2 is known to break down the organometallic - clay complexes in soils. Using a weak hydrogen peroxide solution the treatment is limited to breaking down some of the organic matter without damaging the clay mineral structure (van Langeveld et al., 1978). No marked difference in chemical composition between treated and untreated samples has been found either (Wright, 1972). In the present study the samples are exposed to a 6% (20 v/v) H_2O_2 solution.

All the samples were mounted on a ceramic tile, with a few on a glass slide. The tiles are 2 x 3 cm in size and unglazed, cut from bulk tile supplied by H. & R. Johnson Ltd., Tunstall, Stokes-on Trent. The tiles were placed on a hotplate, warmed to 80^{o}C and drops of suspension with less than 2 micton particles dispersed onto them, with a micro pipette.

By this rapid evaporation differential settling, which can enhance the portion of the mounted material "seen" by the x-ray beam, can be minimized.

The samples were glycolated with ethylene glycol using the vapour pressure method described by Brunton (1955), with the exception that instead of keeping the samples in a desicator for ~1 hour and at 60°C it was left for 24 hours at a room temperature. The last step is to heat the samples to 600°C for 2 hours.

b) X-ray diffraction. The determination of the clay minerals (and of some silt samples) was employed by Philips x-ray diffration equipment (Pw 1010/1050) using Ni filtered Cu radiation ($Cu_{K\alpha}$). The equipment was run at 36 Kv and 20 mA using divergent, scattering, and receiving slits of 1°, 1° and 0.1 inch, respectively. Goniometer speed was either 2° or 1° 2θ/min, but the chart speed was fixed at 1"/min (x40).

Every untreated sample was run from 3° - ca. 25° 2θ and after glycolation and heating at 600°C they were run from 3° - 21° 2θ.

C. CHEMISTRY:

a) Organic carbon. The samples for both of these analyses are prepared in the same way, dried at 80°C for 24 hours and ground.

Total carbon is determined from the amount of CO_2 evolved on combustion in a "LECO" (Laboratory Equipment Corporation) type 521-200 induction furnace - fitted to catalyst furnace model 572-100. About 1 gm of dried sample (80°C) is weighed into a carbon-free crucible and a scoop of tin catalyst and iron chips added for accelerating. After the combustion at temperatures exceeding 1500°C, gases commonly pass through a dust trap, a sulfur trap, and a catalyst furnace that converts CO to CO_2 before entering the burette. The gas burette is first allowed to drain for 1 minute and the CO_2-O_2 mixture is afterwards flushed into a burette with the alkali reagent KOH and this process repeated twice. Finally, the burette is allowed to drain until a consistent level is obtained, the valve is locked and the two columns of red liquid levelled; As the side arm is open to the atmosphere this means that the O_2 in the gas burette is now at atmospheric pressure. The volume of gas dissolved i.e. the level of red liquid in the gas burette can now be measured and the temperature and the pressure recorded. The accuracy of the machine is constantly checked using steel rings of known carbon concentration.

The precision of this combustion method was for some unexplained reason found to be rather poor in measuring total-carbon. If this analytical method was converted to determining organic carbon by treating the samples with diluted HCl for removing the carbonate, the overall precision would be estimated ± 3-4%.

b) Calcium carbonate. For the calcium carbonate determination the "wet" carbonate method is employed using "LECO" type 572-10C. Between 1.0 - 1.5 grams of accurately weighed sediment and 3 ml of distilled water, placed in a 10 ml pear shaped flask. 3 ml of 5% ferrous sulphate is washed in to prevent oxidation of organic carbon. The flask is fit to the apparatus and 3 ml of 2 N HCl is added into the sample from an attached burette. The sample is then heated gently till it effervesces, repeated three times, but is not allowed to boil. Evolved CO_2 is carried in a stream of CO_2-free N_2 through a condenser-tube and water trap into the gas burette. CO_2 is then determined volumetrically by hydroxide absorption in the same way as the total carbon and by recording simultaneously the temperature and the pressure the carbonate is calculated from the formula:

$$\frac{\text{(Burette Reading)(Correction Factor for T \& P)(8.33)}}{\text{Sample weight in grams}} = \%\ CaCO_3$$

Nitrogen gas was used as the carrier gas to inhibit oxidation of organic carbon during the reaction. The precision of these "wet" carbonate determinations is estimated ± 6-7%. By using both the organic-carbon and the carbonate carbon results the total carbon can be calculated. The overall error involved is thus estimated 10-12%.

APPENDIX G

-Microprobe-

Acid glass measurements,

Edinburgh

Sample			SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O / Na loss	K_2O / K loss	P_2O_5	Total
Haganes 1	A5		69.30	13.22	.30	3.07	.10		1.92	3.98/	2.34/		94.23
	A6		70.01	14.07	.32	3.70	.15	.20	2:35	4.05/	2.37/		97.21
	A7		70.50	13.28	.28	2.90	.15	.10	1.80	4.26/	2.52/		95.80
	aver		69.94	13.52	.30	3.22	.13	(.15)	2.02	4.10/	2.41/		95.75
	σ		.61	.47	.02	.42	.05		.28	.14/	.10/		1.49
Haganes 1st	A3		67.39	12.92	.34	2.95	.13		1:94	3.85/	2.38/		91.90
	A4		69.29	13.80	.23	2.82	.13		2.15	3.79/	2.26/		94.48
	A6		68.58	12.94	.21	2.83			1.90	3.77/	2.28/		92.51
	A7		67.50	12.93	.17	2.99			1.98	3.79/	2.47/		91.90
	aver		68.19	13.14	.24	2.90			1.99	3.80/	2.35/		92.70
	σ		.91	.44	.06	.08			.10	.03/	.10/		1.22
Thorsteinsstadir 1	A1		71.00	13.70	.28	2.92			1.95	3.97/	2.47/		96.29
	A2		70.78	13.68	.22	2.97	.13		1.95	3.73/	2.48/		95.94
	A4		69.72	13.50	.23	3.03		.15	1.92	3.96/	2.42/		95.00
	aver		70.50	13.63	.24	2.97			1.94	3.89/	2.46/		95.74
	σ		.69	.10	.03	.07			.03	.12/	.06/		.67
	A3		64.53	13.41	.47	5.30	.15	.21	2.90	3.77/	1.98/		92.79
	A5		65.38	13.02	.36	3.89	.22		2.34	3.66/	2.14/		91.12
	aver		64.95	13.21	.41	4.60	.18		2.62	3.71/	2.06/		91.95
	σ		.60	.26	.08	.99	.05		.40	.08/	.11/		1.18
Thorsteinsstadir 2	A1		68.28	13.11	.34	2.87	.14		1.79	3.91/	2.37/		92.80
	A5		70.25	13.35	.20	3.08			1.89	3.99/	2.55/		95.44
	aver		69.26	13.23	.27	2.97			1.84	3.95/	2.46/		94.12
	σ		1.39	.17	.10	.15			.07	.05/	.13/		1.87
	A6		63.51	13.98	.38	5.47	.16	.36	3.21	3.90/	1.91/		92.95
	A10		64.05	14.05	.36	5.44	.18	.26	3.11	4.03/	1.96/		93.45
	aver		63.78	14.01	.37	5.45	.17	.31	3.16	3.96/	1.93/		93.20
	σ		.38	.05	.01	.02	.01	.07	.07	.09/	.04/		.35
Thorsteinsstadir 3rd	A1		71.73	12.58	.13	1.92			1.30	4.19/	2.70/		94.73
	A2		70.09	12.27		1.89			1.31	4.12/	2.68/		92.36
	A3		73.61	12.58	.15	1.77			1.39	4.44/	2.79/		96.81
	A4		72.45	12.63	.24	1.98			1.30	4.15/	2.82/		95.63
	aver		71.97	12.51	.17	1.89			1.32	4.22/	2.75/		94.89
	σ		1.47	.17	.05	.09			.04	.15/	.07/		1.89

SAMPLE			SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O/Na loss	K_2O/K loss	P_2O_5	TOTAL
CORE: II-2	A1		68.32	12.45	.19	5.13		1.00	2.13	4.23/	2.14/		95.59
	A4		70.35	13.36	.23	2.88			1.98	4.10/	2.40/		95.31
	A5		69.66	14.09	.35	3.70	.11		2.37	3.97/	2.39/		96.71
	A6		67.71	13.51	.28	4.03	.11		2.41	3.78/	2.39/		94.23
	aver		69.01	13.35	.26	3.93			2.22	4.02/	2.33/		95.46
	σ		1.21	.68	.07	.93			.20	.19/	.13/		1.02
CORE: IV-3	A1		63.70	14.15	.60	6.35	.22	.55	3.58	3.91/	1.79/		94.85
	A4		71.09	13.64	.24	2.99			2.11	4.20/	2.51/		96.77
	A7		68.84	13.91	.27	3.55	.15	.13	2.38	4.40/	2.24/		95.88
	aver		69.96	13.77	.25	3.27			2.24	4.30/	2.37/		96.32
	σ		1.56	.19	.02	.39			.19	.14/	.19/		.63
CORE: IV-4	A1		63.19	14.37	.72	7.28	.20	.72	3.96	4.08/	1.77/		96.29
	A3		61.89	14.50	.64	7.91	.23	.75	4.33	3.99/	1.73/		95.97
	A4		64.82	13.91	.41	4.99		.23	3.07	4.08/	2.04/		93.55
	A6		63.42	14.09	.72	7.31	.20	.47	3.95	4.04/	1.83/		96.03
	aver		63.33	14.22	.62	6.87	.21	.54	3.83	4.05/	1.84/		95.46
	σ		1.20	.27	.15	1.29	.01	.24	.53	0.04/	.14/		1.28
CORE: XXI-2	A1		68.85	12.78	.17	2.87			1.88	3.98/	2.29/		92.81
	A3		67.80	12.97	.26	3.13			2.00	4.00/	2.39/		92.56
	A7 A8	} aver	70.29	13.31	.21	3.08			1.93	4.12/	2.42/		95.42
	aver		68.98	13.02	.21	3.03			1.93	4.03/	2.37/		93.60
	σ		1.25	.27	.05	.14			.06	.08/	.07/		1.58
CORE: XXI-3	A1		63.72	13.56	.38	5.00	.17	.15	2.91	3.80/	1.94/		91.64
	A3		63.49	14.53	.64	7.04	.17	.63	4.01	3.97/	1.86/		96.35
	aver		63.60	14.04	.51	6.02	.17	.39	3.46	3.88/	1.90/		93.99
	σ		.16	.68	.18	1.44	.00	.34	.78	.12/	.05/		3.33

APPENDIX H

-Microprobe-

Acid glass measurements,

Rhode Island

SAMPLE		SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O / Na loss	K_2O / K loss	TOTAL / Plus loss
HAGANES 1											
14.2	1	71.64	13.80	.13	3.07	.09	.01	1.95	1.67	2.71	95.07
	2	73.39	14.35	.16	2.85	.13	.04	1.73	1.89	2.84	97.38
	3	70.61	13.89	.14	2.93	.03	.04	2.02	1.96	2.39	94.01
	4	70.64	13.57	.25	2.91	.04	.02	1.99	1.65	2.45	93.52
10.2	1	70.63	13.61	.23	2.87	.13	.02	1.70	1.95	2.61	93.74
	2	71.54	13.89	.23	2.51	.12	.05	1.67	1.49	2.28	93.77
	3	71.86	14.01	.11	2.67	.06	.00	1.67	2.21	2.51	95.11
	3	70.72	14.27	.20	2.53	.13	.10	2.02	2.32	2.47	94.75
	4	71.59	13.87	.26	2.51	.00	.02	1.77	1.76	2.63	94.42
	4	70.92	13.98	.21	2.91	.11	.05	1.97	2.21	2.70	95.06
	5	71.45	13.84	.23	2.69	.17	.05	1.89	1.90	2.47	94.70
	6	72.70	14.03	.12	2.64	.09	.00	1.90	2.30	2.49	96.26
	6	72.06	14.35	.21	3.15	.15	.05	1.87	2.19	2.42	96.45
	7	72.99	14.02	.12	2.57	.00	.03	1.96	1.94	2.68	96.31
	7	71.45	14.13	.22	2.98	.15	.05	1.82	2.27	2.75	95.87
14.6	3	71.91	13.84	.18	2.57		.03	1.98	2.00	2.48	95.13
10.6	1	71.69	14.00	.14	2.80		.05	1.97	1.97	2.43	95.11
	1	70.86	13.91	.12	2.97		.10	2.19	2.37	2.70	95.41
	2	71.82	13.84	.16	2.81		.05	1.83	1.86	2.52	94.98
	2	71.05	13.86	.23	3.06		.05	2.12	2.09	2.43	94.92
	3	73.14	14.31	.19	2.68		.06	1.74	1.96	2.54	96.63
	4	72.55	13.98	.18	2.74		.02	1.66	2.10	2.27	95.61
10.6	5	71.14	13.98	.09	2.51	.11	.02	1.72	2.15	2.36	94.08
	6	71.45	13.50	.17	2.61	.06	.00	1.63	1.72	2.39	93.54
	7	70.77	13.82	.16	2.82	.04	.02	1.77	1.97	2.40	93.77
	7	71.09	13.95	.21	2.50	.08	.02	1.64	1.79	2.30	93.58
aver	26	71.60	13.95	0.18	2.76	0.09	0.04	1.85	1.99	2.51	94.97
σ		.81	.22	.05	.20	.06	.03	.16	.23	.15	1.06
HAGANES 2											
14.10	1	73.70	13.04	.07	1.59	.06	.00	1.05	1.95	2.69	94.14
	2	73.59	13.14	.13	1.77	.12	.00	1.15	1.73	2.25	93.86
	3	74.57	13.32	.07	1.63	.01	.00	1.11	1.94	2.39	95.04
	3	73.86	13.10	.07	1.59	.03	.01	1.39	2.32	2.57	94.94
	4	74.88	13.04	.07	1.79	.00	.00	1.25	2.09	2.60	95.72
	4	74.09	13.43	.11	1.64	.08	.00	1.46	2.06	3.02	95.89
	5	73.64	13.12	.05	1.77	.03	.00	1.27	2.10	2.54	94.51
	6	74.03	12.94	.05	1.74	.03	.00	1.25	2.00	2.31	94.36
	8	73.91	12.86	.11	1.55	.03	.00	1.14	1.97	2.85	94.43
	9	73.22	12.42	.04	1.70	.07	.00	1.08	1.86	2.57	92.95
10.10	1	75.10	13.42	.13	1.71	.09	.00	1.23	2.05	2.35	96.09
	1	73.95	12.88	.06	1.88	.00	.00	1.15	2.23	2.38	94.53
	1	73.51	13.39	.05	1.95	.13	.00	1.46	1.99	2.93	95.41
	2	75.06	13.00	.04	1.42	.07	.00	1.07	1.98	2.48	95.13
	2	73.77	13.17	.08	2.06	.10	.00	1.38	2.06	2.39	95.01
10.10	3	75.22	13.40	.07	1.76	.08	.00	1.12	1.94	2.78	96.37
	3	73.28	13.03	.06	1.86	.10	.00	1.23	2.42	3.04	95.01
	4	73.94	12.88	.04	1.60	.00	.00	1.00	2.10	2.93	94.47
	4	73.92	12.88	.10	2.02	.11	.00	1.37	2.29	2.85	95.48
	5	75.00	13.06	.01	1.75	.14	.00	1.12	2.21	2.74	96.03
	5	73.97	13.02	.16	1.88	.17	.00	1.42	2.33	3.00	95.96
	6	74.52	12.65	.04	1.45	.03	.00	1.05	2.04	2.79	94.57
	6	73.14	12.75	.05	1.74	.10	.00	1.23	2.24	2.71	93.97
	9	74.31	13.00	.10	1.69	.06	.00	1.14	2.07	2.69	95.05
	10	73.90	12.85	.05	1.54	.06	.00	1.09	1.93	2.74	94.16
	11	74.30	13.11	.03	1.83	.07	.00	1.31	2.19	2.71	95.54
	12	73.71	12.59	.09	1.78	.07	.00	1.40	2.05	2.85	94.54
aver.	27	74.08	13.02	0.07	1.73	0.07	0.00	1.22	2.08	2.67	94.93
σ		.59	.25	.03	.16	.04	.00	.14	.16	.23	.80

SAMPLE		SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O / Na loss	K_2O / K loss	TOTAL / PLUS LOSS
GATA 1											
14.17	3	74.54	13.40	.07	1.91	.13	.00	1.30	1.82	2.52	95.68
	7	73.76	13.31	.07	1.89	.13	.00	1.52	2.25	2.88	95.80
	8	74.61	13.32	.09	2.09	.13	.00	1.40	1.64	2.30	95.60
	6	76.24	12.71	.07	1.89	.09	.00	1.27	2.30	2.50	97.09
10.17	7	74.27	13.11	.06	1.97	.12	.00	1.17	2.24	2.96	95.96
aver	5	74.68	13.17	0.07	1.95	0.12	0.00	1.33	2.05	2.63	96.01
σ		.93	.28	.01	.08	.02	.00	.13	.30	.28	.60
14.17	1	72.27	14.36	.22	3.07	.17	.07	2.16	2.18 /	2.63 /	97.13 /
	4	73.23	14.53	.20	3.15	.15	.05	2.07	2.32 /	2.57 /	98.27 /
	5	72.54	14.26	.27	2.86	.08	.09	2.26	1.92 /	2.51 /	96.78 /
10.17	5	72.23	14.34	.17	3.14	.15	.07	1.95	2.45 /	2.35 /	96.85 /
	8	71.70	13.91	.30	3.00	.13	.07	2.15	2.01 /	2.62 /	95.89 /
	9	70.93	14.09	.19	3.13	.14	.05	2.09	2.29 /	2.41 /	95.30 /
	12	72.37	14.21	.14	2.84	.19	.09	2.17	2.13 /	2.65 /	96.78 /
	14	71.79	14.04	.20	3.16	.04	.06	2.16	2.22 /	2.45 /	96.12 /
aver	8	72.13	14.22	0.21	3.04	0.13	0.07	2.13	2.19	2.52	96.64 /
σ		.68	.20	.05	.13	.05	.02	.09	.17	.11	.90
10.17	1	75.38	12.41	.07	1.36	.06	.00	.67	2.26 /	3.59 /	95.81 /
	13	74.40	12.61	.05	1.43	.08	.01	.69	2.00 /	3.17 /	94.43 /
aver	2	74.89	12.51	0.06	1.40	0.07	0.01	0.68	2.13	3.38 /	95.12 /
σ		.69	.14	.01	.05	.01	.01	.01	.18	.30	.98
10.17	4	71.70	13.70	.36	4.20	.20	.14	1.32	2.40 /	3.34 /	97.37 /
	6	71.87	13.93	.25	3.87	.16	.14	1.29	2.20 /	3.21 /	96.90 /
	10	71.23	13.40	.34	3.41	.15	.14	1.29	2.43 /	3.55 /	95.94 /
aver	3	71.60	13.68	0.32	3.83	0.17	0.14	1.30	2.34	3.37 /	96.74 /
σ		.33	.27	.06	.40	.03	.00	.02	.13	.17	.73
10.17	2	66.89	14.48	.50	5.23	.19	.29	3.55	2.05	2.12	95.29
	3	62.48	15.13	.80	8.08	.30	.84	4.50	2.48	1.79	96.40
HAGI H11											
14.20	1	75.11	13.46	.07	1.88	.07	.02	1.17	2.16 /	2.51 /	96.46 /
	2	73.64	13.04	.15	1.69	.04	.00	1.28	1.50 /	2.18 /	93.52 /
	3	73.86	13.14	.11	1.46	.04	.00	1.19	2.50 /	2.74 /	95.05 /
	7	72.86	13.16	.13	1.71	.12	.00	1.34	2.15 /	2.72 /	94.20 /
	9	74.09	13.14	.08	1.89	.09	.00	1.29	2.21 /	2.82 /	95.60 /
aver	5	73.91	13.19	0.11	1.73	0.07	0.00	1.25	2.52 /	2.59 /	94.97 /
σ		.81	.16	.03	.18	.03	.00	.07	.33	.26	1.15
THORSTEINSSTADIR 2											
14.24	1	70.72	13.84	.21	3.05	.16	.05	2.13	1.89 /	2.57 /	94.63 /
	4	71.55	13.87	.16	2.69	.23	.06	2.18	2.05 /	2.66 /	95.45 /
	4	70.70	13.96	.17	3.00	.09	.01	2.10	1.65 /	2.69 /	94.37 /
	5	71.93	13.89	.13	2.71	.15	.07	1.67	1.92 /	2.31 /	94.79 /
	5	72.43	14.54	.14	2.94	.19	.05	1.88	1.60 /	2.61 /	96.38 /
	6	71.56	14.31	.14	2.82	.18	.10	2.01	2.10 /	2.72 /	95.94 /
10.24	1	72.64	14.43	.29	3.02	.17	.09	2.23	2.06 /	2.74 /	97.66 /
	3	71.04	14.00	.22	3.35	.12	.14	2.14	1.84 /	2.69 /	95.54 /
aver	8	71.57	14.11	0.18	2.95	0.16	0.07	2.04	1.89 /	2.62 /	95.60 /
σ		.73	.28	.05	.21	.04	.04	.19	.19	.14	1.08
14.24	2	68.82	15.16	.50	5.73	.22	.29	3.35	1.98	2.30	98.36
10.24	2	68.64	15.26	.44	5.82	.23	.33	3.12	2.13	2.00	97.96
aver	2	68.73	15.21	0.47	5.78	0.23	0.31	3.24	2.06	2.15	98.16
σ		.13	.07	.04	.06	.01	.03	.16	.11	.21	.28

Sample		SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O / Na loss	K_2O / K loss	Total / Plus loss
CORE IV-3											
2.2	4	70.25	14.62	.24	3.90	.11	.09	2.25	1.52	2.62	95.61
	5	70.06	13.75	.22	2.80	.07	.00	1.89	1.62	2.35	92.77
	7	71.71	14.07	.16	3.16	.05	.09	2.14	1.60	2.31	95.30
	8	72.76	14.07	.15	2.68	.04	.00	1.83	2.29	2.57	96.40
aver	4	71.20	14.13	0.19	3.14	0.07	0.05	2.03	1.76	2.46	95.02
σ		1.28	.36	.04	.55	.03	.05	.20	.36	.16	1.57
2.2	1	69.02	14.76	.38	5.07	.15	.23	2.79	1.42	2.46	96.28
	2	67.02	15.08	.39	5.23	.21	.23	3.11	2.18	2.19	95.63
	3	67.54	15.00	.50	5.00	.23	.19	3.05	1.93	2.20	95.63
	9	68.20	15.08	.36	5.49	.20	.23	3.44	2.33	2.13	97.46
	10	69.27	15.18	.37	5.11	.13	.25	3.07	1.45	2.21	97.02
aver	5	68.21	15.02	0.40	5.18	0.18	0.23	3.09	1.86	2.24	96.40
σ		.95	.16	.06	.19	.04	.02	.23	.42	.13	.82
CORE IV-4											
14.6	2	72.75	14.68	.17	2.96	.09	.01	1.79	1.70	2.66	96.81
	5	72.13	14.64	.17	3.17	.01	.03	2.05	1.32	2.63	96.16
aver	2	72.44	14.66	0.17	3.07	0.05	0.02	1.92	1.51	2.65	96.49
σ		.44	.03	.00	.15	.05	.01	.18	.27	.02	.46
14.6	10	67.19	15.54	.54	6.32	.20	.46	3.44	1.95	2.33	97.96
	4	64.33	15.66	.84	8.66	.24	.95	3.92	1.39	1.85	97.86
10.6	4	65.12	15.68	.79	7.50	.30	.73	4.33	2.34	2.00	98.79
	8	65.01	15.60	.76	7.32	.30	.61	4.61	2.26	2.13	98.60
	6	65.60	15.82	.79	6.65	.19	.46	4.43	4.28	1.57	99.80
	9	64.37	15.17	.78	7.47	.18	.67	4.48	2.23	2.23	97.57
aver	4	65.03	15.57	0.78	7.24	0.24	0.62	4.46	2.78	1.98	98.69
σ		.51	.28	.01	.40	.07	.12	.12	1.00	.29	.91
10.6	1	62.51	15.01	.96	9.82	.22	.87	4.28	2.31	2.27	98.25
	5	62.80	15.39	.79	8.25	.27	.88	4.75	2.20	2.11	97.44
aver	2	62.66	15.20	0.88	9.04	.25	0.88	4.52	2.26	2.19	97.85
σ		.21	.27	.12	1.11	.04	.01	.33	.08	.11	.57
10.6	2	64.51	16.16	.63	4.91	.09	.42	4.73	5.13	1.18	97.76
	3	64.26	16.02	.78	6.96	.18	.89	4.28	1.97	1.90	97.24
	11	63.63	15.82	.59	6.32	.14	.59	5.02	4.78	1.18	98.09
CORE IV-5											
6.6	3	70.29	14.17	.30	3.05	.12	.08	2.27	1.95	2.95	95.17
	4	71.30	13.73	.19	3.01	.12	.00	2.07	1.83	2.93	95.18
	6	70.79	14.66	.18	3.23	.09	.03	2.36	2.41	3.00	96.74
	7	72.34	14.58	.16	3.14	.06	.03	2.16	1.65	2.58	96.71
aver	4	71.18	14.29	0.21	3.11	0.10	0.04	2.22	1.96	2.87	95.95
σ		.88	.43	.06	.10	.03	.03	.13	.32	.19	.89

SAMPLE		SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O / Na loss	K_2O / K loss	Total / plus loss
CORE: IV-5 (cont.)											
6.6	5	69.39	15.14	.27	4.18	.10	.07	2.95	1.16 /	2.79 /	96.06 /
	9	66.86	15.26	.45	5.49	.19	.27	3.11	1.79 /	2.54 /	95.96 /
CORE: XXI-2											
2.6	1	71.91	15.60	.16	2.93	.07	.00	2.21	1.57 /	2.82 /	97.28
	2	71.67	14.10	.14	2.94	.07	.00	2.07	1.78 /	2.55 /	95.32
	3	70.34	15.30	.20	2.99	.11	.00	2.04	1.76 /	2.45 /	95.20
aver	3	71.31	15.00	0.17	2.95	0.08	0.00	2.11	1.70 /	2.61 /	95.93
σ		.85	.79	.03	.03	.02	.00	.09	.12	.19	1.17
2.6	6	68.60	15.45	.30	5.05	.16	.19	3.38	1.30 /	2.11 /	96.55 /
14.10	12	66.24	14.98	.54	5.80	.20	.33	3.68	2.10 /	2.27 /	96.13 /
	4	64.68	15.51	.82	6.45	.25	.70	4.67	2.40 /	1.83 /	97.31 /
14.10	2	63.38	17.61	.52	4.39	.11	.37	5.02	5.00 /	1.49 /	97.88 /
	6	62.68	17.28	.86	6.80	.20	.57	5.23	4.79 /	1.18 /	99.60 /
aver	2	63.03	17.44	0.69	5.59	0.15	0.47	5.12	4.89 /	1.33 /	98.74 /
σ		.40	.16	.17	1.22	.05	.11	.10	.12	.17	.90
14.10	13	63.77	15.33	.75	7.33	.16	.68	4.41	2.23 /	2.29 /	96.94 /
14.10	1	61.31	14.97	.78	8.31	.21	.78	4.39	2.08 /	2.05 /	94.89 /
	10	61.99	14.88	.94	8.79	.25	.93	4.61	2.64 /	2.03 /	97.07 /
	8	61.72	15.45	.77	7.66	.27	.71	4.68	2.27 /	1.79 /	95.31 /
aver	3	61.67	15.10	0.83	8.25	0.24	0.81	4.56	2.33 /	1.96 /	95.76 /
σ		.34	.31	.10	.57	.03	.11	.15	.28	.14	1.16
CORE: XXI-3											
10.10	4	71.53	14.04	.18	2.85	.12	.01	2.15	1.76 /	2.88 /	95.52 /
	1	69.73	16.69	.14	1.64	.04	.48	3.18	3.57 /	2.46 /	97.93 /
	3	68.95	14.74	.26	3.77	.09	.10	2.76	1.70 /	2.52 /	94.88 /
10.10	2	65.09	15.97	.41	5.46	.13	.33	3.91	1.79 /	2.29 /	95.39 /
6.10	7	68.79	15.00	.30	4.96	.14	.18	3.40	2.01 /	2.61 /	97.38 /
	6	67.12	15.63	.65	6.78	.20	.54	4.23	1.82 /	2.25 /	99.21 /
aver	3	67.00	15.53	0.45	5.73	0.16	0.35	3.84	1.87 /	2.38 /	97.33 /
σ		1.85	.49	.18	.94	.04	.18	.42	.12	.20	1.91
6.10	4	64.20	15.27	.72	7.63	.17	.63	4.41	1.67	1.80	96.51
	5	64.53	15.55	.78	7.67	.19	.79	4.65	1.89	2.21	98.26
	8	64.33	15.57	.79	7.45	.30	.82	4.68	1.93	2.09	97.95
	10	64.60	15.68	.76	7.45	.23	.75	4.69	2.35	2.05	98.55
aver	4	64.42	15.52	0.76	7.55	0.22	0.75	4.61	1.96	2.04	97.82
σ		.18	.17	.03	.12	.06	.08	.13	.28	.17	.91
6.10	1	63.39	16.08	.78	8.00	.26	.88	4.92	2.61 /	1.93 /	98.85 /
	2	60.39	15.45	.86	8.38	.21	.81	5.05	2.15 /	1.64 /	94.95 /
	3	62.36	15.75	.75	8.60	.25	.96	4.77	1.97 /	2.06 /	97.46 /
aver	3	62.05	15.76	0.80	8.33	0.24	0.88	4.91	2.24 /	1.88 /	97.09 /
σ		1.52	.32	.06	.30	.03	.08	.14	.33	.22	1.98
6.10	11	64.89	16.08	.82	5.45	.17	.60	5.20	4.69 /	1.14 /	99.04 /

APPENDIX J

-Microprobe-

Basaltic glass measurements,

Edinburgh

Sample		SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
II-1-12	B_1	49.25	13.20	1.75	12.62	.23	6.56	11.58	2.12	.24		97.55
	B_3	50.00	13.57	1.79	12.29	.19	7.09	11.71	2.12	.22		98.78
	B_4	50.08	13.66	1.83	11.95	.24	6.92	12.02	2.16	.19		99.04
	B_5	49.50	13.53	1.78	12.01	.24	6.95	11.72	2.04	.18		97.95
	B_7	49.56	13.55	2.27	11.87	.20	6.83	12.56	2.27	.27		99.37
	aver.	49.68	13.46	1.88	12.15	.22	6.87	11.92	2.14	.22		98.54
	σ	.35	.18	.22	.31	.02	.20	.39	.08	.04		.77
	B_6	49.44	13.19	2.55	14.29	.22	5.29	9.64	2.66	.44	.20	98.02
	B_8	47.19	12.52	4.39	14.69	.23	4.83	9.88	3.01	.69	.58	98.04
	aver.	48.31	12.85	3.47	14.49	.22	5.06	9.76	2.83	.56	.39	98.03
	σ	1.59	.47	1.30	.28	.02	.32	.17	.25	.18	.27	.03
II-1-54	B_1	49.40	12.89	3.06	13.47	.21	5.50	10.05	2.74	.52	.22	98.04
	B_2	49.21	12.79	2.62	12.96	.21	5.81	10.79	2.34	.40		97.14
	B_6	50.55	13.06	2.66	13.12	.15	5.32	10.10	2.68	.38		98.04
	aver	49.72	12.91	2.78	13.18	.19	5.54	10.31	2.59	.43	.22	97.74
	σ	.72	.14	.24	.26	.03	.24	.41	.22	.08		.52
	B_3	49.15	13.50	1.73	11.87	.16	7.25	12.21	2.17	.16		98.24
	B_4	49.55	13.26	1.83	12.21	.18	6.47	11.22	2.48	.25		97.45
	B_5	49.07	13.86	1.29	10.63	.21	7.94	13.14	1.80	.13		98.24
	aver	49.26	13.54	1.62	11.57	.18	7.22	12.19	2.15	.18		97.98
	σ	.26	.30	.29	.83	.02	.73	.96	.34	.06		.46

SAMPLE		SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	TOTAL
II-2-144	B1	48.88	12.82	3.01	14.04	.26	5.60	9.99	2.55	.39	S .25 P .20	98.09
	B5	46.18	12.43	4.05	14.10	.28	5.27	10.81	3.00	.61	S .32 P .25	97.36
	aver	47.53	12.62	3.53	14.07	.27	5.43	10.40	2.77	.50	S .28 P .23	97.72
	σ	1.91	.57	.73	.05	.01	.40	.58	.39	.15	.09 .06	1.49
	B2	48.80	13.54	1.57	11.04	.26	7.48	12.62	1.83	.20	S .19	97.67
	B3	48.73	13.70	1.56	11.06	.18	7.74	12.83	1.80	.18	S .16	98.09
	B4	49.44	13.45	1.81	12.06	.14	6.65	11.57	2.26	.15	S .21	97.87
	aver	48.99	13.56	1.65	11.39	.19	7.29	12.34	1.96	.18	S .19	97.88
	σ	.39	.13	.14	.58	.06	.57	.67	.26	.02	.02	.21
II-3-150	B1	48.70	13.30	1.76	11.96	.15	7.21	12.07	2.12	.18	S .28	97.73
	B2	48.87	13.89	1.59	11.22	.17	7.12	12.20	1.81	.11	S .15 P .19	97.16
	B3	48.69	13.99	1.36	10.30	.25	8.15	12.97	1.91	.14		97.76
	B4	50.76	13.57	1.66	11.07	.18	6.43	11.12	2.45	.28		97.54
	aver	49.26	13.69	1.59	11.14	.19	7.23	12.09	2.07	.18	S .21 P .19	97.55
	σ	1.00	.31	.17	.68	.44	.70	.76	.28	.07	S .05	.28
IV-1-15	B1	49.86	13.11	1.81	12.58	.25	6.61	11.34	2.00	.25	S .25	98.06
	B2	49.32	13.46	1.80	12.10	.16	6.96	11.86	2.01	.21	S .28	98.17
	B3	50.14	13.24	1.83	12.56	.17	6.83	11.02	2.33	.24	S .15	98.51
	B4	49.45	13.67	2.32	11.59	.27	6.79	11.36	2.59	.28	S .26	98.58
	B5	49.43	13.49	1.81	11.83	.20	6.99	11.89	2.09	.19	S .24	98.30
	aver	49.64	13.39	1.91	12.13	.21	6.84	11.49	2.20	.23	S .24	98.30
	σ	.61	.22	.23	.44	.05	.15	.37	.25	.03	.05	.22
IV-1-61	B1	49.10	13.39	1.64	11.59	.21	7.22	12.01	2.12	.13	S .21	97.62
	B2	48.70	13.61	1.99	11.84	.19	7.06	11.85	2.29	.24	S .28 P .16	98.36
	B3	49.85	12.99	1.80	13.29	.19	6.32	11.35	2.22	.23		98.26
	B4	49.63	13.60	1.87	12.26	.13	6.74	11.72	2.35	.19	S .31	98.79
	B5	49.31	13.98	1.41	11.10	.23	7.58	12.56	1.92	.09	S .21	98.39
	aver	49.32	13.51	1.74	12.01	.19	6.98	11.90	2.18	.18	S .25 P .16	98.28
	σ	.45	.36	.22	.83	.04	.48	.44	.17	.06	.04	.42
	B6	49.33	12.60	3.27	13.80	.18	5.12	9.54	2.76	.48	S .36	97.46
	B6a	49.41	12.94	3.18	13.94	.24	4.91	9.45	2.74	.46	S .42	97.68
	aver	49.38	12.77	3.23	13.87	.21	5.01	9.50	2.75	.47	S .39	97.57

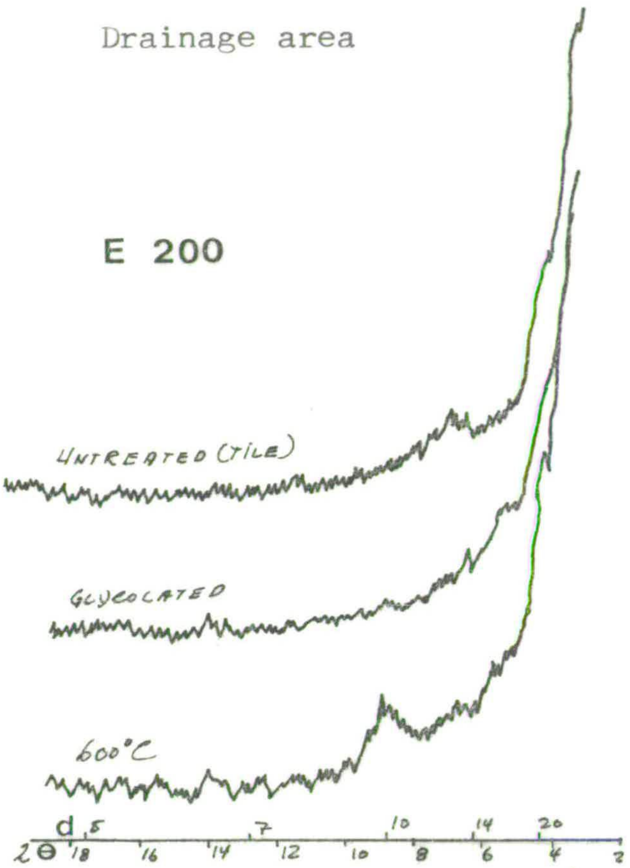
SAMPLE			SiO_2	Al_2O_3	TiO_2	FeO^*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	TOTAL
IV-1-103	B_1		49.99	13.51	1.76	12.28	.19	7.33	12.00	2.18	.24		99.48
	B_3		50.26	14.08	1.44	11.32	.21	7.55	12.90	1.64	.12		99.53
	B_5		50.03	14.29	1.44	10.92	.17	7.69	13.01	2.03			99.59
	B_6		50.19	13.75	1.92	12.11	.18	7.06	11.85	2.24	.20		99.63
	aver		50.12	13.91	1.64	11.66	.19	7.41	12.44	2.02	.19		99.56
	σ		.13	.34	.24	.64	.02	.27	.60	.27	.06		.06
	B_2		49.23	12.12	2.94	16.34	.24	5.05	9.79	2.49	.24	.20	98.65
	B_4		47.59	12.73	4.04	14.80	.29	4.87	9.75	3.14	.76	.47	98.45
	B_7		47.68	12.86	4.35	14.37	.23	4.91	9.56	3.14	.82	.22	98.15
	B_8		47.68	12.75	4.45	14.50	.23	4.78	9.60	2.98	.71	.39	98.08
	B_9		48.19	12.89	4.38	14.22	.12	4.87	9.43	3.15	.84	.26	98.33
	aver.		48.07	12.67	4.02	14.85	.22	4.90	9.63	2.98	.67	.31	98.33
	σ		.69	.31	.63	.86	.06	.10	.15	.28	.25	.12	.23
IV-2-23	B_1	24	50.07	13.32	2.37	13.43	.12	5.67	10.14	2.67	.42		98.21
	B_2		47.43	13.54	3.68	13.64	.14	6.01	11.03	2.95	.50		98.91
	aver		48.75	13.43	3.02	13.53	.13	5.84	10.58	2.81	.46		98.56
	σ		1.87	.16	.93	.15	.14	.24	.63	.20	.06		.49
	B_3		50.08	13.67	1.44	11.11	.29	7.52	12.62	2.15	.12		99.02
	B_4		49.58	13.83	1.63	11.52	.18	7.50	12.17	2.21	.18		98.80
	B_5		49.98	13.62	1.80	11.72	.25	7.00	11.87	2.21	.20		98.65
	aver		49.88	13.71	1.62	11.45	.24	7.34	12.22	2.19	.17		98.82
	σ		.26	.11	.18	.31	.06	.29	.38	.04	.04		.19
IV-2-80													
	B_1		50.06	13.72	1.76	11.98	.21	7.03	11.40	2.47	.18		98.95
	B_2		49.74	13.60	1.74	11.64	.20	7.16	11.94	2.12	.25		98.38
	B_3		49.68	14.02	1.41	10.44	.15	7.84	13.15	1.91	.13		98.74
	B_4		50.08	13.84	1.43	11.07	.18	7.39	12.70	1.72	.12		98.53
	B_5		49.71	13.99	1.45	10.88	.14	7.54	12.71	2.11	.15		98.67
	aver		49.85	13.83	1.56	11.20	.18	7.39	12.31	2.07	.17		98.65
	σ		.20	.18	.18	.61	.03	.32	.70	.28	.05		.21

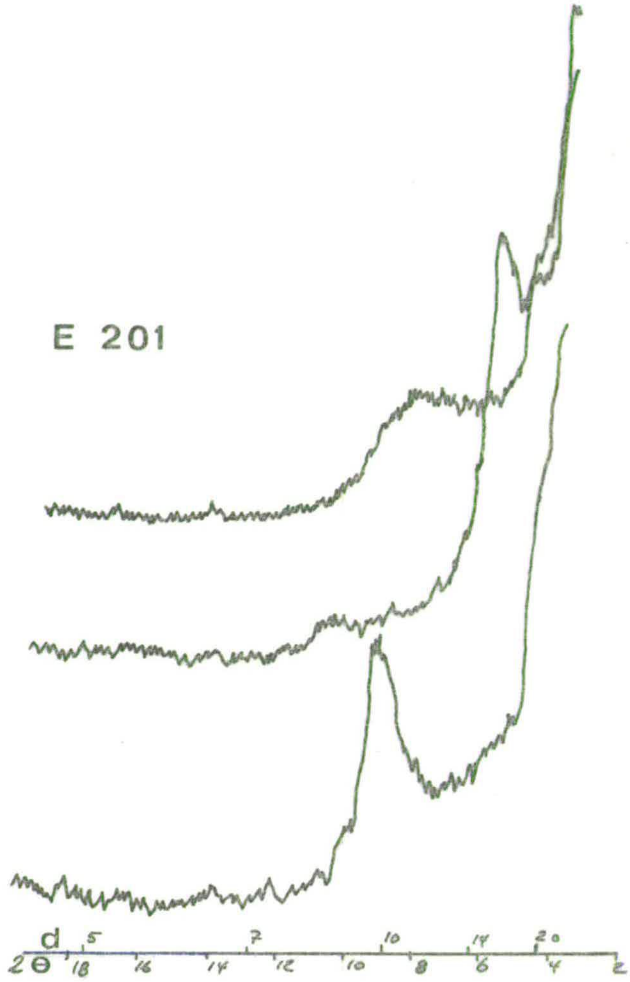
APPENDIX K

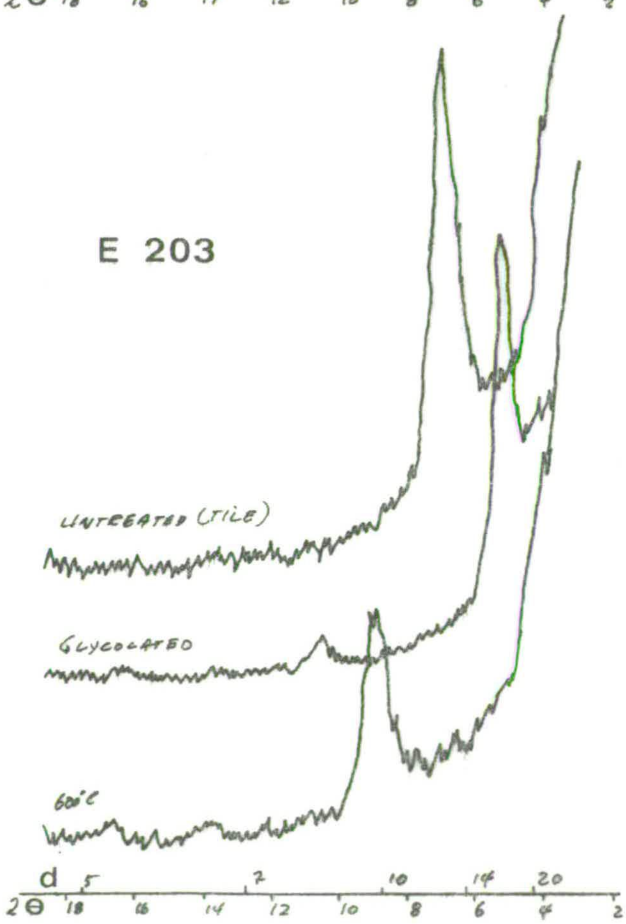
X-ray diffractograms

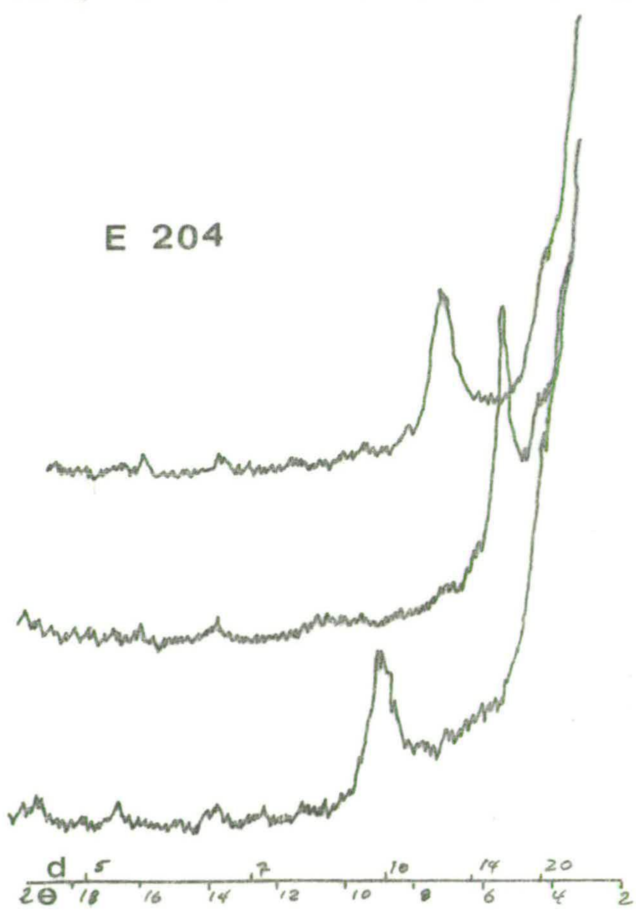
Drainage area
Grab samples
Core samples

Drainage area

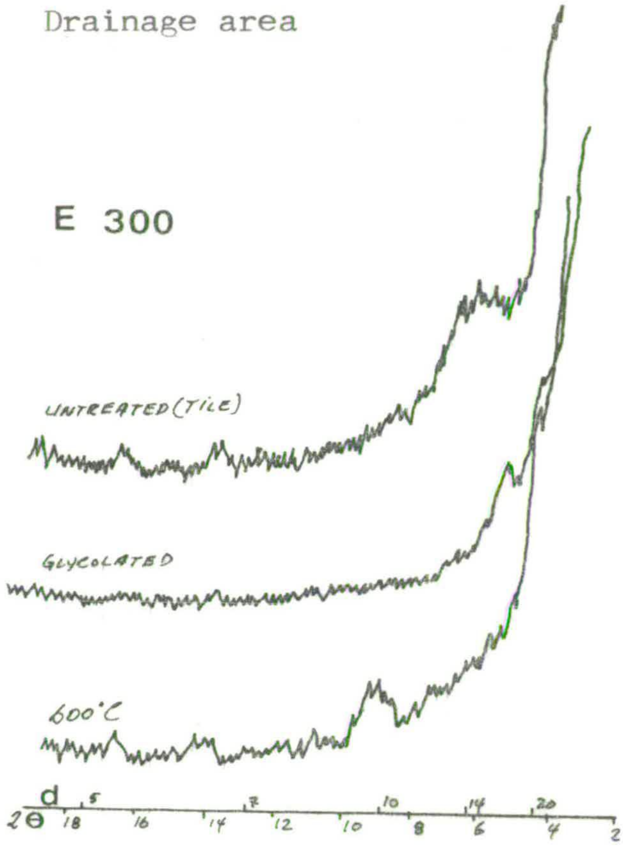


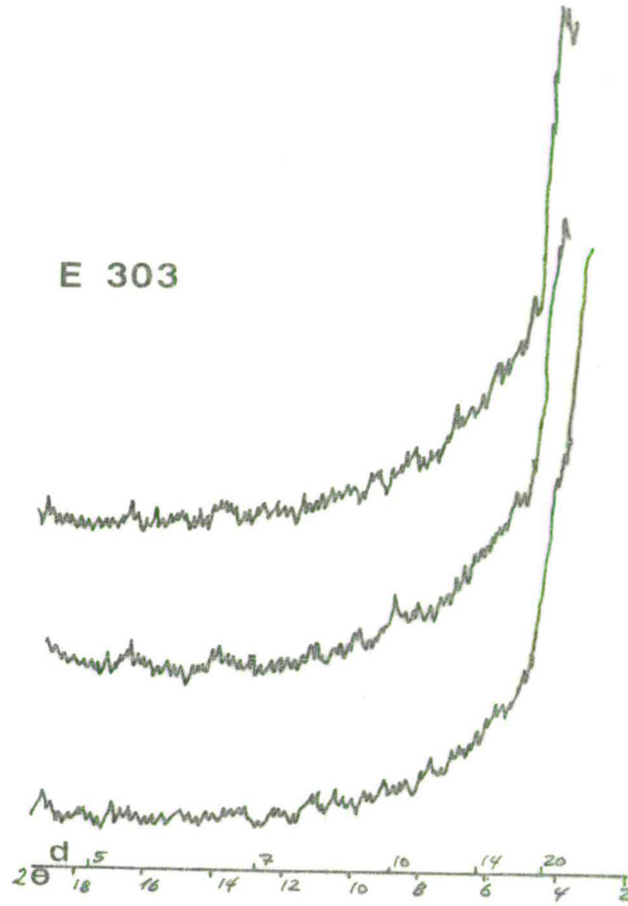


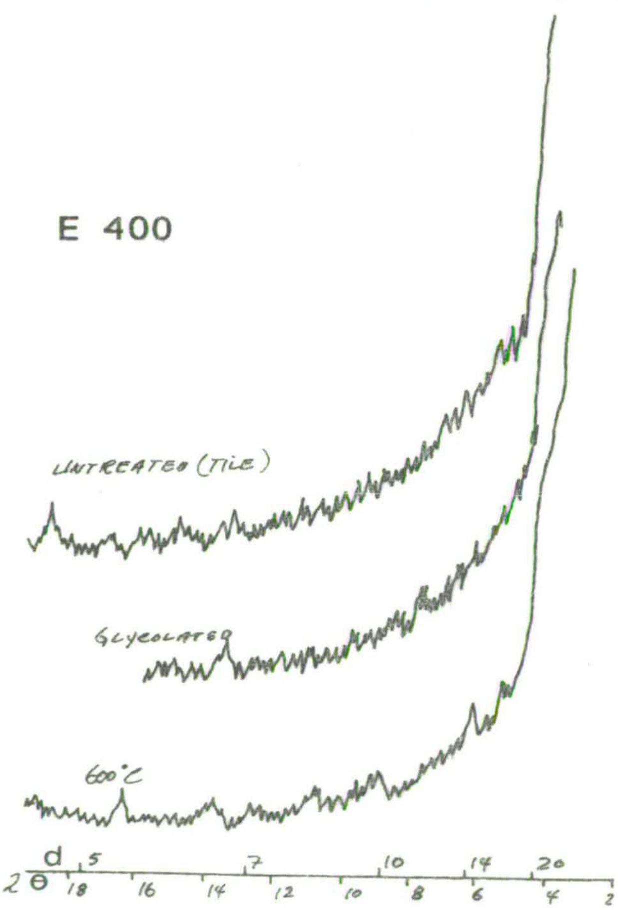


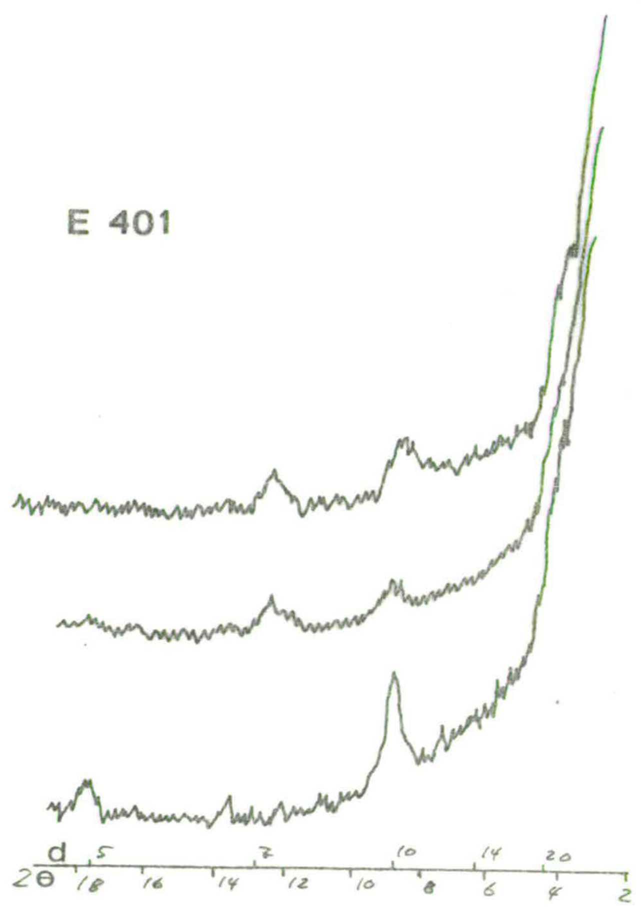


Drainage area

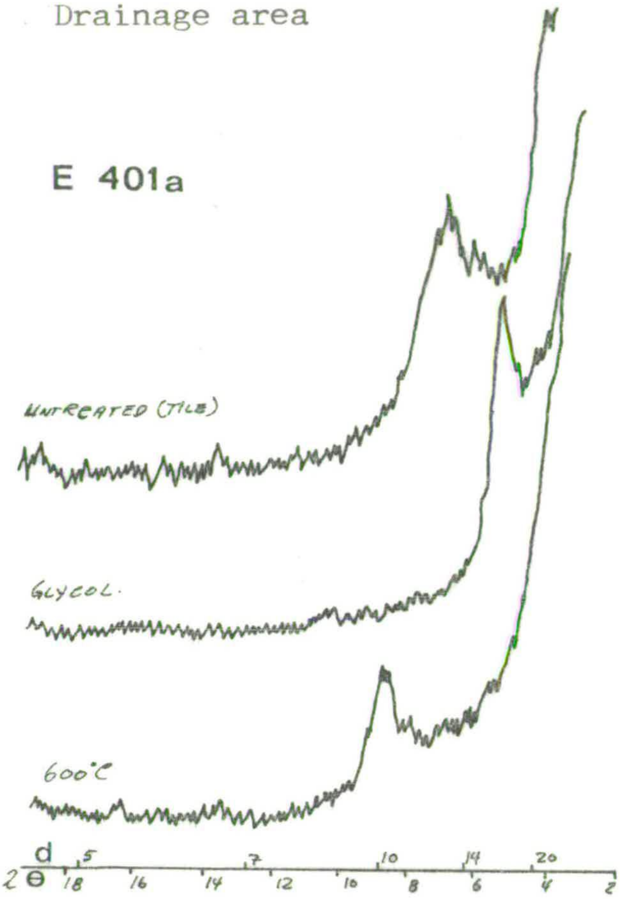


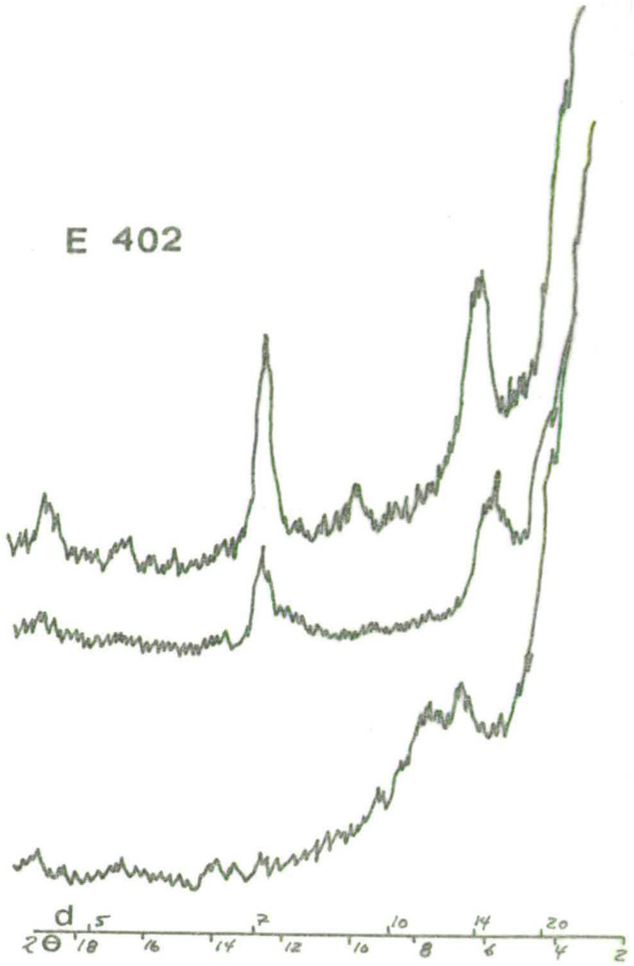






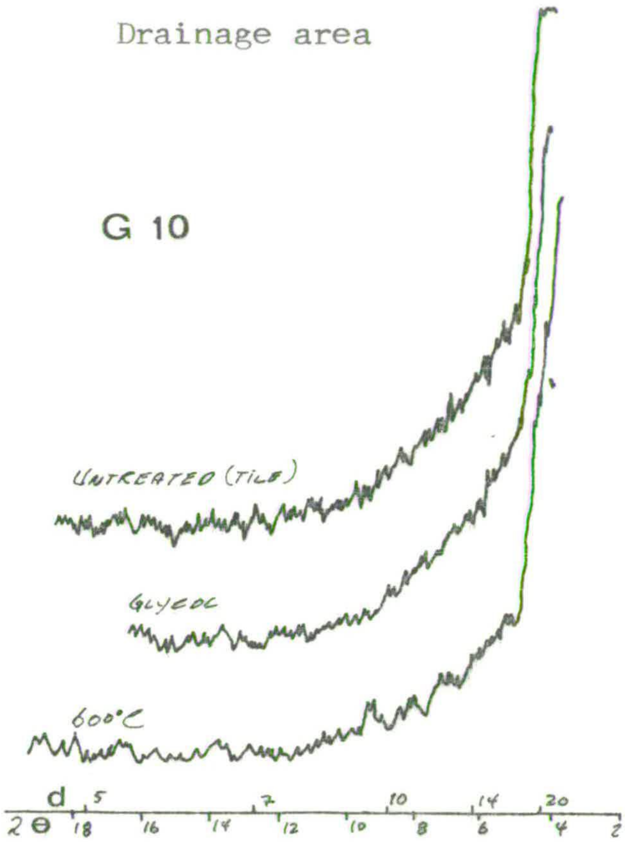
Drainage area



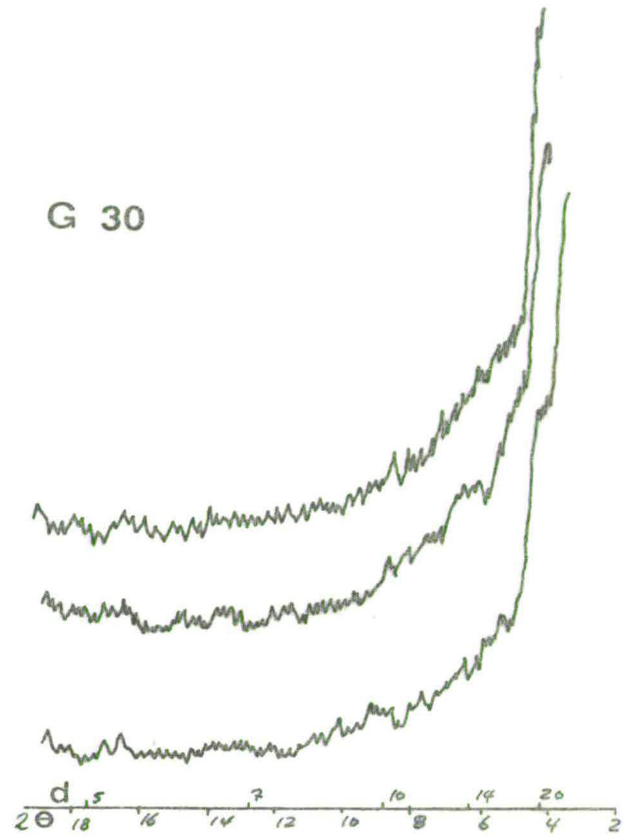


Drainage area

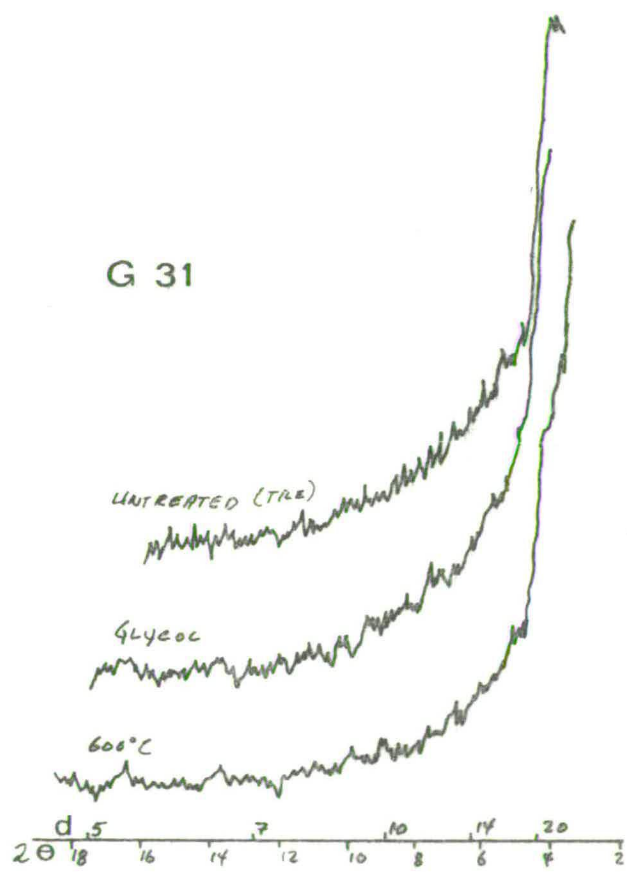
G 10



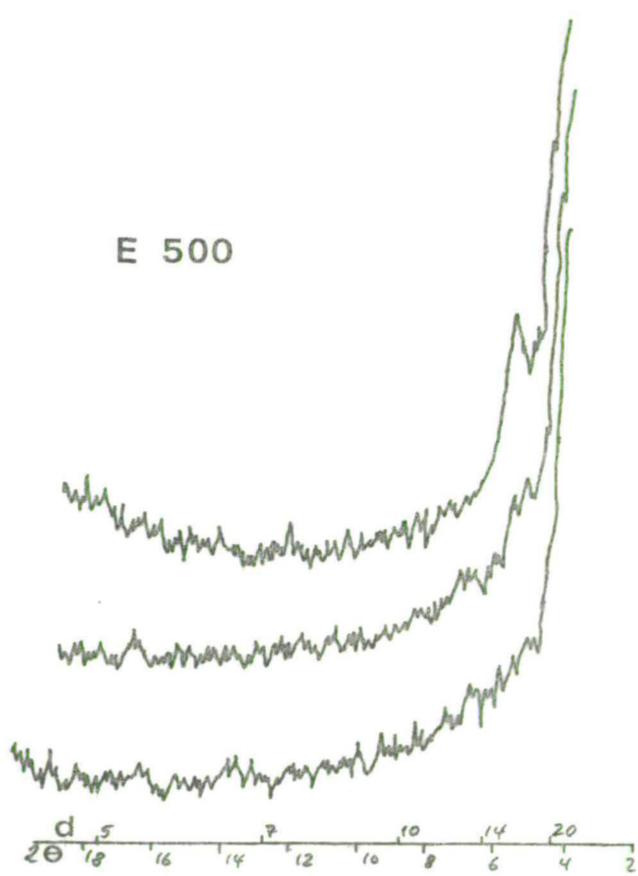
G 30



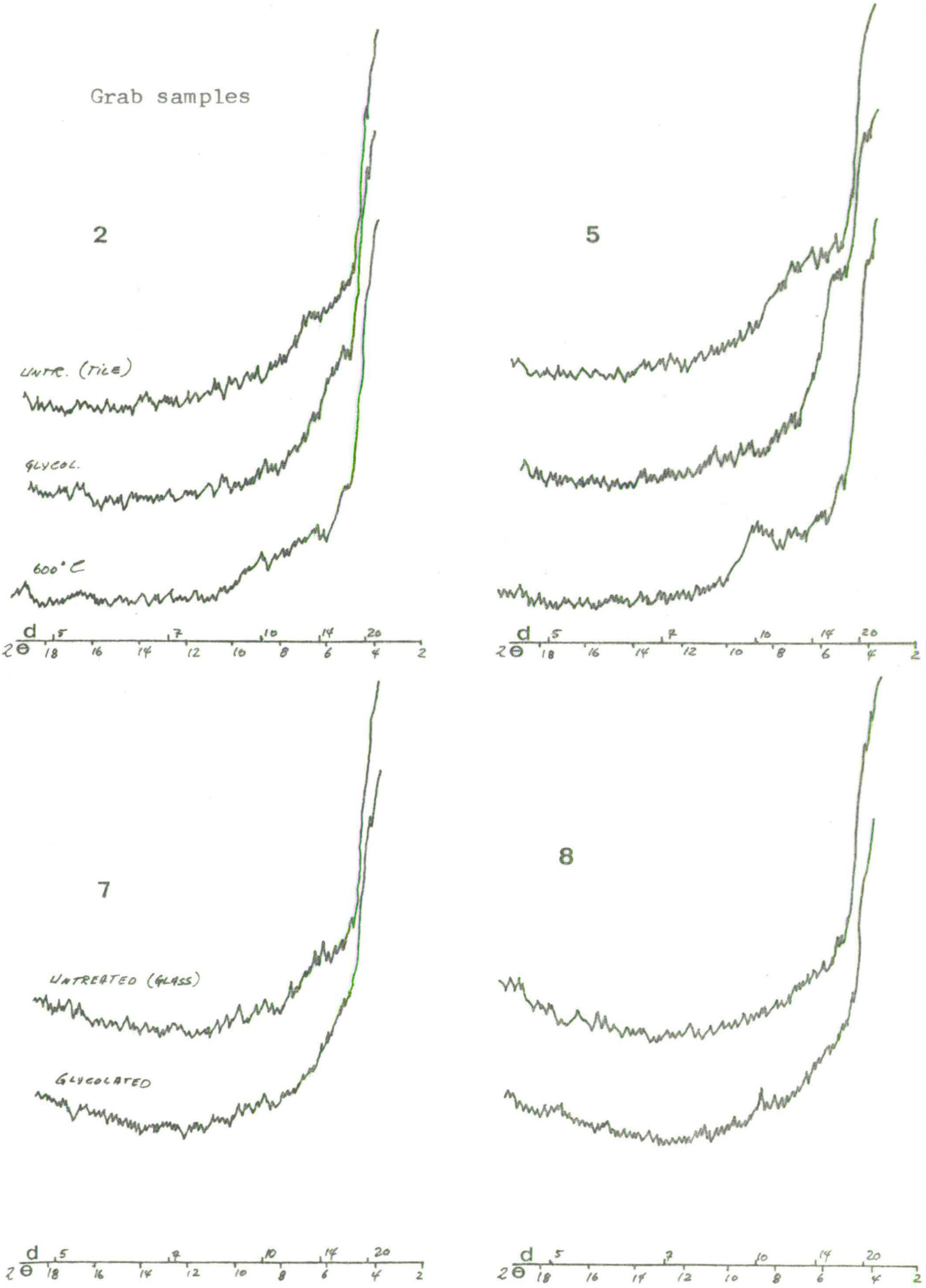
G 31



E 500



Grab samples



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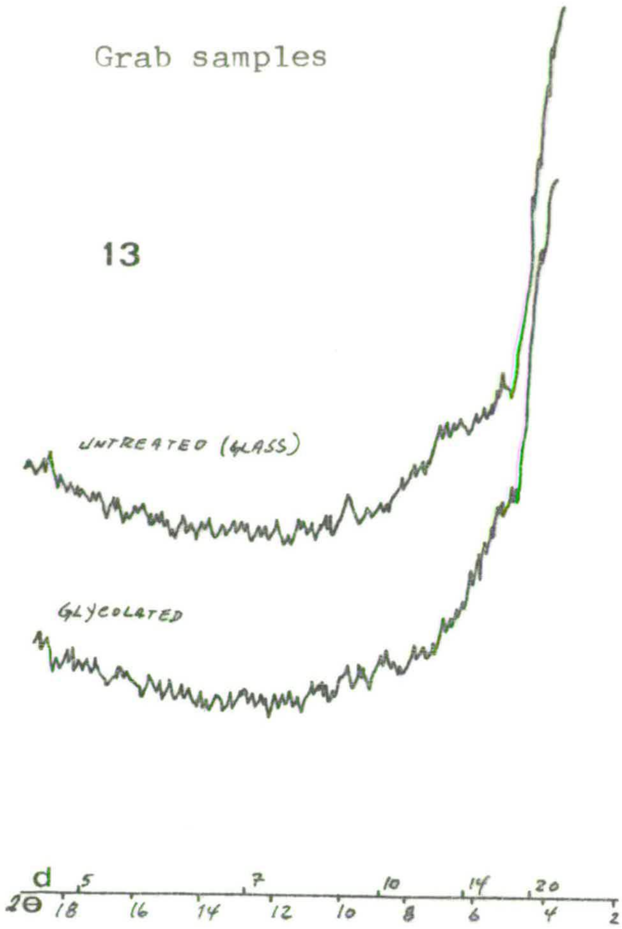
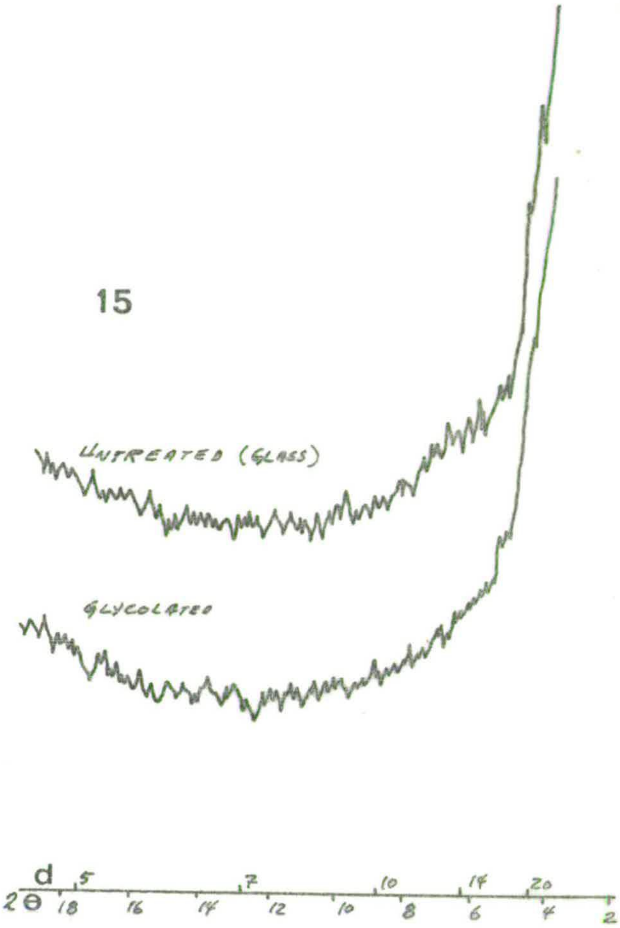
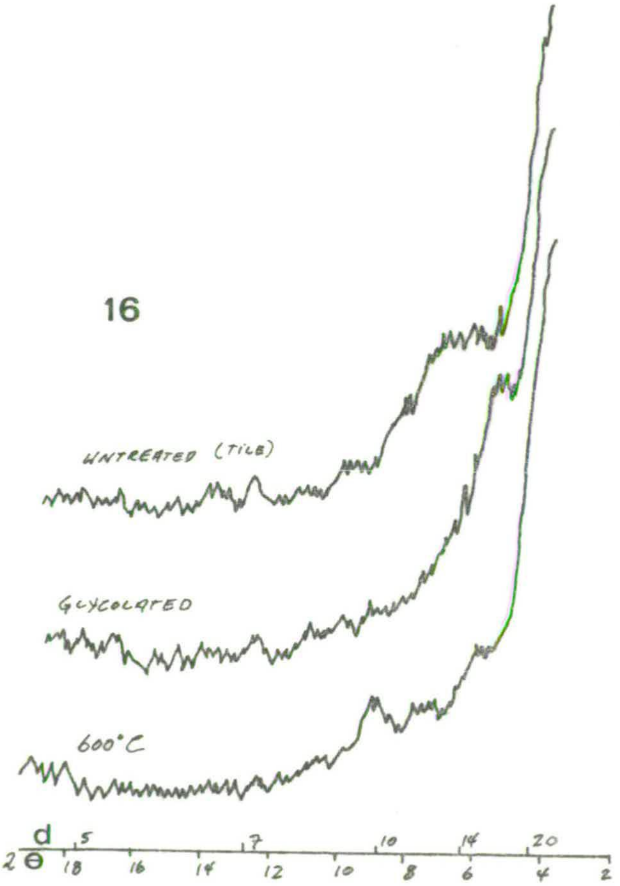
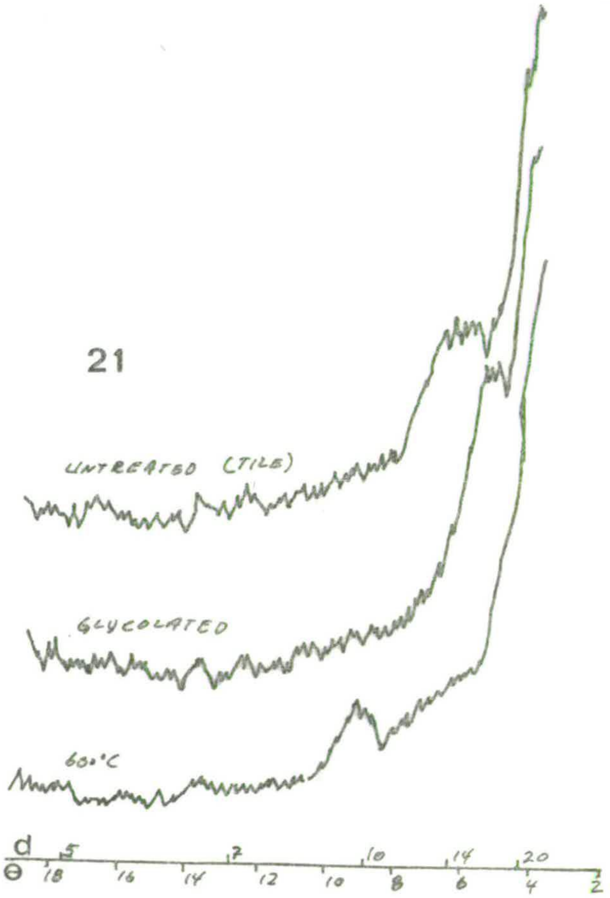
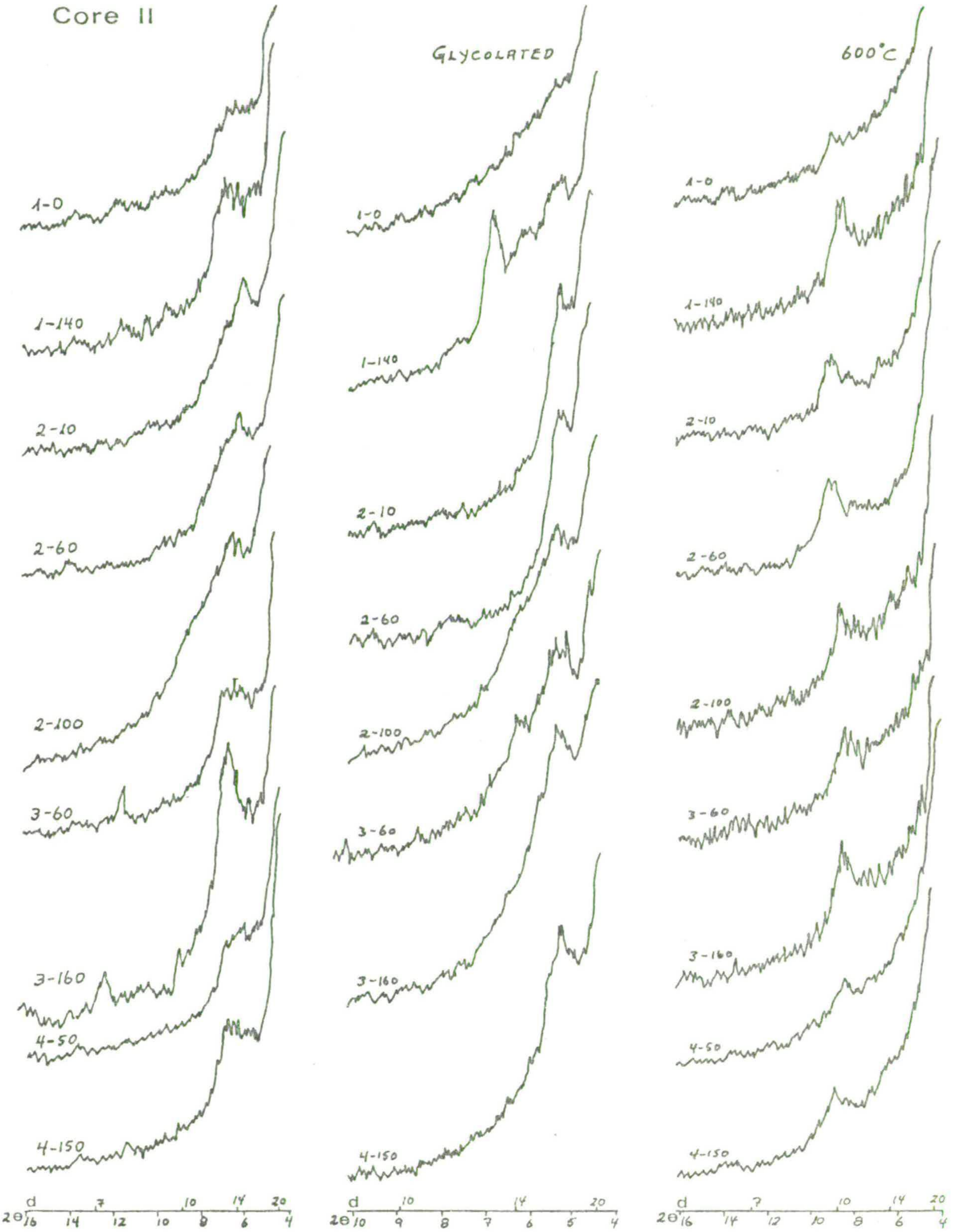
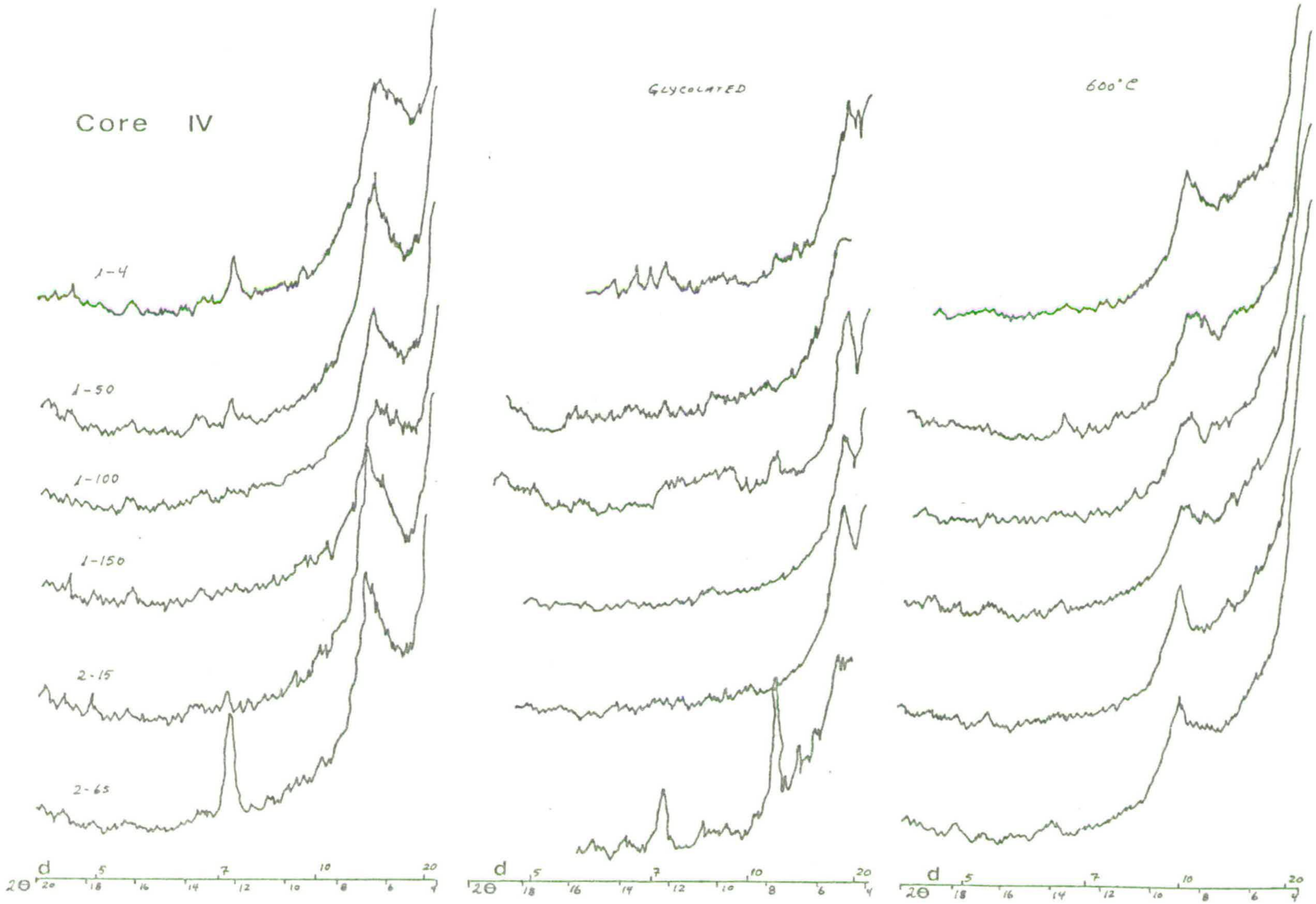


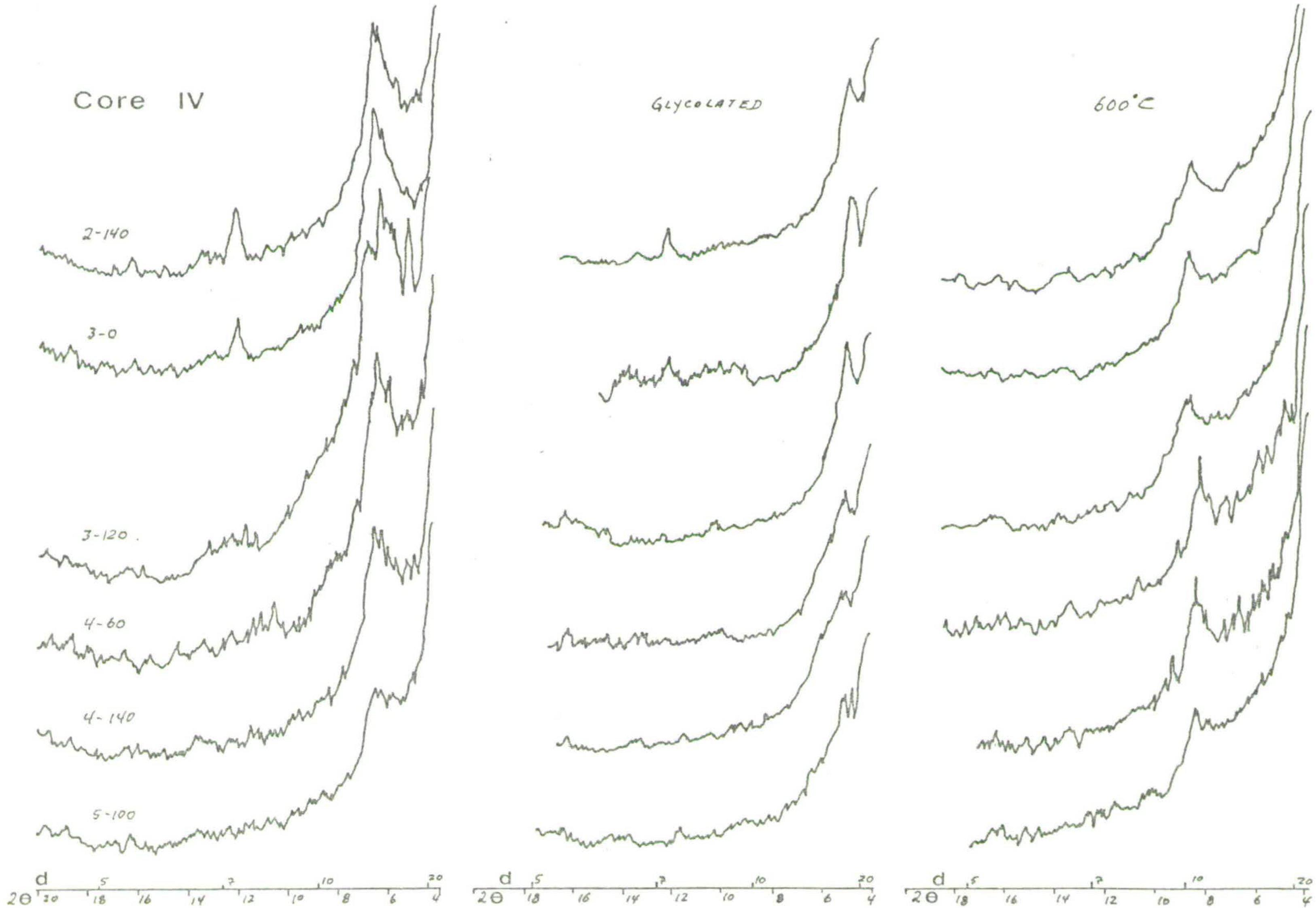


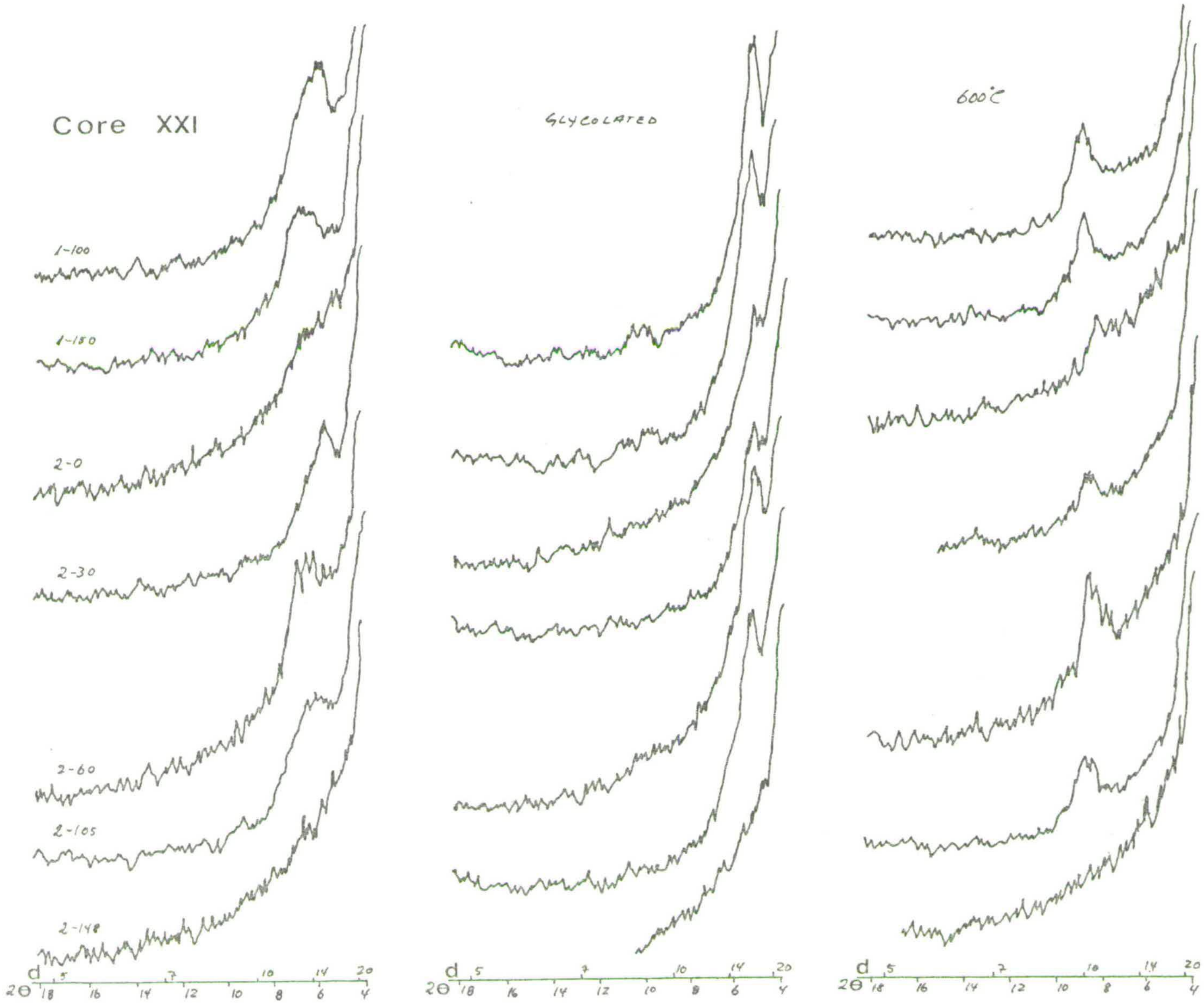


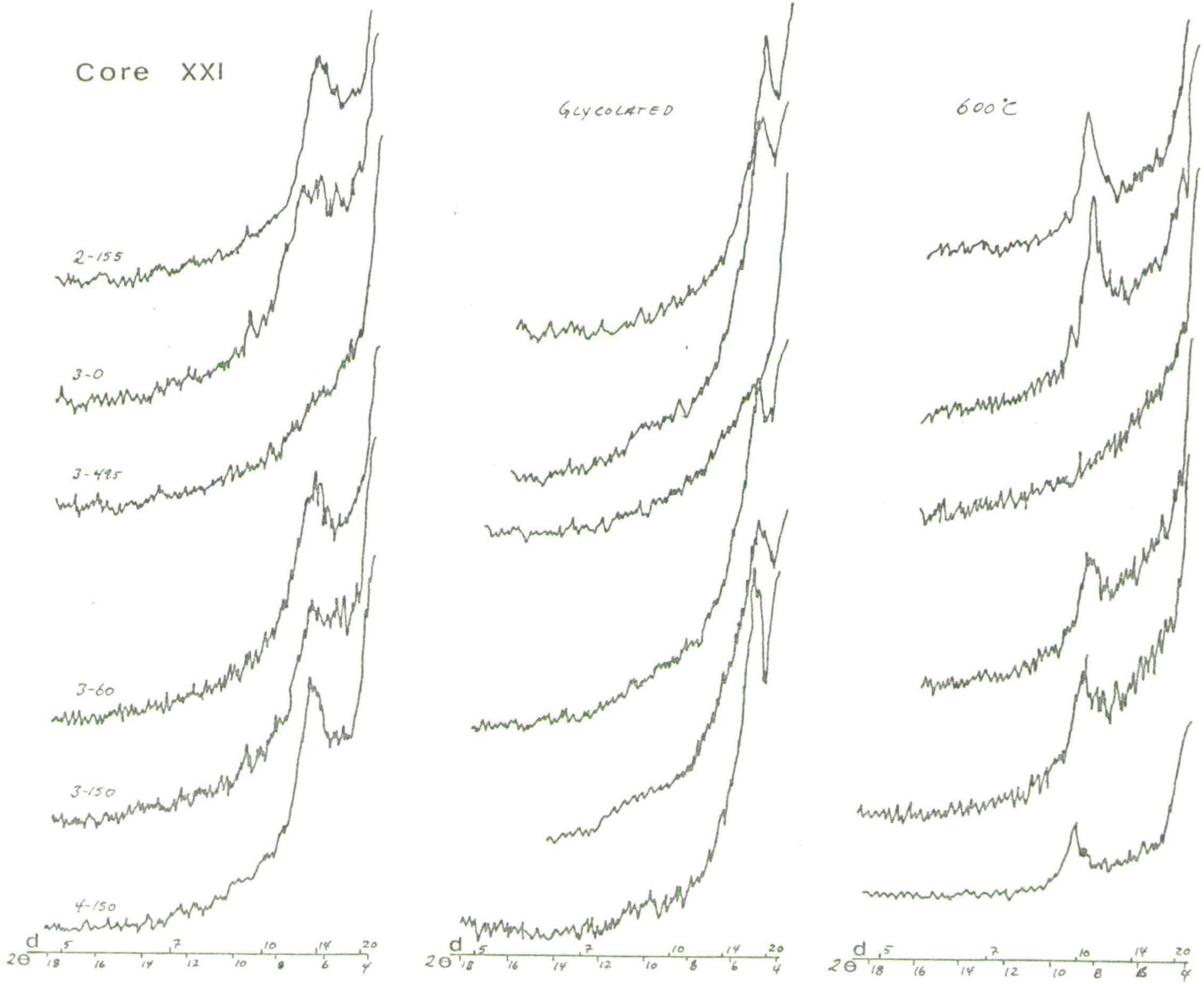



Core II
GLYCOLATED
600°C
1-0
1-140
2-10
2-60
2-100
3-60
3-160
4-50
4-150
d 7 10 14 20
2θ 16 14 12 10 8 6 4
d 10 14 20
2θ 10 9 8 7 6 5 4
d 7 10 14 20
2θ 16 14 12 10 8 6 4


Core IV
GLYCOLATED
600°C
1-4
1-50
1-100
1-150
2-15
2-65
d
2θ


Core IV
GLYCOLATED
600°C
2-140
3-0
3-120
4-60
4-140
5-100
d
2Θ
5
7
10
20
18
16
14
12
8
6
4


Core XXI
GLYCOLATED
600°C
1-100
1-150
2-0
2-30
2-60
2-105
2-148
d 5 7 10 14 20
2θ 18 16 14 12 10 8 6 4


Core XXI
GLYCOLATED
600°C
2-155
3-0
3-49.5
3-60
3-150
4-150
d
2θ
5
7
10
14
20
18
16
14
12
10
8
6
4