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Lithostratigraphy of the upper Tjörnes sequence, North Iceland: The Breidavík Group

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Abstract. The Tjörnes sequence contains four major units, the informal lithozones Kaldakvísl lavas, Tjörnes beds and Höskuldsvík lavas, and the Breidavík Group. Holostratotypes are defined for the Breidavík Group, which is characterized by diamictite beds that alternate with volcaniclastic mudrocks and sandstones, and basaltic lava flows. The vertical rock sequence reveals a repetitive character. Twelve lithological cycles are identified in the coastal sections on Tjörnes peninsula, each one beginning with a diamictite interpreted as lodgement tillite and ending with terrestrial sediments and lava flows. Interbedded fossiliferous marine mudrocks and sandstones indicate repeated marine transgressions in the area following deposition of many of the diamictite sheets. The evidence about the age of the Breidavík Group cycles is reviewed. The oldest cycle is probably less than 2.1 Ma old, and seven of the cycles are older than ca. 1.25 Ma.

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INTRODUCTION

Glacial origin has generally been ascribed to sediments in the uppermost part of the Tjörnes sequence, North Iceland. However, there have been conflicting views on the stratigraphical position and number of glacial horizons, and on the significance of glacial signs in the sequence. Pjetursson (1905) described two lithified "moraine" horizons separated by marine beds interpreted as interglacial deposits in Breidavík, a small bay on the north side of Tjörnes peninsula (Fig. 1). Pjetursson's conclusions were later confirmed by Áskelsson (1935), and an old Quaternary age is given in the Lexique Stratigraphique International (Tryggvason et al. 1956). A stratigraphically lower horizon of glacial sediments in the Furuvík creek was described by Líndal (1964), and later by Th. Einarsson et al. (1967), who demonstrated the presence of nine or ten glacial horizons in the upper Tjörnes sequence, separated by marine sediments and lava flows and suggested that these rocks were of Quaternary age. On the other hand, Bárdarson (1925) and T. Einarsson (1977) have emphasized a Pliocene age of the deposits in Breidavík.

Important questions about the upper Tjörnes sequence concern the number and stratigraphical arrangement of glacial horizons contained in the sequence, and the lithological significance of these glacial horizons as well as interbedded sediments and volcanics. Recent contributions towards a solution of stratigraphical problems on Tjörnes were published by T. Einarsson (1957a, 1957b, 1958, 1963), Strauch (1963), Th. Einarsson et al. (1967), and Geptner (1973, 1977, Akhmetiev et al. 1978). The literature contains widely differing interpretations of lithologies, and some confusion about correlation between outcrops, both in Breidavík and along brook gullies to the south of Breidavík.

A reliable lithostratigraphical classification of any rock sequence is essential for the stratigraphy of an area, and necessary for the interpretation of its geological history. The work presented in this paper was undertaken in the belief that progress in the interpretation of the upper Tjörnes sequence is only possible if based on a firm knowledge of the lithostratigraphy of Tjörnes.

GEOLOGICAL SETTING AND PREVIOUS RESEARCH OF THE TJÖRNES SEQUENCE

Tjörnes peninsula is located near the junction of the zone of rifting and volcanism in North Iceland and the Tjörnes Fracture Zone (Saemundsson 1974, McMaster et al. 1977). Tjörnes was described as a horst by Thoroddsen (1902), and the uplift relative to the area south of the fault swarm at Húsavík was estimated as over 700 m by T. Einarsson (1958). Saemundsson estimated the amount of subsidence in the Axarfjördur trough as 1000 m or more relative to Tjörnes. Th. Einarsson et al. (1967) found that uplift in the southern part of Tjörnes amounted to 500—600 m. The Tjörnes horst exposes a basal unit of Tertiary lava flows (Kaldakvísl lavas, Fig. 3) that have been dated radiometrically (Aronson & Saemundsson 1975, Albertsson 1976). Samples from the Kaldakvísl area yielded ages up to about 10 Ma. The Kaldakvísl lavas are overlain by 500 m thick sediments on the west side of Tjörnes (Bárdarson 1925), but in central and eastern Tjörnes the Tertiary lava unit is truncated by an erosional and angular unconformity (T. Einarsson 1958, Eiríksson 1979). The sediments on the west side of Tjörnes (Tjörnes beds) are conformably overlain by another unit of lava flows (Höskuldsvík lavas), and then by a unit consisting of alternating sediments and lava flows (Breidavík Group). Strata of the two low-

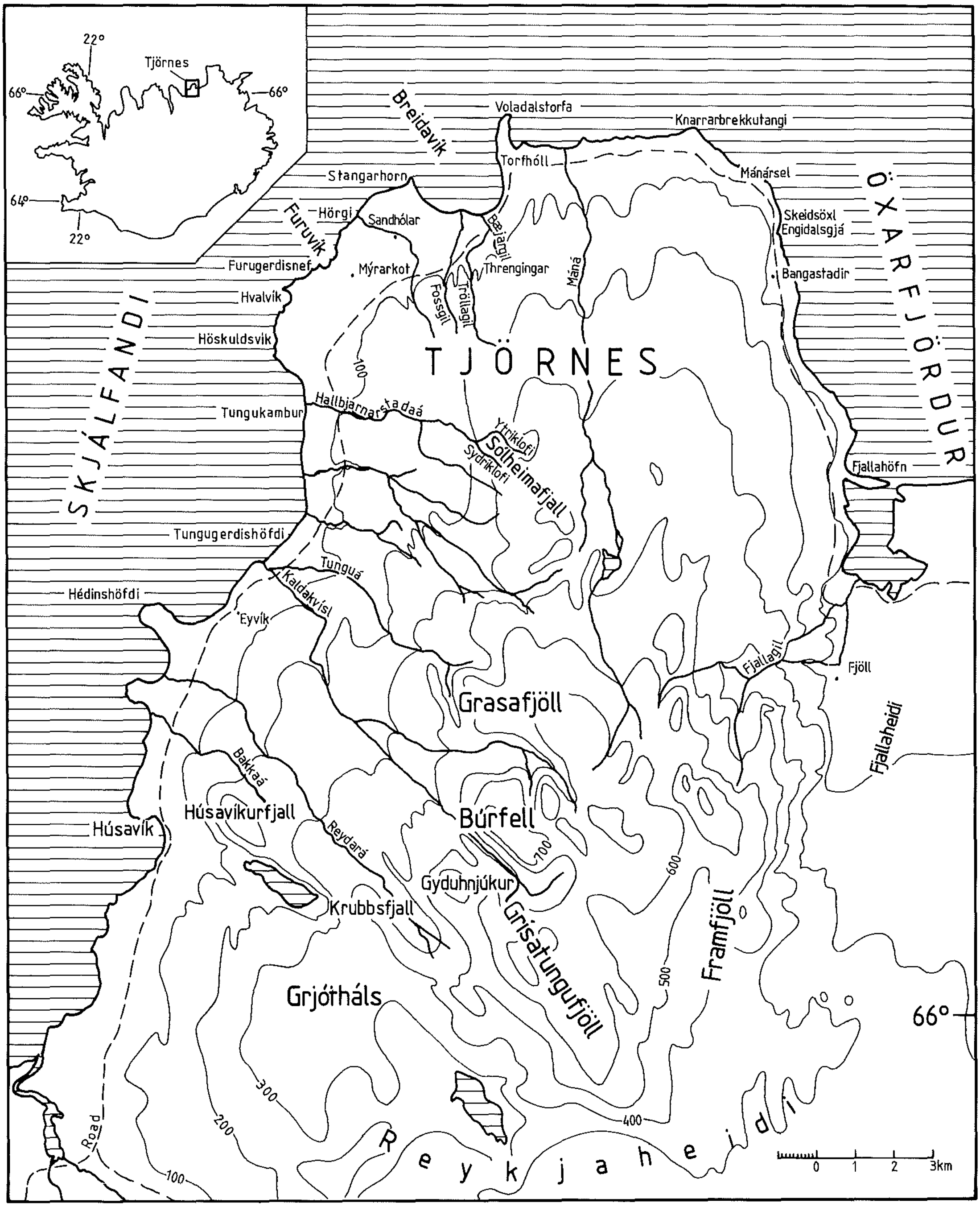

Fig. 1. Location map of Tjörnes.

est formations of the Breidavík Group dip towards northwest, but the erosional plane cutting across the Kaldakvísl lavas in Búrfell, central Tjörnes, reaches sea level in Breidavík. Above the unconformity the dips become northerly and northeasterly. The youngest units of the Breidavík Group on the east side of Tjörnes display irregular dips associated with step faults.

The problem of correlating the Tjörnes sequence with other areas in Iceland has been discussed by several authors. Rocks analogous to the lowest units of the Tjörnes sequence are not exposed in the vicinity of Tjörnes, but palaeomagnetic evidence has been used to correlate the upper units with other units in North Iceland (T. Einarsson 1958, Strauch 1963, Wensink 1964). Áskelsson (1960) correlated the Skammidalur formation in South Iceland with the uppermost part of the Tjörnes beds. The nearest Tertiary lava sequences are located to the west of Skjálfandi.

Tómasson et al. (1969) interpreted borehole sections at Húsavík and concluded that the Tjörnes beds had a subsurface continuation towards south across the Húsavík faults. An alternative interpretation was put forward by Saemundsson (1974), who described the rocks to the south of the Húsavík faults as a plateau basalt sequence with intercalated tillite and hyaloclastite, and inferred an age gap of over 5 Ma across the Húsavík faults. Saemundsson postulated subsidence and westward drift past Tjörnes along the Húsavík faults to explain the age difference.

The research history of Tjörnes was reviewed by Eiríksson (1981). The investigation of rocks here assigned to the Breidavík Group began when Pjetursson (1905) discovered lithified moraines separated by fossiliferous marine sediments in Breidavík. Pjetursson mentioned a moraine at the top of the cliffs between the Tjörnes beds and Breidavík, reaching sea level at one point (Furuvík?). Pjetursson also described a "moraine" intercalated between dolerites and conglomerates in the mountain Búrfell. The relationship between the Tjörnes beds and the deposits in Breidavík remained obscure, however, until Bárdarson (1925) published his study of the Tjörnes sequence. Bárdarson was able to show that the series of lavas between Höskuldsvík and Stangarhorn seemed to be "a continuous formation, younger than the fossiliferous Pliocene deposits on the western side of Tjörnes, but older than the sediments at Breidavík" (Bárdarson 1925, p. 87). Bárdarson divided the Tjörnes beds into three biozones, the basal *Tapes* Zone, the *Mactra* Zone, and the topmost *Serripes* Zone. He described the sediments at Furuvík briefly and suggested that they were partly marine deposits. To Bárdarson the fauna of the Breidavík deposits indicated a Pliocene age. Áskelsson (1935) discovered high arctic mollusc species in the Breidavík deposits and took this to prove their Quaternary age. Later, Áskelsson (1960) compared the fauna of the Quaternary Skammidalur formation in South Iceland with that of the *Serripes* Zone and concluded that the Zone belonged to the Quaternary. Líndal (1964) visited Tjörnes in 1939 and 1941. He described the Furuvík sediments as a possibly marine moraine, and also described moraines in Breidavík and Búrfell. Líndal surveyed the east coast of Tjörnes briefly.

T. Einarsson (1957a, 1957b, 1958, 1963, 1965) investigated the structure of Tjörnes and used palaeomagnetic measurements to map lava units. He identified the angular unconformity beneath the sediments in Breidavík (T. Einarsson 1957b) and found that the youngest rocks on Tjörnes consisted of two groups of lava flows, separated by a moraine-like conglomerate indicating cold climate: an upper, normally magnetized group N1, and a lower, reversely magnetized one R1 that rested conformably on the sediments in Breidavík. The sediments were specified as an upper Pliocene sequence at the unconformity, and the upper part as an early Quaternary sequence. T. Einarsson stated that the Tertiary/Quaternary boundary should be drawn at the base of the R1 (the Quaternary thus spanning the two youngest polarity groups). In a recent paper, T. Einarsson (1977) emphasized a Pliocene age of the Breidavík deposits and emphatically rejected the interpretation that intercalated glacial signs had been produced by Pleistocene ice caps. Instead, he suggested, they were in many cases formed in the vicinity of high, ice capped volcanoes.

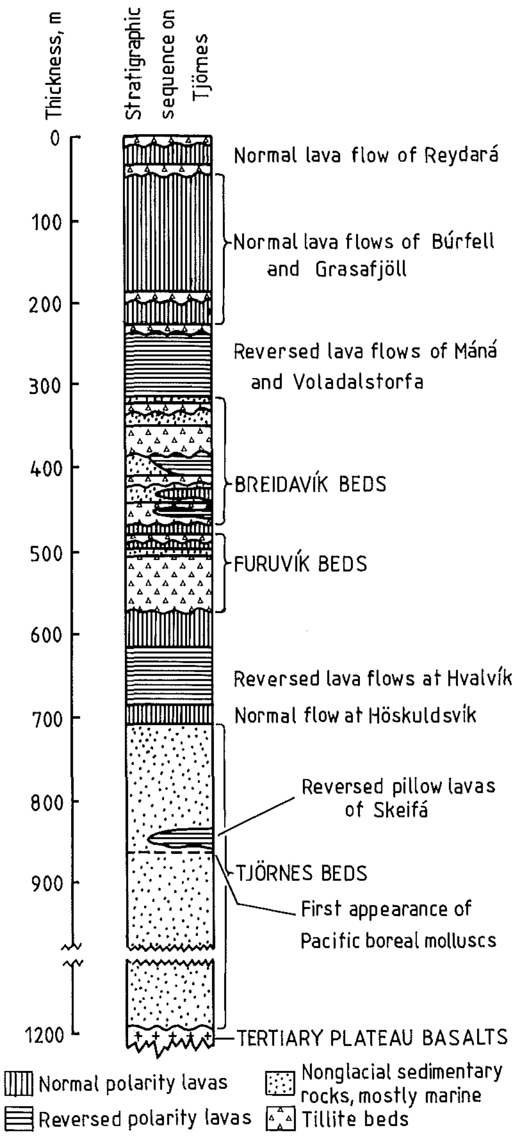

Fig. 2. Columnar section of the Tjörnes sequence after Th. Einarsson et al. 1967.

The Tjörnes sequence was correlated with the palaeomagnetic groups by Wensink (1964), who placed the Breidavík deposits at the base of R1.

Strauch (1963) carried out a detailed study of the stratigraphy and palaeontology of the Tjörnes sequence. He concentrated on the coastal section but studied some of the inland exposures south of Breidavík as well. Strauch considered both the Tjörnes beds and the Breidavík beds to have accumulated in a north-south trending fiord. While he agreed with earlier authors about an early Quaternary age of the deposits in Breidavík, Strauch's interpretation of the stratigraphy in Breidavík was less consistent with earlier contributions. Alternative views and new evidence about this problem were presented by T. Einarsson (1963), Th. Einarsson et al. (1967), Geptner (1973), and Eiríksson (1979).

Hopkins et al. (1965), Th. Einarsson (1966, 1967, 1968, 1969), Th. Einarsson et al. (1967), and Doell (1972) presented results of a reexamination of the Tjörnes sequence including palaeontological and palaeomagnetic studies. Th. Einarsson et al. correlated the *Serripes* Zone of the Tjörnes beds with the Red Crag of England and suggested that the Zone was largely, and perhaps entirely of early Pleistocene age. According to them the oldest record of glaciation in the Tjörnes sequence consists of tillite layers in Furuvík. A comparison with the geomagnetic polarity time scale suggested an age of either 1.9 Ma or between 2.4 and 3.0 Ma for the Furuvík tillites. The authors found evidence of a total of nine or ten glaciations (Fig. 2). Th. Einarsson (1968) correlated the *Mactra/Serripes* Zone boundary with the Gilbert/Gauss reversal and placed the Pliocene/Pleistocene boundary in Iceland at that level. An age of 3.0 to 3.35 Ma was suggested for the boundary.

Several members of the Soviet Geodynamic Expedition in Iceland studied palaeontological and stratigraphical problems on Tjörnes. The results were compiled by Akhmetiev et al. (1978). The lithology and stratigraphy of the Breidavík deposits in particular were studied by Geptner (1973, 1977, Akhmetiev et al. 1978), who verified the existence of tillites in the sequence and contributed towards the solution of stratigraphical problems in Breidavík.

Radiometric ages obtained from lava flows within the Breidavík Group were presented by Albertsson (1976, 1977, 1978), who correlated the Tjörnes sequence with the geomagnetic polarity time scale. Albertsson (1976) concluded that the *Mactra/Serripes* Zone boundary dated from about 3 Ma, and the Furuvík beds from about 2 Ma.

This paper presents a lithostratigraphical scheme for the Tjörnes sequence as exposed along the coasts of Tjörnes and along the brook gullies of Breidavík. The scheme is based on cited previous work, and on mapping and reexamination of the Tjörnes sequence which I undertook in 1975 and 1976. The results were originally presented in my Ph. D. thesis at the University of East Anglia, Norwich (Eiríksson 1979). Geological mapping on the east side of Tjörnes was continued under my supervision in 1979, and in central Tjörnes in 1980. The original scheme for the coastal stratigraphy has been revised in the light of this extended mapping. Information has also been obtained from unpublished reports at the University of Iceland. Reference is made to those in appropriate parts of the text.

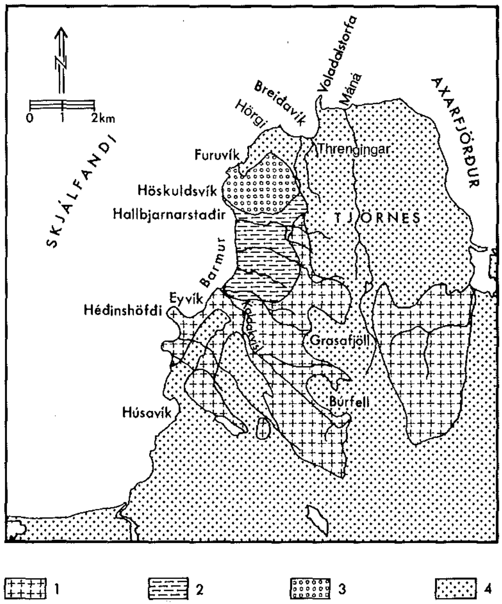

Fig. 3. Areal extent of major lithological units of the Tjörnes sequence. Legend: 1. Kaldakvísl lavas, 2. Tjörnes beds, 3. Höskuldsvík lavas, 4. Breidavík Group (From Eiríksson 1981).

THE TJÖRNES SEQUENCE

The Tjörnes sequence is defined here as the sequence of strata exposed on the surface of Tjörnes peninsula. The southern margin of the peninsula is bounded by Reykjaheidi south of the mountains Grjótháls and Grísatungufjöll, and in the southeast by an escarpment between Fjallaheidi and Framfjöll mountains (Fig. 1). To the west, north, and east, Tjörnes is naturally bounded by the sea.

Traditionally, the Tjörnes sequence has been divided into five informal stratigraphical units. The following subdivision has generally prevailed although nomenclature has varied between authors (from older units to younger): "the Tertiary plateau basalts", "the Tjörnes beds", "the intermediate basalts", "the Breidavík beds", and "the young basalts". Some of the units have been subdivided into horizons or numbered beds.

It is proposed here to adopt a formal lithostratigraphical subdivision of the upper part of the Tjörnes sequence. It is felt that further mapping is needed before a formal scheme can be established for the whole sequence. However, informal units (lithozones) can be defined for the lower part of the Tjörnes sequence. Such lithozones are proposed in Table 1. Particular attention was paid to zone boundaries in the field. Stratigraphical terms proposed here follow the International Stratigraphic Guide by the International Subcommission on Stratigraphic Classification of IUGS Commission on Stratigraphy (1976). It is emphasized that the division is of local significance only and that units should not be directly correlated with conventional units elsewhere in Iceland.

The two lowest units presented in Table 1 are similar to earlier definitions for that part of the sequence. The third unit, however, is reduced here, and the whole upper part of the Tjörnes sequence, from the lowest tillite bed upwards, belongs to the fourth unit, the Breidavík Group. It consists of six formations, each of which contains direct lithological evidence of glaciation.

Table 1. Major lithostratigraphical units of the Tjörnes sequence.

Breidavík Group. Alternating lava flows and thick sedimentary rocks, partly marine. Tillites occur throughout.

Höskuldsvík lavas (lithozone). Lava flows, separated by a few thin sandstone and conglomerate beds. Terrestrial.

Tjörnes beds (lithozone). Fossiliferous sedimentary sequence of alternating marine and terrestrial sandstones, mudrocks, and lignites.

Kaldakvísl lavas (lithozone). Lava flows, commonly separated by thin, red, clayey sandstone beds. Terrestrial.

Areal distribution of rocks belonging to the four major lithostratigraphical units of the Tjörnes sequence is shown in Fig. 3, and a simplified lithostratigraphical column for the Tjörnes sequence in Fig. 4. A summarized outline of the geological relationships and characteristics of the three lowest units (lithozones) of the Tjörnes sequence is given below. This will be followed by a detailed treatment of the Breidavík Group.

The Kaldakvísl lavas

The Kaldakvísl lava zone is the oldest unit on Tjörnes. It is exposed on the west side of the peninsula between Húsavík in the south and the river Kaldakvísl in the north. The mountains Húsavíkurfjall, Krubbsfjall, and Gyduhnjúkur are made up of rocks belonging to the Kaldakvísl zone. In southern Tjörnes the basal part of Grísatungufjöll mountains belongs to this unit, and in the east it is exposed in Framfjöll mountains to the west of the farm Fjöll. The base of the Kaldakvísl zone is not exposed on Tjörnes, and its total thickness is unknown. The geographical term Kaldakvísl was chosen for this unit because the Kaldakvísl river gully reveals good sections through a characteristic part of the zone.

The Kaldakvísl zone consists of basaltic lava flows and thin reddish sedimentary interbeds are common. Vesicles and joints are generally occupied by secondary minerals and the degree of alteration is higher than in lavas of the younger units. The sediments rarely exceed 1 m thickness. Immediately to the south of the river Kaldakvísl steep northwesterly dips are observed in the lava pile. However, the dips are irregular over short distances and are locally affected by numerous faults. In Búrfell the dip is easterly. The upper limit of the Kaldakvísl zone is exposed in eastern Tjörnes at Fjallahöfn, in Búrfell and Grasafjöll, and at the mouth of the river Kaldakvísl. At the two former localities the lavas are uncomformably overlain by rocks of the Breidavík Group, and the boundary represents a hiatus. The uppermost part of the Kaldakvísl lavas is exposed in the coastal section between Hédinshöfdi and the mouth of the Kaldakvísl. Good sections through the zone are also found along the Kaldakvísl gully and in the Fjallagil brook gully of east Tjörnes.

The section at the mouth of the Kaldakvísl was first mentioned in the literature by Pjetursson (1905), who described a pseudoconglomerate at the base of the Crag sediments (Tjörnes beds) at Kaldakvísl. The locality was later investigated by Bárdarson (1925), and has since been a subject of considerable debate in the literature. Bárdarson concluded "that some considerable time must have intervened between the formation of the (underlying) basalt and the first deposits of the Pliocene" (Bárdarson 1925, p. 16).

Later, Bárdarson's main conclusions were supported by Áskelsson (1941) and Líndal (1964).

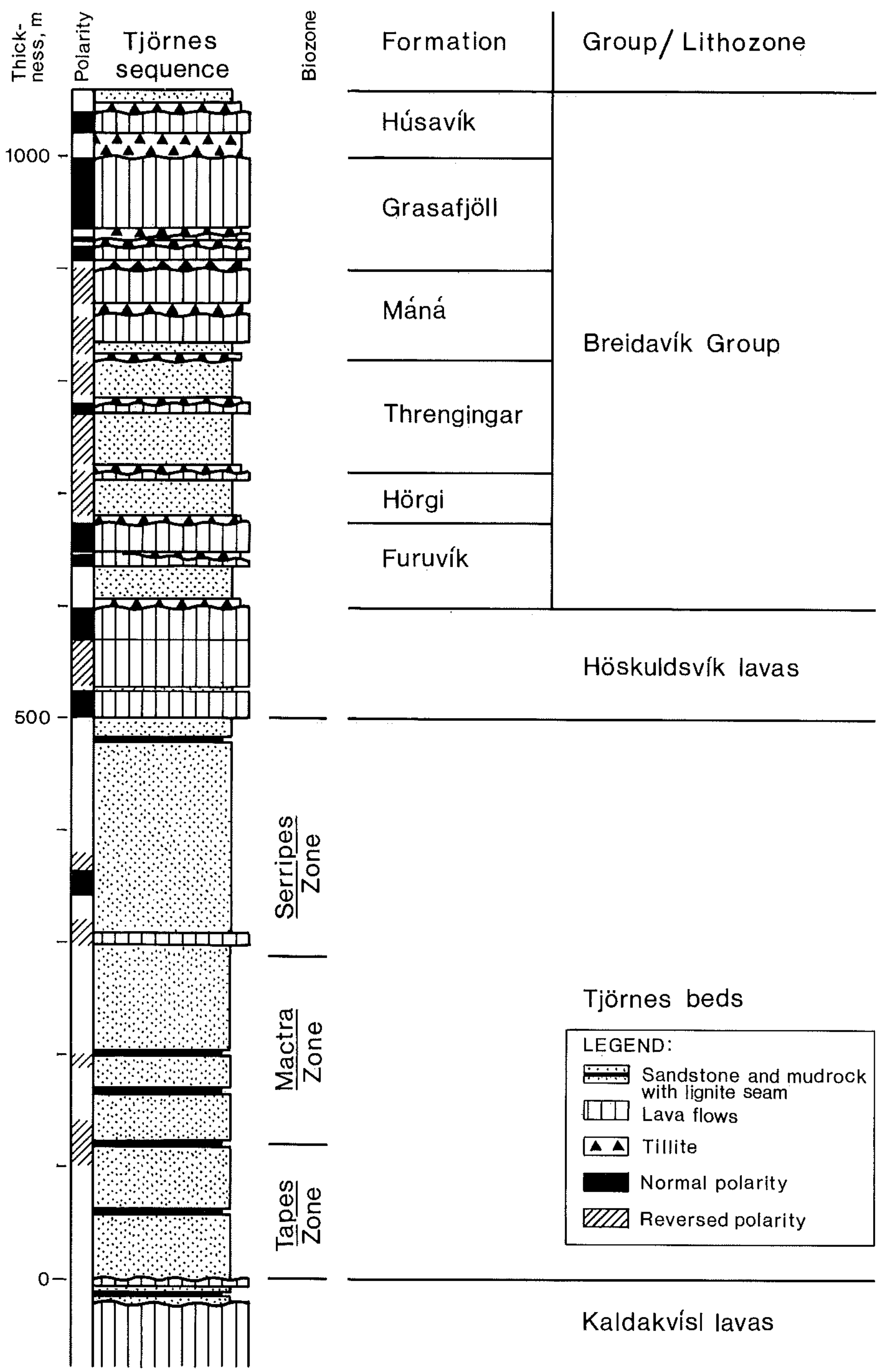

Fig. 4. Composite columnar section of the Tjörnes sequence, based on coastal sections. Palaeomagnetic data from Hospers 1953, Gladenkov & Gurari 1976 and Th. Einarsson et al. 1967 (from Eiríksson 1981).

T. Einarsson (1958) reexamined the Kaldakvísl locality. Based on a study of a section in the spur between the rivers Kaldakvísl and Tunguá, he concluded that a lava flow exposed there had overflowed the lowest part of the Tjörnes beds above Bárdarson's shell horizon 2. T. Einarsson showed that the lava flow beneath the Pliocene sediments to the north of the Kaldakvísl is partly decomposed, possibly due to severe weathering, but he argued that this need not indicate a significant difference in age between the two units. He also pointed out that north of the Kaldakvísl the units are conformable. As to the higher dip values south of the river, he argued that the river Tunguá coincides with a northern boundary of a tectonically disturbed area. The absence of dykes in the Kaldakvísl lava zone (T. Einarsson's Basal basalts) led him to conclude that the zone was of upper Tertiary age. Structural studies of the Tertiary lava pile elsewhere in Iceland have shown that dyke frequency increases downwards in the pile (Walker 1960, Jóhannesson 1975).

Strauch (1963) produced the first geological map of the Kaldakvísl locality. His main conclusions were that sedimentation in the area started with deposition of fluviatile sands and bog formation coupled with an initial subsidence and a lull in volcanism. At least one lava flow reached the area during this terrestrial phase. Gradually, continued subsidence resulted in a transgression only to be interrupted by a final burst of volcanic activity, represented in the section by the second lava horizon within Strauch's West Tjörnes beds. Strauch's findings were challenged by Th. Einarsson et al. (1967) who explained the apparent occurrence of lava flows within the sedimentary sequence as being a result of landslides complicating exposures. Their comments were again discussed and rejected by Strauch (1972). The Kaldakvísl locality was reexamined by myself in 1974 and 1975 (Eiríksson 1979), and it was found that no lava flows occur in the sections above the lowest marine sediments. However, thick sandstones and shales with lignite seams crop out beneath a highly decomposed lava flow succeeded by marine sandstone in the spur between the Tunguá and the Kaldakvísl, where the strata dip NNE.

The boundary between the two lowest lithozones of the Tjörnes sequence at the Kaldakvísl locality is placed at the top of the uppermost lava flow exposed in Tungugerdishöfdi and in the hill between the two rivers. The lava is overlain by conglomerate and marine fossiliferous sandstone above.

Tertiary age of the lava flows and sediments of the Kaldakvísl lava zone has not been questioned. The zone underlies a sedimentary sequence that has generally been assigned to the Pliocene. Saemundsson (1974) estimated the thickness of the plateau lavas of Tjörnes at 1000 m, but the sequence has not been mapped in detail. Radiometric ages range from 4.30 ± 0.17 Ma to 9.9 ± 1.8 Ma for the sequence exposed near the Kaldakvísl (Aronson & Saemundsson 1975, Albertsson 1976). Both sources refer to the values as minimum ages. One of the lava flows of the Kaldakvísl lava zone on the east side of Tjörnes was dated radiometrically at 7.4 ± 0.2 Ma by Albertsson (1976). Aronson and Saemundsson correlated part of the Hédinshöfdi sequence with the Furuvík beds on the basis of radiometric ages, palaeomagnetic data, and sedimentary facies. Preliminary mapping of the area Hédinshöfdi — Kaldakvísl indicates that the correlation is questionable (Hardarson et al. 1978).

The Tjörnes beds

Rocks belonging to the Tjörnes sedimentary lithozone are exposed along the coast north of the Kaldakvísl and in river canyons on the west side of Tjörnes (Fig. 3). Much of the past geological research on Tjörnes has been focused on this unit, commonly known as the Tjörnes beds. The name Tjörnes sedimentary zone has been chosen for the unit because it is by far the thickest sedimentary unit within the Tjörnes sequence, but the informal term Tjörnes beds will be used here as a synonym for the zone. The present definition of the Tjörnes sedimentary zone differs from earlier definitions as far as the base is concerned. Its lower limit is exposed in the spur between the Tunguá and the Kaldakvísl and in Tungugerdishöfdi, where a thin, discontinuous conglomerate overlies a lava flow. The conglomerate is followed by marine sandstone. In Höskuldsvík the Tjörnes beds are conformably overlain by a sequence of lava flows. The uppermost sedimentary bed in the coastal section is an up to 15 m thick non-fossiliferous dark brown sandstone (Bárdarson 1925). This sandstone bed marks the top of the Tjörnes beds.

According to Bárdarson (1925) the Tjörnes beds dip towards NW and reach a total thickness of at least 450 m. Later estimates give a thickness value of 500—550 m and dip values of 5—10° NW (Strauch 1963, Th. Einarsson et al. 1967). The bulk of this thickness is made up of marine fossiliferous sandstones. An intermittent terrestrial or transitional environment is probably indicated by several lignite horizons accompanied by muddy sandstones. A shallow marine to littoral environment has generally been assumed for the mollusc bearing rocks. Bárdarson identified 25 distinct shell horizons, which he numbered 1—25. The ten terrestrial or transitional horizons were designated A—J. Bárdarson grouped the shell horizons into three biozones as described above. His subdivision has been adhered to by subsequent workers on Tjörnes (Áskelsson 1960, Strauch 1963, Th. Einarsson et al. 1967, Gladenkov 1974, Norton 1975), in some cases with modifications.

Pillow lavas occur just above the *Serripes/Mactra* boundary. Palaeomagnetic data obtained from the sediments indicate that the lowest 160 m of the Tjörnes beds are reversely magnetized, and the upper part normally magnetized (Hospers 1953). Additional information about the polarity of the Tjörnes beds was presented by Gladenkov and Gurari (1976), who reported two reversed polarity episodes within the *Serripes* Zone, separated by normal polarity (Fig. 4). This is consistent with an upper Gilbert to Gauss age of the Tjörnes beds, which was already indicated by radiometric ages immediately above and below the zone (2.55 ± 0.27 and 4.30 ± 0.17 Ma respectively, Albertsson 1976). An interpolation from accumulation rates indicates that the pillow lavas should most probably be correlated with either the Kaena or Mammoth event of the Gauss epoch (Albertsson 1976).

The Höskuldsvík lavas

The Höskuldsvík lava zone is characterized by subaerial basaltic lava flows. The areal extent of the zone is shown in Fig. 3. The first detailed survey was made by T. Einarsson (1958) who described individual lava flows and measured their magnetic polarity. This work was extended by Th. Einarsson et al. (1967), who described the zone as follows: "The Tjörnes beds are overlain by a thick lava flow of normal remanent magnetism exposed at Höskuldsvík . . . then by a pair of lava flows of rather obliquely reversed magnetism followed by a clearly reversed flow, and in turn by a thicker sequence of normally magnetized flows exposed at Hvalvík" (p. 317). T. Einarsson (1958) suggested a maximum of eight flows in the zone. According to him the two lowest flows are separated by a 2—3 m thick sandstone bed featuring river gravel at the top. Some of the higher lava flows are separated by fine grained red sediments, up to 2 m thick. No fossils have been observed in the rocks of the Höskuldsvík lava zone. The total thickness probably does not exceed 100 m, but the presence of faults in the coastal section makes this value tentative.

The basal lava flow in Höskuldsvík constitutes the bottom of the Höskuldsvík lava zone. In the coastal section at Furuvík the uppermost lava flow of the zone is discontinous because of a parallel erosional unconformity at the interface with the Breidavík Group rocks above. The boundary is only exposed in the coastal section. Strike and dip measurements at the sole of the uppermost lava flow yielded 40°/10°W. Lava flows in the lowest formation of the Breidavík Group reveal strike and dip of

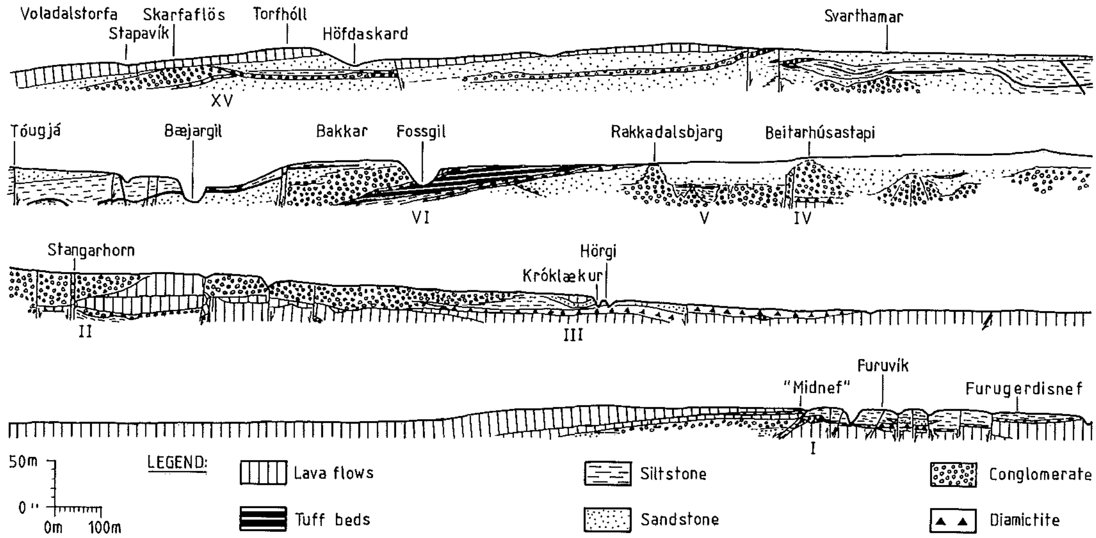

Fig. 5. Coastal section Furuvík-Voladalstorfa. Base of section approximately at sea level. Roman numbers refer to stratotype and hypostratotype sections.

40°/8°W, indicating a structural continuity across the boundary between the two uppermost major units of the Tjörnes sequence. Two radiometric ages from the Höskuldsvík lava zone were considered reliable by Albertsson (1976). The "Höskuldsvík basalt" yielded an age of 2.55 ± 0.27 Ma, and a reversed polarity "Hvalvík basalt" yielded 2.36 ±0.16 Ma. These two ages fix the Gauss/Matuyama polarity reversal within the Höskuldsvík lava zone.

THE BREIDAVÍK GROUP

The three lithozones described above are all composite lithostratigraphical units which contain mappable subunits. Although it is considered premature to give these units a formal ranked status in the lithostratigraphical hierarchy, it is probable that they will materialize as group units in the future. The youngest major unit of the Tjörnes sequence is the Breidavík Group. Its areal distribution is shown in Fig. 3. The Breidavík Group contains diverse lithological elements which occur repeatedly in its component units. It is characterized by sheets of diamictite which occur throughout. The lithologies range from basaltic lava flows, volcanic tuffs, and subglacial/aquatic eruptives to mudrocks, sandstones, conglomerates, and diamictites. All except the very youngest of the Breidavík Group rocks are lithified and form very hard rocks.

The Breidavík Group comprises the whole upper part of the Tjörnes sequence from the lowest diamictite bed in Furuvík up to and including the present soil cover. The Breidavík Group consists of six formations, each of which is conveniently mappable in the field. A detailed survey of the stratigraphy within the Group was carried out during the field seasons 1975 and 1976. Exposures are almost continuous in cliffs along the coast from Furuvík around Tjörnes towards Fjallahöfn, and along the brook gullies Fossgil, Tröllagil, and Baejargil (Fig. 1). Away from the coast, exposures present themselves in the mountains Sólheimafjall, Grasafjöll, and Búrfell, and in the vicinity of Húsavík village. Detailed mapping of central Tjörnes was undertaken in 1980 by students at the University of Iceland. Preliminary results indicate that key horizons will enable a correlation with the type section presented here, and that the central Tjörnes sections may contain additional subunits with diamictite horizons

(A. I. Gudmundsson & S. J. Sigfússon, pers. comm.).

The type section (stratotype) for the Breidavík Group is composite and consists of unit stratotypes for individual formations. A simplified lithostratigraphical column for the Breidavík Group is presented in Fig. 4, but unit stratotypes are defined and described separately for each formation. The geographical term Breidavík was chosen for the group because sea cliffs in the bay of Breidavík expose a thick, characteristic part of the sequence. That part of the Tjörnes sequence has often been informally referred to as the Breidavík beds.

A continuous section was mapped along the coast from Furuvík to Voladalstorfa. This section is presented in Fig. 5. Sections along Fossgil, Tröllagil, and Baejargil were mapped in the same way. The formations of the Breidavík Group are described below. Type sections (holostratotypes) and auxiliary reference sections (hypostratotypes) are presented for each formation. Stratotypes and hypostratotypes have been numbered I, II . . . and individual strata A, B . . . Many of the strata contain recognizable subunits.

Grain size is used to differentiate between individual sedimentary beds in the columnar sections. This property was assessed macroscopically in hand specimens in the field. Twenty-five samples were examined further in thin sections and the classification into sandstones (mean grain size 2.00—0.063 mm) was confirmed. All but the very youngest of the Breidavík sediments are lithified into hard rock, and attempts to disaggregate samples without breaking individual grains and thereby altering the original size distribution were unsuccessful.

The term conglomerate is applied to consolidated sediments consisting of subangular to rounded fragments larger than 2 mm in diameter (Pettijohn 1975). Most of the Breidavík Group conglomerates are moderately to poorly sorted and their matrix may constitute more than 50% of the rock volume. The term diamictite is used to describe rocks which do not have an intact framework of gravel clasts but display instead a dominant matrix of fine grained materials in which the larger clasts are embedded (Pettijohn 1975). The term was introduced by Flint et al. (1960) as a lithified equivalent of diamicton, which they defined as a nongenetic term for "any nonsorted or poorly sorted terrigenous sediment that consists of sand and/or larger particles in a muddy matrix" (Flint et al. 1960, p. 1809).

The composition of the Breidavík Group sandstones was inspected in thin sections. The main components are basaltic volcanic glass and basaltic rock fragments. Plagioclase and pyroxene predominate in the crystal fraction, but olivine, zeolites, and secondary quartz are also present. The matrix of several diamictites was examined in the same way, and found to be of similar composition. The mineralogical composition indicates that the Breidavík Group sediments have been derived from a volcanic source area by erosion and weathering. This is true for all the Furuvík Formation sediments, and is consistent with the predominantly volcanic bedrock composition of Iceland (lava flows and pyroclastics). Sediments of this composition were termed volcaniclastic sediments by Fisher (1961, 1966). In addition, the Hörgi and Threngingar Formations contain fine grained beds which are composed of angular fragments of basaltic volcanic glass with an insignificant amount of rock fragments. These deposits are probably derived from nearby eruptions as tephra (a term introduced by Thorarinsson 1944, 1954), and seem to have suffered only minor reworking.

The Furuvík Formation

Furuvík is a small bay or creek on the northwestern side of Tjörnes. It is accessible by means of a short walk from the farm Mýrarkot off the main road around Tjörnes (Fig. 1). The sea cliffs in Furuvík and northeastwards to Stangarhorn (Fig. 5) reveal a structurally conformable unit of alternating sedimentary rocks and lava flows. The most complete section through this unit is exposed in the Furuvík

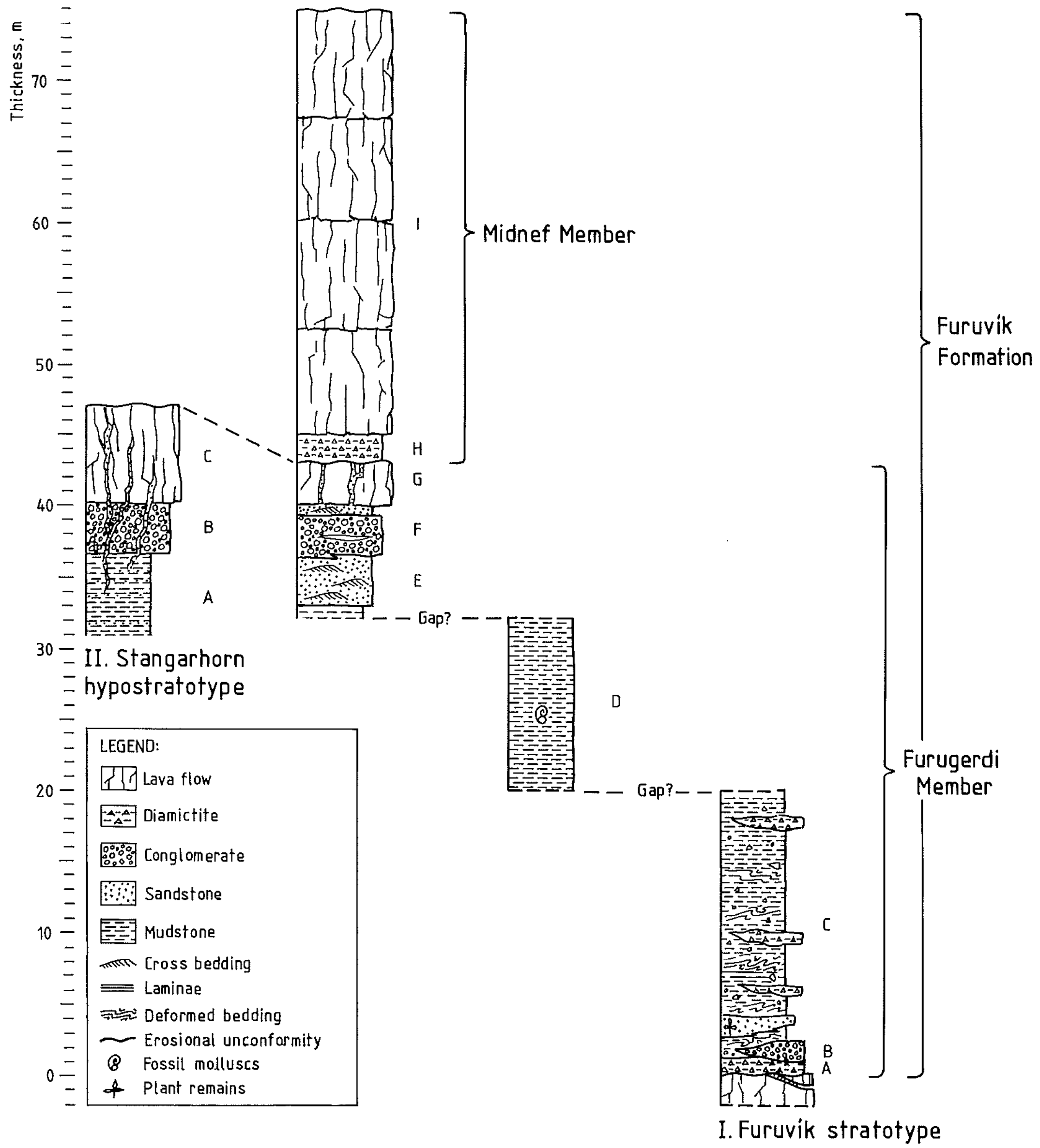

Fig. 6. Stratotype and hypostratotype of the Furuvík Formation.

creek, hence the term Furuvík Formation. It is not seen inland because of unconformable sediments and soil.

The lower boundary of the Furuvík Formation is exposed in Furuvík and in the coastal cliffs to the southeast of the creek (Fig. 5). The lowest stratum of the unit is a diamictite which rests upon an erosional surface of the topmost lava flows of the Höskuldsvík lava zone. The top of the Furuvík Formation is exposed immediately north of the Furuvík creek and consists of a series of thin lava flows without sedimentary intercalations.

The type locality for the Furuvík Formation is the Furuvík creek and its stratotype is made up of the rocks there. The stratotype and a hypostratotype at Stangarhorn are presented in Fig. 6. The exact thickness of the Furuvík Formation cannot be obtained from the stratotype because of two normal faults across which there is no overlap. The stratotype contains two diamictite beds, each of which is eventually followed by subaerial lava flows. The cyclic nature of the sequence is notable already in this lowest unit stratotype of the Breidavík Group. The Furuvík Formation is divided into two member units. The base of each member is defined by a diamictite bed. The lower unit, the Furugerdi Member is named after a small promontory south of Furuvík (Furugerdisnef, Fig. 1). Its basal diamictite is exposed there. The upper unit, the Midnef Member is named after a small crag in the centre of Furuvík (Fig. 5). The lithology of the Furuvík Formation is described in Tables 2 (Furugerdi Member) and 3 (Midnef Member).

Table 2. Lithological description of the Furugerdi Member

I:A. 1—6 m thick sheet shaped diamictite. Maximum thickness in ridges. Rests on an erosional unconformity, upper boundary locally deformed and blurred. Pebbles and boulders up to 1 m in diameter in a silty-sandy matrix. Basaltic lava pebbles predominate, trace of rhyolite and sedimentary pebbles. Locally abundant scoriaceous clasts near base. Streaky appearance due to thin bands enriched in silt and sand. Variations in matrix grain size locally constitute faint bedding near top where deformation structures are also common.

I:B. Up to 5 m thick lenses of medium to poorly sorted cross bedded conglomerate, locally penetrating down through unit *I:A* to solid lava. Largest boulder 1 m in diameter. Sandy-granulous matrix.

I:C. At least 18 m thick laminated siltstone with frequent folds and abundant erratic sand grains, pebbles, and boulders. The erratics are locally found in lenticular concentrations constituting diamictite. The contacts are either sharp or gradational. Unit *I:C* also contains up to 4 m thick wedges of moderately sorted gravelly sandstone with sharp contacts and load structures near the base. The largest wedge contains lignite pebbles and carbonized twigs.

I:D. At least 10 m thick hard, brittle, massive siltstone without erratics. A mold of a closed bivalve was found in this unit.

I:E. Up to 3 m thick coarse pebbly, cross bedded sandstone. Sharp and erosional sole but interfingering top. Basaltic lava pebbles and laminated siltstone pebbles predominate.

I:F. Gradational and interfingering contact with *I:E.* Up to 3 m thick lenticular, moderately sorted, cross bedded pebble conglomerate. Basaltic lava pebbles predominate. Trace of siltstone and sandstone pebbles.

I:G. Regularly jointed normal polarity lava flow revealing ropy structure at base. The top is truncated by an erosional unconformity. Sandstone dykes run vertically through the flow along jointing planes.

II:A. At least 5 m thick laminated siltstone and sandstone. Load structures and folded laminae are common. Numerous sedimentary dykes run through units *II:A, II:B* and *II:C,* some are seen to orginate in *II:A,* others consists of coarse sandstone and granule conglomerate and penetrate all three units.

II:B. Up to 4 m thick, moderately sorted, indistinctly bedded conglomerate with sandstone lenses. Sharp and erosional sole, distinct top. Up to 30 cm pebbles of laminated siltstone occur in the lower part. Point counting on a grid (point and traverse intervals 5 cm, 340 points) yielded the following constituent ratios: sedimentary pebbles 1, basaltic lava pebbles 2.3, matrix 1.7.

II:C. Regularly jointed normal polarity lava flow with glacial striae on the top, which is locally scoriaceous.

Table 3. Lithological description of the Midnef Member

I:H. Up to 2 m thick very poorly sorted conglomerate with angular, striated boulders. Moderately rounded basaltic lava pebbles predominate. The bed rests on an erosional unconformity and wedges out in Furuvík. No internal structures were observed.
I:I. Several thin pahoehoe lava flows that form an interfingering pile without sedimentary intercalations. Aggregate thickness exceeds 30 m.

The Hörgi Formation

The structural uniformity within and between the Tjörnes beds, the Höskuldsvík lavas, and the Furuvík Formation is eventually interrupted at the interface between the Furuvík and Hörgi Formations. This boundary is at the base of a largely sedimentary sequence of rocks, traditionally termed the Breidavík beds.

The type locality for the Hörgi Formation is the coastal section between the brook Króklækur (Fig. 5) and the Fossgil waterfall in the centre of Breidavík. The stratotype for the Hörgi Formation is located fifty metres northeast of the mouth of Króklaekur. The section is accessible on foot from the farm Sandhólar off the main road around Tjörnes. The Formation is named after the small mound Hörgi which is capped by a reversely magnetized lava flow at the mouth of Króklaekur. The stratotype (III) and two hypostratotypes (IV and V) are presented in Fig. 7. Further outcrops are found in the Tröllagil and Fossgil gullies.

The lowest stratum of the Hörgi Formation is a diamictite which rests upon a glacially striated erosional surface. In the coastal section between Hörgi and Breidavík this surface cuts across rocks of the Furuvík Formation. In the mountains Grasafjöll and Búrfell it cuts across the older rocks of the Kaldakvísl lavas. In both cases the erosional substratum reveals a shallow

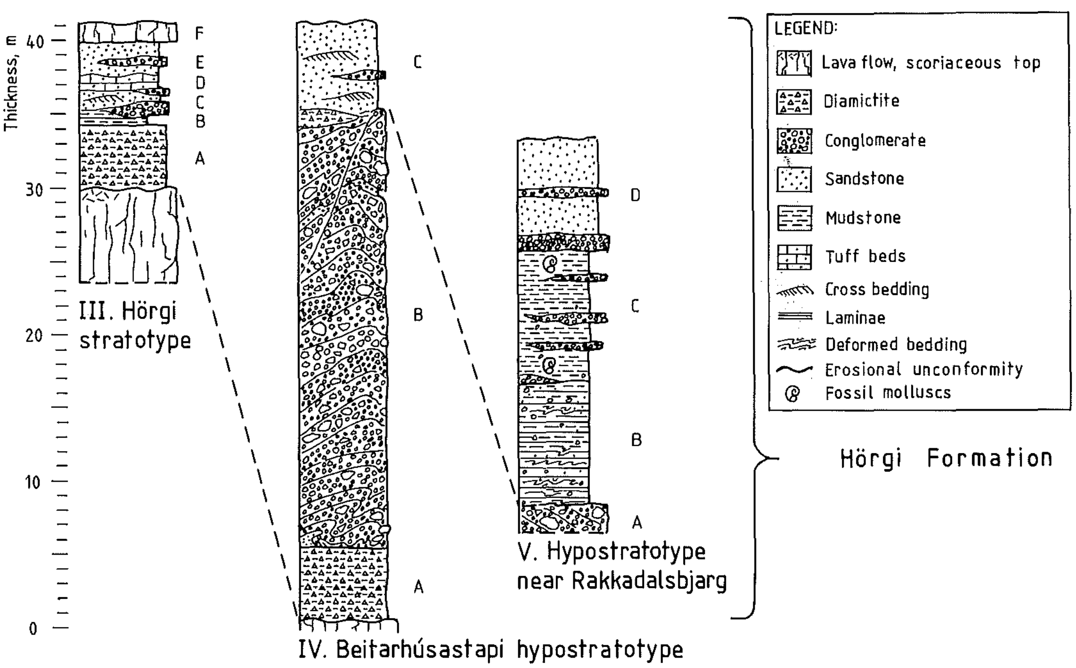

Fig. 7. Stratotype and hypostratotypes of the Hörgi Formation.

valley topography. The basal diamictite is locally replaced by conglomerates. The upper boundary of the Hörgi Formation lies above reversely magnetized lava flows at Hörgi, Fossgil, and Tröllagil.

The Hörgi Formation is truncated by a steep erosional surface in Breidavík just west of the waterfall at Fossgil (Fig. 5). This surface is in turn covered by rocks of the Threngingar Formation. When the erosional surface and the lowest beds of the Threngingar Formation are traced southward along the Fossgil and Tröllagil gullies, a reversely magnetized lava flow crops out beneath the lowest Threngingar Formation beds both in Fossgil and Tröllagil (Fig. 9). The correlation between the Hörgi lava flow and the localized lava outcrops inland is based on the observation that in all the cases the reversed polarity lava flows are succeeded by the lowest Threngingar Formation strata. The lava horizon appears to strike east-west with a northerly dip of 2°.

Table 4. Lithological description of the Hörgi Formation

III:A. Up to 4 m thick diamictite, locally very stony, elsewhere characterized by thin, flat-lying silty bands with diffuse upper and lower limits.
III:B. 30 cm thick laminated, sandy siltstone with erratic pebbles, reaches 8 m thickness in type area.
III:C. Up to 2 m thick lenticular, moderately sorted pebble conglomerate with thin lenses of sandstone.
III:D. Up to 2 m thick lenticular, flat bedded, poorly sorted sandstone, consisting mainly of sand sized basaltic glass fragments. Interfingering contact with lateral sandstone and conglomerates. Erosional top.
III:E. Up to 2 m thick lenticular, flat bedded, pebbly sandstone with thin conglomerate lenses.
III:F. Regularly jointed reversed polarity lava flow.
IV:A. Up to 5 m thick very poorly sorted conglomerate with subrounded and angular boulders in a matrix of pebbles, sand, and silt. Large sedimentary boulders occur. Nearly horizontal bands enriched in sand and silt were observed.
IV:B. Up to 30 m thick but decreases rapidly laterally. Flat and conformable sole. Very poorly sorted, high angle bedded conglomerate, but with moderately to well sorted lenses. Sandy-pebbly matrix. The bedding is typically deformed, folded and faulted. Largest boulders measure 1 m in diameter. Basaltic lava boulders and pebbles predominate but there is a considerable amount of sedimentary pebbles and a trace of rhyolitic ones. Lenses of diamictite are closely associated with the top of IV:B.
IV:C. Over 6 m thick moderately to well sorted, thinly flat bedded sandstone with conglomerate lenses, increasing rapidly in thickness laterally.
V:A. At least 2 m thick poorly sorted conglomerate.
V:B. Up to 8 m thick discontinuous, poorly sorted laminated siltstone with erratic pebbles and sand grains, deformation structures, and numerous small faults. The contact with lateral conglomerates correlated with V:A is steep and intricate, and often collapsed.
V:C. Up to 9 m thick discontinuous, massive, moderately sorted siltstone with erratic pebbles and numerous, up to 1 m thick lenses of conglomerate, partly interfingering with V:A. Fossil molluscs are found both in the siltstone and conglomerate lenses.
V:D. At least 5 m thick flat bedded, coarse sandstone with conglomerate lenses. At the base there is an over 1 m thick conglomerate, locally very rich in angular siltstone clasts. Unit V:D contains fossil molluscs which are not in living positions and have suffered some transport.

Table 5. Fossils from the Furuvík and Hörgi Formations.

Bed	Species
I:D	cf. *Mya (Mya) truncata* Linné
V:C &	*Acmaea (Tectura) rubella* (Fabricius)
V:D	*Natica (Tectonatica) affinis* (Gmelin)
-	cf. *Colus* sp.
-	*Nucula (Leionucula) tenuis* (Montagu)
-	*Nuculana (Nuculana) pernula* (Møller)
-	*Portlandia (Portlandia) arctica* (Gray)
-	*Portlandia (Yoldiella) intermedia* (Sars)
-	*Portlandia (Yoldiella) lenticula* (Møller)
-	*Mytilus (Mytilus) edulis* Linné
-	*Musculus (Musculus) niger* (Gray)
-	*Palliolum (Delectopecten) greenlandicum* (Sowerby)
-	*Astarte (Astarte) crenata* (Gray)
-	*Tridonta (Tridonta) borealis* (Chemnitz)
-	*Tridonta (Tridonta) elliptica* (Brown)
-	*Tridonta (Nicania) montagui* (Dillwyn) var. *striata* (Leach)
-	*Serripes groenlandicus* (Chemnitz)
-	*Macoma (Macoma) calcarea* (Chemnitz)
-	*Hiatella (Hiatella) arctica* (Linné)
-	cf. *Panopea (Panomya) norvegica* (Spengler)
-	*Mya (Mya) truncata* Linné
	Balanus (Balanus) balanus (Linné)

Sources: Eythórsdóttir *et al.* 1980, Eiríksson 1979, Gladenkov 1974.

In his diaries from 1941 Líndal (1964) noted that the lava flows which cover the Breidavík beds in the eastern part of Breidavík and the lava flows above a tillite covering older lava flows in Búrfell were rather similar in appearance, and suggested that they belonged to the same stratigraphical horizon. Such a correlation requires either considerable faults north of Búrfell or an unconformity across the more steeply dipping units beneath the Hörgi Formation. T. Einarsson concluded that "somewhere between Höskuldsvík and the marine Breidavík there is a large unconformity. It probably lies at the base of the Breidavík sediments" (T. Einarsson 1958, p. 7). His conclusion was based on the fact that the reversed polarity lavas in Voladalstorfa can be traced almost continuously to Búrfell. The unconformity cuts across all older units of the Tjörnes sequence.

A description of the lithological features of the Hörgi Formation is presented in Table 4. Marine fossils that have been identified within the Furuvík and Hörgi Formations are listed in Table 5.

The Threngingar Formation

The type area of the Threngingar Formation lies along the coast of Breidavík between Fossgil and Höfdaskard, and along the brook gullies Baejargil, Tröllagil, and Fossgil. The upper reaches of the Bæjargil are called Threngingar, a locality first described by Bárdarson (1925). This name is proposed here for the formation as a whole (Figs. 8, 9, 10).

A continuous section through the Threngingar Formation is exposed in the coastal cliffs of Breidavík (Fig. 5). Good exposures also present themselves along the brooks Fossgil, Tröllagil and Baejargil. Bárdarson (1925) numbered the strata in Breidavík 1—15, beginning with the basalt lava in Stangarhorn (Furuvík Formation) and ending with the lava flow in Voladalstorfa. The Threngingar Formation corresponds aproximately to Bárdarson's horizons 3—12, but it contains strata omitted by Bárdarson and additional strata from inland exposures. Two of the sedimentary horizons, numbered 5 and 9 respectively by Bárdarson, serve as important key horizons.

The holostratotype for the Threngingar Formation is composite. It is divided into two Member units, the Fossgil Member and the Svarthamar Member. No single section contains all subunits. In the coastal cliffs the formation has its base at a northeastward sloping erosional surface west of Fossgil. The slope is conformably covered by the lowest bed of the Fossgil Member, a diamictite (VI B). The slope reaches sea level at the waterfall in Fossgil and truncates the VI A bed (Fig. 11). The composite stratotype and hypostratotypes for the Fossgil Member are presented in Fig. 11. The lithology of the strata is then described in Table 6, and their fossil content is listed in Table 7.

The lowest part of the Threngingar Formation holostratotype is accessible on foot (except at very high tide) along the beach from the mouth of the Baejargil gully at the Breidavík farm (Fig. 1). Three subunits of the stratotype in lower Fossgil (VI B, C & D, corresponding to Bárdarson's 3, 4 & 5) crop out along the gully as

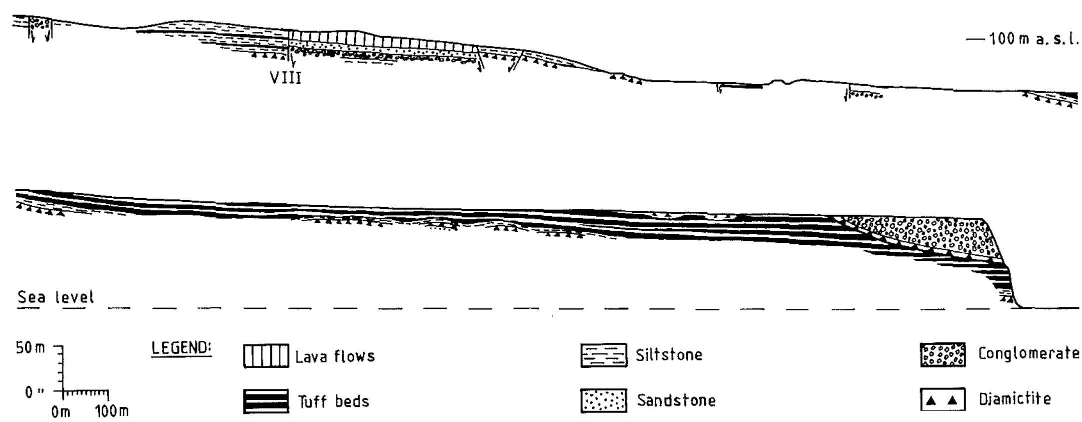

Fig. 8. Section along Fossgil. Base of section follows the brook course. Roman numeral refers to Upper Fossgil hypostratotype.

far south as the main road across Fossgil (Fig. 8). The sandstone VI A (Hörgi Formation) is seen beneath the VI B diamictite in two places. The gully south of the main road reveals a section through beds that are apparently not exposed elsewhere. The section is bounded by faults which define a graben structure. The direction of throw is clear from the relationships in the vicinity of the road across Fossgil, where the unit VI D has been thrown down and is seen at the brook level over a 150 m long stretch. Fig. 8 shows that the graben is traversed twice by the brook course. The amount of throw is probably less than 50 m, but cannot be worked out accurately because the absolute thickness of VI D is unknown at this locality. It is notable that the upper part of the tuff sequence (correlated with VI D) in the section at Sydriklofi becomes increasingly silty towards the top. It is suggested that the unit VIII G in the Fossgil graben corresponds to this upper, silty part of the tuff sequence, and that the sequence VIII G to VIII J (normally magnetized lava flow) belongs above the unit VI D, constituting the top of the Fossgil Member. One could also examine the possibility that the isolated block might correspond to the Stangarhorn hypostratotype (II). This would require a throw of aproximately 200 m at the Fossgil graben faults. Such a large displacement is not borne out by the evidence from the lower traverse across the graben, nor does it seem to fit any observations in the surrounding area. Normally magnetized lava flows are next encountered in the sequence above the Máná Formation. The sequence VIII G-VIII J is proposed as the stratotype for the uppermost portion of the Fossgil Member.

Immediately south of the Fossgil graben the gully exposes a diamictite (VIII A) followed by marine fossiliferous siltstone with sparsely interbedded tuff layers. The section is presented as a hypostratotype in Fig. 11 (VIII A-VIII F) and should be correlated with the base of the Fossgil Member.

Following the Fossgil gully southwards beyond the section in Fig. 8, exposures become discontinuous, but tuff layers crop out from time to time. At an altitude of 200 m in the brook course a diamictite covers a reversely magnetized lava flow. Tuffs crop out just above the diamictite but the contact is not exposed. The diamictite/lava flow contact is considered to represent the boundary between the Threngingar and Hörgi Formations.

In the western slopes of Sólheimafjall mountain, tributaries of the Hallbjarnarstadaá have cut shallow gorges into the bedrock at Ytriklofi and Sydriklofi. A third gully south of Sydriklofi reveals a section, where a diamictite is overlain at an altitude of 240 m by a series of alternating

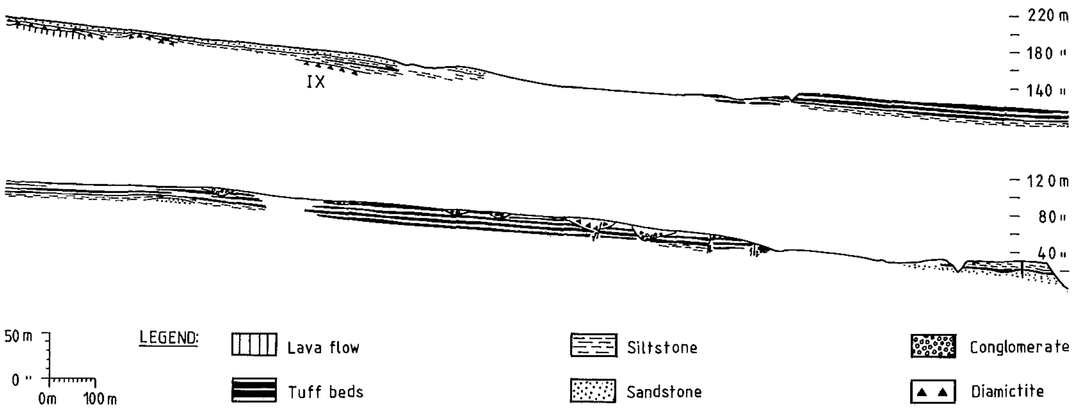

Fig. 9. Section along Tröllagil. Base of section follows the brook course. Altitude above sea level is indicated. Roman number refers to Tröllagil hypostratotype.

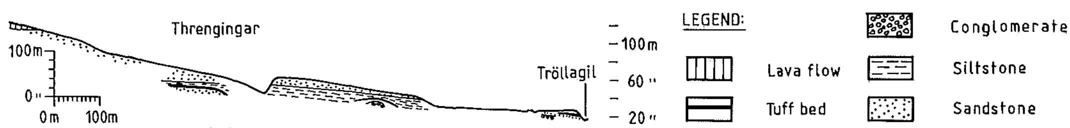

Fig. 10. Section along Baejargil and Threngingar. Base of section follows brook course, altitude above sea level.

tuff and siltstone beds. The Ytriklofi channel reveals only the tuffs and siltstone beds, which reach an altitude of 260 m. This strata sequence is comparable to the lower part of the Fossgil Member in Breidavík and Fossgil. In Sydriklofi the diamictite and the laminated siltstone dip towards west. However, the overlying tuff beds are unconformably banked against the substratum in the same way as in the coastal section (Fig. 5). The westerly dip is therefore interpreted as resulting from topographical relief at the time of deposition. The uppermost part of the Ytriklofi gully is occupied by the Fossgil brook and reveals rocks belonging to the Máná Formation.

Tröllagil is the next gully east of Fossgil in Breidavík. Over a long distance it is eroded into tuff and siltstone beds identical to unit VI D in Fossgil (Fig. 11). In the vicinity of the road the thickness of beds with a high tuff/siltstone ratio is at least 20 m. These are evidently the same tuff layers as the ones exposed in Fossgil because the tuffs crop out at the surface between the two gullies. The tuffs crop out at the present surface over a considerable area thanks to a dip that is almost identical with the present gradient of the brooks.

At an altitude of aproximately 180 m the Tröllagil gully bifurcates. The course of the eastern branch flattens out and disappears some 100 m south of the bifurcation, but the western branch continues for some 600 m towards south. Stratotype IX is located just north of the confluence point (Fig. 11). A lava flow (IX A) is seen at the bottom of the western branch of Tröllagil to the south of a small waterfall. It is irregularly jointed and pillowy, reversely magnetized, and covered by a diamictite. The diamictite is succeeded by a siltstone bed that can be traced along the gully all the way to section IX, where the lowest exposed stratum is a diamictite beneath the siltstone. The tuff beds, which can be traced along Tröllagil up to an altitude of 140 m are not seen with certainty in section IX. However, the western side of Tröllagil just south of the bifurcation, reveals a section where the siltstone IX E is succeeded by a sandstone which consists of redeposited tuff.

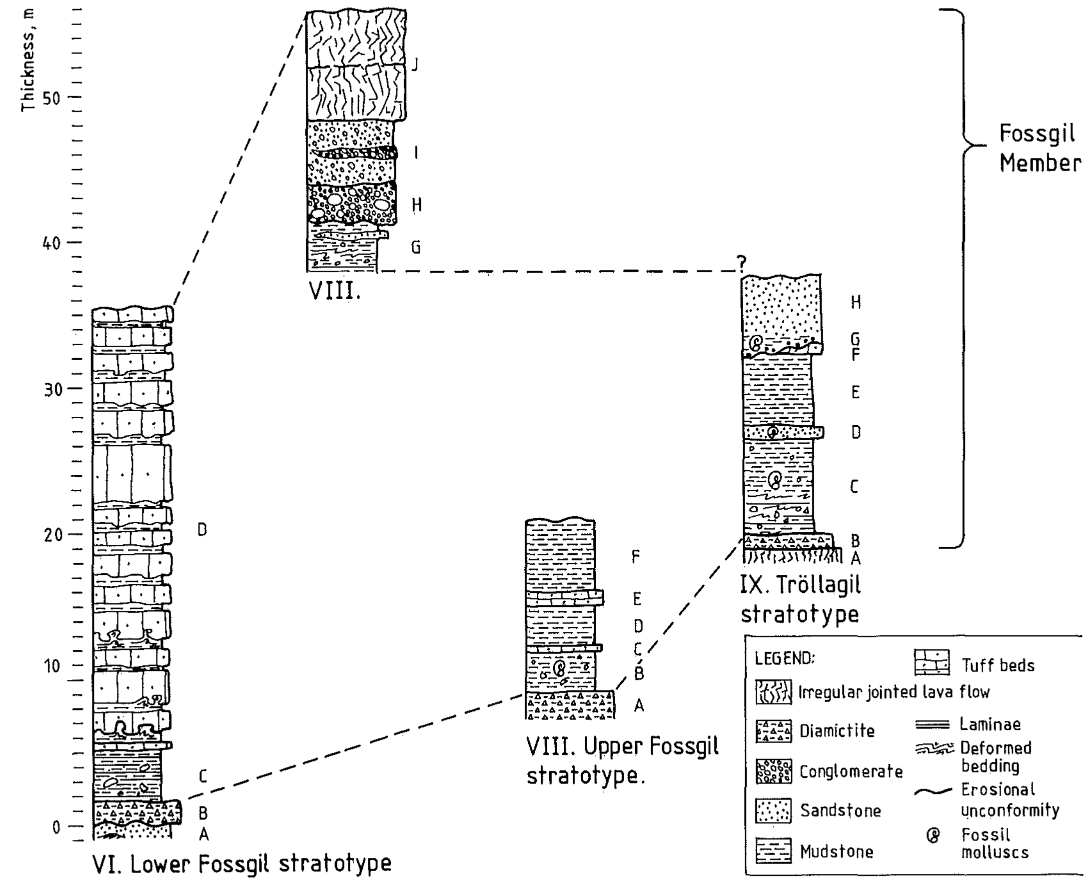

Fig. 11. Stratotype of the Fossgil Member.

In the stratotype itself north of the bifurcation on the eastern side of the gully, the siltstone IX E is followed by marine fossiliferous siltstone and sandstone.

It is concluded that the lava flow of section IX corresponds to the top of the Hörgi Formation (III F, Fig. 7) and that the sequence IX B-IX F should be correlated with the sequence VI B-VI D in the lower Fossgil stratotype. The silt/tuff sequence which is so characteristic for the VI D unit does not have a parallel in the stratotype IX. The sandstone IX H may have been deposited after local erosion and reworking of the tuffs.

The locality of stratotype IX was described by T. Einarsson (1958), who concluded that the strata IX B and IX C corresponded to Bárdarson's (1925) horizons 3 and 4 in Breidavík. T. Einarsson was "practically certain" that the marine deposits higher up in the section represented Bárdarson's horizon 10 (Svartham-ar Member). His conclusion was based on the presence of the species *Mya truncata* and *Macoma calcarea,* and on the absence of *Arctica islandica* in both the horizon 10 and the Tröllagil marine deposits. Since then, *Arctica islandica* has been found in horizon 10 (Gladenkov 1974). It is not considered justifiable to base a correlation on the occurrence of the species *Mya truncata* and *Macoma calcarea.* T. Einarsson later reviewed the correlations between the coastal section and the inland exposures. He stated that there were doubts as to the correlation of the strata, and (referring to Bárdarson's horizons) went on to

Table 6. Lithological description of the Fossgil Member

VI:B. Up to 2.5 m thick diamictite resting on an erosional unconformity. Sharp but non-erosional top displays low relief topography. Basaltic lava boulders (max. diameter over 1 m) and pebbles, often rounded and sometimes striated, predominate and sometimes occur in clusters, but angular sedimentary pebbles are common. Locally distinct banding, upper part platy.
VI:C. Up to 3 m thick thinly bedded to laminated silt- and sandstone with erratic boulders and pebbles, bedding conformable with substratum. Thin tuff beds intercalated in diffuse top.
VI:D. At least 30 m of alternating tuff beds and mudrock. The base is characterized by the appearance of tuff beds in VI:C, which become thicker and more frequent upwards to constitute the bulk of unit VI:D. The top is sharp in this section at an erosional unconformity. The tuff beds consists of black to brown fine-grained basaltic glass. The tuff beds vary from a few cm to a few m in thickness, and lateral variations are common within a bed. Individual beds have a massive appearance. Load casts at the base of tuff beds, and ball and pillow structures are very common. Where the substratum is uneven the tuff layers are banked against the slopes until the topography has been levelled out, after which the tuff layers are essentially flat (with a tectonic dip of 2—3° NE).
VIII:A. Over 1 m thick, massive diamictite with a sharp but non-erosional top. The base is not seen. Angular and subangular basaltic lava pebbles and boulders, up to 40 cm in diameter, predominate over sedimentary ones.
VIII:B. 3 m thick marine fossiliferous, thinly bedded, poorly sorted siltstone with erratics, including rhyolitic pebbles. Bedding severely deformed.
VIII:C. 30 cm thick massive, fine-grained tuff.
VIII:D. 3 m thick irregularly laminated siltstone. Increasingly pebbly and massive towards top.
VIII:E. 1 m thick sandy, upwards coarsening tuff, locally split into subunits by silty lenses.
VIII:F. Over 5 m thick thinly bedded siltstone, partly sandy. Ripple marks in upper part.
VIII:G. Over 3.5 m thick indistinctly laminated siltstone with scattered sand grains and granules. Deformation structures. 50 cm thick flat bedded sandstone bed at 1 m from top, above which the siltstone is regularly laminated and well sorted.
VIII:H. 2.5 m thick well sorted conglomerate, largest boulder 50 cm in diameter, 8—16 cm pebbles predominate. Basaltic lava pebbles except one sedimentary pebble noted.
VIII:I. 4.5 m thick flat bedded coarse pebbly sandstone with up to 30 cm thick conglomerate lenses. Boulders up to 30 cm.
VIII:J. Irregularly jointed normal polarity lava flows.
IX:B. 1 m thick massive diamictite with striated pebbles.
IX:C. 6 m (thinning towards south) laminated, poorly sorted siltstone with sandy lenses and numerous erratics, and marine fossils. Upper part massive.
IX:D. 50 cm medium grained sandstone with shell fragments. Load structures at base.
IX:E. 5 m thick massive, moderately sorted siltstone with occasional thin lenses of sandstone.
IX:F. 1 m thick distinctly bedded fine grained, very hard sandstone, pebbly near base. Main constituent basaltic glass, grades upwards into redeposited, cross bedded tuff with pebbles.
IX:G. Up to 3 m massive siltstone, wedges out in the type area. Abundant marine fossils. A horizon of transported shells is found laterally at an erosional unconformity after the siltstone wedges out towards south.
IX:H. 4 m thick cross-bedded, medium grained sandstone with marine fossils.

suggest that "At the head of Tröllagil is a section with H_8-H_{10}. Apparently on this rests a reverse volcanic breccia covered by a conglomerate (corresponding perhaps to 12x) and sandstone which Strauch thinks is H_{12}" (T. Einarsson 1963, p. 5). The present mapping has shown that the "volcanic breccia" belongs at the base of section IX.

Strauch (1963) also described the locality of section IX, and concluded that the massive conglomerate at the base of the section corresponded to Bárdarson's horizon 2a (III A, Fig. 8), and that the siltstones and sandstones higher up corresponded to Bárdarson's 8, 9, 10 and 12 (Svarthamar Member) in Breidavík. Strauch's suggestion that the conglomerate corresponds to III A is considered unlikely, especially with regard to its position above the reversed polarity lava flow.

The upper part of the Threngingar Formation is well exposed in the sea cliffs of Breidavík between Fossgil and Voladalstorfa and in Threngingar. This part of the sequence constitutes a separate unit, the Svarthamar Member, which is named after a steep conglomerate cliff ("the black cliff") in Breidavík (Fig. 5). The stratotype for the Svarthamar Member is located at the northeastern margin of the Svarthamar cliff. It is accessible by means of a short walk along the beach eastwards from the mouth of the Baejargil gully. The stratotype and hypostratotypes for the Member are presented in Fig. 12, and a lithological description of its beds in Table 8. A list of fossils which have been identified in the Svarthamar Member by various authors has been compiled in Table 9.

The upper boundary of unit VI D (tuff beds, Bárdarson's horizon 5) is generally marked by an erosional unconformity. At the Fossgil waterfall the tuff surface is striated and covered by a diamictite. The erosional surface has a steep northeasterly slope near the waterfall (Figs. 5 & 8), and the diamictite is discontinuous in the coastal section. Immediately above the diamictite (VI E, Fig. 12) there is a thick conglomerate. Bárdarson (1925) did not recognize a separate diamictite bed, but divided the conglomerate (XIV A, VI F) into a coarse lower part, horizon 6, and an upper, fine grained part, horizon 7. The thickness of the conglomerate varies greatly. The thickest bodies are exposed immediately east of Fossgil and in Svarthamar. In Tröllagil there are channel shaped troughs filled with conglomerate carved into the tuff layers (Fig. 9). In the coastal section east of Fossgil the conglomerate becomes finer grained towards the top and sand- and siltstone lenses increase in volume. This finer grained unit (XIV B) can be traced along the coast eastwards beyond Baejargil (at which it becomes fossiliferous) until it disappears beneath sea level to reappear in the vicinity of Svarthamar (XIII B). This unit corresponds to Bárdarson's horizon 8, and its contact with the conglomerate (XIII A, XIV A) is an interfingering one. Unit XIV B (8) becomes increasingly silty towards the top, which is sometimes marked by a tuff bed (although silt continued to accumulate after the eruption of the tuff). Elsewhere, the top of XIV B is marked by an erosional unconformity, and its thickness is variable. This is reflected by the undulating attitude of the tuff bed (9). A second erosional surface indicates that the tuff layer has been swept away by an erosional event that has penetrated into unit XIV B e. g. at Svarthamar, and locally along the Baejargil. The topography which developed during the accumulation of XIII B-XIII C (8—9) and during the initial deposition of XIII D (10), was eventually levelled by the continuing accumulation of the marine mudstone XIII D. A thin, discontinuous tuff band (XIII G) is found intercalated in this mudstone both in Breidavík and Baejargil. Four almost vertical sandstone dykes cut through units XIII B-XIII F (8—9).

Bárdarson (1925) called the Svarthamar conglomerate horizon 11 and mentioned that it looked similar to the horizon 2 conglomerate on the western side of Breidavík. A correlation between these two horizons was later suggested by Strauch (1963). However, it was concluded

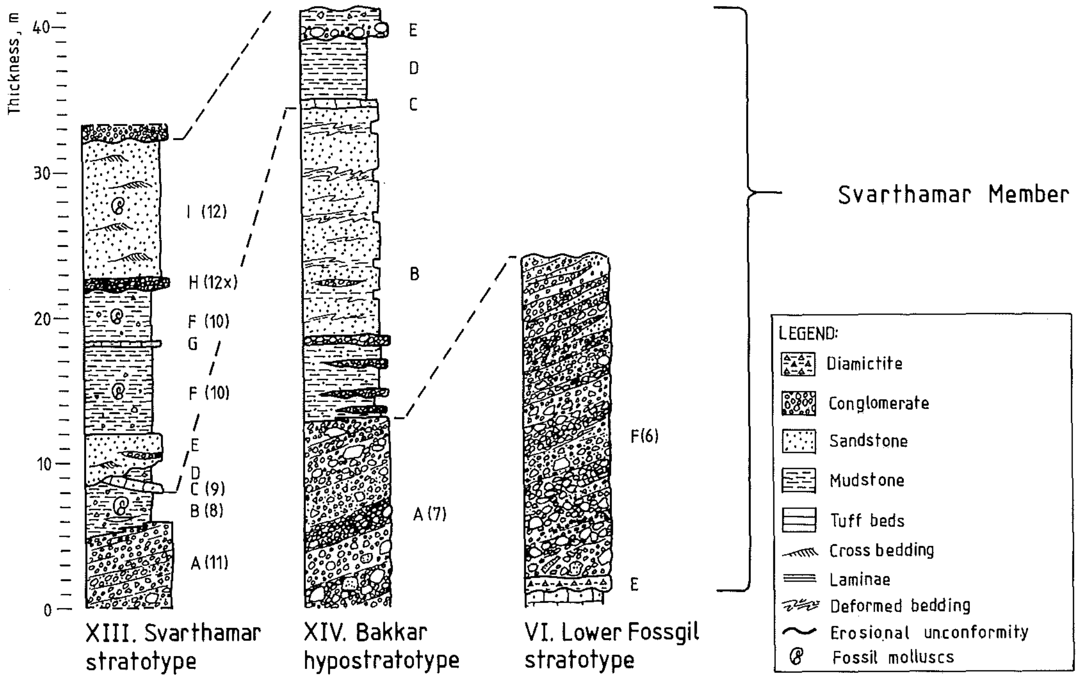

Fig. 12. Stratotypes and hypostratotype of the Svarthamar Member. Numbers in parentheses refer to Bárdarson's (1925) horizons.

by both T. Einarsson (1963) and Geptner (1973) that the Svarthamar conglomerate should be correlated with the conglomerate immediately east of Fossgil. Their conclusion is supported by the present investigation and corroborated by the fact that horizon 9 can be traced across the faults between Baejargil and Fossgil.

The identification of horizon 9 (the tuff bed) in Threngingar places the fossiliferous deposits there within the Svarthamar Member. There is a good agreement between the lithology of these deposits and the corresponding ones in Breidavík. The upper boundary of the Svarthamar Member is defined by the unit XV B (Fig. 14). The unit is cut by an erosional surface exposed in the sea cliffs between Svarthamar and Stapavík (Fig. 5). The unconformity is followed by rocks of the Máná Formation in the coastal section, dipping 4° NE. The Threngingar Formation is wedge shaped and thins out towards south. It appears that the gradual rotation of the direction of dip from NW in the Furuvík Formation rocks to NE in the Máná Formation rocks is completed at the boundary between the Threngingar and Máná Formations.

The Máná Formation

The type area of the Máná Formation is the coastal section from Svarthamar in Breidavík around Voladalstorfa and eastwards to Engidalsgjá near the desolate farm Bangastadir. The rocks of the Máná Formation also crop out in the uppermost part of the Baejargil section above Threngingar (Fig. 10), in Ytriklofi, and in Sólheimafjall (Fig. 1).

The sediments in Breidavík are capped by reversed polarity lava flows which crop out on the northern part of Tjörnes and were named the Máná basalts by Th. Einarsson (1968), and which form a conspicuous part of the lithostratigraphical unit in question. Hence the term Máná Formation. Exposures along the coast become discontinuous immediately east of

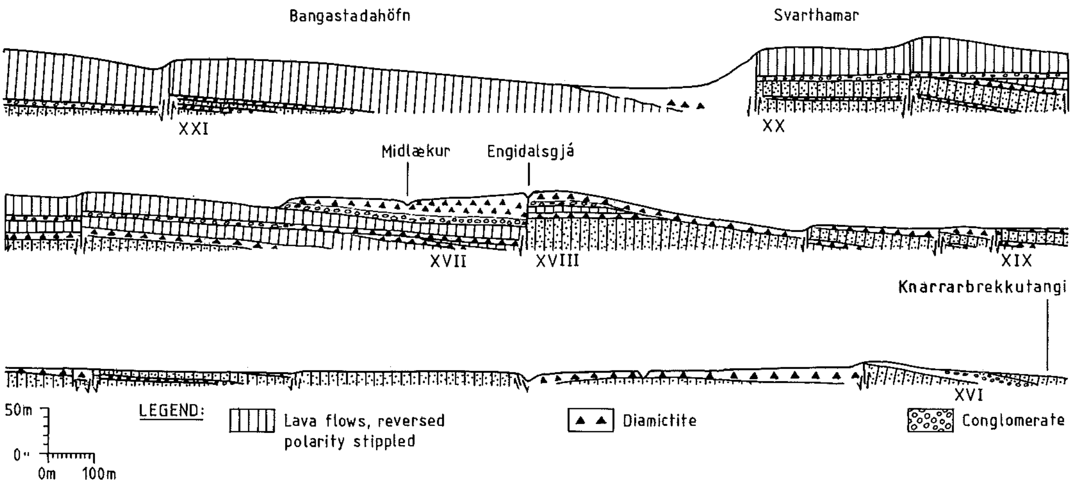

Fig. 13. Coastal section Knarrarbrekkutangi-Bangastadahöfn. Base of section approximately at sea level. Roman numbers refer to stratotype and hypostratotype sections.

Table 7. Fossils from the Fossgil Member.

Bed	Species
VI:C	*Nucula (Leionucula) tenuis* (Montagu)
-	*Macoma (Macoma) calcarea* (Chemnitz)
IX:C	*Nucula (Leionucula) tenuis* (Montagu)
-	*Nuculana (Nuculana) pernula* (Møller)
-	*Portlandia (Portlandia) arctica* (Gray)
-	*Portlandia (Yoldiella) lenticula* (Møller)
-	*Portlandia* sp.
-	cf. *Macoma (Macoma) calcarea* (Chemnitz)
-	Fish vertebrae mold
IX:G	Annelid cast
-	*Natica (Tectonatica) affinis* (Gmelin)
-	Gastropoda sp.
-	*Nuculana (Nuculana) pernula* (Møller)
-	*Tridonta (Tridonta) borealis* (Chemnitz)
-	*Clinocardium ciliatum* (Fabricius)
-	*Serripes groenlandicus* (Chemnitz)
-	*Macoma (Macoma) calcarea* (Chemnitz)
-	*Mya (Mya) truncata* (Linné)
-	*Balanus* sp.

Sources: Axelsdóttir *et al.* 1978, T. Einarsson 1958, Eiríksson 1979, Gudjónsson & Hardardóttir 1980.

Voladalstorfa. The eastern face of the tip is a fault escarpment with downthrow towards east. From Knarrarbrekkutangi eastwards the coastal cliffs steepen again (Fig. 13).

The holostratotype for the Máná Formation is located on the west face of Torfhóll, which is a hill on Voladalstorfa. The whole section can be inspected at low tide. The coastal cliff may be descended with ease at Höfdaskard, and with care at Stapavík (Fig. 5). Two member units are assigned to the Máná Formation here, the Stapavík Member and the Torfhóll Member (Fig. 14). A sequence of lava flows and sediments exposed at Knarrarbrekkutangi and further southeast are also assigned to the Máná Formation.

The base of the Stapavík Member is defined by a diamictite bed (XV C) exposed in Torfhóll and reaching sea level at Skarfaflös in Stapavík (Fig. 5). The diamictite is succeded without an erosional interval by a thick conglomerate. The diamictite and conglomerate are truncated towards south by an erosional unconformity, followed by another conglomerate. This conglomerate contains angular boulders of diamictite that are clearly derived from the Stapavík diamictite. This indicates strongly that the diamictite was already cohesive or even lithified when the conglomerate was deposited and that the unconformity represents a considerable hiatus.

The Torfhóll Member rocks rest directly on the erosional surface that truncates the Stapavík Member in Breidavík. The basal unit in the holostratotype is a cross bedded conglomerate that rests on progressively older rocks towards south (Fig. 5). A lithological description of the Stapavík and Torfhóll Members is presented in

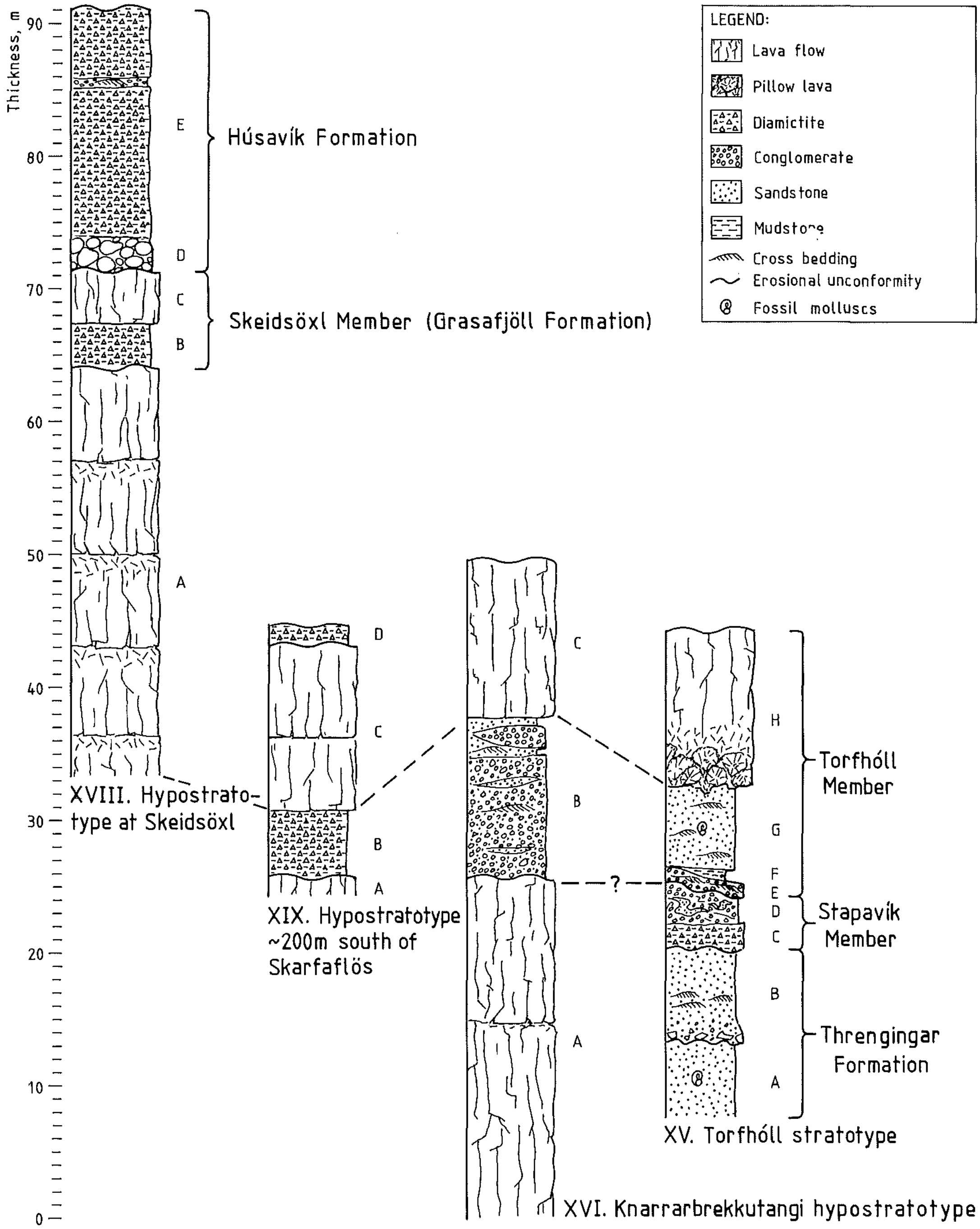

Fig. 14. Stratotype and hypostratotypes of the Máná Formation.

Table 8. Lithological description of the Svarthamar Member

XIII:A. Up to 15 m thick moderately to poorly sorted cross bedded conglomerate. Base not seen, top erosional. Basaltic lava and sedimentary pebbles in approximately equal amounts (30% vol. each). Lateral interfingering with XIII:B.
XIII:B. Up to 3 m laminated and deformed siltstone with fossil molluscs (closed bivalves), locally erosional top. Locally the unit rests on a pebbly sandstone interfingering with XIII:A.
XIII:C. Up to 2 m fine grained dark brown tuff with marine fossils, locally split into a few layers by siltstone lenses. Locally truncated by an erosional unconformity.
XIII:D. Up to 1 m massive siltstone with fossil molluscs. Erosional top.
XIII:E. Up to 3.5 m cross-bedded to flat-bedded coarse sandstone with pebbly lenses, pebbles mainly of laminated siltstone composition.
XIII:F. Up to 35 m massive siltstone with erratic pebbles and boulders and occasional bands of coarse sandstone. Fossil molluscs are common. Becomes pebbly near the contact with XIII:H. Contains the 15 cm thick tuff layer XIII:G.
XIII:H. Up to 4 m thick lenticular, moderately sorted pebble conglomerate with sandstone lenses. The base is erosional where the units rests on XIII:B, C and D, but gradational and interlocked with XIII:F. Top grades into XIII:I. Bands of shell fragments extend from XIII:F into the base of the conglomerate. Up to 50% of the rock volume consists of basaltic lava pebbles, about 15% of sedimentary pebbles, the remaining 35% are made up of shell fragments and sandy matrix. Trace of rhyolite, gneiss and gabbro pebbles (A. R. Geptner, pers. comm.).
XIII:I. 9 m trough cross-bedded medium grained sandstone with fossil molluscs. Thin bands of very hard siltstone occur. In Torfhóll there is an abrupt and irregular erosional break at the top of XIII:I followed by a nonfossiliferous graded bed (XV:B). A string of angular to subrounded intraformational boulders of tuff and siltstone composition constitute the base of that unit, which then grades upwards into flat bedded and cross bedded sandstone.
XIV:A. At least 13 m large scale cross bedded open framework conglomerate with pebbly/sandy interbeds. Sedimentary and tuffaceous boulders over 1 m in diameter.
XIV:B. 22 m wedge shaped coarse sandstone with conglomerate lenses near base, laminated siltstone interbeds becoming more frequent upwards. Deformation structures common. Bedding planes in lower part dip 5° NE.
XIV:C. Up to 40 cm dark brown tuff bed.
XIV:D. 4 m siltstone.
XIV:E. Boulders in a fine grained matrix. Observed from a distance.
VI:E. 1 m streaky diamictite, sedimentary pebbles common. Parallel striae on substratum.
VI:F. 22 m coarse conglomerate with large scale cross beds. Basaltic lava pebbles and boulders tend to be better rounded than the sedimentary ones. Boulders over 1 m in diameter occur.

Table 10, and Table 11 lists fossil species from the rocks of the Torfhóll Member. Two units of marine fossiliferous sandstone are exposed in the coastal section to the north of Höfdaskard. The unit XV G (14) lies above the unconformity that cuts across XV C. The other unit is exposed in Stapavík and also rests on an erosional contact. These marine units are laterally separated by a conglomerate (XV D). Their relative age cannot be established from the section, it is not certain that they rest on the same erosional surface. Both are overlain by a pillowy

Table 9. Fossils from the Svarthamar Member.

Bed	Species	Bed	Species
XIV:B	*Nucula (Leionucula) tenuis* (Montagu)	XIII:I	*Helcion (Ansates) pellucidus* (Linné)
-	*Nuculana (Nuculana) pernula* (Moller)	-	*Margarites* sp.
-	*Tridonta (Tridonta) borealis* (Chemnitz)	-	*Littorina* sp.
-	*Serripes groenlandicus* (Chemnitz)	-	*Epitonium (Boreoscala) greenlandicum* (Perry)
-	*Macoma (Macoma) calcarea* (Chemnitz)	-	*Natica (Tectonatica) affinis* (Gmelin)
-	*Hiatella (Hiatella) arctica* (Linné)	-	*Natica* sp.
-	*Balanus (Balanus) balanus* (Linné)	-	*Thais (Nucella) lapillus* (Linné)
XIII:C	*Nucula (Leionucula) tenuis* (Montagu)	-	? *Buccinum undatum* Linné
-	*Nucula* sp.	-	*Buccinum groenlandicum* Chemnitz
-	*Nuculana (Nuculana) pernula* (Moller)	-	*Nucula (Leionucula) tenuis* (Montagu)
-	? *Nuculana* sp.	-	*Nuculana (Nuculana) pernula* (Moller)
-	*Portlandia (Portlandia) arctica* (Gray)	-	*Mytilus (Mytilus) edulis* Linné
-	*Portlandia* sp.	-	*Modiolus (Modiolus) modiolus* (Linné)
-	*Chlamys* sp.	-	*Chlamys (Chlamys) breidavikensis* MacNeil
-	*Serripes groenlandicus* (Chemnitz)	-	cf. Anomiidae sp.
-	Cardiidae sp.	-	*Tridonta (Tridonta) borealis* (Chemnitz)
-	*Macoma (Macoma) calcarea* (Chemnitz)	-	? *Clinocardium ciliatum* (Fabricius)
XIII:F	*Natica (Tectonatica) affinis* (Gmelin)	-	*Serripes groenlandicus* (Chemnitz)
-	*Cylichna* sp.	-	*Macoma (Macoma) calcarea* (Chemnitz)
-	*Nucula (Leionucula) tenuis* (Montagu)	-	*Macoma* sp.
-	*Nucula* sp.	-	*Arctica islandica* (Linné)
-	*Nuculana (Nuculana) pernula* (Moller)	-	*Hiatella (Hiatella) arctica* (Linné)
-	*Mytilus (Mytilus) edulis* Linné	-	*Panopea (Panomya) norvegica* (Spengler)
-	? *Tridonta (Tridonta) borealis* (Chemnitz)	-	*Cyrtodaria siliqua* (Spengler)
-	*Serripes groenlandicus* (Chemnitz)	-	*Cyrtodaria angusta* (Nyst & Westendorph)
-	*Macoma (Macoma) calcarea* (Chemnitz)	-	*Cyrtodaria* sp.
-	? *Macoma (Macoma) praetenuis* (Woodward)	-	*Mya (Mya) truncata* Linné
-	*Arctica islandica* (Linné)	-	*Mya (Mya) pseudoarenaria* Schlesch
-	*Cyrtodaria angusta* (Nyst & Westendorph)	-	*Mya* sp.
-	*Mya (Mya) truncata* Linné	-	*Balanus (Balanus) balanus* (Linné)
-	*Thracia* sp.	-	*Balanus* sp.

Sources: Áskelsson 1935, Bárdarson 1925, Gladenkov 1974, A.I. Gudmundsson *et al.* 1980, Á. Gudmundsson 1975, Pjetursson 1905, Strauch 1963, Thorsteinsdóttir *et al.* 1976.

lava flow (XV H). The lava flow is also exposed at the head of the Baejargil section above Threngingar (Fig. 10), where it covers marine fossiliferous sandstone, the base of which is not exposed. The flat stretch of the brook course between Threngingar and this top section probably conceals the basal features of the Máná Formation. In the upper reaches of the Fossgil brook (in Ytriklofi) a six metres thick laminated siltstone bed is covered by the Máná basalts at an altitude of just over 300 m. In Sólheimafjall the sequence starts with a laminated siltstone followed by a coarse sandstone which is in turn overlain by the Máná basalts. The lavas dip 4° NE.

The coast east of Voladalstorfa and around Tjörnes towards Fjallahöfn was studied briefly by Líndal (1964), and later by Th. Einarsson et al. (1967). A reconnaissance study of the coastal sections was made by Eiríksson (1979), and detailed mapping commenced in 1979 (Bjarnason 1980, Gísladóttir & Eythórsdóttir 1980). Continuous outcrops present themselves along the coast eastwards from Knarrarbrekkutangi (Fig. 13).

The Grasafjöll Formation

The type area for the Grasafjöll Formation is the coastline on the east side of Tjörnes and the area to the northeast of Grasafjöll and Búrfell mountains. The holostratotype for the formation is located at Engidalsgjá, which is a small ravine cut into the coastal cliffs along a fault on the southeast face of Skeidsöxl (Fig. 13). The name Raudsgjá has been used for this locality in past geological literature. The ravine lies only a few metres from the main road. The

Table 10. Lithological description of the Máná Formation

XV:C. Up to 4 m massive to silt-banded diamictite revealing parallel groove molds on sole striking N2°E and containing internal planes with identical features. Top is non-erosional. The unit is truncated towards south by an erosional unconformity beneath XV:E.
XV:D. Up to 18 m mound-shaped poorly sorted conglomerate with sandstone lenses and common high angle and folded bedding. Sedimentary and basaltic lava pebbles, trace of rhyolite pebbles.
XV:E. Up to 10 m trough cross bedded and flat bedded, moderately sorted conglomerate with sedimentary and basaltic lava pebbles. Grades locally upwards into sandstone. Low relief (20 cm) scour marks on substratum. At one place the bed is severely folded. Striated boulders occur.
XV:F. Up to 4 m thick siltstone, generally massive, but faintly laminated near base, frequent erratics and marine fossils. Gradational top.
XV:G. Up to 14 m faintly cross-bedded fine-grained sandstone with rare erratics. Marine fossils.
XV:H. Reversed polarity, brecciated, plagioclase porphyritic lava flow.

name Grasafjöll has been selected for this formation because it contains normal polarity lava units which are conspicuous on the eastern side of Tjörnes. This succession of lavas was termed the Grasafjöll basalts by Th. Einarsson (1968).

The eastern side of Tjörnes is heavily step-faulted. The general trend of the faults is northerly and the downthrow is to the east. The sequence observed at Engidalsgjá can be followed southwards to Fjallahöfn. The repeated throw at the faults cancels out the effect of the northerly dip of the strata.

Table 11. Fossils from the Torfhóll Member.

Bed	Species
XV:G	*Littorina* sp.
-	*Natica (Tectonatica) affinis* (Gmelin)
-	*Natica* sp.
-	*Buccinum undatum* Linné
-	*Buccinum* sp.
-	*Nucula (Leionucula) tenuis* (Montagu)
-	*Nuculana (Nuculana) pernula* (Møller)
-	*Mytilus (Mytilus) edulis* Linné
-	*Chlamys (Chlamys) breidavikensis* (MacNeil)
-	*Tridonta (Tridonta) borealis* (Chemnitz)
-	*Clinocardium ciliatum* (Fabricius)
-	*Serripes groenlandicus* (Chemnitz)
-	*Macoma (Macoma) calcarea* (Chemnitz)
-	*Macoma* sp.
-	*Arctica islandica* (Linné)
-	*Panopea (Panomya) norvegica* (Spengler)
-	*Cyrtodaria siliqua* (Spengler)
-	*Cyrtodaria angusta* (Nyst & Westendorph)
-	*Mya (Mya) truncata* Linné
-	*Mya (Mya) pseudoarenaria* Schlesch
-	*Balanus (Balanus) balanus* (Linné)
-	*Balanus* sp.

Sources: Bárdarson 1925, Gladenkov 1974, Strauch 1963.

Reversed polarity lava flows are seen on the east side of the fault at Engidalsgjá. These belong to the Máná Formation. The stratotype for the Grasafjöll Formation is presented in Fig. 15. A lithological description of the strata is compiled in Table 12. Three units of the coastal section are assigned to the Grasafjöll Formation: the Midlækur Member, the Skeidsöxl Member, and the Bangastadir Member. The fault at Engidalsgjá has probably been active while the Grasafjöll Formation rocks accumulated as the throw of units at the fault increases with age. As some strata are only found on the downthrow side of the fault it may have been associated with an escarpment, e. g. at the time of formation of the Midlækur and the Bangastadir Members (Fig. 13).

The Midlækur Member consists of a diamictite bed followed by normal polarity lava flows that do not extend across the Engidalsgjá fault (A. I. Gudmundsson & S. J. Sigfússon pers. comm.). The Skeidsöxl Member begins with a diamictite bed that is exposed on both sides of the fault, but the upper unit, a lava flow, wedges out at an erosional unconformity some 130 m south of the Engidalsgjá fault. The Bangastadir Member is only seen to the south of the fault in the sea cliffs. Its basal unit consists of a diamictite followed by a sandstone and

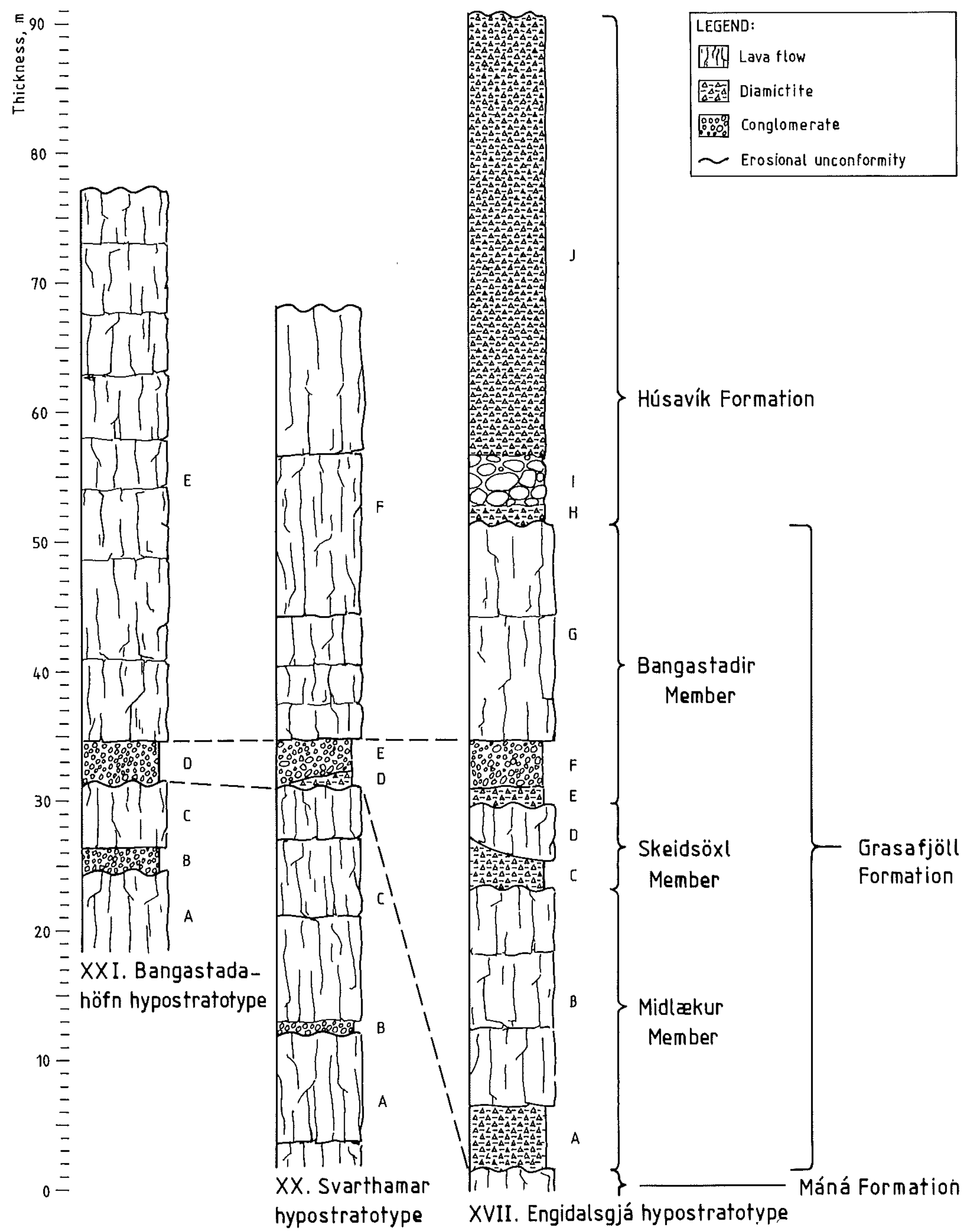

Fig. 15. Stratotype and hypostratotypes of the Grasafjöll Formation.

conglomerates, but the most conspicuous part of the Bangastadir Member is a sequence of porphyritic lava flows of normal polarity. The lava unit is seen in the coastal sections as far south as Fjallahöfn. It is covered by a sandstone bed and then by an olivine porphyritic lava

Table 12. Lithological description of the Grasafjöll Formation

XVII:A. 5 m thick diamictite.
XVII:B. Normal polarity lava flows. Topmost flow with plagioclase and olivine phenocrysts.
XVII:C. 2.5 m thick platy and banded diamictite with grooved internal planes. Lineations parallel to substratum striae (N 23°W).
XVII:D. Normal polarity lava flow.
XVII:E. Up to 5 m diamictite, rich in boulders near base. Silty matrix. Coarse basal part followed by laminated siltstone (discontinuous) with deformation structures.
XVII:F. Up to 4 m thick cross bedded conglomerate with sandstone lenses.
XVII:G. Normal polarity plagioclase porphyritic lava flows.

flow, which represents the top of the Bangastadir Member (A. I. Gudmundsson & S. J. Sigfússon, pers. comm.).

The section at Engidalsgjá is concluded by units assigned to the Húsavík Formation. The boulder conglomerate (XVII I) is also found in the vicinity of Mánársel, where shell fragments are contained in the diamictite above.

The Húsavík Formation

The youngest formation of the Breidavík Group, the Húsavík Formation, was built up after the main features of the present landscape had developed. Rocks and sediments belonging to the Húsavík Formation are found widely on Tjörnes, but were not examined in detail in the present study. The following outline is partly based on the work of Th. Einarsson et al. (1967), who published the most recent description of this part of the Tjörnes sequence. Saemundsson (1974) has mapped the area around Húsavík.

The Húsavík Formation is named after a small bay and a synonymous town, Húsavík, on the east side of Skjálfandi Bay (Fig. 1). The town is sheltered to the north by the 70 m high hill Húsavíkurhöfdi, which is made up of the so called Húsavík tillite. Many of the minor morphological features of the lowlands north of Húsavík have been carved into this thick, lithified diamictite, which also has a conspicuous equivalent near Bangastadir.

Apparently the Húsavík Formation consists of two distinct subunits. The younger one is made up of till and gravels from the last glaciation and Lateglacial marine deposits as well as soils younger than the last glaciation. Rocks of the older unit are found e. g. along the course of the river Bakkaá (Fig. 1). Lava flows of the Kaldakvísl zone form the substratum of a 10 m thick diamictite. It is very bouldery, many of the boulders are derived from the underlying Kaldakvísl zone basalts. The diamictite is covered by a tuffaceous breccia, which grades upwards into a normal polarity lava flow, which probably originated from the interglacial shield volcano Grjótháls southeast of Húsavík. The top of the lava flow is glacially striated. The diamictite at Bakkaá is locally penetrated by normal polarity sills, which are probably related to the lava flow above. If that is a correct assumption, the diamictite must have been soft at the time of the Grjótháls eruption. A sketch of the Bakkaá locality was published by T. Einarsson (1958) with a description. A similar section is exposed along the river Reydará. Gladenkov (1974) has published a list of fossils collected from unconsolidated sediments (of presumed Lateglacial age) at the mouth of the river Hallbjarnarstadaá. The list is reproduced in Table 13.

Table 13. Fossils from the Húsavík Formation.

Nucula (Leionucula) tenuis (Montagu)
Portlandia (Portlandia) arctica (Gray)
Mytilus (Mytilus) edulis Linné
Tridonta (Tridonta) borealis (Chemnitz)
Macoma (Macoma) calcarea (Chemnitz)

Source: Gladenkov 1974. Locality: Tungukambur, near section top.

DISCUSSION

A vertical section through the Breidavík Group rocks reveals a distinct repetitive pattern. The sequence of lithologies within the group was used by Eiríksson (1979) to reconstruct the geological history of the area. Twelve lithological cycles appear in the coastal exposures of the Breidavík Group. Although an analysis of the genesis of the Breidavík Group rocks is beyond the scope of the present paper, the implications of lithologies and fossils may be summarized as the sequence of events has now been established. A clear distinction must be made between lithological cyclicity and climatological cyclicity during the Late Cainozoic ice age. The lithological evidence about climate may be severely limited in that the appearance of a rock facies or an erosional surface in a section only indicates that certain events did happen, but not necessarily the degree or range of the events. A sheet of till in a given sequence is thus evidence of a glacial event in that area, but yields very little evidence about the duration or extent of the glacier advance. Conversely, a series of subaerial lava flows in a sequence indicates that the area was ice free at a time, but as each lava flow is produced within a very short time-span (weeks or months), it does not indicate the duration of ice free conditions. It is necessary to define the lithological cycles clearly, and subsequently the significance of individual steps of the cycles may be assessed.

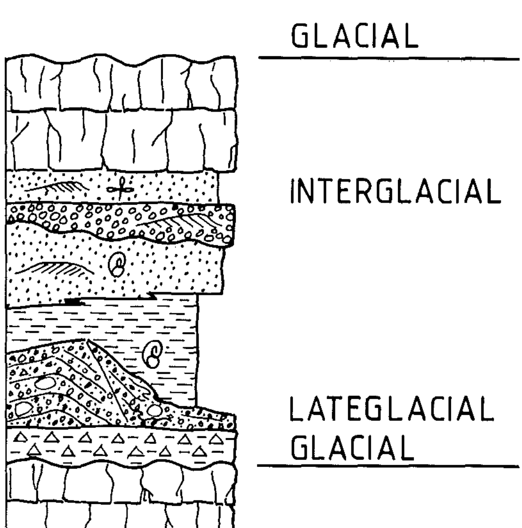

Fig. 16. An idealized Breidavík Group cycle interpreted in terms of climate. Legend, see Fig. 6.

A typical Breidavík Group cycle is presented in Fig. 16. The cycle begins with a period of erosion followed by deposition of till (1). This proves the presence of a glacier on Tjörnes. The nature of the glacier can only be established indirectly. The alternatives seem to be a valley glacier, a piedmont glacier, or an ice cap. The sediments of the Tjörnes sedimentary zone point to a low relief at that time on Tjörnes. The terrestrial sediments are generally very fine grained. The sediments found intercalated in the Höskuldsvík lava zone are either pebbly sandstones or red clayey sandstones. The first evidence of valley erosion on Tjörnes is in the substratum of the Hörgi Formation (the third oldest Breidavík Group cycle), and the relief there amounts to only a few tens of metres. An ice cap therefore seems to be the alternative that fits the available evidence about the palaeogeography. As to the younger cycles, it is known that Tjörnes became increasingly mountainous from the Máná Formation onwards. The high relief area around Búrfell mountain might therefore seem to be a possible source of valley glaciers of local extent. In that case one would expect a radial pattern of striae, and not the uniform northerly to northwesterly pattern found everywhere on Tjörnes, even on top of Búrfell mountain. In fact it seems that all the available data on the direction of ice flow speak against local control of the direction, and it seems that the palaeoslope remained fairly constant in direction during the accumulation of the Breidavík Group.

The till assemblage of the Breidavík Group cycles is followed by a proglacial assemblage (2), such as kames, outwash gravels, and glacio-lacustrine sediments. The deposition of this assemblage proves a recession of the glacier from the area. The proglacial assemblage is then covered by spatially adjacent assemblages. Seawards of the inferred shoreline, a marine assemblage of sediments (3) is deposited, initially interfingering with the proglacial assemblage. Its deposition proves a marine transgression after the waning of the glacier. Landwards of the shoreline an alluvial plain sedimentary assemblage (4) is deposited concurrently with the marine assemblage. Locally, terrestrial outwash sediments and till were eroded away. Finally, lava flows (5) enter the terrestrial environment and cover or interfinger with the alluvial sediments.

An immediate implication of such a cycle is the advance and subsequent retreat of a glacier over Tjörnes. Secondly, the subsequent rise of sea level implies a global reduction of ice volumes during ice free periods in the Tjörnes area. The nature of the proglacial assemblages speaks against an immediate flooding of the area by the sea after the retreat of the glacier, as might be expected if the crust was locally depressed by a local glacier. Ice rafted material in the marine assemblage (including metamorphic and plutonic clasts foreign to Iceland) shows that ice-bergs were carried to the area during the ice free periods. This is consistent with present day conditions, as the present beaches of Tjörnes are littered with pebbles and boulders of quartzite, granite, and metamorphic composition, carried there by ice bergs. Palaeomagnetic and radiometric age data (Th. Einarsson et al. 1967, Albertsson 1976, 1978) obtained from the lava flows of the Tjörnes sequence show that the lava flows of the Breidavík Group are spread over approximately the last 2 Ma. The lithological evidence above is considered to be in agreement with ice age conditions.

In addition to the lithological information the marine sedimentary assemblages offer faunal evidence about the Breidavík Group cycles. Bárdarson (1925) interpreted the marine fossils of the Threngingar and Máná Formations as a boreo-arctic fauna, and concluded that the marine sediments must have been formed under climatic conditions similar to those now prevailing on the west coast of Iceland. He did not find any high-arctic species. Áskelsson (1941) found the high arctic species *Portlandia arctica* in the lowest part of the Svarthamar Member marine assemblage (9). Subsequently, high-arctic species have also been found at the base of the Hörgi Formation and the Fossgil Member as well as in soft sediments of presumed Lateglacial age belonging to the Húsavík Formation. The presence of cold-water molluscs in marine sediments immediately above and interfingering with proglacial sediments, and the replacement of these higher up in a cycle by a fauna similar to that of the present day around Iceland (Bárdarson's interpretation has later been corroborated by Strauch, 1963, and by Th. Einarsson et al. 1967) may suggest that a division of the marine assemblages of the Breidavík Group into biozones is possible. The fossil material has, however, hardly been sufficiently studied, and the conclusions above must be regarded as qualitative. It does seem certain, though, that sea temperatures during ice free periods on Tjörnes were similar to those of the present day at the same latitude. Major climatic fluctuations are implied from glacial to ice free periods.

The palynology of the Hörgi Formation was studied by Schwarzbach and Pflug (1957). They found a high percentage of *Salix* and *Alnus viridis* along with other tree pollen which they suggested might be of secondary origin (redeposited). They inferred a climate which resembled the present Icelandic climate fairly strongly. The sample was taken from prograding alluvial sediments in the Hörgi cycle. Akhmetiev et al. (1975) sampled many of the Breidavík Group strata, both marine and terrestrial. *Betula, Alnus, Alnaster,* and *Salix* were the only trees indicated by pollen. Pollen of several common present day Icelandic genera were also found. According to Th. Einarsson (1961, 1963) these genera are typical for an interglacial flora in Iceland. Th. Einarsson has recently reviewed the evidence about interglacial floras in Iceland (Th. Einarsson 1977). He presented an analysis of a sample from sediments in Búrfell that probably belong to the Máná Formation, and inferred a forest vegetation characterized by *Pinus* and *Alnus*, accompanied by *Betula*, *Salix* and *Juniperus*.

The combined lithological, faunal, and floral evidence about the Breidavík Group lithological cycles is thought to constitute sufficient proof of a climatic control.

The sequence of lithologies in the upper part of the Tjörnes sequence allowed a reconstruction of a succession of palaeoenvironments. A chronological framework is necessary to enable an evalutation of the significance of events, and a meaningful comparison between areas within Iceland and elsewhere. Age relationships within the area and correlations were thoroughly reviewed by Albertsson (1976).

The earliest assessments of the age of the Tjörnes beds were based on palaeontological work which indicated a Pliocene age for the zone. The first attempt to estimate the absolute age of the sequence was made by Th. Einarsson et al. (1967), who correlated the stratigraphical column with the geomagnetic polarity time scale. Radiometric ages are now available within all the major stratigraphical units of the Tjörnes sequence, and provide an independent control on correlations with the polarity time scale. However, the number of dated horizons does not yet put sufficient constraint on such a correlation to allow individual events such as glaciations to be fixed chronologically with absolute certainty. Using a mean accumulation rate value from a reliably dated part of the sequence, Albertsson (1976) derived interpolated ages for key beds and horizons within the sequence.

New evidence about age presented in this work comprises a clarification of the boundary between the Kaldakvísl lava zone and the Tjörnes sedimentary zone, a new estimate of thickness values for the Breidavík Group rocks, and a different position of lava flows (palaeomagnetic data) within that Group.

Several problems arise when a correlation of the Breidavík Group lithological cycles with an absolute time scale is attempted. The first problem is the presence of angular unconformities within the sequence. These occur below the Hörgi Formation, the Svarthamar Member, and the Bangastadir Member, and result from an apparently gradual shift from a westerly tilt direction towards an easterly one. The unconformities reflect steps in this change, and the probability of gaps in the sequence is considered highest at these levels.

Erosional unconformities present a second problem. They are present at the base of every Breidavík Group cycle, and gaps cannot be excluded with certainty. However, the preservation of many complete cycles indicates that such gaps are not frequent because if they were, one would expect to find fractions of cycles in such a long sequence. In other words, there is no reason to expect erosion to have stopped at cycle boundaries every time. Gaps of this kind may exist in the younger part of the Breidavík Group where their detection is more difficult because of the relative simplicity of the cycles compared with the lower part of the Group. The tectonic subsidence of the northern part of Tjörnes and the shielding effect of the lava flows probably reduced the destructive elements of advancing glaciers. The question remains, however, if the resolution of the sequence was tectonically controlled in the sense that the subsidence rate allowed only a certain number of events to be recorded. The absence of half cycles seems to indicate that this was not a limiting factor. A better understanding of the tectonic environment is needed before this problem can be resolved. It may be pointed out that even the terrestrial part of the ice free phase of the Breidavík Group cycles was rendered constructive rather than destructive by the pouring out of lava flows, a process which may have partially influenced the rate of subsidence.

A third problem lies in the chronological inhomogeneity of the Breidavík Group cycles. Within one cycle, a relatively thin lodgement tillite bed represents a "long" glacial phase, while a thick sedimentary/lava sequence may represent the corresponding ice free phase. The thickness ratios within the lithological cycles will thus give a highly distorted picture of the time ratios. Evidently, allowance must be made for this factor when a correlation with an absolute time scale is attempted. The time transgressive nature of many of the sedimentary horizons is on a scale smaller than the inferred interglacial-glacial cycles, and does not affect the age considerations here.

The aggregate thickness of the Breidavík Group rocks in the coastal sections is about 600 m. The thickness of the Group as a whole seems to decrease towards south. Two lava flows within the Group have been dated successfully (Albertsson 1976, 1978). The lowest Torfhóll Member lava flow yielded a radiometric age of approximately 1.25 Ma, and the uppermost reversed polarity flow in the Engidalsgjá section yielded an age of 0.7 ± 0.05 Ma. As no reversed polarity lava flows have been found above the rocks of the Máná Formation, the latter radiometric age indicates that all lava flows above the Midlaekur Member sedimentary horizon belong to the Brunhes polarity epoch. The Torfhóll age shows that the Torfhóll cycle was in an interglacial phase at approximately 1.25 Ma. The base of the Breidavík Group can be placed with confidence as younger than 2.1 Ma as the top of the Höskuldsvík lava zone is probably of Réunion (lower Olduvai of Cox, 1969) age. Albertsson (1976) suggested a round figure of 2 Ma as the age of the tillite at the base of the Furugerdi Member.

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