Notes on the Nature of some Indurated Moraines in South Iceland.

By Arne Noe-Nygaard.

1. Introduction.

The first discovery of old moraines in the hardened rocks of the Icelandic "Palagonite System" is due to the late Dr. *Helgi Pjetursson (Pjetursson,* 1900, 1901).

In a preliminary report briefly describing part of the results of the IV Danish-Icelandic Expedition in 1936 *Niels Nielsen* and the author gave a summary division of the various facies in this complex *(Nielsen* and *Noe-Nygaard,* 1936 pp. 9—16). These quaternary deposits were here divided into two main groups or form-complexes, viz.:

1) Deposits on non-glaciated ground, i. e. interglacial lavas and subaëric sediments.

2) Deposits under or in the immediate vicinity of icecaps and glaciers, i. e. sub-glacial volcanic accumulations, indurated moraines ("tillites") and sediments occurring in association with these (viz. glacio-fluviatile deposits).

According to our investigations the deposits, mentioned under 2 play a considerable rôle in Skaptafellssyssla, indicating that conditions of this region conform with those described earlier by *H. Pjetursson,* for instance from the areas west of Myrdalsjökull. A treatise on subglacial volcanic accumulations was published by the author some years ago *(Noe-Nygaard,* 1940).

In the present paper observations on the indurated moraines along South Iceland from Svínafell in Öræfi in the east to Eyafjall in the west are recorded; they do by no means give a complete picture of these deposits, but should be considered as supplemen-

tary observations which form an eastward continuation of the areas already known to us through the works of Dr. *Pjetursss*. The greater part of the investigation in the field was carried out together with Professor *Niels Nielsen*.

Since our expedition in 1936 some of *Pjetursss'* localities in North Iceland have been revisited and his interpretation of some of the coarse clastic boulder-beds as moraines has been questioned *(Hawkes,* 1938, *Einarsson,* 1946). I have not seen the deposits of the said localities myself and consequently I dare not express any definite opinion on their origin; however, fresh observational data from other localities, where a glacial origin can be proved, or at least seems very likely, will help us to explain also more intricate deposits in other localities.

Einarsson (op. cit.) thinks that a more thorough microscopic study of the petrographic features of the indurated moraines (and the disputed moraines) is needed. I have tried this, but I do not think that it helps us very much since the bulk of material of several "facies" within the Palagonite-System is almost the same. As far I can see the main thing is to undertake a careful examination of the field geology and the macroscopic features; that is to say a geologist being familiar with normal glacial deposits would as a rule be able to tell a moraine from a non-glacial conglomerate — even if the whole series is hardened to a solid rock — if only he has a decent section, or even better, a non-vegetated part of a landscape with several good outcrops.

2. Description of localities with indurated moraines and other glacial phenomena.

Svínafell: On the southwest side of Svínafellsfjall not far from the farms four small creeks with good outcrops were examined in the lower part of the mountain.

The youngest hardened rock met with — dipping about 15 degrees N-NW, was a brownish moraine (tillite) which lies in flat cup-shaped depressions discordantly on the rock-complex behind. The tillite can be followed some hundred meters upwards towards Svínafellsheiði.

The boulder material in the tillite varies in composition and many blocks are beautifully striated *(Nielsen* and *Noe-Nygaard,* 1936, fig. 3); single blocks may reach a size of well over 1 m in diameter. In several places the tillite contains smears of stratified gravel and sand.

In cross section this deposit reveals three more or less well defined layers where it reaches its optimum thickness: At the bottom of the cup-shaped depressions we find a tillite abt. 7 m thick *(Nielsen* and *Noe-Nygaard,* 1936, fig. 2), it passes upwards gradually into a 2 m thick deposit mainly consisting of the same material, evidently once moved by solifluction; on top we have another tillite abt. 5 m thick which is not disturbed in its upper part.

The complex underlying the tillite dips 5 degrees southeast. The lowermost outcrops in this show another, and older, brown tillite, which in uppwards sequence is succeeded by a basalt-globe-breccia,

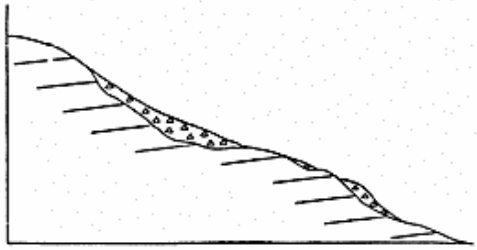

Fig. 1. Schematical section of Svínafell. Younger moraine lies discordantly on top of older strata, which contain an older moraine.

which I consider of sub-glacial origin (comp. *Noe-Nygaard,* 1940 p. 13). The globes consist of a plagioclase-porphyritic basalt.

The subglacial deposits are covered by subaëric lavas which look fairly young; still higher up slag- and tuf-accumulations are encountered; they consist of porous materials.

Rauðhellar in Morsárdalur:

Mowing from Bæjarstaðarskógur into Morsádalur a continuous series of basalt flows is seen to constitute the lower part of Rauðhellar, it is of plateau basaltic appearance. The first well marked ravine was climbed and the following observations made.

The basalt flow series was passed first; some of the flows were rather porous, while others were more compact, and still others were rich in zeolites. Numerous thin basalt dykes with a SW-NE strike intersect this sequence.

150 m above the plain a red tillite was met with, 5—6 m thick. The rock is well cemented and fairly rich in zeolites. Colour as well as consistency give the rock an "old" appearance.

The blocks in the tillite vary as to material, but the following rock types dominate, viz. one rather light coloured, very hard grey basalt, another of darker basalt with many amygdules with zeolites,

and a red heterogeneous rock reminiscent of a weathering breccia. The red colour of this rock is the same as that of the tillite itself. Prior to the glaciation causing the formation of the tillite a period of subaëric weathering must be anticipated, in which this breccia was formed. No liparitic blocks were found in the tillite although a considerable section was examined.

The tillite is again covered by basalt flows of plateau basalt appearance. I do not know how thick this basalt flow sequence is, since time did not permit me to climb the steep upper part of Rauðhellar, but in the ravine several blocks of a brown tillite were found, indicating that an upper tillitic horizon may be expected in the upper half of the mountain. In other words the Rauðhellar mountain contains a lower red and an upper brown tillite separated by a considerable sequence of lava flows. The two tillites may both be of Quaternary age, in which case the red tillite must lie very far down in the Quaternary system, or the red tillite may be of Tertiary age and the brown of Quaternary age in the sense hitherto used in Iceland, comp. i. a. *Jón Jónsson's* investigations near Hornafjördur in East Iceland *(Jónsson,* 1953). If we adopt the view of the "Committee on the Tertiary-Quaternary boundary" the glacial origin of the red tillite should be taken as an indication of Quaternary conditions. If this is the case we may conclude that volcanism of Tertiary type (flood-basalts) continued well into Quaternary time, giving rise to a considerable thickness of post-Tertiary plateau-basalts.

Harðskafi:

In the neighbourhood of Kálfafell tillitic beds are seen in many places in the lower parts of the mountain walls facing the plains to the south. The common colour is grey with a brownish tinge. In all probability they belong to one period of glaciation since their present altitude above sea level is practically the same from place to place, this also applies to their lithological character.

A section was measured in the Harðskafi mountain, its main elements dipping gently to northeast are:

Basalt, porous (top).
Tillite — 2 m — striated boulders.
Weathering-breccia.
Basalts.
Sandstone.
Basalts.

Solifluction-breccia.
Basalt.
Sandstone.
Tillite — 10 m — striated boulders *(Nielsen* and *Noe-Nygaard,* 1936, fig. 4).
Weathering-breccia of basalt.
Basalt (bottom).

The two tillites are situated in the section separated by a series of strata of about 300 m.

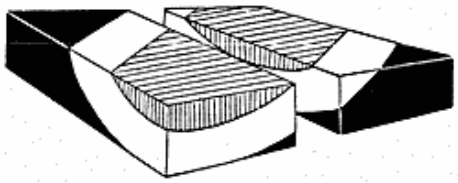

Fig. 2. Fossil valley in Seljalandsheiði filled with interglacial (white) and glacial (ruled) deposits.

Seljalandsheiði: In the steep wall bordering Seljalandsheiði towards the south is seen an oblique section of an old valley which has been filled up with deposits belonging to the Palagonite-System.

At the bottom of this we find the topographical remnants of the old valley sides; in the valley lie old lava flows up to about 50 m. The lavas are covered with solifluction-breccias, partly blocks from the valley lavas, partly from other places; higher up the material becomes fine grained and may contain some loess. The total thickness of this breccia amounts to abt. 100 m. The breccia is succeeded by glacial deposits, including five tillite beds and intercalated glacio-fluviatile strata. On top is a lava flow which fills up the last depression left over from the original valley. Here and there small patches are seen of a weathering-breccia which covers the basalt flow; the whole mountain has later on been glaciated. Some intrusive basalt from at least two periods are founds in the section.

Two of the tillite beds carry blocks more than a meter in diameter, and many beautifully striated stones were found.

The geological history of the old valley is thus likely to be as follows: In an interglacial period a valley was in part filled with subaëric lavas and solifluction-breccias; in the following glacial period a glacier moved down into the same valley, where it deposited glaciofluviatile sediments and moraines. When in the next interglacial period the ice melted a little of the valley depression

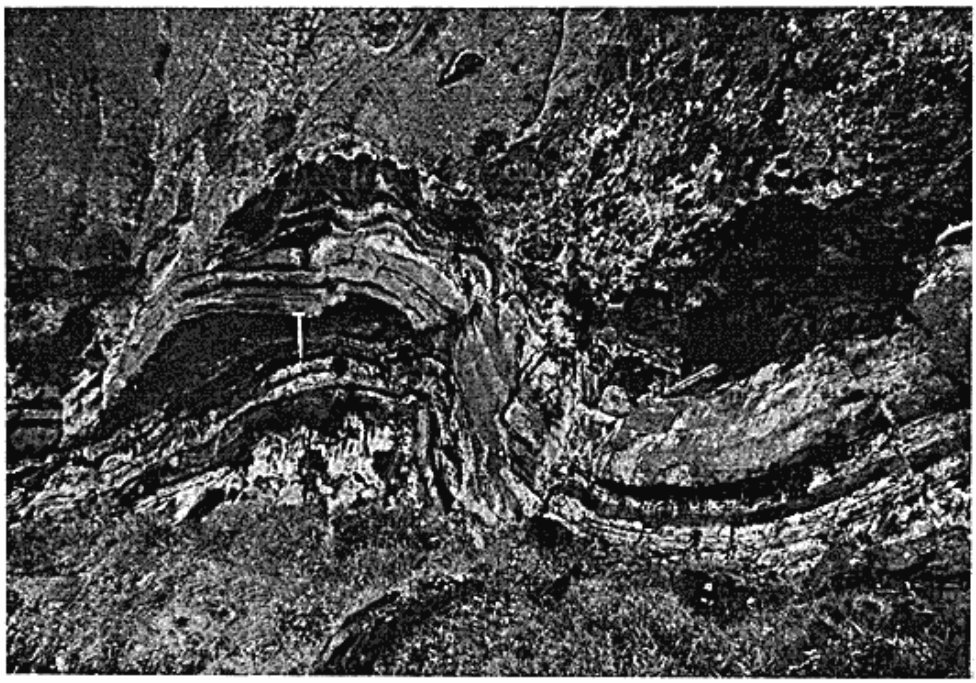

Fig. 3. Folded strata below and tillite above Eyafjall.

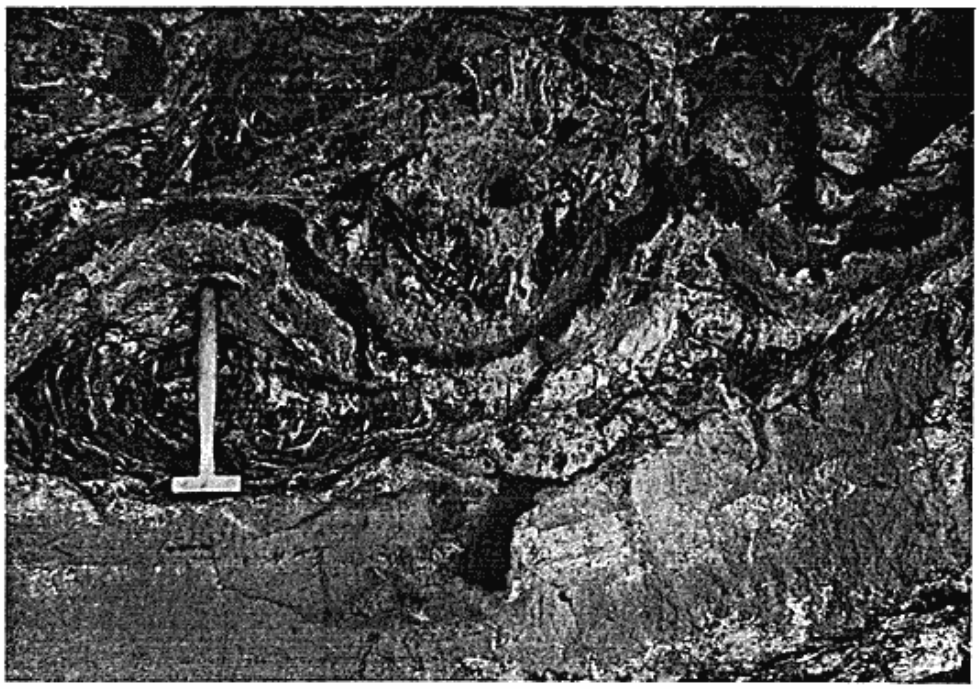

Fig. 4. Competent clay layer forms rolls whereas the incompetent sand layer (bottom) is almost undisturbed. Base of lower tillite. Eyafjall.

was still left over and filled by subaëric lavas, which weathered on top. After the filling of the valley a later glaciation at one time covered the whole complex.

Fig. 5. Single fold in the sand and clay layers at the base of lower tillite. Eyafjall. (Length of hammer 50 centimeters).

Nunataqs and border mountains along the western part of the south edge of Vatnajökull:

In several localities an almost black, indurated, but most often not very hard moraine is met with resting on the brownish breccias of the Palagonite-System proper; it is covered by unconsolidated moraine-deposits of a recent date.

The black moraine carries blocks of a brown tillite and numerous liparites originating from the liparite province in western Vatnajökull *(Noe-Nygaard,* 1952 pp. 44—45).

Eyafjall:

This locality was pointed out to us by Dr. *Pjeturss,* and it was visited by the author together with *Pálmi Hannesson* and *Niels Nielsen;* it is mentioned here because it reveals some remarkable features very similar to those found for instance in several Danish ice-dislocated deposits.

Above a solifluction-breccia which in upward direction is rather finegrained follows a tillite partly resting on, partly containing several lenses and layers of glaciofluviatile(?) sand and clay in its lower part. The tillite is covered by another tillite which again has a bottom zone with sand and clay. The sand and clay layers are beautifully folded (figs. 3 and 5), and "clay-rolls" evidently formed in a "lubrication-horizon", are numerous (fig. 4). The form and scale of deformation and the position of the deformed strata at the bottom of the tillites seem to be conclusive evidence for accepting its glacial origin; viz. they were due to ice-pressure.

3. Conclusions.

The description of the various localities may be summed up as follows:

1. *Evidence supporting the view of a glacial origin of the boulder beds:*

Striated boulders, were met with in several localities, i e. Svínafell, Harðskafi, Seljalandsheiði.

Dislocations due to ice-pressure of underlying or incorporated sediments: Eyafjall (figs. 3, 4, 5).

Striae on the surface of the underlying rock were not observed within the examined localities, i. a. because the rocks consisted of loose accumulations originally. Striae have been reported from several other localities in Iceland.

2. *Various types of glaciation:*

Boulder-beds which can be followed continuously for long distances on the same level and with an almost constant thickness are considered to represent *a regional glaciation:* For instance the lower moraine in the Harðskafi-Kálfafell-region.

The five successive tillites and intercalated fluviatile sediments of Seljalandsheiði which fill up a fossil valley (fig. 2) are considered to represent *an oscillating valley glacier.*

The tillite on the slopes of Svínafellsfjall, resting discordantly on

an older complex (fig. 1) is probably the result of a younger *local glaciation* of the high Öræfi mountains.

3. Number of glaciations.

It must be emphasized that a glacial boulder-bed, a tillite, may be a local phenomenon (Svínafell), and further that several tillites overlying one another with only thin deposits in between — for instance of fluviatile sediments — do not indicate a number of successive glaciations on the spot, but should in all probability be interpreted as oscillations during one period of glaciation (Seljalandsheiði).

When, however, indurated moraines are met with which are separated by thick deposits of non-glacial origin it seems justified to consider them as belonging to different periods of glaciation (Harðskafi). This point of view seems even more justified if the lithological nature of the tillites from different levels is varying (Rauðhellar).

In the localities Svínafell, Rauðhellar, Harðskafi and the border mountains along Vatnajökull evidence of two separate tillites is met with in each locality, but they are by no means considered the same two tillites, in which connexion I wish to call attention to the lithological character of the rocks, particularly to the colour.

In my opinion *the oldest moraine* met with in the localities described in this paper *is the red moraine* in the lower part of *Rauðhellar. Younger* than this is the brownish moraine in the upper part of the same mountain; this may, or may not, correspond to *the older, brownish moraine* in Svínafell which later has been covered by a *local moraine, also brownish of colour.*

In Harðskafi we have two brownish moraines separated by some 300 m of non-glacial sediments and lavas, and on top of that whole complex near the ice-edge of Vatnajökull *a blackish* moraine *covered only by non-consolidated morainic material* along the present edge of the glacier.

Trying to combine the observations with regard to the succession of indurated moraines we find that in Austur Skaptafellssyssla we have as a minimum the following ones, mentioned from the top:

Black moraine.
Brown moraine.
Brown moraine.
Red moraine.

I should not be surprised if it appeared in future investigations that the black moraines are fairly young and only represent an ice-advance in late Glacial time. Further I think that the red moraine belongs to the oldest glaciation period in Iceland. The main number of the indurated moraines which dominate the Palagonite-System, are of brown or greyish colour, moreover there may very well be more than the two moraines recorded with certainty in the region treated here, as a matter of fact I think there are.

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