5. Scottish Peat Mosses.

A contribution to the knowledge of the late-quaternary vegetation and climate of North Western Europe.

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(With a map, Plate 13.)

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I. Introduction.

Several attempts of correlating the strata of the Scandinavian and the North British peat mosses have already been made. But a complete correlation could not be carried out without investigating the peat mosses of both countries from more homogeneous points of view. With the purpose of making if possible such a comparison with greater safety I examined a number of peat mosses in Scotland and Northern England during a journey in the summer of 1909.

The investigations were carried out in June (1909). During the main part of the journey I was accompanied by Mr W. NISSER, Cand. phil., Uppsala. I visited several districts in Northern England, the Scottish Southern Uplands, the Grampian Mountains, the North West Highlands, and the Outer Hebrides (Lewis).

As I could devote only a very short time to the field work, I had to restrict myself to an examination of sections in the peat-hags, and, consequently, I could not study in detail the history of the development of larger peat deposits. I therefore thought it most suitable to visit some peat mosses carefully described by F. J. LEWIS. In this way I should also better understand the descriptions of other districts investigated by him. Mr LEWIS, who embraced my studies with great kindness and interest, pointed out some particularly instructive districts to me. By this I was enabled to visit many of the most interesting peat mosses in a short time.

Further I endeavoured to get as good an idea as was possible of the different types of vegetation which are met with in Scotland.

Before discussing the results of my investigations I wish to express my thanks to my friend and travelling-companion Mr W. NISSER by whose generosity I was enabled to make this journey; to my friend and teacher Professor R. SERNANDER, Uppsala, for giving rise to the journey and following my work with the greatest interest; and to Mr F. J. LEWIS, Liverpool, for much kind advice and help during the field work.

In the following paper I shall first describe the stratification of some peat mosses and then discuss what they show as to the history of the late-quaternary vegetation and the post-glacial geology of Scotland. At last I intend to make an attempt of correlating the North British and the Scandinavian peat strata.

II. **The stratification of some peat deposits.**

The peat mosses of Great Britain generally occur on undulating and rather sloping ground (see fig. 1). In places where the peat is rather deep the inclination of the surface seldom exceeds 10° (HARDY 1905, p. 119), though it can occasionally be considerably greater. In such cases, however, the peat is shallower and covered with ling and grass heaths. Marshes (»flows») are seldom met with, which depends on the rare occurrence of peat deposits originating from the filling up of lakes and pools.

The vegetation of the British peat mosses differs in many respects from that characterizing the Swedish ones. This is principally due to the insular climate of Britain. The chief difference consists in the unimportant part played by *Sphagnum* on the British peat mosses.

moors with a closed carpet of *Sphagnum* are seldom met with. The most frequent associations are dominated by *Scirpus cæspitosus*[1] and *Eriophorum vaginatum*. Both these species give rise to more or less pure associations with either species exclusively dominating over large areas. These two have been the most important peat forming associations during the post-glacial time.[2] Associations characterized by the dominance of *Calluna vulgaris*, *Erica tetralix*, and *Eriophorum vaginatum* also occur very often. During some stages of the development of the peat mosses *Calluna* moors

Fig. 1. Carn a Choire Mhoir (Inverness-shire). The slopes are entirely covered with deep peat.

and related forest associations have covered almost the whole surface of the moorlands. The succession of the different associations is very little known (As to the peat associations see particularly W. G. SMITH 1905, p. 125). The same associations characterize also the peat mosses of the

[1] The nomenclature of J. D. HOOKER's The Student's Flora of the British Islands, third edition, is generally followed.

[2] The peat formed by these most predominant associations contains very few plant remains. Nor do microorganisms occur so frequently as they generally do in the Scandinavian peat. Algæ and rhizopods are nearly entirely wanting. As to the microorganisms in the Scottish peat very little work has been done as yet. Some peat samples of mine have been examined by Professor G. LAGERHEIM, Stockholm. The fossils that he has found will be mentioned in the following.

Færöes (OSTENFELD 1908, pp. 947—952) and Western Norway. In the following description of different peat districts some examples of the vegetation will be given.

1. The Pennines.

The slopes of Cross Fell in Cumberland, rising to 879 m., are nearly entirely covered with peat, sometimes reaching a depth of 4,5 m. (LEWIS 1907 b, p. 414). The denudation of the peat is very great. In places where the peat is rather deep it contains a sharply marked forest bed, at last at an altitude not exceeding 780 m. (LEWIS 1907 b, p. 416). In reference to the features met with in the Tyne Basin LEWIS writes: »In most places the remains of an arctic or sub-arctic vegetation rest upon the drifts: this is covered with a considerable thickness of peat formed from *Phragmites communis*. Above this the birch zone forms a datum line over the whole district.» June 7, 1909 I examined a district N. W. of Cross Fell. The vegetation consists of an association, where the field stratum[1] contains plentiful *Calluna vulgaris* and *Eriophorum vaginatum,* sparse *Empetrum nigrum* and *Erica tetralix*, and solitary *Eriophorum polystachion*, *Rubus chamæmorus, Scirpus cæspitosus,* and *Vaccinium vitis-idæa;* the ground stratum is not closed and consists of *Cladonia rangiferina* (abundant on the tufts), *Hylocomium sp.* (solitary), and *Sphagna* (sparse — scattered between the tufts). In the investigated district the forest bed rested everywhere immediately on the till. In a peat-hag the following section was laid bare (about 700 m.):

A. 125 cm. of *Scirpus cæspitosus* peat, yellow-brown in colour, very rich in humus, not mouldered, containing remains of dwarfshrubs. Washing a sample I found nothing but numerous small specimens of *Cenococcum geophilum.*

B. 75 cm. of *Phragmites-Carex* peat, containing numerous large stools, stems, twigs, and roots of birch. The finer material consists to a great extent of wood detritus. Any coal was not found. From a peat sample nutlets of *Ajuga reptans* and seeds of *Viola sp.* were washed out. LAGERHEIM has found pollen grains of elm, hazel, and pine, spores of a fern, and leaves of *Sphagnum sp.*

C. Boulder clay.

At other places in the neighbourhood LEWIS has also found remains of *Alnus glutinosa, Elatine hexandra, Lychnis diurna, Viburnum opulus*, and *Ranunculus repens* in the forest bed. In strata lying below this (»silt and clay») he has found e. g. *Arctostaphylos alpina, Salix arbuscula*, and *reti-*

[1] For denoting the strata of the vegetation and the frequence of the species I have followed the nomenclature of R. HULT's (Meddel. Soc. Faun. Flor. Fenn., VIII, 1881). The degrees of frequence are abundant (Sw. ymnig), plentiful (Sw. riklig), scattered (Sw. strödd), sparse (Sw. spridd, tunnsådd), and solitary (Sw. enstaka).

culata. When the oldest layers were deposited, the vegetation of this district was characterized by the occurrence of alpine plants, the remnants of which however are not found *in situ*. At a later time large areas consisted of extensive reed swamps, which were, in most places, succeeded by a wet birch forest, containing several species that do not generally occur at so high an altitude. During this period nearly the whole area of Cross Fell, where scarcely a single tree is met with nowadays, was covered with birch forest. This woodland was replaced by wet moorland associations.

According to LEWIS (1904, II, p. 273) a birch forest bed very often occurs in the peat mosses of the Pennines from the Cheviots to Derbyshire, where I myself have seen birch remains at a height of nearly 600 m. near the top of The Peak. In the mosses of Yorkshire trunks of oaks have been found up to 375 m., hazel nuts to about 500 m. (SMITH and RANKIN 1903, pp. 160 and 161).

2. The Scottish Southern Uplands.

The mosses lying between the Merrick and Kells ranges in Kirkcudbrightshire and Ayrshire belong to the peat deposits that have been most carefully investigated by LEWIS, and are also among the most interesting ones. In the company of Mr LEWIS I visited this district June 19, 1909. Large areas are covered with a *Calluna-Erica tetralix-Eriophorum vaginatum* association. These species are scattered — plentiful. In the field stratum scattered *Molinia coerulea,* sparse *Erica cinerea* and *Narthecium ossifragum,* solitary *Carex sp., Myrica gale,* and *Polygala serpyllacea* are also met with. The ground stratum containing *Cladoniæ* (solitary), *Racomitrium lanuginosum* (solitary), and *Sphagna* (sparse) is not closed. In other areas we find *Sphagnum* bogs, *Scirpus cæspitosus* or *Molinia* associations. Numerous sections can be studied in the peat-hags. In one of these, situated between Dungeon Hill and Back Hill of Garrary (about 300 m. above sea-level) I found the following strata:

A. 100 cm. of *Scirpus cæspitosus* peat, mixed with *Eriophorum vaginatum,* and also containing solitary *Calluna* stems. LAGERHEIM has found pollen grains of alder, birch, grasses, hazel, pine, *Typha latifolia,* and an ericaceous species, and spores of *Polypodium vulgare* and *Sphagnum sp.*

B. 30 cm. of a sharply marked *stool layer* of pine. The stools sometimes exceed 50 cm. in diameter (fig. 2); they were seldom burnt, but solitary coal fragments were met with. The surrounding peat was highly mouldered and contained numerous *Calluna* stems and birch twigs. One hazel nut was also found.

C. 45 cm. of *Eriophorum vaginatum* peat, rich in humus, containing some birch fragments, very likely the roots that had penetrated from the layer above. The washing of a sample gave a few specimens of *Cenoccocum geophilum*, some *Calluna* shoots, and six stones of *Empetrum nigrum*. LAGERHEIM has found pollen grains of birch, hazel pine, and probably *Empetrum*.

D. 20 cm. of *Eriophorum vaginatum* peat, very little mouldered, containing rare remains of *Sphagnum*, numerous *Empetrum* stems, and a few small birch twigs. Stones of *Empetrum*, numerous achenes of *Potentilla comarum*, and some not identified seeds and other plant remains were washed out. LAGERHEIM has found pollen grains of birch, pine, and an ericaceous species, spores and leaves of *Sphagnum*, and brown fungus hyphæ.

Fig. 2. A pine stool in the upper forest bed. (Merrick-Kells district, Ayrshire.)

E. 45 cm. of *forest peat*, rather rich in humus, hard and firm. The fine material chiefly consists of wood detritus. The peat contains very numerous trunks and twigs of birch. Coal was not met with. Washing gave achenes of *Potentilla comarum*, seeds of *Viola sp.*, and numerous fruits of different *Carex* species. LAGERHEIM could not find any determinable microorganisms.

F. Moraine with large stones.

All the sections in the cental part of the valley showed the same sequence of the layers. Further to the north, LEWIS (1905, p. 703) has found the same features. Sometimes the strata, lying between the two forest beds, are thicker. Layers of *Eriophorum vaginatum* and *Sphagnum* peat may also occur below the *Empetrum* layer (D). In this stratum LEWIS has also found abundant remains of *Salix herbacea* and *reticulata*. These two species are now confined to the highest Scotch mountains, *S. reticulata* is confined to the Highlands.

The features just described show that during a period following the close of the Mecklenburgian ice age — moraines of this age occur in the valley, and they sometimes are covered with peat — the main part of this valley was overgrown with birch forest. This forest was replaced by more hydrophilous associations, which had then to give place to a rigorous pine forest. During a phase of the time of the hydrophilous associations, grew on the surface of the mosses societies characterized by the occurrence of *Empetrum, Salix herbacea*, and *reticulata*. The pine forest was succeeded by *Scirpus cæspitosus* and *Eriophorum vaginatum* associations. Consequently *Sphagna* have generally not been of any importance at all. This change of woodland into moorland has also stretched over ground which was previously dry. At the margin of the peat deposits I namely sometimes found pine stools resting immediately on the till.

I have not seen any other district in the Scottish Southern Uplands. Several other districts have been examined by LEWIS (1905). The most interesting type is represented by the Upland Mosses of the Tweedsmuir and St Mary's Loch District (about 300 m. above sea-level). Here, too, two distinct forest beds are met with. The tree remains consist chiefly of birch. In a lake deposit below the older forest bed e. g. *Ajuga reptans, Alnus glutinosa, Corylus avellana, Salix purpurea,* and *Potamogeton sp.* have been found. Between these forest beds there are layers of a depth of about 1 m. The middle part of these strata consists of a zone, about 1 dm. in thickness, formed mainly of *Empetrum nigrum* with *Loiseleuria procumbens*. The upper forest was replaced by an *Eriophorum vaginatum-Polytrichum* association.

The Flow of Dergoals (Wigtownshire), lying about 75 m. above sea-level, shows a stratification to a certain extent analogous. In all parts of the mosses the bottom strata consist of a birch forest bed, where hazel and alder also occur, particularly in the upper parts of the layer. This forest had to give place to a reed swamp that stretched over the whole peat district, until 1—1,5 m. of perfectly homogeneous *Equisetum-Phragmites* peat had been deposited. But once more a forest, this time a pine forest, spread over the main part of the moss, the surface of which was surely drier than before. Large pine stools occur abundantly, surrounded by a forest peat. The most central parts of the moss were not dried up enough to allow this pine forest to spread over it. This forest vegetation was destroyed by a *Sphagnum* moor, closely agreeing with that now clothing the surface of the moss (LEWIS 1905, p. 713).

3. The Grampian Mountains.

LEWIS has described several peat districts in the Grampian Mountains, mainly in the north-eastern parts. I myself examined two small peat mosses in the neighbourhood of Killin at the western end of Loch Tay (June 14 and 15, 1909). South of Killin the northern slopes of Beinn Leathan were partly covered with peat. The thickness of the peat varies greatly; its surface is much denuded, sometimes the underlying till is laid bare. At an altitude of about 500 m. above sea-level the vegetation sometimes consists of a *Sphagnum* bog (*Sphagnum* abundant) with the following associates: plentiful *Calluna vulgaris*, scattered *Scirpus cæspitosus*, sparse *Eriophorum vaginatum* and *Vaccinium myrtillus*, sparse *Carex panicea, Empetrum nigrum, Erica tetralix, Juncus squarrosus, Narthecium ossifragum*, and *Sphærocephalus palustris*. At other places *Eriophorum vaginatum* and *Scirpus cæspitosus* associations are dominant. A section in a peat-hag showed the following strata:

A. 45 cm. of *Scirpus cæspitosus* peat, somewhat mixed with *Sphagnum*, in the upper part very mouldered, in the lower part yellow-brown and fresh. In the lowest layers very small solitary birch twigs were found. By washing were obtained ends of branches and flowers of *Calluna*, solitary stones of *Empetrum*, fruits of *Betula odorata* and *Carex sp.*, one seed of *Viola sp.*, and a few specimens of *Cenococcum geophilum*.

B. 150 cm. of *Carex* peat, rich in humus and in wood detritus, containing numerous *Phragmites* rhizomes and abundant birch remains, e. g. rather large stools, trunks, twigs, bark, etc. Coal was not found. Near the bottom the wood detritus was still more abundant; the peat was also mixed with sand and clay. A sample from the middle part of the layer contained fruits of *Betula alba* and *Carex spp.*, seeds of *Viola cfr. palustris*, stones of *Rubus idæus*, and numerous small specimens of *Cenococcum*. Near the bottom two hazel nuts, *Betula odorata* (bracts and fruits), *Salix aurita* (leaves), *Ajuga reptans* (nutlets), *Rubus idæus* (stones), *Carex sp.* (fruits), and a few specimens of *Cenococcum* were found. In the same sample LAGERHEIM has found pollen grains of alder, birch, elm, and pine, and spores of *Lycopodium clavatum, Polypodium vulgare*, and another fern (probably *Nephrodium oreopteris*).

C. Boulder clay.

This forest bed (layer B) occurred at all places where the peat was not too shallow. This slope, nowadays nearly quite disforested, was once covered with a birch forest, the disappearence of which was in some cases due to the spreading of hydrophilous associations.

On the northern slope of Meall Laith (north of Killin) a rather large area is covered by peat. By the denudation the till is in places laid bare. The vegetation consists of a *Calluna* moor with *Erica tetralix, Eriophorum vaginatum, Rubus chamæmorus*, and *Scirpus cæspitosus* as its most characteristic associates. Sometimes this association is replaced by a *Calluna* heath. A section (in a peat-hag) showed the following sequence:

A. 40 cm. of *Eriophorum vaginatum* peat, in the upper part highly mouldered.

B. 30 cm. *Carex-Eriophorum vaginatum* peat, containing abundant birch remains, as stools *in situ*, etc.

C. 25 cm. of *Eriophorum vaginatum-Carex* peat.

D. 40 (+) cm. of *Sphagnum* peat, in the lower part containing many remains of dwarf shrubs. Washing only gave solitary *Carex* fruits. At another place the layer C rested on the till. Nowhere the forest bed was seen directly resting on the till.

In this district two distinct forest beds were never seen. A section near Achnafree (600 m.), given by HARDY (1905, p. 131), shows that two forest beds may also occur in the Highlands of Perthshire.

In one of the wildest districts of the Grampian Mountains lies the large Moor of Rannoch (Argyllshire and Perthshire) which »forms an extensive undulating region lying at 900—1500 feet» (270—450 m.; LEWIS 1907 a, p. 43). The present vegetation mainly consists of a *Scirpus cæspitosus-Racomitrium lanuginosum* association. The stratification of the peat is described by LEWIS, but unfortunately in a rather confused manner. A section towards Kingshouse shows, according to LEWIS (1907 a, p. 44), the following sequence:

»Characteristic plants.	Accompanying plants.
1. *Scirpus cæspitosus.*	1. Sphagnum, *Eriophorum vaginatum.*
2. *Pinus sylvestris.*	2. *Calluna vulgaris.*
3. *Scirpus cæspitosus.*	3. Sphagnum, Eriophorum.
4. *Grimmia sp.*	4. — — — — — — — — — — —
5. *Betula nana.*	5. *Salix Arbuscula, Empetrum nigrum, Arctostaphylos alpina.*
6. Equisetum, Sphagnum.	6. Many broken and water-worn fragments of *Betula alba.*
7. — — — — — — — — — — —	

Sand and clay, with angular stones.»

LEWIS writes (p. 44): »Quantities of water-worn birch fragments occur towards Kingshouse, not only with the marsh plants at the base of the peat, but in the drift below. The wood bears traces of prolonged water action, and although many of the fragments are small twigs, some are larger and evidently belong to fairly large trunks of birch mixed with fragments of birch bark. This wood evidently did not grow *in situ*, and it can hardly represent the drift of a few streams, as the material occurs in many sections spread over a large area». In spite of these statements I believe that the basal peat bed represents the remains of a moist forest, that has grown at the place. The roots of the trees have penetrated into the boulder clay, and it is, I think, these roots that LEWIS has found in the drift below the peat. This view is further supported by the Section I, given by LEWIS, »where *Pinus sylvestris* is underlaid, first by a Sphagnum bed and then by a layer of birch. . . . . . This shrubby birch agrees in character and in position with that described from the Spey-Findhorn and Findhorn-Nairn watersheds, Coire Bog, and Caithness» (LEWIS 1907 a, p. 45). This lower forest bed is sometimes wanting, a feature, however, of small importance. LEWIS gives no measures of the thickness of the different strata.

Quite analogous stratigraphical features have been found by LEWIS in the Forfarshire Grampians, i. e. the most easterly parts of the Grampian Mountains. These mosses are chiefly covered with a *Scirpus cæspitosus* association (LEWIS 1907 a, p. 41).

A section, I (600 m. above sea level), shows the following sequence:

»Characteristic plants.	Accompanying plants.
1. *Scirpus cæspitosus.*	1. *Eriophorum vaginatum.* Sphagnum.
2. *Pinus sylvestris.*	2. *Calluna vulgaris.*
3. *Carex sps., Salix Arbuscula.*	3. *Betula nana.* Mosses.
4. *Betula alba.*	4. *Calluna vulgaris.*
5. Mossy peat, with traces of *Betula alba.*	5. *Viola palustris.*

Sand and gravel.»

Another section, II (675 m.), shows:

»Characteristic plants.	Accompanying plants.
1. *Eriophorum vaginatum.*	1. *Calluna vulgaris.*
2. *Calluna vulgaris.*	2. — — — — — — — — — —
3. *Potentilla Comarum.*	3. *Salix Arbuscula.*
4. *Betula alba* (large).	4. *Viola palustris, Ajuga reptans.*
5. *Salix reticulata, S. Arbuscula.*	5. *Equisetum sps., Carex sps., Sedum Rhodiola.*

Boulder clay.»

The layers 4 and 5 in I and 4 in II on the one side and 2 in I and II on the other are probably of the same age.

In the most northerly districts of the Grampians some mosses on the Spey-Findhorn and Findhorn-Nairn watersheds (Inverness-shire) have been investigated by LEWIS. As to the Spey-Findhorn watershed he writes (1906 a, p. 346): »The peat over most of the hills above 1800 feet has an average depth of 11—13 feet, and the upper forest zone, lying about $3\,^{1}/_{2}$

feet below the present surface of the peat, forms a useful datum line over the whole area.» A typical section (540 m.) shows according to him:

	»Dominant plant.	Accompanying plants.
1.	Recent peat.	— — — — — — — — — — —
2.	*Pinus sylvestris*, L.	— — — — — — — — — — —
3.	Sphagnum.	— — — — — — — — — — —
4.	*Pinus sylvestris*, L.	Calluna (abundant).
5.	Sphagnum.	Eriophorum, Calluna (traces towards the base).
6.	*Betula alba*, L. (fairly large shrubby trees).	— — — — — — — — — — —
7.	*Empetrum nigrum*, L.	Eriophorum sp., *Menyanthes trifoliata*, L., *Polytrichum juniperinum*, and in the lower layers abundant *Betula nana*, L.
8.	*Salix Arbuscula*, L.	*Lychnis alpina*, L., *Potentilla Comarum*, Nestl., Carex sp., *Viola palustris*, L., *Mnium pseudopunctatum*.
9.	*Salix reticulata*, L. *S. herbacea*, L., leaves.	*Veronica alpina*, L.
10.	Stone pavement.	— — — — — — — — — —»

Nothing is mentioned concerning the thickness of the layer 5. The layer 6 »forms a continuous and well-marked layer in the peat of this area» (LEWIS 1906 a, p. 348). According to LEWIS (1906 a, p. 351), a nearly identical sequence characterizes the mosses on the Findhorn-Nairn watershed. The layer 6 (the birch layer) is, I think, formed under quite the same conditions as the lower forest bed in the Scottish Southern Uplands, on the Moor of Rannoch, and in the Forfarshire Grampians. LEWIS has another opinion. — »The upper forest zone in this district consists of an upper and lower layer of *Pinus sylvestris*, separated by about 1 1/2 feet of Sphagnum peat. This doubling of the pine zone has now been noticed in several distinct areas in the North of Scotland» (LEWIS 1906 a, p. 350). I thought it a matter of importance to see these features myself and therefore, on the advice of Mr LEWIS, I visited one of the mosses lying on the Spey-Findhorn watershed, where I made some investigations on the slopes of Carn a Choire Mhoir, i. e. the same district where LEWIS had taken the section just quoted. The south-western slope is nearly entirely covered with thick peat, unusually little denuded. At about 480 m. above sea-level I dug a section, showing the following strata:

A. 120 cm. of *Eriophorum vaginatum* peat.

B. 50 cm. of *Eriophorum vaginatum* peat with large pine stools in the upper zone. Below this numerous stems, trunks, and twigs of birch occurred.

C. 45 cm. of *Eriophorum vaginatum-Polytrichum* peat. A sample from this layer — unfortunately I do not remember from which part it was taken — was very rich in pine needles, bark of birch and pine, birch twigs, heather stems, etc., seeds of *Pinus sylvestris,* stones of *Rubus idæus,* fruits of *Betula odorata* and *Carex sp.*

D. Boulder clay.

Layer C seemed not to consist of the remains of a forest that had grown at the place. As not peat-covered ground occurs close to the section, the plant remains found may possibly originate from its ancient vegetation. The features just described show that, when the surface of the bog became dry enough to allow a forest to grow on it, a birch wood first spread over it. But the bog dried up still more, and then this birch wood was succeeded by a luxuriant pine forest, which was after some time replaced by an *Eriophorum vaginatum* association. — The same sequence was seen in several peat-hags. The forest bed was sharply marked; it was generally very rich in heather stems. Further towards the north the peat was to a very great extent channelled into peat-hags. Sometimes the underlying till was laid bare. Large pine stools were everywhere met with. In one section the uppermost layer consisted of 180 cm. of *Eriophorum vaginatum-Sphagnum* peat with solitary heather remains. Below this zone there was a layer of a thickness of 30 cm., containing large pine stools, abundant birch twigs, and also more numerous *Calluna* stems. This layer rested on the till. Another section showed the following layers:

A. 70 cm. of *Eriophorum vaginatum* peat.

B. 100 cm. of *Eriophorum vaginatum* peat with numerous large pine stools in all parts of the layer.

C. 50 cm. of *Eriophorum vaginatum* peat with plentiful remains of dwarf shrubs, e. g. *Calluna, Empetrum*, etc. By the washing of a sample some small birch twigs and fruits of *Carex sp.* were also found.

D. Boulder clay.

As I had not time to make extensive cuttings through the peat, I had to confine my investigations to an examination of the stratification in the peat-hags. In these the bottom layers were visible only at places where the peat was rather shallow. At such places the older strata were often wanting. Therefore, I did not see the layers 6–9 in the cited section of LEWIS'. The two distinct layers of pine stools in the upper forest bed, which, according to LEWIS (e. g. 1906 a, p. 350), are characteristic of the mosses of this district and several other Highland mosses, were nowhere seen. In fact, I think, they do not exist. My investigations on the Spey-Findhorn watershed show that LEWIS' two layers of pine stools separated by 1—3 feet of peat belong to one forest bed, consisting of peat, 1—3 feet in thickness, of various composition, containing pine stools at every level. The different results obtained by LEWIS are caused, I think, by the fact that he has not examined the large and long sections that are laid bare in the peat-hags, but has confined himself to dug cuttings, and in every section he has found stools only at two levels.

4. The North West Highlands.

In this part of Scotland LEWIS has also examined some peat districts. One of these is Coire Bog in Easter Ross. A section of LEWIS' (1906 a, p. 344) shows the following sequence of strata (about 375 m. above sea-level):

Dominant plant.		Accompanying plants.
1. Scirpus-Sphagnum.	3 ft.[1]	1. — — — — — — — — —
2. *Pinus sylvestris,* L.		2. — — — — — — — — —
3. Sphagnum.	1—3 ft.	3. — — — — — — — — —
4. *Pinus sylvestris,* L.		4. — — — — — — — — —
5. Eriophorum.	5 ft.	5. Calluna (abundant in the upper layers of Eriophorum).
6. *Betula alba,* L.	2—3 ft.	6. *Menyanthes trifoliata,* L., *Eriophorum vaginatum,* L.
7. *Empetrum nigrum,* L.	$1^1/_2$ ft.	7. Eriophorum, Polytrichum.
8. *Salix Arbuscula,* L.		8. *Betula nana,* L. (abundant in the upper layers), *Dryas octopetala,* L., *Potentilla Comarum,* Nestl. (abundant in the lower layers).
9. Sand.		9. — — — — — — — — —
10. Closely packed stones.		10. — — — — — — — — —

This stratification shows quite the same features as were met with in the Grampians. On the Caithness-Sutherland border LEWIS has found an analogous sequence. One section of his shows the following strata (Halladale about 200 m. above sea-level; cf. 1907 b, p. 411):

»Characteristic plants.	Accompanying plants.
1. *Scirpus cæspitosus.*	1. *Sphagnum.*
2. *Pinus sylvestris.*	2. *Calluna vulgaris, Betula alba.*
3. *Betula nana.*	3. *Salix reticulata, Empetrum nigrum.*
4. *Betula alba.*	4. *Calluna vulgaris, Empetrum nigrum* (scarce).

[1] The thickness of the different strata is taken from LEWIS' discussion of the found features.

5. *Hypnum* sp. and lichens.	5. — — — — — — — — — — —
6. *Salix reticulata.*	6. *Salix arbuscula, Dryas octopetala, Hypnum* sp.

Sand and gravel.

Total depth 17 feet.»

About the same layers are shown by the other 5 sections of LEWIS'. Arctic plants, however, are found between the two forest beds only in the section just cited. At other places the basal beds have also yielded *Arctostaphylos alpina* and *Betula nana.* At one place the bottom layers are deposited in a lake and contain e. g. *Potamogeton natans, obtusifolius,* and *Zizii*, but also in this case two sharply separated forest beds occur.

Some peat mosses in the Assynt district of Sutherland have been investigated by LEWIS (1907 a, p. 39). During my journey I examined the neighbourhood of Inchnadamff rather carefully. South of Inchnadamff the valley of the river Loanan is nearly entirely covered with deep peat. The main part of the vegetation consists of *Calluna-Erica tetralix-Eriophorum vaginatum* and *Scirpus cæspitosus* associations. Particularly on the banks of the river very instructive sections could be seen. One section showed the following strata:

A. 80 cm. of *Scirpus cæspitosus* peat, mixed with *Eriophorum vaginatum* remains, also containing solitary *Calluna* stems. From a sample some *Calluna* flowers and several very small specimens of *Cenococcum* were washed out. LAGERHEIM has found pollen grains of alder, elm, and an ericaceous species.

B. 50 cm. of *forest* peat, a little mixed with *Scirpus cæspitosus,* very rich in birch branches and twigs, and in the uppermost zone containing large pine stools. By washing no other plant remains were found. LAGERHEIM has found pollen grains of alder, birch, elm, hazel, pine, and an ericaceous species (plentiful), and spores of a fern and of *Sphagnum.*

C. 40 cm. of *Scirpus cæspitosus* peat, very mouldered. From the above lying layer some birch roots had penetrated into this layer. Some large specimens of *Cenococcum* were washed out. LAGERHEIM has found pollen grains of birch, hazel, pine, and an ericaceous species, and spores of *Sphagnum.*

D. 15 cm. of *Carex* peat, containing solitary *Eriophorum vaginatum* remains and very abundant *Empetrum* stems. By washing only numerous *Carex* fruits (without perigynium), belonging to several species, were obtained. LAGERHEIM has found pollen grains of an ericaceous species, spores of a fern (probably *Nephrodium oreopteris),* spores and mouldered leaves of *Sphagnum,* and *Amphitrema flavum* (a sphagnophilous rhizopod).

E. 20 cm. of *Carex* peat, containing a few birch twigs and very numerous *Carex* fruits, but no *Empetrum* stems. LAGERHEIM has only found some spores of a fern.

F. Boulder clay.

A forest peat layer, 50 cm. in thickness, containing very numerous birch trunks and twigs, was found below all these strata in another section in the vicinity. In this layer LAGERHEIM has found pollen grains of birch, hazel, pine, and an ericaceous species, and spores of *Sphagnum*.

The sections given by LEWIS closely agree with that described above. In the layer characterized by the abundance of *Empetrum* stems he has also found numerous remains of *Betula nana*. In the lower forest bed he has found *Corylus avellana*. The same feature is, according to LEWIS (1907 a, p. 40), met with further to the south in the neighbourhood of Loch Urigill.

In most sections that I examined the upper forest bed rested directly on the till. Its thickness generally varied between 45 and 60 cm. (in one case 100 cm.). At several places hazel nuts were met with. The finer material of the peat consisted of *Scirpus cæspitosus* remains, sometimes a little mixed with *Eriophorum vaginatum.* Large pine stools occurred chiefly in the upper part of the layer. Abundant *Calluna* stems also occurred. The pine stools were acuminate and generally not charred. Some small coal pieces however were found. Above this layer 80—90 cm. (sometimes 110 cm.) of *Scirpus cæspitosus* peat, sometimes mixed with *Eriophorum vaginatum,* had been deposited. A few *Calluna* stems occurred in this stratum. Closer to the flanks of the valley the peat was shallower. Nearest to the hills the forest bed was wanting. The history of the whole moss agrees then in all more important points with that of the mosses between the Merrick and Kells ranges in the Scottish Southern Uplands.

The main part of the tableland above the precipice of the limestone cliffs south of Inchnadamff is likewise covered with peat of much varying thickness. The vegetation generally consists of a *Calluna-Erica tetralix-Eriophorum vaginatum* association. At one place the field stratum contained plentiful *Scirpus cæspitosus*, scattered *Calluna vulgaris, Erica tetralix,* and *Juncus squarrosus,* sparse *Carex Goodenovii, Eriophorum vaginatum, Molinia coerulea, Narthecium ossifragum*, and *Potentilla tormentilla,* solitary *Drosera rotundifolia*, *Empetrum nigrum*, *Erica cinerea, Eriophorum polystachion, Listera cordata, Pinguicula vulgaris, Polygala serpyllacea*, and *Vaccinium myrtillus*. The ground stratum contained *Racomitrium lanuginosum* (solitary), *Sphagnum* (scattered), and hepatics (solitary). A section in this moorland showed:

A. 80 cm. of *Scirpus cæspitosus-Eriophorum vaginatum* peat.

B. 80 cm. of *Scirpus cæspitosus-Eriophorum vaginatum* peat, containing abundant small stools, trunks, and twigs of birch.

C. Boulder clay.

The same stratification generally occurred in the peat-hags. At the periphery of the moss the forest bed was wanting. The peat was here shallower.

Above Inchnadamff extensive peat deposits occupy the valley of Allt Poll an Droighinn. The peat is very much channelled into peat-hags; the till is often laid bare. Where the peat is not deep enough, it consists of a homogeneous layer of *Scirpus cæspitosus* peat (sometimes 50 cm. in thickness). At a few places birch remains were found. Such a section showed:

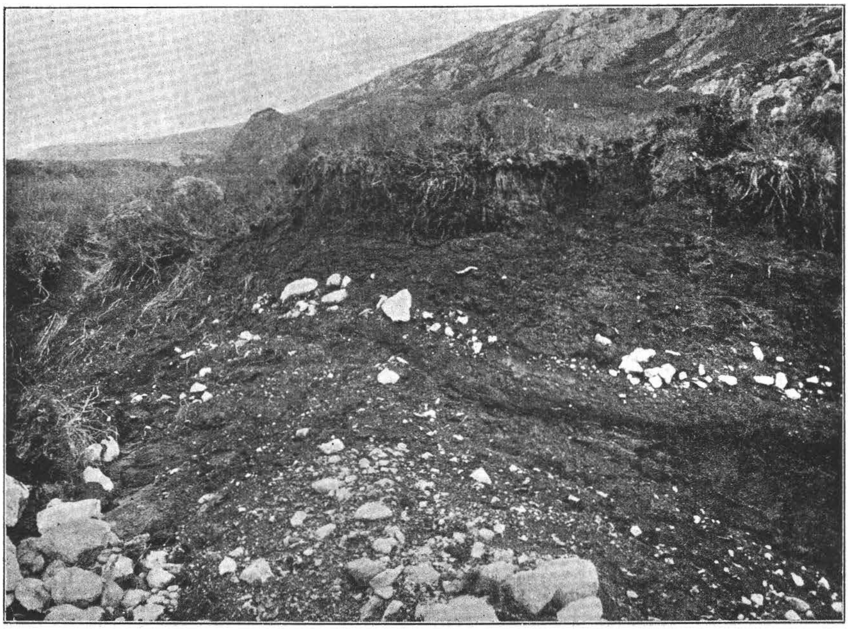

Fig. 3. Section near Inchnadamff, showing a layer of gravel and stones in a stratum of *Scirpus cæspitosus* peat, crowded with *Calluna* stems.

A. 75 cm. of *Scirpus cæspitosus* peat, containing very solitary *Calluna* stems.

B. 30 cm. of *Eriophorum vaginatum* peat, crowded with *Calluna* stems of a large size and solitary small birch twigs.

C. Boulder clay.

This sequence of the strata was found almost everywhere in the central parts of the bog. Sometimes the layer B was thicker (70—90 cm.). Birch remains were often wanting, but the layer was always sharply marked by the abundant heather remains. A somewhat different sequence is shown by the following section:

A. 60 cm. of *Scirpus cæspitosus* peat, almost without *Calluna* stems.

B. 20 cm. of *Scirpus cæspitosus* peat, very rich in *Calluna* stems.

C. 30 cm. of *Scirpus cæspitosus* peat, containing a few small *Calluna* twigs.

D. Boulder clay.

Higher up in the valley (about 350 m. above sea-level) a layer of gravel and rather large stones occurred in the middle of the peat. It was found in a section lying about 50 m. from the mountain hill to the east of the stream. The sequence is shown by fig. 3. The gravel and stone layer generally had a thickness of 20 cm., but disappeared to the left (see fig. 3). It was seen for a length of 8 m. Furthest to the right it rested directly on the till; but else it was underlaid by 50 cm. of *Eriophorum vaginatum* peat, containing abundant *Calluna* stems and some small birch twigs.[1] This kind of peat with the same associates also occurred above the gravel. Its depth was about 20 cm. The uppermost layer consisted of 60—75 cm. of *Scirpus cæspitosus* peat, somewhat mixed with *Eriophorum vaginatum*, but containing only very few *Calluna* remains. On the opposite side of the peat-hag (4 m. from the section just described) the gravel was totally wanting. The stratum containing the *Calluna* stems, however, was sharply marked (55 cm. in thickness). It is obvious that the gravel originates from a slip. The stones never exceeded 30 cm. in diameter.

The above-mentioned features show that this glen has at a certain period been covered with an extensive *Calluna* moor, containing also some shrubby birch. The same association also grew at places where peat deposits already covered the ground. Not even the slip alluded to above has modified the drainage in the district affected by it to such an extent, that the vegetation has undergone any change. After some time this *Calluna* moor has however been replaced by more hydrophilous associations, particularly *Scirpus cæspitosus* associations. Nowadays more xerophilous plants again begin to predominate.

That the climate of these districts is unusually favourable to the formation of peat mosses, is for instance illustrated by the occurrence of small peat deposits on the tops of some larger stones in the glen just described. The top of such a stone, rising about 1 m. above the surrounding moorland, was covered by a peat layer of a thickness of 55 cm. in the deepest part. This peat was very mouldered at the bottom. Nearer the surface it consisted of *Racomitrium* peat. Abundant *Racomitrium lanuginosum* and scattered *Calluna, Empetrum*, and *Eriophorum vaginatum* grew on the surface.

5. The Hebrides and the Shetland Islands.

LEWIS (1906 a, pp. 337—340) has examined several moss districts in Skye. Everywhere at the base of the peat deposits he seems to have

[1] A sample from this layer contained a stone of *Rubus idæus*, a *Carex* fruit, numerous *Calluna* flowers, and small specimens of *Cenococcum*.

found the remains of a birch forest, also containing numerous hazel nuts and remains of *Alnus glutinosa*. Above this forest beds occur thick layers of *Scirpus cæspitosus* peat, sometimes mixed with *Sphagnum* and *Phragmites*. The thickness of the peat varies highly; in one section it was 9 m. But according to LEWIS' statements the relative measures of the different strata seem to agree rather well. It is therefore possible that the forest beds in all the mosses are of the same age.

Nearly the whole of Lewis north of Loch Erisort is peat-covered. The peat extends over level as well as rising ground and hillsides. The highest mountain rises to about 270 m. The peat is much denuded, the underlying till however is more seldom laid bare. The main part of the present vegetation consists of a *Calluna-Erica tetralix-Eriophorum vaginatum* association. Sometimes a nearly closed carpet of *Racomitrium lanuginosum* may occur. *Sphagna* have never been of great importance.[1] LEWIS who has investigated the district between the river Bragor and Monung has everywhere found a sharply marked birch forest bed. He has nowhere found any pine remains. A section of his shows the following layers (1907 a, p. 48):

»Characteristic plants.	Accompanying plants.
1. *Scirpus cæspitosus.*	1. Sphagnum, *Calluna vulgaris* (generally scarce, but more plentiful near the present surface of the peat).
2. *Eriophorum vaginatum.*	2. *Calluna vulgaris. Racomitrium lanuginosum. Polytrichum sp.*, Sphagnum.
3. *Betula alba.*	3. *Corylus Avellana.*
4. *Eriophorum vaginatum.*	4. — — — — — — — — — —
5. *Salix Arbuscula.*	5. *Empetrum nigrum* (scarce). *Betula nana, Potentilla Comarum, Viola palustris.*
6. *Empetrum nigrum.*	6. *Potentilla Comarum*, Sphagnum.
7. Structureless peat with seeds of *Potentilla Comarum*, *Menyanthes trifoliata, Viola palustris*, *Potamogeton prælongus, Phragmites communis.*	7. — — — — — — — — — —

Sand and peaty clay.
Rock.»

The layer 7 is a lake deposit. Unfortunately LEWIS does not mention the thickness of the different strata. He has nowhere found more

[1] LEWIS' statement that *Potentilla reptans* occurs on the surfaces of the mosses must depend on a wrong determination. I saw it nowhere; on the other hand *P. tormentilla*, which is not mentioned in LEWIS' list, was common.

than one forest bed. At the end of june (1909) I made investigations in the district south-east of Barvas. Especially good sections were found on the banks of the river Barvas. They showed:

A. 130—200 cm. of *Eriophorum vaginatum* peat, sometimes a little mixed with *Sphagna* and *Scirpus cæspitosus.*

B. 45—90 cm. of *forest* peat, containing large birch stools and abundant branches and twigs of birch and heather. Sometimes numerous hazel nuts also occur. The lowest layers have the character of forest humus, somewhat mixed up with sand. A sample of this humus contained enormous numbers of *Cenococcum*, large specimens as well as small ones. Washing also gave a few *Carex* fruits.

C. Moraine.

Sometimes the forest bed was wanting, but this was the case only where the peat was exceptionally shallow. About 4 km. south of Barvas a section close to the road showed the following strata:

A. 200 cm. of *Eriophorum vaginatum* peat, also containing *Scirpus cæspitosus* remains, not mouldered and entirely without any remains of trees, but with solitary *Calluna* stems.

B. 25 cm. of *Eriophorum vaginatum* peat, highly mouldered, very rich in trunks and twigs of birch and heather.

C. 50 cm. of *Eriophorum vaginatum* peat with solitary remains of dwarf shrubs.

D. 10 cm. of *Eriophorum vaginatum* peat with numerous *Empetrum* stems.

E. 25 cm. of *Eriophorum vaginatum* peat with numerous birch branches and twigs of at least as large a size as those found in the upper forest bed.

F. Moraine.

This stratification shows that this district has twice been covered by a birch forest. that has been replaced by more hydrophilous associations. During this process *Sphagna* have been of no importance, which is shown by the character of the peat. That LEWIS has nowhere found any analogy to this lower forest bed, may possibly depend on the character of the oldest strata (lake deposits) at the point where he has found the most complete stratification. Layers of so high an age seem not to be of general occurrence. A stratification quite analogous to that which I found on the banks of the river Barvas has been described by LEWIS as occurring in North Uist (1906 a. p. 340).

On the Shetlands Islands LEWIS has examined two districts on the Mainland. The Wall-Sandness district lies on the western coast and is an undulating moorland lying mostly between 60 and 90 m. above sea-level. The vegetation is chiefly composed of *Calluna, Eriophorum vaginatum, Scirpus cæspitosus,* and *Racomitrium lanuginosum* (LEWIS 1907 a, p. 50). According to LEWIS (p. 50) the sequence of the strata in one district is:

»Characteristic plants.	Accompanying plants.
1. *Scirpus cæspitosus.*	1. Sphagnum, Calluna (scarce).
2. *Eriophorum vaginatum.*	2. — — — — — — — — — —
3. Dense light-coloured structureless peat crowded with the stems of Calluna.	3. — — — — — — — — — —
4. *Salix Arbuscula.*	4. *Empetrum nigrum, Betula nana, Erica tetralix.*
5. *Betula alba.*	5. *Corylus Avellana.*
6. Sphagnum and *Eriophorum vaginatum.*	6. — — — — — — — — — —
7. *Salix reticulata, S. herbacea.*	7. *Betula nana.*
8. *Potamogeton pectinatus.*	8. *Menyanthes trifoliata, Viola palustris, Ranunculus repens, Equisetum sp.*

Sand and rock.»

The *Calluna* layer (3) »marks a period of denudation during which the surface of the bed became wasted and channelled into peat-hags like those met with on the present surface of the peat» (LEWIS 1907 a, p. 53). In a section of his (fig. 3, p. 55) the peat reaches a depth of 10 feet below the water-level of a loch. From this statement and his fig. 3 the thickness of the different strata can be made out, and the following sequence is obtained (p. 54):

Characteristic plants.		Accompanying plants.
1. *Eriophorum vaginatum.*	115 cm.	1. Sphagnum, *Scirpus cæspitosus.*
2. *Calluna vulgaris.*	30 cm.	2. *Erica tetralix.*
3. *Betula nana.*	40 cm.	3. — — — — — — — — — —
4. *Betula alba.*	115 cm.	4. — — — — — — — — — —
5. Structureless peat with clay.	65 cm.	5. — — — — — — — — — —
6. *Salix Arbuscula.*	60 cm.	6. *Empetrum nigrum.*

Stone pavement.

An almost identical stratification is also met with in the other district investigated by LEWIS. The peat deposits of both districts is at the present time highly denuded.

III. Some evidences of the late-quaternary geology and vegetation of Scotland furnished by the peat mosses.

The occurrence of large stools and other remains of trees in the British peat mosses has naturally long since been noticed by many authors. Several different attempts of explaining their occurrence have been made. Some authors are of opinion that these forest beds are the remnants of forests destructed and cut down by the Romans (Cf. e. g. HARDY 1905, p. 122 and also GEIKIE 1881, p. 530). It is probable that the overthrow and destruction of some forests that grew on the peat mosses was caused by the Romans, but this, I think, is not the rule. HARDY's (1905, p. 120) opinion that most peat mosses originate from that time is surely wrong, which is shown e. g. by the rather frequent occurrence of arctic plants in the basal peat layers. The lower forest beds in particular, which, as I have shown, very often occur, must be of considerably earlier date than the entrance of the Romans. The influence of man cannot have caused the disappearance of these forests. According to ANDERSSON (e. g. 1896, p. 13) the forests that once grew to such an extent on the surface of the Swedish mosses have been buried by the spreading of *Sphagna,* owing to the biological qualities of these plants. This however cannot be the true reason, in cases when the woodland has been replaced by other formations than *Sphagnum* associations. The above-described stratification of Scottish peat deposits show that the old forests of these mosses have very seldom been destroyed and buried by *Sphagna.* Another related attempt to explain the features in question is made by HAGLUND (1908 and 1909). His theory is founded on the observation that the stools of the forest beds of the Swedish mosses have generally been on fire, or that coal is common in these strata. By the conflagration of the forest growing on the surface of the peat, the peat has according to HAGLUND become unsuitable for the growth of forest vegetation; on the contrary *Sphagna* have found a favourable habitat and replaced the forest. As I have mentioned above, coal sometimes occurs in the forest beds of the Scottish peat mosses (Cf. also HARDY 1905, p. 122), but this is by no means always the case. Evidences of fire are particularly seldom met with in such forest beds as derive their origin from deciduous woods. On account of this and for the same reasons that have been stated against ANDERSSON's theory, it is obvious that HAGLUND's theory cannot give any general explanation of the occurrence of the forest beds. The Swedish investigators of peat mosses are nowadays practically unanimous with reference to the opinion that the alternation of forests and more hydrophilous associations on the surface of the mosses is chiefly caused by changes of the level of the ground water. But the unanimity scarcely stretches any longer. HAGLUND has called attention to the fact that the disappearance of the forests over large areas causes a considerable elevation of the level of the ground water. By this the depressions occupied by lakes and peat deposits receive increased quantities of water, which, according to HAGLUND, results in a replacement of the forests by swamp and marsh formations. The supposition of an extensive forest fire or the cutting down of the trees on the surrounding dry ground might then explain the conversion of forest into marsh. Such an explanation may be possible with reference to peat mosses occupying depressions in the ground. But I scarcely believe that the temporary disappearance of the forest on dry ground over not too wide areas would to such an extent change the conditions on peat deposits that, like the majority of the Scottish ones, occur on sloping ground. In some districts, e. g. the northern part of Lewis, not peat-covered ground is scarcely met with. The old forests of Lewis show very few signs of having been on fire. That the lack of forests on dry ground in the Scottish Highlands below a certain level is to a great extent due to the influence of man, is highly probable. But the origin of the greater part of the forest beds of the Scottish peat mosses must no doubt be referred to a time, when man had not yet got so great an influence on the vegetation.

The theory which according to my opinion gives the most plausible explanation of the stratification of the peat mosses, starts from the supposition that during the post-glacial time dry and rainy periods have alternated. The founder of this theory is JAMES GEIKIE, professor at Edinburgh. In 1867 he tried to show that in nearly all Scottish peat mosses a layer containing large stools, i. e. the remains of a forest that had grown on the surface of the moss, is met with. He also showed that such forest beds occur in peat deposits, lying below the present sea-level. He thought that these features went to prove that during a certain part of the post-glacial time the climate of Scotland was much more continental than during the other parts. GEIKIE was of opinion that during that time the extent of the British Isles was much greater than now and that they were even connected with the European Continent. According to GEIKIE the greater extension of the land area caused a more continental climate. He has the same opinion in 1874 (p. 354). In 1881 he has somewhat modified his point of view. His classification of the late-quaternary deposits of that time coincides with what he still maintains. A good summary of this given by him (in LEWIS 1906 b, p. 252) may be quoted here:

»Succession of the Later Glacial and Interglacial Stages in Scotland.

Upper Turbarian or Sixth Glacial Stage.

High-level corrie glaciers, with snowline at 3500 feet; peat overlying Upper Forest; raised beaches at 25 to 30 feet; somewhat cold and wet climate.

Upper Forestian or Fifth Interglacial Stage.

Upper Forest overlying Lower Peat; relatively dry and genial climate; land area somewhat more extensive than now.

Lower Turbarian or Fifth Glacial Stage.

Valley-glaciers, with average snowline at 2400 to 2500 feet; Lower Peat overlying Lower Forest; raised beaches at 45 to 50 feet; cold and wet climate.

Lower Forestian or Fourth Interglacial Stage.

Lower Forest overlying morainic accumulations of Fourth Glacial Stage; genial climate; land area of greater extent than now.

Mecklenburgian or Fourth Glacial stage.

District ice-sheets and large valley-glaciers of Highlands and Southern Uplands; raised beaches at 100 to 135 feet; Arctic climate, with snowline ranging from 1000 feet in west and north-west to 1500 feet or thereabout in Central Scotland.»

The names of the different periods originate from 1895. In 1881 GEIKIE knew the classification of the post-glacial deposits of Norway which had been drawn up in 1876 by A. BLYTT, who did not then know the theories of GEIKIE's.

We are now going to discuss some features as to the late-quaternary climate and vegetation of Scotland shown by the stratigraphy of the Scottish and North English peat mosses described above.

In 12 of the 16 different districts mentioned above two distinct forest beds or other xerophilous zones are found. The lower forest bed always consists of the remains of a birch forest. In 7 of these districts arctic-alpine plants are found between the two forests in a layer which is usually sharply marked by its abundance in *Empetrum* stems (Cf. LEWIS 1905, Fig. 2). In 8 districts arctic plants have been found in the bottom layers of the mosses. In cases when only one forest bed has been met with (Cross Fell, Lewis), it is quite possible that these plants date back from the same period as the arctic ones that occur between the forest beds. In 6 districts arctic plants have been found below two forest beds, and in these cases, I think, there is no doubt that the plants in question represent the flora that covered the ground at the close of the Mecklenburgian ice age. The three overlying peat zones: lower forest bed, zone with arctic plants (»second arctic bed»), and upper forest bed immediately invite to a correlation. I am even of opinion that if stratigraphy founded on palæontology concerning the peat mosses of Scotland will at all be possible, 1st the second arctic bed must be regarded as contemporaneous in all districts, 2nd the forest beds lying below this zone and sometimes above another arctic layer must represent a certain fixed time, and 3rd the upper forest beds in such mosses where the last-mentioned strata occur must be contemporaneous. If these forest beds are regarded as homologous in mosses where the one lies above, the other below the second arctic bed, it must also be conceded that this alternation of different associations on the surface of the same moss must depend, not on the local drainage of the different mosses, but on changes of the climate, the effects of which have stretched over the whole of Scotland. But if this conclusion is true, we must also be of opinion that the forest beds which are met with in mosses where the second arctic bed is wanting reflect the same changes of the climate. Consequently, I must entirely agree with GEIKIE's opinion

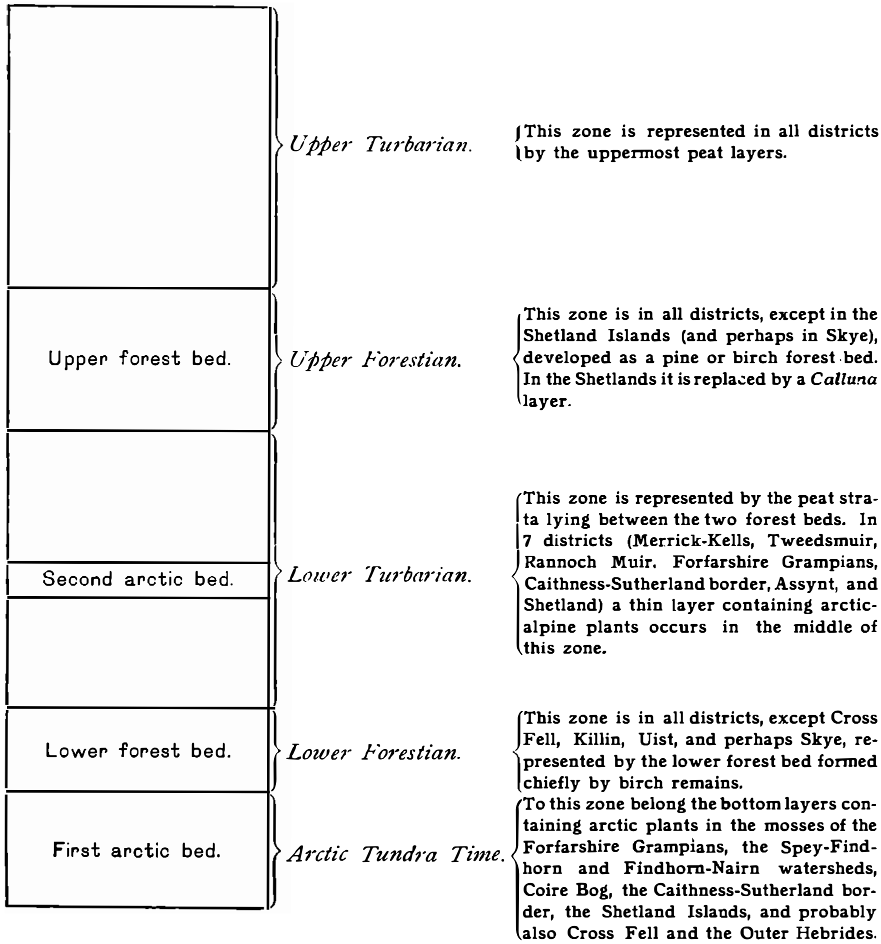

Fig. 4. The stratification of a typical Scottish peat moss.

as to the occurrence of the forest beds. From this discussion it will be obvious which strata of the different mosses described above I believe to be contemporaneous. In order to illustrate this I have on fig. 4 drawn a skeleton section of a typical Scottish moss where all strata are represented. The districts where the different zones have been found are also enumerated.[1] The geographical distribution of the different types of mosses

[1] The age of the forest bed in the mosses of Skye (investigated by LEWIS) is very doubtful, but I find it most probable that it dates back to the Upper Forestian.

is, so far as they have been examined, shown by Pl. 13. The stratigraphy of the mosses consequently agrees in all more important points with GEIKIE's classification of the post-glacial deposits.

Before going on further I must however give an account of LEWIS' opinion of the stratigraphy of the Scottish peat mosses. LEWIS has started from GEIKIE's points of view and endeavoured to bring his results into accordance with GEIKIE's opinion as much as possible. But by holding one-sidedly on to the correctness of GEIKIE's classification of the late-quaternary history of Scotland, LEWIS has been led to some conclusions that are certainly wrong. Upon the whole I have nothing to say against his interpretation of the sequence of the mosses of the Southern Uplands and the Shetland Islands. But as to all other districts I cannot in all points agree with LEWIS. In the Outer Hebrides LEWIS has found only one widely spread forest bed, which he refers to the Lower Forestian. Because of my discovery of a lower forest bed, separated from the upper by several strata, one of which very rich in *Empetrum* stems, I regard the forest bed examined by LEWIS and also observed by me as belonging to the Upper Forestian. The difference between LEWIS' interpretation and mine is greatest in reference to the the mosses of the Grampians and the North West Highlands. LEWIS is of opinion that the oldest strata of the Highland mosses investigated by him were deposited during the latter part of the Lower Turbarian (1907 a, p. 64). As to the peat which, according to LEWIS, lies between the second arctic bed and the upper forest bed he writes: »In some of the Highland areas, such as the Spey-Findhorn watershed, Findhorn-Nairn watershed, Coire Bog, Cape Wrath district, Rannoch Muir, remains of small *Betula alba* shrubs occur in the lower parts of this zone. The wood is very local in occurrence, whilst the main mass of the peat is formed of *Scirpus cæspitosus*, *Eriophorum angustifolium, E. vaginatum,* and Sphagnum. Evidently these small clumps of shrubby birch were soon displaced, as no wood is met with above the first foot or so of the Upper Peat Bog» (1907 a, p. 65). In reference to the upper forest bed he writes: »As soon as the Highland areas are entered the Upper Forest divides into two distinct zones separated by 1—3 feet of peat in which no wood is found. . . . in areas examined in the Grampians and in Assynt, *Betula nana* and *Salix Arbuscula* are abundant between the two layers of forest remains. The presence of these plants in some districts, and of Sphagnum beds in others, between two layers of well-developed pine forest, is significant . . . » (LEWIS 1907 a, p. 65). Against this I will say that, according to LEWIS (1906 a, p. 345), after the disappearance of the arctic plants from the Coire Bog district: »A growth of *Betula alba* of small size — most of the stems being less than 8 inches is diameter — covered the whole district and persisted until a thickness of 2 or 3 feet of Betula remains had accumulated.» Almost quite the same in recapitulated by him as to the mosses on the Spey-Findhorn watershed in connection with which he sums up the facts in the following words (1906 a, p. 348): »At the same time the wide occurrence of a shrubby growth of birch above the basal Arctic and sub-Arctic beds over the present watershed, the Findhorn-Nairn watershed, in Coire Bog and in Caithness, suggests that we are not dealing with a local phenomenon, but with a feature which characterised large areas at the same time.» His descriptions of this layer identically show the same features as those I saw in the lower forest bed of the Merrick-Kells mosses, and I therefore also regard the two zones as contemporaneous. I have already tried to show (p. 208) that the opinion that the upper forest bed of the Highland mosses consists of two distinct pine stool layers is not right. The statement just quoted that arctic plants have sometimes been met with between two such p i n e stool layers is wrong. In the districts in question, the Forfarshire Grampians, the Caithness-Sutherland border, and the Assynt district, the lower forest zone consists of birch remains. LEWIS regards this forest bed in these districts as a development facies of that lower pine stool layer which he believes to have found in some Highland mosses. The incorrectness of this interpretation seems to me to be obvious; I will further on return to the circumstances that have led LEWIS to these conclusions.

We will now a little more closely examine the evidences yielded by the peat mosses in reference to the late-quaternary history of Scotland and especially its vegetation.

1. **The Arctic Tundra Time.**

LEWIS (1907 a, p. 59) thinks that he has only found remains of an arctic flora, which immigrated after the disappearance of the glaciers of the Mecklenburgian ice age in the Outer Hebrides and the Shetland Islands. As already mentioned, I am of opinion that remains representing the vegetation in question have been met with at least in 6 of the above-described chief districts. The plants that have been found in the first arctic bed are either arctic-alpine species or have a much wider distribution. To the first type belong *Arctostaphylos alpina, Betula nana, Dryas octopetala, (Empetrum nigrum,) Lychnis alpina, Salix arbuscula, herbacea,* and *reticulata, Sedum rhodiola,* and *Veronica alpina.* In other places *Loiseleuria procumbens, Oxyria digyna,* and *Salix polaris* have also been found in lake deposits (Cf. e. g. REID 1899, p. 62). All others that LEWIS has met with are aquatic or marsh plants. They are *Carex ampullacea, Equisetum sp., Hippuris vulgaris, Menyanthes trifoliata, Potamogeton natans, obtusifolius, pectinatus,* and *Zizii, Potentilla comarum, Ranunculus repens,* and *Viola palustris.* REID mentions some other plants of the same kind, but his lists sometimes also contain such as have surely not been found in the same layers as the arctic ones. The places where LEWIS has found arctic plants in the basal layers are rather equally distributed in the Highlands. The finds quoted by REID chiefly originate from the lowlands. Therefore, we have good reason to think that an arctic-alpine flora of the just described type has spread over the whole of Scotland and the adjacent islands, when the last large glaciers had melted away. According to LEWIS (1907 a, p. 60), the occurrence of a rather luxuriant water flora »indicates a wet cold climate rather than dry conditions with an arctic temperature». It »was not arctic like that, for instance, of North Greenland, but rather resembled South Greenland at the present time». (Cf. also ANDERSSON 1903, p. 6).

2. The Lower Forestian.

This period seems to have almost immediately followed the disappearance of the arctic-alpine vegetation from the lower parts of Scotland. The origin of a great number of more extensive peat deposits dates back to this period. The lower forest bed of several Scottish peat mosses is the most characteristic stratum af that time. But in cases when the development of a peat moss has begun with the silting and filling up of a lake basin, layers developed in another way may also occur. The climate of this period was rather continental and warm. The extent of the land area was then greater than it is at present, which is shown by the frequent occurrence of buried forests below the sea-level on the British coasts[1]. The Outer Hebrides and the Shetland Islands, where wild forests are now entirely absent, were then covered with extensive birch forests. In the forests of the Shetlands the hazel also occurred. These islands seem scarcely to have had any forests, at least not of greater extension, since the Lower Forestian. The mainland of Scotland was forest-clad up to about the present upper limit of the pine forests (about 600 m. above sea-level in the Grampian Mountains). A section of LEWIS' from the mosses near Unach Water in the Forfarshire Grampians (750 m. above sea-level) suggests a still higher tree limit, if the layer 4 of that section dates back from the Lower Forestian. The occurrence of *Ajuga reptans* in a forest

[1] GEIKIE has by means of a map (1881, Pl. E. and 1894, Pl. XII) illustrated his opinions as to the extent of the land area in that time. GEIKIE is of opinion — and many other authors, particularly botanists, agree with him — that the Færöes, Iceland, and Greenland were then connected with Europe by a continuous, or nearly continuous, land bridge (1881, p. 518). But particularly the botanical facts brought forward by E. WARMING (in Medd. om Grönland, XII, 1888, pp. 169—215 and in Botany of the Færöes, II, 1903, pp. 662—674) and the geological evidences discussed by TH. THORODDSEN (in Ymer 1906) seem to disprove the existence of such a land bridge in the quaternary period. Such a land bridge would apparently shut off the northern part of the Atlantic from the Gulf Stream, which must absolutely have highly changed the climate and vegetation of Scandinavia. The conditions would then very likely have been arctic in character in large parts of Scandinavia (Cf. THORODDSEN l. c., p. 97). But such a change of the climate would no doubt be reflected in the stratigraphy of the peat mosses. But though the peat mosses of Scandinavia have been very carefully investigated no such signs have been found. I have called attention to this fact, as I think that the total absence of all such signs proves the impossibility of the existence of the hypothetical land bridge, at least after the close of the Mecklenburgian ice age.

bed lying between two arctic beds in the same district (675 m. above sea-level; Cf. LEWIS 1907 a, p. 42) is also a significant fact. The more detailed statements of GEIKIE's as to the distribution and composition of the different forest beds are vague and sometimes rather doubtful. He has seldom made any more careful investigations of the peat mosses and has also in his papers quoted a great number of statements of other authors which surely often are wrong. LEWIS (1907 a, p. 62) has never found any pine remains in the lower forest bed. That the pine had immigrated in the country is however shown by the occurrence of pine pollen in the lower forest bed in the above-described peat moss in the valley of the river Loanan, south of Loch Assynt. The chief part of the trees occurring in the lower forest bed are birch and also, on lower levels, oak, alder, and hazel (Cf. e. g. LEWIS 1905, p. 716). According to G. H. KINAHAN (Manual of the Geology of Ireland, 1878, p. 268) two distinctly marked forest beds also occur in the Irish peat mosses. The lower forest usually consists of oak stools, directly resting on the glacial deposits, the upper, of pine. ANDERSSON (1908, p. 262) has suggested the possibility of the birch forest bed which, in several Scottish mosses, lies below the second arctic bed, having been deposited during a part of the late-glacial time when the temperature for a shorter time rose and then again fell. Such a supposition, it is true, gives a plain explanation of the occurrence of the second arctic bed. Notwithstanding this, I think, is not acceptable. The thickness of the forest bed, for instance 115 cm. of peat grown *in situ* in the Shetland Islands, 45 cm. in the Merrick-Kells district, etc. also indicates a long time of development. This forest bed, or other layers below it, contains plant remains at a high level (e. g. *Corylus*, *Alnus glutinosa*, *Ajuga reptans*, etc.; Cf. LEWIS 1905, p. 707, etc.), which show most certainly that the climate of these districts was during the Lower Forestian at least as genial as the present.[1]

3. The Lower Turbarian.

This period is represented by more or less thick peat strata formed by highly hydrophilous formations, particularly *Sphagnum* bogs, *Eriophorum vaginatum* and *Scirpus cæspitosus* associations, which indicate a very moist insular climate. Usually in the middle of these layers, sometimes in the larger part of them, remains of arctic-alpine plants occur. In places where this second arctic bed has been met with lying above a real birch forest bed, the following arctic-alpine plants have been found: *Arctosta-*

[1] ANDERSSON (1908, p. 262) thinks that the determination of the hazel remains found by LEWIS may be incorrect. Be that, however, as it may, the occurrence of hazel pollen in the lower forest bed at Assynt (see above p. 211) shows that the hazel was a native of the district before the second arctic bed having been deposited, which, in the district in question, contains *Betula nana*. The other fossils and features of the lower forest also show unanimously that a long time elapsed between the first and the second arctic bed.

phylos alpina, Betula nana, (Empetrum nigrum,) Loiscleuria procumbens, Salix arbuscula, herbacea, and *reticulata*, while *Erica tetralix,* which has also been met with, is a rather southern atlantic species. *Loiseleuria, Salix herbacea,* and *reticulata,* which occur between two forest beds in the Merrick-Kells and Tweedsmuir districts are according to LEWIS (1906 b, p. 245) »typical Arctic plants, and their presence at a certain level throughout the peat in Galloway and Tweedsmuir points unmistakably to a decided decrease in temperature — to a time, in fact, when the valleys in the South of Scotland had a climate at least as rigorous as that at present obtaining on the summits of the highest Scottish mountains» (Cf. also LEWIS 1905, p. 709). LEWIS therefore agrees in all respects with GEIKIE's opinions with reference to the climate of the Lower Turbarian. GEIKIE writes (1895, p. 251): »The invasion by the sea which marked the passing of the Lower Forestian stage was continued into the Lower Turbarian stage. The climate at the same time became more humid and colder — hence the restriction of forest-growth and the increase of snow-fields. In Scotland glaciers here and there came down to the sea and dropped their moraines upon the beach-deposits — the large majority, however, terminated inland, some of these being true valley-glaciers while a larger number were corrie-glaciers. The general distribution of the moraines indicates a snow-line ranging between 2000 and 2600 feet.» That the glaciers in question sometimes descended to the sea, is according to GEIKIE obvious for several reasons. He writes (1894, p. 297): »When we come to examine the coasts of the Northern and Western Highlands, few traces of the 45 to 50-ft. beach are seen . . They are seldom, however, developed at the heads of the great sea-lochs of the mainland. Here and there they do occur, and when this is the case, it sometimes happens that they are capped by moraines.» As instances of places where moraines rest upon the 45 to 50-ft. beach, he mentions Glen Thraill near Loch Torridon (according to HINXMAN) and Glen Brora in Sutherland, and Glen Messan in Argyllshire (according to MACLAREN) (Cf. GEIKIE 1894, p. 297, and 1881, p. 411). The Carse clays belong according to GEIKIE to the same period. The Highland mosses examined by LEWIS apparently lie in districts which ought to have been covered with those glaciers, and therefore LEWIS quite naturally is of opinion that the forming of those peat mosses did not begin, until these glaciers disappeared. LEWIS writes (1906 b, p. 247): »The Highland mosses began their history at a stage later than the peat examined in the Southern Uplands. In the north none of the beds below the Arctic plant zone of the Southern Uplands are present, as the recurrence of cold conditions represented by the Arctic bed in the south produced glaciation in the north, thus sweeping away all peat beds representing the preceding interglacial period during which the lower forest beds of the Southern Uplands were formed.»[1] I have already tried

[1] It is these opinions that have caused LEWIS' peculiar conclusions alluded to above (p. 222).

to show that such a difference between the different districts examined by LEWIS and myself does not exist (see also Pl. 13). On the contrary numerous Highland mosses, in the Grampian Mountains as well as in the North West Highlands, have existed since the close of the Mecklenburgian ice age. These facts seem to irrefutably show that glaciers of such an extent, as is believed by GEIKIE, LEWIS, etc., cannot have existed in Scotland in so late a part of the post-glacial time. The statements that moraines sometimes rest on the 45 to 50-ft. beach, are certainly rather doubtful. At the heads of some large sea lochs this beach has not been discovered on the level where it was expected to occur, but on this level such moraines as are regarded as post-glacial have been found. It is highly probable that from this fact the conclusion has been drawn that the beach is capped by moraines. It is, however, very improbable that conspicuous beaches should have been developed at the heads of those narrow sea lochs. I therefore think that the moraines which are considered to belong to the Lower Turbarian are much older and were deposited during the last part of the Mecklenburgian glaciation at a time when the ice movement had taken other directions than during the maximum of glaciation. It is, however, possible that glaciers also existed during the Lower Turbarian. But this being the case, their occurrence has certainly been limited to the most lofty parts of the Highlands. The traces of glaciation which have been found by GEIKIE (Cf. 1895, p. 252; 1894, p. 313) above 3500 feet belong perhaps to this time. GEIKIE thinks that they date back to the Upper Turbarian. Both GEIKIE and LEWIS are of opinion, as has already been mentioned, that the climate of the Lower Turbarian was much colder and moister than that of the Lower Forestian. LEWIS compares the climatical conditions of Scotland at this time to the present ones of South Greenland (1905, p. 709; 1907 a, p. 60), GEIKIE to those of Northern Norway (1894, p. 313). That its climate was more insular than during the Lower Forestian, is beyond doubt, a fact that may partly be due to the submergence of the land (Cf. GEIKIE 1894, p. 321). But if the temperature had been particularly low, the Carse deposits ought not to contain the same shells that now live on the coasts of Scotland. No more northerly shells have been found (Cf. GEIKIE 1894, p. 296). LEWIS is of opinion that the presence of those arctic-alpine plants which he has met with between the two forest beds cannot be explained without supposing that the lower land had a tundra character (1905, p. 709). SERNANDER (1908, p. 265) has called attention to the occurrence of *Erica tetralix* in the second arctic bed of the Shetland Islands, the presence of which species contradicts LEWIS' supposition. SERNANDER thinks (1908, p. 266) that »the second arctic bed in mosses at a lower level needs probably not . . . to have been deposited below the tree limit of that time». In his opinion this view is supported by the fact that numerous alpine plants in the *Ilex* region of Western Norway often descend to the sea-level. Though SERNANDER has on several occasions treated this subject, he has never investigated it more thoroughly. Therefore, we will now a little further examine the distribution of the alpine plants in a moist insular climate.

According to SERNANDER (1899, p. 52) the characteristic plants of the *Dryas* formation (and some colonies of alpine plants in the open vegetation of the stream banks) »descend to very low levels at the Atlantic coasts of Norway». This fact is indisputable, but seemingly contrasts with the opinions of A. BLYTT'S as to the continental character of the alpine flora of Scandinavia. BLYTT (1876) has given many instances of the fact that the alpine plants generally avoid the Norwegian coast districts with their insular climate. He writes for instance (1876, p. 19): »Thus our coast mountains in the province of Bergen, are especially poor as regards botany, and not least so in alpine plants. In going through my flora of Sogn I find that out of our about 170 mountain plants, only 31 are found to the west of Vik and Balestrand; only 19 are frequent right out to the sea, and 136, among which 51 of our commonest mountain plants, seem to be entirely wanting in Western Sogn.» But BLYTT also very often calls attention to the occurrence of alpine plants at a very low level, often at the sea-level, on the western coast of Norway. But he says that this happens particularly south of the Trondhjem fjord at the interior parts of the West Norwegian fjords, e. g. in Sogn (1869, p. 37): »Here the inconsiderable horizontal distance of the high mountains from the fjord eminently favours the natural forces which contribute to the carrying down of the alpine plants in the lowlands . . . And the narrower the valley, the steeper its slopes, the more often such descended alpine plants are met with.» Descriptions of the vegetation of the Norwegian coast districts, however, seem to indicate that two types of Scandinavian alpine plants occur, the one avoiding an excessive insular climate, the other not.

We are now going to examine the question if alpine plants occur more often below the alpine region of the high mountains on the western coast of Norway than in some more continental parts of Fennoscandia.

We will then start from BLYTT's list of the Scandinavian arctic plants (1893, pp. 22—25). We do not take into consideration such plants as exclusively, or almost exclusively, occur on sea shores, nor those which only occur in the northernmost parts of Scandinavia, nor plants of a very limited distribution. None of these types are suitable for our investigation. Among the other we may distinguish one group apart, the species of which are scattered and sometimes rather common in large parts of the pine forest region of Northern Sweden and often occur north of Medelpad down to the sea. Such species can, of course, not answer our question.[1]

[1] To this group belong: *Agrostis borealis, Andromeda polifolia, Androsace septentrionalis, Arctostaphylos uva ursi, Astragalus alpinus, Bartsia alpina, Betula nana, Calamagrostis lapponica, Campanula rotundifolia, Cardamine pratensis, Carex alpina, capillaris,* and *capitata, Cystopteris fragilis,* and *montana, Deyeuxia neglecta* (syn. *Calamagrostis stricta),* *Empetrum nigrum, Epilobium alsinifolium, davuricum, Hornemanni,* and *lactiflorum, Equise-*

The main part of these descend to the sea in Western Norway, but some others avoid the neighbourhood of the sea. It is very curious that *Betula nana* seems to belong to the last type (Cf. BLYTT 1869, p. 106; R. E. FRIDTZ in Christiania Vid.-Selsk. Skr., I, 1903, p. 108).

The majority of the other arctic species of BLYTT's may occasionally descend to the sea in the arctic parts of Norway (north of the Ranen fjord). I have seen statements that, south of Nordland, the following plants have been met with at very low levels:[1]

Alchemilla alpina, Arctostaphylos alpina, Draba incana, Hieracium alpinum, *Loiseleuria procumbens, Oxyria digyna, Salix herbacea*, *Saxifraga aizoides*, and *oppositifolia, Sedum rhodiola, Silene acaulis,*

Arabis alpina, and *petræa, Asplenium viride, Carex atrata,* and *rupestris*, *Cerastium alpinum,* and *trigynum, Dryas octopetala, Erigeron alpinum, Eriophorum Scheuchzeri, Habenaria albida, Juncus castaneus, trifidus,* and *triglumis, Luzula spicata*, *Poa cæsia, Potentilla Sibbaldi* (syn. *Sibbaldia procumbens*), *Salix arbuscula*, and *myrsinites*, *Saxifraga cæspitosa, cotyledon, nivalis,* and *stellaris*, *Sedum villosum, Thalictrum alpinum, Vahlodea atropurpurea,* and *Viola biflora.*

These species are 38, only 11 of which (those first mentioned) occur at the open sea. The greater part of them very seldom occur near the sea. They are not even commonly met with on edaphically favourable habitats. The following species are also usually restricted to the mountain districts but descend to the sea in Western Norway:

Angelica archangelica, Cryptogramme crispa (this species also occurs at the open coast), *Festuca ovina v. vivipara, Myosotis sylvatica*, *Rumex arifolius,* and *Woodsia hyperborea.*

Of very great interest is the regular occurrence of numerous alpine plants at the lower ends of the glaciers in the West Norwegian valleys. On the moraines of the Suphellebræen in Sogn (about 30 m. above sea-level) BLYTT found 21 alpine species (1869, p. 37). Here, and in some other places (Cf. also O. DAHL in Christiania Vid.-Selsk. Forh., 1898), some species which have not elsewhere been found at so low a level also are met with.

76 of the arctic species of BLYTT's, that occur on the high mountains south of the Trondhjem fjord, do not descend to the sea and are not,

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tum scirpoides, and *variegatum*, *Festuca ovina, Gentiana nivalis, Habenaria viridis, Ledum palustre, Lychnis alpina*, *Parnassia palustris, Petasites frigidus, Phleum alpinum*, *Pinguicula villosa, Poa alpina, Potentilla salisburgensis* (syn. *maculata*), *Pulsatilla vernalis*, *Pyrola rotundifolia, Ranunculus confervoides* (syn. *Batrachium eradicatum)*, and *lapponicus, Rubus arcticus*, and *chamæmorus, Saussurea alpina, Saxifraga hirculus, Selaginella selaginoides*, *Sparganium submuticum, Stellaria alpestris,* and *crassifolia, Taraxacum officinale*, *Thymus serpyllum, Tofieldia palustris*, *Vaccinium oxycoccos, uliginosum,* and *vitis idæa.*

[1] These statements have been taken from papers by BLYTT (1869), O. DAHL (in Christiania Vid.-Selsk. Forh., 1891, 1892, 1893, 1894, 1896, 1898, 1906, and 1907), R. E. FRIDTZ (in Christiania Vid.-Selsk. Skr., I, 1903), O. A. HOFFSTAD (in Nyt Mag. f. Naturv., Bd 37, 1900), A. E. LINDBLOM (in Bot. Not., 1843), S. K. SELLAND (in Bergens museums aarbog, 1906 and 1908), etc.

below the tree limit, more common in the coast districts than in the more continental parts of the country. Numerous species avoid the neighbourhood of the open sea, which is shown by almost every description of the vegetation of Western Norway (Cf. particularly the quoted papers by BLYTT and DAHL). The species in question are to a great extent confined to shale areas, but notwithstanding, they are very rare on the shale mountains of the outer parts of the Hardanger and Bukken fjords.

We will, however, now also give some instances of the occurrence of alpine plants in the pine forest region in and east of the Scandinavian mountain range. Numerous examples of this kind are given by SERNANDER (1899 and in Bot. Not., 1894). He has especially called attention to the fact that the alpine plants do not occur equally scattered over the pine forest region, but that colonies of them are met with at certain habitats. When growing in natural formations, they belong particularly to associations of a constantly open vegetation; they are therefore for instance met with on the banks of streams, on the shores of lakes, on crags and rocks, but also in marshes and on other peaty ground. SERNANDER has also described two small areas of the *Dryas* association in the uppermost part of the pine forest region (1899, p. 13). He thinks that these associations are relics of the atlantic period, which, however, seems to me rather doubtful. SERNANDER is of opinion that the species in question had a greater distribution at that time. But to me it appears almost impossible that these plants should have been more or less equally scattered over the districts where the colonies occur, at the same time as the district was covered by forests, even if the climate was in other respects most favourable to them. We must therefore suppose that there existed also at that time so wide leaps in their distribution, that the plants must have spread over long distances in order to reach their present habitats. That their habitats are so scattered, may be due to the fact that numerous species are, as we have already mentioned, confined to certain rocks, generally shales, and that habitats favourable in other respects do not occur everywhere. It therefore seems most probable that those outposts have spread from the high mountains little by little during successive ages and have settled down on habitats of favourable edaphic conditions. SERNANDER (1899, pp. 41—47) has given very significant examples of a recent dispersal over long distances in a description of the occurrence of some typical arctic plants on roadsides etc., sometimes far away from the high mountains. In all parts of the Scandinavian mountain range alpine plants are met with in the valleys, carried down by streams and rivers. They occur especially on banks and shores of rivers and lakes. It may be sufficient to refer to examples from northern Norrbotten and central Lapland, mentioned by S. BIRGER (in Arkiv för Botanik, Bd 3, N:o 4, 1904, and in Bot. Not., 1909), from Dovre by E. HAGLUND (in Bot. Not., 1901), and from Valders by M. N. BLYTT (in Bot. Not., 1845) and A. BLYTT (in Nyt Mag. f. Naturvid., Bd 13, 1864). Of great interest are BIRGER's lists of such species in the parish of Pajala (northern Norrbotten), as this district lies in one of the most continental parts of Scandinavia. It also lies at a rather large distance from mountains of more considerable height. The climate of Dovre is also rather continental. Alpine plants often occur on crags and rocks in the whole pine forest region. They are most numerous in the neighbourhood of the high mountains (Cf. e. g. S. BIRGER in Arkiv f. Botanik, Bd 7, N:o 13, 1908; R. F. FRISTEDT in Bih. t. Bot. Årsber. f. år 1850, Stockholm 1853; A. BLYTT in Nyt Mag. f. Naturvid., Bd 13, 1864; SERNANDER 1899; etc.).[1] But also at longer distances from the high mountains typical alpine plants may occur on crags and rocks. I can mention the occurrence of *Arabis petræa, Juncus trifidus,* and *Saxifraga cæspitosa* on the coast of the Gulf of Bothnia (Cf. R. F. FRISTEDT in Bot. Not., 1858, p. 77, and Växtgeografisk skildring af Södra Ångermanland, Akad. Afh., Uppsala 1857, pp. 23 and 26; E. COLLINDER, Medelpads Flora, Norrländskt Handbibliotek, II, p. 160; P. OLSSON in Bot. Not., 1896, p. 40), *Saxifraga cæspitosa* and *nivalis* on mountains in northern Helsingland (P. W. WISTRÖM, Förteckning öfver Helsinglands Fanerogamer och Pteridophyter, Wimmerby 1898, p. 62), *Woodsia hyperborea* in the islands off Stockholm [K. BOHLIN in Bot. Not., 1900, p. 16; S. SELANDER och R. BRYANT-MEISNER in Svensk Bot. Tidskr., 1909, p. (174)], *Cryptogramme crispa* on Vårdö in the Åland Islands (HJ. HJELT in Acta Soc. Faun. Flor. Fenn., V, 1888, p. 32). In Southern Finland several alpine plants also occur, especially in the Ladoga district, e. g. *Arabis petræa, Asplenium viride, Cerastium alpinum, Draba hirta, Echinospermum deflexum, Saxifraga cæspitosa*, and *nivalis, Woodsia hyperborea* (Cf. e. g. H. LINDBERG in Acta Soc. Sc. Fennicæ, XXXVII, N:o 10, 1909, p. 150; etc.). An unusually great number of such plants have been met with on the mountain Randkleven in western Medelpad at 400—500 m. above sea-level (according to COLLINDER, Medelpads Flora): *Asplenium viride, Cerastium alpinum*, *Echinospermum deflexum, Erigeron elongatum, Lycopodium alpinum, Myosotis sylvatica, Saxifraga adscendens*, *cæspitosa,* and *nivalis,* and *Woodsia hyperborea.* On the adjacent Getberget *Poa cæsia* and *Sagina Linnæi* also occur.

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[1] Such a locality is the Kvamskleven in Valders, Central Norway (about 500 m. above sea-level). Because of the unique number of alpine plants that have been found here, I will give a list of them (according to M. N. and A. BLYTT). The following have been met with:

Antennaria alpina, *Arabis alpina, Arctostaphylos alpina*, *Astragalus alpinus, Bartsia alpina*, *Betula nana, Carex alpina*, and *atrata*, *Cerastium alpinum*, and *trigynum*, *Draba incana*, and *rupestris, Dryas octopetala, Epilobium alpinum,* and *origanifolium, Erigeron alpinum, Gnaphalium norvegicum*, and *supinum, Juncus biglumis, Lactuca alpina* (syn. *Mulgedium alpinum*), *Loiseleuria procumbens, Luzula spicata, Oxyria digyna, Phyllodoce coerulea*, *Potentilla Sibbaldi* (syn. *Sibbaldia procumbens*); *Ranunculus aconitifolius, Sagina Linnæi*, *Salix hastata, herbacea, lanata, lapponum*, and *reticulata, Saxifraga adscendens, aizoides, cæspitosa, cernua, cotyledon, nivalis, oppositifolia*, and *stellaris, Sceptrum carolinum*, *Sedum rhodiola,* and *villosum*, *Silene acaulis, Stellaria alpestris, Tofieldia palustris, Veronica alpina*, and *saxatilis*.

Some of them occur at a still lower level in the valleys of Valders, e. g. *Saxifraga cotyledon* (150 m. above sea-level), *Salix herbacea* (350 m.).

East of Archangelsk (Northern Russia) occur on dry hills colonies of *Arabis petræa, Arctostaphylos alpina, Arenaria* (syn. *Alsine) verna,* and *Dryas octopetala,* together with e. g. *Anemone silvestris, Astragalus hypoglottis, Helianthemum oelandicum, Pulsatilla patens, Scorzonera austriaca, Silene otites,* and other more or less typical steppe plants (R. POHLE in Acta Hort. Petropolitani, XXI, Fasc. I, 1903, pp. 92—93). These localities lie at a low level two parallels south of the polar limit of trees in a region with a very continental climate.

More instances from other districts might be quoted, but these may be sufficient.

From the evidences above discussed, it appears very doubtful whether the occurrence of a number of alpine plants below the tree limit on the western coast of Norway is due to any climatical causes (Cf. A. HEINTZE in Arkiv f. Botanik, Bd 7, N:o 11, 1908, p. 44). That they occur at an absolutely lower level on the western side of the Scandinavian mountain range, may depend on the fact that here the high mountains lie nearer to the sea. By this, the alpine plants can on this side be carried down to the sea as easily as on the eastern side to the bottom of the glens (Cf. BLYTT 1869, p. 37). On the contrary numerous alpine plants seem to avoid the neighbourhood of the open sea. An excessively insular climate seems to affect them injuriously. Such plants are for instance *Dryas* and *Salix reticulata*. *Dryas* occurs, however, in a few places in Western Norway at the sea-level (BLYTT 1876, p. 6). Of great interest is its occurrence at Langesund in Southern Norway. According to WILLE and HOLMBOE (1903), who have very carefully described this locality, *Dryas* (and numerous southern plants) occurs here at a level of 0—30 m. above the sea on limestone cliffs with an eastern or southern aspect. These habitats are consequently sheltered against the sea breezes, and the climate is not so insular as that of the western coast of Norway. WILLE and HOLMBOE think for some reasons that *Dryas* has immigrated to this locality about 100 years ago.

BLYTT's opinion as to the continental character of the alpine flora of Scandinavia seems on the whole to be right. It is, however, an undisputable fact that the upper limits of the trees lie at lower levels in regions with an insular climate than in more continental districts. In insular regions, therefore, some alpine formations of a comparatively hardy type, descend to lower levels (than in the continental ones). But this is more due to the occurrence of favourable habitats than to the climate. But as we have mentioned above, certain alpine plants occur at the sea or close to the sea-level also on the open coast of Western Norway. Two of them (*Alchemilla alpina* and *Sedum rhodiola*) are also met with on the western coast of Sweden. Of particular significance is, I think, the fact that (according to A. BLYTT, Norges Flora) some of the species in question, e. g. *Arctostaphylos alpina, Bartsia,* etc., occur rather commonly at the level of the sea on the open coast but not in the interior fjord districts. These circumstances indicate that the insular climate favours the occurrence of these plants (see above p. 228) in the lowlands.

We have so far examined the distribution of the alpine plants only in Scandinavia (and a district of Northern Russia); we will now see if the same features are met with in some other regions of North West Europe.

The Færöes are characterized by a highly insular climate. According to OSTENFELD (1908, p. 919), »nearly all the more common mountain plants on the Færöes are also found in the lowland». The following species descend to the sea or close to it (OSTENFELD in Botany of the Færöes, I, 1901, and III, 1907):

Aira alpina, Alchemilla alpina, and *færoensis, Draba hirta,* and *incana, Epilobium alsinifolium, anagallidifolium,* and *lactiflorum, Festuca ovina v. vivipara, Habenaria albida, Juncus triglumis, Koenigia islandica, Luzula spicata, Lycopodium alpinum, Oxyria digyna, Poa alpina,* and *cæsia, Salix herbacea, Saxifraga cæspitosa, nivalis, oppositifolia,* and *stellaris, Sedum rhodiola,* and *villosum, Silene acaulis,* and *Thalictrum alpinum.*

Most of these occur in rock crevices or on stream banks. The other not mentioned alpine plants of the Færöes — some are rather common — do not descend to the sea; the majority does not occur below 400 m., only occasionally a little lower. *Dryas,* for instance, is »rare and found only on some of the highest hills on the northern islands», the lowest habitat lies at 200 m. Though forests are entirely wanting in the Færöes, numerous alpine plants are confined to the real high mountains. Those which occur in the neighbourhood of the sea-level are mostly such as descend to the sea also in Western Norway. The occurrence of some alpine plants only on the northern islands (OSTENFELD in Botany of the Færöes, I, p. 104) may partially depend on the circumstance that these islands are better sheltered against the moist south-western winds.

In the Shetlands, Orkneys, and Hebrides, where trees are now almost entirely wanting, several alpine plants occur (J. W. H. TRAIL, Topographical Botany of Scotland, Ann. Scott. Nat. Hist., 1898—1900), but I know very little as to their vertical distribution. Most of them belong to that type which descends to the sea on the open coast of Western Norway. The most noticeable exceptions are *Dryas* (Orkney), *Arenaria norvegica* (Shetland), and *Cerastium Edmonstonei* (Shetland); the last two species occur only on serpentine and euphotide in Shetland (R. TATE in Journ. of Botany, IV, 1866, p. 12). In Ireland several alpine plants are also met with (R. L. PRÆGER in Proc. Roy. Irish Acad., XXIV, Sect. B, 1902, p. 9), most of them belong to the type just mentioned, but others also occur, e. g. *Dryas*, which descends to the sea.

In Great Britain most of the alpine plants are confined to the Scottish Highlands, but several also occur on the mountains of Southern Scotland, Northern England, and Wales.[1] The greatest number of the alpine

[1] An interesting find was made by me on Cross Fell in Cumberland. At an altitude of about 450 m. I namely found *Cerastium trigynum*, which seems not to have before been met with in England (see J. D. HOOKER, The Student's Flora of the British Islands).

plants of Scotland are met with only in the eastern regions of the Grampians (Cf. e. g. HARDY 1905, p. 182; etc.), i. e. in the most continental districts. In the Clova district many of them descend below 600 m., at the lowest levels occur *Alchemilla alpina, Oxyria digyna, Saxifraga aizoides*, and *stellaris* (about 200 m. above sea-level) (J. C. WILLIS and J. H BURKILL in Trans. and Proc. Bot. Soc. Edinburgh, XXII, 1901, pp. 111—119). In the neighbourhood of Killin (Loch Tay, Perthshire) I have seen *Alchemilla alpina* on rocks and *Saxifraga aizoides* at streams about 200 m. above sea-level. The alpine plants, however, are not common before the alpine region is reached (above 600 m.). Their chief habitats are crags and rocks (Cf. W. G. SMITH 1905, p. 64). Colonies of alpine plants may, however, be met with at lower levels. At a water-course about 500 m. above sea-level (in the stream Allt Tir) close to Killin I saw such a colony, containing the following species:

Alchemilla alpestris, and *alpina, Anthoxanthum odoratum, Brunella vulgaris, Calluna vulgaris, Campanula rotundifolia, Crepis paludosa, Erica cinerea, Festuca ovina v. vivipara, Hieracium saxifragum, Nephrodium oreopteris, Oxalis acetosella, Oxyria digyna, Saxifraga aizoides,* and *oppositifolia, Spiræa ulmaria, Taraxacum officinale, Thymus serpyllum,* and *Viola riviniana.*

In the North West Highlands the alpine plants are considerably less numerous, though very favourable rocks occur. The most rainy districts of Scotland lie here. The alpine plant associations descend here to 500 m. (HARDY 1905, p. 95). At solitary places certain alpine plants come down to the sea (according to HARDY 1905, p. 97): *Aspidium lonchitis, Dryas octopetala, Oxyria digyna, Poa alpina, Saxifraga stellaris, Sedum rhodiola,* and *Thalictrum alpinum.* Mr LEWIS has told me that *Dryas* occurs at the sea-level on the limestone cliffs of Durness where the Silurian rocks of North Western Scotland reaches the sea. *Dryas* seems moreover to be rather common along the whole western border of the Silurian. According to G. C. DRUCE (in Ann. Scott. Nat. Hist., 1895, pp. 35—38), *Dryas* is »a prominent feature in the vegetation» on the limestone rocks at the base of Cnoc-an-t'-Sasunnaich; and it was also found by him by she roadside at Elphin (150 m. above sea-level). At a level of 250—300 m. some other alpine plants (*Aspidium lonchitis, Asplenium viride, Carex rupestris, Draba incana, Silene acaulis,* and *Thalictrum alpinum*) were also found. According to HARDY (1905, p. 32) *Dryas* is a characteristic species of the limestone cliffs below Ben More Assynt. I saw it grow abundantly on such rocks at Inchnadamff. Below the steep rocks of Stonechrubie, which have chiefly a westerly aspect, I noticed the following plants:

Alchemilla alpestris, alpina (G), and *filicaulis, Anthoxanthum odoratum* (G), *Anthyllis vulneraria, Asplenium ruta-muraria, trichomanes,* and *viride, Avena pubescens, Bellis perennis, Betula odorata, Brachypodium sylvaticum, Brunella vulgaris, Calluna vulgaris* (G), *Cardamine flexuosa* (syn. *sylvatica*), *Carex glauca, lepidocarpa,* and *pulicaris* (G), *Cerastium triviale, Circæa alpina, Cnicus* (syn. *Cirsium*) *lanceolatus, Corylus avellana, Cystopteris fra-*

gilis, Dactylis glomerata, Dryas octopetala, Euphrasia sp., Festuca ovina (G), and *v. vivipara, Galium boreale* (G), and *saxatile, Geranium robertianum, Hedera helix, Hieracium saxifragum* (G), *Hypericum pulchrum* (G), *Ilex aquifolium, Lapsana communis, Linum catharticum, Lotus corniculatus, Lychnis diurna* (syn. *Melandrium sylvestre*), *Lysimachia nemorum, Oxalis acetosella* (G), *Pinguicula vulgaris* (G), *Plantago lanceolata,* and *maritima* (G), *Poa annua,* and *pratensis, Polygala serpyllacea* (G), *Polygonum viviparum, Potentilla tormentilla* (G), *Pyrus aucuparia* (G), *Primula vulgaris* (syn. *acaulis), Ranunculus acris,* and *repens, Ribes rubrum, Rosa cfr. canina, Rumex sp., Sagina procumbens, Salix aurita, Saxifraga aizoides* (G), *Scabiosa succisa* (G), *Scilla nutans* (syn. *Endymion non-scriptum), Selaginella selaginoides* (G), *Solidago virgaurea* (G), *Spiræa ulmaria, Taraxacum officinale* (G), *Teucrium scorodonia, Thymus serpyllum* (G), *Ulmus montana, Urtica dioica, Veronica chamædrys, Viola riviniana* (G), and *tricolor.*

On the gravel banks of the river Loanan *Alchemilla alpina* and *Saxifraga aizoides* grew at a level of about 70 m. above the sea. In the western precipice of Beinn an Fhurain north-east of Inchnadamff a similar society was met with. The rock was an overthrust mass of Lewisian gneiss. Several of the plants just enumerated (in the list marked with a »G») grew also here in crevices and on rocky escarpments. The following species were noticed, too:

Angelica sylvestris, Antennaria dioica, Carex binervis, Oederi, panicea, and *pilulifera, Erica cinerea, Geum rivale, Hypochæris radicata, Juniperus communis, Lomaria (*syn. *Blechnum) spicant, Luzula maxima, Lycopodium selago, Molinia coerulea, Narthecium ossifragum, Nephrodium oreopteris, Orchis maculata, Oxyria digyna, Polypodium phegopteris, Rubus saxatilis, Scirpus cæspitosus, Sedum rhodiola, Thalictrum alpinum, Trollius europæus,* and *Vaccinium myrtillus.*

The vegetation of these precipices represents an intimate mixture of plants belonging to different types of distribution, typical alpine plants as well as lowland and atlantic specis. Some plants have probably been introduced by man; but they may perhaps be indigenous. I will call attention to the occurrence of *Lapsana,* which is one of the most common plants of the rubble heaps of Western Norway. Some of the lowland plants, particularly the elm and the hazel, are probably relics from a time when this district was forest-clad (Cf. the fossils of the peat moss in the valley of the river Loanan).

Besides those already mentioned I saw no other alpine plant in this district, except *Saxifraga stellaris,* which grew in the outlet of a spring (about 300 m. above sea-level). The vegetation consisted of abundant *Sphagna,* plentiful *Anthoxanthum odoratum,* scattered *Juncus squarrosus* and *Nardus stricta,* sparse *Saxifraga stellaris* and *Viola palustris,* and solitary *Calluna vulgaris, Erica tetralix, Eriophorum polystachion,* and *vaginatum, Luzula campestris, Orchis maculata, Pinguicula vulgaris, Potentilla tormentilla, Scabiosa succisa,* and *Scirpus cæspitosus.*

The occurrence of the alpine plants in question at this level seems not to be due to the climate. It seems more probable that the proximity of the high mountains favours the carrying down of the alpine plants into the valleys, where afterwards they settle down in habitats of a favourable edaphic character.

The features now described chiefly agree with the results obtained by the examination of the distribution of the alpine plants of Scandinavia. At the same time as the upper limits of the trees lie lower in insular regions, the alpine plant associations come down to lower levels. But numerous alpine plants seem to avoid a strongly marked insular climate, or they occur in such districts in especially favourable habitats rather independent of the altitude. Some others seem to thrive better nearer the sea-level in insular regions than in more continental ones.

Most of the arctic-alpine species which have been found in the second arctic bed of the Scottish peat mosses belong to the type that occurs in regions with a highly insular climate more or less commonly distributed also in the neighbourhood of the sea-level. Two species, *Betula nana* and *Salix arbuscula,* seem not to belong to this type, but it is possible that these plants would be much more common e. g. in Scotland, the Færöes, and Western Norway, if the localities where they may be expected to occur were not so extensively grazed. That the grazing has highly reduced the distribution areas of some shrubs and other plants cannot be doubted. The remaining species, *Salix reticulata,* seems to belong to the more continental group of the alpine plants.

This analysis has consequently not given any definite information as to the climatical conditions that could, during the Lower Turbarian, cause such a general descent of the alpine plants to the lowland. I think, however, that such an immigration of alpine plants to the lowland may have taken place, even if at that time Scotland was not characterized by a colder climate than certain parts of the present *Ilex* region of Western Norway. This must, however, be regarded as an open question. We know very little as to the situation of the tree limits in Scotland during this time. It is probable that they lay lower than now. LEWIS has nowhere found any tree remains in the strata of the peat mosses belonging to the Lower Turbarian. From my find of pine remains in a layer below the upper forest bed on the Spey-Findhorn watershed no general conclusions can be drawn. The occurrence of mixed deciduous woods, containing for instance oak and hazel, in the lowland is shown by the numerous drifted remains of these (and other) species in the Carse clays of the Tay and Earn valleys (Cf. LEWIS 1905, p. 716).[1]

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[1] During my journey I examined a section through such deposits near Forgandenny in the Earn valley. This section showed the following layers:

A. 230 cm. of clay, in the lower part containing numerous plant remains.

B. 6—10 cm. of drifted peat containing large drifted oak stools; some oak cupules, hazel nuts, and *Carex* fruits were met with. LAGERHEIM has in a sample found only birch

4. The Upper Forestian.

At this time the climate became once drier and more continental. The surfaces of the mosses were again mostly covered with forests. Their vertical range was still greater than in the Lower Forestian. The Outer Hebrides, where trees are now absent, were then covered with birch forests, where the hazel was an common associate. LEWIS has not met with pine remains in this district, nor have I, but GEIKIE (1894, p. 287) says that such remains have been found. On the contrary, the forests seem to have entirely disappeared from the Shetlands before this time. The vegetation on the Shetland mosses consisted according to LEWIS (1907 a, p. 53) of ling heaths. The peat »became wasted and channelled into peat-hags». Only the most lofty parts of the Scottish Highlands were not forest-clad. The highest finds of tree remains that I know of have been made at about 900 m. above sea-level. At this altitude pine stools have been met with in Banffshire (and also in the north of England) (GEIKIE 1874, p. 320). In this time the pine predominated over enormous areas. The wide distribution of the pine is probably partly due to the continental climate. The pine is namely a species of a rather continental character, which does not endure a too insular climate. The present climatic upper limit of forests may be regarded as lying at about 600 m. in the eastern parts of the Grampians (Cf. LEWIS 1907 a, p. 68; R. SMITH 1900, p. 465). In all places where pine remains occur above this level they are met with in the form of stool layers. It is scarcely probable that the upper limit of the pine forest region has much exceeded 900 m. in any part of the post-glacial time.[1] LEWIS (1907 a, p. 67) writes: »My own observations in Scotland would place the difference between the upper limit of trees during the Upper Forestian and at the present day at not much less than 2000 feet in the Highlands; in Cumberland and Westmorland at rather more.» It is obvious, I think, that the lowering of the tree limits is not so great, but that they have descended about 300 m., cannot be doubted. This higher situation of the tree limits might possibly be explained, if we suppose that the climate was highly continental. It would then not be necessary to assume that the temperature of the summer months of that time was considerably higher than in the present time. But other features necessitate, I think, also such a supposition.

Several plants are found in the upper forest zone above their present climatic limit. Such species are *Ajuga reptans, Alnus glutinosa, Corylus*

pollen, spores of a fern, and diatoms of the genus *Epithemia, Gomphonema,* and *Pinnularia.*

C. 180 cm. of clay, towards the bottom extensively mixed with sand.

D. Moraine with large blocks.

[1] LEWIS (1907 a, p. 68) takes the upper limit of the upper forest as close upon 3500 feet. He does not mention the author of this statement, but in 1906 (b, p. 249) he places this limit at 3000 feet.

avellana, Elatine hexandra, Quercus robur, and *Viburnum opulus*. These species have scarcely any climatic northern boundary in Scotland. To state the general vertical range of the species in question on the mountains is very difficult. The statements given in descriptions of the vegetation mostly refer to the extreme heights where they may thrive on particularly favourable localities. Highest on the mountains *Ajuga* occurs (600 m. Cf. e. g. R. SMITH 1900, p. 452). These species have their proper abode in the oak region (»region of deciduous trees»), where they (except *Elatine*) occur particularly in oak woods and wood meadows. These associations are scarcely met with above 300 m. (Cf. R. SMITH 1900, pp. 397 and 446; W. G. SMITH 1905, p. 6; LEWIS 1904, I, p. 318; SMITH and RANKIN 1903, p. 161; SMITH and MOSS 1903, p. 388; HARDY 1905, p. 55). As so numerous statements referring to different districts of Scotland as well as Northern England agree, it may be concluded that the upper climatic limits of those species lie at about 300 m. above sea-level, for some species perhaps a little higher, for others lower. *Ajuga reptans* has been found in the upper forest bed in the Cross Fell district by LEWIS and me (up to 700 m.)[1] and south of Killin by me (about 500 m.). *Alnus*, *Elatine*, and *Viburnum* have been found by LEWIS only on Cross Fell (about 600--700 m. above sea-level).[2] *Quercus* remains occur in the peat mosses of Yorkshire at least 100 m. above its present limit (see above p. 201). *Corylus* occurs rather commonly at present a little higher than the oak, particularly on southern exposures it sometimes passes 300 m. In the Yorkshire mosses hazel nuts occur up to at least 500 m. (see above p. 201). In Scottish mosses LEWIS has found hazel remains in layers that no doubt belong to the Upper Forestian only in the Outer Hebrides, where I also found numerous hazel nuts. In these islands the hazel now seems not to endure the excessively insular climate. Only solitary stunted hazel shrubs grow in especially favourable habitats. Possibly the hazel nuts found by LEWIS in Skye are of the same age. All other finds of his belong, according to my opinion, to the Lower Forestian. I myself found hazel nuts in the upper forest bed, except at Barvas in Lewis, in the Merrick-Kells mosses (300 m. above sea-level), on the northern slope of Beinn Leathan south of Killin (500 m.), and in the moss in the valley of the river Loanan south of Inchnadamff (about 100 m. above sea-level). The most remarkable find is doubtless that made south of Killin. Here *Ajuga reptans* and *Salix aurita* were also found in the same birch forest bed. This forest containing the species just mentioned consequently had a character entirely different from that of the woods that now grow at the same altitude. The upper limit of the hazel communities lies scarcely higher than 300 m. Very little attention has been paid to the fact that whole plant associations and consequently other species than some trees

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[1] As mentioned above (p. 224), this species has also been met with in the lower forest above its present limit. The layer on the Moorfoot Hills where LEWIS (1905, p. 711) has also found *Ajuga* nutlets is possibly of the same age.

[2] *Alnus* has, however, also been found in some other places, but only at a rather low level.

have formerly occurred on the British mountains at higher altitudes than they do at present. Numerous instances of this feature will certainly be found in the future. I will, however, call attention to LEWIS' statements in reference to his finds in Cumberland (1907 b, p. 417). He writes: »The presence of such plants as *Elatine hexandra, Ajuga reptans, Viburnum opulus,* birch and hazel trees af large size at altitudes of 2,400 feet, points to the fact that the upper forest grew under conditions more temperate than those of the present day».[1] But he also says that no analogous finds have been made in Scotland. My discovery of hazel nuts, etc. in the moss south of Killin fills this gap.

We thus come to the conclusion that some species characteristic of the oak region reached a higher altitude during the Upper Forestian, than they do at the present time. It is not yet possible to estimate exactly the size of this vertical change, but it probably amounts to about 200 m. It seems to be of very little importance to the distribution of those species if the climate is more or less continental or insular. We must, I think, therefore suppose that in the Upper Forestian the mean temperature of the season of vegetation was higher than it is now. The lowering of the wood limit seems to have been a little greater than that of the southern warm loving species in question, a feature which may possibly be due to the fact that the situation of the upper limit of trees is more influenced by the continental or insular character of the climate. The time of the highest wood limit coincides with the period when the mosses above the present tree limit were covered with forests and the traces af a warmer period in the post-glacial time fall in the upper forest bed and disappear when this layer passes into the peat above it. These features show, according to my opinion, perhaps better than all other facts that the upper forest beds of the mosses are synchronous and represent a distinct part of the post-glacial time.

If the fossils of the peat mosses of a district prove the existence of a warmer, not too remote age, remnants of the vegetation of this period are generally met with in places lying more or less outside the proper abode of the types of vegetation in question. I have endeavoured to show that the oak region of the Upper Forestian stretched to about 500 m. above sea-level in the central parts of Scotland. Before looking round for such relic associations we will, however, give some instances of the most characteristic associations of the oak region. The forest associations rich in warm loving deciduous trees give the oak region its character. The areas occupied by such »mixed deciduous woods» are, however, highly reduced by the influence of man. Any natural associations of this kind which are not in some degree modified by human influence are scarcely met with. A large part of the beech and oak woods are certainly planted,

[1] Any find of hazel at the altitude in question is not mentioned in his sections. The occurrence of hazel pollen in my peat samples does not either show that the hazel has ever grown at so high a level.

but I think, notwithstanding, that some of the present deciduous woods agree very well with the primitive deciduous woods of Scotland as to their physiognomy and the occurring species. It is true that some species, especially some trees and shrubs, have been introduced by man. In the associations in question, however, they are of relatively small importance. But in my opinion the English and Scottish phyto-geographers overestimate the number of the not indigenous woody plants. HARDY (1905, p. 49) gives a list of 24 such species which he thinks have undoubtedly been introduced by man. Other authors mostly share this opinion and consider some other species as having probably also been introduced (e. g. *Pyrus aria,* Cf. R. SMITH 1900, p. 397; etc.). This opinion is in some cases founded on the fact that the species in question have never been found in peat mosses or other deposits containing plant remains. For the same reason we would have to regard some of the most characteristic trees and shrubs of Southern Scandinavia as having been introduced by man. Though very careful investigations of the Swedish peat mosses have been carried out for the last 40 years, no remains of e. g. *Carpinus betulus* and *Fagus sylvatica* have been met with until a few years ago. *Evonymus europæus,* etc. have not yet been found in the post-glacial deposits. Some of those species occur in England and Scotland under the same conditions as in Scandinavia. They also often grow far away from inhabited places. It is therefore most probable that some of them are indigenous and belong to the primeval vegetation of the country. Such species are for instance *Fagus sylvatica, Tilia parvifolia,* etc.

The composition of the »mixed deciduous woods», »oak woods», »beech woods», etc. has been described by several authors (e. g. R. SMITH 1900; W. G. SMITH 1905; SMITH and MOSS 1903; SMITH and RANKIN 1903; LEWIS 1904); but these authors have not carefully kept the different associations apart, nor have they given any representative lists of the vegetation of particularly typical spots. As such lists throw more light on the physiognomy of the associations than more comprehensive lists, I will here describe the vegetation of some rather small spots.

Very rich in luxuriant deciduous woods is the Tay valley, at least from the neighbourhood of Dunkeld to the upper end of Loch Tay. The woods least modified by man which are at the same time the most luxuriant have the character of oak groves. They are characterized by a generally abundant shrub stratum and by the large frequence of the herbs of the field strata. One single species often predominates over large areas, particularly in the middle field stratum. I will first give a list of the vegetation of such an oak grove a little way east of Dunkeld on a rather steep eastern slope towards the river Tay (fig. 5). Small spots of the ground were devoid of vegetation and were covered by oak leaves (june 11, 1909).

The tallest tree stratum consisted of sparse *Quercus sessiliflora.*

The lowest tree stratum contained abundant *Quercus sessiliflora* and solitary *Q. pedunculata.* This stratum passes into

The shrub stratum, where one specimen of *Lonicera cfr. tatarica* also occurred.

The tallest field stratum consisted of plentiful *Pteris aquilina* and one specimen of *Sambucus nigra*.

The middle field stratum contained abundant *Scilla nutans* (one specimen with white flowers) and solitary *Anthoxanthum odoratum*, *Conopodium denudatum* (syn. *Bunium flexuosum*), *Nephrodium filix-mas*, *Rumex acetosa*, *Scrophularia nodosa*, and *Urtica dioica*.

The lowest field stratum contained sparse *Corydalis claviculata* and *Oxalis acetosella*, and solitary *Ajuga reptans*, *Anemone nemorosa*, *Cir-*

Fig. 5. Oak grove close to Dunkeld (Perthshire). *Scilla nutans* is predominant in the field strata.

cæa lutetiana, *Digitalis purpurea*, *Galeopsis sp.*, *Galium aparine*, and *saxatile*, *Geranium sylvaticum*, *Nepeta glechoma* (syn. *Glechoma hederacea*), *Nephrodium filix-mas*, and *spinulosum*, *Primula vulgaris* (syn. *acaulis*), *Rumex acetosella*, and *obtusifolius*, *Sambucus nigra*, *Senecio jacobæa*, *Teucrium scorodonia*, *Valeriana sambucifolia*, *Veronica chamædrys*, *Viola riviniana*, and a sterile grass.

Ground stratum was wanting.

The association was homogeneous over an area of at least 10 000 square metres. In all places *Scilla* was abundant, on solitary very small spots another species occasionally predominated.

On the slopes af the northern side of Loch Tay the oak groves are very luxuriant. Close to the Loch Tay station (near Killin) I examined the vegetation of a southern slope (june 15, 1909). The trees generally were abundant and consisted of large oaks, elms, beeches, *Abies* species (planted). The shrub stratum generally contained plentiful hazel. The ivy climbed in the the heads of the trees. Over a large area *Mercurialis perennis* was dominant. The steepness of the slope sometimes reached 30°. In a more open place an area of 300 square metres was carefully examined. The field strata were nearly entirely closed, but some small spots were devoid of vegetation and covered by old leaves.

The tree strata were wanting.

The shrub stratum contained sparse *Alnus glutinosa* and *Corylus avellana.*

The tallest field stratum with scattered *Asplenium filix-foemina* and *Nephrodium filix-mas,* sparse *Arrhenatherum avenaceum* (syn. *Avena elatior*), *Pteris aquilina,* and *Rubus idæus,* and solitary *Betula odorata, Cnicus* (syn. *Cirsium*) *lanceolatus, Rubus fruticosus* (coll.), *Scrophularia nodosa,* and *Urtica dioica.*

The middle field stratum with abundant *Mercurialis perennis,* scattered *Galium aparine,* sparse *Myosotis arvensis,* and solitary *Cardamine flexuosa* (syn. *sylvatica*), *Carex sylvatica, Epilobium montanum, Geum urbanum, Hypericum hirsutum,* and *tetrapterum, Poa pratensis, Rumex sanguineus, Sanicula europæa,* and *Scilla nutans.*

The lowest field stratum with plentiful *Poa pratensis* (sterile), scattered *Circæa intermedia,* sparse *Geum urbanum,* and solitary *Ajuga reptans, Cerastium triviale, Chrysosplenium oppositifolium, Galium saxatile, Lysimachia nemorum, Potentilla fragariastrum, Primula vulgaris* (syn. *acaulis*), *Ranunculus ficaria,* and *repens, Veronica chamædrys,* and *Viola riviniana.*

The ground stratum contained plentiful mosses.

Physiognomically these two oak groves correspond entirely to the ash groves on the Upplandian skerries in Sweden (Cf. H. HESSELMAN in Beih. z. bot. Centralbl., Jahrg. 1904, p. 338). But as to the occurring species of the field strata there is a great difference. Many of the most characteristic species of the Scottish oak groves, especially *Scilla nutans,* are totally wanting in the ash (and oak) groves of Central Sweden.

Sometimes no species plays so important a part in the physiognomy of the field strata as in the examples just quoted. A great number of other species may also occur. Because of its very different physiognomy I will give one more instance of the composition of a »mixed deciduous wood». In the neighbourhood of Dunkeld the south-western shore of Loch of Lows was overgrown by such a wood, where the vegetation of an area of about 400 square metres had the following composition (see fig. 6; june 11, 1909).

The tallest tree stratum with scattered *Betula odorata,* sparse *Fraxinus excelsior,* and *Pinus sylvestris,* and solitary *Quercus sessiliflora.*

The lowest tree stratum with sparse *Alnus glutinosa* and *Betula odorata,* and solitary *Ilex aquifolium.*

The shrub stratum consisted of scattered *Corylus avellana* and solitary *Fraxinus excelsior* and *Juniperus communis.*

The tallest field stratum with scattered *Rosa spinosissima* (syn. *pimpinellifolia*), sparse *Corylus avellana,* and solitary *Cytisus* (syn. *Sarothamnus*) *scoparius, Juniperus communis,* and *Rosa sp.*

The middle field stratum with scattered *Pteris aquilina* and *Spi-*

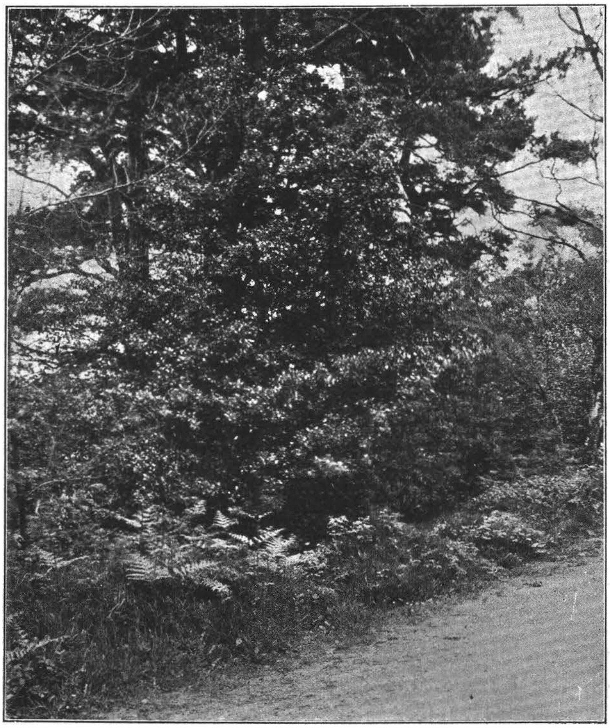

Fig. 6. ***Ilex aquifolium*** in a mixed deciduous wood near Dunkeld (Perthshire).

rea ulmaria (locally plentiful), sparse *Anthoxanthum odoratum, Rosa spinosissima,* and *Rubus idæus*, solitary *Fraxinus excelsior, Nephrodium filix-mas,* and *spinulosum,* and *Ulex europæus.*

The lowest field stratum with plentiful *Festuca ovina* (and other sterile grasses), scattered *Oxalis acetosella* and *Viola riviniana,* sparse *Ajuga reptans, Potentilla fragariastrum, Primula vulgaris* (syn. *acaulis*), and *Scabiosa succisa,* solitary *Anemone nemorosa, Angelica sylvestris, Bellis perennis, Brunella vulgaris, Campanula rotundifolia, Centaurea nigra, Cerastium triviale, Cnicus* (syn. *Cirsium*) *palustris, Cratægus sp., Epilobium montanum, Fragaria vesca, Fraxinus excelsior, Galium aparine,* and *saxatile, Geranium robertianum, Geum urbanum, Hieracium murorum, Hypericum* *pulchrum, Hypochœris radicata, Ilex aquifolium, Lomaria* (syn. *Blechnum*) *spicant, Luzula campestris,* and *vernalis* (syn. *pilosa*), *Orchis maculata, Poa pratensis, Polypodium vulgare, Potentilla tormentilla, Pyrus aucuparia, Quercus sessiliflora, Ranunculus repens, Rubus fruticosus* (coll.), *Rumex acetosella, Taraxacum officinale, Teucrium scorodonia, Trientalis europœa, Vaccinium myrtillus, Valeriana sambucifolia, Veronica chamædrys,* and *officinalis.*

The ground stratum with scattered mosses (e. g. *Hylocomium triquetrum*).[1]

We will now examine the question if any remnants of a vegetation of the now described type have been left since the time when the oak region stretched higher on the mountains. The vegetation of the precipice of the limestone rocks at Inchnadamff (see above p. 233) probably reprerents such a rest, but this formation still lies in the oak region. Here the disappearance of the deciduous wood is no doubt principally due to the influence of man. The associations which occur on limestone rocks and rubble heaps in Yorkshire about 300 m. above sea-level (Cf. SMITH and RANKIN 1903, pp. 167—169) belong to the same type. R. SMITH (1900, p. 454), LEWIS (1904, I, p. 329 and II, p. 270), and W. G. SMITH (1905, p. 61) mention several instances of the occurrence of species, the proper abode of which is the oak region, above the upper limit of this region. They occur especially in the shelter of rocks. But these authors have not given any examples of the occurrence of whole associations of that kind. In consequence of the generally small absolute distances between the oak

[1] It cannot be doubted that several species mentioned in the lists given above are not indigenous in Scotland, but have been introduced. But these species play a very insignificant physiognomical rôle. By clearing and mostly also by the regular mowing of the field strata man has sometimes modified the natural deciduous woods. In this way another association, which agrees completely with the proper Swedish wood meadows has originated. But it is probable that also these have got their characteristic park-like physiognomy by the same influence of man. In the wood meadows grasses and mosses play a more predominant part than in the groves described above. Wood meadows of this type are common in Great Britain. As an instance I will give a list of the vegetation of a very typical wood meadow in the neighbourhood of Skirwith in Cumberland. On a spot of 200 square metres the vegetation had the following physiognomy (june 8, 1909).

The tallest tree stratum contained sparse *Quercus sessiliflora.*

The lowest tree stratum was wanting.

The shrub and tallest field strata with solitary *Prunus communis* (syn. *spinosa*).

The middle field stratum with plentiful *Scilla nutans,* scattered *Anthoxanthum odoratum, Conopodium denudatum* (syn. *Bunium flexuosum*), and *Lathyrus macrorrhizus* (syn. *Orobus tuberosus*), sparse *Centaurea nigra, Hypochœris radicata, Nephrodium filix-mas, Rumex acetosella,* and *Stellaria holostea,* and solitary *Cynosurus cristatus, Dactylis glomerata, Galium cruciata, Luzula campestris, Poa pratensis. Pteris aquilina,* and *Vicia sepium.*

The lowest field stratum with abundant *Anthoxanthum odoratum* (sterile), sparse *Anemone nemorosa* and *Oxalis acetosella,* and solitary *Campanula rotundifolia, Cardamine pratensis, Cratægus sp., Primula vulgaris* (syn. *acaulis*), *Ranunculus ficaria, Rhinanthus sp., Stachys betonica* (syn. *Betonica officinalis*), *Taraxacum officinale, Veronica chamædrys,* and *Viola sylvestris.*

The ground stratum with plentiful mosses, particularly *Hylocomium loreum.*

region and rock precipices with a southerly aspect lying high above this region, the different species may possibly have little by little spread from the present oak region and settled down in edaphically favourable habitats at a higher altitude. I should therefore not either regard such colonies of »oak plants» as being relic associations, if the plant remains of the peat mosses did not unmistakably show that in a warmer period the oak region stretched much higher on the mountains than it now does. Last summer

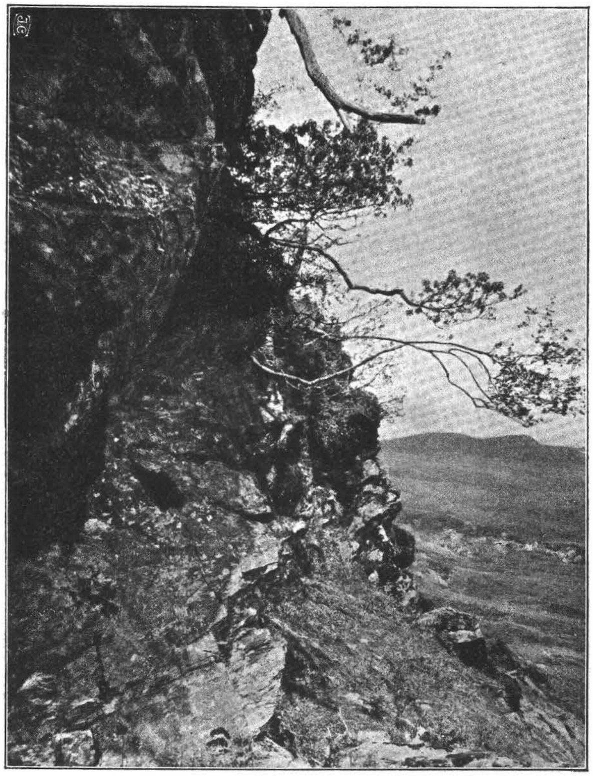

Fig. 7. A relic association with hazel and oak in the southern precipice of Meall Laith close to Killin (Perthshire).

I discovered a very interesting relic association of this kind on the slope north of Loch Tay close to Killin. In the southern precipice (crevices and in the rubble heap below the precipice) of Meall Laith the following species were met with (at an altitude of about 500 m. above sea-level, see fig. 7):

Anemone nemorosa, Antennaria dioica, Anthoxanthum odoratum, Asplenium filix foemina, Calluna vulgaris, Campanula rotundifolia, Cardamine flexuosa (syn. *sylvatica*), *Carex binervis,* and *pilulifera, Corylus avellana* (one single small shrub), *Epilobium augustifolium, Erica cinerea, Festuca ovina v. vivipara, Galium saxatile, Hieracium spp., Hypericum pulchrum,* *Lomaria* (syn. *Blechnum*) *spicant, Lonicera periclymenum, Luzula maxima, Mercurialis perennis, Nephrodium filix-mas v. Borreri, oreopteris,* and *spinulosum, Oxalis acetosella, Pinguicula vulgaris, Polygala serpyllacea, Polypodium phegopteris,* and *vulgare, Populus tremula, Potentilla fragariastrum,* and *tormentilla, Pyrus aucuparia, Pteris aquilina, Quercus robur* (one single shrub), *Rosa sp., Rubus saxatilis, Salix aurita, Saxifraga aizoides, Scabiosa succisa, Scilla nutans, Solidago virgaurea, Taraxacum officinale, Thymus serpyllum, Vaccinium myrtillus,* and *vitis idæa, Veronica officinalis,* and *Viola riviniana.*

This list may naturally not be regarded as representing a perfectly homogeneous association, but, according to my opinion, it contains to an essential extent the remnants of a primitive oak grove. The number of species characteristic of this association that occur here is unusually great. This is the only instance I can give, but on more careful investigations of similar localities in the Scottish Highlands numerous such associations will no doubt be discovered.

We have mentioned above that in the Lower Turbarian the sea invaded over large parts of the land. Traces of this submergence can be seen on all the coasts of Scotland. It also stretched to the islands. The presence of raised beaches on the coasts of the mainland of Scotland »proves a recent gain of land, while the complete absence in the Outer Hebrides, the Shetlands, and the Færöe Islands, of any such deposits shows that those regions have either been stationary for a very long time, or else have undergone a recent submergence, the latter, as I believe, having been the case» (GEIKIE 1881, p. 520). An observation that I made in the neighbourhood of Stornoway in Lewis shows that also in this island the submergence has been followed by an elevation of land. South-east of Stornoway I namely discovered a peat stratum overlaid by a sand layer in a shore bank in the bay between Rudha Shilldinish and Gob Shilldinish (the sequence is shown by fig. 8). The thickness of the different strata varied considerably. Sometimes the sand above the peat was about 75 cm. in thickness, and the gravel and conglomerate (Torridonian) below it could attain a depth of 225 cm., before the sand strand was reached. The base of the bank lay about 2 m. above the sea-level (at 2 o'clock p. m., june 27, 1909). A section a little further to the north (of the photographed one) showed the following layers:

A. 15 cm. of sand, penetrated by the roots of the present vegetation (*Nardus* association).

B. 8 cm. of sand mixed with peat.

C. 27 cm. of rather fine sand, somewhat mixed with humus.

D. 28 cm. of peat, highly mouldered, in the upper layers containing some very fine sand strata. Probably a decomposed *Scirpus cæspitosus* peat.

E. 36 cm. of peat, mixed with gravel (stones sometimes 2 dm. i diameter).
F. 20 cm. of conglomerate.

Below this the sand strand follows.

It cannot be doubted that it is the same peat layer which has been described by LEWIS (1907 a, p. 49) as occurring below the mean high water in Sandwick Bay, i. e. in the immediate neighbourhood. It is obvious that the peat (layer D) was formed at a time when the land surface was

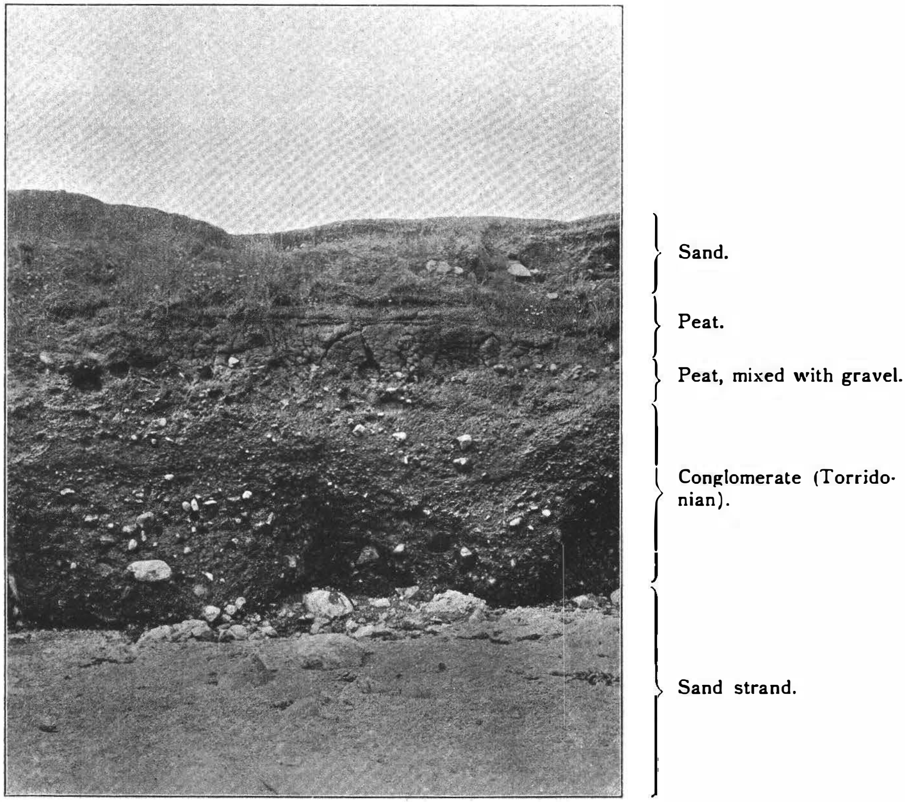

Fig. 8. Shore bank in the neigbourhood of Stornoway (Lewis), showing a peat layer overlaid by sand.

at least somewhat greater than now. But a submergence took place and at that time the sand above the peat was deposited in ihe sea. Then there followed again an elevation of the land.

GEIKIE (1895, p. 251) thinks that the mainland of Scotland had a somewhat larger extent in the Upper Forestian than it now has, an opinion which we will discuss later on.

I will at last mention that GEIKIE (1881, p. 537) regards the Upper Forestian as at least partly contemporaneous with the bronze age of Scotland.

5. The Upper Turbarian.

After the forest period the level of the ground water rose, which caused the disappearance of the forests of the peat mosses and their replacement by more hydrophilous formations, especially *Eriophorum vaginatum* and *Scirpus cæspitosus* associations. This change of the vegetation must, in my opinion, be due to the climate becoming more insular and consequently also moister. At the same time a very considerable deterioration of the climate took place, which caused a lowering of the oak region of probably about 200 m. For the same reason and because of the insular character of the climate, the pine and birch limits on the slopes of the high mountains were lowered, probably about 300 m. The influence of man has in many respects totally changed the primitive vegetation of Scotland. The extent of the forests has been highly reduced. And also the vegetation of the peat deposits has been highly affected by man, thanks to the burning of peat, drainage works, the grazing of the sheeps etc. GEIKIE (e. g. 1867, pp. 381—384) is of opinion that the present time is characterized by a somewhat drier climate than the preceding period. Especially the vast denudation of the peat at the present time should, according to him, go to prove this opinion. As far as I could see, this denudation is principally due to the erosion of the wind, only to a rather small extent to that of the water. That the denudation of the peat is essentially caused by the burning and the draining of the moorlands, cannot, I think, be doubted. I cannot, however, express any opinion, whether these agencies alone can give a sufficient explanation of the matter. The wasted aspect of the present moss surfaces and the structure of the peat walls developed by the erosion of the wind are illustrated by the figs. 9 and 10.

I have mentioned above (p. 246) that GEIKIE is of opinion that in the Upper Forestian the land »gained on the sea, until the latter had retreated considerably beyond its present limits. . . . By-and-by, however, another oscillation of the sea-level took place — the land was again partially submerged, forest-decay recommenced, and peat-bogs once more flourished vigorously. To this epoch of more humid and colder conditions we assign the later raised-beaches of our coast-lands» (1894, p. 313). The only fact that would go to prove this opinion seems to be the existence of the 25 to 30-ft. beach, which is supposed to have been formed during a submergence. I do not understand the necessity of such a supposition. LEWIS (1905 pp. 716—718) has described the sequence of some mosses resting on the raised beach in question in Wigtownshire and Dumfriesshire. He has here generally found a forest bed with birch, alder, hazel, and oak at the base of the peat, the depth of which varied between 2,5 and 4 m. in the quoted sections. The forest beds rested immediately on sand or clay. It seems very probable that this forest bed has been deposited

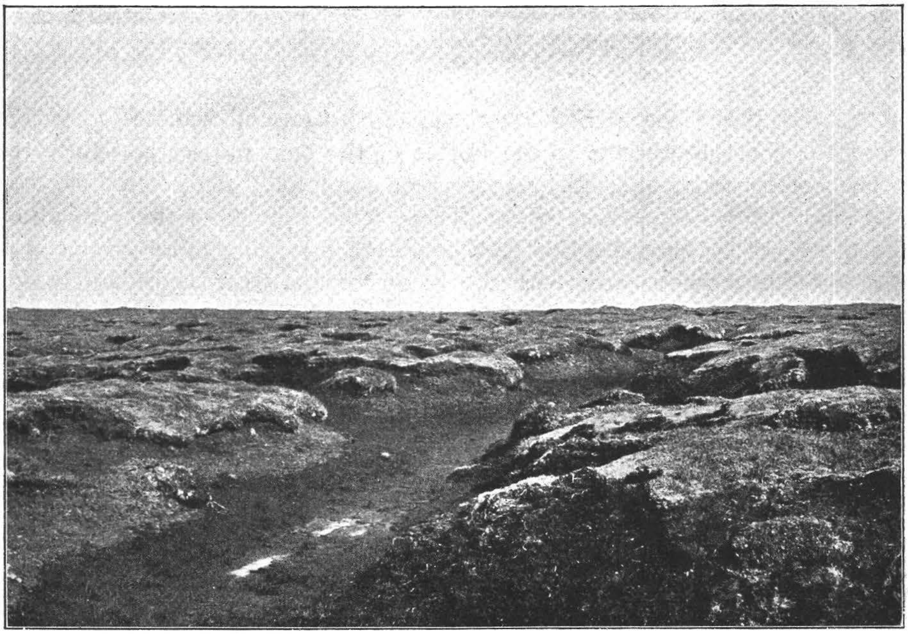

Fig. 9. Peat-hags on Carn a Choire Mhoir (Inverness-shire).

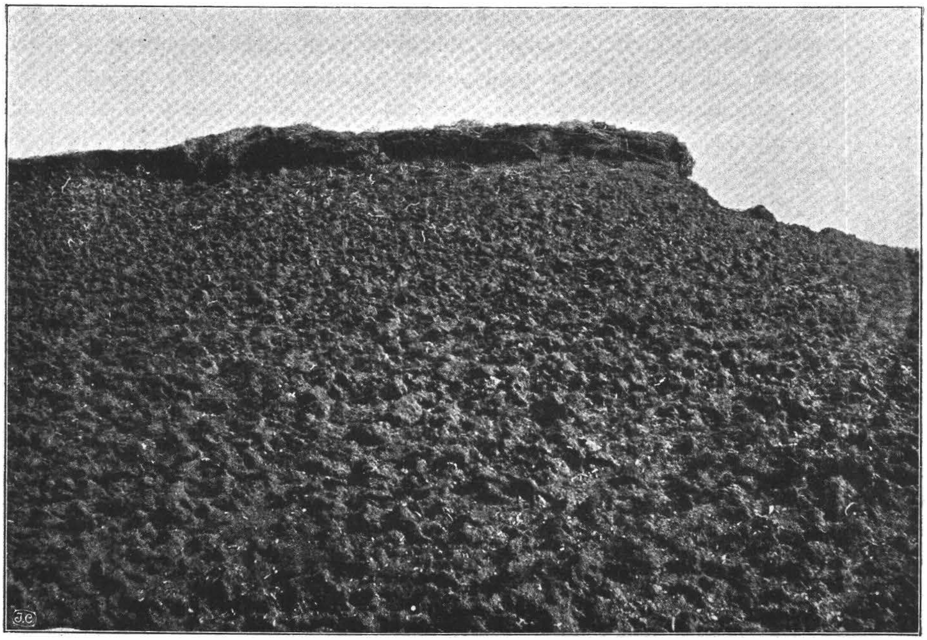

Fig. 10. A peat wall in a peat-hag, showing the structure caused by the erosion of the wind (Meall Laith, Killin, Perthshire).

during the Upper Forestian. If this interpretation is right, it is obvious that the 25 to 30-ft. beach has been formed before or during some part of the Upper Forestian. There is consequently no room for any submergence of the land in the Upper Turbarian. It is most probable that the elevation of the land which began in the latter part of the Lower Turbarian has since that time been going on without intermission and that the extent of the land has not been larger than now since the Lower Forestian.

IV. **Some comparisons between the peat mosses of Scotland and those of Scandinavia.**

We have so far chiefly considered only the post-glacial history of Scotland, but we will now also give a brief account of that of Scandivavia, in order to draw, if possible, a parallel between them.

STEENSTRUP (1842) was the first to examine the sequence of Scandinavian peat mosses more thoroughly. He investigated several Danish mosses. He considered their stratification to show that the Danish vegetation has changed several times in different ages. These changes were characterized by the immigration of a wood forming tree not before indigenous in the country. In this way he distinguished the birch, pine, oak, and alder periods. By NATHORST's (1870) discovery of arctic plant remains in the late-glacial lake clays of Scania it was known that, immediately after the disappearance of the last ice sheet from Southern Scandinavia, an arctic vegetation, characterized especially by the predominance of *Dryas octopetala* and *Salix polaris,* immigrated. Almost the same sequence of the palæontological zones has been found in the Scanian and other South Swedish peat mosses by ANDERSSON. He has, however, in some important points modified STEENSTRUP's classification (see e. g .1896, 1906, and 1909 a). The same succession of the trees has also been found by SERNANDER (1894 b) in the mosses of Gothland. STEENSTRUP-NATHORST's classification has been regarded to hold good of the peat mosses of Denmark and Southern Sweden south of the late-glacial straits of Närke. VON POST (1909, p. 695) is, howver, of opinion that in Närke and probably also in the whole of South Sweden the temperature rose so considerably at the close of the late-glacial period, that the flora of the Swedish wood meadows immigrated immediately after the disappearance of the arctic *Dryas* vegetation. He founds this opinion on LAGERHEIM's discoveries of *Corylus* and *Ulmus* pollen in silt immediately above clays containing e. g. *Dryas* and *Salix polaris* in some mosses in Scania (see N. O. HOLST in Sver. Geol. Unders., Årsbok 2, 1908, N:o 8, p. 24) and his own finds of *Corylus, Quercus, Tilia,* and *Ulmus* pollen in the lowest peat layers of the Mosjö moss in Närke, resting directly on late-glacial sand and clay with *Dryas, Arctostaphylos alpina, Betula nana,* etc. (VON POST 1909, p. 694). He therefore replaces STEENSTRUP-NATHORST's periods with the *Dryas,* hazel (probably very short), oak, and spruce periods. In Sweden north of the straits of Närke the oldest fossiliferous deposits contain pine remains. As numerous mosses in the whole of Svealand and Norrland have been examined without any remains of a decidedly arctic-alpine vegetation having been found, it must be assumed that the pine settled down immediately on the areas left bare when the ice melted away (Cf. ANDERSSON 1903, pp. 8—9). In the peat mosses of the largest part of Norrland occur only the pine and spruce zones (the latter approximately contemporaneous with the beech-alder zone of Scano-Dania). Only in the southernmost parts of Norrland an oak zone is also met with. The palæontological zones of Southern Scandinavia taken in STEENSTRUP's, NATHORST's, and ANDERSSON's sense and the strata of the Scottish peat mosses do not, I think, agree in any other respects than as to the occurrences of basal strata containing a purely arctic-alpine flora in both countries. But in this case the agreement is complete as to the character of the flora. In both countries a luxuriant water flora existed (Cf. LEWIS 1907 a, p. 60). In Scandinavia the *Dryas* zone consists everywhere of sediments, in Scotland, however, it seems that it may possibly also consist of peat formed *in situ*. If VON POST's interpretation of the facts alluded to above is right, the agreement becomes closer. We then find that in Scotland as well as in Scandinavia the warmth increased very rapidly when the glaciers of the Mecklenburgian ice age disappeared and that as to the temperature of the period of vegetation the climate of a certain district probably very soon corresponded to the present one of the district in question. In the mosses of both countries we find evidences which prove the existence of a period in post-glacial time warmer than the present one.[1]

About 10 years after GEIKIE and without knowing his opinions A. BLYTT (1876) worked out a theory on the immigration of the Norwegian flora during alternating rainy and dry periods. The foundation of this theory was taken from the character and distribution of the different types of the Norwegian vegetation and from the stratification of the peat mosses. BLYTT divided the late-quaternary time of Norway into seven periods: the arctic, subarctic, boreal, atlantic, subboreal, and subatlantic periods, and the present time. The boreal and subboreal periods were characterized by a dry, continental climate and are according to BLYTT represented by stool layers in the mosses. In the boreal time oak and other deciduous trees, in the subboreal time pine predominated on the surfaces of the mosses. The present time was also regarded to be rather dry. Later on BLYTT modified this schema, and divided the subarctic period into three subdivisions (Cf. BLYTT 1893, p. 10). This theory of BLYTT's has in Sweden been embraced and supported by a great number of scientists, in the first place R. SERNANDER, who has, upon the whole, accepted BLYTT's

[1] LEWIS (1906 a, p. 357; 1907 a, p. 58) has made some attempts of correlating the zones of the Swedish and Scottish peat mosses, but they start from the wrong supposition, that the zones of STEENSTRUP's represent four distinct forest beds, characterized by four different dominant trees.

classification. Neither SERNANDER nor any other Swedish scientist has found anything corresponding to the subdivisions of BLYTT's subarctic period. SERNANDER has also tried to connect BLYTT's periods with the changes of the water level of the South Baltic (Cf. e. g. 1908 b, p. 471). VON POST (1909) has given the last account of the post-glacial history of Southern Sweden. His opinions differ in some respects from those of SERNANDER's, but as they must be regarded to be the most up-to-date I will follow him. According to VON POST (1909, p. 638) the Baltic was during the arctic (and subartic) period a sea, the fauna of which had a high-arctic character (the *Yoldia* sea). The boreal period coincides with the *Ancylus* time, when the Baltic was a fresh water lake, and the atlantic period with the time immediately before and after the maximum extent of the *Litorina* sea. The subboreal period comprehends the largest part of the retreat of the *Litorina* sea, whilst the subatlantic period which merges continually into the present time comprehends only the very last stage of this retreat. The climate of the boreal, atlantic, and subboreal periods was warm, and at least during the subboreal period, the temperature of the season of vegetation was considerably higher than now. The climate of this period was no doubt the warmest of the whole post-glacial time. For instance, the main part of the *Trapa* finds in Southern Sweden and Southern Finland originate from silts (»gyttjas») deposited at that time. The climate was during the atlantic period, at least in Southern Sweden, moister and more insular than during the boreal and subboreal periods and probably also than at the present time. The subatlantic period was characterized by a moist and cold climate; SERNANDER also concurs in BLYTT's opinion as to the rather dry character of the present time. According to VON POST (1909, p. 638) and SERNANDER (1908 b, p. 471) the latter part of the subboreal period coincides with the bronze age. The Scandinavian stone age comprehends, according to them (see particularly VON POST 1909, p. 638), the atlantic period and the former part of the subboreal period. — North of the late-glacial straits of Närke nothing corresponding to the boreal period has as yet been found. In Norrland the climate of the *Ancylus* time seems not to have had any especially dry chracter. On the other hand the atlantic, subboreal, and subatlantic strata are generally distinctly marked in the peat mosses of Northern Sweden (Cf. particularly VON POST 1906). The investigations of the last years generally highly argue in favour of the correctness of BLYTT's theory (with the modifications made especially by SERNANDER and VON POST).

Before looking for any correspondence between the post-glacial history of Scotland and that of Scandinavia (according to BLYTT's theory), we will, however, discuss some other features which are of a certain importance in connection with such a comparison.

SERNANDER has repeatedly maintained the view that at the time of the *Litorina* submergence in the South Baltic the climate of the whole of Scandinavia was considerably moister than now. All the Scandinavian phyto-geographers who have treated this subject have agreed with him. Most of them have also assumed that the temperature of the season of vegetation was at that time higher than at present. The occurrence of certain fossils in the peat strata of that time (the atlantic period) has yielded the proofs of this opinion. A great number of southern species had once a more northerly distribution in Scandinavia (see e. g. ANDERSSON 1909 a, pp. 62—64), but it is often very difficult to determine the age of the fossil finds in question. The example examined most thoroughly is the hazel (ANDERSSON 1902). For instance SERNANDER (e. g. 1905, p. 77) and I myself (1906) have tried to show that a great number of these finds of fossil hazel originate from the subboreal period, but HEDSTRÖM's (1893) investigations and mine (1906) show, I think, that the hazel was a native of the southern parts of the Norrlandian pine forest region also during the atlantic period. A great number of the hazel finds published by ANDERSSON (1902) are naturally also atlantic, but his descriptions very seldom permit a sure conclusion with reference to their age. HÖGBOM (1907, p. 70) is of opinion that a supposition of the *Litorina* time having been characterized by a strongly marked maritime climate would be enough to explain the large distribution of the hazel and other southern plants characteristic of the wood meadows in Norrland of that time. HÖGBOM lays stress upon the fact that the hazel lives at the coast of Western Norway, as far to the north as Stegen in Salten (67° 56'). In these regions the temperature of the season of vegetation is much lower than in large parts of Norrland. HÖGBOM therefore, and for some other reasons (see below), draws the conclusion that the summer temperature of the *Litorina* time was lower in Norrland than it is at present. The supposition of a highly maritime climate with a long period of vegetation may possibly be sufficient to explain the large distribution in Norrland of the southern plants in question during the atlantic period (SERNANDER 1907, p. 72). But this supposition cannot explain the wide distribution of the same plants during the continental subboreal period. This fact must be due to the higher temperature of that time. As a consequence of the opinions just quoted, HÖGBOM also thinks that the upper limits of trees were lowered during the *Litorina* time. It cannot in my opinion be called in question that the tree limits lay considerably higher during a part of that time than it now does. GAVELIN who has recently (1909) put together our knowledge of this fact estimates the lowering of the tree limits since that time to 200 m. on an average. In Southern Norway the lowering is a little greater. The investigations of SERNANDER (1905) and FRIES (1910) seem to show that the tree limits reached this higher situation during the subboreal period. The observations of FRIES seem also to prove that the tree limits of the atlantic period lay considerably higher than now, a fact which is not consistent with a so strongly marked maritime climate as that supposed by HÖGBOM. We must therefore think that the temperature of the season of vegetation was higher during the atlantic as well as the subboreal period than now. A detailed discussion of the occurrence of the hazel has led ANDERSSON (1902; see also 1909 a, pp. 63—65) to the conclusion that the time of vegetation was considerably longer than now and its mean temperature about 2,5° C. higher.

As already mentioned HÖGBOM had other more important reasons for his opinions as to the climate of the *Litorina* time than the former distribution of the hazel. He is namely of opinion that »the advance of a great number of western alpine plants towards the east and south-east, which took place at that time according to several different and unanimous evidences, is also most consistent with the supposition of a lower summer temperature» (1907, p. 70). HÖGBOM bases this supposition upon SERNANDER's opinion (see e. g. 1899, p. 54) that the calcareous tufas of Jämtland, containing a flora with e. g. *Dryas, Salix herbacea* (Cf. K. KJELLMARK in Geol. För. Förh., Bd 26, p. 200), and *S. reticulata,* are of atlantic age, and also upon the opinion of the same author that a great number of colonies of alpine plants in the pine forest region in different districts of Central Scandinavia are relics of the atlantic period. For several reasons SERNANDER thinks that the tufas just mentioned were deposited »during a time with a climate even warmer than the present» (1899, p. 54). I have just tried to show that the atlantic period was characterized by a climate with warmer summers than that of the present time. SERNANDER thinks that those calcareous tufas and the alpine colonies just mentioned date back to the atlantic periods for the following reasons.» At Digernäs close to the lake Storsjön» (Jämtland) »tufa and lake marl with tufa lie partly below a peat stratum at the bottom of which a pine stool layer occurs. I regard this pine stool layer as subboreal and the tufa as atlantic. The tufa contains as glacial outposts *Dryas* and *Salix reticulata,* intermingled in a flora with *Pinus silvestris, Salix caprea, Betula alba, Hippophaë rhamnoides,* etc.» (1899, p. 54). »The insular climate of the western coast of Norway would then have stretched considerably further into the land than now» (SERNANDER 1894 a, p. 199). Such a climate is supposed »to have caused a descent of several alpine plants into the pine forest region» (1899, p. 52). This opinion has been discussed above (pp. 227—235). I have also already said that I cannot agree with SERNANDER's opinion that the alpine plants that occur at water courses and on rocks are relics of a time with a more insular climate. Such a climate seems scarcely to favour the occurrence of these plants below the wood limit. Nor ought such colonies of alpine plants to occur far below the upper limit of the pine forests in the most continental parts of Scandinavia, which cannot during the atlantic period have had a climate of the same character as that prevailing at present on the western coast of Norway. It is in my opinion more probable that these colonies are relics of the time when the last ice sheet melted. In this way the occurrence of a great number of such plants in certain localities might also be explained. But as I have mentioned above, it is not probable that an arctic flora immigrated over the lower parts of Northern Sweden at the close of the ice age. If those colonies were relics of this time we ought to find almost as great a number of such plants in edaphically favourable habitats in the neigbourhood of the Gulf of Bothnia as closer to the high mountains. The farther one retires from the mountainous districts, the smaller becomes the number of alpine plants in the habitats in question, a fact which seems to go to prove that these species have spread from the mountains successively in different ages with various climate, sometimes over long distances, and have settled down in habitats, where the edaphic conditions prevent the vegetation becoming closed.

It is consequently very improbable that a climate of that kind which SERNANDER regards as characteristic of the atlantic period should have caused a descent of such plants as *Dryas* and *Salix reticulata* into the lowland of Jämtland. Nor can the stratigraphy of the Norrlandian calcareous tufas prove the existence of such a descent during the atlantic period. A comparison with the tufa at Leine in Gudbrandsdal (Norway) described by BLYTT (1892) renders their atlantic age still more improbable. If, upon the whole, the different strata of the tufa of Leine are to be regarded as reflecting changes of the climate, we must think that the layer with *Dryas* and other alpine plants was deposited during a continental period. BLYTT is of opinion that the *Dryas* tufa was formed in the boreal period. Be that, however, as it may, it seems to me most probable that the calcareous tufas, containing *Dryas* etc. (and also pine), of Jämtland and the Gudbrandsdal were deposited a rather short time after the melting away of the last ice sheet, before the different phyto-geographical regions had yet become fixed.

There are no reasons to suppose that during the atlantic period Northern Scandinavia had a considerably more insular climate than now. A climate of the character that HÖGBOM has assumed must no doubt have caused an increase of the glaciers in the mountainous districts of Northern Scandinavia. But, according to A. HAMBERG (in Ymer 1901, p. 189), such an increase has not taken place at least in the Sarek district (N. Lapland).

The stratigraphy of the peat mosses of Scotland and Southern Scandinavia (according to BLYTT's theory) invites immediately to a correlation. We have seen that the mosses of both districts have twice been to a large extent covered with forests. In particular this is true of the Scottish mosses. That the surfaces of the mosses of Southern Scandinavia have more seldom been overgrown with forests during the boreal period, depends surely on the fact, that these mosses, that generally derive their origin from the filling and silting up of lake basins, were at that time on the lake stage. The woods of both these forest periods have been replaced by more hydrophilous association owing to the rising of the ground water. In the earlier forest period the surfaces of the peat mosses have generally not been so dry as during the latter, which is for instance shown by the small size of the tree remains of the lower forest. At the time when the upper forest beds were formed the forests stretched higher on the mountains in both countries, in Northern Scandinavia probably about 200 m., in South Western Norway and in Scotland about 300 m. In Northern Sweden as well as in Scotland the most important traces of a warmer climate belong to the upper forest beds. The Lower Forestian in Scotland and the boreal period in Southern Scandinavia fall within a time when the land surface had a larger extent than at the present time, whilst the succeeding periods, the Lower Turbarian and the atlantic one, fall within a time when the sea-level was higher than now. We then find that the vegetation of the Scottish and the South Scandinavian peat mosses has passed the same stages of development. The changes of levels seem also to have followed the same course, apart from the differences in the South Baltic caused by the turning over southwards of the *Ancylus* lake. We then have not far to the supposition that the analogous layers of both districts also are approximately synchronous. Such a correlation has also been made. GEIKIE (1881, Cf. also 1894 and 1895) was the first who tried to draw a parallel. BLYTT's (1893, p. 14) opinions as to this subject are, however, best and most completely worked out. His correlation agrees closely with that which I regard as most probable. SERNANDER (1908 a and b) is of almost the same opinion. But he also thinks that the »second arctic bed» of the Scottish mosses and the calcareous tufas of Jämtland are contemporaneous and formed under analogous climatic conditions. For the above given reasons it is obvious that I cannot concur in this opinion. — In the table on pp. 256 and 257 a summary of some features of the post-glacial history of Scandinavia and Scotland is given.

Against my correlations it may, however, be objected that Scotland and Southern Scandinavia have certainly passed the same phases of development, but peat strata that are petrographically and stratigraphically developed in the same way are not therefore necessarily contemporaneous. Such a remark is no doubt *a priori* legitimate. Both GEIKIE and SERNANDER have, independent of each other, placed the bronze age, the former during the Upper Forestian, the latter during the subboreal period. If this opinion is right, at least the partial synchronism of these periods has also been proved, as the bronze age must have fallen in about the same time in Scandinavia and in Scotland.

One of the most prominent features of the postglacial history of North Western Europe is undoubtedly the existence of a xeroterm time, when the forests and southern warm loving plants occurred at higher levels and farther towards the north than now, and when large parts of the mosses were overgrown with forests, mostly pine forests. It is also very probable that the *Litorina* submergence, a correspondence of which HOLMBOE (1903, p. 91) has also found on Jäderen in South Western Norway, and the time when the Carse clays were deposited coincide. If the Lower Turbarian falls within the time of the Carse clays, it seems then probable that the atlantic period and the Lower Turbarian are synchronous. If these conclusions are right it seems also very plausible that the Lower Forestian and

Attempt to draw a parallel between the post-

Scotland during the post-glacial time.		
The climatic periods of GEIKIE'S.	Changes of the sea-level.	General development of vegetation.
Upper Turbarian. Moist and cold.	Raising of the land.	Large extent of moorlands. Lowering of the upper limits of the different regions.
Upper Forestian. Dry and warm. The warmest part of the post-glacial time.	Raising of the land.	Almost the whole of Scotland was covered with forests, below 500 m. to a large extent mixed deciduous woods (e. g. oak groves), elsewhere pine and birch forests.
Lower Turbarian. Moist climate.	Submergence of the land. The 45 to 50-ft beaches were formed.	Large extent of moorlands, on the surface of which alpine plants sometimes occurred. Tree limits probably somewhat lower than now.
Lower Forestian. Dry and warm	Land area greater than at present.	Almost the whole of Scotland (also the islands) were overgrown with forests at least up to the present tree limit. Oak, hazel, etc. were natives of the country.
Arctic Tundra Time.	Sea-level higher than now. Formation of the 100 to 135-ft. beaches.	An arctic-alpine vegetation dominated over the areas left bare at the disappearance of the glaciers; aquatic vegetation comparatively luxuriant.

glacial history of Scotland and that of Sweden.

Southern Sweden during the post-glacial time. (Chiefly according to VON POST 1909.)			
The Climatic Periods of BLYTT'S.	Changes of level.	Archæological Time.	General development of vegetation.
The Subatlantic Period. Moist and cold.	*Mya Time.*	*Historical Time. The Iron Age.*	Northern plants migrate southwards.
The Subboreal Period. Warm and dry. The warmest part of the post-glacial time.	*(Limnæa Time).* *Litorina Time.*	*The Bronze Age.* *The Stone Cist Time.* *The Passage Grave Time. The Dolmen Time.*	»The post-glacial climate deterioration.» *Trapa natans* is a common plant of the lakes. The wood meadows have their maximum extent. *Picea excelsa* immigrates. (In Norrland the tree limits lay about 200 m. higher; *Corylus* and other southern plants went further towards the north than at present.)
The Atlantic Period. Warm and moist.	Maximum extent of the *Litorina* sea.	*»The first period of the Swedish stone age.» The time of the Kitchenmiddens.* (Magle Mose.)	Wood meadows and pine forests are the characteristic associations of the dry ground.
The Boreal Period. Warm and dry.	*Ancylus Time.*		
(The Subarctic Period.) The Arctic Period.	*Yoldia Time.*		*Dryas* flora. Aquatic vegetation comparatively luxuriant. At the end of this period more temperate plants immigrate.

the boreal period represent about the same time. — I will, however, explicitly emphasize that much further work must be done before a complete correlation can be made. Particularly, this holds good with reference to the lower forest beds and the second arctic bed of the Scottish mosses. The correlation of these zones with the boreal and atlantic layers of the South Scandinavian mosses unquestionably meets with certain difficulties. But the correlation given above must be regarded as the most probable.

If the post-glacial climatic periods of GEIKIE's and BLYTT's are identical, whose terminology ought then to be preferred? GEIKIE's theory is certainly somewhat older, but BLYTT's theory was first worked out in that form which is now regarded as approximately right. And as BLYTT's terminology dates back from 1876, while that of GEIKIE's is given in 1895, the rules of priority claim, I think, the acceptation of BLYTT's names, though they are in several respects unsuitable.

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Plate XIII.

Plate XIII shows the situation of the Scottish peat mosses described in the present paper and the geographical distribution of some important zones of the mosses.

1. Cross Fell, Cumberland (The figure as well as the sign has unfortunately been very indistinct by the reproduction). 2. Merrick-Kells district, Kirkcudbrightshire and Ayrshire. 3. Tweedsmuir, Selkirkshire. 4. Flow of Dergoals, Wigtownshire. 5. Beinn Leathan and 6. Meall Laith close to Killin, Perthshire. 7. Moor of Rannoch, Argyllshire and Perthshire. 8. Forfarshire Grampians. 9. Spey-Findhorn watershed, Inverness-shire. 10. Findhorn-Nairn watershed, Inverness-shire and Nairnshire. 11. Coire Bog, Ross-shire. 12. Caithness-Sutherland border. 13. Assynt, Sutherlandshire. 14. Skye. 15. Barvas, Lewis. 16. N. Uist. 17. Mainland of Shetland.

Geographical distribution of the different zones in the peat mosses of Scotland. ⊕ District where two forest beds (or other xerophilous zones) and an intercalated stratum with arctic-alpine plants (second arctic bed) occur. ○ District with two forest beds, but no arctic-alpine plants between them. + District where only one forest bed has been met with.