# DEVELOPMENT OF PALSA BOG IN CENTRAL HIGHLAND, ICELAND

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*Abstract* Topography and deposits in two selected bogs with permafrost in the central highland of Iceland are described. Radiocarbon dates and tephrochronological observation reaveal that development of permafrost in the bog started around 4,000 to 3,000 years B.P., succeeding to the formation of almost all deposits of bogs during the Atlantic time. Present irregularly undulating topography with slightly hilly microlandforms and varied depressions indicates that a thermokarst resulted from the more extensive development of former permafrost. That has occurred during these several hundred years since the beginning of the Middle Ages. Typical palsa, mineral palsas in most cases, formed only in such thermokarst depressions have occurred after the partial disappearence of the extensive permafrost.

## 1. Introduction

It has been well-known that palsas develop in the boggy area of the central highland in Iceland, at an elevation of 500 to 800 m above sea level (ex. Friedman *et al.*, 1971; Schunke, 1975). These palsa bogs are distributed in shallow depressions formed in pleistocene Grey Basalt, tillite and palagonite. Palsa is an excellent indicator to represent the presence of permafrost, or discontinuous permafrost. This is one of the significant reasons why research on frozen ground has been carried out in Iceland.

Palsas have been studied mainly with reference to the present bog environment, and therefore we have as yet very little information as to the historical development of permafrost in Iceland. In this paper, first some topographic features and constituent materials of two bogs (Fig. 1) will be described on the basis of tephrochronological observation in the field and air-photo interpretation, and then several radiocarbon dates are presented. Based upon these data, development of bogs will be discussed especially in relation to problems of both permafrost and holocene climatic and/or environmental changes in Iceland.

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## 2. Description of Palsa Bog

### Topography and deposits of palsa bog

*Orravatnsrűstir* (65°05′N, 18°30′-35′W)

The name of this bog means a pond (vatn) with palsas (rűst) in Icelandic. This bog 710-715m above sea level is located at about 15 km north of the margin of the Hofsjökull (Fig. 1 and 2). The boggy area is covered with grasses, sedges and lichen in contrast to the very poorly to non-vegetated surface of the surrounding slopes. A small river

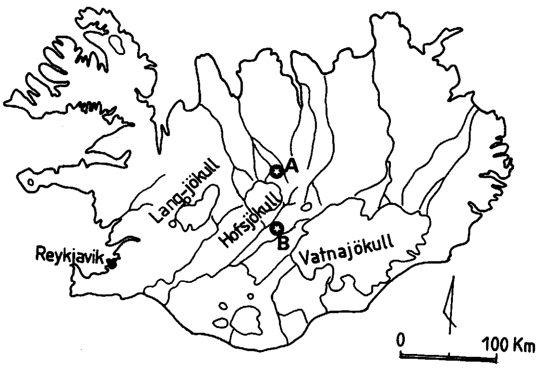



**Fig. 1** Locality of surveyed bogs
A : Orravatnsrűstir; B : Svörtubotnar
Shadow indicates ice caps.

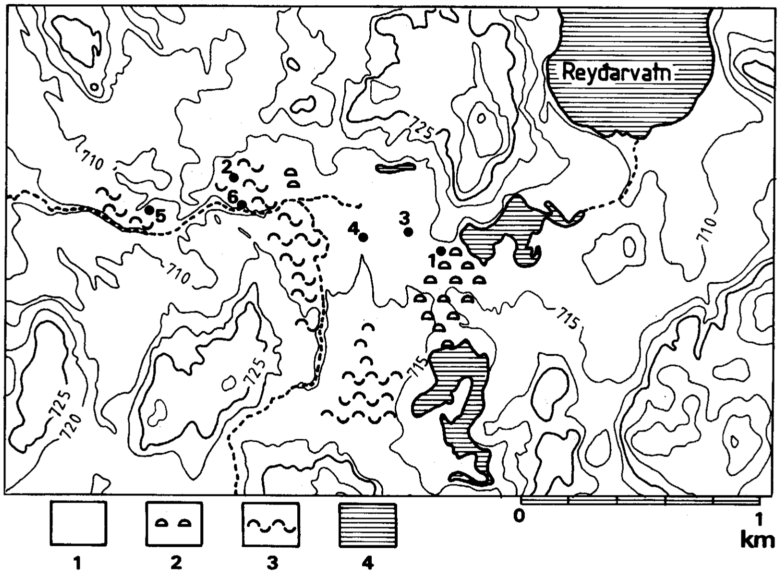



**Fig. 2** Topography of the Orravatnsrűstir.
1 : Boggy Surface ; 2 : Area occupied mainly by typical palsa ;
3 : Irregularly undulating surface ; 4 : pond.

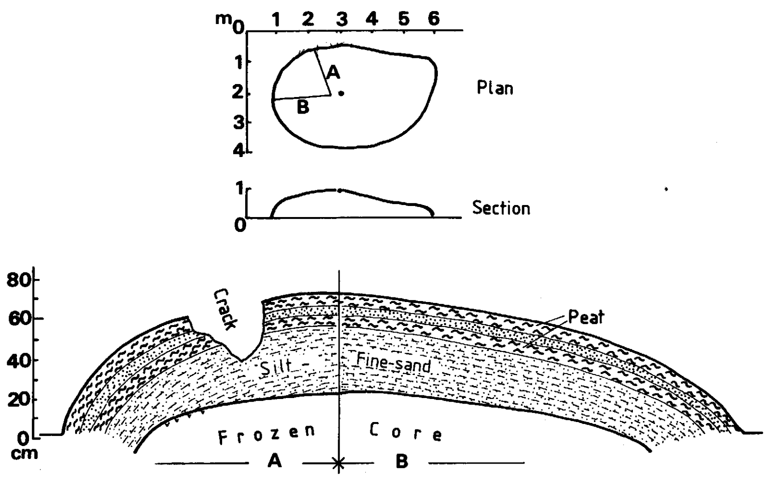



**Fig. 3** Topography and structure of a palsa in the Orravatnsrūstir.

draining water begins to dissect the bog. The valley reaches 3-10 m in width and 2-3 m in depth at the marginal area of the bog.

As shown in Photo 1, the surface of the bog is characterized by very irregular microlandforms with slightly hilly topography and shallow depressions containing water in most cases. This slightly hilly topography is mainly due to palsas and plateau-shaped landforms with permafrost. Typical palsa mounds have width of 3-6 m and heights of 60-80 cm. The top surface of frozen core corresponding to the mound shape can be found at the depth of 45 cm in July to 65 cm in September, as shown in Fig. 3 and Photo 2. As the peat layer covering a palsa is only 10 to 15cm in thickness and the constituent material under the peat is silt or sandy silt, these palsas should be regarded as mineral palsa. In other bogs, there exist palsas consisting of coarse sands to granules without any peat cover, in some cases including boulders. Such mineral palsas will be discussed in an other paper.

The plateau-shaped landforms due to permafrost develop to 10-100 m in width and 1-1.5 m in height, the smaller ones sometimes taking the form of mesa (Photo 1). Owing to the development of permafrost, the surface is kept relatively dry. The heights of all plateau-shaped landforms are at almost the same level. Large-scale polygonal patterned ground with furrows is observed on the surface. However, the nets of the patterned ground are partly cut down at the margin of the plateau forming a low cliff. This means that the large-scale polygonal nets formed on a more widely developed permafrost surface. Although just the uppermost part of constituent materials of the plateau-shaped landform can be observed along the marginal cliff, they are composed of a peat layer reaching 1m (Fig. 4 - Section 2, 3 and 4). This peat layer is well compacted in contrast to the loose peat covering of the palsas. The peat layer forming plateau-shaped landform is covered with fine sands and the well-known pumice layers of Hekla 3 and/or Hekla 4 dated to 2,900 y.B.P. and 4,500 y.B.P. respectively.

**Photo 1** Orravatnsrústir bog characterized by irregular microlandforms with slightly hilly topography and shallow depression.

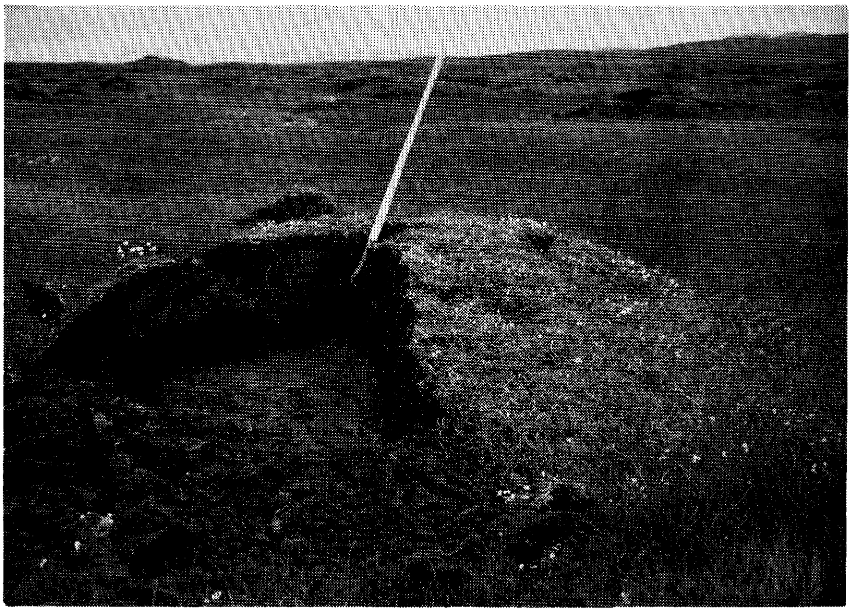


**Photo 2** Typical palsa.
Frozen core is exposed. The length of shovel is 1.5 m.

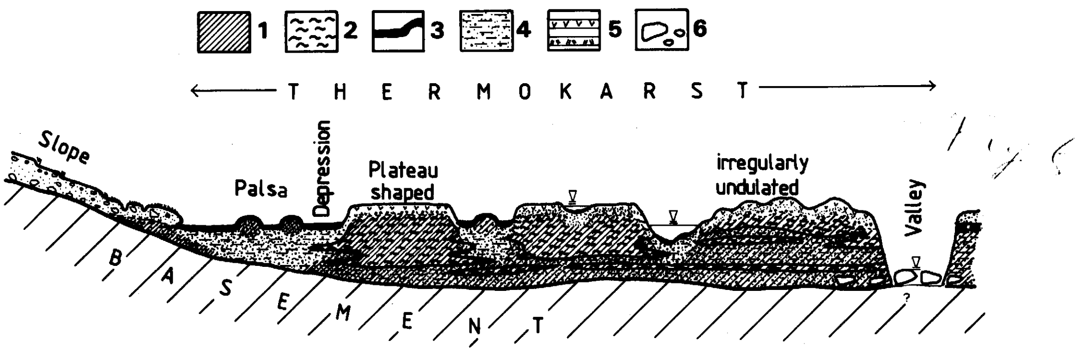



**Fig. 4** Columnar sections of constituent materials of bogs and radiocarbon dates. Sections 1-6 are from Orravatnsrústir (locatities are shown in Fig.2), and 7 from Svörtuvotnar.
1 : Frozen ground ; 2 : Soil ; A-horizon ; 3 : Eolian sand and/or reworked tephra ; 4 : Pumice layers of Hekla 3 and Hekla 4 ; 5 : Scoriae ; 6 : Peat ; 7 : Silt ; 8 : Sand.

The irregularly undulating topography (Photo 3) with relative heights of 1-2 m is composed of such deposits as shown in columnar section 5 of Fig. 4. The uppermost part, 40-50 cm thick, is mainly composed of peat layer intercalating scoriae and pumice layers, and underlain by frozen sandy deposits having ice lenses up to 2 cm in thickness. The white pumice layer could be identified with Hekla 4 from its macroscopic character.

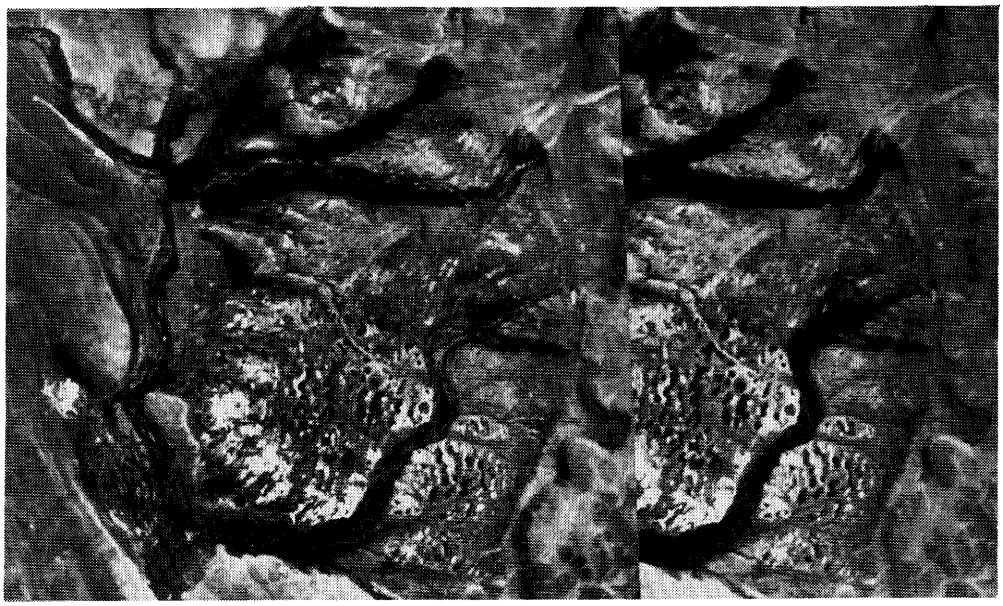
Topography of depressions within the palsa bog is also characterized by various forms, scales, distribution pattern and so on. Relatively large depression occupies the area among the plateau-shaped landforms, and are filled with water or covered mainly with sedges. Only in this relatively low-lying area, typical palsas mentioned above develop (Fig. 2, Photo 4). Boring by peat core sampler reaveals that these low-lying areas are mainly composed of fine sands including pumice and scoriae grains covered with peat layer, 45 cm thick (see Fig. 4-Section 1), although organic materials are contained in some horizions. A hardly penetrable surface was reached at the depth of 190 cm, that seems to indicate the presence of permafrost, if it is not the base of the boggy deposits.

Another types of depression shows a round form. Widths are commonly 5-20 m and depths 50 cm to 3 m. Some of them are distributed on the surface of plateau-shaped landforms, which could be regarded as the beginning of more extensive low-lying swampy depressions.

Consequently, plateau-shaped landforms seem to correspond to the area with thick peat, while typical palsas or large swampy low-lying areas are restricted to the area of mineral deposits. That should depend on differences of the thermal conductivity between peat and mineral deposits. In other words, the present distribution of permafrost within a bog depends on the constituent materials, or thickness of peat layer of the uppermost horizon. It should be stressed that the relief of a boggy area represents the collapse stage decaying a more extensively developed former permafrost. In this respect, except for the typical palsa, plateau-shaped landforms or irregularly undulating surface with round depression should be regarded as a thermokarst topography as a whole.

**Photo 3** Very irregularly undulating bog surface in Orravatnsrústir.

**Photo 4** Area with many palsas in Orravatnsrústir.



0 500m

**Photo 5** Vertical airphoto of the Svörtuvotnar (Air-Photo No. 10134 and 10135 taken by Iceland Geodetic Survey).

**Photo 6** Svörtuvotnar with many depressions having water.

*Svörtubotnar* (64°30′N, 18°30′ W)

A lot of small boggy areas are distributed in Holtamannaafrētur between Hofsjökull and Vatnajökull. Svörtubotnar, with a width of approximately 1.8 km, about half of which has been already buried by coarse fluvial deposits, is located at an elevation of ca. 630 m above sea level along Route F 28. As show in Photo 5 and 6, this bog is characterized by the development of many round depressions filled with water. The widths of depressions are commonly 12-50 m and depth 2-3 m. They are developed into permafrost ground forming a slightly hilly topography and show a longate form in case of being connected to one another. However, the slightly hilly topography here dose not indicate such independent plateaus or mesas as thoes in Orravatnsrūstir. These topographies should originate from the partial decay of permafrost which had formerly extended in the whole bog, and therefore indicate a thermokarst landform. Typical palsa develops poorly in this bog.

Along the wall to the depression, the constituent materials are outcropped (Fig. 4-Section 7): well compacted peat layers, 1.5 m thick, are intercalated by thin silt or scoriae layers, and overlain by fine sands intercalating both Hekla 4 and Hekla 3 pumice layers.

**Absolute ages of deposits**

Radiocarbon dates of 5 peat samples were obtained from Orravatnsrūstir and 2 samples from Svörtubotnar. These dates and stratigraphic positions are indicated in Fig. 4. Approximate absolute ages of marker tephra layers from the volcano Hekla were determined on the basis of radiocarbon dates as follows (Larsen & Thororinsson, 1978): Hekla 5; 7,000 y.B.P., Hekla 4; 4,500 y.B.P., Hekla 3; 2,900 y.B.P., Hekla 1; 880 y.B.P., (by eruption in A.D. 1104). On the basis of these radiocarbon dates and key tephra layers, the following can be concluded.

1) In each columnar section, the peat layer is overlain by Hekla 3 and/or Hekla 4 pumice layer (Fig. 4-Section 2-7). Radiocarbon dates range from 3,160 ± 120 to 4,620 ± 130 y. B. P. except for a younger date (2,050±90 y.B.P.) of a columnar section 7 from Svörtubotnar. As both pumice layers overlying the peat are identified with Hekla 4 and Hekla 3 respectively, the younger radiocarbon date seems to be caused by contamination with root of present vegetation.

2) In the columnar section 6 obtained in the small valley dissecting bog, the radiocarbon age (5,160 ± 130 y.B.P.) is older than that of the lower Hekla 4 layer (4,500 y.B.P.). But a Hekla 3 pumice layer can be found in the upper horizon. Therefore the formation of peat seems to have finished around 4,000 years B.P.

3) The oldest radiocarbon date, 6,930 ± 200 y.B.P., was obtained from the section 6 in Fig. 4. This peat layer can be considered to show a horizon close to the base of the bog, because many large blocks originated from the ground maraine of the Last Glacial are distributed on the valley bottom.

## 3. Discussion and Conclusions

**Succession of palsa bog development**

As shown in columnar sections 2-6 of Fig. 4, the Orravatnsrűstir bog began to form around 7,000 years before present at latest. Friedman et al. (1971) described a peat layer dated back to 8,240 ± 85 y.B.P. in the other bog of the central highland. Based on the stratigraphic position of the Hekla 4 and Hekla 3 pumice layers, an adequate environment for the development of peat probably prevailed between 8,000 and 4,500 y. B.P. After the development of peat, only thin medium to fine sand bed, 10-20 cm thick, had deposited. The Hekla 3 pumice layer can be found in the uppermost horizon of the boggy deposits. It can be consequently said that sedimentation in the boggy area had largely ceased around the time of the fall Hekla 4 to Hekla 3 at latest. This relatively abrupt change of sedimentary environment was probably caused by the development of permafrost over the whole boggy area. Due to the development of permafrost, a relatively dry condition occurred on the surface of the boggy area, just as shown on the present surface of the plateau-shaped landforms. No further significant sedimentation in the bog occurred.

There is no direct indication as to when the extremely developed permafrost began to decay. Columnar section 1 of Fig. 4 represents an example of constituent materials of the low-lying area close to a typical palsa, or between plateau-shaped landforms, as

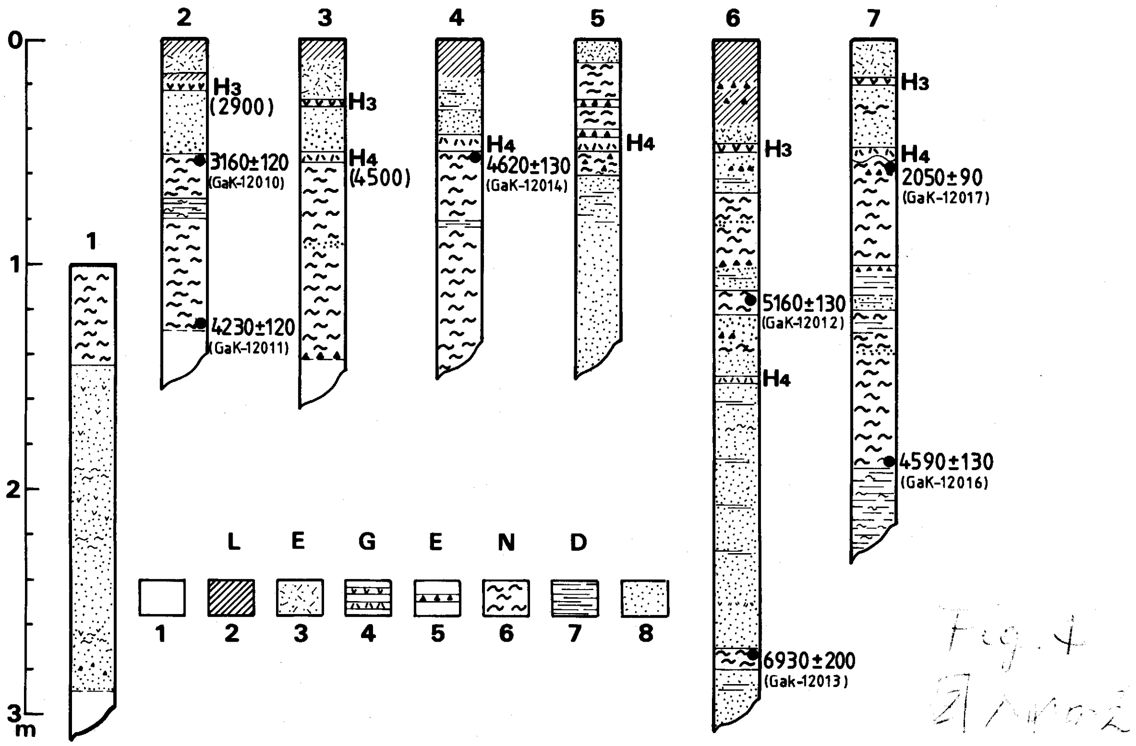



**Fig. 5** Schematic geologic and topographic section of palsa bog
1 : Permafrost ; 2 : Peat ; 3 : New peat ; 4 : Mineral deposits (mainly Siltfine Sand) ; 5 : Pumice layers of Hekla 3 and Hekla 4 ; 6 : Gravels and blocks.

described earlier. There exists a very loose peat layer, 45 cm thick, underlying sandy-silty fine materials including pumice grains probably identified with Hekla 3. Only the peat layer can be considered to have been formed after the decay of permafrost. In any case, the present landscape of the boggy area with several types of slightly hilly topographies and depressions originated from the partial decay of extensive permafrost in most cases, and also from the newer permafrost to a much smaller extent. Such present distribution of discontinuous permafrost is strongly affected by the differences of constituent materials within the bog, that is reflected on the various micro-landforms (Fig. 5). A river draining water from the depression surely led the downcutting into the bog with permafrost, especially in Orravatnsrűstir.

Concerning the several types of slightly hilly present topographies, Schunke (1975) classified them into hump shaped, ring shaped, dike shaped, plateau shaped and shield shaped palsa. He described the plateau-shaped form as plateauförmige Palsa in German. But in his English summary, it is suggested that palsas except the typical shield-shaped palsa should be designated as cryokarst (thermokarst) mound, because they are degradational forms. As Washburn (1979) pointed out, if we accept thermokarst features as a type of palsa, palsa must be classified into an agradational type and a degradational type. Because palsa is principally an agradational form by ice segregation, it is not adequate to use the term palsa to indicate a plateau-shaped landform representing a type of thermokarst, although it is mainly a problem of terminology.

**Development of permafrost and climatic change**

According to the tephrochronological studies by Thorarinsson (1956, 1964), small, steep glaciers on high mountains in Iceland reached their maximum extent around 2,500 years B.P.. They have probably existed before the climatic deterioration of Neoglaciation. On the contrary, large ice caps like Hofsjökull or Vatnajökull are supposed to have started to form during the cold period which began around 2,500 years ago (Kaldal, 1978). The ice caps reached their maximum extent in AD 1890. On the basis of these facts, it is very likely that permafrost had not developed at least during the period of peat accumulation in the bog indicating radiocarbon dates from 7,000 to 3,100 y.B.P.. This period can be regarded to correspond to Atlantic time. Permafrost is supposed to have developed in accordance with climatic deterioration along with the growth of glaciers, that occurred around 4,000 years B.P. to 3,000 years B.P.. Perhaps permafrost developed corresponding to the growth of large ice caps. Probably the growth of ice caps had a great influence on the condition of permafrost in Iceland. That could be a reason why extensively developed permafroast does not seem to have reacted to the succeeding moderate variation in climate, at least untill the beginning of the Middle Ages. Development of peat layers during the Atlantic time should play an important role in creating suitable conditions not only for the formation of permafrost but also for the present distibution.

As mentioned earlier, there is not direct indication as to when permafrost began to decay. Schunke (1975) supposed that the decay started with the increase of temperature after the Little Ice Age of the 17th to 19th century. However, according to Thorarinsson (1951), Svein Palson carried out scientific work on permafrost in 1793, and used the Icelandic word "rűst" to describe the slightly hilly topographies. This description should be used for both plateau-shaped landforms and typical palsa mounds. It is therefore known that almost the same landscape as the present one existed already in 1793. This fact reveals that a thermokarst occurred even during the Little Ice Age. Also, judging from the thickness of the new peat layer in the depression, thermokarst is supposed to have developed before the Little Ice Age. It is therefore impossible to suppose that ice wedges had developed to form large scale polygonal patterned ground during the Little Ice Age as interpreted by Friedman *et al.* (1971). On the basis of the thickness of new peat layer, it can be supposed that thermokarst began to occur in accordance with the general increase of temperature during the Little Optimum in the beginning of the Middle Ages. We should also consider the disturbance of nature, especially the destruction of vegetation, through human settlement during this period.

Consequently, the development of bogs has been very sensitive to relatively moderate climatic and/or environmental change during the Holocene. This means that the central highland of Iceland occupies a critical geographic region for the development of permafrost corresponding to the southern margin of the discontinuous permafrost region.

Friedman *et al.* (1971) introduced the description of field observation by a teacher who has frequently visited the bogs in the central highland: the typical palsa which existed in the 1920's had almost completely disappeared by the 1950's. Present palsas have been formed during the 1960's and 1970's. Even at present, therfore, it can be observed that some palsas are newly formed, while others are disappearing in the same bog. This means that there is a cyclic development of palsas without any macroclimatic cause.

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## References Cited

Friedman, J.D., Johansson, C.E., Oskarsson, N., Svensson, H., Thorarinsson, S. and Williams, R. S. Jr. (1971): Observations on icelandic polygone surfaces and palsa areas. Photo interpretation and field studies. *Geogr. Annal.*, **53A**, 115-145.

Kaldal, I. (1978): The deglaciation of the area north and northeast of Hofsjökull, Central Iceland. *Jökull*, **28**, 18-31.

Larsen, G. and Thorarinsson S. (1978): $H_4$ and other acid Hekla tephra layers. *Jökull*, **27**, 28-46.

Schunke, E. (1975): Die Periglazialersheinungen Islands in Abhängigkeit von Klima und Substrat. *Abh. Akad. Wiss. Göttingen*, **Nr. 30**, 273 S.
Thorarinsson, S. (1951): Notes on patterned ground in Iceland. *Georgr. Annal.*, **33**. 144-156.
—— (1956): On the variations of Svinafellsjökull, Skaftafellsjökull and Kviårjökull in Oraefi. *Jökull*, **6**, 1-15.
—— (1964): On the age of the terminal moraines of Brũarjökull and Hålsajökull. A tephrochronological study. *Jökull*, **14**, 67-89.
Washburn, A.L. (1979): *Geocryology. A Survey of Periglacial Processes and Environments.* Arnold, London, 406p.