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THE STRUCTURE AND MORPHOLOGY OF MINEROGENIC PALSAS IN NORTHERN NORWAY

Abstract

Northern Fennoscandia belongs to the zone of sporadic permafrost. In the investigated area in northern Norway the outer coastal region has an annual mean temperature of 1—3°C, while the inner fjord region has a temperature around 0°C. The most continental area is in the southeast where the mean annual temperature varies between -2° and -3°C. Where the mean annual temperature is below 0°C palsas are numerous in bogs. In the more continental region, permafrost has been found even outside bogs, though little is known about its areal extent. From airphoto analyses and field work a morphological classification of palsas in different main types has been possible. Palsa plateau: low palsas 1.0—1.5 m high, covering areas from 1000 m² to 1 km². A thin peat layer and a mineral core with low clay and silt content. Esker palsa: ridges 2—6 m high and 50—500 m long, parallel to the bog inclination. A mineral core of a clayey silt and fine sand. String palsa: ridges 1—2 m high and 25—100 m long, perpendicular to the bog inclination, develop often from fen strings and are normally built of pure peat but can have a mineral core if the peat layer in the bog is thin. Conical palsa: 2—6 m high with a circular to oval basal circumference. Mostly pure peat palsas with no minerogenic core. Palsa complex: large palsa areas of different types and stages of development. Heavy erosion and disintegration occur close to growing and newforming palsas. The height varies from 1—9 m over the bog surface. Best developed when a thin peat layer covers a mineral core with a high clay and silt content. The grain size distribution in the minerogenic core is usually a clayey silt with a clay content between 10—30% and silt between 40—60%. In palsa plateaus, however, the clay content is often no more than 2—6% and fine to medium sand constitutes 60—80%. The ice (water) content largely exceeds the capillary capacity of the soil. In a section through a palsa complex the following values of the water content were measured: 36, 67, 87, 114, and 178% of the dry weight of the soil.

Palsas are generally considered to have a peat cover which insulates the frozen corele during the summer. The physical processes, however, are the same whether the palsa formation takes place in a peat bog or in a pure mineral soil. The missing peat layer must then be compensated for by a lower summer temperature.

Northern Fennoscandia, which includes the northern part of Finland, Norway and Sweden, constitutes a boundary area of the extensive Eurasian permafrost zone. In spite of its northern position (Fig. 1) Fennoscandia belongs to the zone of sporadic permafrost (BLACK, 1954) or what is also called "the southern fringe of the discontinuous permafrost zone" (BROWN, 1967).

In this area permafrost occurs only in small scattered areas separated by wide regions with no permafrost at all. The occurrence of permafrost is primarily a response to climatic conditions. Within the investigated region climate is a very complex factor with great influence on the distribution of permafrost. In the outer coastal areas with profound maritime influence, the annual mean temperature is between 1° and 3°C and consequently no permafrost is found. The inner fjord region has an annual mean temperature that varies around 0°C. Here permafrost is general in bog areas.

In the most continental region in the south and southeast the mean annual temperature varies between —2° and —3° C and permafrost is ubiquitous in bogs. Even

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outside bog areas permafrost has been found frequently though very little is known about its areal extent.

The Fennoscandian countries have since long been considered a key area for investigations of the special features of permafrost that develop in bogs in the sporadic permafrost zone. Probably the first scientific description of these phenomena was made by an Icelandic glaciologist, SVEINN PÁLSSON, in a diary from his travels in 1792 in the Icelandic highland N of Langjökull. He writes (quoted from S. THORARINSSON, 1951): "The so called 'flas' are morasses covered with numerous sedges, but differ from other bogs in that hummocks of various shapes, often close together, rise everywhere on them between the pools. These hummocks are quite level, dry and wind-worn on the top, though without stones, but their sides are perpendicular and full of fissures. The soil in them seems to resemble peat soil but is much looser and mixed with sand. These hummocks are called 'rusts' and make the bogs look like cemeteries full of grave mounds. Nothing is known of how they are formed, but the winter frost and the thawing of the ground in spring are most likely contributing to their formation on soils of varying density". The Icelandic word *rust* means a ruin and was probably used because of the resemblance with ruins of Icelandic turf houses (THORARINSSON, 1951).

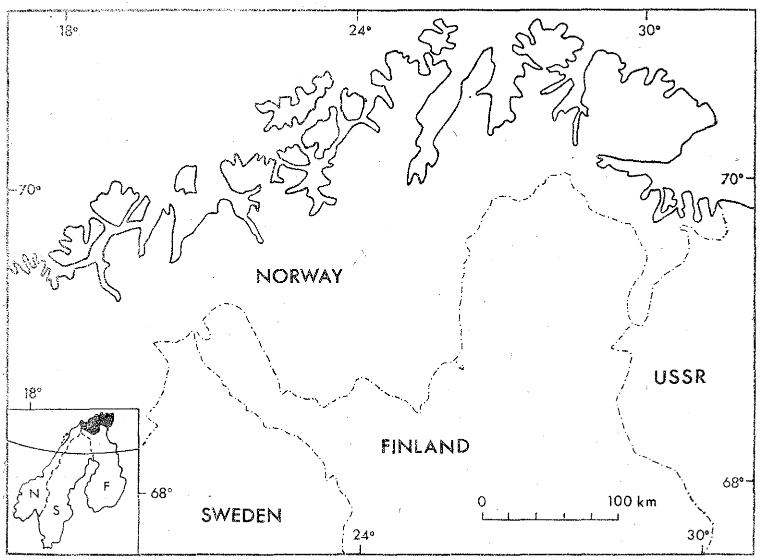

Fig. 1. The investigated region in northern Norway

At the beginning of the 20th century some Swedish scientists (FRIES and BERGSTRÖM, 1910) made a description of a bog in northern Sweden with a peculiar hummocky morphology. These hummocks were called *palsar* (sing. palse), which was the name used by the local Finnish speaking population. Later the form pals (in sing.) and palsar (in plur.) have been used in Swedish texts. In English the form palsa has been adopted. The word *palsa* is of Lappish-Finnish origin and means a hummock with a frozen core, rising out of a bog (SEPPÄLÄ, 1972).

According to FRIES and BERGSTRÖM (1910) the palsas were exclusively built of peat and their upheaval was mainly due to a transport of peat from the surrounding bog underneath the palsa when the bog froze. The initial stage in palsa formation was a wind-blown undulating bog surface with an uneven snow cover. Where the snow cover is thin, the frost penetrates deeper and raises the bog surface. The small hummock thus formed is swept free of snow the following winter with a still deeper penetration of the frost and so on (FRIES, 1913).

It was not until the works of TABER (1930) and BESKOW (1935) on the formation of segregated ice in fine soils, and the heaving of these soils due to the accumulation of ice lenses that a new approach to palsa formation was taken. It became evident that the heaving of palsas has the same cause as the heaving of mineral soils namely the formation of segregated ice in the palsa body.

Physically there are no differences whether the ice segregation takes place in a minerogenic soil or in a peat soil (G. LUNDQVIST, 1951, 1953). In Fennoscandia palsas with a minerogenic core and a cover of peat have been described by i.a. RUUHIJÄRVI (1960), SVENSSON (1962, 1964, 1969), WRAMNER (1965, 1972), and ÅHMAN (1964, 1967, 1969, 1975).

Within the investigated area in northern Norway peat palsas as well as palsas with a mineral core and peat cover are numerous. In the southwestern part of this area peat palsas are most common, whereas palsas with a minerogenic core occur only in locally favourable places. Towards the north a gradual transition to palsas with a mineral core takes place. In the inner fjord region, where the annual mean temperature is just below 0° C, this kind of palsas are totally dominant. Purely minerogenic palsas with no peat at all have so far not been found in Norway. SVENSSON (1969) describes what is probably collapsed forms of this kind of palsas, and similar variants have been observed in a few other places. These areas have all a severe climate with a mean annual temperature between −3° and −4° C at an altitude of ca. 500 m above sea level.

Airphoto analysis has proved to be a useful tool in detecting palsas. On airphotos boggy areas reveal themselves as very distinct regions depending on the specific pattern of small ponds and peat formations which are so characteristic of palsa areas. In this way the regional distribution as well as a morphological classification of the palsas have been possible. Furthermore, the airphotos have been used to select the special sites where field investigations have been considered necessary. On the basis of the knowledge derived from field investigations and airphoto analysis the following classification of palsas in main types is suggested.

PALSA PLATEAU

Palsa plateaus are normally 1.0 −1.5 m high and cover areas from 1000 m² to 1 km². The sides are steep, almost vertical, whereas the upper surface has an even, gently undulating, almost horizontal extension. A few water filled hollows, thermokarst depressions, are the only irregularities (Pl. 1).

The peat cover is usually thin, often no more than 50—75 cm. Beneath the peat is a sediment where fine- and medium sand makes up 60—80%. The clay content is normally no more than 2—6% and the rest is silt. The low height and great areal extent of the plateau indicate a thin but even distribution of the frost susceptible soil, where the amount of water is limited. Palsa plateaus are no doubt the most common palsa type in the investigated area.

ESKER PALSA

Esker palsas consist of long ridges, 2—6 m high and 50—500 m long, with their long axes parallel to the bog inclination (Pl. 2). Here and there palsas of this type occur in wide palsa bog areas. The palsa is clearly connected with the drainage system in the bog. This is easily discernible on airphotos due to the grey-tone contrasts, which in their turn are caused by vegetation differences between the waterlogged drainage-course and the drier bog. The palsas closely follow the winding drainage pattern for several hundreds of metres. Best developed palsas of this kind have proved to consist of minerogenic material with a peat cover 0.5 to 1.5 m thick.

STRING PALSA

String palsas consist of 1—2 m high and 25—100 m long parallel ridges, the long axes of which are perpendicular to the bog inclination. This kind of palsas are closely connected with normal fen strings. It might then be expected that this kind of palsas should only occur in the outmost zone of palsa formation. This is not the case, however, and string palsas have been found all over the investigated region. In extensive bogs where both strings and palsas occur, the gradual trasition from one type to another can be detected. Normal fen strings are always made up of peat only, and string palsas often have the same composition. If, however, the peat layer in the bog is sufficiently thin, minerogenic sediments often take part in the heaving of the palsa.

CONICAL PALSA

Conical palsas are the classical palsa type, *sensu stricto*, with a height of 2—6 m and a circular to oval basal circumference (Pl. 3). According to literature on the subject, this is the most common palsa type but in the investigated area this is not the case. On the contrary, it is rather uncommon. Best developed it seems to be in the southern fringe of palsa formation, where the peat accumulation in the bogs is thick, as pure peat palsas. If minerogenic soils take part in the palsa formation, more elongated or complex forms are normally developed.

PALSA COMPLEX

Palsa complexes are formed by large connected palsa areas of great variation. Individual palsas are hardly discernible, but palsas of different shapes, types and in various stages of development have grown together, forming an alternating and morphologically very complex formation. Heavy erosion and disintegration of the palsa occurs close to areas where growing and new forming palsas are located (Pl. 4).

This kind of palsa seems to develop most frequently in wide shallow bogs, where a frost susceptible soil is covered by a thin peat layer. The greater part of the upheaval is caused by the formation of segregated ice in the soil. The peat acts as an insulating cover to protect the frozen core. Palsas with a height of 9.0—9.5 m above the bog surface and covering areas several thousands of square metres are not unusual.

THE MINEROGENIC CORE

The minerogenic core has proved to consist of a clayey- silt with some slight deviations. The clay content varies from 5—30% and the main part of the soil is composed of particles with a grain size of 0.006—0.2 mm. Soils with this grain size distribution have in both laboratory and field experiments proved to have an intensive heaving capacity depending on water suction.

The boundary between the peat and the minerogenic soil is very sharp. On the surface of the minerogenic soil a thin layer of gravel and often a few stones and blocks have gathered through frost heaving (Pl. 3). The minerogenic core is intersected by vertical and horizontal ice lenses, which give the soil a reticulate pattern (Pl. 5). The ice (water) content greatly exeeds the capillary capacity of the soil. In the upper part of the core the ice content is often very great, more than 100% of the dry weight of the soil. A section of the core, therefore, have often a "petrografic" fabric (Svensson, 1964). At a depth of 1.5—2.0 m most of the ice lenses are horizontal, and from 5—25 cm thick (Pl. 6). The lenses are normally concentrated to certain levels with an interspace of 50—75 cm. The ice (water) content in the soil shows great variations depending on where a sample is taken. The following values of the content (expressed in percent of the dry weight of the soil) in each sample were recorded: 36%, 67%, 87%, 114%, and 178%.

DISCUSSION

Palsas are generally considered to have a peat cover, more or less developed, on the surface. However, the peat is merely a consequence of the bog environment where the palsa has been developed and has nothing in particular to do with the genesis of the palsa. The effect of the peat is to insulate the frozen core and protect it from thawing in the summer. The most important factor in palsa formation is a soil with high water holding capacity and low heat conductivity in summer. These pre-requisites are mostly available in peat bog areas and therefore palsas are most common in them.

Minerogenic soils, as a clayey silt, have a lower water-holding capacity and a much greater heat conductivity leading to thawing of the soil in the summer. That is why palsas are rare in these soils. If, however, the minerogenic soil is covered by a thin blanket of peat, which is often the case in shallow bogs, extensive palsa complexes can be formed. In such palsa areas the upheaval is due to the formation of segregated ice in the minerogenic soil. The peat blanket only functions as an insulating cover for the frozen core.

Further to the north or at higher altitudes, the peat cover needed for insulating the core might be thinner. At last no peat cover at all will be necessary, and we will have a pure minerogenic palsa. The premises for this type of palsa to develop and

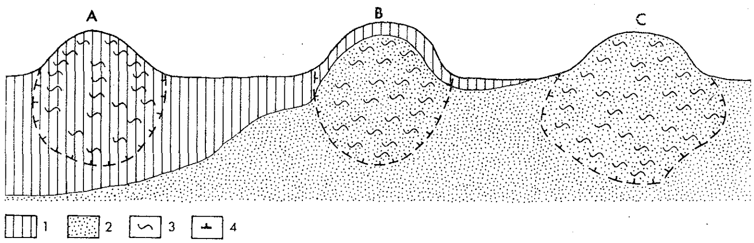

Fig. 2. A skeleton drawing of three different types of palsas

1. peat; 2. silt; 3. segregated ice; 4. permafiost boundary A: purely peat palsa without contact with the mineral bottom iu the bog. The upheaval is due to formation of segrcgated ice within the peat; B: minerogenic palsa with a cover of peat. The upheaval is due to formation of segregated ice in the soil; C: a purely minerogenic palsa with no peat cover. The upheaval is due to formation of segregated ice in the soil. The figure does not pretend that all three types develop close together but will point out the physical similarities in palsa formation in different types of soils under different climatic conditions

continue to exist are a severe climate with low summer temperature to compensate for the missing peat layer. Descriptions of this type of palsas with no peat cover at all are very rare in Scandinavian and Finnish literature. SVENSSON (1969) gives a description of some circular lakes which he thinks are collapsed remnants of frost mounds of a palsa type, where the heaving of the soil has been due to formation of segregated ice.

The rarity of pure minerogenic palsas with no peat cover in the investigated region is undeniable. As this kind of palsas are more sensitive to a warmer climate than peat-covered ones, the warming of the climate, which has taken place during the first half of the 20th century, might be sufficient to cause a general collapsing and disappearance.

According to the opinion of the present author, the existence of a more or less developed peat layer on palsas should not be decisive of the nomenclature of this morphological feature. The existence of peat on most palsas is just an expression of the physical processes being most favourable for palsa formation in peat bog areas. However, genetically there is no difference in the physical processes forming a palsa in a peat bog or in a pure minerogenic soil (Fig. 2). In all cases the upheaval of the palsa surface is due to formation of segregated ice within the palsa core.

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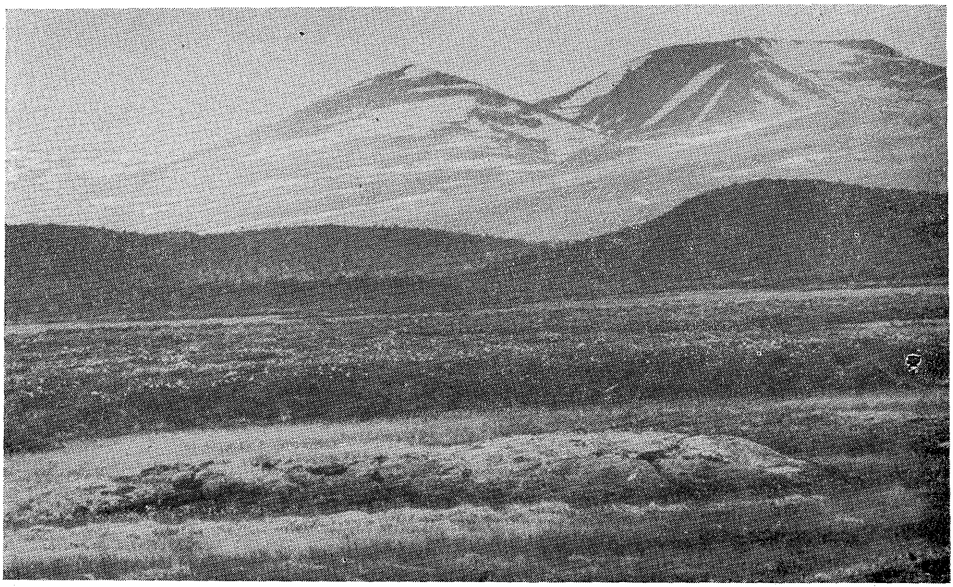
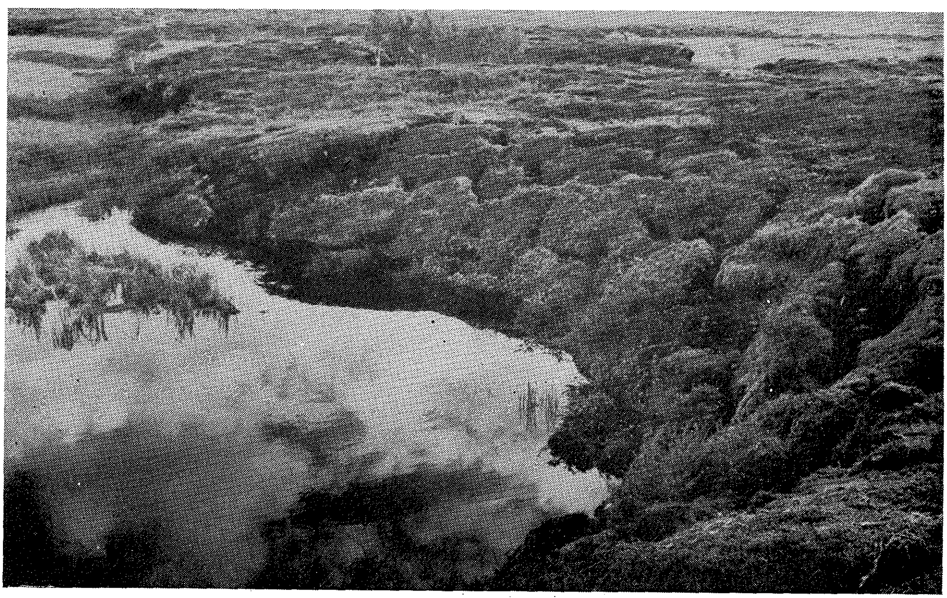
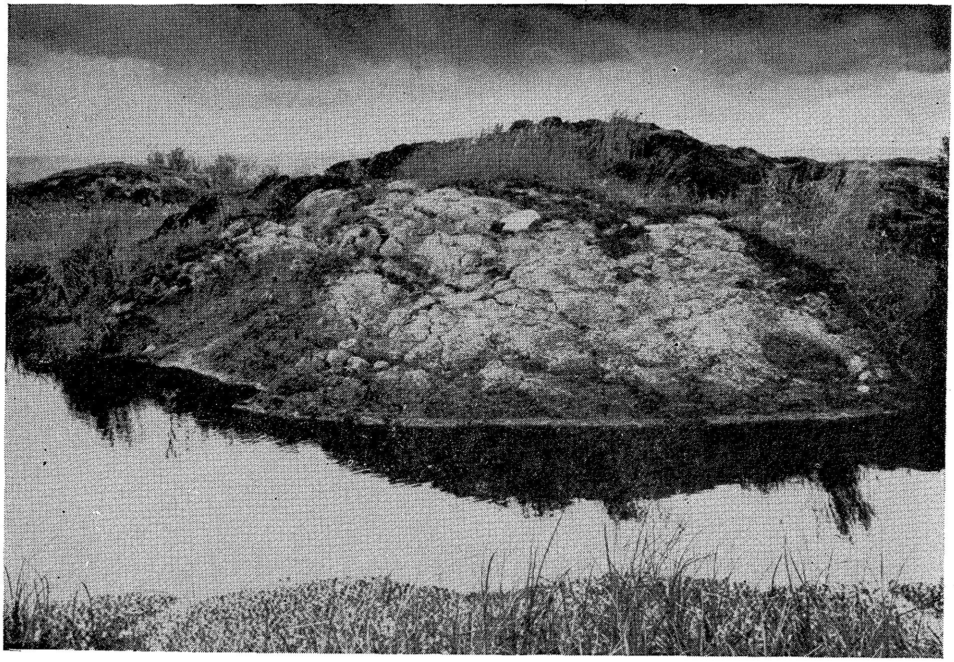


Pl. 1. Palsa plateau with an even, almost horizontal surface. In the foreground a new developing palsa in a thermokarst depression

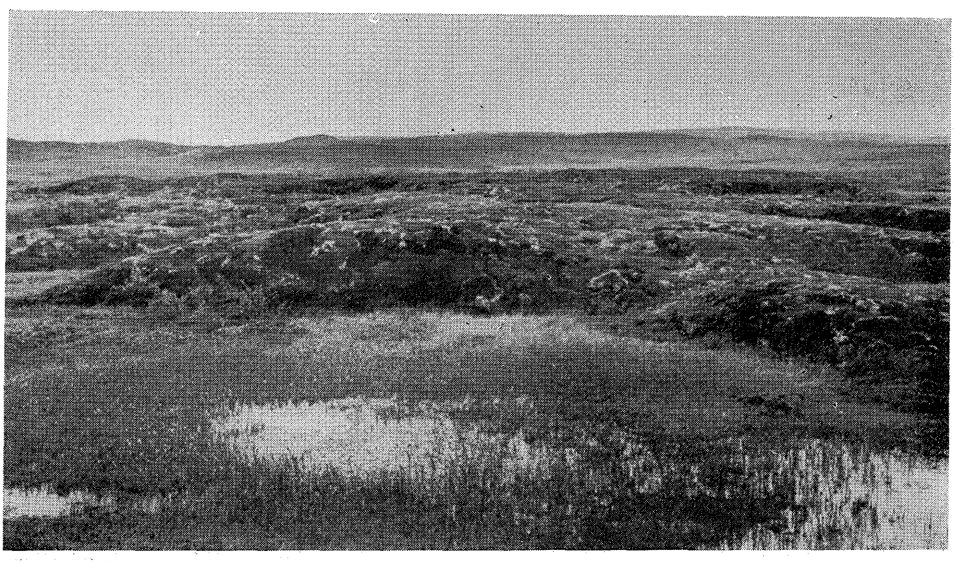


Pl. 2. Esker palsa, a 300 m long and 2—4 m high anastomosing ridge parallel to the bog inclination. In the foreground lagg development through block erosion

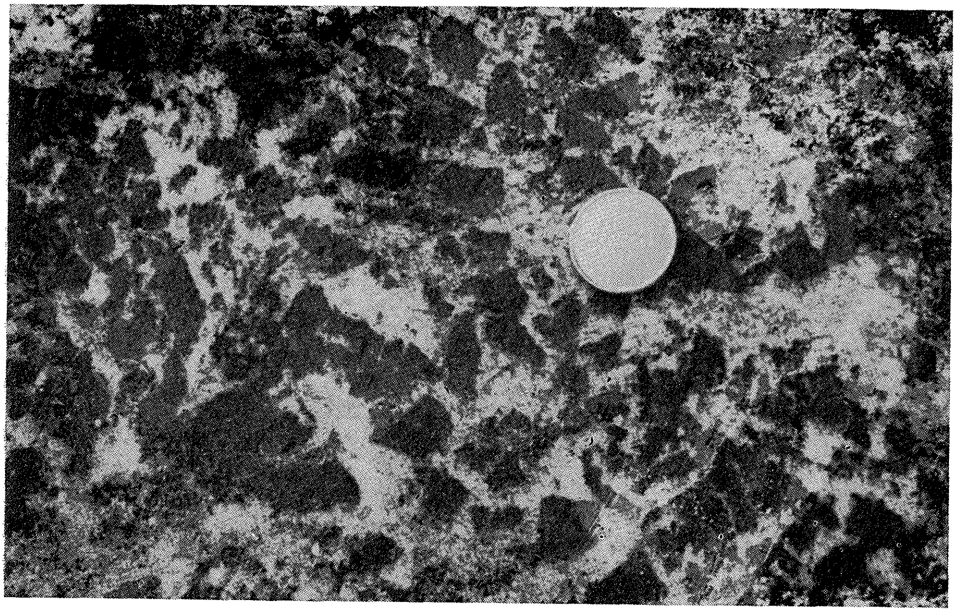


Pl. 3. Conical minerogenic palsa where the peat layer has been burnt away

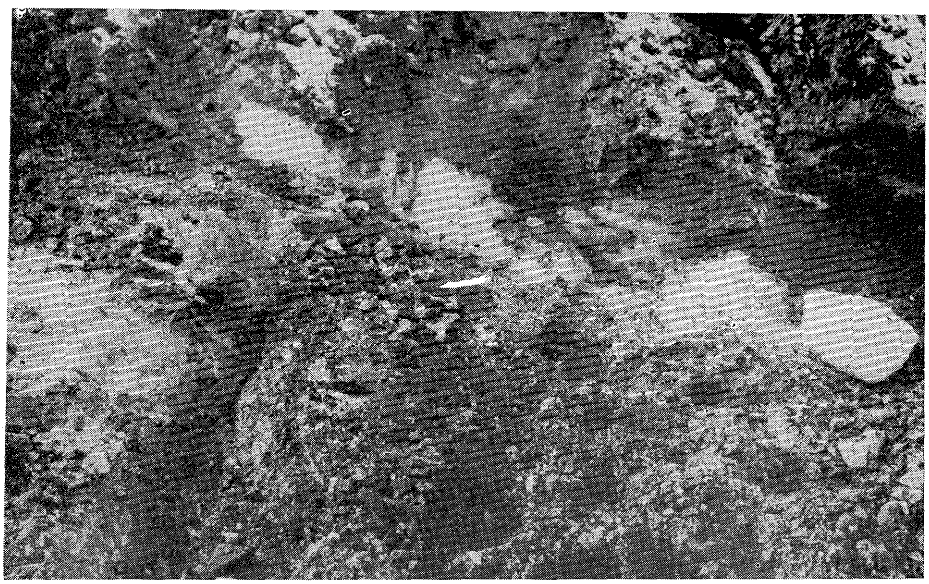
The soil is a clayey silt with a few stones and blocks on the surface. After the peat has disappeared the mineral core is sinking together due to melting of the segregated ice in the core



Pl. 4. Palsa complex, wide areas covered by palsas of different types and stages of development



Pl. 5. The mineral core 1 m below the surface is intersected by ice lenses giving the section i the core a petrografic fabric



Pl. 6. Massive ice layers 20 to 40 cm thick 2.5 m below the palsa surface

The palsa centre is to the left in the picture and the ice layers have been raised due to the upheaval of the palsa (Notice the carpenter's rule to the left)