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A GENETIC CLASSIFICATION OF THE PALSA-LIKE MOUNDS IN WESTERN CANADA

Abstract

In Western Canada, there appear to be five main groups of true palsa-like landforms. *Floating palsas* are developed entirely in peat and float like an iceberg. They exhibit increased ice content due to addition of meteoric water, but are under 60 cm high. *Minerogenic palsas* are developed in a thin peat cover, with the permafrost extending down into the mineral substrate. They represent the bulk of the palsas and their height is dependent on the expansion due to water changing to ice in their core. 2–4 m is typical, with ice contents up to 90% by volume in some layers. *Lithalsas* are developed entirely in a mineral substrate at sites where fen peat cannot develop. They go through a different sequence of stages and can develop a cover of ericaceous peat. A typical mature lithalsa has an average ice content of over 60% in its core, and its height and shape are similar to those of a minerogenic palsa.

Floating peat plateaus differ from palsas by having a flat top rising only 1–2 m above the fen. The icy core is limited to the peat and contains less H_2O than the surrounding unfrozen peat. Air has replaced some of the water so that it floats considerably higher than the floating palsas. Where the icy core of a peat plateau extends down into a mineral substrate, an anchored peat plateau is produced. Since the rate of peat formation on the mound is half that in the fen, the anchored peat plateaus slowly drown and are eventually destroyed without the intervention of a climatic change.

These true palsa-like landforms can be mimicked by other processes, e.g. intrusion of water producing pingos or seasonal frost mounds. Other examples described include permafrost that has subsequently developed in a blanket bog on a slope, and thermokarst caused by melting snow at the foot of slopes in areas of continuous permafrost. These are not considered to be palsa mounds, since palsas are regarded as distinct from other types of permafrost.

The first description of the features now called palsas appears to be by SVEINN PALSSON in 1792 (see THORARISSON, 1951, p. 149). There were periodic studies by others in Finmark (Norway) and Finnish Lappland during the nineteenth century, but it was FRIES and BORGSTRÖM (1910) who introduced the term "palsa" to the scientific literature.

The key features of the concept of palsas were:

1. Occurrence in fens or bogs on valleys floors;

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2. Small mounds (greater than 2 m diameter) of various shapes, usually with a vegetation cover adapted to the better drained conditions on their surface;

3. A core containing perennial ice;

4. The surface of the mounds consisting of peat.

Inevitably a considerable variety of landforms were described as palsas, including what are now called pingos (see for example, PORSILD, 1938). However, when subsequent studies of pingos demonstrated that the icy core was due to intrusion of water under pressure (MÜLLER, 1959; PISSART, 1967; MACKAY, 1973, 1979), pingos became separated as a group of mounds characterized by an intrusive icy core.

The remaining mounds referred to as palsas had a core consisting of lenses of segregation ice interbedded with mineral or peaty soil. ROGER BROWN (1970) separated them into two morphological groups, viz.: the palsas with a very hummocky surface which may reach up to 10 m in height, and peat plateaus which are extensive (up to 10 km2 in area) but only 1–2 m in elevation above the surrounding fen. A landmark study was that of RICHARD ÅHMAN (1977) who carried out a detailed examination of Norwegian palsas. He demonstrated that there was a transition between palsas developed wholly in peat, those developed in shallow peats over silts (minerogenic palsas), and those that were developed entirely in mineral soil. The latter have also been called "cryogenic mounds" (e.g. PAYETTE and SEGUIN, 1979; LAGAREC, 1982) in Quebec, while DIONNE (1978, 1984) used the term "mineral palsa" for these eastern counterparts. Since then, there have been many more studies, some of which examined the processes involved, and some their characteristics and distribution, while others have proposed additional types of mounds to be included under the term "palsa" (e.g. WASHBURN, 1983b; NELSON *et al.*, 1991).

In 1984, the writer and his students commenced a detailed study of the various types of palsas in western Canada with a view to determining their characteristics and relationships. The results have been published in a series of papers (HARRIS, 1993; HARRIS, SCHMIDT, 1994; HARRIS *et al.*, 1992, 1993; HARRIS, NYROSE, 1992). In this paper, the range of landforms in this region that are sometimes called palsas is examined in order to arrive at a genetic classification of these landforms.

METHODS USED

Typical examples of the various types of landforms broadly grouped as being "palsas" were selected at sites which were reasonably accessible the year round (Fig. 1). Each example was mapped and a series of boreholes drilled across the feature. The cores were recovered and PVC access

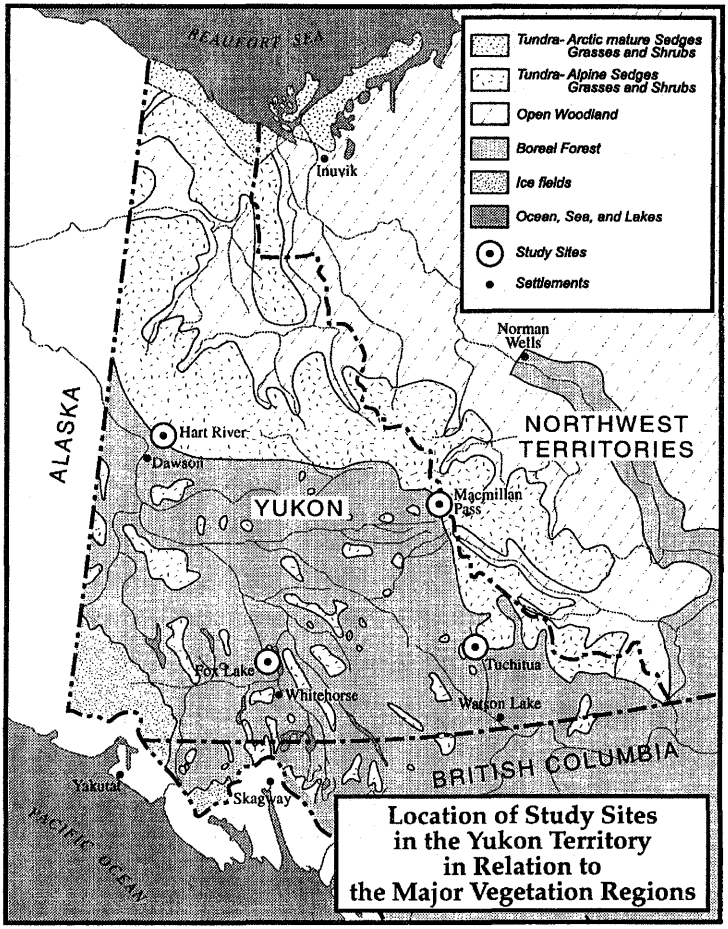

Fig. 1. Location of the study sites in western Canada

tubes, closed at one end, were installed in the holes. Ground temperature cables, (using YSI 33036 thermistors) were placed in these tubes to permit regular monitoring of the ground temperatures.

The cores were taken back to Calgary and the stratigraphy ascertained. The type of peat was determined based on teasing the peat in water so that the plant structures could be recognized. Grain size (pipette method) was determined on the mineral material. The soil water was separated and the wet and dry density determined, along with the moisture content.

Automatic measurements of air temperature and humidity were made by Lakewood data loggers (UL–16) based on observations every 20 minutes, at the key sites. Depth of snow cover was also recorded on all visits.

RESULTS

1. *Specific types of "palsas"*

Floating palsas. These have been described from the MacMillan Pass by HARRIS and NYROSE (1992). They consist of peat floating in a deep water body where a sufficient thickness of peat occurs to permit low mounds to form. Permafrost develops beneath these raised portions although the average height of the floating palsa above the water in the surrounding fen is only about one ninth of the thickness of the permafrost layer (Fig. 2). Perhaps for this reason, they have rarely been identified and studied.

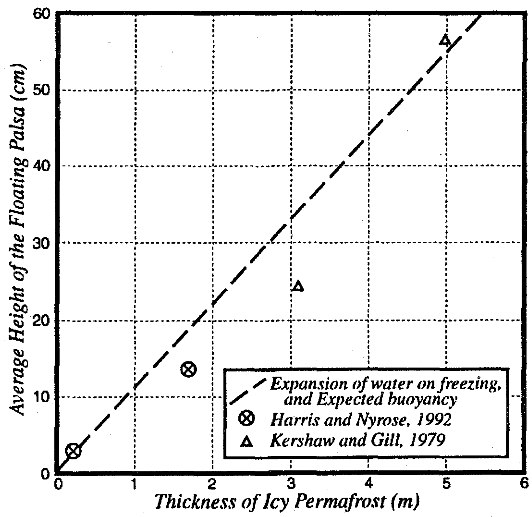

Fig. 2. Comparison of the average height of a mound with thickness of icy permafrost in floating palsas. The figures for average height of the palsas described by KERSHAW and GILL (1979) are based on halving the maximum height reported

The moisture distribution within them shows a significant increase in moisture content in the upper part of the permafrost soon after it forms (HARRIS and NYROSE, 1992, Fig. 13), while the electrical conductivity of the icy layers indicated that the excess water came from the surface precipitation, not the fen. As with other kinds of true palsas, there is a substantial accumulation of excess water in the form of ice lenses in the icy core, especially near the permafrost table.

Minerogenic palsas. If all palsas floated, the 10 m high palsa reported by SCHUNKE (1983) from Tungsten, Northwest Territories would require at least 110 m of peat saturated in perennial ice beneath it. The fen around it would need to be over 100 m deep. Since almost all the peat deposits are postglacial and may have only been forming for 6,000 years (ZOLTAI, VITT, 1990), this is impossible. Furthermore, the permafrost bulb within palsas in western Canada has never been proven to exceed 10 m in thickness, although that at Tungsten is probably thicker. The depressions in which fens form are not usually deeper than 3–6 m. Given these facts, it is not surprising that most palsas consist of fen peat over a mineral substrate. The permafrost bulb forms in the peat and extends into the underlying materials without any difficulties. These palsas are as thermally stable as other permafrost landforms in the same area, and do not show signs of the degradation phase of a cycle that was proposed for similar landforms in Finland (SEPPÄLÄ, 1986, Fig. 8). Instead, the mineral substrate acts as a solid base, so that the height of the mound is proportional to the increase in moisture in the form of ice in the permafrost bulb. The interior of these palsas exhibits the same segregation ice lenses (Pl. 1) as the floating palsas (see SVENSSON, 1964), and they were therefore given the name minerogenic palsa by M. FRIES in FOSGREN (1968, p. 118).

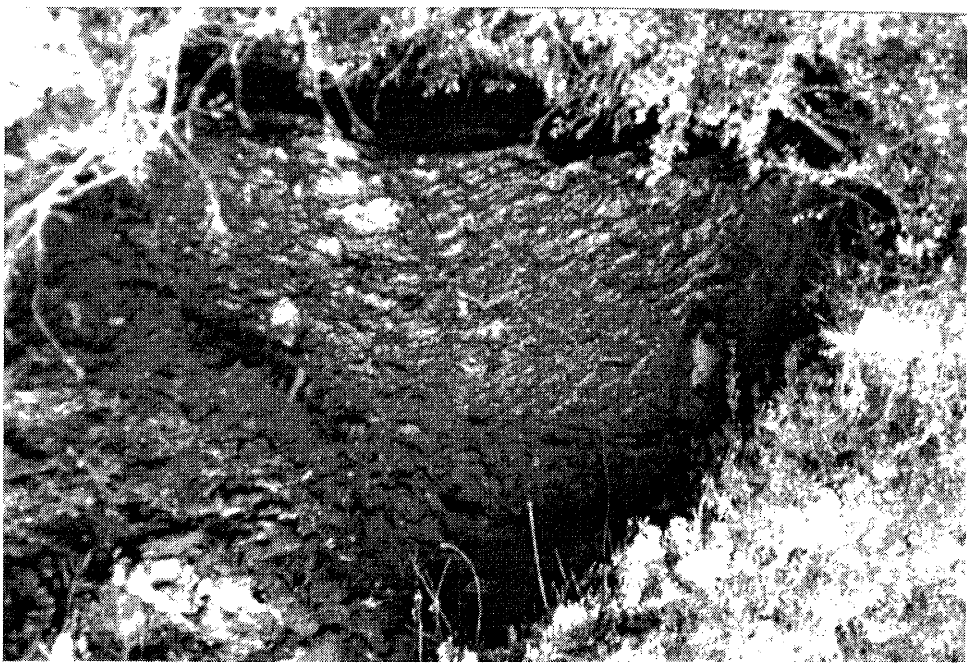

Photo by the author

Pl. 1. Segregation ice lenses and structures in minerogenic palsas at MacMillan Pass

ZOLTAI and TARNOCAI (1971) described a typical cross-section of a wooded minerogenic palsa from northern Manitoba. It had a maximum height of 2.24 m above the water table, and the permafrost bulb was under 5 m thick. The highest ice content occurred in the upper part of the permafrost (94% by volume), emphasizing the role of ice accumulation in the updoming. Their measurements (Fig. 3) suggest that the ice content doubled compared with the moisture content in the surrounding fen, thus producing the 2.2 m uplift from a permafrost bulb just under 5 m thick.

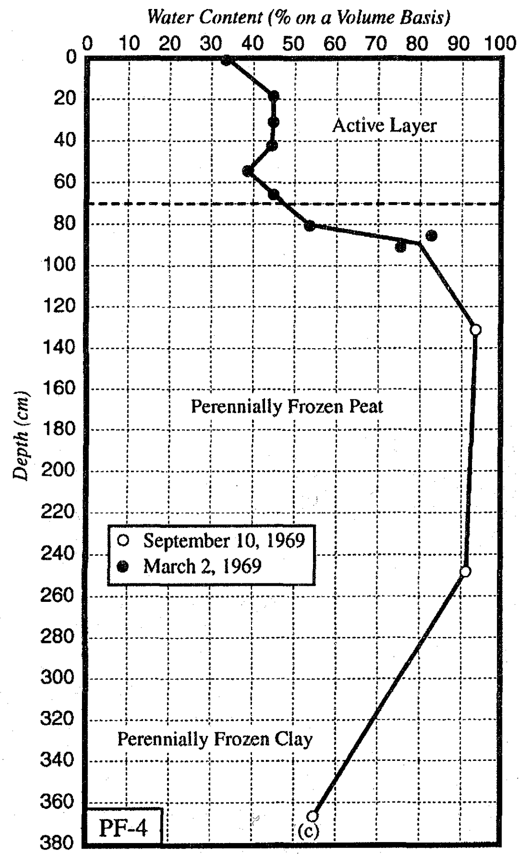

Fig. 3. Water content of the organic and clay layers at PF–4 in the Fall and Winter in a minerogenic wooded palsa in northern Manitoba (Zoltai, Tarnocai, 1971)

Lithalsas. Fosgren (1966) and Åhman (1977) reported that palsas also occurred that were entirely developed in mineral soil. At first they were included in the minerogenic palsas, but clearly, the initial heat exchange processes on mineral soils should be different from those at the surface of peat (Brown, 1968), and so a new name was warranted.

At Fox Lake, Yukon Territory, Harris (1993) examined an palaeontological series of palsa-like mounds developed on mineral soils. They can pass through five developmental stages, commencing with low grassy mounds, followed by invasion by shrubs (*Betula* spp., *Arctostaphylos* spp., and *Salix* spp.) and by *Picea glauca*. The series takes at least 380 years to reach stage V and some of the mounds may be considerably older. The soils on the grassy mounds lack organic matter or an Ah horizon, but once shrubs appear, a peaty layer of leaves is developed and saprophytic lichens move in. This peat can exceed 50 m in thickness before the white spruce shades out the bulk of the shrubs. These mounds can reach almost 3 m in height and contain segregated ice just like minerogenic palsas (Pl. 2). The ice content ultimately reaches 65–70% by volume in the permafrost core,

Photo by the author

Pl. 2. Segregation ice lenses and structures in lithalsas at Fox Lake

which is usually about 5 m thick in the mature stages, and the extra ice appears to be primarily meteoric in origin. The mounds differ from palsas and minerogenic palsas in the absence of aquatic plants, peat fen or sphagnum peat on the surface in all stages. The developmental sequence is different and so, too, will be the heat exchange processes. Accordingly the name lithalsa was proposed for them.

In the Yukon, lithalsas only occur where the precipitation and humidity are too low for peat to develop (Fig. 4) and they are confined to the drier zone in the lee of the coastal mountains from Atlin, B.C. (see SEPPÄLÄ, 1980) north to Carmacks. In stable mounds, height above the surrounding water table matches the volume of extra ice accumulated in the core. When the ice melts, the silts initially retain the same structure, but are gradually eroded along the flanks of the mound, aided by blocks sliding

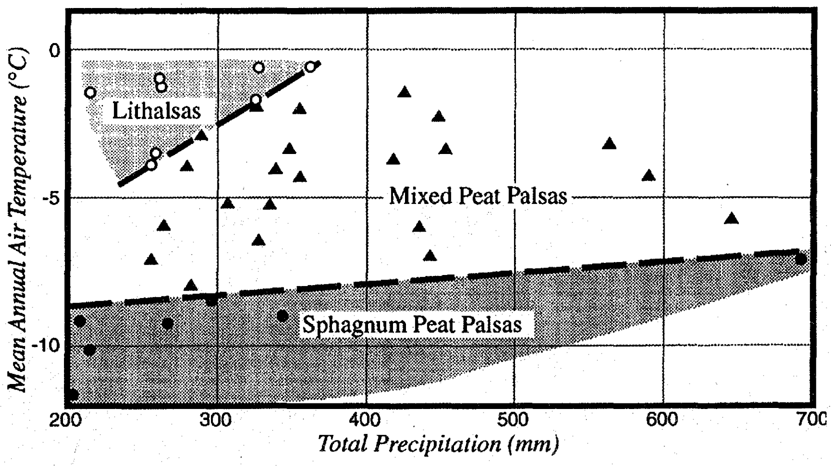

Fig. 4. Mean annual climatic conditions for lithalsas and palsas in the southern Yukon Territory

into the water. When this happens, some of the blocks float until enough air has escaped and been displaced by water.

The distribution of lithalsas in Central Yukon is clearly controlled by climate inhibiting peat growth in marked contrast to the lithalsas (cryogenic mounds or mineral palsas) developed over the marine silts from the Tyrrell Sea along the eastern shores of Hudson Bay (see DIONNE, 1978; PAYETTE and SEGUIN, 1979; LAGAREC, 1982; DIONNE, 1984). The latter develop as soon as the silts rise above the sea because of the exceptional frost susceptibility of these sediments (see ALLARD *et al.*, 1996).

Peat plateaus. BROWN (1970) separated the low, plateau-like, permafrost--cored mounds in Canadian peatlands from the less extensive, higher and sloping-surfaced palsas, and named them peat plateaus. They rise 1–2 m above the surrounding fen, but can extend for 10 km^2. He also recognized that some were developed in peat but in many cases the permafrost extended down into underlying mineral materials.

ZOLTAI (1971) studied the structure of twenty-six peat plateaus in central Manitoba and Saskatchewan, and found that the permafrost did not extend down into a mineral substrate in any of them. He ascribed their updoming to the change in volume of water to ice on freezing and to buoyancy (Fig. 6), but the way he envisaged the latter taking place was not clear. He found no evidence of an increase in moisture content in the permafrost in the peat plateaus. Clearly the height of the plateaus plotted against permafrost thickness shows a different relationship to that of floating palsas (Fig. 2), so a process other than simple buoyancy is in- volved. Since the discrepancy with floating palsas increases linearly with permafrost thickness, the unexplained process has a progressively greater effect with growth of the permafrost core.

HARRIS and SCHMIDT (1994) examined two peat plateaus at Tuchitua, Robert Campbell Highway, Yukon Territory. Both contained the 1,100 year-old White River Ash, so that rates of peat formation on the mound

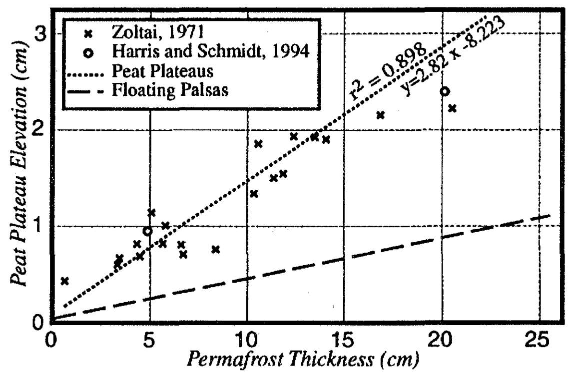

Fig. 5. Discrepancy between the effect of expansion of water on freezing and actual elevation on peat plateaus (data from ZOLTAI, 1971; Table 2, and HARRIS, SCHMIDT, 1994) and floating palsas (Fig. 2)

and in the fen could be determined. The peat plateau at km 166.7 had already commenced the formation of woody peat which is typical of the surface of a peat plateau, by 1,100 years B.P., but it stood almost 2 m above the contemporary surface of the fen. Now its surface is only about 1m above the fen due to peat formation being much slower there. The base of the permafrost lies in the underlying mineral substrate and the peat plateau is slowly drowning; already a small thermokarst pond has developed. This peat plateau is therefore anchored to the substrate and will eventually collapse due to the drowning process. Clearly peat plateaus anchored to a mineral substrate must go through a cycle of growth and decay independently of climatic influences.

The peat plateau at km 166 is developed entirely in peat and is free to float, adjusting its height to allow for the higher sedimentation rates in the fen. It has no thermokarst features although it extends westwards for a kilometre. It is these floating peat plateaus that would reliably indicate climatic warming in the area if that were to occur. At present, they look very healthy, and climatic data from nearby weather stations does not indicate any appreciable climatic change in the last 40 years.

Since peat plateaus consist of peat, ice and air, the origin of the extra buoyancy indicated in figure 5 could be due to air replacing ice in the permafrost. The data shown in figure 8 of ZOLTAI (1971, p. 300) are consistent with this. Figure 6 shows the moisture contents found in two profiles, 5 m apart, at km 167.0, Robert Campbell Highway. The profile

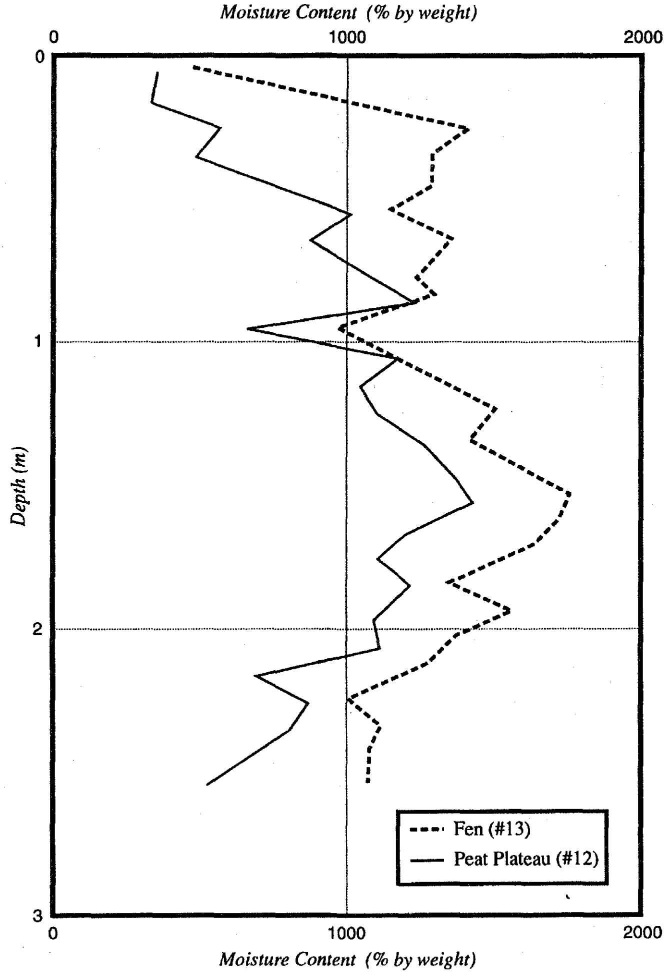

Fig. 6. Comparison of the moisture contents of the fen (#13) and peat plateau (12) at km 167.0, Robert Campbell Highway, Yukon Territory. The profiles are 5 m apart

from the peat plateau contains noticeably less moisture at all levels and the difference is greater than the 9% expansion of water on freezing. This would appear to confirm the decrease in water content in the permafrost profile since the dry densities in the two profiles were virtually identical. The dry density is a measure of the percentage of voids present. The voids can be filled by either air or water, so the best test of whether there is a moisture deficit in the permafrost relative to the fen is to plot the data for moisture content against dry density for all the samples. Figure 7 shows the data for all the samples obtained from km 167.0. The samples from the

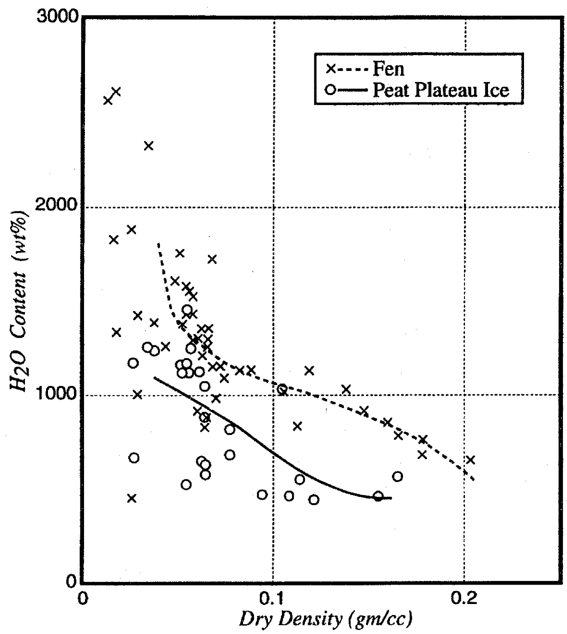

Fig. 7. Comparison of moisture contents in relation to dry density for samples from the fen and the permafrost in the peat plateau at km 167.0, Robert Campbell Highway, Yukon Territory

ice in the peat plateau show 20–40% lower moisture contents than the fen samples for a given dry density. This would seem to confirm a moisture loss after the fen water freezes in a peat plateau. It is therefore the air replacing the moisture which helps to buoy up the plateau to the unexpected heights in figure 5. The mechanism or mechanisms by which this occurs remain to be established.

Palsa "look-alikes": the frost mounds

There are several types of mounds that mimic palsas but are formed in quite different ways. Unless the term palsa is to be used for any mound containing permafrost, these look-alikes must be identified and treated separately. HARRIS *et al.* (1988, p. 60) recommended that these be called frost mounds.

Permafrost plateaus. When permafrost enters the ground, water turns to ice and heaving of the ground surface occurs. This produces a raised surface which mimics a peat plateau. As time passes, moisture is added to the upper layers beneath the permafrost table, producing the characteristic high ice content there (HARRIS, 1988, 1989). This distinguishes the normal permafrost from the peat plateau with its moisture deficit. RADFORTH and BELLAMY (1973) used the term *permafrost plateau* for these features. In the case of the lithalsa studied by ALLARD (ALLARD *et al.*, 1996) from the shores of Hudson Bay in northern Quebec, the structure of the icy layers showed ice surrounding small blocks of mineral soils, as in Pl. 1 & 2.. Unfortunately this same structure occurs in many different kinds of permafrost landforms and so is not particularly valuable in differentiating the various landforms.

Permafrost mounds and hills. NELSON (NELSON *et al.*, 1991, Fig. 13.1) used a photograph of "a dome-shaped palsa" from the MacMillan Pass area, Yukon Territory as a typical palsa "whose relief is believed attributable solely or predominantly to the accretion of segregation ice." Unfortunately, this peaty mound occurs appreciably above the valley on the lower slopes of the mountain side in an area of knob and kettle topography. The location is marked by the appearance of springs and lies in alpine meadow tundra, just above present-day tree-line. The 1,200 year-old White River Ash lies just below the peat surface and overlies a bed of logs in the peat. Clearly, this is in the wrong situation for a classical palsa and represents a deposit that has been accumulating for thousands of years under varied climatic regimes.

A series of boreholes across the mound (Fig. 8) show that it actually consists of a 3–5 m blanket of peat that has grown over a hummocky till

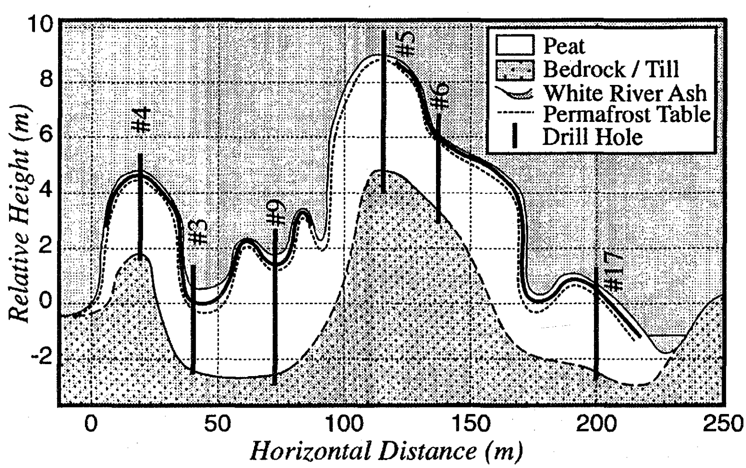

Fig. 8. Cross-section of the palsa-like mound in the MacMillan Pass, Yukon Territory

surface which originally had a local relief of about 9 m. The growth of the peat has increased this relief to nearly 11 m. The peat contains wood fragments with one log measuring about 30 cm in diameter. Since the site now lies above tree-line, some of the peat was formed under a warmer climate than now. The peaty landform would be classified as being either a blanket bog, a hanging bog, or a spring fen, according to MAGNUSSON (MAGNUSSON *et al.*, 1957), and as a hanging or spring mire (RADFORTH, BELLAMY, 1973). These are rare in Canada since few places receive sufficient precipitation, but the MacMillan Pass has the highest precipitation in the central and northern Yukon Territory (>700 mm/a; WAHL *et al.*, 1987). In the last 1,200 years, the climate appears to have cooled and permafrost has spread through the peat and into the underlying mineral materials. Mean annual air temperature today is estimated to be about −7°C. Thus these mounds are certainly not developed by ice segregation, even though they contain segregation ice. The location, shape of the material and late arrival of permafrost argue against them being classed as minerogenic palsas.

Superficial thermokarst. Some low mounds are found at the bottom of a slope in the Hart River Pass, east of the North Fork Pass at km 78 on the Dempster Highway. They are up to 2 m high and 15 m long, and occur in an area of continuous permafrost. Superficially, they look like lithalsas. The parent material is silt loam with under 5 cm of organic matter at the surface. Similar mounds have been described as being palsas by WASHBURN (1983a) who cored one at Resolute, N.W.T.

In the Hart River Pass, two boreholes were made, one in the centre of a low (c. 80 cm high) mound that was about 15 m across, and one in the surrounding low area (Fig. 9). The drill hole in the mound passed through a thin thawed layer into frozen silty loam with thin icy layers. These

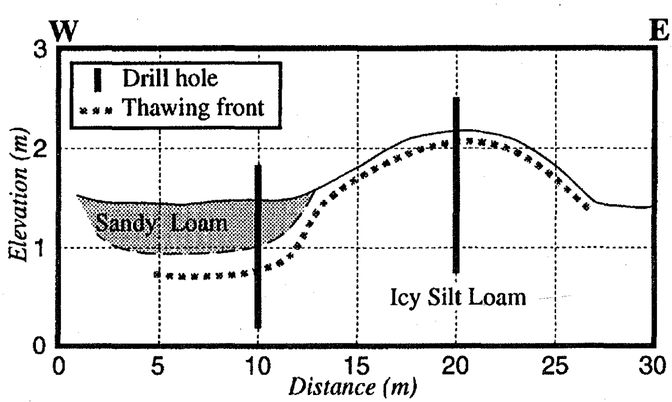

Fig. 9. Stratigraphy and thickness of the thawed layer in and around the mounds on July 6, 1996, Hart River Pass, Yukon Territory

continued to at least 140 cm depth. The drill hole in the lower area surrounding the mound showed 40 cm of sandy loam with horizontal bedding overlying the same silty loam as in the mounds. The thawed layer was over three times as thick, presumably due to the effects of meltwater from the snowpack upslope bringing in extra heat. This same water probably washes out the fines from the surface layers and leaves behind the more sandy material. The conductivity of the soil water in the thawed layers in the swales is much lower than in the profiles in the mound and also in the frozen silty loam beneath the depressions.

The depressions form a network with the mounds as islands. Upslope the channels coalesce into a shallow valley, down which waters move in the early summer as the winter snows melt. Thus the mounds appear to represent the unaffected permafrost between areas of shallow superficial thermokarst. As such, they are clearly not palsas.

CONCLUSIONS

In Western Canada, there appear to be five main groups of true palsa-like landforms:

1. **Floating palsas** developed entirely in peat and floating like an iceberg. Even the larger ones are low since 8/9ths of the permafrost lies below the water level. They exhibit increased ice content due to addition of meteoric water from above.

2. **Minerogenic palsas** developed in thin fen peat. The permafrost extends down into a mineral substrate which anchors it. The height of the palsa depends on the expansion of water changing to ice in the permafrost developed in both peat and mineral host materials, so that 2–4 m is typical. Ice contents can reach 90% by volume in some layers.

3. **Lithalsas** developed in an entirely mineral substrate. In Western Canada they are formed in climates where fen peat does not form. They can go through a series of stages, and a mature lithalsa typically contains >60% ice by volume in its core. In the stage characterized by *Betula glandulosa* and ericaceous shrubs, the quantity of litter may be such that a peaty surface layer may form.

4. **Floating peat plateaus** with a permafrost core lying completely in peat. These float higher than floating palsas, apparently due to replacement of some of the ice in the permafrost by air, hence increasing their buoyancy.

5. **Anchored peat plateaus** where the permafrost core extends down through the peat into the mineral substrate. They have a lower moisture content than the surrounding fen but are anchored to the mineral material

beneath. Since the rate of formation of peat in the fen is about twice that in the mound, the mound eventually drowns and is destroyed without the intervention of a climatic change.

Several other processes can form mounds that mimic these, of which pingos and seasonal frost mounds are the best known. However, formation of permafrost in the ground can produce localized heaving, permafrost can develop in pre-existing unfrozen mounds, or superficial thawing of continuous permafrost by runoff can cause confusion if their mode of formation is not carefully studied.

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