THIRD INTERNATIONAL WORKING-MEETING ON SOIL MICROMORPHOLOGY
WROCŁAW, 1969

ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH 1972 z. 123

The micromorphology of fossil soils in the Cypress Hills, Alberta, Canada

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INTRODUCTION

The Cypress Hills in southeastern Alberta consist of a plateau that descends gradually from an elevation of 1,463 m at its western end, to 1,384 m at the Alberta-Saskatchewan border (Fig. 1). Steep slopes separate the plateau from pediments that slope away toward the surrounding Great Plains. These pediments are erosional surfaces of low gradient cutting across soft rocks of Upper Cretaceous and Tertiary age and ve-

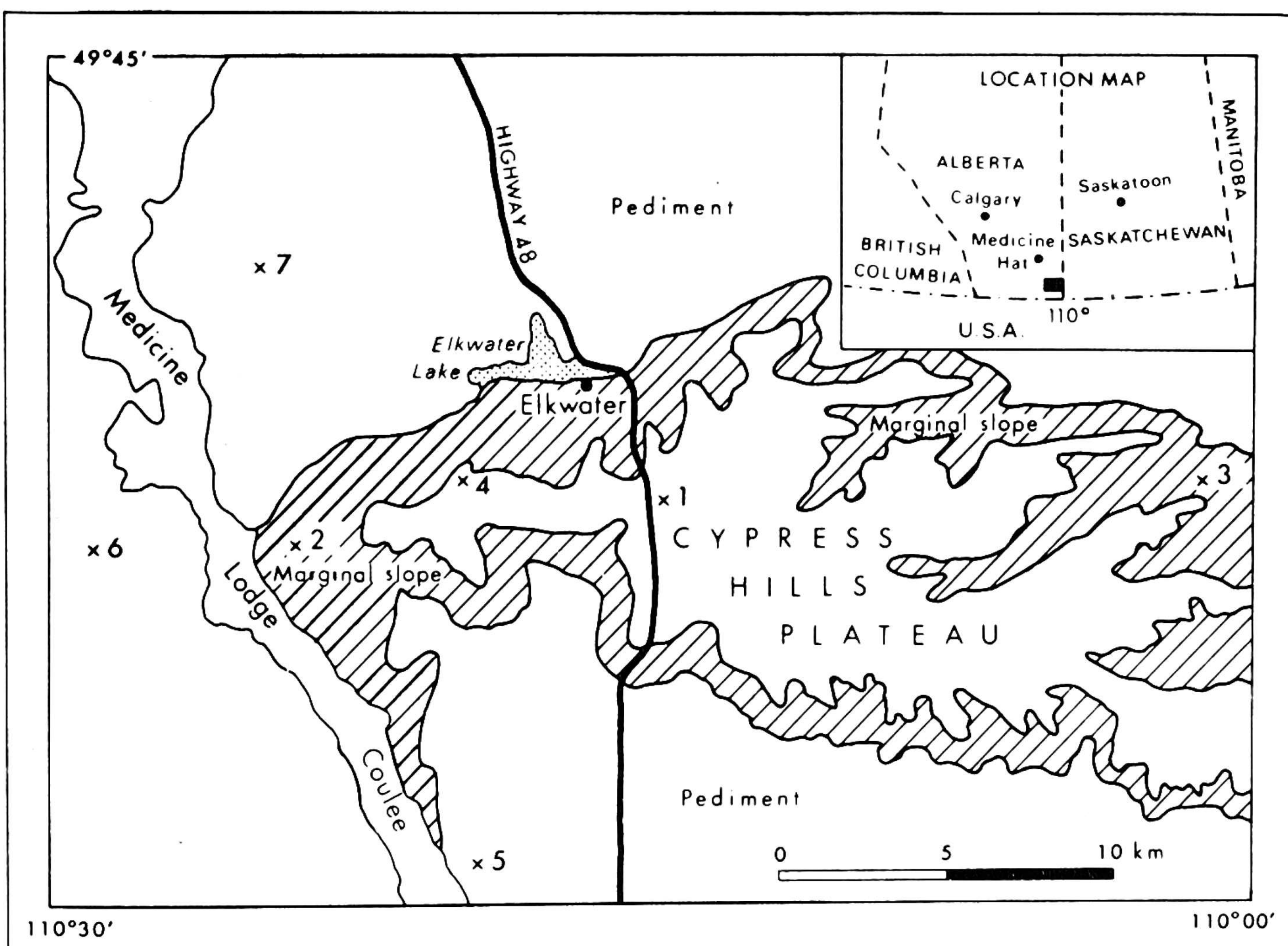

Fig. 1. The Alberta section of the Cypress Hills with the location of the profiles.

neered with a thin layer of alluvial and colluvial material. The plateau is capped by the Cypress Hills Formation composed of coarse gravels of Oligocene or Pliocene age. This gravel is covered by about 30 to 60 cm of loess-like material. Plateau and most of the southern pediment rose above the limits of the Wisconsin glaciation, but it is possible that they were overrun by glaciers during an earlier glacial stage. The geomorphology and pedology of the area not covered by Wisconsin ice have been investigated by the first author [6-8].

The Cypress Hills experience a semi-arid climate with the major part of the precipitation falling in the summer months. The average annual precipitation is about 460 mm on the plateau but decreases to 300 mm on the southern pediment. Mean annual temperatures range from 2°C on the plateau to 5°C towards the lower areas in the south. The climatic differences are reflected in vegetation and soils. Most of the area is under grass, but there is a change from mixed-grass and fescue prairie on the plateau, to short-grass prairie on the southern pediment. In the same direction, soils change from black and dark brown chernozemic to brown chernozemic and, finally, solonetzic (classification system proposed by the National Soil Survey Committee of Canada [12]. The colour differences are closely related to changes in organic matter content reflecting shifts from meso- to xerophytic vegetation.

The chernozemic soils are characterized by a fairly thick A1 horizon overlying a brown, prismatic B2 horizon. In the solonetzic soils is the prismatic structure of the B2 horizon more developed, the ped surfaces exhibiting pronounced staining by organic matter.

The marginal slope on the northern and southwestern side of the plateau are covered by dense forests composed of *Pinus contorta, Populus tremuloides* and *Picea glauca*. The associated soils meet the requirements of the Gray-Wooded Group in which a thin organic A1 horizon is underlain by a light-coloured platy A2 horizon depleted of clay, and a dark brown B2t horizon with blocky structure and high clay content.

Polygenetic and buried soils are found in the bedrocks as well as in the surficial mantle of loose materials. They range in age from Upper-Cretaceous to Holocene. With age, their properties differ increasingly with those of modern soils. Therefore, the interpretation of the oldest paleosols is no more than tentative.

The micromorphological interpretation was carried out by the second author. Thin sections were prepared according to methods described by Altemüller [1, 2] and Jongerius and Heintzberger [5]. Terms proposed by Brewer [3] have been added to the descriptions where the observed features met the necessary requirements.

HOLOCENE

Minor changes in climatic conditions caused significant fluctuations in the forest-prairie boundary on the Cypress Hills plateau, and the accompanying changes in soilforming processes produced polygenetic soil profiles. About 4,000 years ago during the Climatic Optimum, climatic conditions favoured tree growth, and forests covered those parts of the plateau where the loess-like mantle is sufficiently thick to provide space for root development [8]. The modern chernozemic soil of these sites is developed from the A2 horizon of an ancient forest soil (profile 1). The upper part of the fossil A2 horizon has been appreciably disturbed by the present grass vegetation, but the chernozemic B2 horizon is weakly developed and the platy structure of the former forest soil has been preserved. The underlying B2t horizon at about 40 cm depth was also little affected and resembles the B2t horizon of modern Gray-Wooded soils.

The fossil platy structure of the surface soil was not evident in thin section. The crumbly micro-structure of the chernozemic A1 horizon dominates, changing to a spongy micro-structure lower down. Most skeleton grains in this horizon range in size from 30 to 60 micron but larger particles occur and the grain-size distribution is not typical for loess. The content of weatherable minerals such as felspar and mica is high.

The matrix consists of dispersed humus, clay and silt, and fills the intergranular space incompletely. Clay-humus skins (organo-argillans) less than 10 micron thick occur in voids. The organic material is associated with the present chernozemic soil and decreases downwards. Iron-oxide concretions are relatively abundant. They contain skeleton grains and are commonly of sedimentary origin. There is no continuous horizon of calcium-carbonate accumulation associated with the surface chernozemic soil, but there are traces of secondary calcium-carbonate near plant roots.

The matrix of the underlying fossil B2t horizon also consists of fine silt and clay, but here the plasma occurs as a porous groundmass in which the skeleton grains are embedded (intertextic). Much of the plasma has a preferred orientation developed in two directions at right angles to each other (right bimasepic fabric, Fig. 2). This is presumably due to the effects of pressures and tensions produced by wetting and drying of the clay which consists dominantly of montmorillonite.

Illuvial clay skins composed of a mixture of clay minerals and iron oxides are scarce and associated with pores (channel ferri-argillans) in the upper part but become more abundant lower down the profile. There are many iron concretions, some of which were formed *in situ*. A few of the latter exhibit a concentric fabric (sesquioxidic concretion).

During this mid-Holocene period when forests were more extensive than they are today, landscape stability prevailed in the Cypress Hills and a soil was formed on the surface of alluvial fans. This soil profile

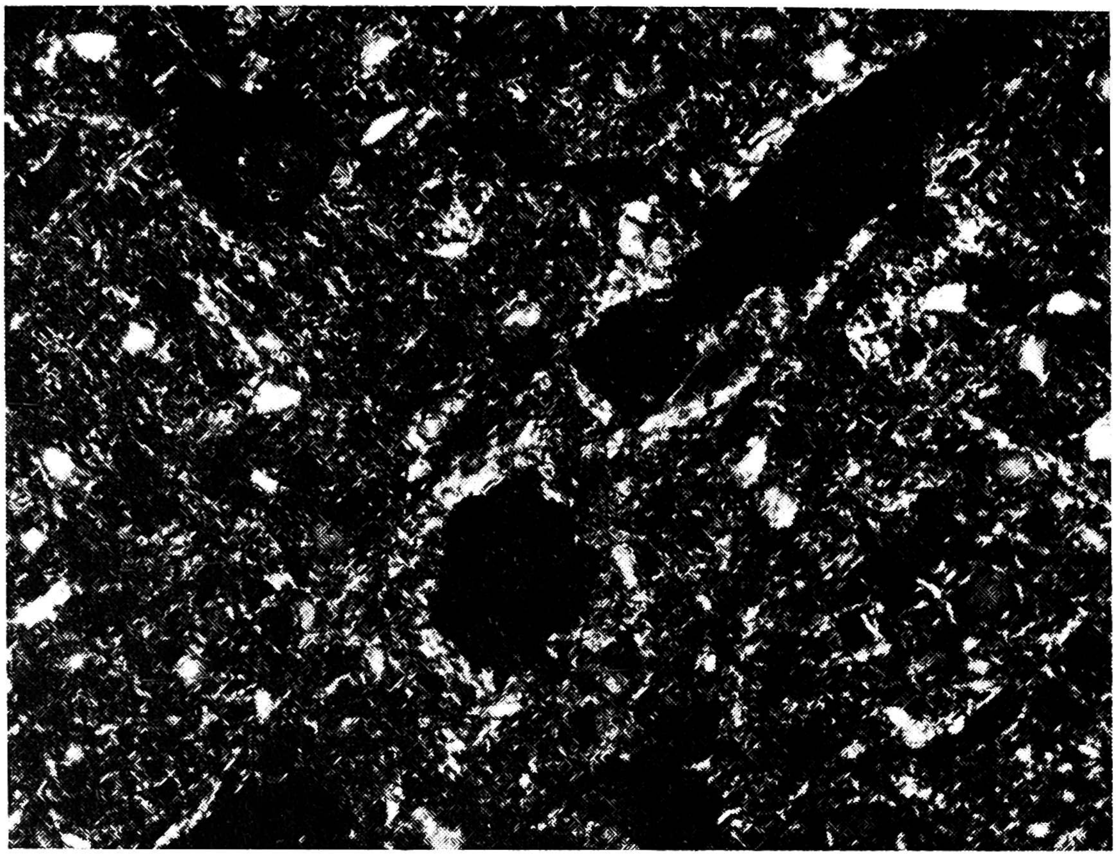

Fig. 2. Weak right bimasepic plasmic fabric with a channel ferriargillan in a B2t horizon of a Gray-Wooded soil of mid-Holocene age. Vertical thin section M. 49 under crossed polarizers. ×42.

has been buried by colluvial material in the subsequent period of erosional instability. Colour and structure suggest that the buried soil was formed under somewhat more humid conditions than the surface soil at the same site, but there is an analogous grade to lighter-coloured chernozemic soils and solonetzic soils from the plateau towards the south. Apparently the climatic and vegetational zones were similar to those of today except that they were displaced to the south.

The skeleton in a thin section of a black chernozemic A1 horizon buried at 37 cm depth in an alluvial fan west of the plateau (profile 2) comprises mainly angular grains of fine sand size arranged in an open structure (agglomeroplasmic). The matrix consists of fine silt and clay, mixed with particles of amorphous humus in the size classes of 20 to 40 micron and less than 2 micron. This brown-coloured, floc-like plasma fills up all intergranular spaces and adheres to the surface of microaggregates and walls of voids as very thin skins (free grain organo-argillans).

The macro-structure of the buried A1 horizon is subangular blocky while the chernozemic soil at the surface of the alluvial fan has a crumbly A1 horizon. However, the buried soil has retained the very porous, spongy micro-structure that is characteristic for chernozemic soils. The shift toward drier conditions at the end of the mid-Holocene period of soil formation apparently changed the composition of the soil fauna and, consequently, the processes of humus formation: the major portion of the humus appears to be of anmoor type, but particles resembling "small moder" [4] were formed in the latest channels (Fig. 3).

Profile 3 exhibits a similar morphology but the matrix is less abundant in the A1 horizon of the buried black chernozemic soil. The colluvial origin of the soil parent material is evidenced by the stratification of skeleton grains and by the occurrence of allochthonous calcium-carbonate particles and spherical iron-concretions. The calcium-carbonate accumulation around channels (channel calcitans) is formed in situ as part of the overlying chernozemic soil at the surface of the alluvial fan. The radiocarbon age of the organic matter in the buried soil is 3,610±100 years [8].

PLEISTOCENE

Where the Cypress Hills rose above the surface of the Wisconsin glaciers, interglacial paleosols have been preserved in and beneath the surficial mantle of loose deposits.

In scattered localities on the plateau, a truncated soil with redder hues than Holocene soils is found in the upper part of the Tertiary conglomerate, beneath the loess-like cover which is of Wisconsin age [14]. That the paleosol is appreciably younger than the Tertiary parent material has been inferred from the deformation of the upper 1 or 2 m of the conglomerate prior to the formation of the paleosol. The de-arrangement of the pebbles may have been caused by frost action [14] or solifluction during an earlier glaciation, but it is also possible that it is the result

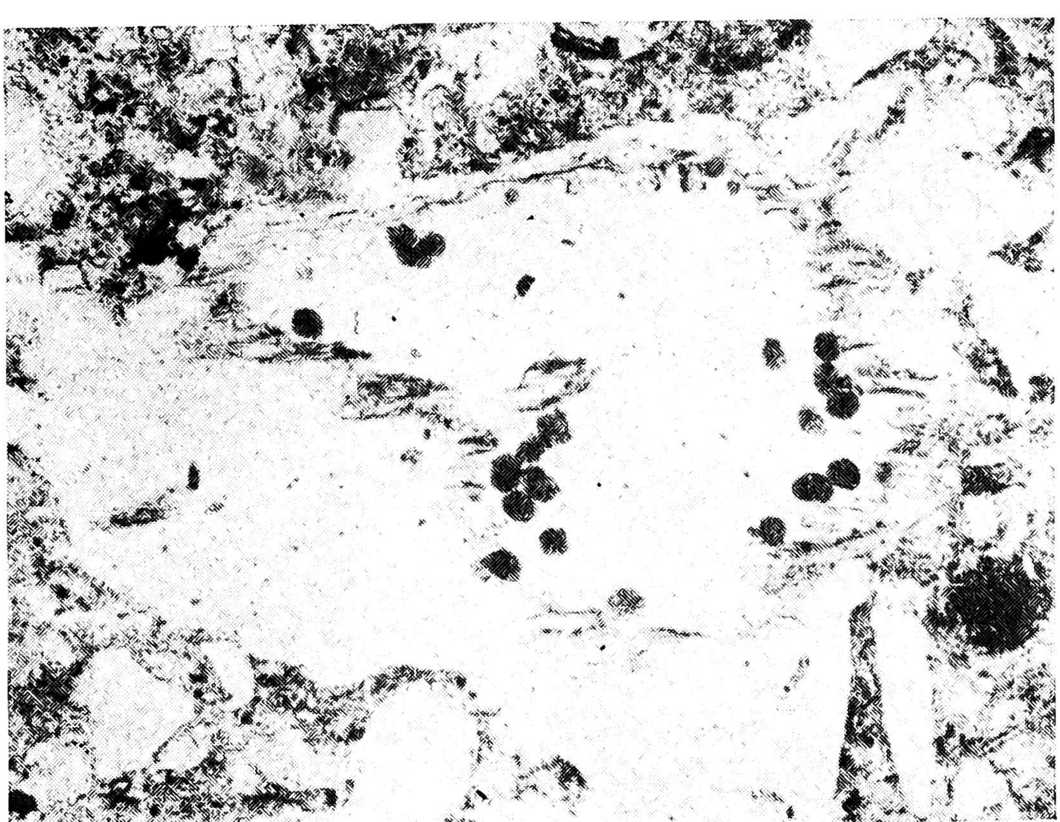

Fig. 3. Small moder particles in a buried chernozemic soil of mid-Holocene age. Vertical thin section M. 37 in plain light. ×100.

of direct pressure by glaciers; the fine-grained matrix in the upper section of the conglomerate has a specific composition and resembles the till of the surrounding Plains in grain-size distribution and heavy mineral content.

The interglacial paleosol in profile 4 represents remnants of a textural B2 horizon presumably formed under forest in a climate that may have been somewhat warmer and moister than it has been in Holocene times [7]. The fossil horizon is similar in many respects to the B2t horizon in modern Gray-Wooded soils formed in the conglomerate, except that the

Fig. 4. Pseudosand grains in a B2t horizon of an interglacial soil. Thin section M. 52 in plain ligth. ×100.

cutans are more developed and have redder hues. The remnants of the paleosol are mainly found near the northern edges of the plateau where environmental factors favour tree growth also at the present day.

The material filling interpebble spaces forms aggregates of pseudosand grains when viewed in thin section (Fig. 4). These spherical particles have been transported as stable aggregates prior to the formation of the soil. They are composed of soil material: mineral grains and rock fragments in a matrix of clay showing randomly distributed domains with striated orientation (insepic). Thin brown clay skins (ferri-argillans) surround the spherical particles but occur also around the skeleton grains within them (embedded grain cutans). Similar skins have been formed where the interpebble material joins the surface of the pebbles.

The orientation of the plasma grains in these cutans is moderate and it is not clear whether they result from pressure or from illuviation. Very small black particles which are difficult to identify form a common constituent of their plasma. Thin calcium-carbonate skins (calcitans) between the brown clay skin and the pebble is associated with the recent chernozemic soil formed in the overlying aeolian cover.

A paleosol profile with a very different morphology occurs in interglacial alluvium deposited on the southern pediment, at the base of a thick cover of calcareous solifluction material (Fig. 5). The surface horizons of the soil are no longer present but remnants of the subsoil remain. They consist of light yellowish sandy loam with two or three thin and discontinuous caliche strata. No stratification is apparent in thin section.

The calcium-carbonate of the caliche comprises many forms. There are inherited fragments not formed in situ but deposited by the stream. Many of these well-defined particles ranging in size from 0.3 to 3 mm were rounded during transport. There are also rare concretions with a concentric fabric which may owe their origin to biologic activity.

The remaining matrix consists of closely packed carbonate particles which are generally smaller than 30 micron. The voids reach diameters of 2 mm but they are commonly also filled up with calcium-carbonate (channel calcitan, Fig. 5). The infilling material is either microcrystalline with few scattered crystals of larger size, or forms aggregates of distinct crystals up to 40 micron in diameter. Needles which could indicate evaporation from a solution of low concentration [9] are absent.

The calcium-carbonate enrichment is much stronger than has been observed in modern soils. Its abundance also in the overlying solifluction

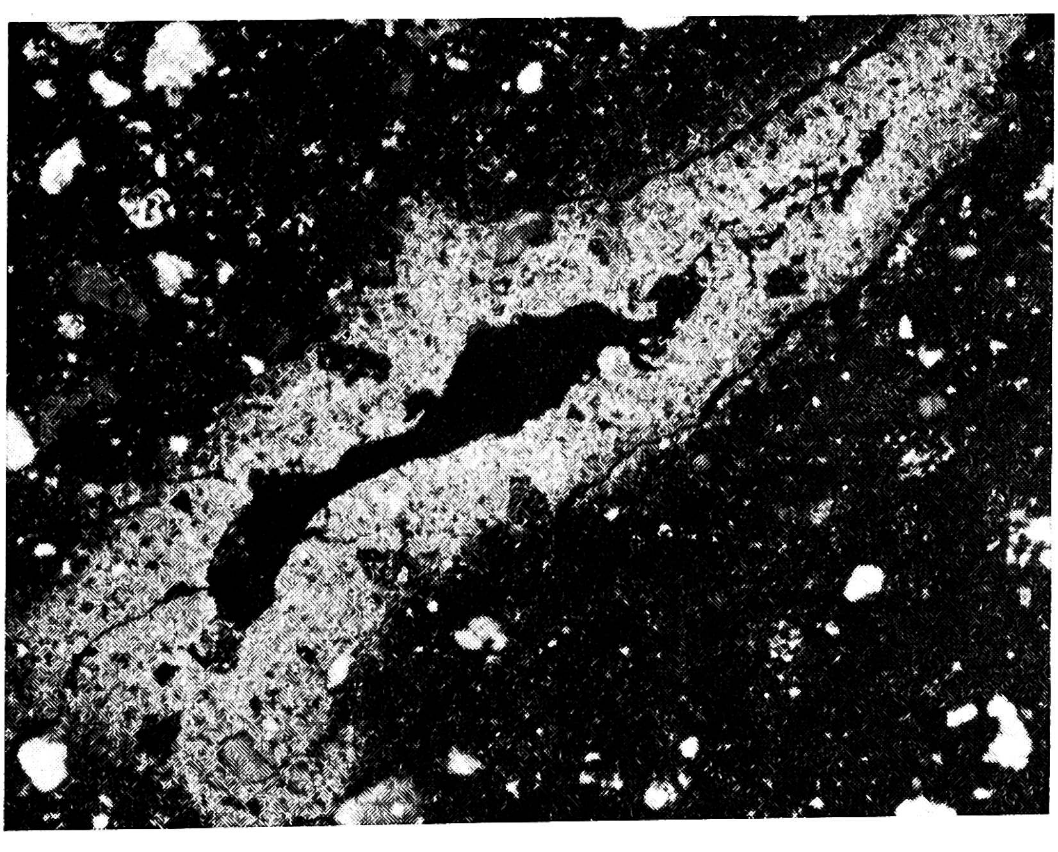

Fig. 5. Channel calcitan in an interglacial soil. Vertical thin section M. 41 under crossed polarizers. ×25.

mass which is composed largely of material derived from the interglacial soil suggests that the climatic conditions during the interglacial stage when the caliche was formed were more arid than they are at present. It has not been possible to establish with certainty the relationship with the interglacial soil found on the plateau.

TERTIARY AND UPPER CRETACEOUS

The Upper Cretaceous and Tertiary sediments underlying plateau and pediments suffered little disturbance and follow each other with apparent conformity [15]. The upper strata were laid down in a continental environment and include soil-like features formed during periods of non-deposition. The pedological significance of these phenomena is uncertain because they are associated with an environment different from that of today. Moreover, the rocks suffered diagenesis after deposition.

The lower facies of the Ravenscrag Formation of Palaeocene age consists of rather regular repetitions of grey and buff carbonaceous clays and silts. Lignite seams have been reported in other sections. Some of the grey strata are thin and very dark grey, containing sufficient organic matter to resemble A1 horizons. They are underlain by an equally thin band of light grey colour resembling a leached horizon. There are no B horizons.

Field evidence suggests that this "soil" was formed under very wet conditions which is confirmed by micromorphological studies. Thin sections of profile 6 show that the upper dark grey layer is the surface horizon of a semi-terrestric soil according to Kubiëna's [10, 11] classification. It comprises a sediment with a high amount of amorphous humus distributed as opaque particles in distinct bands which have been little disturbed. There are also charred plant fragments in which pyrite is present as a secondary formation. The matrix is composed of clay and fine silt, and exhibits flecked orientation on different patterns.

From the little disturbed stratification and the presence of pyrite it has been inferred that the profile was formed in a brackish-water environment near the coast [13].

In the Battle Formation of Upper Cretaceous age, a vertisol-like profile is developed. This formation has been described in geological literature as part of a highly weathered sequence including black, bentonitic soft clay of non-marine origin. The section described (profile 7) consists of approximately 175 cm of dark grey clay with a strongly developed angular blocky structure. The upper 20 cm beneath the covering sediments are black have a hard granular structure in places. In other sections the dark colour is restricted to the surface of the peds which will crush to colours of higher chroma and value. The clay is dominantly montmorillonitic and there are slickensides on vertical and sloping cracks as in true vertisols.

Vertisols properties are not immediately apparent in thin section because calcium-carbonate is absent and the soil mass was instable and highly mobile throughout most of its development. The yellowish matrix is composed of dense, lacker-like plasma with an irregular extinction pattern (masepic plasmic fabric, Fig. 6). This plasma is largely inherited from former cutans that were repeatedly disturbed due to extreme conditions of swelling and shrinking and occur in various degrees of disrupture (papules). Skeleton grains are unimportant.

The most conspicuous feature of the soil is the abundant presence of clay cutans (argillans). They resulted largely from illuviation, although

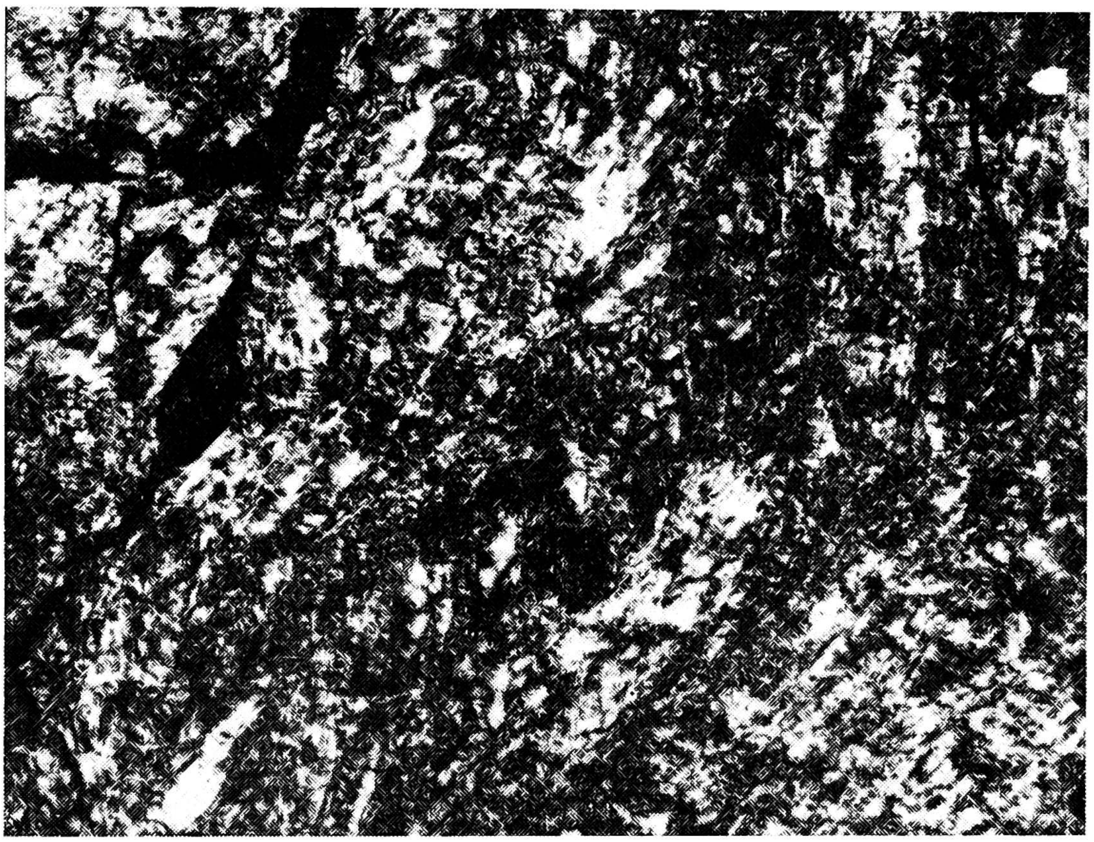

Fig. 6. Masepic plasmic fabric in a paleosol of Upper Cretaceous age. Thin section M. 50 under crossed polarizers. ×100.

pressure skins are also present. The illuviation cutans show strong continuous orientation. They are commonly uniform (simple cutans), but may be layered in places (compound cutans). Cutans composed of clay and iron oxides (ferri-argillans) occur associated with the walls of some voids. These cutans have not been disrupted, presumably because they were formed after the Battle Formation was covered by younger deposits from which the iron oxide was leached. The same phenomenon was observed in the Tertiary soil described above.

Acknowledgements. Fieldwork for the study reported here was carried out under a contract with the Geographical Branch, Department of

Energy, Mines and Resources, Ottawa, Canada. The authors are greatly indebted to Dr. Ir. A. Jongerius, Stichting voor Bodemkartering, Wageningen, Holland; to Dr. R. Schmidt-Lorenz, Institut für Forst- und Holzwirtschaft, Reinbek b. Hamburg, Germany; and to Dr. Ir. S. Slager, Landbouwhogeschool, Wageningen, Holland, for valuable help with the micromorphological interpretation of the thin sections. The photographs included in this paper have been prepared in the Department of Micropedology, Stichting voor Bodemkartering, Wageningen, Holland, through the courtesy of Dr. Ir. A. Jongerius.

SUMMARY

The paleosols in the Cypress Hills area range in age from Upper Cretaceous to Mid-Holocene. Their analogy with modern soils decreases with age. The profiles described include (a) fossil forest soil remnants in modern chernozemic soils, and soils buried in alluvial fans formed about 4,000 years ago when climatic conditions were somewhat more humid than they are today; (b) a truncated interglacial soil with a B2t horizon formed under forest, and an interglacial soil with caliche; (c) a semi-terrestric soil in Palaeocene formations resulting from deposition of organic material in a brackish-water environment; (d) a vertisol-like soil of Upper Cretaceous age.

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