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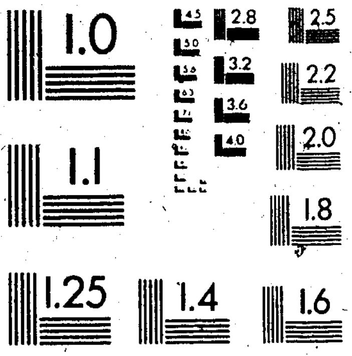

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THE UNIVERSITY OF ALBERTA

PALEOPEDOLOGY IN THE CYPRESS HILLS AND WATERTON AREAS, ALBERTA

by

WILLIAM S. TAYLOR

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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M. J. Dudas
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Date: April 1, 1987

Abstract

Buried profiles in the Cypress Hills plateau and Waterton (Cloudy Ridge) areas of Alberta were studied to determine the cause of their soil-like features.

The Cypress Hills profile, under Wisconsin loess and another drift (the hill's own till?), is in Tertiary fluvial gravels. Much of its plasma underwent preWisconsin diagenesis *in situ* to smectite.

Disruption accompanied burial, so the gravels' surface is not likely a preWisconsin landscape surface. That surface eroded as the mantle was deposited (glaciation, colluviation), or effectively became new from periglacial activity (cryoturbation) following burial.

The soil-like features (granularity, clay films, redness) are not pedogenic. They probably formed during and/or following burial: structure by physical processes in the high-smectite system (flocculation, shrink-swell); "clay films" are merely the stress-oriented surfaces of the clay-rich grains; redness is probably from recently precipitated hematite. Iron (excess from diagenesis?) likely occurred in moderately acidic groundwater. Carbonate infusing from the new mantle raised the pH, precipitating hematite at the top of the gravels.

The Cloudy Ridge profile is beneath Wisconsin Cordilleran till. Its medium (often called preWisconsin Cordilleran till) likely originated as Tertiary or early Pleistocene fan (fluvial-mudflow) gravels: Kennedy drift as first defined. It weathered thoroughly *in situ* and contains regularly interstratified chlorite-vermiculite.

Disruption accompanied burial, so the drift's surface is not likely a preWisconsin landscape surface. That surface probably eroded as the Wisconsin till was deposited. The weathered gravels were incompetent to stress from the Wisconsin glacier. Disruption and compaction accentuated the already till-like aspect of the fan materials. Lenses of fluvial gravel among the mudflow survived, indurated by carbonate. Rotten rock fragments, destroyed above, survived at depth where disruption was less intense.

Soil-like features (structure, redness) are not directly pedogenic. They probably formed during and/or following burial. Structure comes from compaction. Color may reflect the weathering, but the oxides are redistributed. Hematite may have precipitated with reintroduction of carbonate into the top layers, especially if iron from the weathering was present in mildly acidic groundwater.

Acknowledgements

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Chapter 1

PALEOPEDOLOGY

Definitions

The scope of paleopedology is still being defined (Ruellan 1971), though Ruhe (1965) proposed that paleopedology is the study of paleosols. It is generally accepted that paleosols are soils that formed in landscapes of the past (Ruhe 1965, 1975; Working Group 1971; Yaalon 1971a).

Principles governing the scope of paleopedology, and of paleopedological case studies in particular, have seldom, if ever, been discussed in depth. Paleopedology is closely related to pedology; paleosols are analogs of present soils. However, the "general agreement that the same methods as used in pedology must be used in the study of paleosols" (Working Group 1971) is symptomatic of an insufficiently incisive approach common in paleopedology. As the following shows, some methods commonly used in pedology are not valid when applied in paleopedology.

In pedology, soil is first distinguished from nonsoil. This first step is paramount, as will become evident. Only then can soil types be established.

Soil types are based on either a) soil genetic processes, or b) profile features. Each basis of grouping is radically different. To appreciate the difference, it is essential to distinguish between conceptual and parametric definitions.

Conceptual definitions create groups around central ideas (*e.g.* of genetic process). Parametric definitions create groups edge bounded by values of measurable properties (*e.g.* of features). The following example illustrates the limitations of each in sciences like pedology (where phenomena occur with a continuum of characteristics that evolve over time).

Many processes are thought to operate in soil genesis. For instance, "the genesis of *(certain)* soils is thought to involve . . . downward movement of . . . suspended clay with the soil solution, and deposition of the translocated clay at depth . . . ." (C.S.S.C. 1978a). In concept, soils so developed form a group that can be named and given a definition based on the process. Thus, "soils of the Luvisolic order . . . have illuvial B horizons in which silicate clay has accumulated" (C.S.S.C. 1978a). The preceeding is a conceptual definition that groups Luvisols by the clay illuviation process that formed them.

A common genesis could be seen as the ideal basis for classifying soils. Though that may be the underlying aim, it is not the operational method in pedology. Soils are usually studied at a single point in time in which genesis processes are not observable. Instead, properties inferred to reflect genesis are all that can be seen. So classification creates groups bounded by specified values of observable properties that are quantifiable. To classify a soil as a Luvisol, a horizon in it must exhibit a certain minimum percentage clay increase, frequency of clay skin occurrence, and thickness (C.S.S.C. 1978a). However, not all soils with attributes in the defined range are necessarily Luvisols. There are other measurable features a Luvisol must not contain (*e.g.* a Chernozemic A horizon). In classification, it is the soils that meet specific parametric criteria that are Luvisols, *independent of the processes in their formation.* This contrasts with the conceptual, ~~genesis~~ based definition above.

A soil profile's classification does not necessarily imply its genesis. Soil processes produce a continuum of characteristics. To break the continuum on boundary criteria of some measured feature invariably excludes soils where the process is weakly or abnormally expressed. Just as unacceptably, soils that meet definition limits are included even if their features have arisen by a different cause than the process in question. The soils encompassed by a classification definition may be aimed at, but can only approximate the set encompassed by a genesis definition. In summary, there are two disparate definitions for a Luvisol: the conceptual (genesis) definition that groups by *process, regardless of properties,* and the parametric (classification) definition that groups by *properties, regardless of process.* There may be overlap in the sets of soils encompassed by each definition, but the two sets are not congruent.

In fact, it is impossible to group soils genetically in practice. That is because profile properties or features are studied, a factor that controls logic systems. Classification bases definitions directly on the properties and features observed, so it is syllogistic (the simplest form of deductive logic). For instance: *Luvisols have this range of measurable properties. This soil has certain specific measured properties. Therefore this soil is (or is not) a Luvisol.* The conclusion is certain from the premisses (logic form is at issue here, not validity of the premisses). In classification, where soils are grouped by what is observed, whether or not a profile is a Luvisol is a matter of deductive fact. In contrast, if the profile's genesis must be determined, the logic changes radically. Genesis, the basis of the definition, has not been observed. An inference relating it to properties is needed. The instance becomes: *Luvisols are formed by this particular process. The process typically produces this range of effects in soil properties. This soil has certain specific measured properties.* Through the inference, data merely support speculation that *possibly the given process is (or is not) involved.* But to conclude with certainty that the soil is a genetically defined Luvisol cannot be done. The conclusion goes beyond information in the premisses. No account beyond speculation can be taken of possible abnormalities the process may have actually produced, nor alternate causes that have produced similar effects. The logic for such conclusions is ampliative induction. Von Wright (1973) stated, "Induction is called ampliative (or incomplete) if its conclusion goes beyond its premisses in the sense that the former is not a logical consequence of the latter. Ampliative induction is thus an inconclusive argument. It proceeds 'from the known to the unknown'." Thus, whether a given profile is a conceptually defined Luvisol, by study of its properties, is inherently inconclusive. This consequence is inevitable with inductive logic.

Applied Paleopedology

The need to justify use of the term paleosol in applied paleopedology has been acknowledged only occasionally (*e.g.* Westgate 1972). However, the constraints on what constitutes justification must be examined.

If paleosols are soils that formed in a landscape of the past (as defined above), then paleopedology studies conceptually defined phenomena. The essence of a paleosol is that it must have been subjected, however long or briefly, to paleopedogenesis (a process discussed more fully below). Just as pedology's universe is not restricted to Luvisols, neither is paleopedology's just paleosols. Paleopedology is given what may be called profiles, from which the paleopedologist must first discriminate those that have undergone paleopedogenesis, something inherently unobservable.

It has been recommended that recognition could be based in the tangible. For instance, Ruhe (1965) stated, "Paleosols are recognized by the same kind, arrangement, and distribution of features that occur in soils on the present landscape." Working Group (1971) concluded, "The field recognition of more than one distinct pedogenic feature forms the basis for the recognition of a paleosol." To define paleosols by process but recognize them by profile features requires the inductive inference that features unequivocally reflect unique genetic processes. However, the presence of features cannot confirm speculation about process as fact, but rather, merely supports the speculation to various degrees. To defer recognition to only "distinct pedogenic features" just presents the same problem in different terms. To call a profile a paleosol because it contains, for instance, a "podzolic B horizon" then requires justification of "podzolic B horizon" in the genetic, not parametric sense. Further, that approach excludes paleosols with features which are indistinctly paleopedogenic (*e.g.* some former Regosols, Brunisols, Cryosols). The deferred task, biased toward instances where there is merely less uncertainty, is no less inductive. Paleopedogenesis, the ultimate basis of the paleosol definition, is simply not observable. Therefore, inductive logic is fundamental to all applied paleopedology.

But there is more to paleopedogenesis (and pedogenesis) than mere process. Processes have levels of generalization from fundamental (*e.g.* oxidation, reduction, solution, precipitation) to complex (*e.g.* illuviation, gleyzation, podzolization, melanization). The latter, called pedogenic, are really groups of more fundamental processes that commonly operate together within soil (Yaalon 1971a). Processes are "pedogenic" only because the place where they operate has first been identified as soil. Virtually anything that transforms, translocates, adds, or removes is pedogenic (Simonson 1959), but only if the medium is first considered soil. A process is not pedogenic in itself. Its context of soil versus nonsoil must be recognized. For instance, oxidation, though sometimes pedogenic, is by no means confined to the pedogenic milieu. It occurs throughout nature as conditions are favourable. Oxidation is pedogenic only as it operates in a medium qualified to be called soil. Very few of the processes common in soils are exclusively pedogenic (Buol et al. 1973). For a process to be pedogenic requires a soil context. Paleopedogenesis and pedogenesis are really the same processes considered within a different setting. Paleopedogenesis is thus *a process that operated within a prescribed context.*

The requirements for material to be called soil vary among the branches of pedology. Soil has been defined conceptually, *e.g.* as the medium for plant growth, or as those landscape materials near the earth's surface where factors of climate, organisms, and relief operate on parent material over time (Canadian Society of Soil Science 1976). Conversely, soil has been defined parametrically for classification, *e.g.* the control section (CSSC 1978a). The context for paleopedogenesis has been conceptually defined to consist of coincident location and time: a landscape of the past. (A control section equivalent of the past has not yet been proposed.)

Context introduces a second inductive aspect to paleopedological interpretations. For instance, profile features may first support speculation that oxidation was their cause, a conclusion inductive in itself. Oxidation, though sometimes paleopedogenic, has frequently occurred in other natural settings. A second conclusion is necessary that links this apparent oxidation to specific occurrence within soil in a landscape of the past. The conclusion about context, again about the unobserved, compounds the inductive nature of paleopedological interpretations.

The constraints of inductive logic must be recognized in applied paleopedology. Von Wright (1973) described induction as "conjecture about the unobserved," called inductive arguments "inconclusive," and said that "induction, in a sense has no rational justification." Whether a given profile is (or is not) a paleosol cannot be known with certainty. Any paleosol interpretation is conjecture and supporting arguments, by nature, are inconclusive. To call a profile a paleosol, in a sense, can have no rational justification.

It has been recommended (cited above) that paleopedology should follow the same methods as pedology. Pedology's solution to the dilemma of inductive logic was to establish a separate but allied deductive system: classification. That option is not open to paleopedology. As in the genetically-defined Luvisol example above, setting parametric criteria for paleosols would include some profiles that are not genetically paleosols and exclude some that are. Property-based definitions cannot be set for paleosols because a mode of genesis and its context are what constitute every paleosol, regardless of its properties.

Logic form is independent of the correctness of an interpretation. Even unsupported guesswork might be correct, but it is quite unreliable. Inductive logic influences both the analytical strategy and how conclusions should be reported if there is to be integrity to any case study. Paleopedological interpretations, even if in reality correct, are inductive. The constraints of inductive logic should be acknowledged, although the opposite practice is ubitiquous in paleopedological literature. Conclusions set forth as unqualified fact rather than as interpretation imply deduction and in that sense are a misleading violation of logic. Equally ubitiquous, but more misleading, is the use, from the study outset of interpretation as a *premise* (*i.e.* the profile is assumed to be a paleosol from the start). Instead, interpretation should be presented following evaluation of competing theories and in light of all evidence as the inductive *conclusion* it is. Applied paleopedology's very integrity as a science depends on these correct responses to the controlling logic form.

Paleopedology cannot be just the study of paleosols. Proposing that restriction (cited above) misrepresents applied paleopedology's inductive nature, since the paleopedologist's first and most fundamental problem is to reliably discriminate paleosols from profiles that are not. An essential but ethereal facet of inductive science is the generating of the hypotheses to be evaluated, the "guesses or leaps which are out of the reach of method" (von Wright 1973). They spring from intangibles, including observer expertise, ingenuity, and perseverance. A continual concern is that the actual answer might not even be among those conceived. Where the objective is to explain the origin of soil-like profile features, numerous ideas shuold arise during a study. It is wrong, whether by intention or oversight, to limit these hypotheses to only paleopedogenetic ones, a narrowing that would preclude the possibility of even envisioning the ~~correct~~ solution if the profile is not in fact a paleosol. Each study must follow an iterative course determined by the results of analyses as they emerge, the theories they support and the new explanations they conjure up in the imagination. The theory best supported at some arbitrary point when it is believed reasonable doubt has been dispelled should be presented, but as interpretation. Interpretation reliability depends on the range of theories considered, the profile characteristics chosen for study, and the amount of documentation, *i.e.* the information readers need to evaluate the interpretation. Applied paleopedology is perhaps the study of profiles that, to the observer, initially appear (by features and/or context) to be paleosols. Expertise for the paleopedologist, far beyond the domain of soils, is knowledge of typical features produced by *any* earth science processes in *any* profile context. That is the open ended scope of applied paleopedology.

Theoretical Paleopedology

It is implicit in theoretical paleopedology that paleosols rather than profiles are under consideration. Ruhe (1965) envisioned three kinds of paleosols:

1. Buried soils - paleosols buried and preserved by younger sediment (also called fossil soils).
2. Relict soils - soils that formed in a pre-existing landscape but were never buried, so that some of their formation dates from the original landscape, and
3. Exhumed soils - soils formerly buried but re-exposed by erosion of the covering mantle.

Pedolith was added by Gerasimov (1971) to apply to the products of geological destruction of soils that nevertheless preserve pedogenic properties.

Perhaps no existing profile should be thought of as a paleosol. Profile features genuinely formed in a landscape of the past usually undergo alteration following separation from that landscape (Yaalon 1971a). If a paleosol is viewed instead as the soil as it was within the former landscape, while what exists now is merely the present expression of that paleosol, many conceptual problems that arise (see Gibbs 1971) could be averted. Pedogenic features may be subsequently altered any number of ways. In case studies, the question of whether a feature was paleopedogenic in the first place is complicated by interpretation (whether stated or not) about subsequent alteration, adding to the inductive constraint.

The above uncertainties serve as backdrop to considering how the near limitless variety of features that are more or less distinctive of present soils apply to paleopedology. Yaalon (1971a) listed some of the more common soil horizon features and related their relative persistence to genesis. Processes graded from reversible ones producing features easily altered, to irreversible ones producing very persistent features. Example features from reversible processes include soil organic matter, mottles, and horizons in early stages of genesis. Indurated or strongly expressed mineral horizons were more persistent. However, horizonation is not the only relevant level. Pedogenic relationships can be inferred from characteristics in a range of scales from the surface of an individual mineral grain to an entire landscape situation.

Significance of Paleosols

Paleosols are of interest both for their potential information content about past landscapes and for their effect on present land processes and management. They are relevant to any discipline that deals with natural phenomena at the earth's present or past surface. These include, for instance, pedology, geomorphology, geology, geography, paleontology, paleontology, climatology, engineering, and anthropology. The significance of paleosols to various fields is discussed by Ruhe (1965), Turchenek (1971), and Buurman (1975).

In some cases, questions regarding paleopedogenesis are secondary, and do not immediately affect the interpretation's importance, *e.g.* Parsons (1979), Muckenhausen (1979). The presence of a distinctive recurring layer is sufficient in some stratigraphic applications. In others, a distinctive physical or chemical property of a layer may be of importance, rather than its genesis.

Studies frequently use the assumption that since soils develop in response to their environmemt, the nature of a paleosol is the key to the paleoenvironment. Examples of this approach are by Jungerius (1966), Foscolos et al. (1977), King et al. (1978), and Singer and Nkedi-Kizza (1980). Dating of events or the profiles themselves is common (*e.g.* Hogan and Beatty 1963; Forsyth 1965; Jungerius 1966; Turchenek et al. 1974; Yevseyev and Ilichev 1975; Mills and Veldhuis 1978; Dumanski et al. 1980; Valentine et al. 1980). Profiles thought to be paleosols representing the earth's early history have been reported (Kalliokoski 1975).

History of Paleopedology

Paleosols were first considered in the late nineteenth century, but pioneering work in paleopedology postdates the first quarter of the twentieth century (Joffe 1949). In the main, paleopedological principles have only been outlined in brief preambles to case study reports. Many case studies originate from the midwest of the United States where loess is a burying agent (Ruhe 1965). Paleosols under volcanic ash are frequently reported from New Zealand (Gibbs 1971). David (1966), Dormaar and Lutwick (1969a, 1969b, 1975), Pawluk (1969), Dormaar (1973, 1983), Turchenek et al. (1974), Foscolos et al. (1977), King et al. (1978), Mills and Veldhuis (1978), Sanborn and Pawluk (1980), and Valentine et al. (1980) have provided noteworthy studies from western Canada.

The most concerted effort on paleopedology to date springs from a Commission on Paleopedology established in 1965 by the International Union for Quaternary Reseatch (INQUA). This commission, in conjunction with the International Society of Soil Science, in 1970 held a symposium on paleopedology from which the collected papers were published (Yaalon 1971b). The same group has also published a bibliography on paleopedology (Ruellan 1974).

Chapter 2

CASE STUDY REVIEWS

The Cypress Hills plateau in southeastern Alberta (Fig. 1) and Cloudy Ridge near Waterton Lakes National Park in southwestern Alberta (Fig. 2) both contain profiles with features that, from a cursory examination, appear to have been formed paleopedogenetically.

Genetic processes, the contexts in which the processes occurred, and the nonpedogenic alteration of supposedly pedogenic features have been identified (Chapter 1 above) as the major concerns in a paleopedological study. Information pertinent to all three concerns has been published in studies of the areas containing the profiles.

Cypress Hills Profile

Location

The Cypress Hills straddle the Alberta - Saskatchewan boundary about 70 km north of the Canada - U.S. border. The plateau expressed by the hill tops is a salient feature of the area (Williams and Dyer 1930). Alberta's portion of the plateau spans 25 km east to west and stands more than 500 m above the surrounding plains (Jungerius 1966), and most of it occurs within Cypress Hills Provincial Park (Fig. 1).

Cypress Hills Landscapes of the Past

Within disagreement over the plateau's origin (Broscoe 1965), there is accord. The plateau has evoked images of an ancient landscape surface in all investigators.

McConnell (1885) implied the plateau was depositional. He saw it as the surface of a Miocene fluvial conglomerate from the Rocky Mountains that caps the hills. Cope (1891) and Lambe (1908) reassigned an Oligocene age to fossils in the conglomerate. (Their conclusion, easily overinterpreted, merely constrains the plateau's maximum probable age.)

Alden (1924, 1932) expanded the above to the Cypress Plain concept, an Oligocene-Miocene surface now evidenced by erosional surfaces high in the mountains and the many depositional plateaus on the plains (*e.g.* the Cypress Hills). Adherents gave the Cypress Plain different ages.

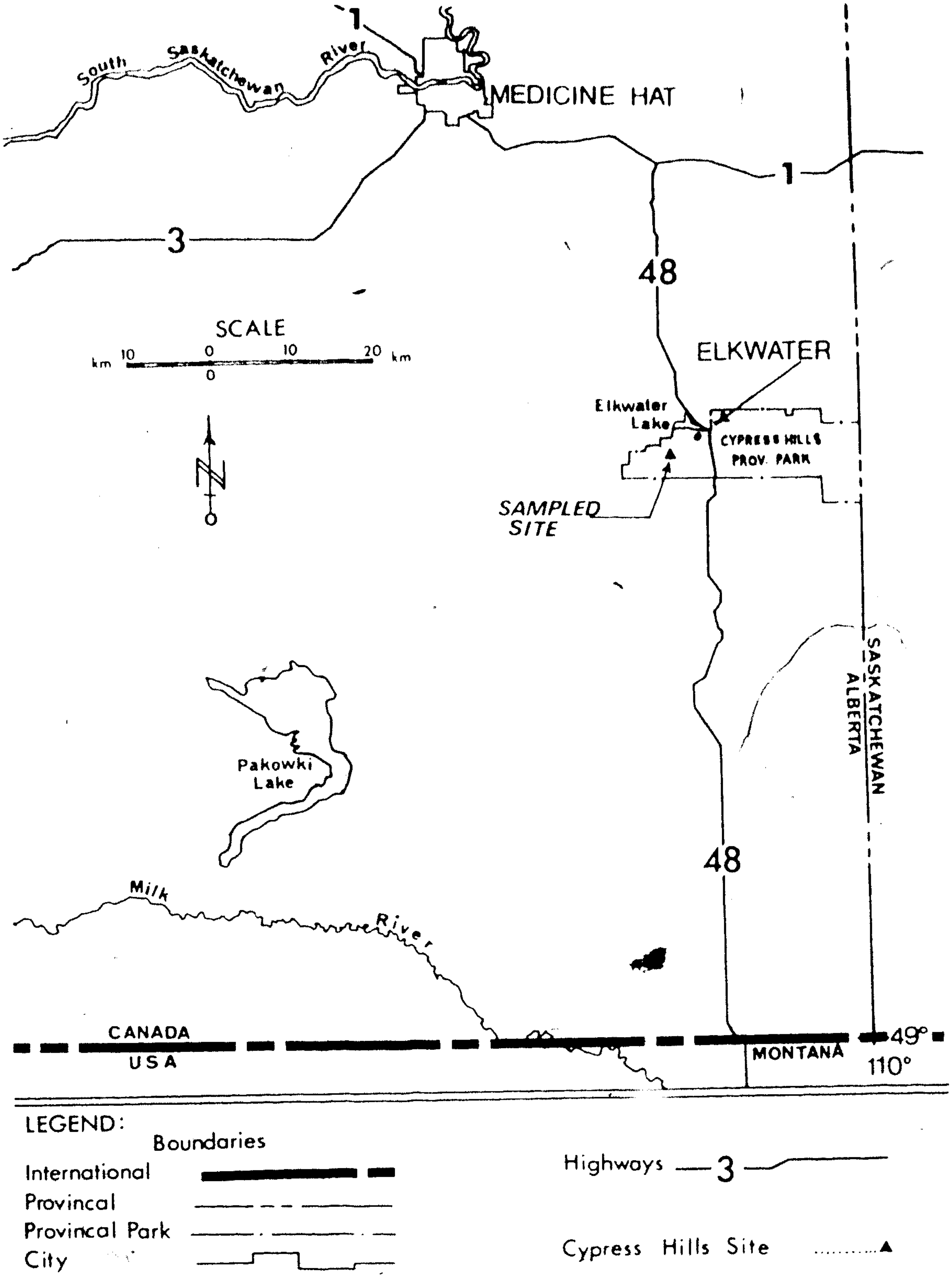

Figure 1. Location of the Cypress Hills site.

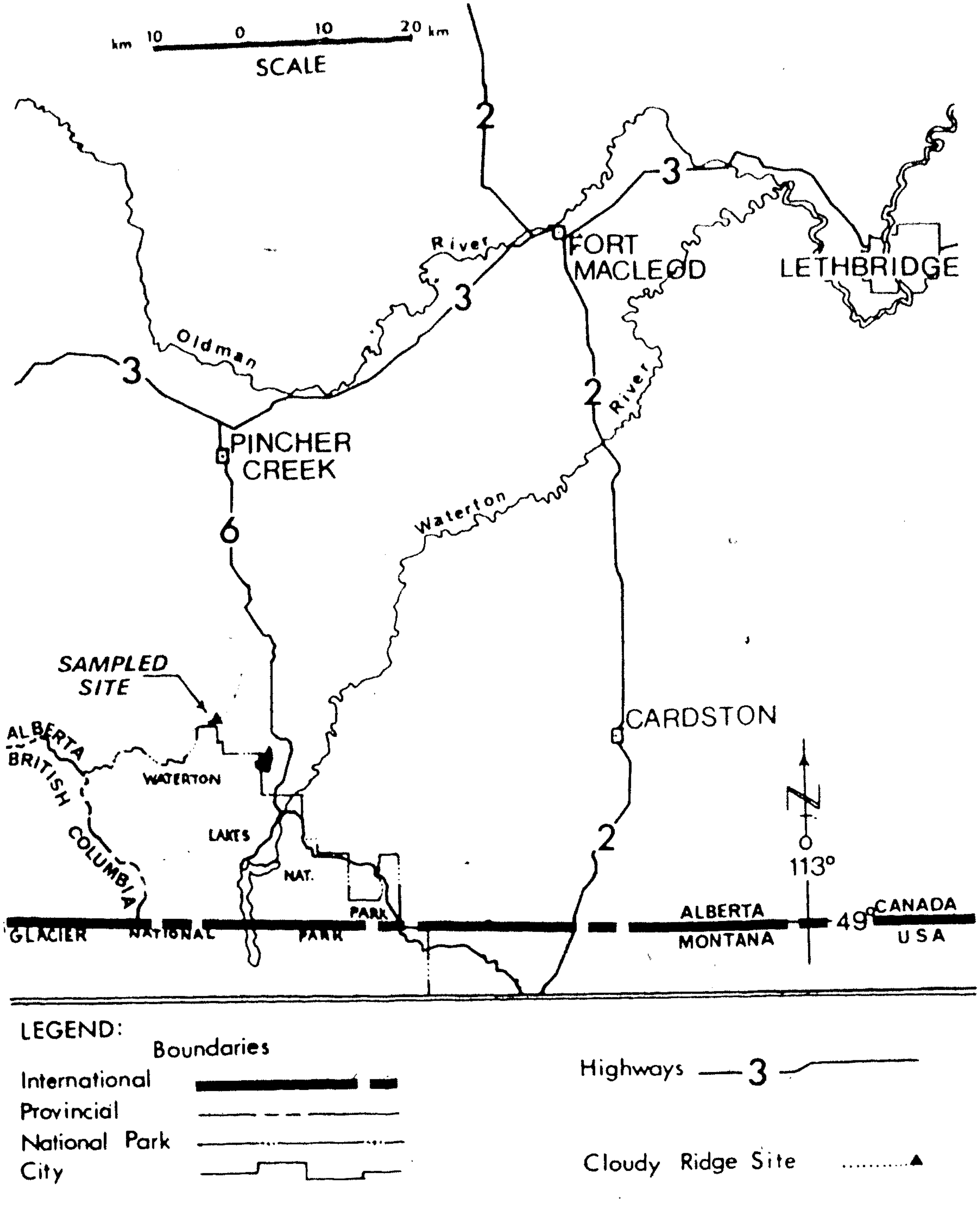

Figure 2. Location of the Cloudy Ridge site.

Lawson (1925) called it Oligocene. Warren (1939) said the hills mark the "land surface . . . that existed just after the Rockies were elevated." Horberg (1954) suggested "a possible Pliocene age" for it. Broscoe (1965) believed the "preserved" plateau was Cypress Plain that "was depositional and that the upper surface represented a cessation of sedimentation."

Russell (1957) said the plateau was not part of a larger Cypress Plain because fossils under the many plateaus in Alberta and Saskatchewan were not coeval within the Tertiary. From his stated depositional perspective, since the Cypress Hills fossils were Oligocene, so was the plateau.

Others said the Cypress Plain was a precursor. The plateau, if erosional, would be younger than the conglomerate. Williams (1929) stated that "erosion . . . reduced the land surface" and gave a Miocene age for the plateau, which was "preserved in approximately pre-glacial condition." Williams and Dyer (1930) echoed both points. Alden (1932) said Williams' Miocene age for the *Cypress Plain* was possible, which overlooked the erosional thrust of Williams' view.

Contrary to original usage, Cypress Plain recently has been attached to the erosional theory of the plateau's origin (Gravenor and Bayrock 1961; Westgate 1965). Westgate (1968) again called the plateau both erosional and Cypress Plain, but conversely assigned it an Oligocene age from the depositional perspective by citing Cope (1891).

Ignoring any wider context, Crickmay (1932) simply called the plateau erosional. He believed the current surface "has not long been exposed to *(further)* erosion. It is not old. It may antedate the Pleistocene, but is probably not much older."

Some have invoked additional preglacial deposition. Mackin (1937) saw "two distinct gravel beds in the Cypress district - an older sequence, containing an Oligocene fauna . . . and an overlying gravel sheet, containing no fossils, which is younger than the Oligocene gravels . . . and older than the oldest drift of the Keewatin glacier." The source of the upper gravels was believed to be closer than the Rocky Mountains. Crickmay (1965) said that sands and gravels which "may well be of Pliocene or Pleistocene age" overlie the conglomerate. Further, the plateau shows "an almost intact survival of a part of a formerly broad plain . . . ."

Jungerius (1966) argued the plateau expression does not in itself evince a surface of the past. But still, scattered about the plateau were physiographic lows of a previous irregular surface that was "probably not much older than early-Pleistocene."

Pleistocene Modification of the Plateau

Age of the gravels and physiography do indicate that ancient landscape surfaces likely existed in the Cypress Hills area. They fail to show that the hills now exhibit any of those surfaces. Calling the plateau *per se* a relic ignores stratigraphy. The implication is really that the top of the gravels governing the plateau expression forms the ancient surface. Those gravels (usually called the Cypress Hills Formation) are buried. Further, it is doubtful the current upper gravel layer ever was exposed. The top of the conglomerate is likely a Pleistocene erosional surface.

Russell and Landes (1940) noted the Cypress Hills Formation varies with depth. Without suggesting agent or time, they commented that since "the matrix of this upper part is more clayey than sandy, there is some possibility that this much of the deposit has been reworked." Disruption of the conglomerate's top 1 to 2 m by periglacial frost was reported by Westgate (1964, 1965, 1968, 1972), Jungerius (1966, 1969), and Jungerius and Mucher (1972).

Jungerius (1966) held that "late Pleistocene degradational forces" had made the hilltops flat. The older, irregular surface "had not much coincidence" with the present surface. The plateau was "an altiplanation surface probably dating from the Wisconsin glacial stage" that was "produced by mass-wasting processes that were operative independent of base level control . . . ."

Opinion that the Cypress Hills were never glaciated (Williams and Dyer 1930; Allan 1941; Breitung 1954; Broscoe 1965; Stalker 1965; Westgate 1965, 1968; Bird and Halliday 1967; Bostock 1970; Prest 1970; Beaty 1975; Catto 1983; Rutter 1985) is now public lore. The belief arose and persists solely because Laurentide erratics are absent from the hill tops (*e.g.* McConnell 1885; Johnston and Wickenden 1931; Westgate 1965, 1968). Those who suspected the plateau had been glaciated (*e.g.* Jungerius and Mucher 1972) demurred, at a loss to explain the absence.

The evidence does indicate the plateau likely was never under *Laurentide* ice. That is not to say it is unglaciated. Stalker (1965) acknowledged that continental ice nunataks (including the Cypress Hills) could have been "covered by inactive ice from local accumulation. . . ." McCorquedale (1965) raised "the possibility of the Cypress Hills plateau supporting its own small ice cap." His suggestion has merit. Glaciation of the plateau by its own ice cap in addition to (occasionally instead of) the published interpretations better accounts for the evidence in total from the plateau and vicinity.

First, the top few metres of the Cypress Hills Formation likely has been reworked (Russell and Landes 1940) or perturbed (Westgate 1964, 1965, 1968, 1972; Jungerius 1966, 1967, 1969; Jungerius and Mucher 1972). Frost was not necessarily the exclusive agent; Jungerius and Mucher concluded that "it is also possible that it is the result of direct pressure from glaciers" and mentioned the till-like aspect of the disturbed conglomerate. Indeed, the disturbed conglomerate might technically be till, *i.e.* material transported (however minimally) and deposited by a glacier.

Secondly, till-like material overlies the Cypress Hills Formation. Heterogeneous drift resting on the Oligocene gravels was first reported by Mackin (1937). But a diamicton has not always been recognized as a discrete unit within the conglomerate's mantle. Westgate (1965, 1968) saw the mantle as one great whole. He called it loess despite his 1968 caveat that the entire sediment was "poorly sorted and in places coarse grained" which were "atypical characteristics for a loess." He suggested frost had mixed some of the conglomerate up into the loess. Jungerius and Mucher (1972) said coarseness in the "loess-like mantle" was "not typical for loess." Westgate twice (1965, 1968, emphasis added) asserted the "fabric of the loess *resembles that of till* (that is, unsorted)," but balked claiming "no erratics" were present. (More incisively, no clasts had Laurentide lithologies, so it is unlikely the mantle is Laurentide till.)

Sections show the mantle as two discrete units (Jungerius 1966; Westgate 1972; Catto 1981). A diamicton (till?) rests on the Cypress Hills Formation. The loess-like veneer is above it. Jungerius described the diamicton in detail; transport was evident by an "erosive effect . . . on the underlying conglomerate, its level surface, and its occurrence over non-pebbly material," observations inconsistent with a cryoturbated loess origin. Jungerius, believing that glaciation was not an option, turned to colluviation to explain the diamicton. Westgate (1972) finally split the mantle, but still called both units eolian even though the lower one was decidedly heterogeneous.

Catto (1981, 1983) recognized a discontinuous diamicton beneath the loess. Concurring with Jungerius (1966) on its origin, he named it the "Cypress Hills Colluvium" (1981). Catto (1983) argued that Westgate's (1968) view of it as loess was untenable, but did not explain why a colluvial origin was indicated. He even suggested a glacial link, saying the plateau's diamicton (*n.b.* above the recognized limits of Laurentide ice) might contain "glacially transported material from the Ravenscrag Formation" (which lies well below the plateau).

The diamicton apparently is not restricted to the plateau proper. Catto (1983) traced it down the plateau's northern escarpment. Jungerius (1967) equated it with drift on surrounding scarps and pediments that extends to the upper limit of Laurentide deposits and beyond. He recognized that Cypress Hills Formation quartzites were erratics in the latter locations and implied the material was like till, but dismissed the notion by listing the diamicton's differences from Laurentide till (none of which bore on whether the material was till *per se*). That oversight led him (thence Catto) to the less satisfactory view that the diamicton was colluvium; most slopes admittedly were of 1 degree or less.

Explaining the evidence with widespread colluviation and attendant theories of the plateau's origin appears inferior to McCorquedale's (1965) suggestion that a Pleistocene ice cap originated within the Cypress Hills themselves. If the plateau has been glaciated, all preglacial landscape features have possibly been effaced.

Suggestions that preglacial biotic relics inhabit the plateau have depended on the idea that the plateau is unglaciated, whereas they should serve to confirm it. The arguments are back to front for the circumstancses. For example, Breitung (1954) said it is "not improbable that the plateau . . . , which was not glaciated*(?)*, provided a refuge for the submontane forest and grassland flora to survive" instead of arguing that, since there appear to be relics among the flora, it is probable the plateau was not glaciated. It remains to be shown that any species likely endured the glacial period there. Other ice aside, Bird (1962) believed it "very unlikely that any *(vegetation)* could have survived" on the Laurentide nunatak. McCorquedale (1965) and Bird and Halliday (1967) argued that all the Cypress Hills' flora and fauna could have been established since glaciation. Biotic evidence is equivocal.

In summary, the Cypress Hills area had landscapes of the past, but detail (*e.g.* the age of the conglomerate's surface or the degree of correspondence between it and material exposed in a former landscape) is far from certain.

Paleopedological Studies - Cypress Hills

By definition, soils were part of any landscape of the past associated with the Cypress Hills plateau. If pedogenic features developed, they might persist. The buried top of the Cypress Hills Formation has been the focus of paleopedological interest.

Paleopedogenesis has been the suggested cause of some features in Cypress Hills Formation profiles. Jungerius (1966) described a "well developed B horizon" in a Cypress Hills Formation "paleosol" with an "increase in the percentage of clay" that was "interpreted as a result of illuviation from a former A horizon" (now absent). Related processes were "the liberation of iron under the conditions of illuviation and oxidation" and "chemical weathering *(that)* was restricted and of limited duration . . . ."

Jungerius and Mucher (1972) referred to an "interglacial paleosol" on the Formation with "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." It was "not clear whether they *(the cutans present)* result from pressure or from illuviation."

Westgate (1972) discussed a "paleosol" with a "B-horizon" in which clay distribution with depth was "suggestive of an alluvial *(sic)* origin." (Context suggests "alluvial was a misprint for "illuvial," since clay distribution was one point used to justify use of the term paleosol.) Weathering that decreased with depth was the only other process mentioned.

Catto (1981) proposed that buried profiles along the plateau's northern escarpment were the Orthic Humo-Ferric Podzols of an Aftonian or Yarmouth aged podzolic-gleysolic catenary association. Iron oxidation and a fluctuating water table operated in genesis of the Podzols. The paleoclimate was inferred to have been temperate, possibly like eastern Ontario has now. A conifer dominated vegetation was postulated, based on the profiles' envisioned genesis and because neither organic forms nor plant opal were detected. Plentiful clay skins in the profile were left unexplained.

The Problem - Cypress Hills

Paleopedological case studies must focus first on profile feature genesis and (perhaps) alteration (Chapter 1 above). The pitfall here is to presume the plateau represents a landscape of the past, hence paleosols must be fashioned to fit the evidence (or lack of evidence), an argument as backwards for the circumstances as the boitic relics one demonstrated above. It is necessary to argue from evidence toward interpretation, *i.e.* profile features likely did (or did not) arise from paleopedogenesis, thus the plateau probably does (or does not) represent an ancient landscape.

Catto (1981) implied that features in some plateau profiles reflected paleopodzolization. He advanced the idea indirectly (*i.e.* by classifying the profiles as Podzols) and proceeded as if paleopodzolization was proven. However, the Podzol classification was unwarranted. His data showed even the "best developed" profile was not a Podzol. The IIBf horizon designation for the red conglomerate layer in it (and thus the classification) was incorrect on two counts. Neither the organic carbon (0.13%) nor the pyrophosphate-extractable Fe + Al: clay ratio (0.02) met the 0.5% and 0.05 minima respectively of a Bf (CSSC 1978a). Fe, Al, and organic carbon are the pivotal factors in Podzol classification. Low values mean the profile was atypical of a Podzol. That is further evident by comparing the profile descriptions (*e.g.* the lack of dark coatings or silty microaggregates; amount of oriented clay) with features typical of Podzols (CSSC 1978a).

But incorrect classification is incidental; the real issue is feature genesis. Data are directly relevant in paleopedological case studies as they address process, not classification (Chapter 1). Catto's only justification for calling the profiles (paleo)Podzols rests in the unrealized argument that the red layer's 0.63% pyrophosphate-extractable Fe + Al was diagnostic, not of a Podzol, but of paleopodzolization. (Since biotic features were essentially *absent*, it also is the sole basis for the subsequent speculations on the paleoenvironment.) However, two factors invalidate the fundamental assumption required for Catto's argument: the assumption that podzolic complexes were among the sources of the extracted Fe and Al. First, the low Fe + Al: clay ratio reflects the red layer's high (28%) clay content, and in clay-rich samples much Fe and Al may be extracted by pyrophosphate from finely divided nonpodzolic sesquioxides associated with clay mineral surfaces (Soil Survey Staff 1975). Secondly, Westgate (1972) and Catto both indicated there is secondary carbonate in the conglomerate. Free lime in the sample might have tended to neutralize the extraction solution pH. Near neutral pH, not only is pyrophosphate extraction from nonpodzolic sesquioxides increased (Soil Survey Staff 1975), but Fe and Al may also be extracted from the lattice structure of clay minerals themselves (Kononova et al. 1964). Under the prevailing conditions, the Fe + Al and organic carbon values are not compelling evidence that podzolic complexes occurred in the sample. The data might indicate that podzolic complexes were absent.

Since Catto's (1981) profiles are not currently classifiable as Podzols and the presence of products of the podzolization process in them is doubtful, feature alteration becomes the issue. To justifiably argue that the profiles were once podzolic, something unique from the alteration of features that were specifically podzolic must be shown in them and the alteration pathway elucidated, but that case was not presented. Catto felt that pHs indicated the profiles had been chemically altered, but at that stage his argument was proceeding with a podzolic starting point assumed rather than as a demonstration that a podzolic starting point was essential. A change in pH does not show the profiles must have been podzolic. Considering the clay skins, a former luvisolic expression (Jungerius 1966; Jungerius and Mucher 1972; Westgate 1972) is more likely, which could explain the persistence of unaltered smectite that Catto pondered. The paucity of organics and absence of phytoliths do not necessitate a concomitant coniferous vegetation; on the contrary (consistent with the probability of Pleistocene disruption), that evidence strongly indicates no paleolandscape whatever was directly associated with the profiles. From a broader perspective, given the evidence, why must the profiles have been paleosols at all?

Other questions may be raised about previous interpretations. First, the scant published evidence equivocally supports alternate views on the primary issue: the genesis of profile features. Depositional variations could account for most features which have been cited as evidence of paleopedogenesis, other than the color and clay skins. Their causes remain largely enigmatic. Secondly, it is assumed loess-like material preserved the conglomerate's preburial characteristics (Jungerius and Mucher 1972; Westgate 1972). But as shown above, the conglomerate is often overlain by a diamicton, not loess, and its upper layers are perturbed. Disturbances (*e.g.* glaciation?) may have altered or destroyed any surface features recorded in the conglomerate.

The purpose of my Cypress Hills study was thus to determine the most probable causes of the soil-like features in profiles on the Cypress Hills plateau.

Cloudy Ridge Profile

Location

Cloudy Ridge is a high, rugged bedrock ridge of the Rocky Mountains within Waterton Lakes National Park (Harrison 1976, G.S.C. map 1422A). However, the piedmont of Cloudy Ridge proper that extends north-northeast beyond the park between Yarrow and Dungarvin Creeks has also been called Cloudy Ridge. The latter usage is followed here (Fig. 2.).

Cloudy Ridge Landscapes of the Past

Cloudy Ridge is a gently sloping, dissected bench forming a step between the Rocky Mountains and the plains (Plates 1, 2; National Airphoto Library A19979-199, 200; Horberg 1954 Plate 5 Fig. 1; Wagner 1966 Fig. 11; Harrison 1976). In expression and materials it is like (and has been correlated with) other benches in the vicinity as discussed below. Both Horberg and Wagner thought Cloudy Ridge was bedrock cored, but neither of them recorded any outcrops. Drift exposed on it has been used to interpret the post-orogenic history of southwestern Alberta and vicinity. Some writers have implied the drift formed a surface in a landscape of the past. Various landscape histories for Cloudy Ridge have been proposed, as follows.

Horberg (1954) called one geological material within his study area "Early Wisconsin mountain drift. His area-wide generalization described it as hard, stony, sandy matrix till with commonly associated sand and gravel beds that, in places, form cemented ledges. No sections from Cloudy Ridge were described, though the drift was identified there, expressed in "faint traces of knolls and swales." Wherever it cropped out, the drift showed slightly deeper weathering than "Late Wiscondin mountain drift." This younger material was also present on Cloudy Ridge. Horberg (p. 1105) thus implied that the older materials on Cloudy Ridge had been part of a Wisconsin interstadial landscape.

Wagner (1966) said his own view of Cordilleran deposits and chronology of the same area was in "sharp disagreement" with Horberg's (1954). Disagreement centred on age and areal distribution of like materials. Wagner detailed seven points, one dealing specifically with Cloudy Ridge, to refute the supposed existence of Horberg's Early Wisconsin mountain drift. The same disagreement extends to their respective landscapes of the past ~~in~~ which Cloudy Ridge figures.

Wagner (1966) called an old drift unit of the area "Mountain till M I." It was commonly composed (p. 61) of till and gravel beds. It occurred exclusively beneath younger Wisconsin mountain drift everywhere it was identified. Wagner described a section from Cloudy Ridge where these materials appeared to be thoroughly weathered. He felt the drift was "possibly as old as early Pleistocene (Nebraskan ?)," but assigned it an "Illinoian (?)" age. In his view (p. 94), the materials had been part of a Sangamonian interglacial landscape.

Plate 1. Cloudy Ridge site, view southwest.

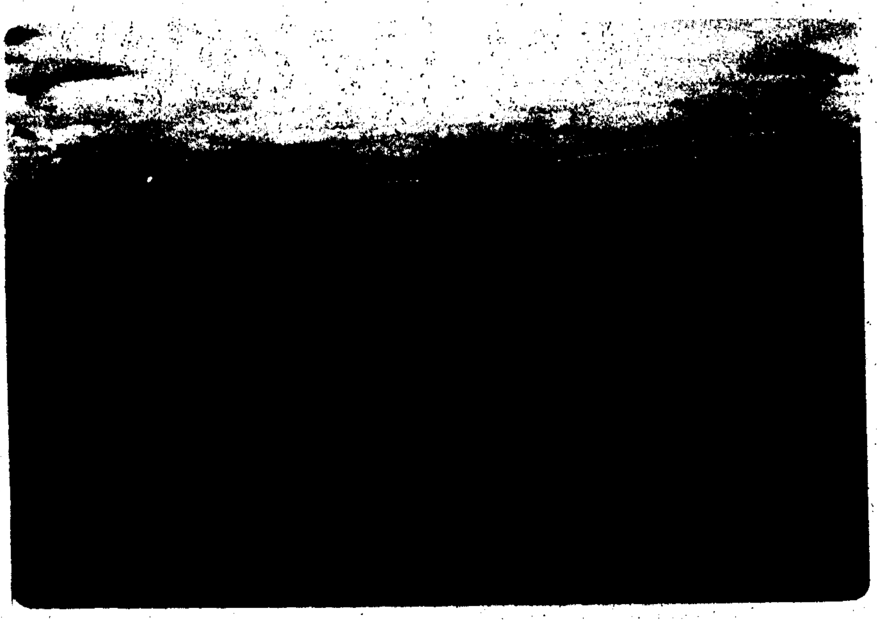

Plate 2. Cloudy Ridge site, view northeast.

Stalker and Harrison (1977) presented a version of a landscape of the past involving Cloudy Ridge, apparently from a hybrid of previous information and interpretation. They quoted Horberg's (1954) area-wide generalization of Early Wisconsin mountain drift that crops out (*i.e.* moderately weathered, stony, sandy matrix till with sand and gravel beds) to describe the specific deposits of Cloudy Ridge. At the same time, they emphasised the deep weathering reported for Wagner's (1966) older, exclusively buried drift. Thus, they did not resolve (nor acknowledge) the drift expression issue. They simply gave a legal subdivision location on Cloudy Ridge as the area in question. Their estimated depositional age was Illinoian, and weathering of materials, however they are expressed, therefore is related to a Sangamon interglacial landscape.

Stalker and Harrison (1977 p. 888) acknowledged that the old drift on Cloudy Ridge has received little study. Putting that problem aside, they, like others, correlated further afield in reconstructing the extent of their envisioned depositional event. They stated, "Though they have no proof, the authors consider that the deposits on Mokowan *(sic, elsewhere Makowan)* Butte and Cloudy Ridge are of similar age and that both were deposited by the Great Cordilleran Glacier." Wagner (1966) hinted at a similar correspondence. This Cloudy Ridge - Makowan Butte correlation implied that Cloudy Ridge deposits are another example of Kennedy drift, a name with precedence for pre-Wisconsin drift on Makowan Butte and numerous nearby benches and mesas similar to both it and Cloudy Ridge (Willis 1902; Alden 1912, 1914, 1924, 1932; Daly 1912; Alden and Stebinger 1913; Horberg 1954, 1956; Richmond 1957, 1960, 1965; Wagner 1966).

Some of the drift on Cloudy Ridge could indeed correspond with Kennedy drift. The older units of the Cloudy Ridge section that Wagner (1966) described share similarities (*e.g.* topographic setting on a high, dissected, mountain border bench, apparent degree of weathering, lithology, textures, materials variation with depth including ledges of indurated drift, stratigraphic relationships) with Kennedy drift in sections described by authors listed in the paragraph above. Even if incorrect, the correlation is valuable. Because of the similarities, the various interpretations of Kennedy drift are options that should be at least considered for drift on Cloudy Ridge.

Kennedy was a Formation name that Willis (1902) coined for dissected, tabular, gently sloping, high elevation gravels bordering the Rocky Mountains. The type occurrence was a mesa just south of the international boundary (Fig. 2) beside Kennedy Creek in Montana, and another of Willis' examples (p. 329) was Makowan Butte. He believed the gravels were the remnants of alluvial cones from the Pliocene or early Pleistocene stage of mountain development. Daly (1912) examined Kennedy drift and concurred with Willis on its deposition. Alden (1912, 1914, 1924, 1932) and Alden and Stebinger (1913) identified further examples of Kennedy Formation. They then reinterpreted all of it (including drift on Makowan Butte) to be older Cordilleran glacial drift (mantling piedmont fluvial surfaces, see Billings 1938). Slope processes supposedly had by now planed any morainal expression to a smooth, gentle incline. Alden (1932) said this "first"Cordilleran glaciation was probably contemporaneous with the advance of the Keewatin ice sheet of the Nebraskan stage" and saw it "marking the beginning of Pleistocene time." The glacial view of Kennedy drift was repeated, but with an array of other pre-Wisconsin ages (Billings 1938; Horberg 1954, 1956; Richmond 1957, 1960, 1965; Wagner 1966). However, Ross (1959) said that "in spite of Alden's discovery that some of the high-level gravel is of glacial origin, it seems clear that benches . . . which are in part still mantled by alluvial gravel of suitable age *(Miocene to early Pleistocene)* remain on the plains close to the mountain border.

A subtle oversight was made when Kennedy drift was reinterpreted. Alden (1932 p. 34), Horberg (1954 p. 1102, 1956 p. 204), and Ross (1959 p. 105) assumed that Willis (1902) had said Kennedy drift was deposited from flowing water. Although Willis referred to it as "water-washed" and "water-worn material," more importantly, his chief reference was to an "alluvial cone." Daly's (1912) lone genetic term for Kennedy drift was "gravel fan." Alluvial fans, despite the connotations of their name, are neither purely alluvial, nor are their materials distinct from till. Landim and Frakes' (1968) definition illuminated both points:

> *Alluvial fan.-- A cone shaped deposit of sediment deposited subaerially, mainly by swift currents and mudflow. The sediment of an alluvial fan is referred to . . . simply as an alluvial fan deposit, and much of it closely resembles till.*

This fluvial and mudflow complexity to fans, with mudflow often the major constituent, has been recognized (Norton 1917; Blackwelder 1928; Sharpe 1938; Twenhofel 1939; Fryxell and Horberg 1943; Sharp and Nobles 1953; Van Houten 1957; Winder 1965; Hooke 1967; Landim and Frakes 1968; Broscoe and Thomson 1969; Ryder 1971, 1981; Blatt et al. 1972; McPherson and Hirst 1972; Owens 1972; Roed and Wasylyk 1973; Clague 1974; Ruhe 1975; Pe and Piper 1975; Jackson 1979; Nasmith and Mercer 1979; Rachocki 1981; Jackson et al. 1982; Walker et al. 1982). The resemblance between fan material (especially mudflow) and till has also been mentioned (Blackwelder 1928; Sharpe 1938; Twenhofel 1939; Sharp and Nobles 1953; Crandell and Waldron 1956; Van Houten 1957; Harland et al. 1966; Landim and Frakes 1968; Lindsay 1968; Hester and DuMontell 1971; Pe and Piper 1975; Ryder 1981). Discriminating glacial from fan materials is even harder when original surface expression is masked by dissection (Van Houten 1957). Plate 3 shows the contribution from a recent, observed mudflow to fan construction and the till-like aspect of mudflow material.

It was necessary for Alden and others to champion glaciation in order to legitimize it as a theory (Flint 1965), but the promotion was perhaps overly successful. Van Houten (1957) described the early part of this century as "a time in the history of American geology when a newly aroused interest in ancient glaciation tended to exaggerate its geologic importance. As a consequence, poorly sorted, heterogeneous conglomerates commonly were considered to be tillites, and little attention was given to other possible modes of origin." In 1953, Alden was more equivocal. He frequently mentioned fan as a credible alternative for what he felt were pre-Wisconsin Cordilleran glacial deposits. In light of all this, the grounds on which he earlier reinterpreted Kennedy drift *en masse* warrant scrutiny.

Beyond his opinion that Kennedy drift's appearance "was rather that of gravelly glacial drift than of *stream gravel*" (Alden 1932 on the type section, emphasis added), the only new grounds for reinterpretation were striations discovered exclusively on an admittedly restricted number of argillites (Alden 1912, 1914, 1924, 1932; Alden and Stebinger 1913). However, striated fragments occur in fan deposits, especially mudflow (Blackwelder 1930; Sharpe 1938; Twenhofel 1939; Sharp and Nobles 1953; Van Houten 1957; Curry 1966; Harland et al. 1966). Boulders in Kennedy drift have been cited as evidence for its glacial origin (Horberg 1954, 1956), but boulders can be carried by mudflow for kilometers down fans, even on gentle grades (Plate 3; Blackwelder 1928; Twenhofel 1939; Sharp and Nobles 1953; Broscoe and Thomson 1969). Horberg (1954) and Stalker and Harrison (1977) noted that Kennedy drift on Makowan Butte retains no surface constructional forms typical of till. However, the form *is* constructional for fan, as are the "traces of knolls and swales" Horberg (1954) saw on Cloudy Ridge. Others have simply repeated that Kennedy drift is glacial, but disturbingly rich in outwash. Horberg's (1956) discussion of a drift

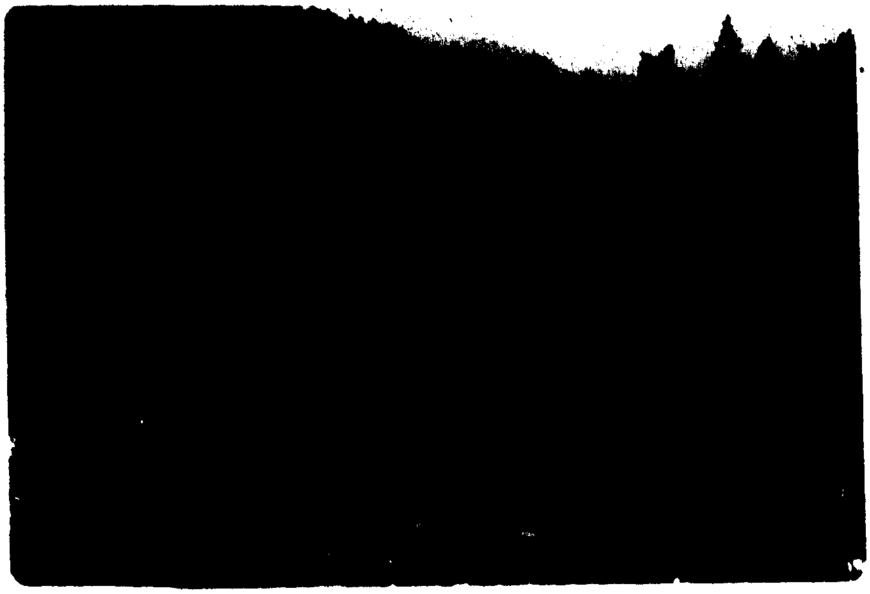

Plate 3. Typical mudflow material with till-like aspect, Washout Creek fan in the Rocky Mountain Trench just south of Golden, British Columbia.

section is illustrative. It arguably describes fan materials as readily as it does glacial:

> *(Kennedy) drift includes gravelly till and coarse bouldery outwash gravel, which in many places are difficult to differentiate . . . . There is considerable variation in texture throughout the profile . . . . From the mechanical analyses alone the deposit as a whole might be considered a silty, gravelly sand of glaciofluvial origin. However, the relatively high silt content, the lack of stratification, and the occurrence of boulders up to 8 feet in diameter indicate that most of the deposit, like mountain drift elsewhere in the region, is a till from which much of the fines were removed during deposition. Sand, gravel, and silt layers and lenses are present, but the bulk of the deposit is considered a true till.*

Regardless of what Kennedy drift might be, a litany of confusion exists between glacial and fluvial (read fan) origins for old drift bordering the Rocky Mountains (*e.g.* Hares 1926a, 1926b). Reinterpretation has often gone the opposite way, *i.e.* drift called pre-Wisconsin till was later recognized as Tertiary or early Pleistocene fan gravel instead (Ray 1940 pp. 1889-1891; Sharp 1948; Van Houten 1957; Mathur and Wengerd 1965; Hambrey 1981). Horberg (1954, 1956) compared Kennedy drift to Blackwelder's (1915) Buffalo Till, drift thought at that time to reflect an early Pleistocene Cordilleran glacial stage which has often been invoked for correlation. Despite that precedent, Richmond (1965) dropped the Buffalo glacial stage, in part because "some deposits called 'Buffalo Till' . . . are now known to be bouldery fan gravels of Pliocene age." Richmond further revealed that "the type deposit of the *(pre-Wisconsin)* Prairie Divide Till . . . is *(now recognized as)* a bouldery facies of the Miocene and Pliocene Ogallala Formation." Ogallala Formation denotes a dissected, high elevation Tertiary alluvial apron bordering the mountains near Denver (Scott 1965).

At minimum then, both glacial and fan origins should be evaluated for older, high elevation gravel in benches bordering the Rocky Mountains. Cloudy Ridge is that exact type of bench. But drift on Cloudy Ridge has received little study (Stalker and Harrison 1977). It has been called: till with gravel beds (Horberg 1954; Stalker and Harrison 1977); moraine that "includes much associated outwash" (Stalker 1959); till with gravelly indurated layers (Wagner 1966); and till with some glaciofluvial deposits (Harrison 1976). The quote from Stalker and Harrison (p. 21 above) also reads that no proof exists that any glacier whatsoever was the source of the Cloudy Ridge drift. From the scant published interpretations and descriptions, the older Cloudy Ridge deposits readily may be of either glacial or fan origin.

In summary, both the extent and correlation of older drift on Cloudy Ridge are uncertain. The material may be glacial or fan and of Miocene to Wisconsin age. The constant in previous interpretations is that some drift there relates to a landscape that occurred prior to late Wisconsin. It is not immediately evident how Cloudy Ridge's present expression reflects any such landscape.

Paleopedological Studies - Cloudy Ridge

In theory, soils occurred in any of the landscapes of the past thought to be associated with Cloudy Ridge. Paleopedological interest has focused on the upper portion of the drift sheets considered older than late Wisconsin. Horberg (1954), Wagner (1966), and Stalker and Harrison (1977) all described soil development that implied paleopedogenesis on their respective versions of the drift.

Horberg (1954) implied paleopedogenesis during a Wisconsin interstadial by differentiating the degree of soil development on Early Wisconsin and Late Wisconsin Mountain drifts, both of which were identified on Cloudy Ridge. The Early Wisconsin drift was considered older because its soils generally had textural B horizons, deeper leaching, and often, stronger colors than the incipient soils typical of the Late Wisconsin drift. The extent of relict component in profile features was not evaluated, as he stated, "The soils on Early Wisconsin mountain drift . . . clearly fall within the category of modern soils studied by soil scientists." He classified one Cloudy Ridge surface profile on the older drift as a Chernozem, giving data for horizon colors and depths only.

Wagner (1966) applied the term paleosol to a much different profile in his version of the older drift on Cloudy Ridge. It was buried by Late Wisconsin till. The profile apparently contained a weathered B horizon of unstated pedogenic character. His interpretation was based on qualitative description and pebble counts.

Stalker and Harrison (1977) mentioned "soils developed on this ridge" but presented neither data nor further paleopedological interpretation of them. They recognized that "little has been published about them."

The Problem - Cloudy Ridge

The above interpretations invite further paleopedological study. First, the scant published data on each profile's features is equivocal, supporting other interpretations as readily as those given. For instance, variation in initial lime content in equal aged materials could account for the differences in weathering depth that Horberg (1954) observed. Secondly, the extent of alteration of profile features during the late Wisconsin is uncertain.

The purpose of my Cloudy Ridge study was thus to determine the most probable causes of the soil-like features occurring in profiles on Cloudy Ridge.

Chapter 3

STUDY OUTLINE

Strategy

To determine the most probable causes of features in Cypress Hills plateau profiles that appear to be the remnants of paleosols, a profile from the Cypress Hills Formation buried by a seemingly unweathered mantle and containing soil-like features (Plate 4) was selected by literature search and field observation.

Similarly, to determine the most probable causes of features in Cloudy Ridge profiles that appear to be the remnants of paleosols, Wagner's (196[illegible] profile was selected for further study because of the soil-like features there (Plate 5).

Each profile was then characterized by the analyses below. Results were evaluated to determine the probable genesis and alteration of features, and the contexts implicated.

Materials and Methods

Methods were similar for both the Cypress Hills and Cloudy Ridge studies except as specifically noted. Symbol convention follows SI (System International) except in the reporting of X-ray diffraction and cation exchange capacity results.

Field descriptions were of three types. Following description of the site, the profile with the best expression of apparent paleopedological features was selected from within the geologic section. Sample layers containing relevant features were then identified at intermittent depth intervals in the profile. Some features were also photographed. Descriptions generally follow the precepts of C.S.S.C. (1978b), with additional terminology usage following Gary et al. (1972).

Two types of samples were taken (where possible) from each sample layer for laboratory analyses. Oriented clods with 5 to 10 cm vertical axes, and bulk samples (less cobbles and larger gravels) of 2 to 5 kg were obtained and subsequently air dried at room temperature.

For micromorphological study, clods were used in the preparation of vertically oriented thin sections (30 µm) as outlined by Brewer and Pawluk (1975). These conventionally prepared glass slides were photographed with a petrographic microscope. One thin section from the Cypress Hills

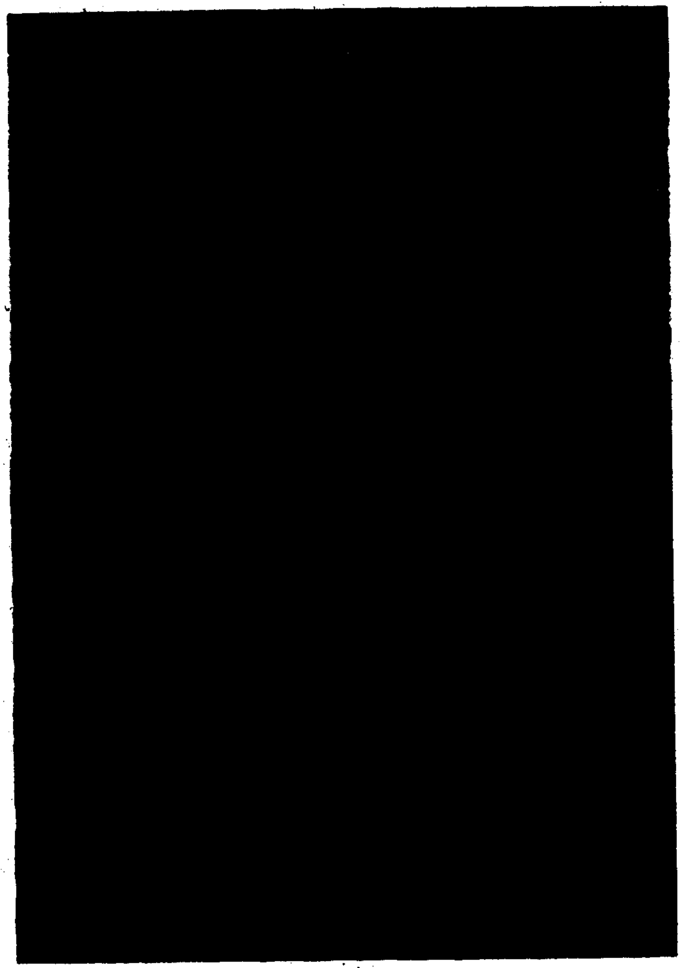

Plate 4. Soil-like features in the Cypress Hills Formation, buried by two layers of unweathered mantle.

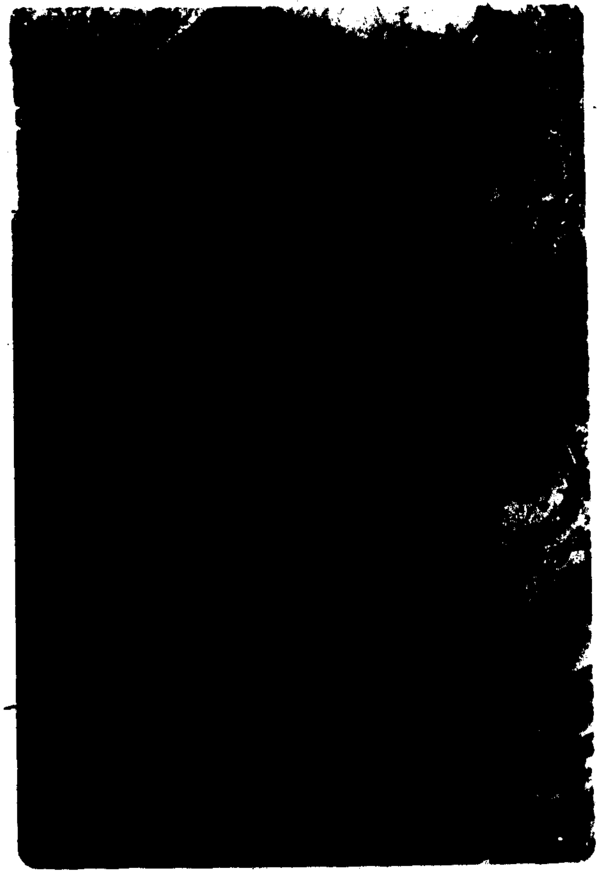

Plate 5. Soil-like features in older Cordilleran material, buried by younger, unweathered Cordilleran till on Cloudy Ridge.

H1 sample layer was ground to approximately 100 µm, left without a cover slip, and photographed using a macro lens in plain transmitted light. Micromorphological terminology follows or was adapted from Brewer and Pawluk (1975) as outlined by Fox (1979). Some terms are also after Brewer (1976, 1979) and occasionally Gary et al. (1972). Similar but smaller clods were used for bulk density determinations of Cloudy Ridge samples only, by the saran coated method of C.S.S.C. (1978c).

Bulk samples were hand ground (mortar and pestel) to pass a 2 mm dry sieve. Fine earth fractions were stored in glass jars for subsequent analyses. Dark colored staining on the Cypress Hills coarse fragments and in the 100 µm H1 thin section was investigated with 3% H_2O_2.

Structures identified in micromorphological analysis were removed from both clods and whole fine earth by tweezers and binocular microscope in selected samples. Slaking tests were observed under this microscope. The infrared absorption spectrum of the pure mineral observed in Cypress Hills samples H1 to H4 was obtained from H1. This mineral, and granular structures from H1 and H6 were carefully crushed to expose fresh faces and mounted on carbon stubs. Elemental analyses on these were determined by an energy dispersive unit attached to a Cambridge S150 scanning electron microscope. Similar samples were sputter coated with 15 nm of gold for scanning electron microscopy (S.E.M.), and photographed using the above machine.

Whole fine earth samples were used for several analyses. The pH was measured in 0.01 M $CaCl_2$ (C.S.S.C. 1978c), Calcium carbonate equivalent followed Bundy and Bremner (1972). Organic carbon was determined by the wet combustion, titration method (C.S.S.C. 1978c). Samples were dissolved by the HCl-HF method of Pawluk (1967). From this solution, total phosphorus by the determination portion of the acid digestion procedure of C.S.S.C. (1978c), and totals of iron and aluminum by the atomic absorption spectophotometry method of Pawluk (1967) were found. Extractable iron and aluminum were determined by the sodium pyrophosphate, acid ammonium oxalate, and dithionate-citrate-bicarbonate followed by atomic absorption spectrophotometry methods of C.S.S.C. (1978c).

Fine earth separates were determined by dry oven weight following 3 minutes of uncooled ultrasonic wet suspension dispersion, adapted from C.S.S.C. (1978c). Sand was obtained by 270 mesh wet sieving. Silt and clay passing the sieve were separated by gravity sedimentation and decantation (Jackson 1956). Oven dry silt and sand values were used to determine clay by difference from total. Clay separates were divided into two portions, then one calcium and the other potassiun saturated.

Some of each calcium saturated clay sample was freeze dried. Total potassium, iron, and aluminum in clays were determined by HCl-HF dissolution and atomic absorption spectrophotometry following Pawluk (1967). After removal of carbonates by sodium acetate buffered to pH 5.5 (C.S.S.C. 1978c), clay surface area (Heilmann et al. 1965) and cation exchange capacity by ammonium acetate (C.S.S.C. 1978c) were determined.

Both the calcium and potassium saturated clays were prepared for X-ray diffraction (X.R.D.) on glass slides by the paste method of Theisen and Harward (1962). Diffractograms were obtained with a Philips X.R.D. unit equipped with a curved crystal monochronometer and the use of Cu-Kα radiation under the following conditions:

1) K-saturated clay, heated to 105°C and run at 0% relative humidity,
2) K-saturated clay, heated to 105°C and run at 54% relative humidity,
3) K-saturated clay, heated to 300°C and run at ambient conditions,
4) K-saturated clay, heated to 550°C and run at ambient conditions,
5) Ca-saturated clay run at 54% relative humidity, and
6) Ca-saturated clay, solvated with ethylene glycol, and run at ambient conditions.

Sands were 60 mesh wet sieved. From sand not passing, in selected Cypress Hills samples biotite and muscovite flakes were removed with tweezers and binocular microscope for S.E.M. as above. Fine and very fine sand passing was treated to remove carbonate as above, then separated at specific gravity 2.72 by s-tetrabromoethane and bromobenzene (Jackson 1956). Oven dry percentages were determined.

On the lighter mineral subsample, totals of sodium, calcium, and potassium were determined by the HCl-HF dissolution and atomic absorption spectrophotometry method of Pawluk (1967). These values were recalculated to percent albite, anorthite, and orthoclase. Petrographic thin sections (30 µm) were prepared of the heavier mineral subsample in a manner similar to the micromorphological samples above.

Chapter 4

CASE STUDY RESULTS

Cypress Hills - Results and Discussion

The Cypress Hills Formation appears to have undergone change at the site since deposition. Characteristics of the sampled profile appear to reflect alteration and/or reorganization of some components. Discussion is centered on the upper portion of the the Cypress Hills Formation that exhibits the soil-like features (samples H6 to H1, Fig. 3).

Field Descriptions and Analyses

Present landscape setting of the Cypress Hills site (Fig. 1) is described in Table 1 and shown in Plate 6.

The geologic and type sections are described in Table 2, and some aspects are shown in Plates 7 to 9. A schematic of the type section (Fig. 3) identifies the layers referred to in text. The outstanding features are the color distribution and the apparent disruption of sedimentary structures and stratification in the Cypress Hills Formation. Jungerius (1966) and Westgate (1968, 1972) discussed derangement in the topmost 1 to 2 m. Complete disruption of the matrix near the top and partial disruption going beyond depths of 4.4 m are reflected by the uniformity of the upper layers and the increasing heterogeneity with depth (Table 3; Plates 10, 11).

Micromorphological Analyses

Speculations about change since deposition of the Cypress Hills Formation are supported by micromorphological analyses (Table 4; Plates 12 to 20). Changes appear to be of three kinds:

1) fabric and plasma reorganization. Granular structures with their related features constitute the upper layers (Plates 13,14; Jungerius and Mucher 1972 Fig. 4) and finer textured portions of the lower layers (Plate 17). The internal similarity of the structures throughout the profile is evident (Plates 21, 22). Jungerius and Mücher believed the grains were "transported as stable aggregates" and thus antedate deposition, but that is unlikely because they slake instantly. They probably formed *in situ* ;

Table 1. Cypress Hills site description.

Location:	Northwest edge of Cypress Hills plateau, near fire observation tower above Elkwater, Cypress Hills Provincial Park, Alberta (Figure 1)
Map Reference:	Elkwater Lake, 1:50,000 (72 E/9, Edition 1 MCE, Series A 741)
Military Grid:	12 U WK483982
Elevation:	1440 m a.s.l.
Vegetation:	Fescue prairie (Bird and Halladay 1967)
Landform:	Eolian blanket/Fluvial level (scale 1:50,000)
Slope:	2 complex (0.5-2.5%), overall aspect east
Drainage:	Well to rapid
Seepage:	Absent
Stoniness:	Nonstony
Rockiness:	Nonrocky
Land Use:	Natural grazing
Classification:	Orthic Black Chernozemic (present solum)
Described:	August, 1975

Table 2. Cypress Hills geologic and type section descriptions.

Nature of exposure:	Actively eroding slump scarp. Lateral variation was well exposed across the upper face of the geologic section. At depth, lateral variation was obscured by a colluvial veneer, and only the type section was exposed.
Scarp slope:	70%
Aspect:	Northwest

Stratigraphic Layers*

Cover II: Depth 0-1.1 m. Characteristics uniform with depth except as indicated, and as modified by present solum in the upper 70 cm.

Light yellowish brown (10YR 6/4 m); no effervescence; massive bedding; very weak coarse prismatic to structureless; friable; heterogeneous mixture of clay to gravel particle sizes, dominated by silt; silt loam.
Coarse fragments - < 5% by volume, gravels; content maximum in a band near the bottom of the layer (Plate 8); subrounded and rounded, high sphericity; quartz sandstone lithology dominant, often pitted surfaces or fractures superimposed on rounding; quartzite lithology subdominant, smooth surfaces occasionally with thin, patchy manganese oxide coatings; elongated axes generally highly inclined.
Lateral variation - The type section has the maximum observed depth of Cover II and it overlies Cover I. Cover II may be as thin as 50 cm, and overlie the Cypress Hills formation directly (Plate 9). In the latter case coarse fragment content is higher and the present solum influences the entire layer.
Lower boundary is gradual, wavy across the geologic section.
Grab sample taken.

Cover I: Depth 1.1-1.6 m. Characteristics uniform with depth.

Yellowish brown (10YR 5/4 m); strong effervescence; massive bedding; medium pseudoplaty; very friable; heterogeneous mixture of clay to cobble particle sizes, dominated by silt; silt loam.

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*Names within the Cypress Hills Formation after Westgate (1972)

(cont.)

Table 2. Cypress Hills geologic and type section descriptions.

Coarse fragments - 5% by volume, gravels > cobbles; subrounded and rounded, high sphericity; quartz sandstone lithology dominant, often pitted surfaces or fractures superimposed on rounding; quartzite lithology subdominant, smooth surfaces, occasionally with thin, patchy manganese oxide coatings; many have elongated axes highly inclined.
Lateral variation - Type section has maximum observed depth of Cover I. Deposit found lensing in and out, each 2 to 3 m lateral dimension, across geologic section, always bounded by Cover II above and Cypress Hills formation below. Material was observed to fill frost wedges formed in the upper metre of the underlying Cypress Hills Formation. Lower boundary is clear, wavy except where material is discontinuous, and in frost wedges.
Sample H7 was taken to represent the entire Cover I layer (Figure 3).

Cypress Hills Formation 4, 3, 2: Depth 1.6 to ≈ 8 m, lower 2 m not observed. Characteristics change at nonuniform rate with depth except as indicated. Changes described occur with depth.

Red (10R 4/8 m), becomes dominantly brown (10YR 5/3 m), but reddish colours occur throughout (Table 3); moderate effervescence, becomes very weak effervescence; massive bedding (solimixtion?), becomes weakly stratified with strong involutions; strong (pseudo)granular, becomes variable; friable to firm, becomes variable from firm to very friable; heterogeneous mixture of clay to cobble sizes, with depth remains similar but in sorted pockets depending on involutions; gravelly clay loam, becomes heavy clay to gravelly sandy loam in pockets depending on involutions.
Coarse fragments - 40 to 55% by volume, gravels > cobbles throughout; subrounded and rounded, high sphericity; quartz sandstone lithology, often with pitted surfaces superimposed on rounding, dominant near upper layer boundary; with depth, dominance of quartz sandstone gives way to dominance of quartzite lithology, with smooth surfaces, frequently with thin, patchy manganese oxide coatings; at top elongated axes highly inclined, but with depth no preferred imbrication.
Lateral variation - Type section has thickest, most red coloured upper layer of Cypress Hills Formation

(cont.)

Table 2. Cypress Hills geologic and type section descriptions.

observed in the geological section (Plates 4 and 9).

Samples H6, H5, H4, H3, H2, and H1 were taken from near upper to near lower unconsolidated Cypress Hills Formation layer boundaries respectively (Figure 3).

Cypress Hills Formation I: Depth ≈ 8-12+ m. Layer was not examined in detail.

Light gray (10YR 7/1 m); strong effervescence; indurated with carbonate cement; massive bedding to weakly stratified; heterogeneous mixture of clay to cobble particle sizes, probably low in silt and clay prior to cementation.

Coarse fragments - ≈ 70% by volume, gravels > cobbles; subrounded and rounded, high sphericity; quartzite lithology dominant, frequently with thin, patchy manganese oxide coatings.

Plate 6. Cypress Hills site.

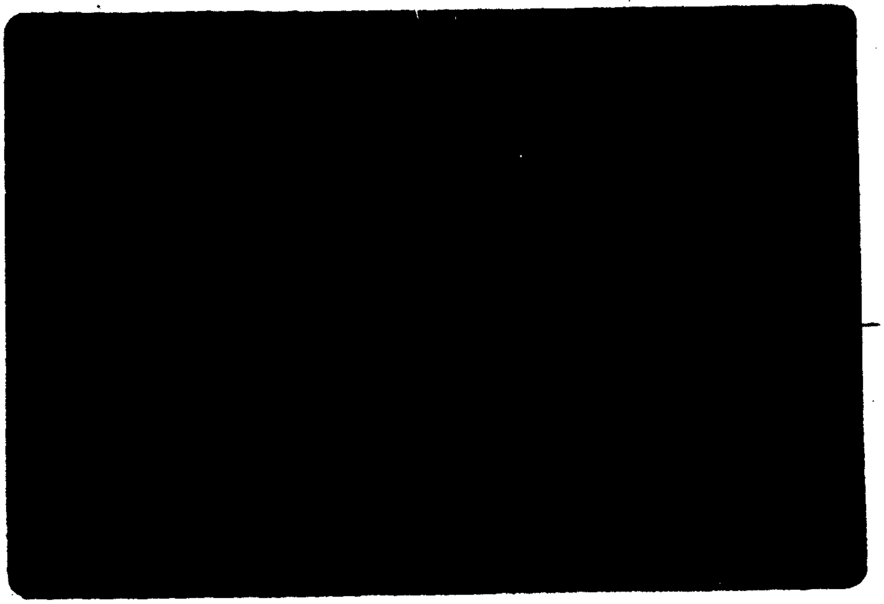

Plate 7. Cypress Hills geologic section.

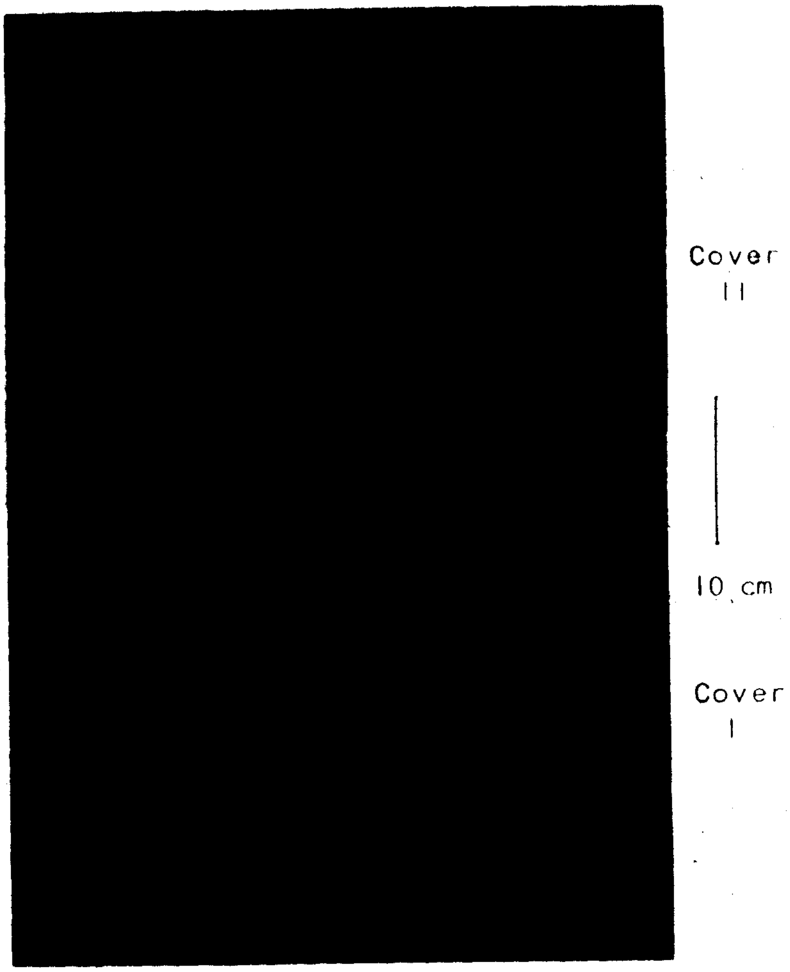

Plate 8. Contact of Cover II (above) and Cover I (below) showing Cypress Hills Formation gravels elevated completely through the lower.

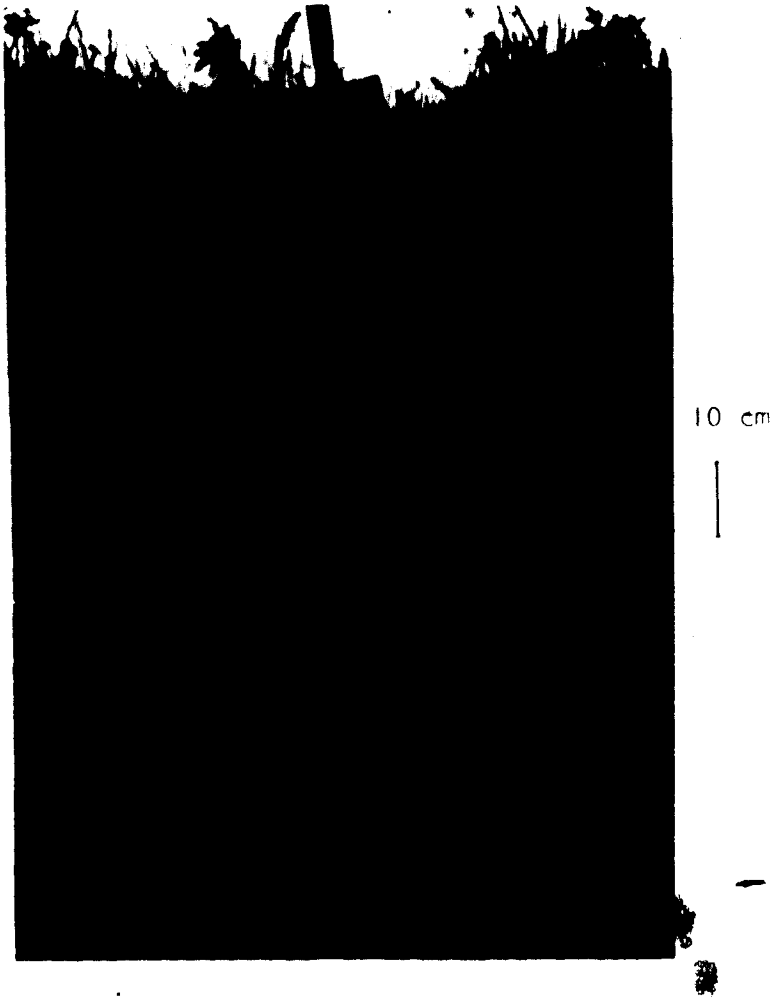

Plate 9. Section lateral variation, showing absence of the Cover I layer and subdued color in the Cypress Hills Formation upper layer, and mixing at the contact.

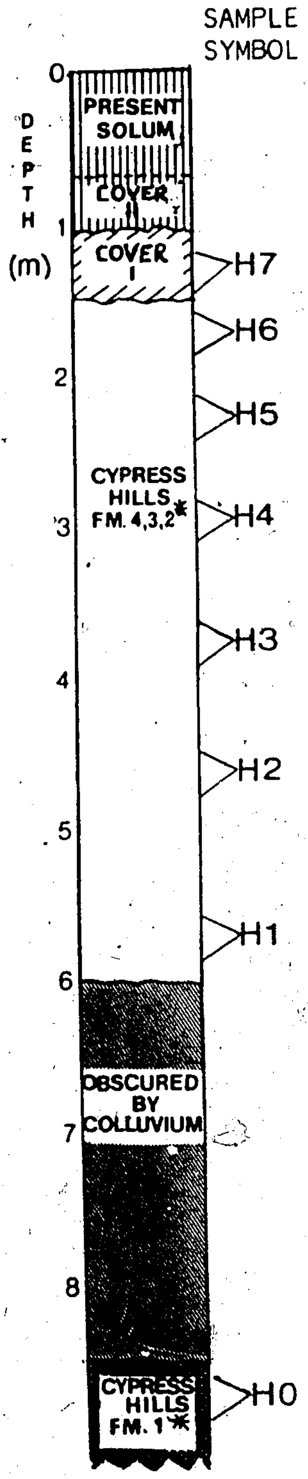

Figure 3.

Schematic of the Cypress Hills type section showing sample layers.

*names after Westgate (1972).

Table 3. Cypress Hills sample descriptions.

H7 Depth 1.3-1.6 m; yellowish brown (10YR 5/4 m), pale brown (10YR 6/3 d); silt loam; medium pseudoplaty; very friable; few, very fine roots; highly porous; strong effervescence; many, fine, medium, and coarse secondary carbonates along many pores and root channels; est. coarse frag. 5% gravels, 2% cobbles.

H6 Depth 1.7-1.9 m; red (10R 4/8 m), red (2.5YR 4/8 d); gravelly clay loam; moderate to strong, fine, (pseudo)granular; friable to firm; many, thin and moderately thick cutans on coarse fragments and forming outer surface of granular structures; few, very fine roots; slightly porous; moderate effervescence in matrix; common, fine, medium, and coarse secondary carbonate accumulations in pores and under coarse fragments; est. coarse frag. 25% gravels, 5% cobbles.

H5 Depth 2.1-2.4 m; red (2.5YR 5/8 m), yellowish red (5YR 5/8 d); gravelly sandy clay loam; moderate, fine, (pseudo)granular > patches of structureless, single grain; friable; many, thin cutans on coarse fragments and forming outer surface of granular structures; very few, very fine roots; slightly porous; moderate effervescence in matrix; few secondary carbonate accumulations in pores, common coating under coarse fragments; est. coarse frag. 25% gravels, 15% cobbles.

H4 Depth 2.9-3.2 m; red (2.5YR 4/8 m), yellowish red (5YR 5/8 d); gravelly sandy clay loam; areas of moderate, fine, (pseudo)granular, and structureless, single grain; friable; common, thin cutans forming outer shell of granular structures, and on some coarse fragments; very few, very fine roots; slightly porous; weak effervescence; few secondary carbonates in pores and coating under coarse fragments; est. coarse frag. 30% gravels, 15% cobbles.

(cont.)

Table 3. Cypress Hills sample descriptions.

H3 Depth 3.7-4.0 m; nonuniform sample layer--occasional

A) finer textured end member: red (2.5YR 4/8 m), yellowish red (5YR 5/8 d); occasional patchy secondary colour brown (10YR 5/3 m), very pale brown (10YR 7/3 d); gravelly clay; moderate, fine, (pseudo)granular; friable; few cutans on granular structures; very few, very fine roots; slightly porous; weak effervescence; few secondary carbonates coating under coarse fragments.

Above is intimately mixed with

B) coarser textured end member: red (25YR 4/8 m), yellowish red (5YR 5/8 d); gravelly sandy loam; structureless, single grain; very friable; very few, very fine roots; moderately porous, weak effervescence; few secondary carbonates coating under coarse fragments.

Est. coarse frag. 30% gravels, 15% cobbles, uniform distribution throughout layer.

H2 Depth 4.5-4.8 m; nonuniform sample layer--

A) finer textured end member: red (2.5YR 4/8 m), yellowish red (5YR 5/8 d); patchy secondary colour brown (10YR 5/3 m), very pale brown (10YR 7/3 d); gravelly clay; medium to coarse (pseudo)subangular blocky, occasionally moderate, fine (pseudo)granular; friable; slightly porous; very weak effervescence;

Above is intimately mixed with

B) coarser textured end member: red (2.5YR 4/8 m), yellowish red (5YR 5/8 d); patchy secondary colour pale brown (10YR 6/3 m), very pale brown (10YR 7/4 d); gravelly sandy loam, structureless, single grain; very friable; moderately porous; very weak effervescence; few secondary carbonates coating under coarse fragments.

Est. coarse frag. 35% gravels, 20% cobbles, uniform distribution throughout layer.

(cont.)

Table 3. Cypress Hills sample descriptions.

HI Depth 5.6-5.9 m; nonuniform sample layer--

A) finer textured end member: brown (10YR 5/3 m), very pale brown (10YR 7/3 d); patchy secondary colour red (2.5YR 4/8 m), yellowish red (5YR 5/8 d); gravelly clay; medium to coarse (pseudo)subangular blocky; friable; slightly porous, very weak effervescence: occasional pockets reddish brown to red (2.5YR 4/5 m), red (2.5YR 5/6 d); heavy clay.

Above is intimately mixed with

B) coarser textured end member: pale brown (10YR 6/3 m), very pale brown (10YR 7/4 d); patchy secondary colour red (2.5YR 4/8 m), yellowish red (5YR 5/8 d); gravelly sandy loam; structureless, single grain, very friable; moderately porous; very weak effervescence; few secondary carbonates coating under coarse fragments.

Est. coarse frag. 25% gravels, 15% cobbles; uniform distribution throughout layer.

HO Depth 8.7-9.0 m; light gray (10YR [illegible]) very gravelly loamy sand prior [illegible]tion(?); continuous, indurated [illegible]te cementation; slightly porous; strong effervescence; est. coarse frag. 50% gravels, 20% cobbles.

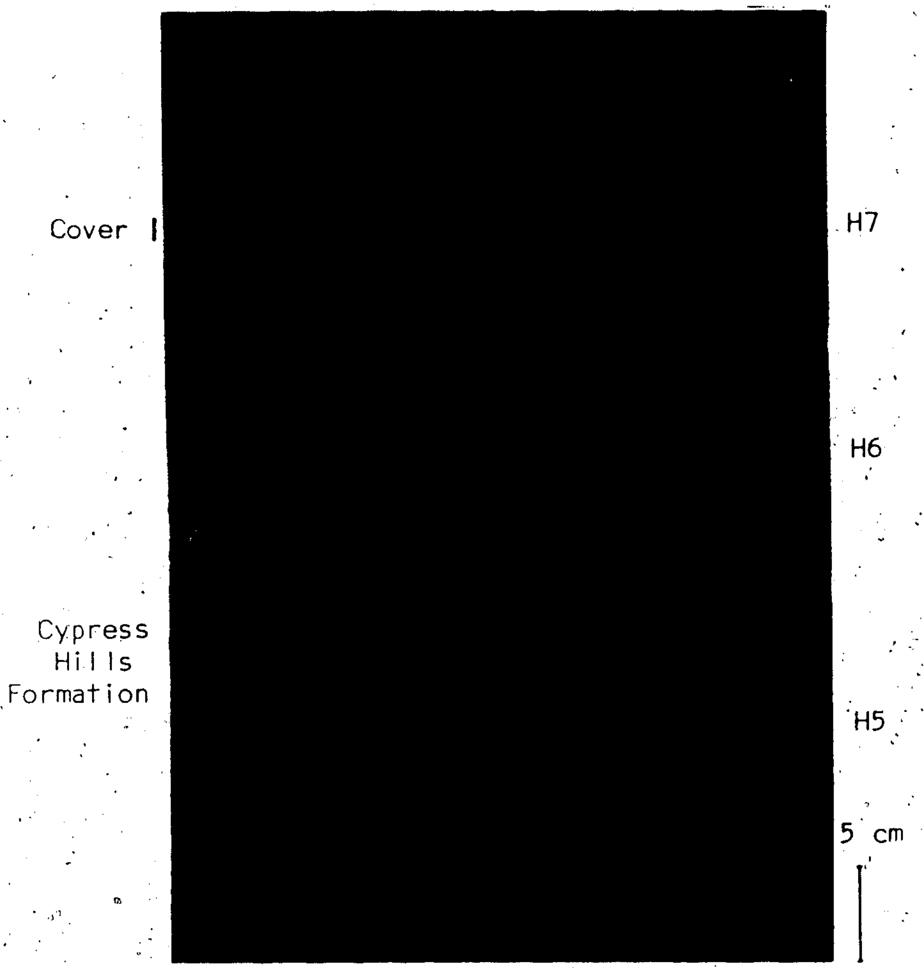

Plate 10. Contact of Cover I (above) and the Cypress Hills Formation (below) showing sample layers.

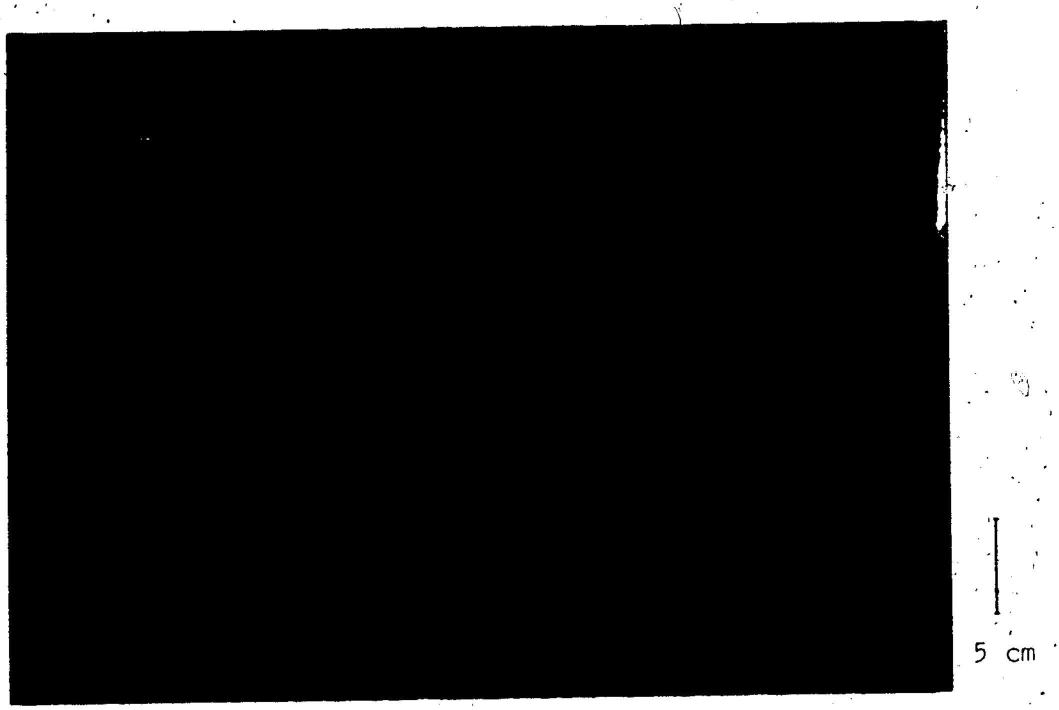

Plate 11. Sample layer HI showing material variability 4 m down into the Cypress Hills Formation.

Table 4. Micromorphological descriptions of Cypress Hills samples.

H7 1.3-1.6 m.

Fabric type: Matrifragmic - matrifragmoidic (mixed complex).
Weak, local internal fragmoidic porphyroskelic fabric in some granular structures.
Densely packed, except for very large (1-4 mm), occasional, horizontal and vertical joint planes.
Frequent vughs (.5 mm), often oval (channels?), and connected by frequent skewplanes.
Plasmic fabric: Silasepic (skelsepic at higher magnification).
Phenoclasts: Very few; smaller angular (fractured) and larger subrounded and rounded medium grained sandstone and quartzite.
Features: Roots occupy some joint planes.
Thin, discontinuous embedded grain argillans on phenoclasts.
Most matrix skeleton grains are encased in very thin embedded grain argillans, producing skelsepic plasmic fabric.
Frequent, very small, bright orange-brown papules.
Common, medium (up to 1 mm) bright orange-brown nodules encased in argillans (similar to granular structures in H6); variable ratio of skeleton grains to plasma.
Frequent, thick (up to 3 mm) void neocalcitans.

H6 1.7-1.9 m.

Remarks: Layer boundary between H7 and H6 has mixed complex characteristics of each.
Fabric type: Matrifragmoidic - matrifragmic (mixed complex).
The matrix has coalesced into well expressed, nodule-like granular structures (up to 2 mm) in matrifragmic areas; matrifragmoidic areas appear similar but the voids terminate and plasma separations defining granular structures are less well developed.
Plasmic fabric: Skelsepic and mosepic.
Phenoclasts: Subrounded and rounded, medium grained sandstone and quartzite; frequent sesqui- and manganese oxide interstitial staining in sandstone; occasional pitted and fractured surfaces superimposed on rounding.
Features: Frequent, moderately well oriented argillans and matri-argillans, often with diffuse inner boundaries, encasing granular structures and free grains; embedded grain matri-argillans produce skelsepic plasmic fabric; discontinuous on phenoclasts, but as frequently present on fractured as rounded surfaces.
Common, medium (up to 1 mm) void neocalcitans.
Common, opaque, medium (up to .5 mm) manganese oxide nodules.

H5 2.1-2.4 m.

Fabric type: Matrifragmoidic - matrifragmic (mixed complex).
The matrix has coalesced into nodule-like granular structures

(cont.)

Table 4. Micromorphological descriptions of Cypress Hills samples.

(up to 2 mm) in matrifragmic areas; matrifragmoidic areas appear similar but the voids terminate and plasma separations defining granular structures are less well developed.

Plasmic fabric: Skelsepic and mosepic.

Phenoclasts: Subrounded and rounded, medium grained sandstone and quartzite; frequent sesqui- and manganese oxide interstitial staining in sandstone; occasional pitted and fractured surfaces superimposed on rounding.

Features: Cutans. Frequent, moderately well oriented argillans and matri-argillans encasing granular structures and free grains; discontinuous on phenoclasts, but as frequently present on fractured and pitted as rounded surfaces.
Occasional, medium (up to 1 mm) void neocalcitans.
Common, opaque, medium (up to .5 mm) manganese oxide nodules.

H4 2.9-3.2 m.

Remarks: Complex micromorphology because of involutions in this sample layer.

Fabric type: Plectic - plectic porphyroskelic (mixed complex). The less common plectic areas are sand and commonly sand sized granular structures, with nearly continuous very thin and thin matri-argillans; more common plectic-porphyroskelic areas are a heterogeneous mixture of sand grains, occasional, small granular structures, and plasma, with a tendency toward plasma separations defining a weak matrifragmoidic fabric.

Plasmic fabric: Skelsepic and mosepic.

Phenoclasts: Subrounded and rounded, medium grained sandstone and quartzite; frequent sesqui- and manganese oxide interstitial staining in sandstone; few pitted and fractured surfaces superimposed on rounding.

Features: Papules. Common, small, truncated tabular papules of a pure, bright orange-brown phyllosilicate mineral; associated with all fabrics.
Cutans. 1) Occasional bright orange-brown void argillans throughout. 2) Common thin matri-argillans throughout; embedded grain matri-argillans produce skelsepic plasmic fabric; discontinuous on phenoclasts, but as frequently present on fractured as rounded surfaces.
Granular structures often contain sandgrains, often an internal fragmoidic porphyroskelic fabric.
Very few medium (up to 1 mm) void neocalcitans.
Common, opaque, medium (up to .5 mm) manganese oxide nodules.

H3 3.7-4.0 m.

Remarks: Complex micromorphology related to involutions in this sample layer. There are three distinct elements plus intergrades.

(cont.)

Table 4. Micromorphological descriptions of Cypress Hills samples.

Fabric type: 1) Partially accomodated matrifragmic / 2) plectic porphyroskelic = 3) plectic (separated and mixed complexes). In the primary subdivision, the separated complex, each has strongly contrasting overall characteristics.

1) Partially accomodated matrifragmic. This fabric occurs in occasional patches up to a few cm in size in a matrix of the other fabrics; consists of granular structured material with individuals up to 1 cm; frequent, strong, internal fragmoidic porphyroskelic fabric defined by weak matri-argillans within the granular structures; most granular structures are low in sand; plasmic fabric silasepic, skelsepic at higher magnification. This internal fabric occurs in granular structures throughout the sample.

2) Plectic porphyrskelic. A heterogeneous mixture of sand, variable sized (up to 5 mm) granular structures, and plasma, with a tendency toward plasma separations in the form of frequent matri-argillans defining a weak matrifragmoidic fabric.

3) Plectic. Sand and commonly sand sized granular structures, with nearly continuous very thin and thin matri-argillans.

Plasmic fabric: Skelsepic / silasepic.

Phenoclasts: Subrounded and rounded, medium grained sandstone and quartzite; frequent interstitial sesqui- and manganese oxide staining in sandstone; occasional pitted surfaces superimposed on rounding; discontinuous, thin matri-argillans on both rounded and pitted surfaces.

Features: Papules. Common, medium (up to 1 mm), truncated, tabular papules of a pure, bright orange-brown phyllosilicate mineral; associated with all fabrics.

Cutans. 1) Common bright orange-brown void argillans throughout. 2) Common thin matri-argillans throughout; embedded grain matri-argillans produce skelsepic plasmic fabric.

Common, opaque, medium (up to .5 mm) manganese oxide nodules.

H2 4.5-4.8 m.

Remarks: Complex micromorphology because of involutions in this sample layer; there are three distinct elements plus intergrades.

Fabric type: 1) Partially accomodated matrifragmic / 2) plectic porphyroskelic - 3) plectic (separated and mixed complexes). In the primary subdivision, the separated complex, each has strongly contrasting overall characteristics.

1) Partially accomodated matrifragmic. This fabric occurs in common patches varying up to several cm in size in a

(cont.)

Table 4. Micromorphological descriptions of Cypress Hills samples.

matrix of the other fabrics; consists of granular structured material with individuals up to 1 cm; frequent, strong, internal fragmoidic porphyroskelic fabric defined by weak matri-argillans within the granular structures; most granular structures are devoid of sand; plasmic fabric silasepic, skelsepic at higher magnification. This internal fabric occurs in granular structures throughout the sample.

2) Plectic porphyroskelic. A heterogeneous mixture of sand, variable sized (up to 5 mm) granular structures, and plasma; often with continuous, thin matri-argillans.

3) Plectic. The most common fabric element; sand and occasional sand sized granular structures; nearly continuous, very thin matri-argillans.

Phenoclasts: Subrounded and rounded, medium grained sandstone and quartzite; frequent interstitial sesqui- and manganese oxide staining in sandstone, occasional pitted surfaces superimposed on rounding; discontinuous, thin matri-argillans on both rounded and pitted surfaces.

Features: Papules. Occasional, medium (up to 1 mm), truncated, tabular papules of a pure, bright orange-brown phyllosilicate mineral; associated with all fabrics.

Cutans. Common bright orange-brown void argillans throughout, as well as the previously mentioned matri-argillans. Common, opaque, medium (up to .5 mm) manganese oxide nodules.

HI 5.6-5.9 m.

Remarks: Complex micromorphology because of involutions in this sample layer; there are four distinct elements plus intergrades.

Fabric type: 1) Plectic - 2) plectic porphyroskelic / 3a,b) partially accomodated matrifragmic.

In the primary fabric subdivision, the separated complex, each has strongly contrasting overall characteristics. Further subdivision is on a mixed complex fabric basis (1 and 2), and mineralogy (3a, 3b).

1) Plectic. Sand and sand sized granular structures; most are coated with very thin matri-argillans.

2) Plectic porphyroskelic. A heterogeneous mixture of sand, variable sized (up to 5 mm) granular structures, and plasma; often with very thin to thin matri-argillans.

3a) Partially accomodated matrifragmic. Pure, bright orange-brown phyllosilicate mineral in structures up to 4 cm; varying from nearly isotropic, to simultaneous extinction of stockade arranged crystals in tabular sheets up to 1 mm thick; contorted crystal sheets most frequent, usually free but occasionally adhering to or mixed with granular structures.

(cont.)

Table 4. Micromorphological descriptions of Cypress Hills samples.

3b) Partially accomodated matrifragmic. The most common fabric element; occurs nearly continuously with other fabrics interfingering; consists of granular structured material with individuals up to 1 cm; frequent, strong, internal fragmoidic porphyroskelic fabric defined by weak matri-argillans within the granular structures; most granular structures are devoid of sand; plasmic fabric silasepic, skelsepic at higher magnification. This internal fabric occurs in granular structures throughout the sample.

Phenoclasts: Subrounded and rounded medium grained sandstone and quartzite; frequent interstitial sesqui- and manganese oxide staining in sandstone; occasional pitted surfaces superimposed on rounding; discontinuous thin matri-argillans on both rounded and pitted surfaces.

Features: Occasional bright orange-brown void argillans throughout, as well as the previously mentioned matri-argillans.

Common, opaque, medium (up to .5 mm) manganese oxide nodules.

H0 8.7-9.0 m.

Fabric type: Orthoiunctic - porphyroskelic (mixed complex). The sample is highly infused with secondary carbonate. Considering the carbonate to be plasma, complete infusion produces porphyroskelic areas, locally incomplete produces gefuric areas with simple packing voids.

Prior to cementation the sample is inferred to have been loosely packed gefuric - chalmydic.

Plasmic fabric: Crystic. This fabric occurs where carbonate is the only visible plasma.

Prior to cementation the plasmic fabric is inferred to have been silasepic.

Phenoclasts: Subrounded and rounded, medium grained sandstone and quartzite; frequent interstitial sesquioxide staining in sandstone.

Features: Crystallaria. Few, large (5 mm) intercalary crystal groups, with 0.1 mm crystals.

The sample matrix is encased in frequent, large (5-10 mm) carbonate nodules; diffuse outer boundaries; 0.1 mm crystals.

Very few mica skeleton grains with secondary carbonate crystals intercalated between exfoliated layers.

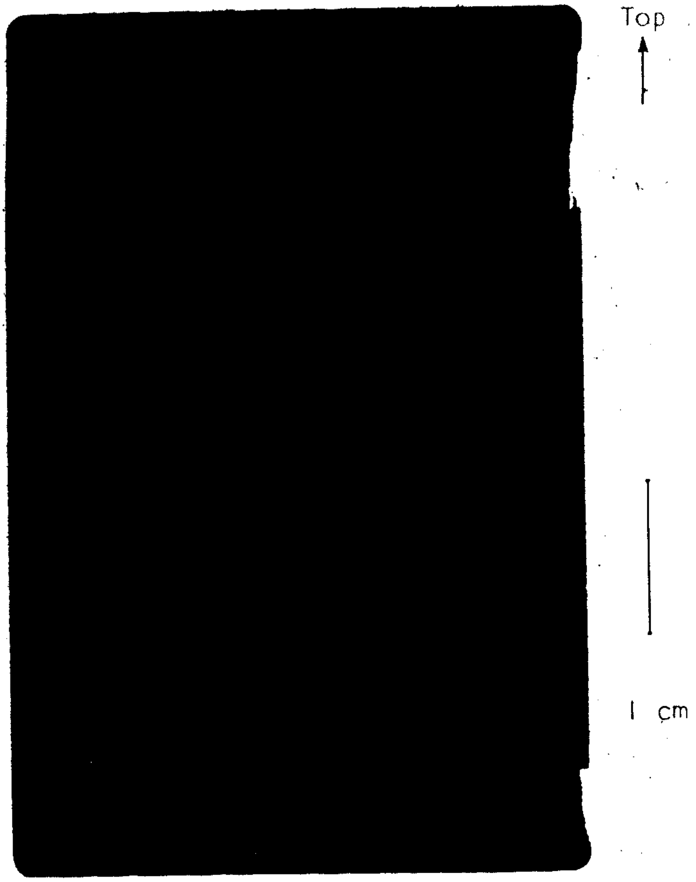

Plate 12. Oriented thin section in plain transmitted light from Cypress Hills sample layer HI showing the effect of involutions.
Note: the black mineral is ~~a~~ manganese oxide. Discoloration at the slide center is an artifact of the H_2O_2 test.

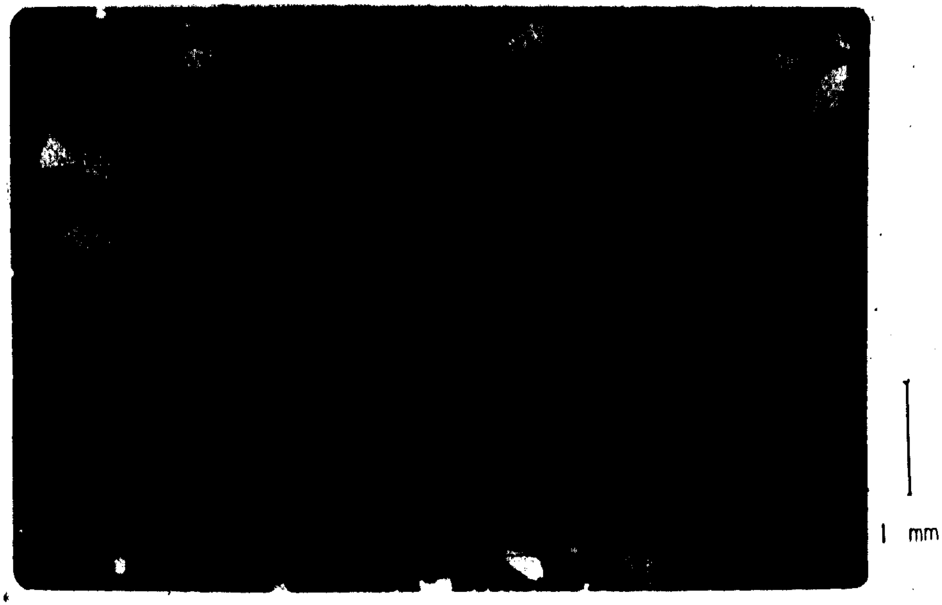

Plate 13. Thin section of metamatrifragmoidic fabric in Cypress Hills sample H6.

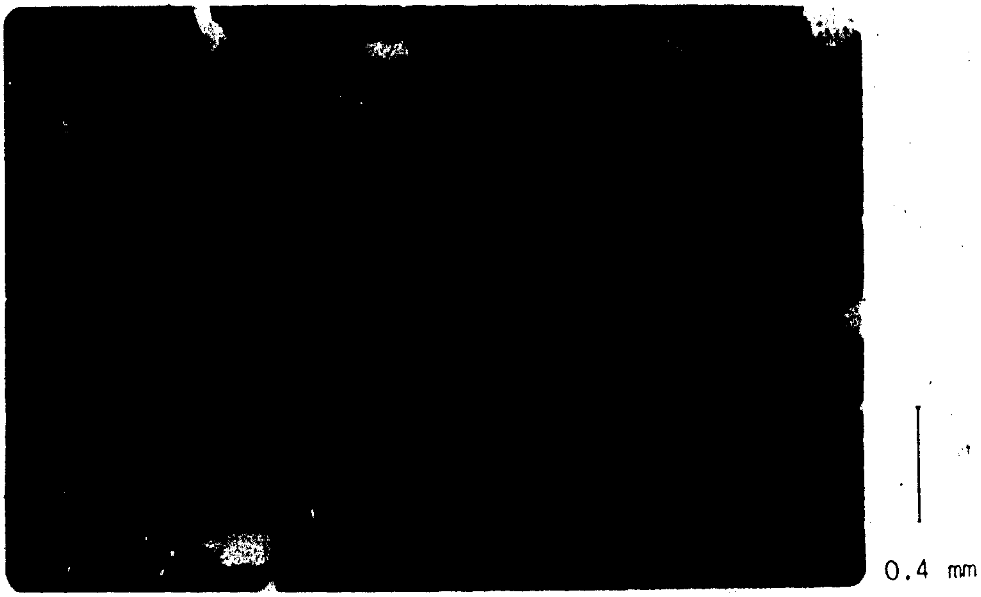

Plate 14. Thin section of metamatrifragmic granular structure in Cypress Hills sample H6.

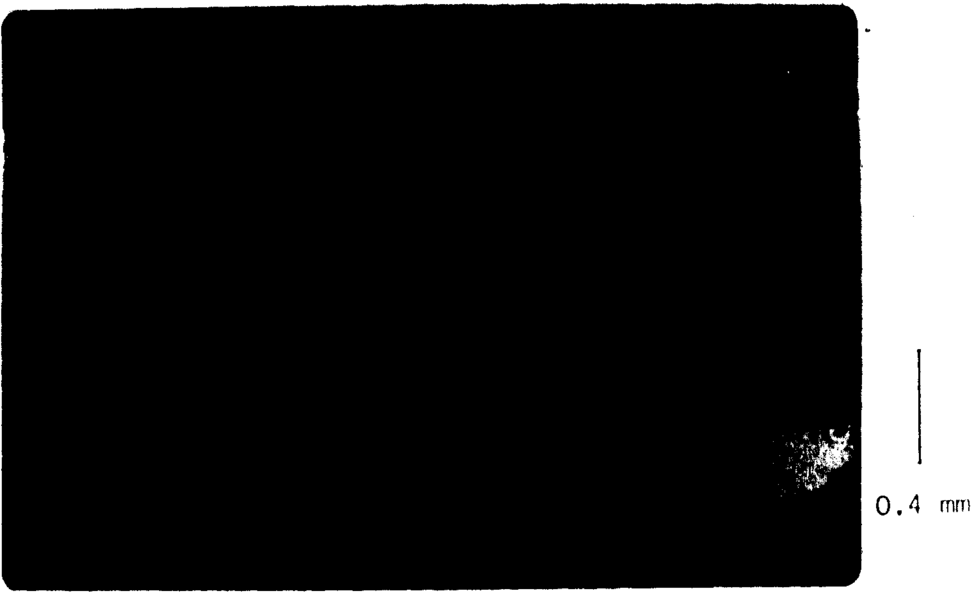

Plate 15. Thin section showing mixing of truncated papules of a pure phyllosilicate, granular structures, and sand grains in Cypress Hills sample H4.

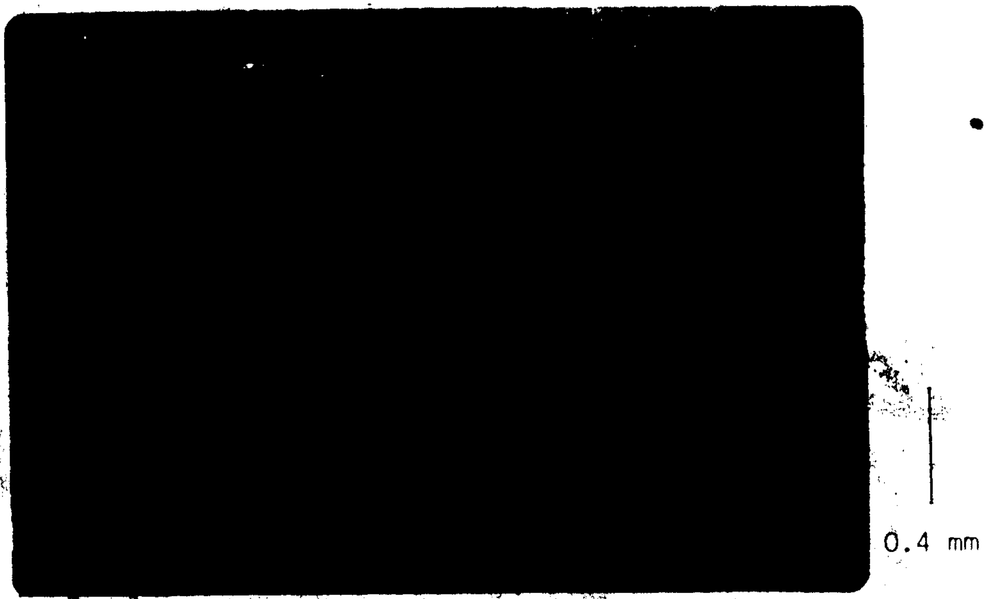

Plate 16. Thin section showing void argillans in Cypress Hills sample H3.

Plate 17. Thin section of fragmoidic porphryskelic fabric in Cypress Hills sample H2.

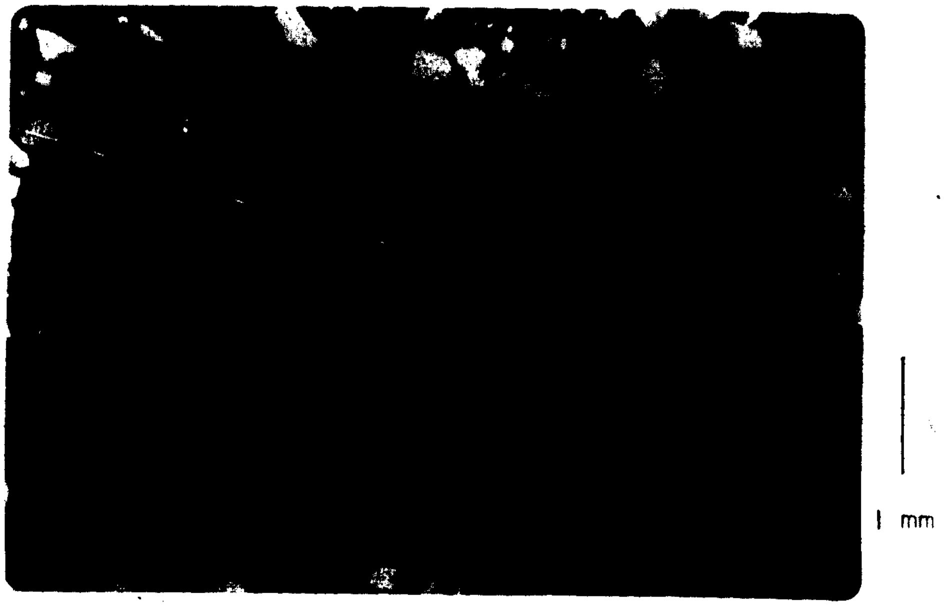

Plate 18. Thin section of plectic fabric in Cypress Hills sample H2.

Plate 19. Thin section of a pure phyllosilicate mineral both concentrated in and dispersed through the matrix of Cypress Hills sample H1.

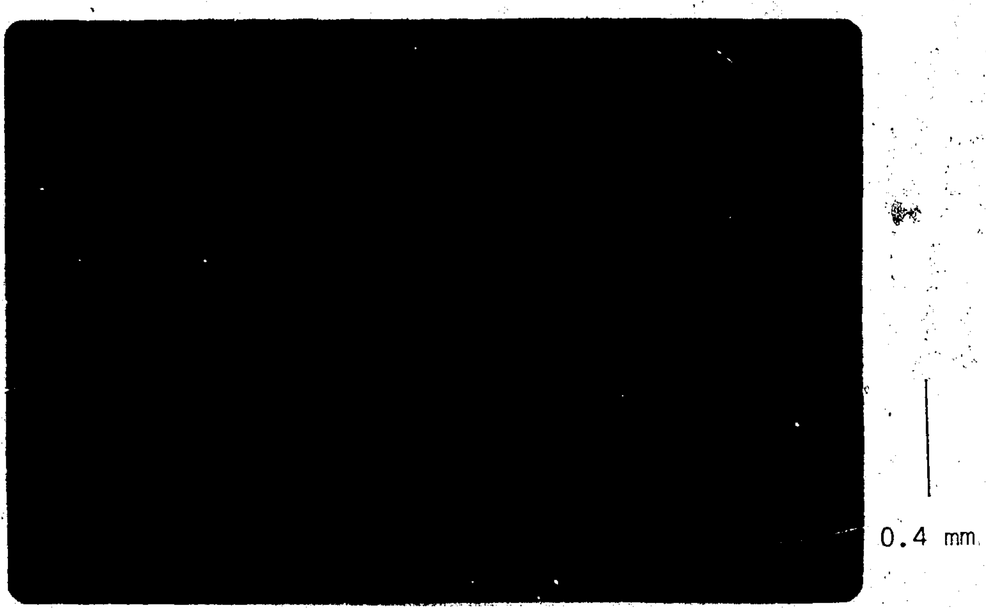

Plate 20. Thin section of a mica with intercalated carbonate in the Cypress Hills conglomerate sample H0.

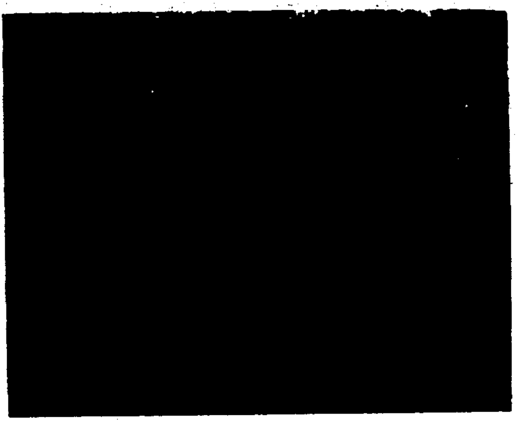

Plate 21. Scanning electron micrograph of a granular structure interior from Cypress Hills sample H6.

Plate 22. Scanning electron micrograph of a granular structure interior from Cypress Hills sample H1. Note: structure at left is an artifact.

2) physical disruption. Plate 12 shows the involutions at depth. In the upper layers, the textural uniformity and absence of both structures and stratification typical of fluvial sedimentation imply mixing there was complete; and

3) mineral neogenesis. The lower samples H1 to H4 contain concentrations of a pure phyllosilicate mineral, some up to a few centimeters in size (Table 4; Plate 19). These also slake instantly, so were probably not inherited. The relationship between the larger concentrations and the matrix, and the way the mineral is dispersed in lower concentrations throughout the matrix indicates it is likely neogenic rather than illuvial. The mineral appears to be a smectite (Fig. 4), probably beidellite-montmorillonite (Borchardt 1977). Figures 5 and 6 are the first of several pieces of evidence to be presented indicating there was mineral neogenesis throughout the profile. The degree throughout is not known.

The three suggested processes, as well as burial of the profile, can be arranged in a probable chronosequence. Mineral neogenesis preceeded disruption because the pure mineral was affected (Table 4; Plates 15, 19). Disruption preceeded genesis of the granular structures because of the intimate mixing of particle sizes where mixing was complete (*c.f.* Plate 13 with Plates 17, 18). That conclusion is also supported by the relationship between matri-argillans and broken faces of coarse fragments if, as presumed, the fracturing occurred during disruption (Table 4). Jungerius and Mucher (1972) felt that many features in profiles on the plateau were generated following disruption. But at least some of the disruption must be contemporaneous with or postdate burial since there are coarse fragments incorporated into even the upper layer of silty mantle (Table 2; Plate 8; Westgate 1972). Therefore, it is probable that the present fabric and features of the apparently thoroughly mixed top layers of the conglomerate (H5 and H6) were generated during or following burial. If the preceding conclusion is correct, there is no pedogenic record held in the micromorphological fabric or features at the top of the Cypress Hills Formation at this site.

Other preburial agents capable of mixing and generating granular fabric, such as roots or soil organisms, have not been proposed by previous workers and there is no record these agents were ever present, though smooth (meta) granular structures like those throughout the profile have been associated with pedogenesis. Brewer and Pawluk (1975) interpreted some to be faecal

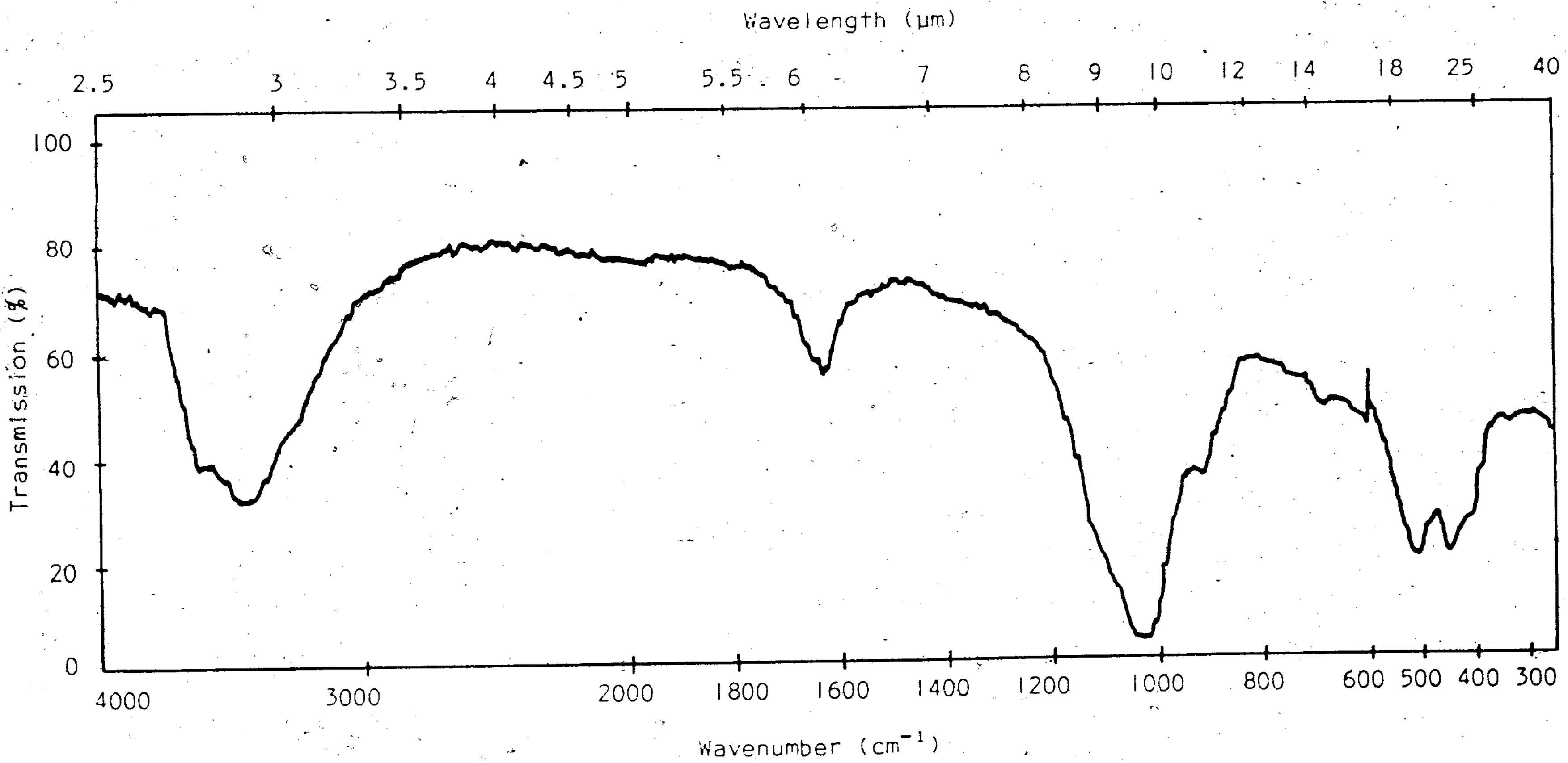

Figure 4. Infrared absorption spectrum typical of smectite for pure mineral from Cypress Hills sample HI and observed in samples HI to H4.

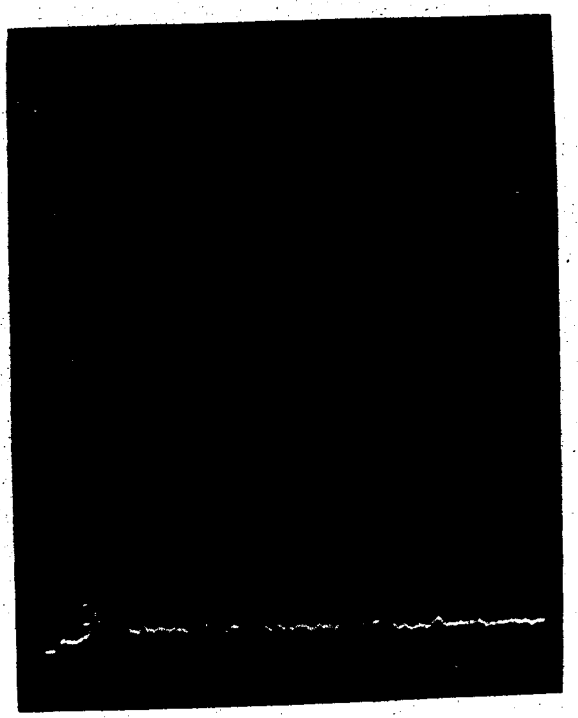

Figure 5. Energy dispersive spectra comparing pure smectite (broken white line) with interior of a granular structure, both from sample HI.

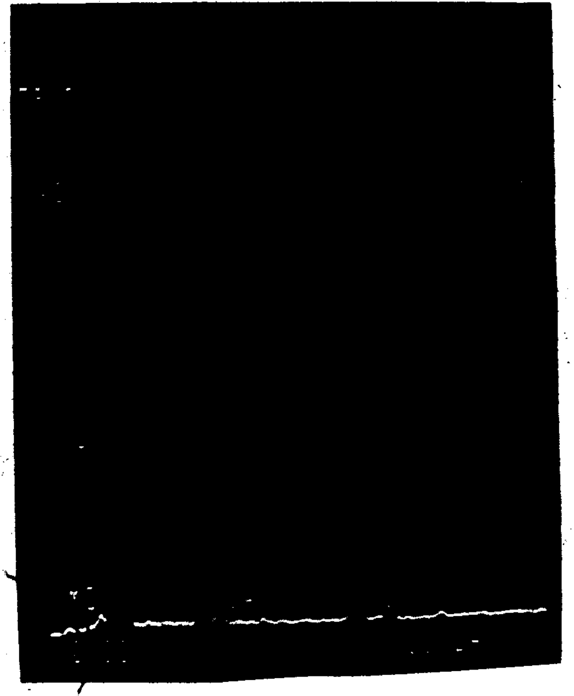

Figure 6. Energy dispersive spectra comparing pure smectite from sample HI (broken white line) with interior of a granular structure from H6.

pellets of soil-ingesting organisms, and Dumanski (1969) showed similar structures in a Chernozemic A horizon. However, in the present case their degree of accomodation and structural similarity regardless of depth (Plates 13, 17, 21, 22), and the occurrence of incipient granular structures in the similar but unweathered H7 sample (Table 4) argue a physical genesis. Freeze-thaw and shrink-swell in a system high in smectite could have generated the granular strucrures and their related features such as matri-argillans. Frost wedges (Table 2; Westgate 1972) and involutions at depth (Plate 12) attest to the pronounced occurrence of these processes. The embedded grain cutans that relate to skelsepic and mosepic plasmic fabrics (Plate 14; Jungerius and Mucher 1972) also often result from stress (Brewer 1976).

Thin sections reveal that the "clay skins" seen in hand specimen (Table 3; Jungerius 1966; Catto 1981) and micromorphology study (Jungerius and Mucher 1972 Fig. 4) are not typical of argillans formed by clay illuviation. Instead, they are matri-argillans, simply the clay-rich exterior of the granular structures (Plate 14). They likely formed at the same time and by the same physical processes as the granular structures. The clays in them appear to have been moderately oriented by stress.

The infrequently occurring void argillans (Plate 16) probably did form by movement of the neogenic clay, but following disruption. The calcitans are also likely of recent origin. Any paleopedogenic record, if present, must be found by analyses other than field description or micromorphology.

Whole Soil Analyses

Calcium carbonate equivalent (Fig. 7) decreases with depth, suggesting it was eluviated from the overlying calcareous material (H7). An infusion of carbonate could have affected micromorphological fabric and structures by flocculating previously dispersed clay in a recently disrupted system, a post-burial process. The pH of all layers was between 7.0 and 7.5 , values and uniformity to be expected with free lime (Buckman and Brady 1969).

Organic carbon (Fig. 8) increases upwards but values overall are very low. Distribution parallels and content probably reflects the corresponding upward increase in root incidence (Table 3). Catto (1981) found there were no significant organic forms in profiles in the upper Cypress Hills

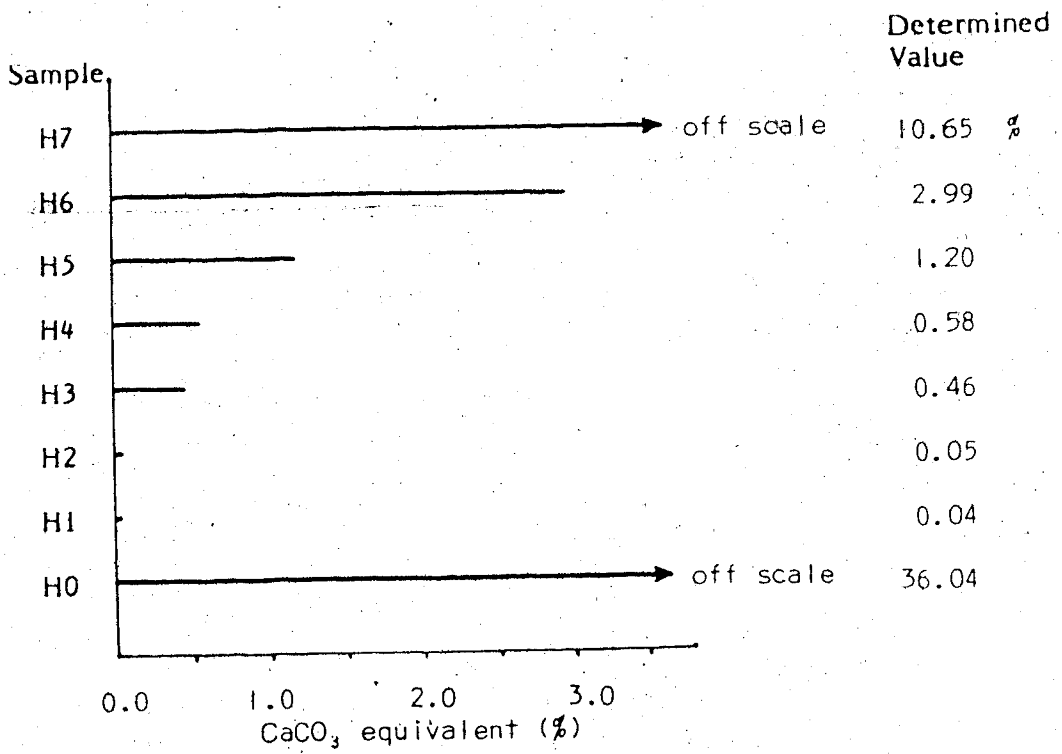

Figure 7. Percent calcium carbonate equivalent of Cypress Hills samples.

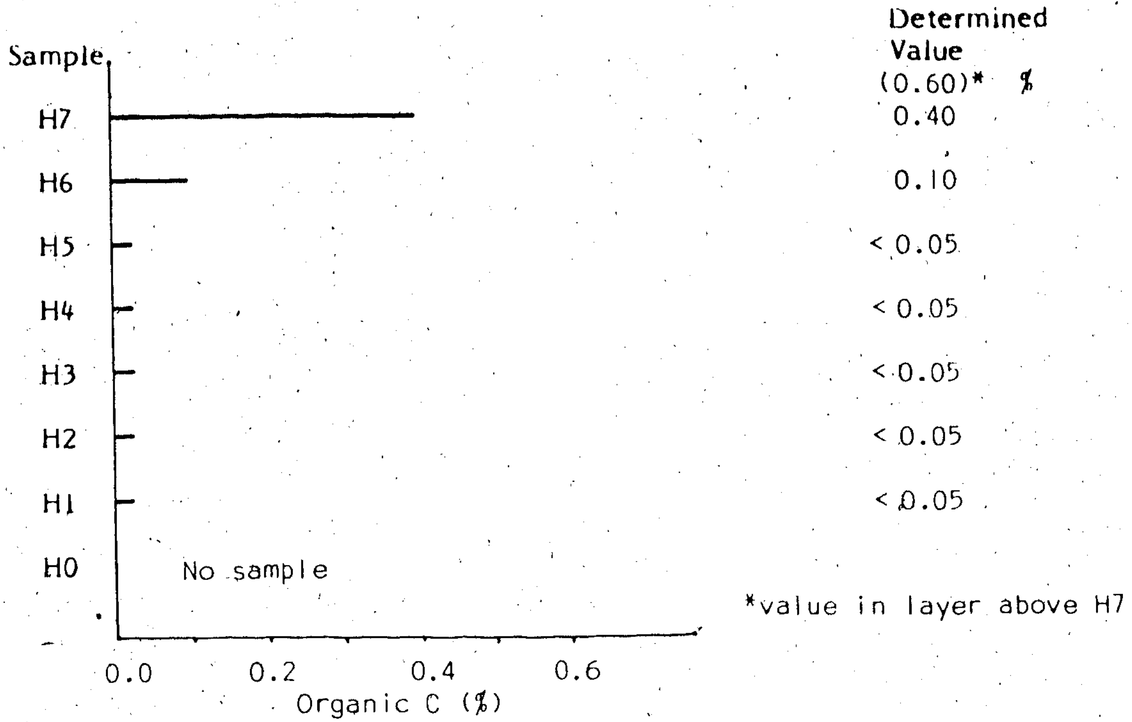

Figure 8. Percent organic carbon as C in Cypress Hills samples.

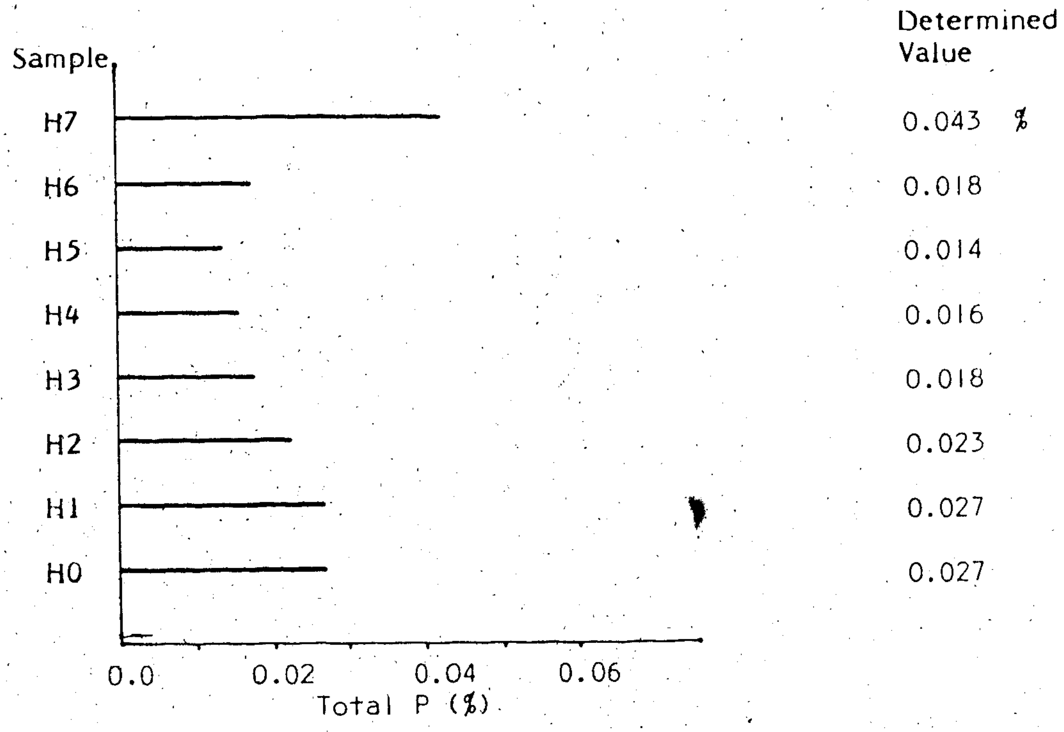

Figure 9. Percent total phosphorus as P in Cypress Hills samples.

Formation. No paleopedogenic record readily exists in the organic component.

Total phosphorus content (Fig. 9) is very low (Buckman and Brady 1969) throughout. The variation in distribution with depth is not significant. This contrasts with findings in some modern soils (Smeck 1973) and paleosols (Runge et al. 1974; Leamy 1975). Their studies also rely on organic P for interpretation.

Textural Analyses

The micromorphological observations above prove that textural analyses on bulk samples are of restricted significance. Textural variability within the lower sample layers is undoubtedly greater than between them (Plate 12). Textures perhaps indicate longterm trends within the depositional environment. Sand (Fig. 10) shows a negative correlation with clay (Fig. 12) while silt remains nearly constant (Fig. 11). This could support an alluvial rather than illuvial explanation for clay content in the topmost sample layers. If illuvial, clay should increase at the expense of both sand and silt, assuming initially uniform material.

Clay Separate Analyses

Clay separate analyses are consistent with a theory of uniform smectite neogenesis throughout the profile, since the elemental, surface area, cation exchange capacity (C.E.C.), and X-ray diffraction (X.R.D.) analyses all show a general uniformity in clay mineralogy with depth.

Elemental analyses of clay separates for potassium (Fig. 13) shows a uniform decrease upwards. This is probably related to a decrease in mica content, a trend also observed subjectively in the heavy mineral thin sections. This decrease might alternately represent depositional, diagenetic, or weathering gradients.

Elemental analyses for iron (Fig. 14) and aluminum (Fig. 15) in clay demonstrate general clay uniformity. There may be a slight positive correlation with sand content, negative with clay.

Clay surface area (Fig. 16) and C.E.C. (Fig. 17) values are both uniform and high, evidence consistent with a theory of uniformity and predominance of smectite throughout.

Clay mineral identification is presented in Figures 18 to 24 and Table 5. The occurrence of neogenic smectite in the presence of mica and the absence of vermiculite is not consistent with a

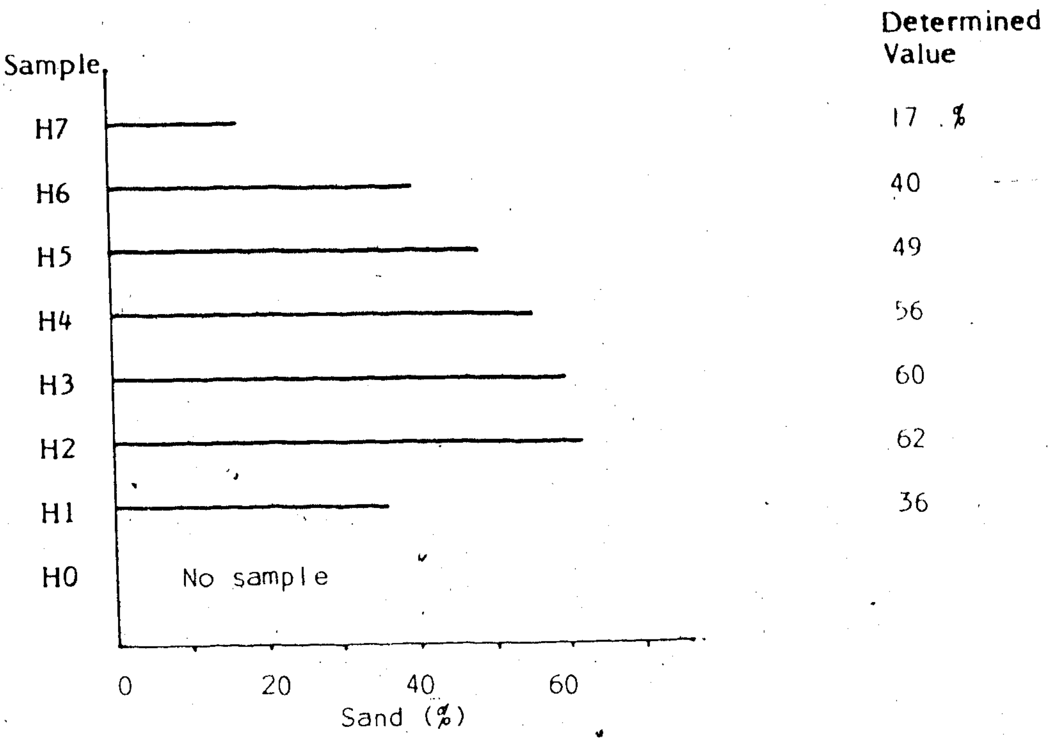

Figure 10. Percent sand in Cypress Hills samples.

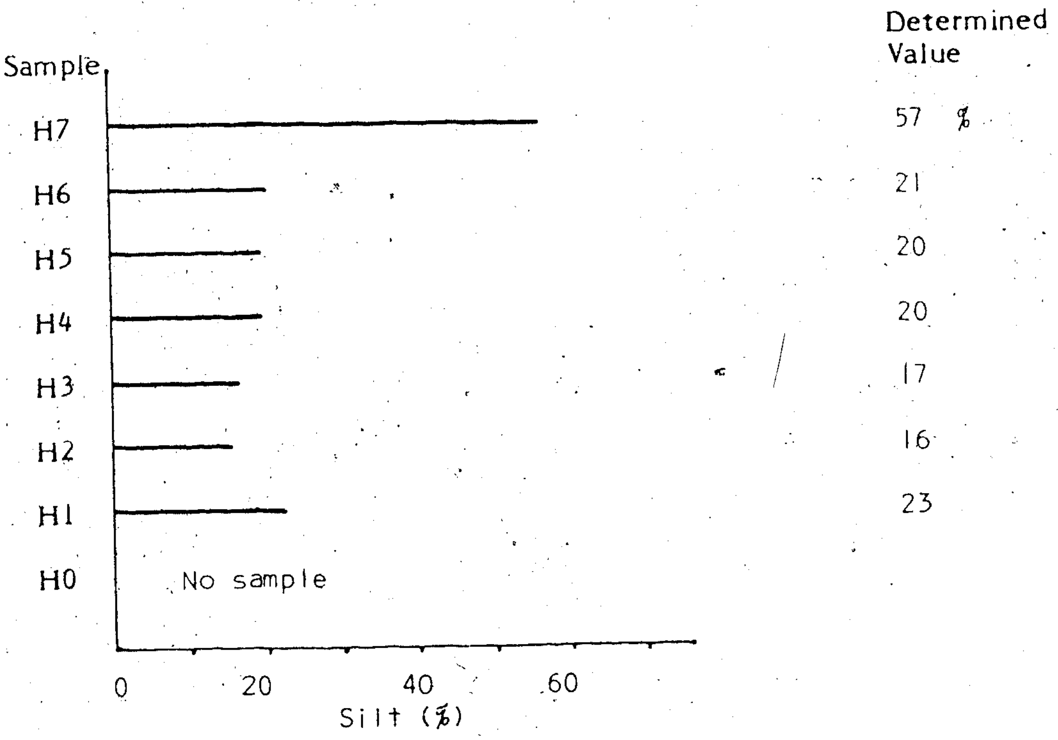

Figure 11. Percent silt in Cypress Hills samples.

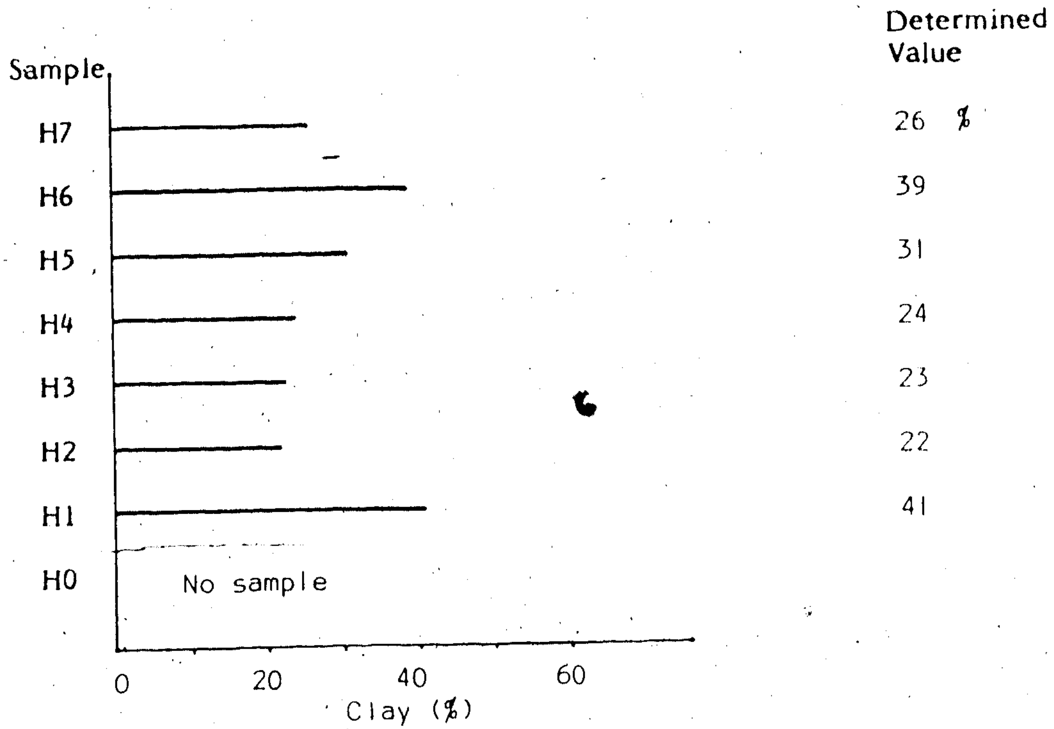

Figure 12. Percent clay in Cypress Hills samples.

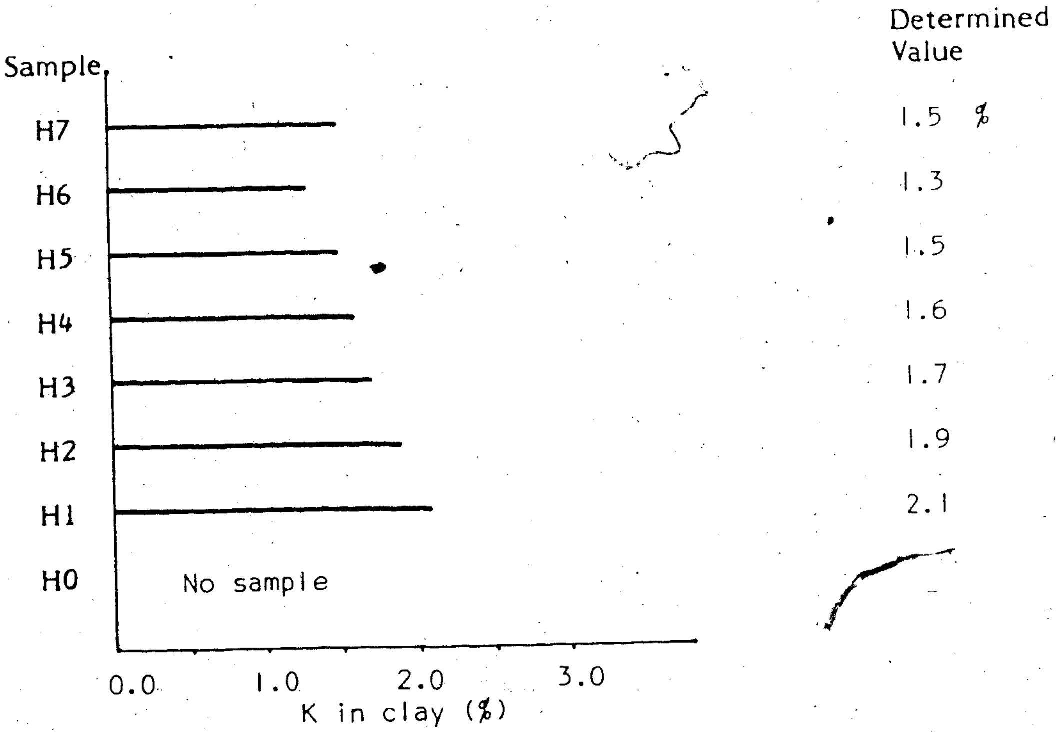

Figure 13. Percent potassium as K in clay separates from Cypress Hills samples.

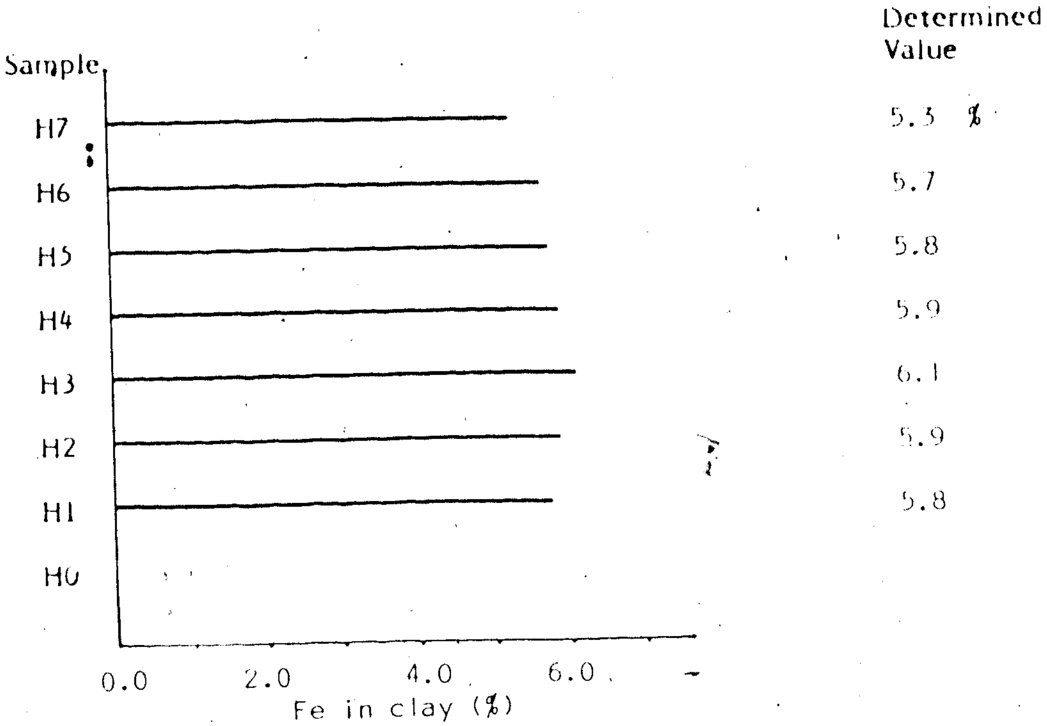

Figure 14. Percent iron as Fe in clay separates from Cypress Hills samples.

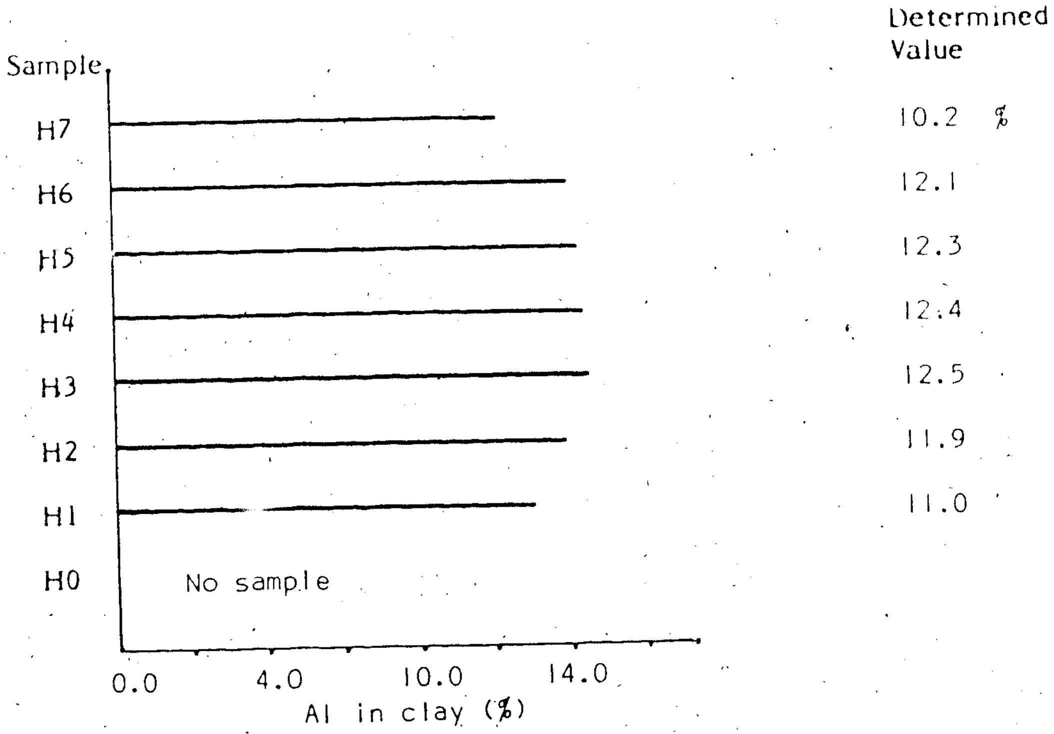

Figure 15. Percent aluminum as Al in clay separates from Cypress Hills samples.

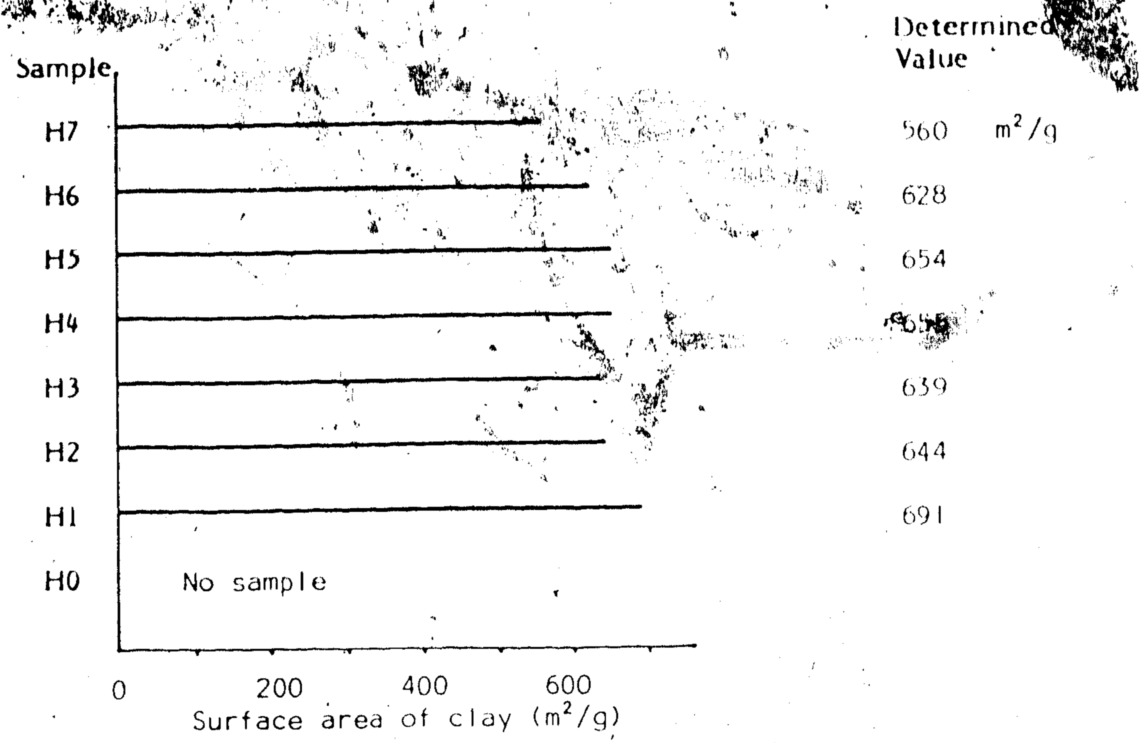

Figure 16. Surface area of clay separates from Cypress Hills samples.

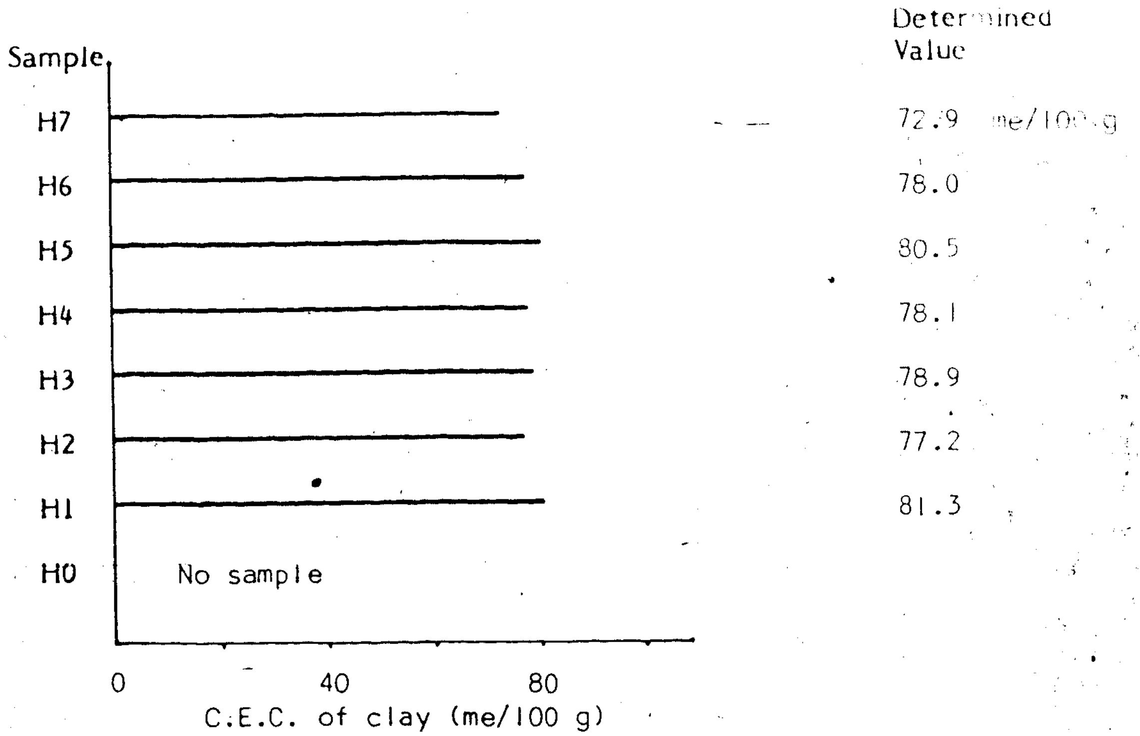

Figure 17. Cation exchange capacity of clay separates from Cypress Hills samples.

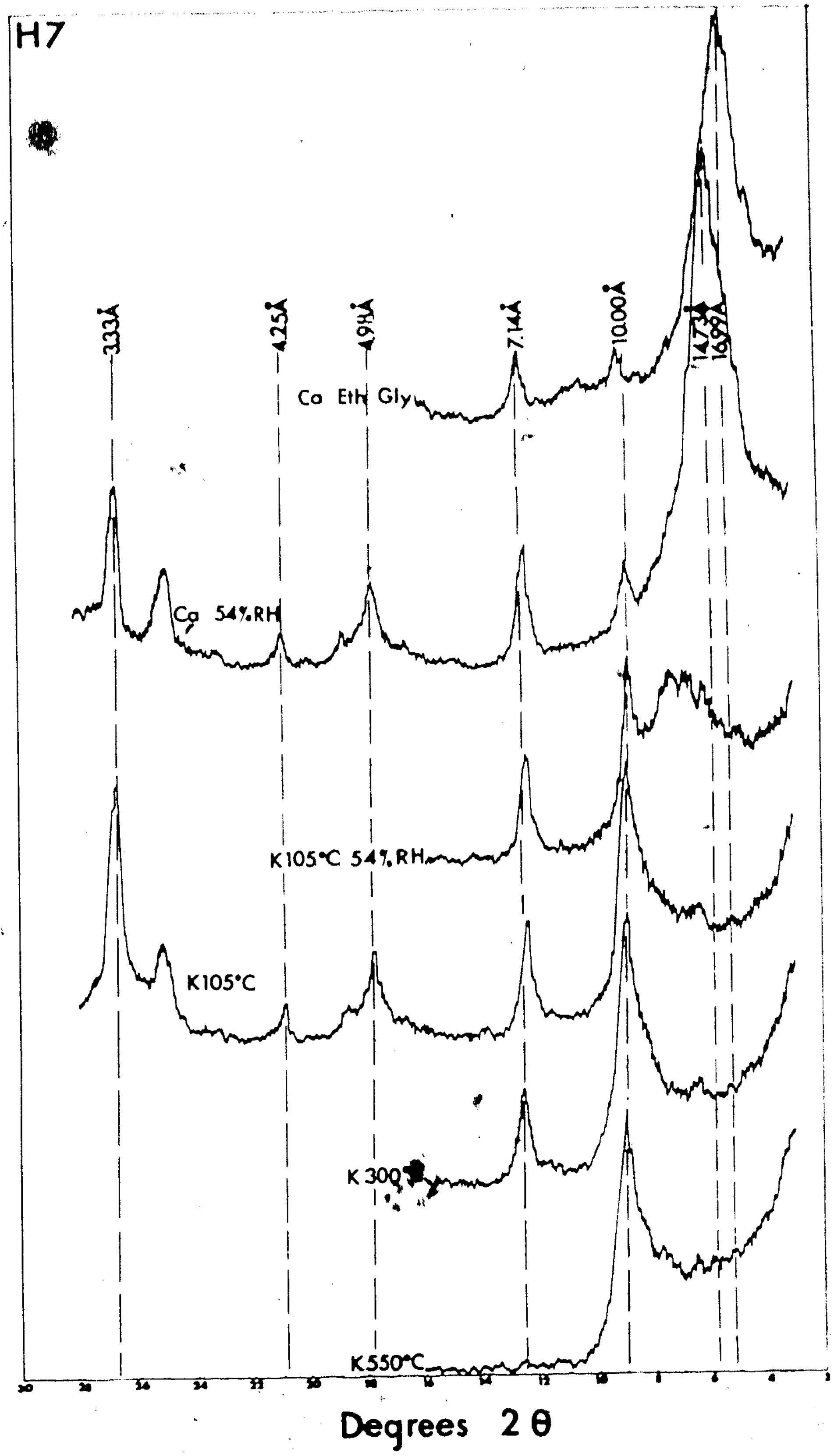

Figure 18. X-ray diffractogram of clay separate from Cypress Hills sample H7.

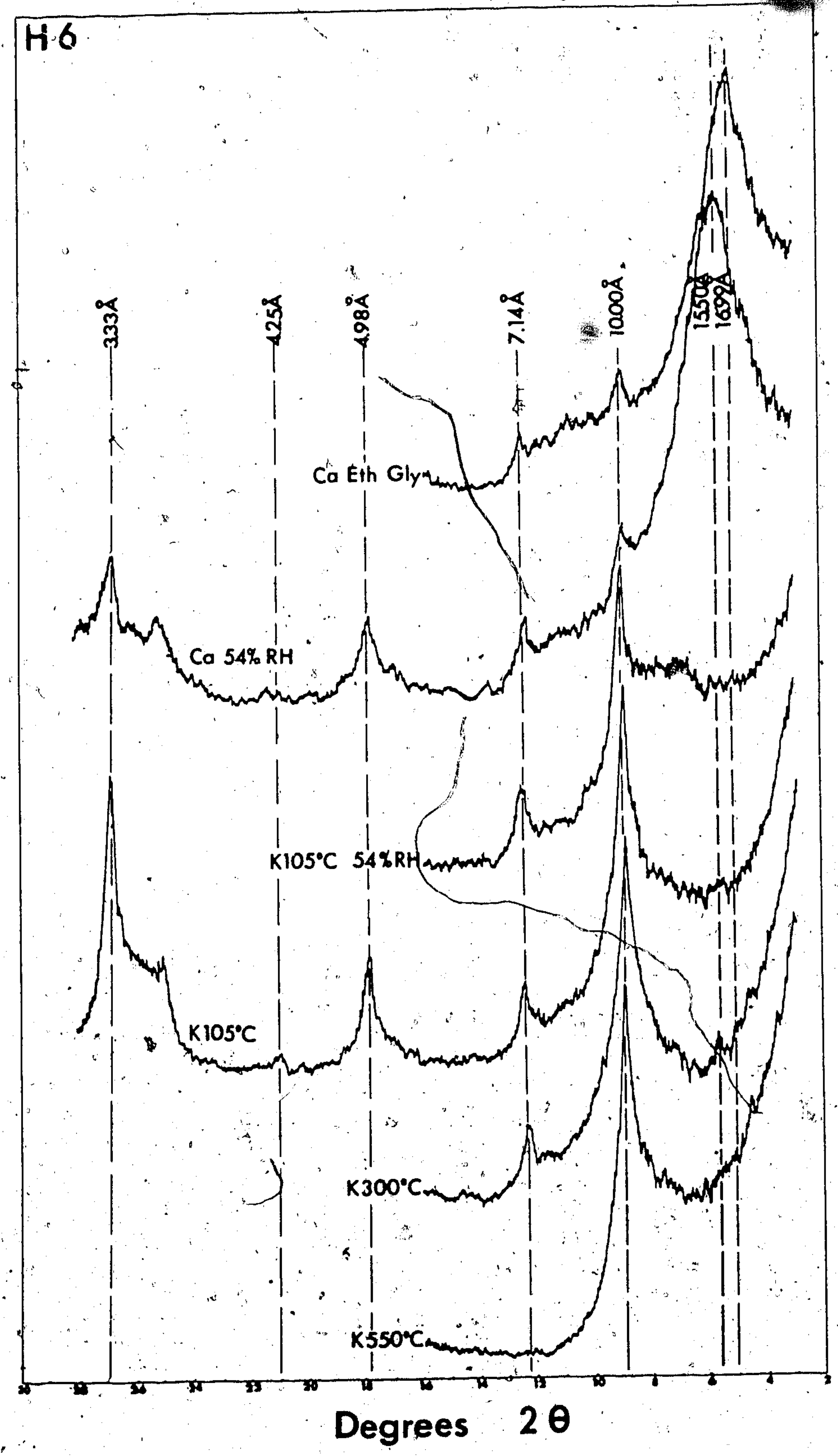

Figure 19. X-ray diffractogram of clay separate from Cypress Hills sample H6.

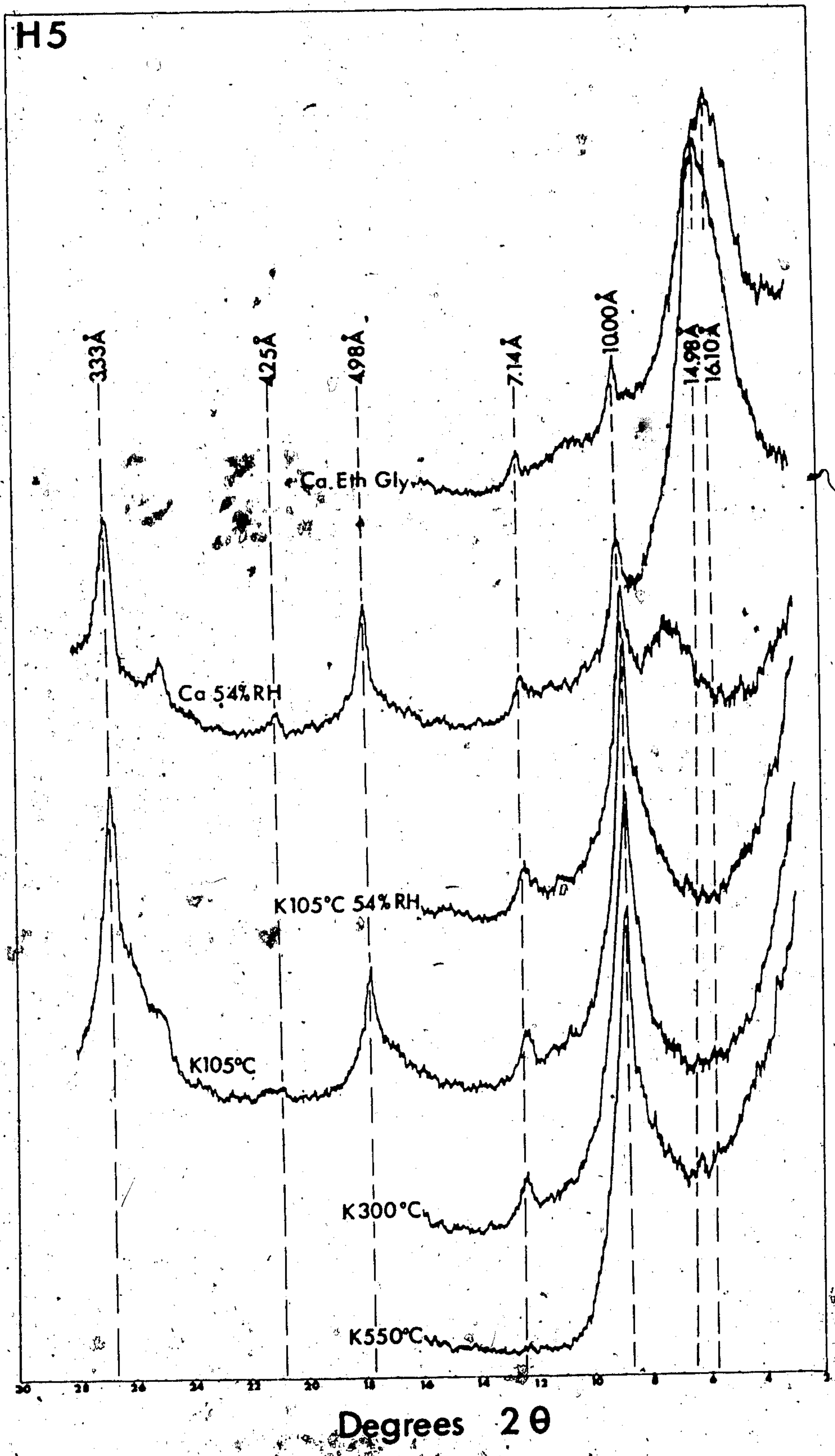

Figure 20. X-ray diffractogram of clay separate from Cypress Hills sample H5.

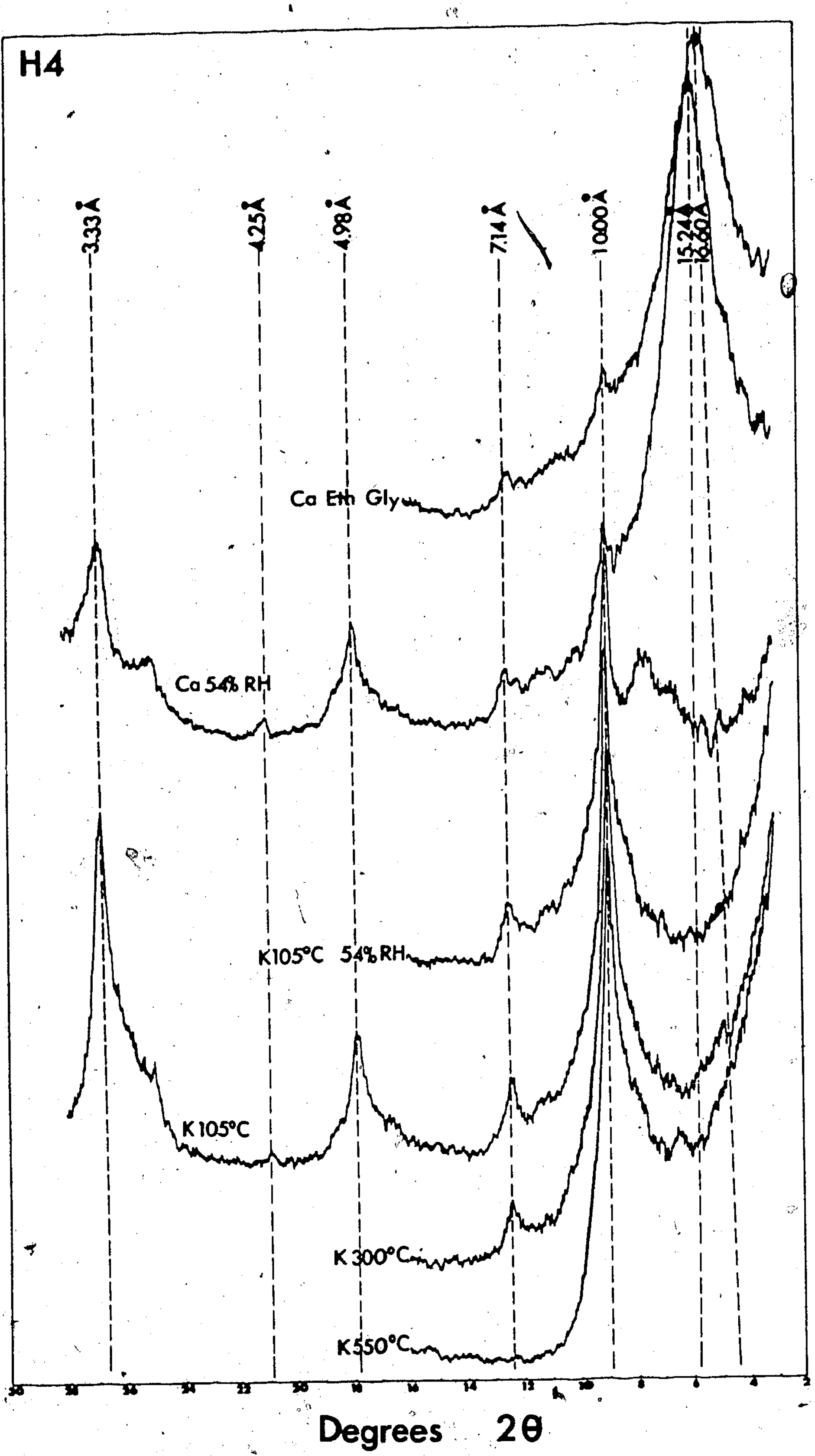

Figure 21. X-ray diffractogram of clay separate from Cypress Hills sample H4.

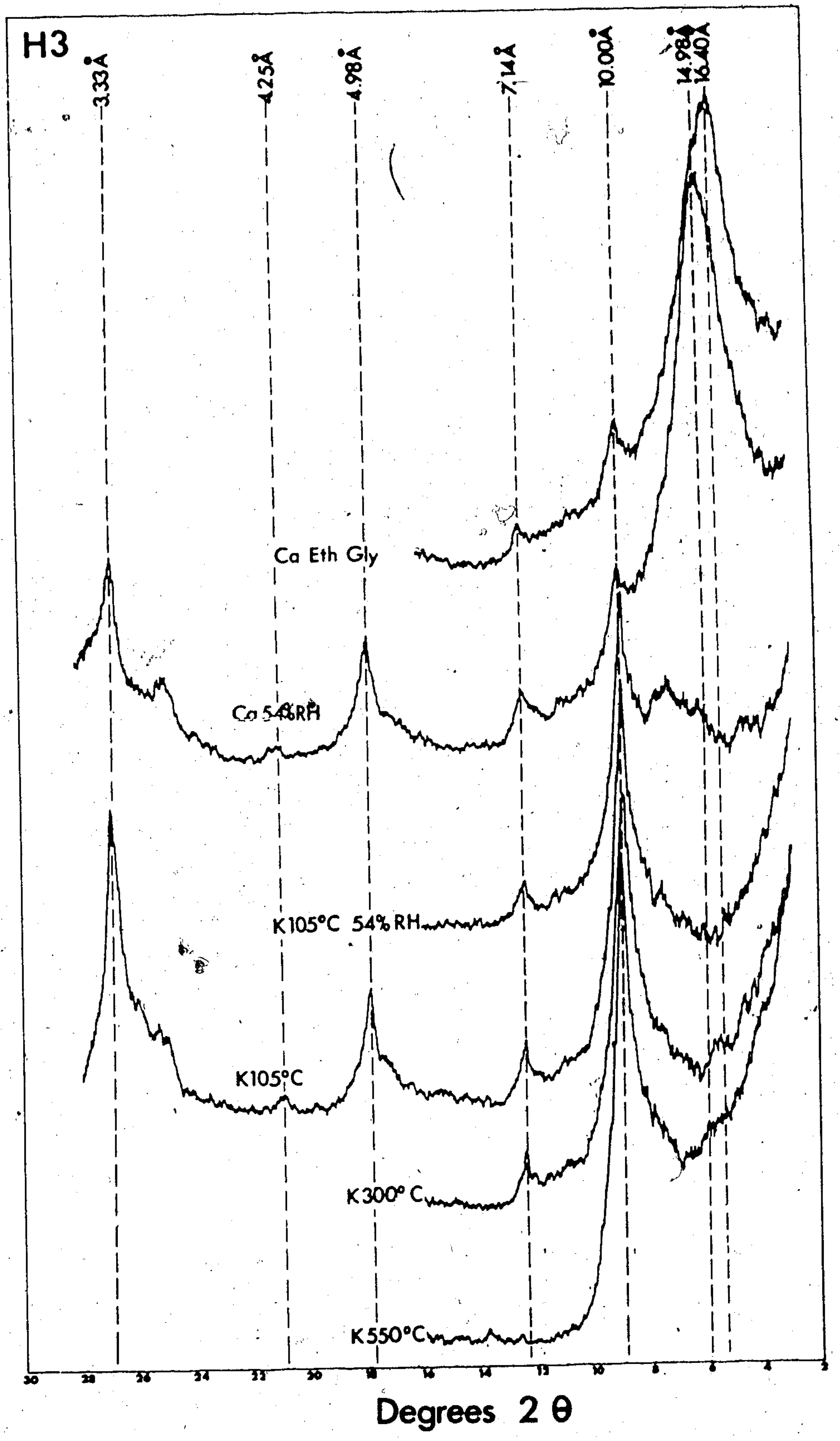

Figure 22. X-ray diffractogram of clay separate from Cypress Hills sample H3.

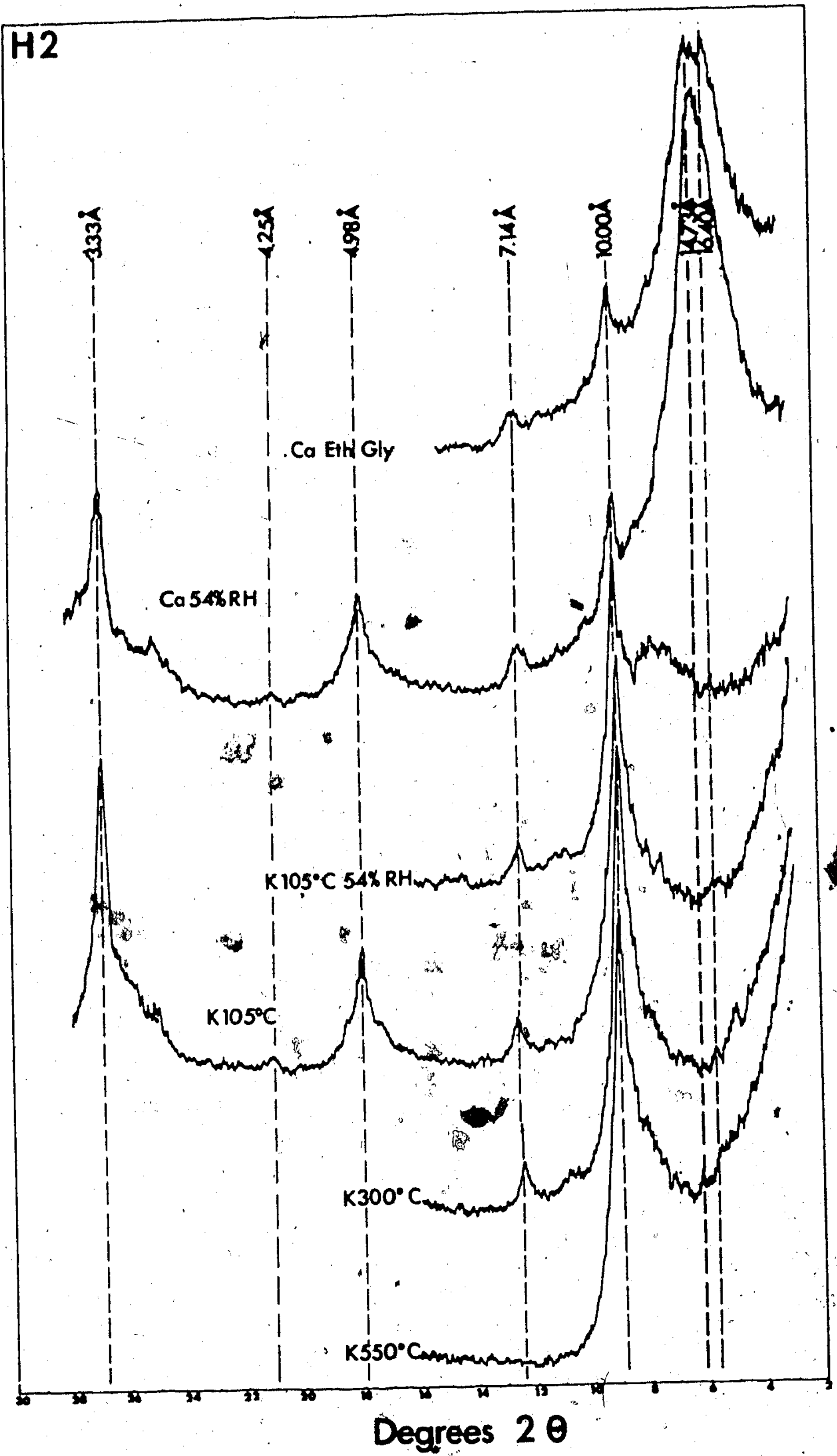

Figure 23. X-ray diffractogram of clay separate from Cypress Hills sample H2.

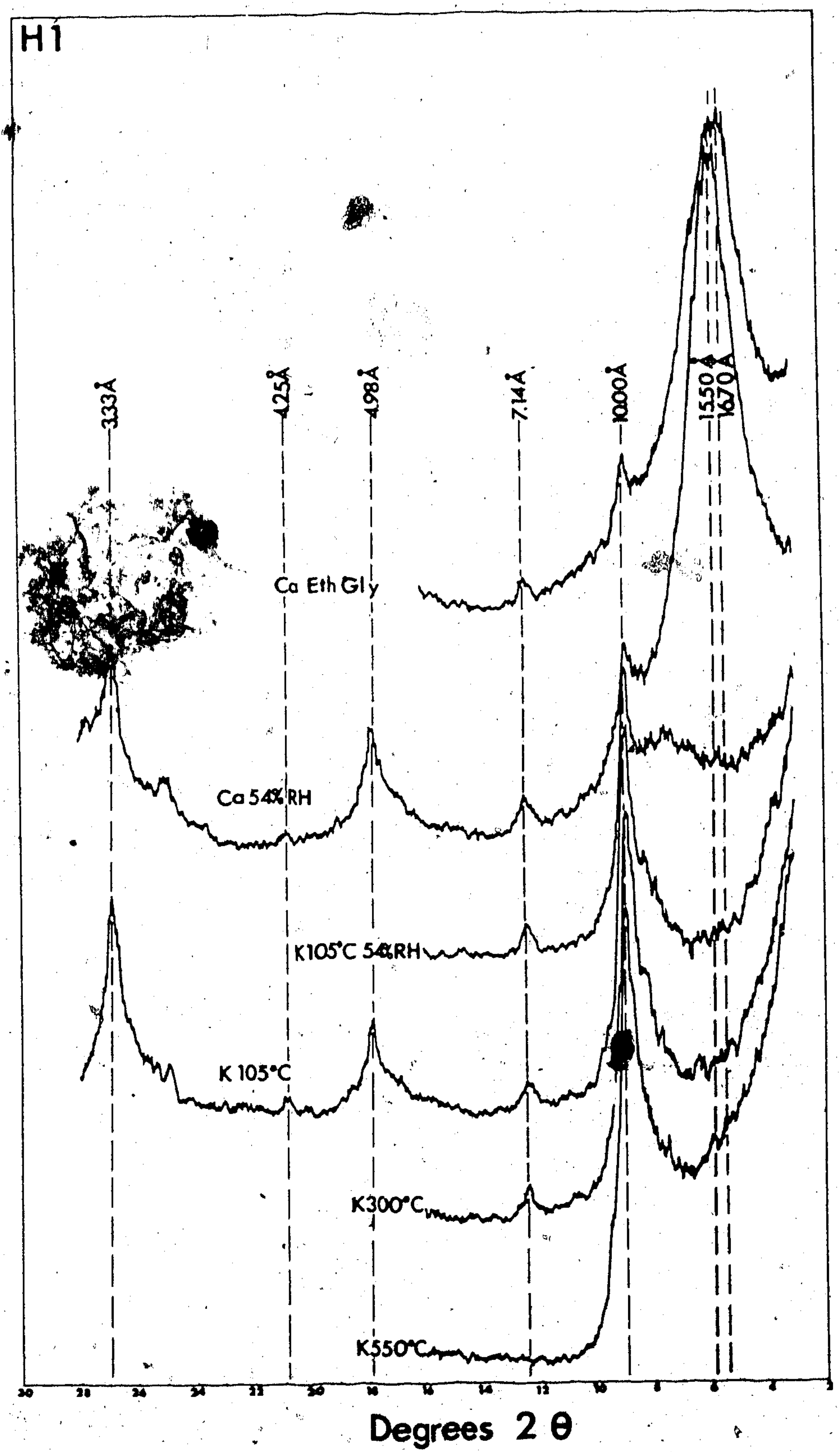

Figure 24. X-ray diffractogram of clay separate from Cypress Hills sample H1.

Table 5. Mineral groups present in clay separates from Cypress Hills samples as identified by X-ray diffraction.

Sample	Mineral Groups Present				Reference
H7	i) quartz	ii) kaolin	iii) mica	iv) smectite	Figure 18
H6	i) quartz	ii) kaolin	iii) mica	iv) smectite	Figure 19
H5	i) quartz	ii) kaolin	iii) mica	iv) smectite	Figure 20
H4	i) quartz	ii) kaolin	iii) mica	iv) smectite	Figure 21
H3	i) quartz	ii) kaolin	iii) mica	iv) smectite	Figure 22
H2	i) quartz	ii) kaolin	iii) mica	iv) smectite	Figure 23
H1	i) quartz	ii) kaolin	iii) mica	iv) smectite	Figure 24
H0	no s[illegible]le				

soil or weathering environment, where vermiculite is the common intermediate product (Borchardt 1977).

Sand Separate Analyses

Feldspar analyses are presented in Figures 25, 26, and 27. Distribution with depth of the plagioclases may reflect increased weathering upwards. However, a strong positive correlation exists between calculated albite and anorthite, indicating the plagioclase present may be of restricted composition. Distribution may then as readily indicate a decreasing supply in the sediment source. Orthoclase content is nearly constant with depth. Assuming this distribution is depositional, processes affecting orthoclase have been uniform throughout.

Heavy mineral content (Fig. 28) shows a positive correlation with sand (Fig. 10), negative with clay (Fig. 12). This distribution can relate to fluvial deposition, a greater percentage of heavy minerals occurring in a rejuvinated higher flow regime that followed deposition of the H1 sample layer. Lower values near the surface may indicate a weathering or diagenetic gradient.

Micas from all samples observed by S. E. M. exhibited at least major splitting if not exfoliation (Table 6; Plates 23 to 26). This weathered condition of the micas likely predates their deposition or occurred in an early post-depositional period, since the flakes even at great depth (sample H0) must have been split or exfoliated to allow intercalation of the carbonate (Plate 20), something that presumably occurred as the conglomerate was becoming cemented. The postdepositional alteration of micas has thus probably been generally uniform throughout the sampled Cypress Hills Formation Profile, including in the cemented conglomerate. If so, relative mica distribution within the profile is likely depositional, although absolute content may have decreased by weathering or other alteration.

Plant opal was not determined because of expected low content in the presence of apparent physical disruption and absence of any suspected A or other surface horizon. The meaning of low values would be confounded by recent contamination, as was the case with organic compounds. Catto (1981) found an absence of phytoliths in profiles on the conglomerate.

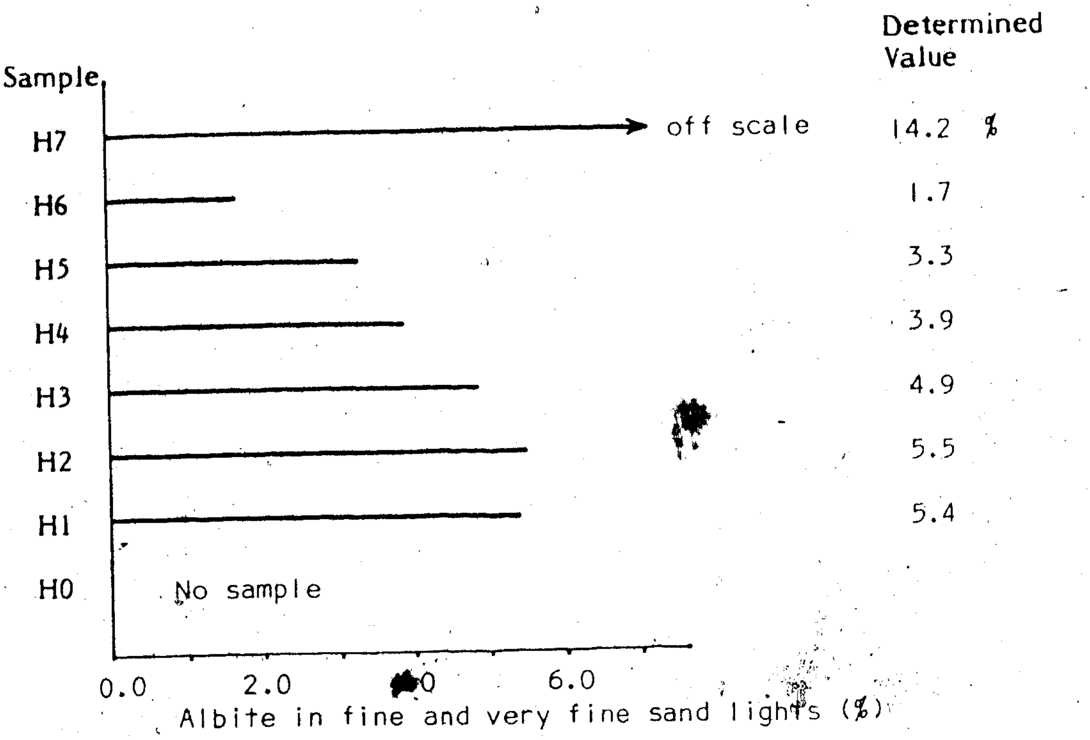

Figure 25. Percent albite (calculated from Na) in fine and very fine sand light (sp. gr. < 2.72) separates from Cypress Hills samples.

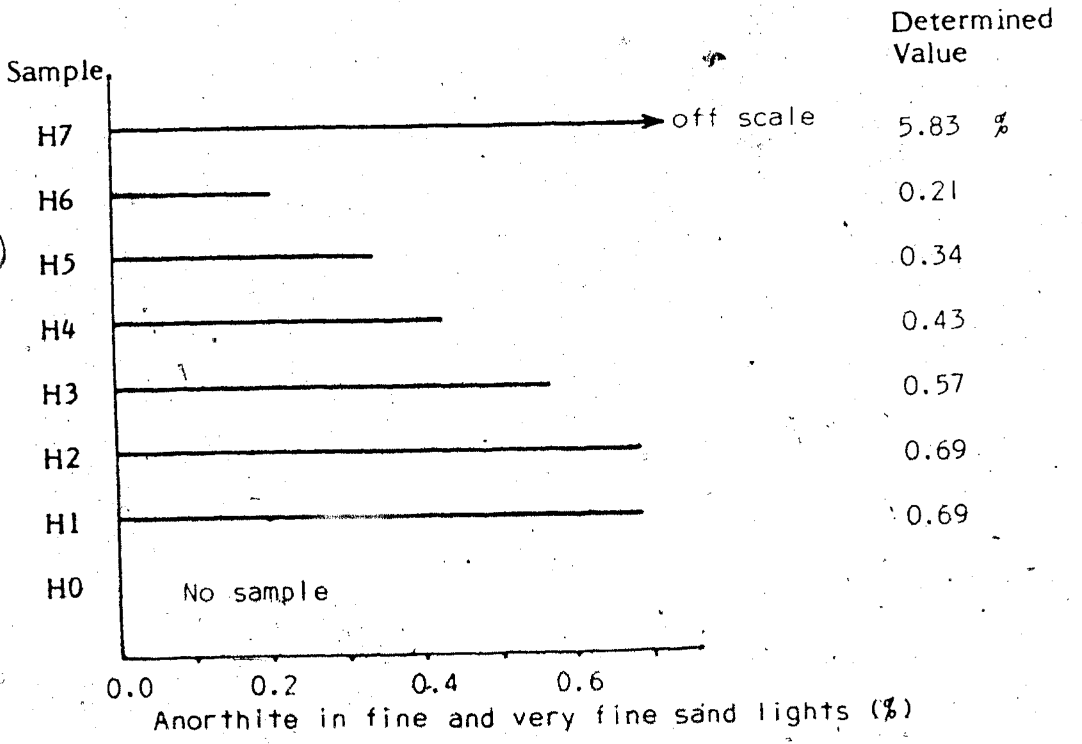

Figure 26. Percent anorthite (calculated from Ca) in fine and very fine sand light (sp. gr. < 2.72) separates from Cypress Hills samples.

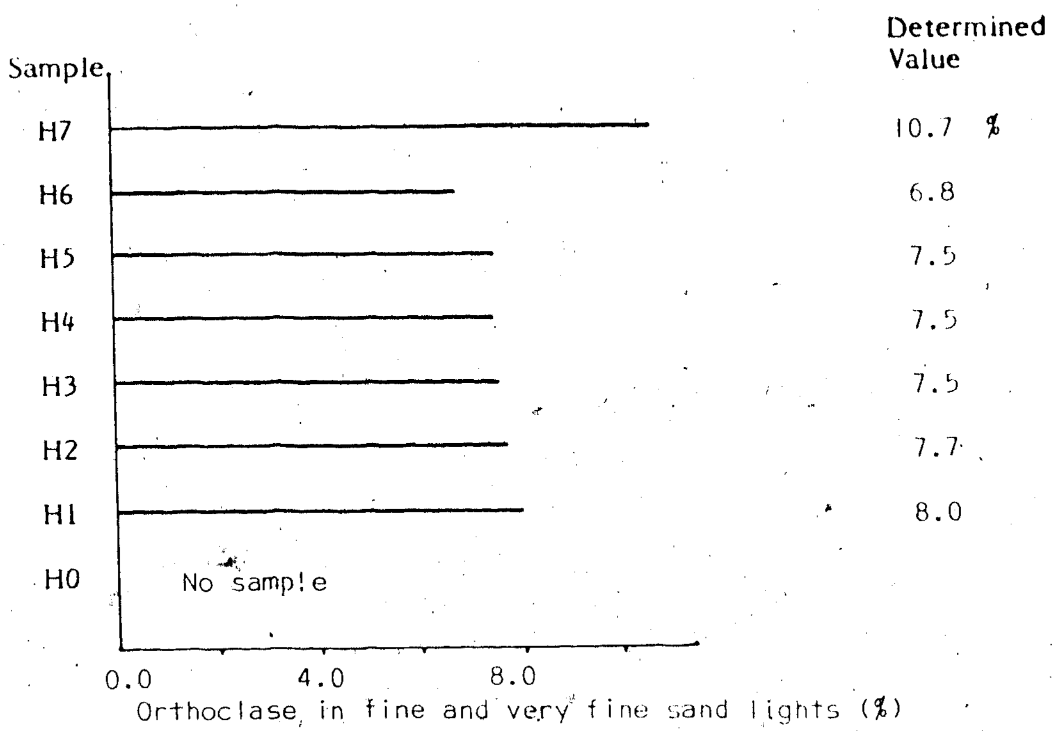

Figure 27. Percent orthoclase (calculated from K) in fine and very fine sand light (sp. gr. < 2.72) separates from Cypress Hills samples.

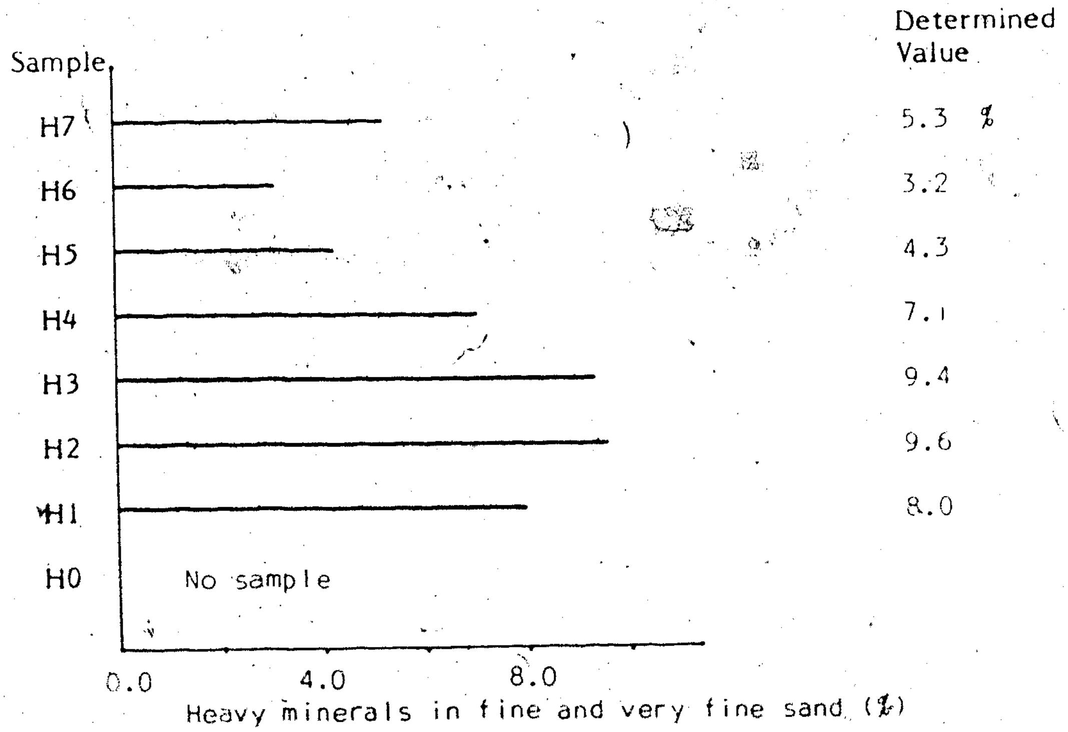

Figure 28. Percent heavy minerals (sp. gr. > 2.72) in fine and very fine sand separates from Cypress Hills samples.

Table 6. Classification of mica morphology by S.E.M. (after Tarzi 1976).

Intact: No apparent splitting or division of any kind in the edge of mica particles.

Splitting: Separation or division of layers of a mica particle along cleavage lines parallel to (00ℓ) planes. Divided as: minor and major.

i) Minor Splitting: Particle divided along 1-10 lines over a thickness of 100 µm.

ii) Major Splitting: Particle divided along more than 10 lines over a thickness of 100 µm.

Exfoliation: Separation of part or whole of a particle into leaflets no thicker than 3 µm with a separating distance less than 1 µm.

Plate 23. Scanning electron micrograph of mica from Cypress Hills sample H6 showing major splitting.

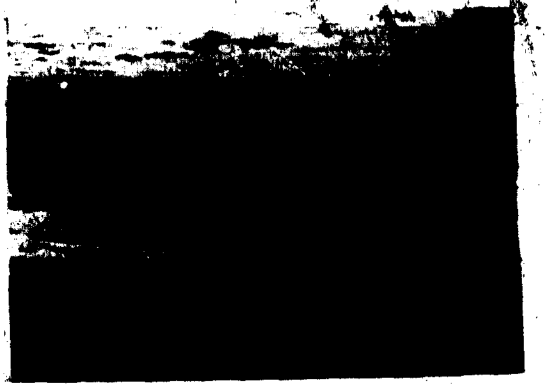

Plate 24. Scanning electron micrograph of mica from Cypress Hills sample HI showing major splitting.

Plate 25. Scanning electron micrograph of mica from Cypress Hills sample H6 showing exfoliation.

Plate 26. Scanning electron micrograph of mica from Cypress Hills sample HI showing exfoliation.

Explanation of Plates 23, 24, 25, and 26.

Typical Cypress Hills Formation micas from near surface (H6) and from depth (HI). Exfoliation and Major Splitting were the only conditions observed. Mineral freshness varies as much within as between samples.

Iron and Aluminum Analyses

The color in the top of the conglomerate (Plate 10) is probably most responsible for the view that the remnants of paleosols occur on the Cypress Hills plateau. Color in the H6 sample (Table 3) is redder than any reported in the profiles studied by previous workers. The iron and aluminum analyses (Figs. 29 to 36) reveal a likely cause for the profile's color distribution.

Total iron and aluminum contents (Figs. 29, 30) parallel clay content (Fig. 12). When iron in clay is subtracted from total iron, in all conglomer[illegible]es approximately 1% iron is uniformly left over. Most of the iron is therefore in the clay siz[illegible]n.

Pyrophosphate extractable iron (Fig. 31) and aluminum (Fig. 32) contents are very low throughout, and decrease upwards, su[illegible]ting the values simply reflect water soluble rather than organic complexed iron (C.S.S.C. 1978c).

Oxalate extractable iron (Fig. 33) is low, and subtracting its values from Dithionite extractable (Fig. 35) reveals that finely divided hematite and/or goethite (Schwertmann and Taylor 1977; C.S.S.C. 1978c) increases upwards until it is just under 1% in sample H6. Hematite frequently causes a bright red color (Munsell 5R to 2.5 YR) in soils and sediments, in concentrations of as little as 0.1% (Blatt et al. 1972; Schwertmann and Taylor 1977). Increased hematite content upwards likely gives the redder color to the top of the Cypress Hills conglomerate and could account for the slight decreases upwards in clay surface area (Fig. 16) and C.E.C. (Fig. 17).

Hematite forms in oxidizing conditions at high pH (Buol et al. 1973; Schwertmann and Taylor 1977). It can be precipitated from solution by a rise in pH under oxidizing conditions. The diagenesis of smectites can leave excess iron in solution (Walker 1967; Blatt et al. 1972), and the pre-Wisconsin Cypress Hills Formation was probably somewhat acidic in its upper layers. The infusion of carbonate from the Wisconsin mantle into the gravels could have resulted in the formation of hematite. This would have been most pronounced in the top of the gravels because the rise in pH there would have been most rapid.

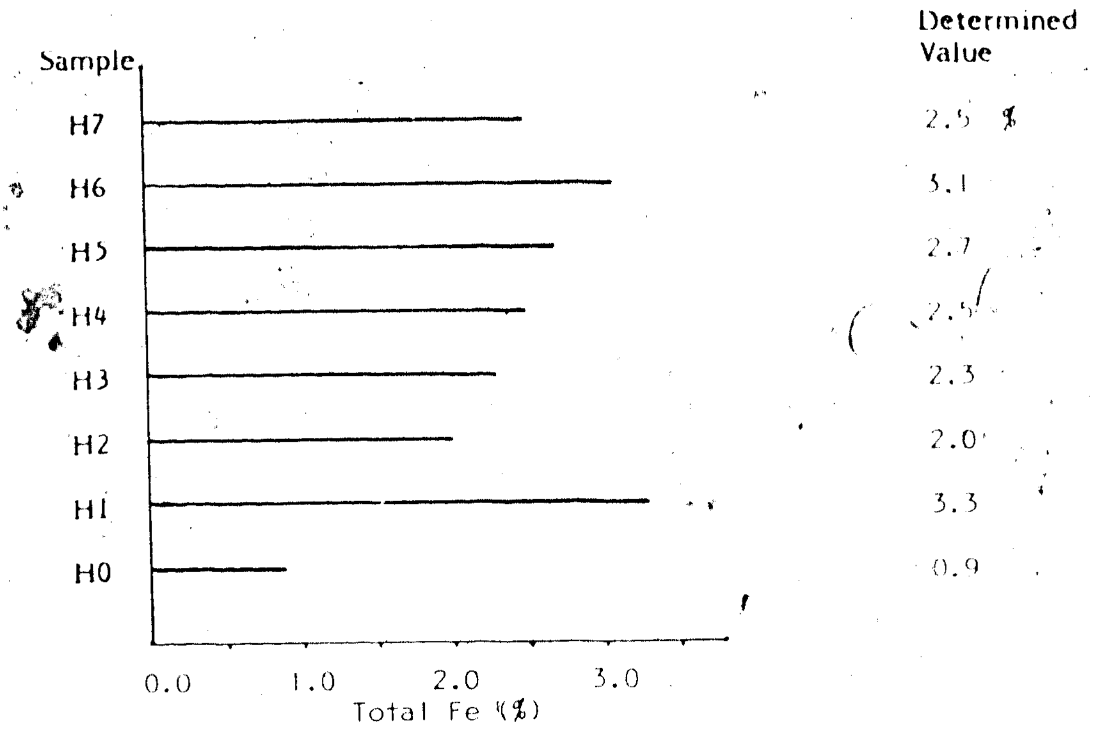

Figure 29. Percent total iron as Fe in Cypress Hills samples.

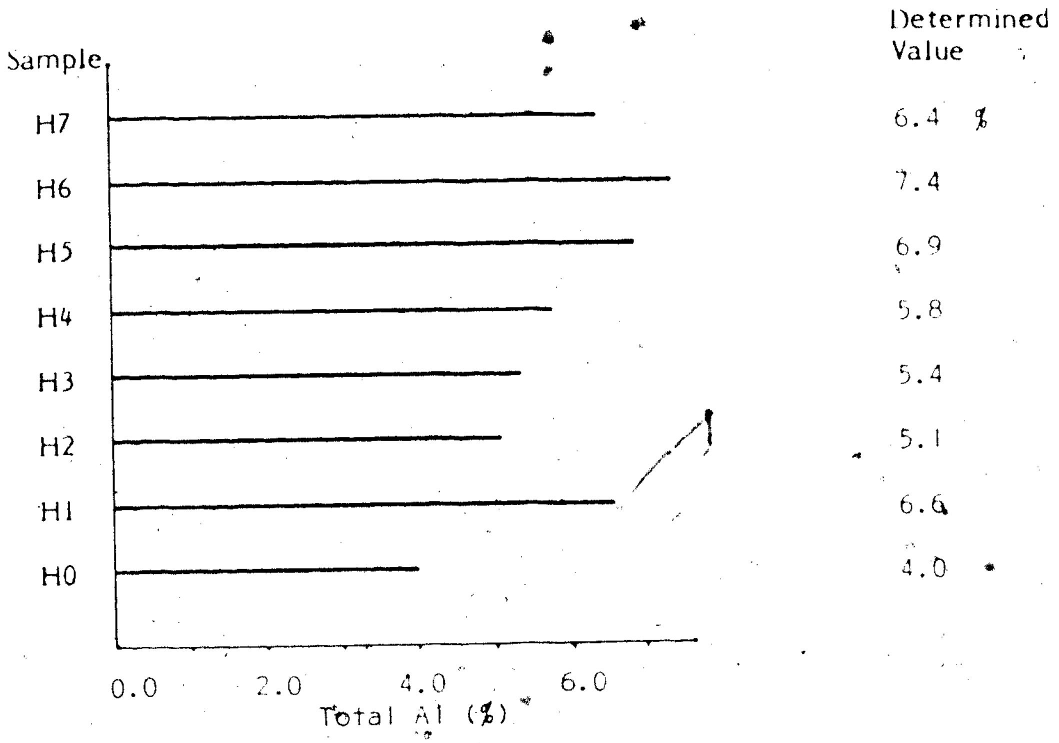

Figure 30. Percent total aluminum as Al in Cypress Hills samples.

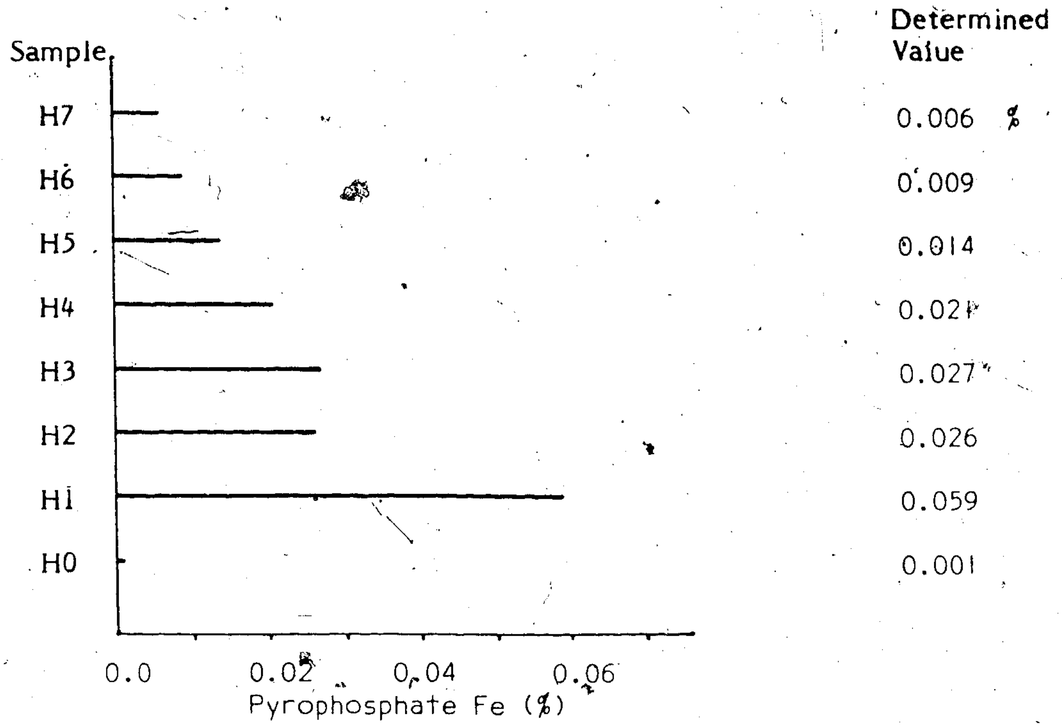

Figure 31. Percent sodium pyrophosphate extractable iron as Fe in Cypress Hills samples.

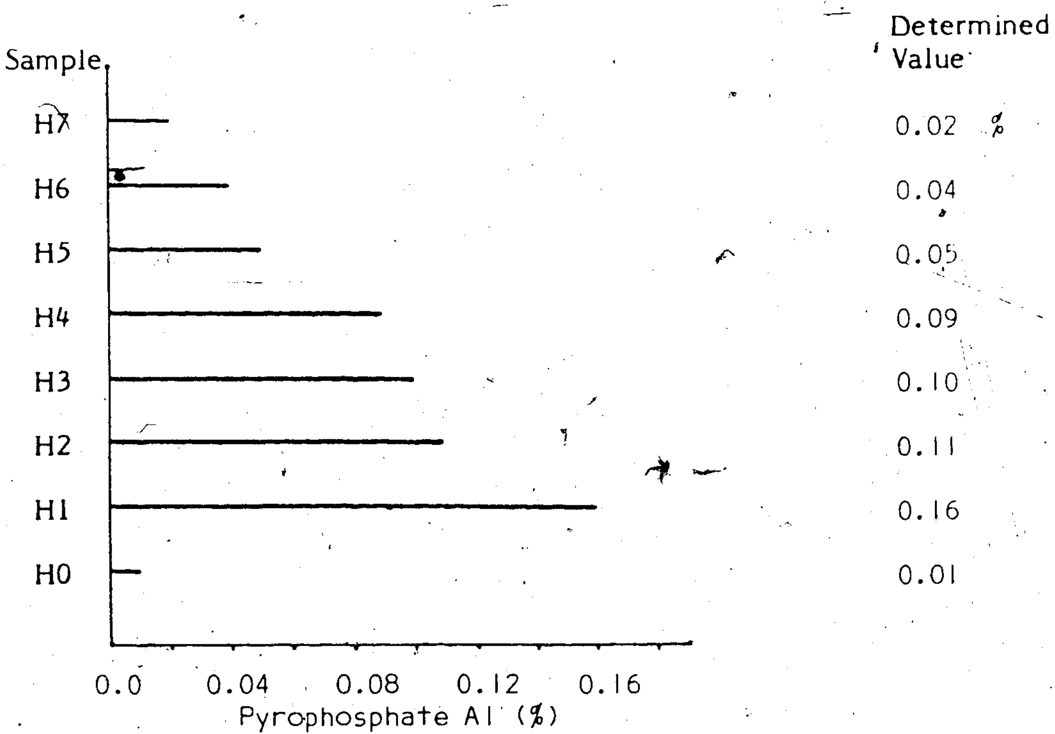

Figure 32. Percent sodium pyrophosphate extractable aluminum as Al in Cypress Hills samples.

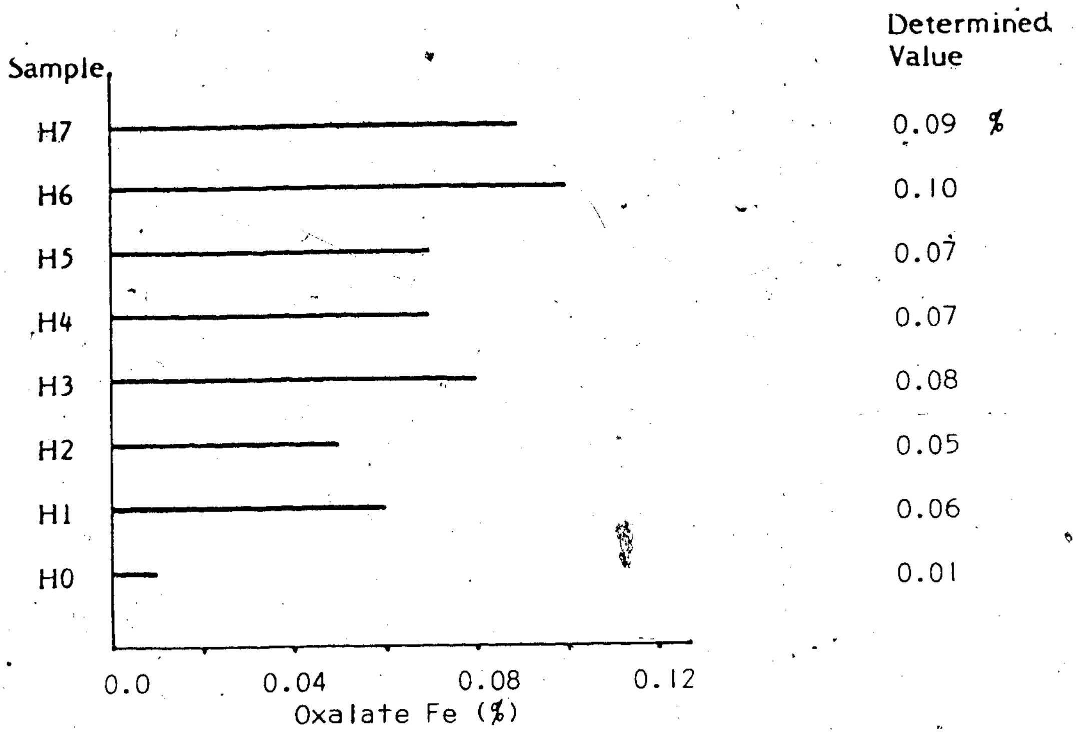

Figure 33. Percent acid ammonium oxalate extractable iron as Fe in Cypress Hills samples.

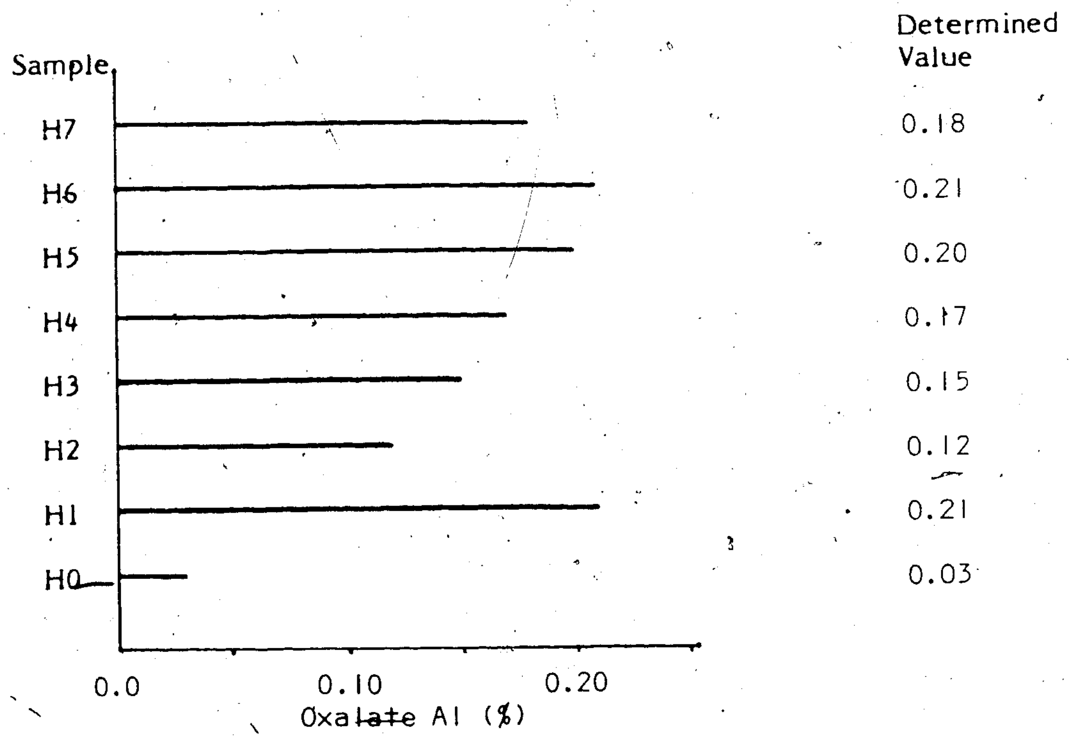

Figure 34. Percent acid ammonium oxalate extractable aluminum as Al in Cypress Hills samples.

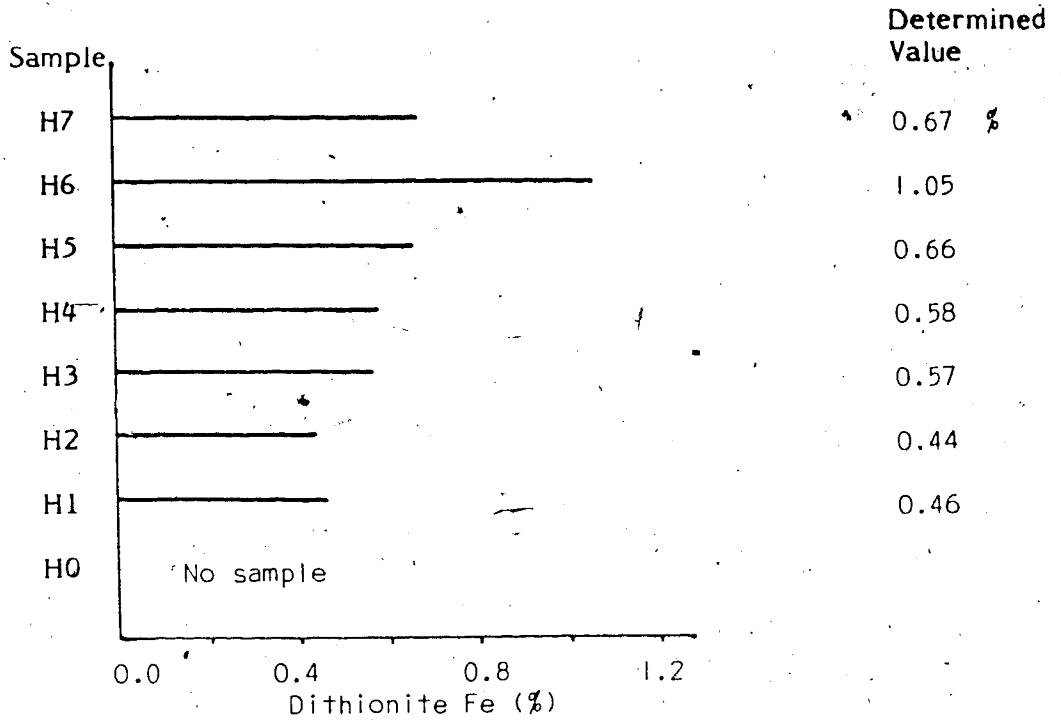

Figure 35. Percent dithionite-citrate-bicarbonate extractable iron as Fe in Cypress Hills samples.

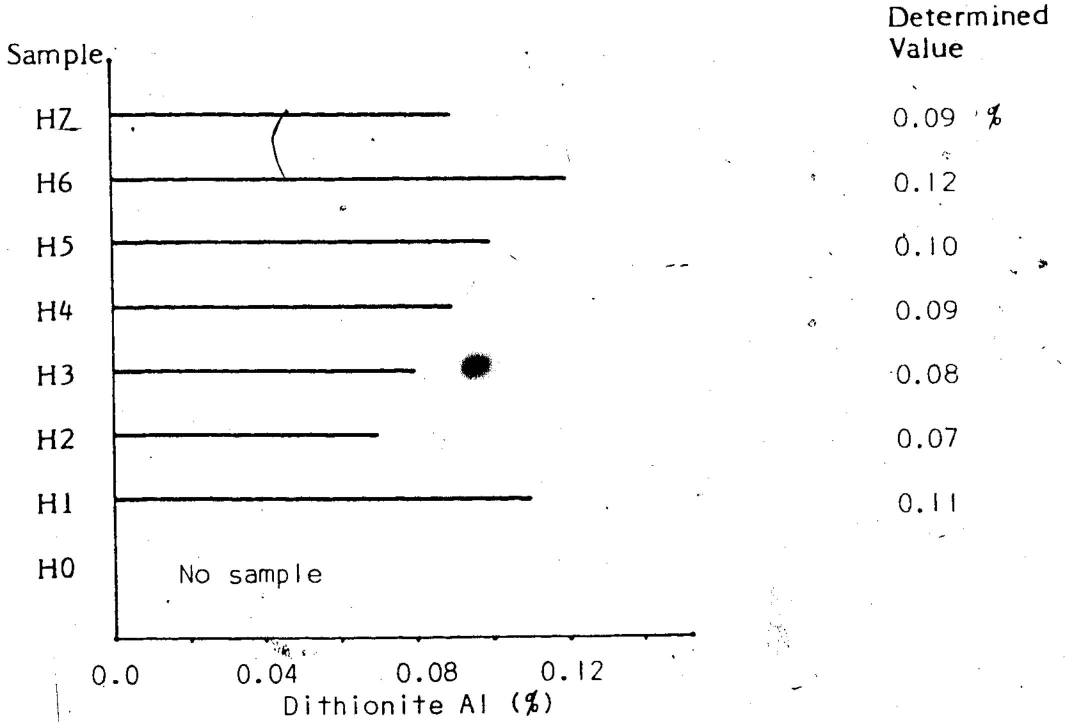

Figure 36. Percent dithionite-citrate-bicarbonate extractable aluminum as Al in Cypress Hills samples.

Summary of the Cypress Hills Interpretation

No features indicative of paleopedogenesis were found in the physical, chemical, micromorphological, or chemical components studied. They indicate that any paleopedological record from this site could only be elucidated by more sophisticated techniques.

The following events are interpreted to account for characteristics of the upper Cypress Hills Formation at the profile site:

1) deposition (Tertiary?) producing typical fluvial stratification and structures (McConnell 1885; Williams and Dyer 1930 ; Alden 1932; Russell and Landes 1940; papers compiled by Zell 1965);
2) gradual geochemical alteration of some of the fine earth fraction to produce smectite, (mainly?) throughout that portion of the formation now above the cemented conglomerate. (Only coarse textured samples of cemented conglomerate were observed). The smectite precipitated both in papule-like pure concentrations and diffusely throughout the matrix. A small fraction of the neogenic clay was mobile in voids and produced argillans, a few of which are possibly still preserved at depth. Also, there was a tendency in the finer textured layers towards plasma rearrangement that produced features resembling those now present in the lower sample layers. A weathering (oxidation?) or diagenetic gradient increasing upwards is suggested by a few of the chemical analyses;
3) disruption of sedimentary and geochemically produced structures, either by glacial or periglacial processes or both, with disruption greatest upwards. The number of disruptions is unknown (1 or more), but the lower and at least part of the upper of the two units that mantle the conglomerate were in place during a strong final stage; and
4) readjustment of the upper layers into the the present well defined granular structures with their heterogeneous particle sizes, concurrent with the addition of calcium carbonate from the overlying mantle. The carbonate could have served to flocculate the clays and by raising pH, to precipitate hematite, especially near the top of the conglomerate where the chemical conditions changed relatively rapidly.

Cloudy Ridge - Results and Discussion

The buried drift on Cloudy Ridge appears to have undergone change at the site since deposition. Characteristics of the sampled profile reflect both alteration and reorganization of some components. Discussion is centered on Unit C that contains the soil-like features (samples R2 to R6, Fig. 37).

Field Descriptions and Analyses

Present landscape setting of the Cloudy Ridge site (Fig. 2) is described in Table 7 and shown in Plates 1 and 2.

The geologic and type sections are described in Table 8. Some aspects of these are shown in Plate 27. A schematic of the type section (Fig. 37) shows the names of layers referred to in text. One outstanding feature is the apparent degree of weathering expressed in the profile. It is doubtful that either the rottenstone fragments or the "ghost" coarse fragments could have survived transport and deposition in their present state, so most of the weathering was probably *in situ.* These features, especially the "ghosts," are most common in the lower layers just above the cemented layer R1. Clay films are most frequent at these greater depths as well.

The above and other features are detailed in the sample layer descriptions (Table 9). There, an increasingly firm consistence upwards is also recorded. Plates 28 to 30 show some of the sample layers.

Micromorphological Analyses

Micromorphological analyses (Table 10) confirm the distribution of coarse fragments, clay films, and physical characteristics observed in the field. As recorded in Table 10 and Plates 31 to 36, they support speculation on changes since deposition of Unit C. Changes appear to be of three distinct kinds:

1) plasma reorganization of two types. Lower samples contain void argillans (Plate 36) while upper ones contain embedded grain seperations resembling sesqui-argillans (Plate 31);
2) weathering *in situ.* This is evidenced by the neosesquans, staining in phenoclasts, and occurrence of "ghost" coarse fragments at depth (Plate 33), and;

Table 7. Cloudy Ridge site description.

Location:	On Cloudy Ridge, 0.9 km north of most northern boundary of Waterton Lakes National Park, Alberta (Figure 2)
Map Reference:	Waterton Lakes, 1:50,000 (82 H/4, Edition 2 MCE, Series A 741)
Military Grid:	12 U TK549853
Elevation:	1580 m a.s.l.
Vegetation:	Prairie grassland Habitat Type (extrapolated from Kuchar 1973)
Landform:	Morainal inclined and ridged, gullied (scale 1:50,000)
Slope:	4-5 complex (6-15%), overall aspect northeast
Drainage:	Well
Seepage:	Absent
Erosion:	Deep occasional gullies
Stoniness:	Very stony
Rockiness:	Nonrocky
Land Use:	Natural grazing
Classification:	Orthic Black Chernozemic (present solum)
Described:	August, 1975

Table 8. Cloudy Ridge geologic and type section descriptions.

Nature of exposure: Gully erosion scarp incised by an intermittent stream. The geologic section is obscured by a vegetated colluvial veneer. Only the type section was examined, thus lateral variation is unknown.

Scarp Slope: 65%

Aspect: Southeast

Stratigraphic Layers*

Surface: Coarse fragments only; very stony veneer; gravels to boulders; angular and subangular; shield and Cordilleran lithology.
No sample taken.

Unit D: Depth 0.0-1.2 m. Characteristics uniform with depth except as modified by present solum in the upper 25 cm.

Light brownish gray (10YR 6/2 m); strongly effervescent; massive bedding; structureless; loose; heterogeneous mixture of clay to boulder particle sizes; gravelly sandy loom.
Coarse fragments - 65% by volume, gravels to boulders; angular and subangular; fresh; Cordilleran lithology; random orientation.
Lower boundary to Unit C clear, wavy.

Sample was R7 taken from near the lower boundary to represent the entire Unit D layer (Figure 37).

Unit C: Depth 1.2-3.6 m. Characteristics change at nonuniform rate with depth except as indicated. Changes described occur from top to bottom of layer respectively.

Reddish brown (5YR 4/4 m), becomes yellowish brown (10YR 5/6 m); moderate effervescence, becomes very weak effervescence, except strong in small carbonate cemented lenses near middle of unit; massive bedding throughout; strong (pseudo)subangular blocky, becomes weak (pseudo)subangular blocky; firm, becomes friable; absence of cutans, becomes presence of cutans on coarse fragments and in pores; heterogeneous mixture of clay to cobble particle sizes throughout; gravelly clay loam, becomes gravelly loam.

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*Names after Wagner (1966).

(cont.)

Table 8. Cloudy Ridge geologic and type section descriptions.

Coarse fragments - content increases from 35 to 60% by volume with depth, mainly gravels and cobbles; angular to subrounded throughout; fresh and "weathering" rind and rottenstone, with depth becomes fresh and "weathering" rind and rottenstone and "ghost" coarse fragments with a noncoherent residue (Plates 28 and 29); Cordilleran lithology throughout; random orientation throughout, but suggestion of weak layering of co[illegible]nts lower in the Unit (Plate 27).
Lower boundary to Unit B clear, wavy.

Samples R6, R5, R4, R3, and R2 were taken from near upper to near lower Unit C layer boundaries respectively (Figure 37).

Unit B: Depth 3.6-5.3+ m. Only the upper two metres were exposed in this study, so entire variation with depth is unknown. In the exposed portion, characteristics are uniform with depth.

Light yellowish brown (10YR 6/4 m); strong effervescence; indurated with carbonate cement; massive bedding; cutans on coarse fragments and in pores; heterogeneous mixture of clay to cobble particle sizes, but probably lowest in silt and clay content prior to cementation.
Coarse fragments - 75% by volume, gravels and cobbles; uniform content; angular to subrounded; fresh and "weathering" rind; Cordilleran lithology; more spherical coarse fragments have random orientation, while more tabular coarse fragments have strong imbrication with dipslope to the southwest (Plate 30).

Sample R1 was taken from near the upper boundary to represent the entire exposed Unit B layer (Figure 37).

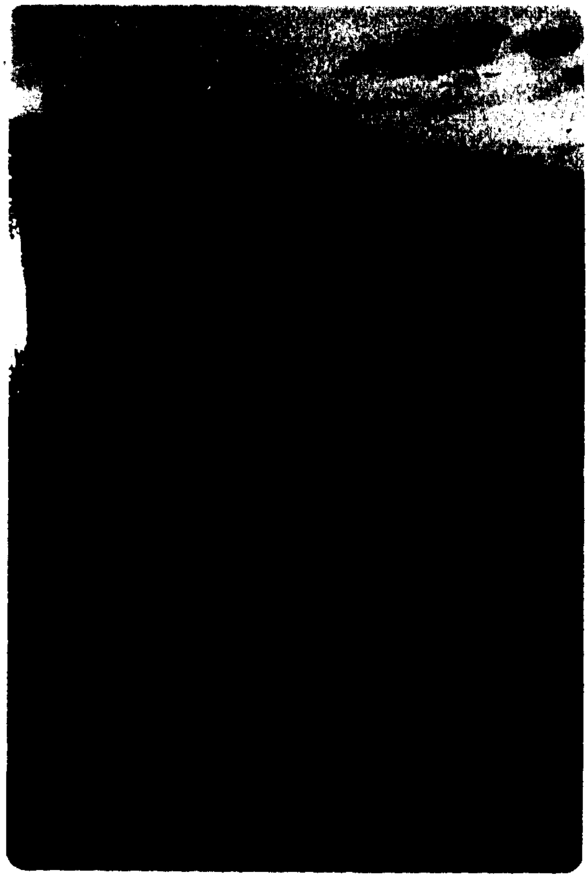

Plate 27. Cloudy Ridge geologic section.

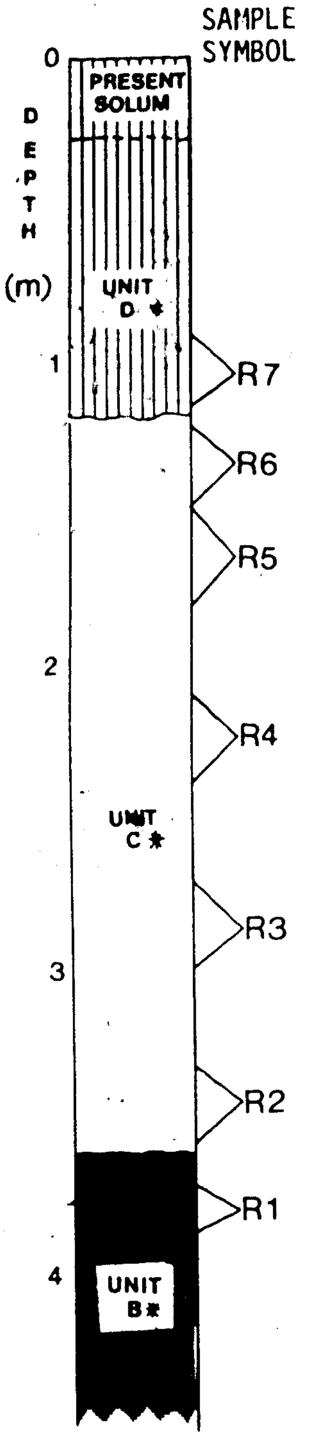

Figure 37.

Schematic of the Cloudy Ridge type section showing sample layers.

Table 9. Cloudy Ridge sample descriptions.

R7 Depth 0.9-1.2 m; light brownish gray (10YR 6/2 m), light gray (10YR 7/2 d); gravelly sandy loam; structureless, weakly massive to single grain; loose; plentiful, very fine roots; highly porous; strong effervescence; est. coarse frag. 45% gravels, 15% cobbles, 5% boulders.

R6 Depth 1.2-1.5 m; reddish brown (5YR 4/4 m), reddish brown (5YR 5/4 d); gravelly loam to clay loam; moderate to strong, medium (pseudo)subangular blocky; firm; few, fine roots; slightly porous; moderate effervescence; est. coarse frag. 25% gravels, 10% cobbles.

R5 Depth 1.5-1.8 m; reddish brown (5YR 5/4 m), light reddish brown (5YR 6/4 d); gravelly loam; moderate, medium (pseudo)subangular blocky; firm; few, very fine roots; slightly porous; weak to moderate effervescence; est. coarse frag. 30% gravels, 10% cobbles.

R4 Depth 2.1-2.4 m; brown (7.5YR 5/4 m), light brown (7.5YR 6/4 d); gravelly loam; weak to moderate, medium (pseudo)subangular blocky; friable to firm; discontinuous, strong, carbonate cementation; few, thin cutans on coarse fragments; few, very fine roots; slightly to moderately porous; weak matrix effervescence, strong in cemented areas; est. coarse frag. 35% gravels, 15% cobbles, very few "ghost" coarse fragments.

R3 Depth 2.7-3.0 m; dark yellowish brown (10YR 4/4 m), pink (7.5YR 7/4 d); gravelly loam; weak, medium (pseudo)subangular blocky; friable; few, thin cutans on coarse fragments; few, very fine roots; moderately porous; weak effervescence; est. coarse frag. 40% gravels, 20% cobbles; occasional "ghost" coarse fragments (Plate 29).

*names after Wagner (1966).

(cont.)

Table 9. Cloudy Ridge sample descriptions.

R2	Depth 3.2-3.5 m; yellowish brown (10YR 5/6 m), very pale brown (10YR 7/4 d); gravelly loam; weak, medium, (pseudo)subangular blocky; friable; few thin cutans on coarse fragments and in pores; few, very fine roots; moderately porous; very weak effervescence; est. coarse frag. 40% gravels, 20% cobbles; occasional "ghost" coarse fragments.
R1	Depth 3.7-3.9 m; light yellowish brown (10YR 6/4 m); very gravelly loamy sand prior to cementation(?); continuous, indurated carbonate cementation; ~~few~~, thin cutans on coarse fragments and in pores; moderately porous; strong effervescence; est. coarse frag. 50% gravels, 25% cobbles (Plate 30).

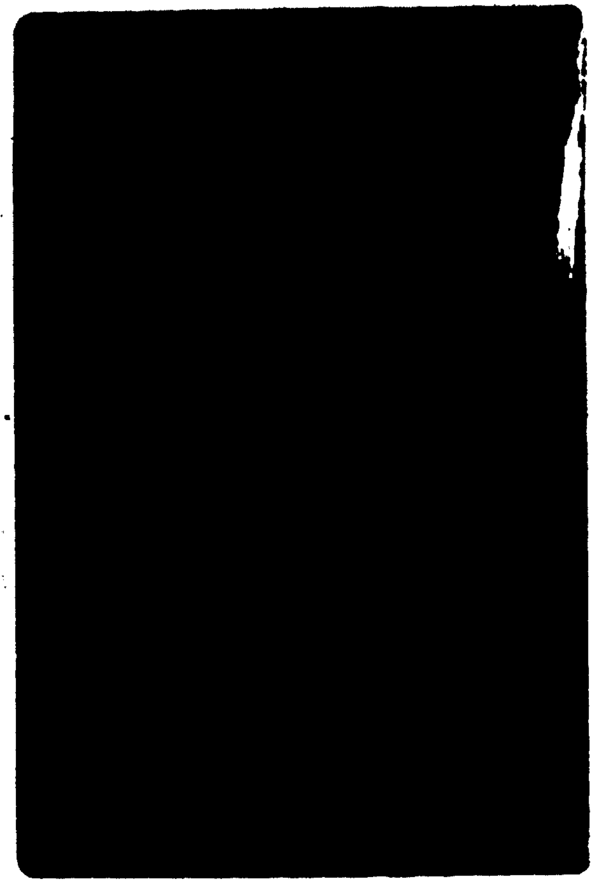

Plate 28. Cloudy Ridge sample layer R6.

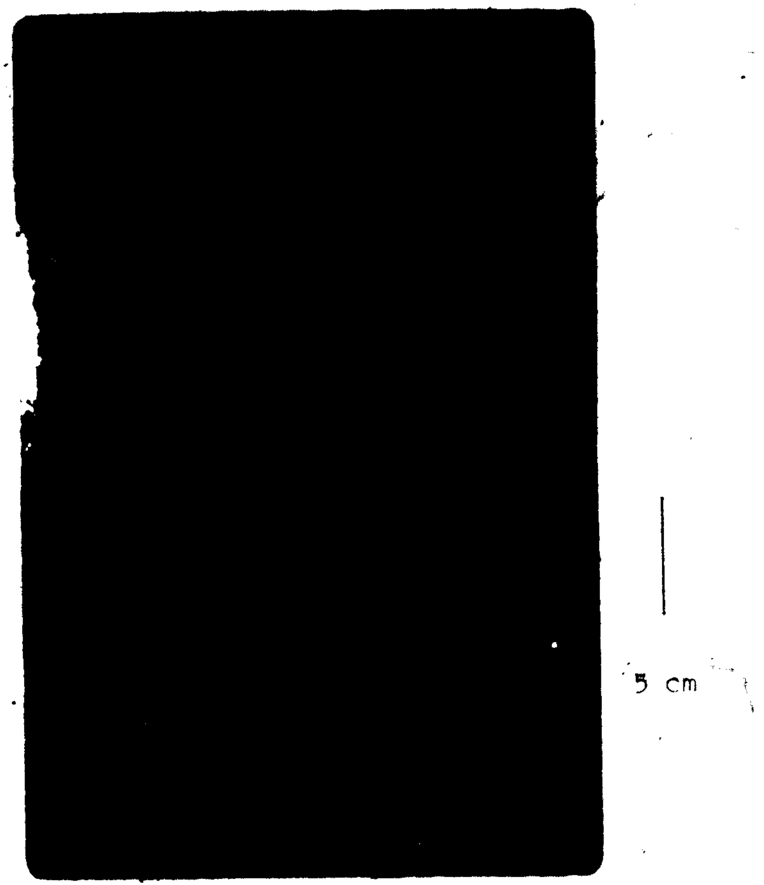

Plate 29: Cloudy Ridge sample layer R3 showing rottenstone and "ghost" coarse fragments.

Plate 30. Sample layer RI in Unit B of the Cloudy Ridge type section showing cementation and imbrication of the more tabular coarse fragment dipslopes toward the lower left (southwest).

Table 10. Micromorphological descriptions of Cloudy Ridge samples.

R7 No sample.

R6 1.2-1.5 m.

Fabric type: Matrifragmoidic - matrifragmic (mixed complex).
Densely packed; frequent skewplanes, occasional vughs.
Plasmic fabric: Silasepic. Skelsepic at higher magnification.
Phenoclasts: ~25% coarse fragments in cross section, angular to subrounded; dominantly medium and fine grained clastic; subdominant medium and fine grained igneous with variable degrees of alteration.
Sesquioxide staining in some phenoclasts of all lithology, varying from thin and patchy adjacent to outer surfaces, to complete internal staining.
Features: Infrequent roots disturb fabric locally.
Discontinuous and continuous (diffusion?) neosesquans around some phenoclasts of all lithology.
Skeleton grains in the matrix are encased in very thin, embedded grain cutans, producing skelsepic plasmic fabric.
Occasional void calcitans.

R5 1.5-1.8 m.

Fabric type: Matrifragmoidic - matrifragmic (mixed complex).
Densely packed; frequent skewplanes, occasional vughs.
Plasmic fabric: Silasepic. Skelsepic at higher magnification.
Phenoclasts: ~25% coarse fragments in cross section; angular to subrounded; dominantly medium and fine grained clastic; subdominant medium and fine grained igneous with variable degree of alteration.
Sesquioxide staining in some phenoclasts of all lithology, varying from thin and patchy adjacent to outer surfaces, to complete internal staining.
Features: Infrequent roots disturb fabric locally.
Discontinuous and continuous (diffusion?) neosesquans around some phenoclasts of all lithology.
Skeleton grains in the matrix are encased in very thin, embedded grain cutans, producing skelsepic plasmic fabric.
Very few void calcitans.

R4 2.1-2.4 m.

Fabric type: Partially accomodated matrifragmoidic - matrifragmic (mixed complex).
Well packed; frequent skewplanes, occasional vughs.
Plasmic fabric: Silasepic. Occasionally skelsepic at higher magnification.
Phenoclasts: ~30% coarse fragments in cross section; angular to subrounded; dominantly medium and fine grained clastic; subdominant medium and fine grained igneous with variable degrees of alteration.

(cont.)

Table 10. Micromorphological descriptions of Cloudy Ridge samples.

Sesquioxide staining in some phenoclasts of all lithology, varying from thin and patchy adjacent to outer surfaces, to complete internal staining.

Features: Infrequent roots disturb fabric locally.
Discontinuous and continuous (diffusion?) neosesquans around some phenoclasts of all lithology.
Very few, very small papules.
Few, nearly opaque but containing mineral grains, irregular sesquioxidic nodules.
Occasional patches where all skeleton grains in the matrix are encased in very thin, embedded grain cutans; these are the areas with skelsepic plasmic fabric.
Common, small and very small truncated papules.

R3 2.7-3.0 m.

Fabric type: Partially accomodated matrifragmoidic.
Well packed; frequent interconnected vughs and skewplanes.
Plasmic fabric: Silasepic.
Phenoclasts: ~40% coarse fragments in cross section; angular to subrounded; dominantly medium and fine grained clastic; subdominant medium and fine grained igneous with variable degrees of alteration.
Sesquioxide staining in some phenoclasts of all lithology, varying from thin and patchy adjacent to outer surfaces, to complete internal staining.
Features: Marked lighter matrix colour than sample layer above (R4).
Infrequent roots disturb fabric locally.
Discontinuous and continuous (diffusion?) neosesquans around some phenoclasts of all lithology.
Occasional, very thin and thin void argillans.
Common, variable sized (up to 1 mm) papules; larger are occasionally subparallel to void walls and f-members; papules are occasionally concentrated locally.
Common, nearly opaque but containing mineral grains, irregular, sesquioxidic nodules, occasionally concentrated locally.
Few "ghost" coarse fragments, portions nearly opaque with sesquioxid staining; very few void argillans in "ghosts."

R2 3.2-3.5 m.

Fabric type: Partially accomodated matrifragmoidic.
Well packed; frequent large (1 mm) interconnected vughs and skewplanes.
Plasmic fabric: Silasepic.

(cont.)

Table 10. Micromorphological descriptions of Cloudy Ridge samples.

Phenoclasts: ~40% coarse fragments in cross section; angular to subrounded; dominantly medium and fine grained clastic; subdominant medium and fine grained igneous with variable degrees of alteration.
Sesquioxide staining in some phenoclasts of all lithology varying from thin and patchy adjacent to outer surfaces, to complete internal staining.
Features: Infrequent roots disturb fabric locally, and some have associated calcitans.
Discontinuous and continuous (diffusion?) neosesquans around some phenoclasts of all lithology.
Occasional, very thin and thin void argillans.
Frequent, truncated papules, occasionally subparallel to void walls and f-members, but generally randomly mixed through the matrix with slight local concentrations.
Common, nearly opaque but containing mineral grains, irregular, sesquioxidic nodules.
Few "ghost" coarse fragments, portions nearly opaque with sesquioxidic staining; very few void argillans in "ghosts."

RI 3.7-3.9 m.

Fabric type: Plectic - porphyroskelic (mixed complex).
The sample is highly infused with secondary carbonate. Considering the carbonate to be plasma, complete infusion produces porphyroskelic areas, locally incomplete produces plectic areas with irregular vughs.
Prior to cementation a majority of the sample is inferred to have been loosely packed gefuric - chalmydic with simple packing voids.
Plasmic fabric: Crystic. This fabric occurs where carbonate dominates the plasma.
Prior to cementation, the plasmic fabric is inferred to have been silasepic.
Phenoclasts: ~50% coarse fragments in cross section; angular to subrounded; dominantly medium and fine grained clastic; subdominant medium and fine grained igneous with variable degrees of alteration.
Sesquioxide staining in some phenoclasts of all lithology varying from thin and patchy adjacent to outer surfaces, to complete internal staining.
Features: Frequent free, embedded grain, and void calcitans in plectic areas.
Discontinuous and continuous (diffusion?) neosesquans around a few phenoclasts.
Occasional, discontinuous void argillans sandwiched between matrix and void calcitans.

Plate 31. Thin section of an embedded grain cutan in Cloudy Ridge sample R6.

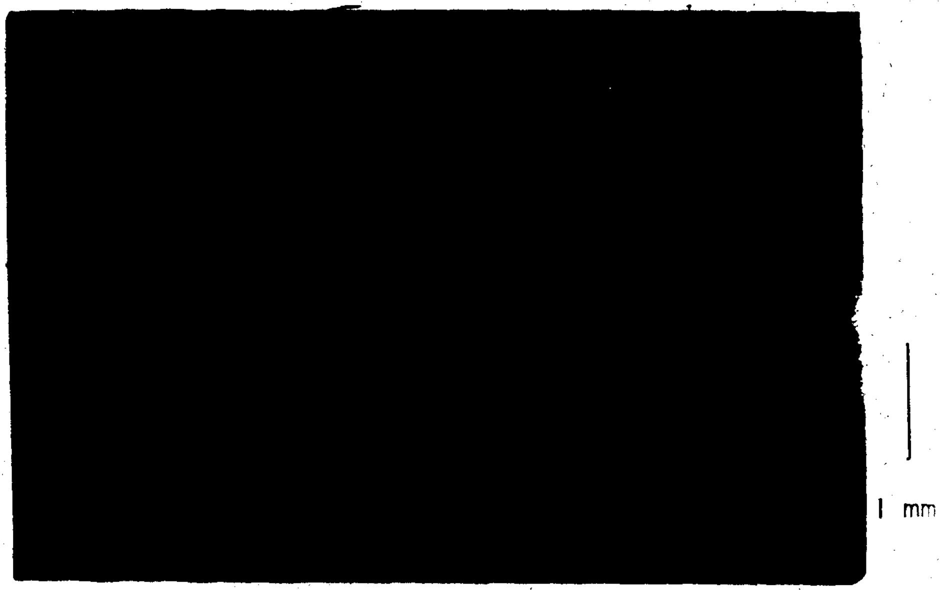

Plate 32. Thin section of well packed fabric and many small yellowish truncated papules in Cloudy Ridge sample R3.

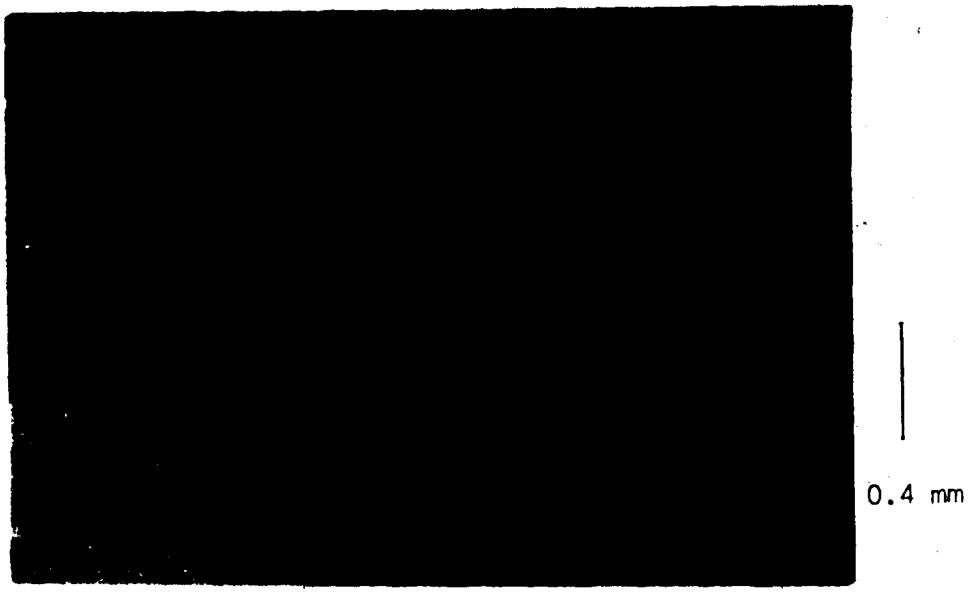

Plate 33. Thin section of a "ghost" coarse fragment in Cloudy Ridge sample R3.

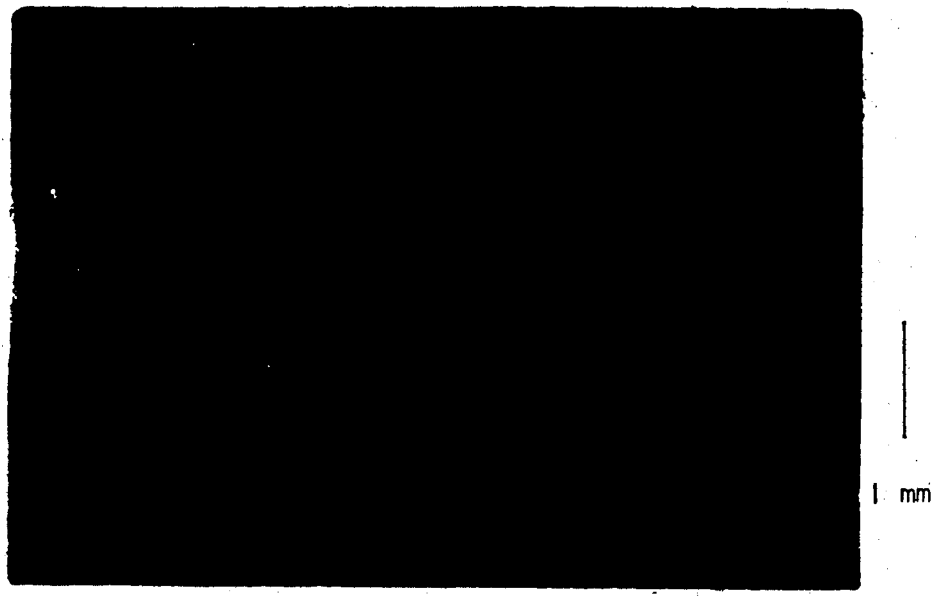

Plate 34. Thin section of a truncated papule in Cloudy Ridge sample R2, assumed formerly an argillan.

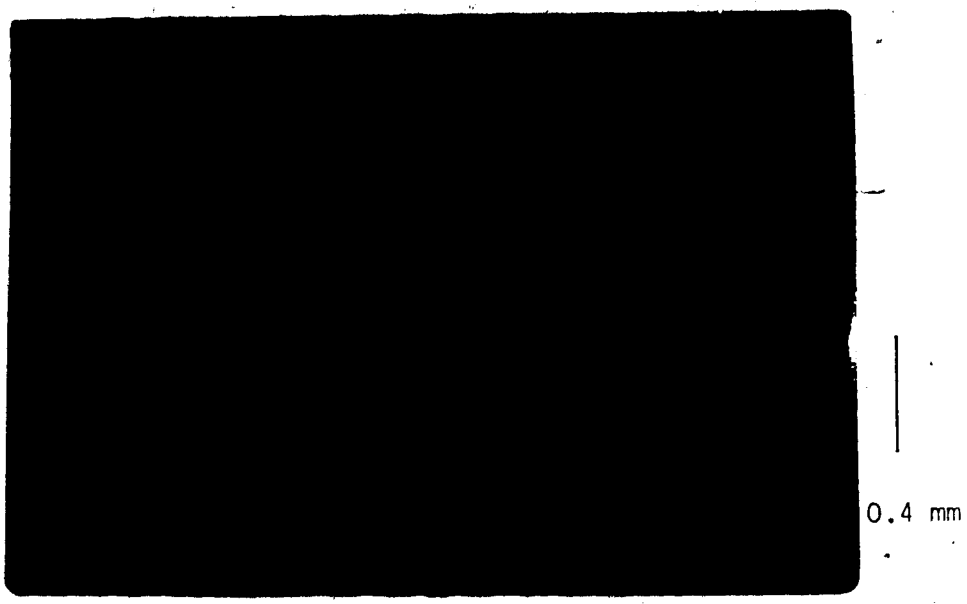

Plate 35. Thin section of void calcitans in Cloudy Ridge sample RI. Such large voids are not typical of till.

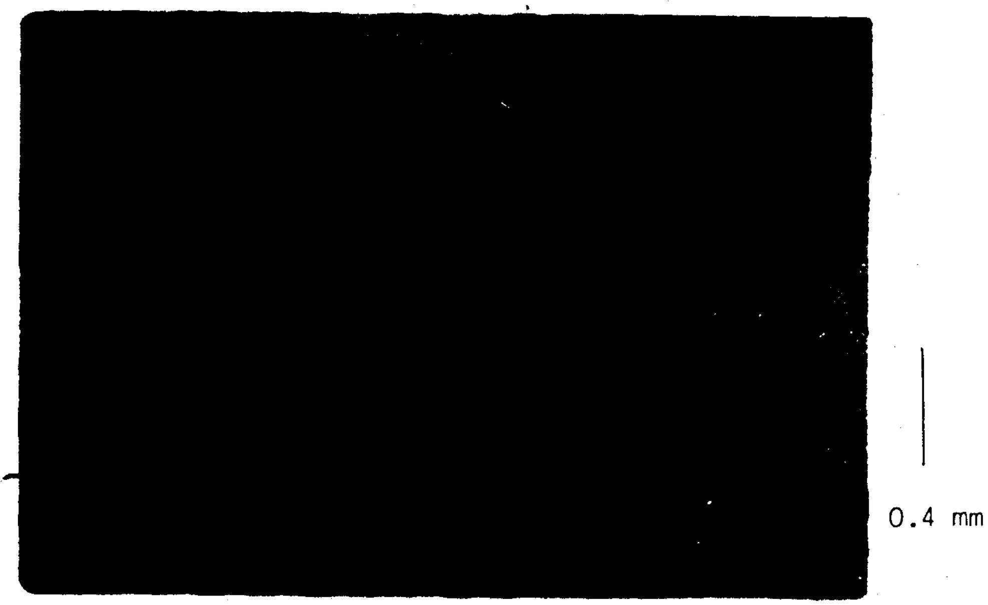

Plate 36. Thin section of a void argillan between a phenoclast and complete carbonate infusion in Cloudy Ridge sample RI.

3) physical disruption. The disruption became more severe upwards as evidenced by the effect on argillans (Plates 32, 34) and distribution of "ghosts." Although it is possible that neither of these features were ever present in the topmost sample layers, their absence there is interpreted to mean the disruption there was complete.

The proposed processes can be arranged in a probable chronosequence. Plasma reorganization and weathering were contemporaneous, since clay films are encased by precipitated weathering products (Plate 36) but also occur in voids in "ghosts" (Table 10). Both preceeded disruption, as inferred from the present state of both the argillans and weathered fragments.

The trend of increased disruption upwards is paralled by increasingly dense fabric upwards (Table 10) and more firm consistence upwards (Table 9), both of which are consistent with compaction of the surface layers. The occurrence of embedded grain cutans near the top probably indicates stress (Brewer 1976). A source of both stress and compaction could have been the glacier that apparently overrode the site, depositing the overlying till, Unit D (Wagner 1966). It is then probable that the fabric and features of the completely mixed layers R5 and R6 were generated during or following this burial.

If the above polygenetic history is correct, it is unlikely there is a pedogenic record held in the micromorphological fabric or features at the top of Unit C which contains the reported paleosol. Previous characteristics might have survived if the topmost portion was frozen, but there is no evidence of such a shear in the profile, and fabric density, physical character, and absence of "ghosts" argues the top was thoroughly affected. The calcitans, neosesquans, and embedded grain argillans are probably recent. Any specific pedogenic record, if present, must be determined by other analyses.

Whole Soil Analyses

Bulk density (Fig. 38) increases slightly upwards. This trend is opposite from modern soils and values are well above those common in pedogenic horizons (Buckman and Brady 1969). High values that increase upwards could have resulted from increasing compaction upwards by weight of the glacier that deposited the overlying till, Unit D (Wagner 1966). That theory is consistent with the increase in fabric density and disruption upwards noted in the micromorphological analyses.

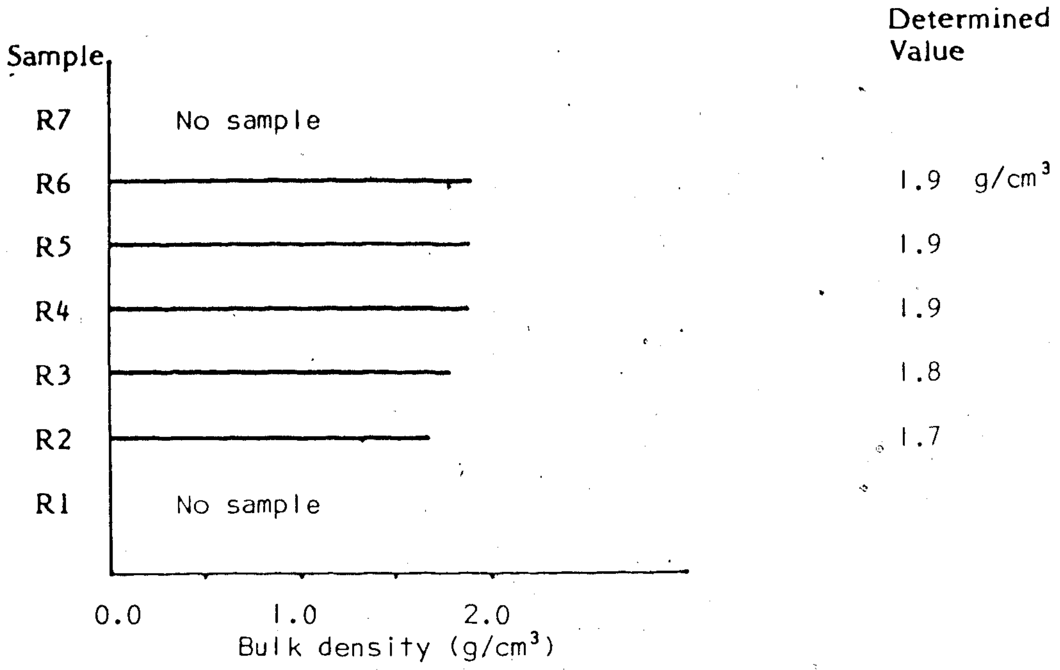

Figure 38. Bulk density of Cloudy Ridge samples.

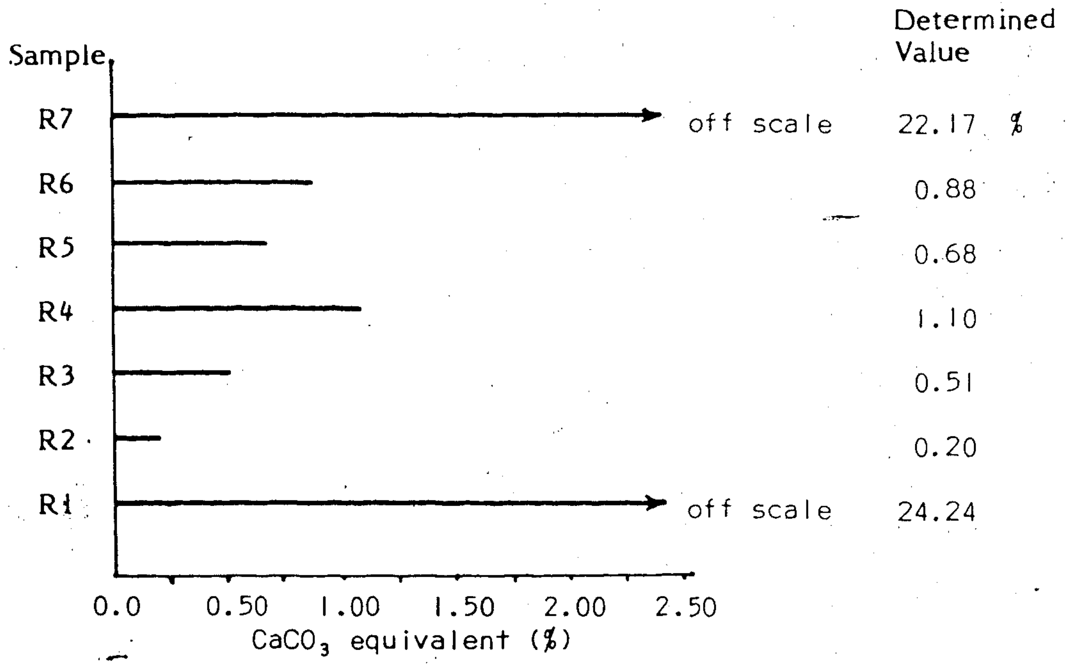

Figure 39. Percent calcium carbonate equivalent of Cloudy Ridge samples.

Calcium carbonate equivalent (Fig. 39) generally increases upwards which could indicate it was illuviated from the overlying drift. Remnants of more ancient cementing occur in R4 (Table 9) explaining the divergence from the trend. The pH of all layers was between 7.0 and 7.5, values and uniformity to be expected from the carbonate content (Buckman and Brady 1969).

Organic carbon content (Fig. 40) increases upwards, but all values are low. Distribution parallels and thus probably reflects the upward increase in the incidence of roots (Table 9). No paleopedogenic record may readily be educed from the organic component.

Total phosphorus (Fig. 41) decreases uniformly upward. The distribution may reflect weathering, but contrasts with results from some modern soils (Smeck 1973) and paleosols (Runge et al. 1974; Leahy 1975).

Textural Analyses

Micromorphological analyses above show that the significance of bulk texture is restricted. Since deposition, values have probably been altered by disruption of weathered constituents. However, it is probable that the clay increase in upper layers (Fig. 44) is not illuvial because the increase is at the expense of sand (Fig. 42) while silt (Fig. 43) remains constant.

Clay Separate Analyses

Elemental analyses of the clay separates for potassium (Fig. 45), iron (Fig. 46), and aluminum (Fig. 47)demonstrate no significant relative change, consistent with a uniform clay mineralogy with depth.

Clay surface area (Fig. 48) and C. E. C. (Fig. 49) both increase slightly upwards. This may reflect the increased physical disruption upwards to which the weathered samples have probably been subjected.

The clay mineral assemblage (Figs. 50 - 55 & Table 11) is uniform in the older drift, but unusual for Alberta. The distinctive element is regularly interstratified chlorite-vermiculite.

Origin of the chlorite-vermiculite is not clear. It may be inherited. Elsewhere the mineral's genesis has been related to aggradation from 2:1 layer silicates either by diagenesis or metasomatism in magnesium rich environments, or degradation from chlorites under moderate acid

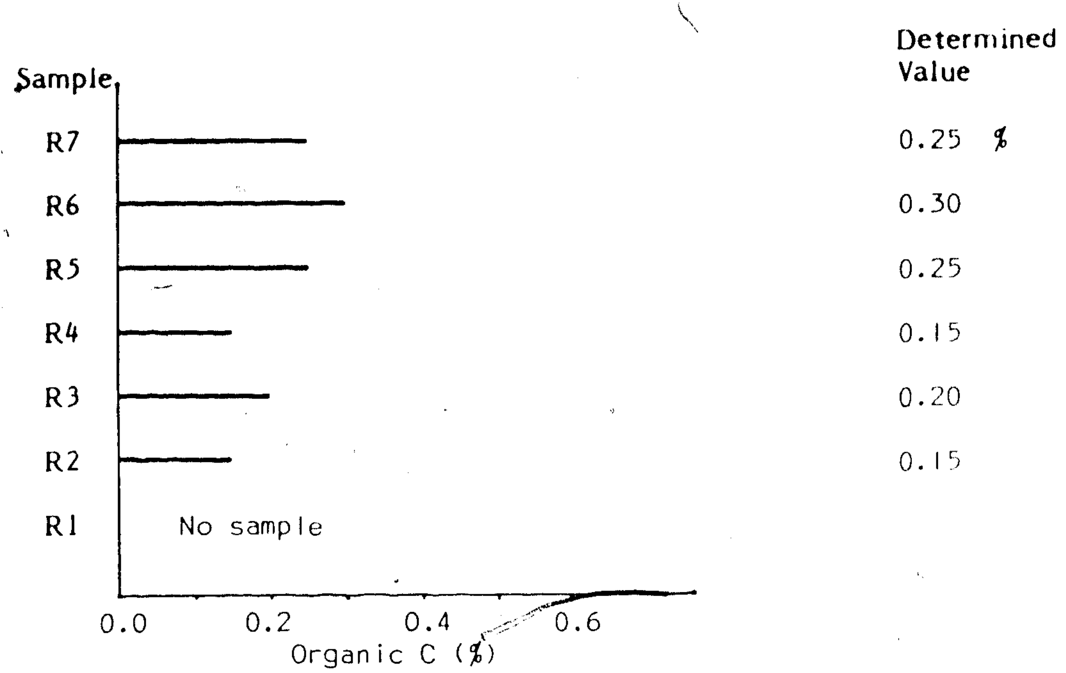

Figure 40. Percent organic carbon as C in Cloudy Ridge samples.

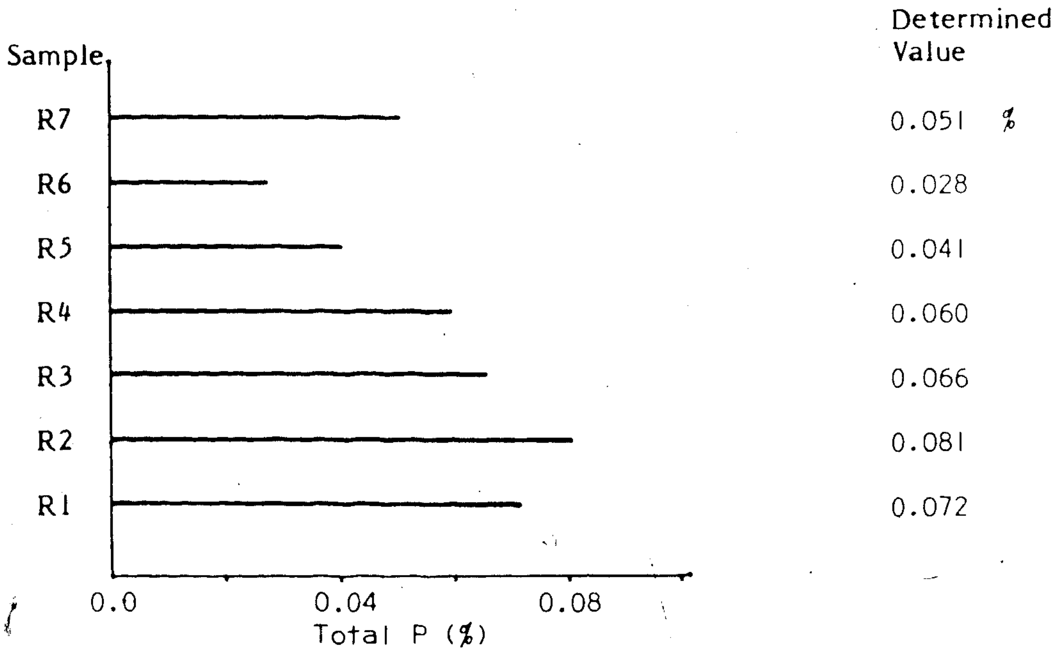

Figure 41. Percent total phosphorus as P in Cloudy Ridge samples.

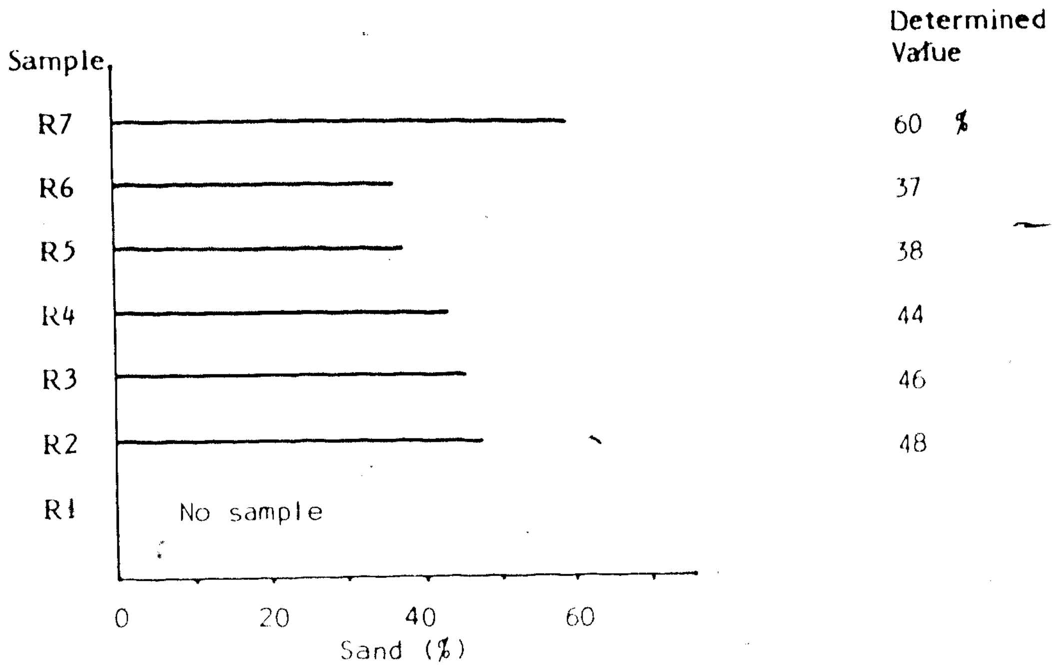

Figure 42. Percent sand in Cloudy Ridge samples.

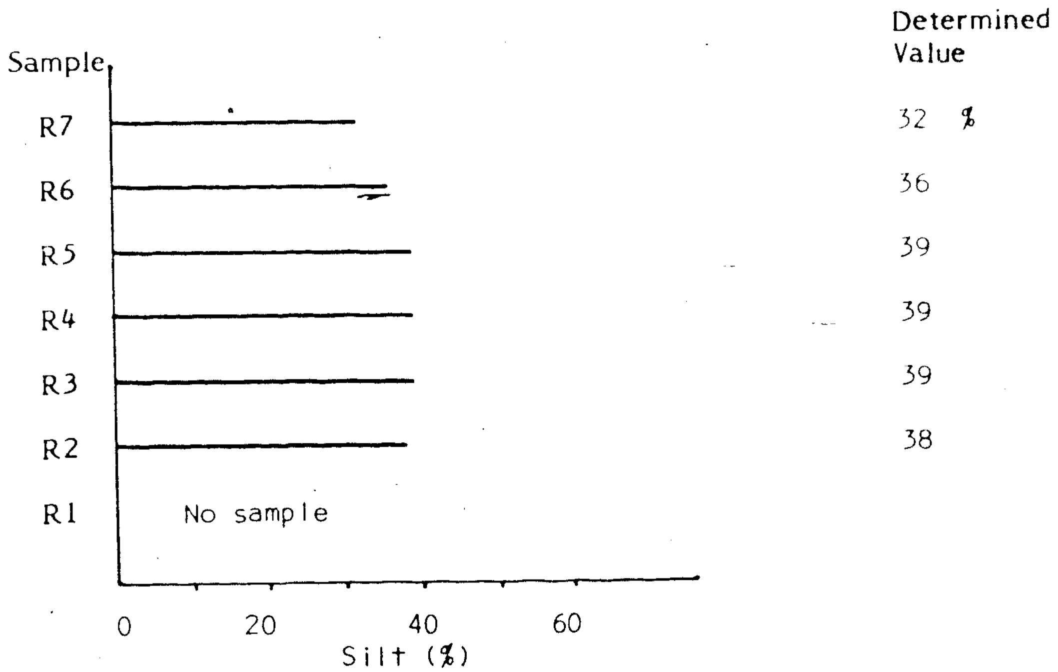

Figure 43. Percent silt in Cloudy Ridge samples.

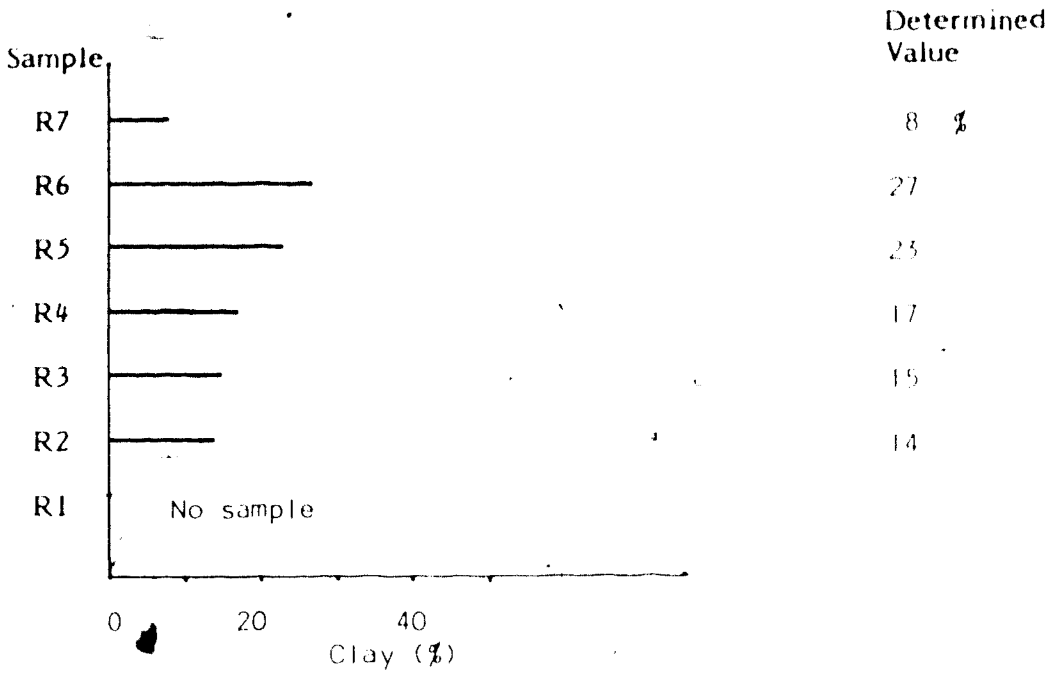

Figure 44. Percent clay in Cloudy Ridge samples.

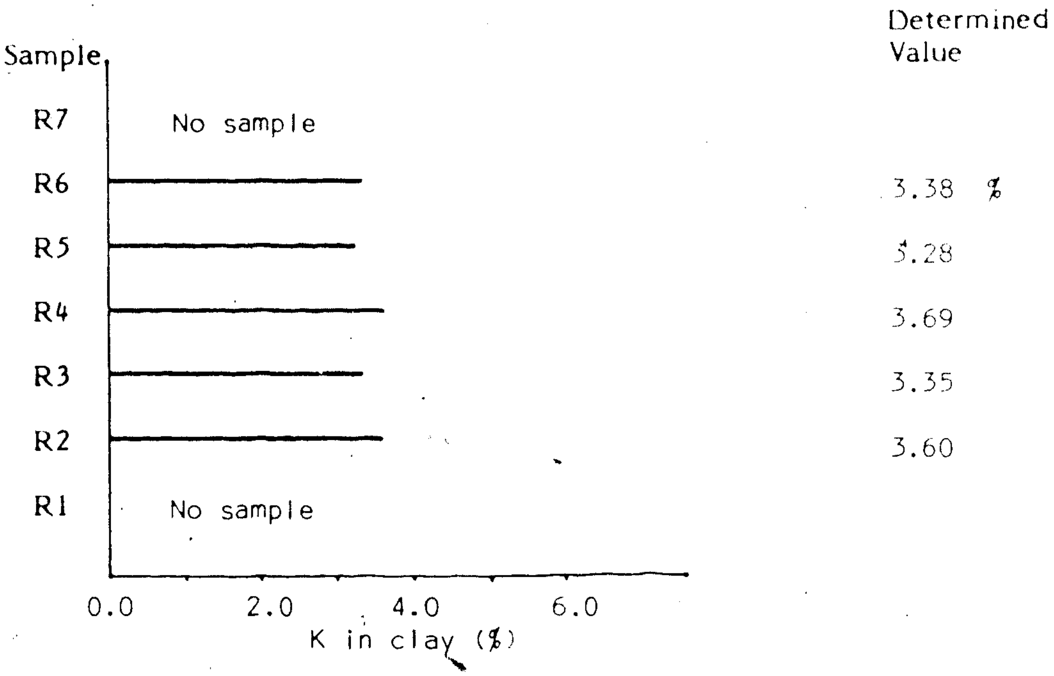

Figure 45. Percent potassium as K in clay separates from Cloudy Ridge samples.

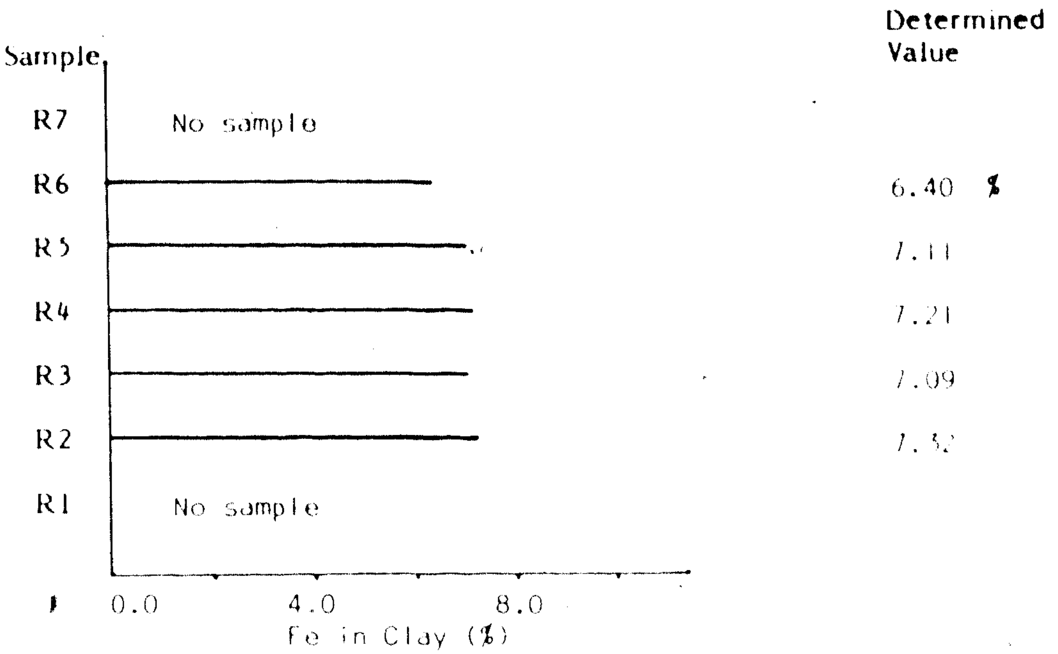

Figure 46. Percent iron as Fe in clay separates from Cloudy Ridge samples.

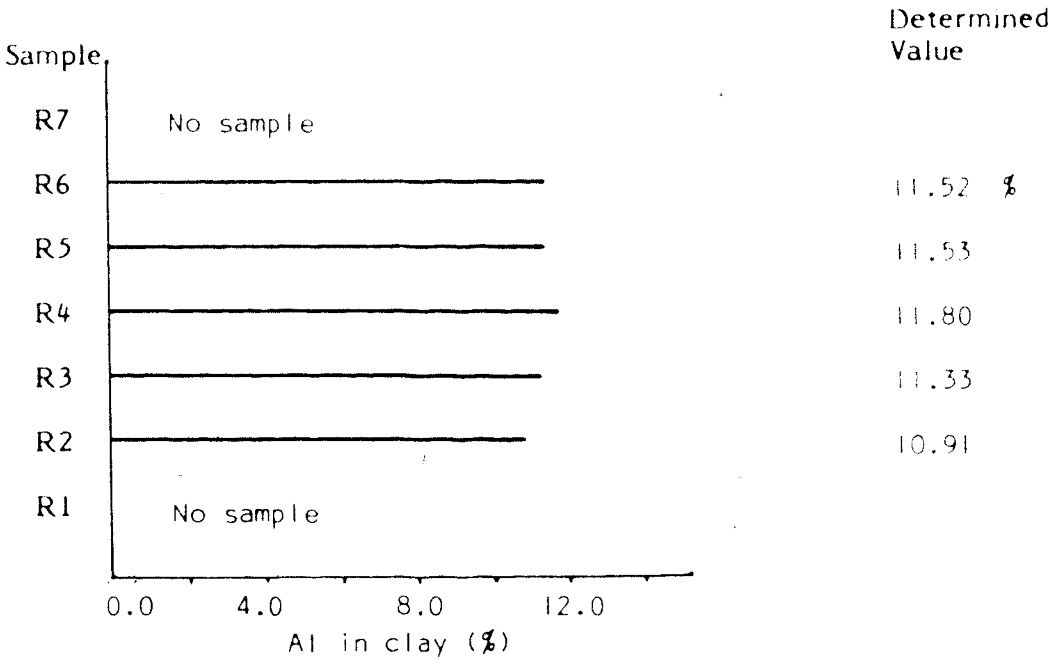

Figure 47. Percent aluminum as Al in clay separates from Cloudy Ridge samples.

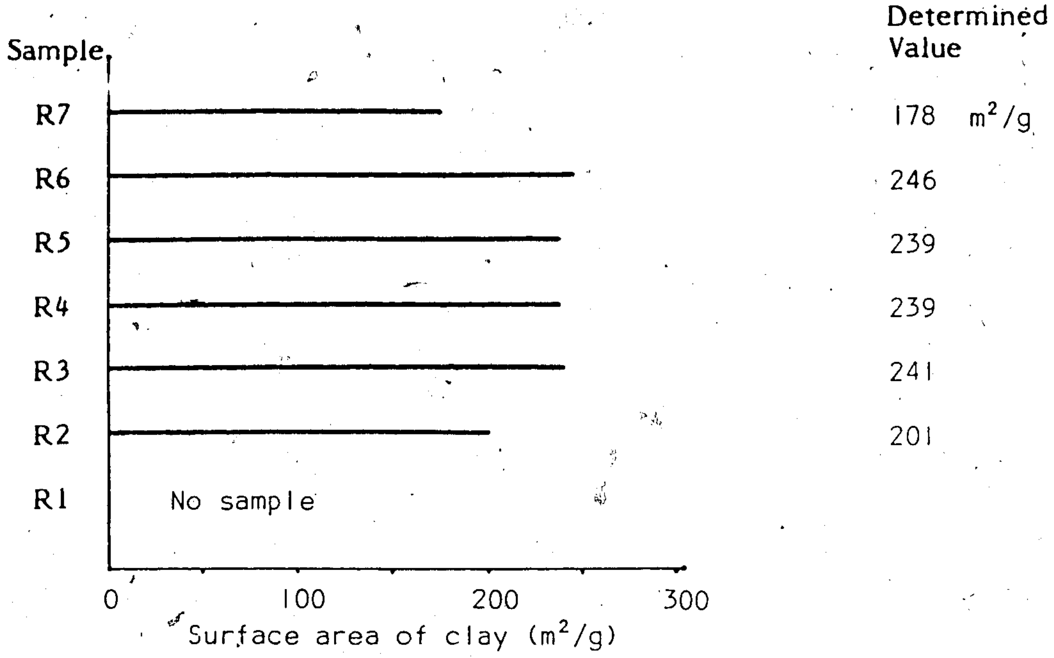

Figure 48. Surface area of clay separates from Cloudy Ridge samples.

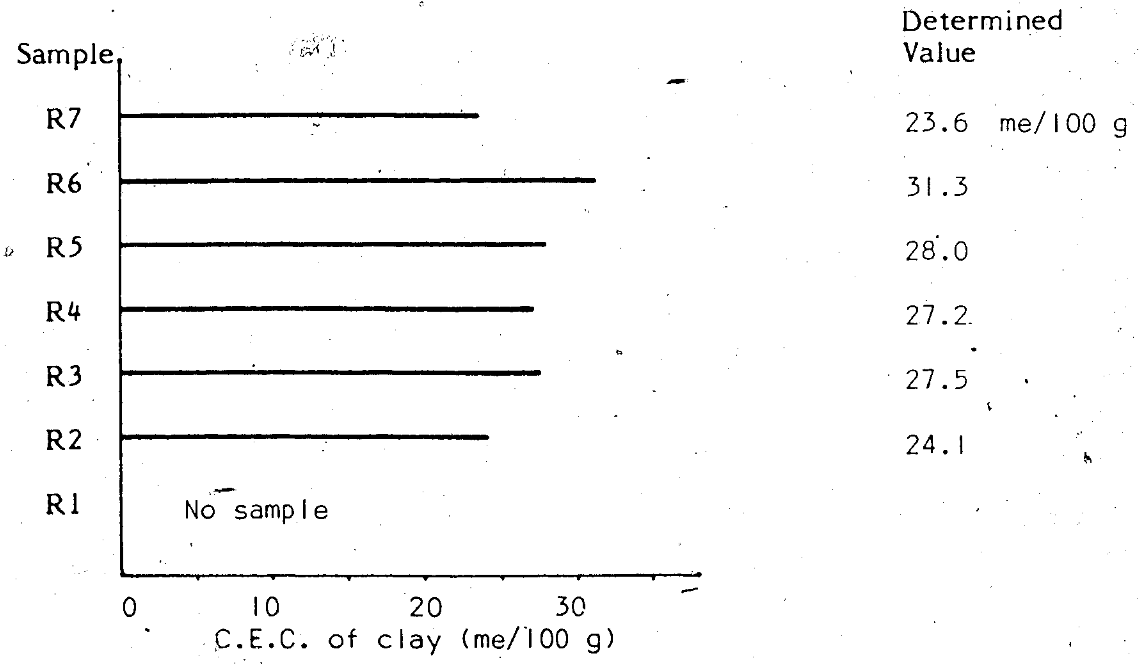

Figure 49. Cation exchange capacity of clay separates from Cloudy Ridge samples.

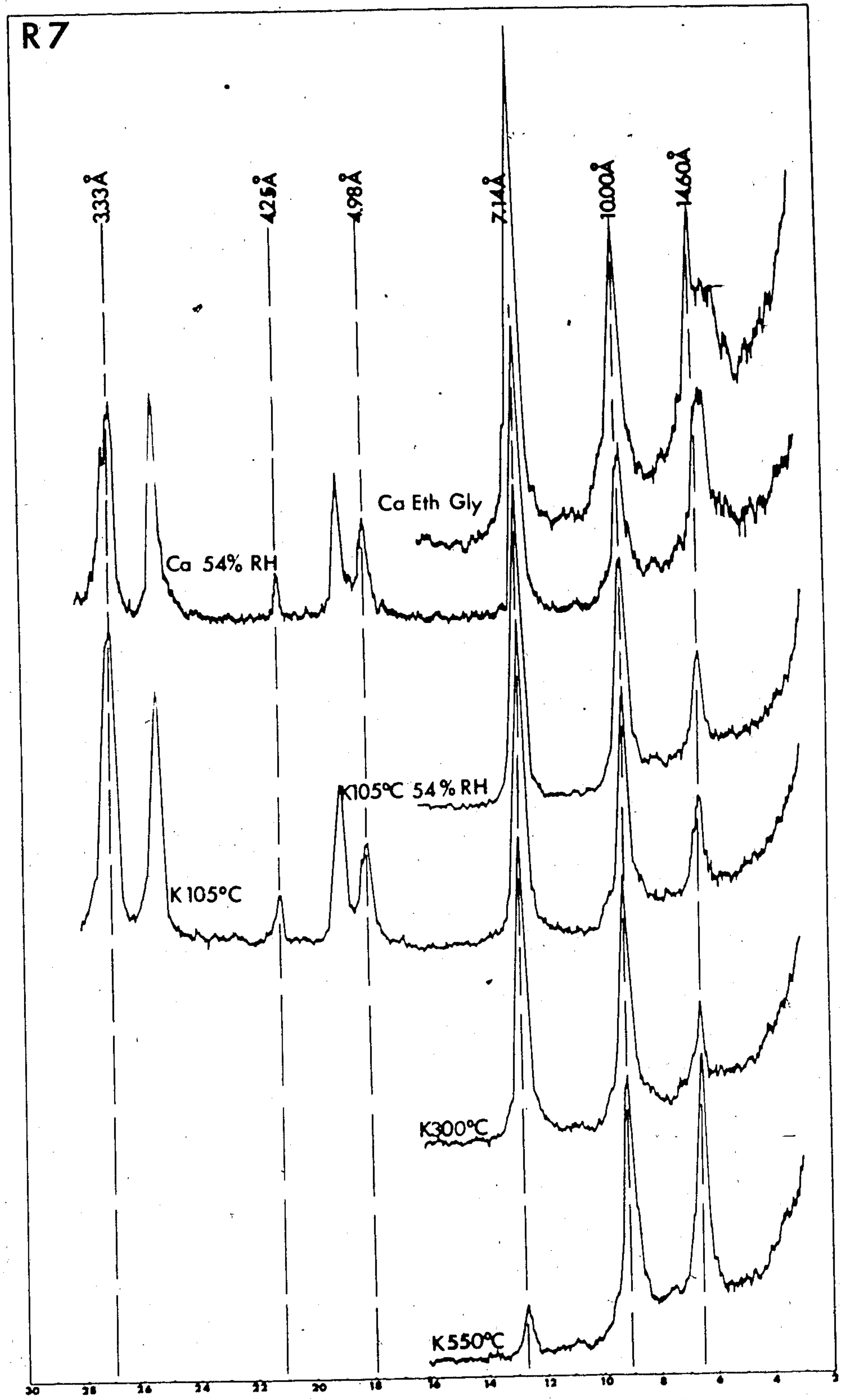

Figure 50. X-ray diffractogram of clay separate from Cloudy Ridge sample R7.

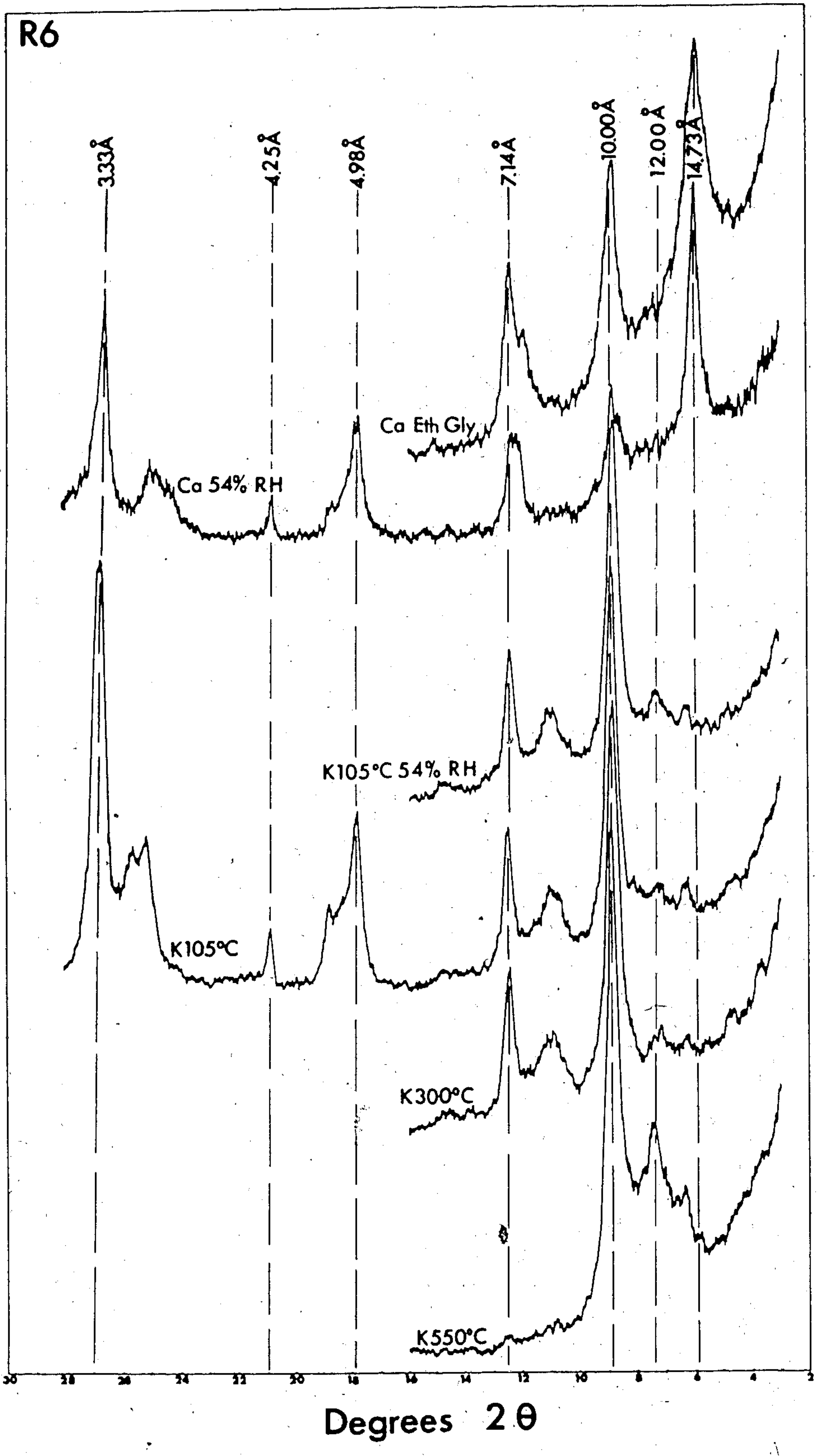

Figure 51. X-ray diffractogram of clay separate from Cloudy Ridge sample R6.

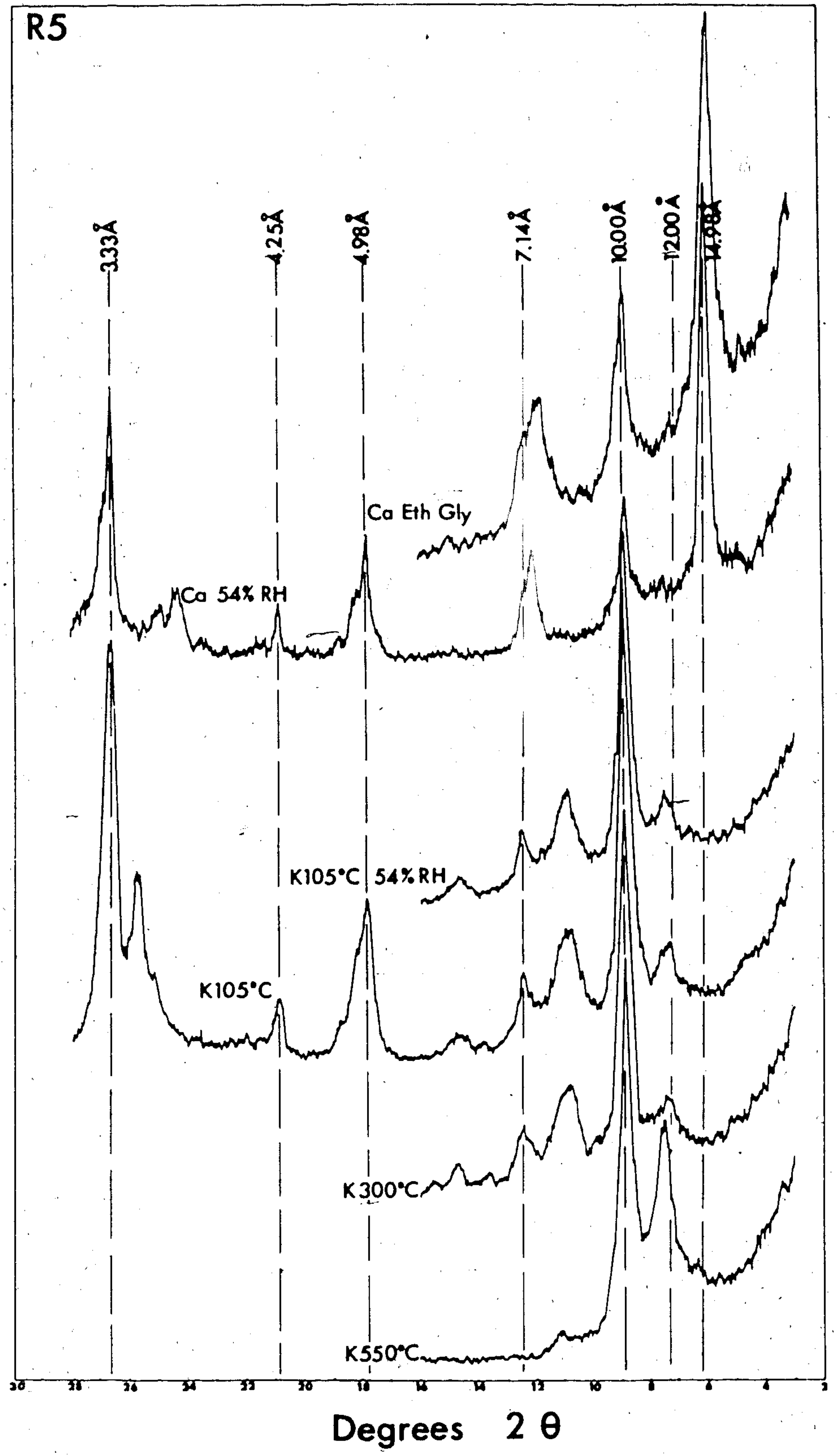

Figure 52. X-ray diffractogram of clay separate from Cloudy Ridge sample R5.

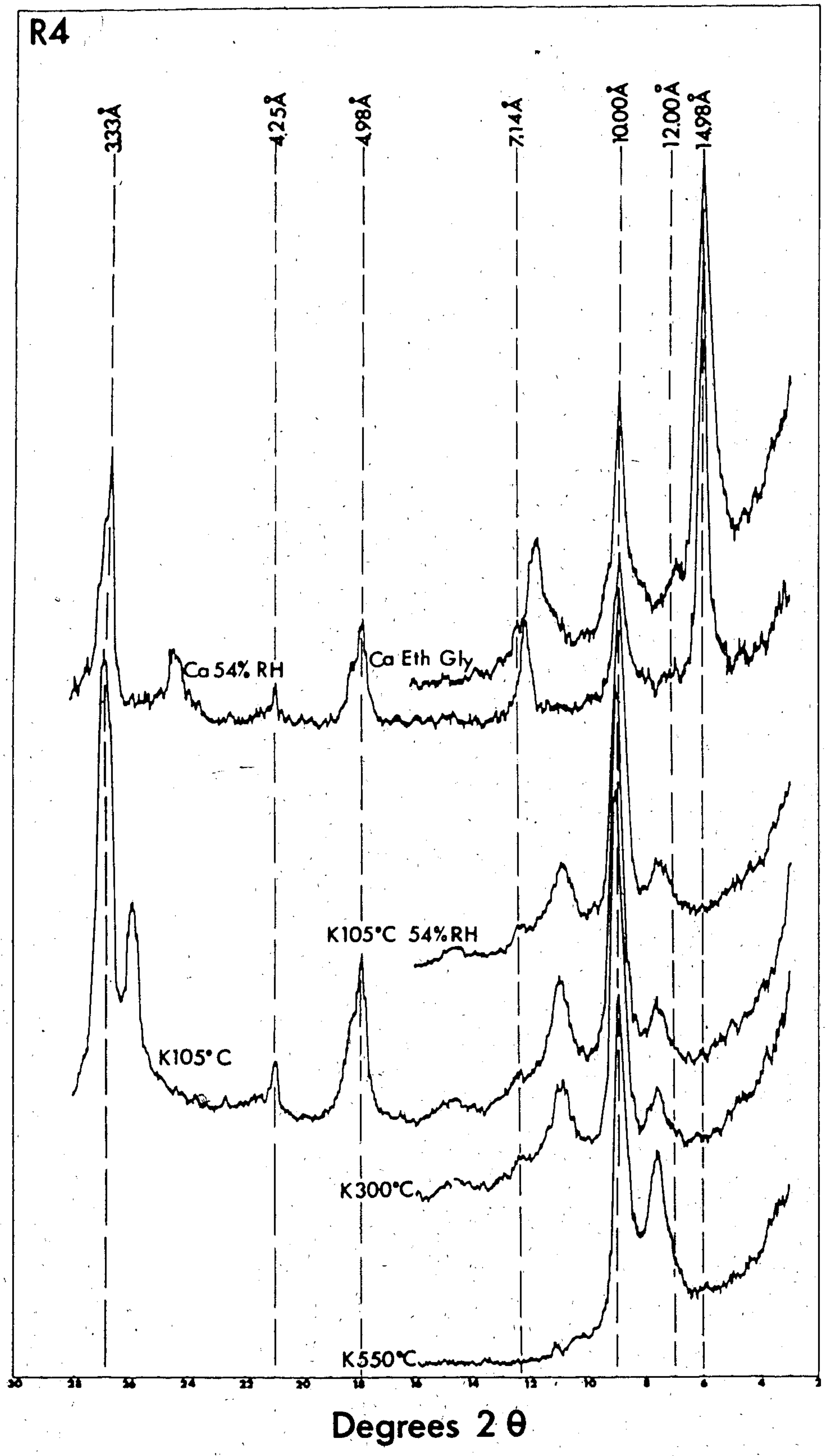

Figure 53. X-ray diffractogram of clay separate from Cloudy Ridge sample R4.

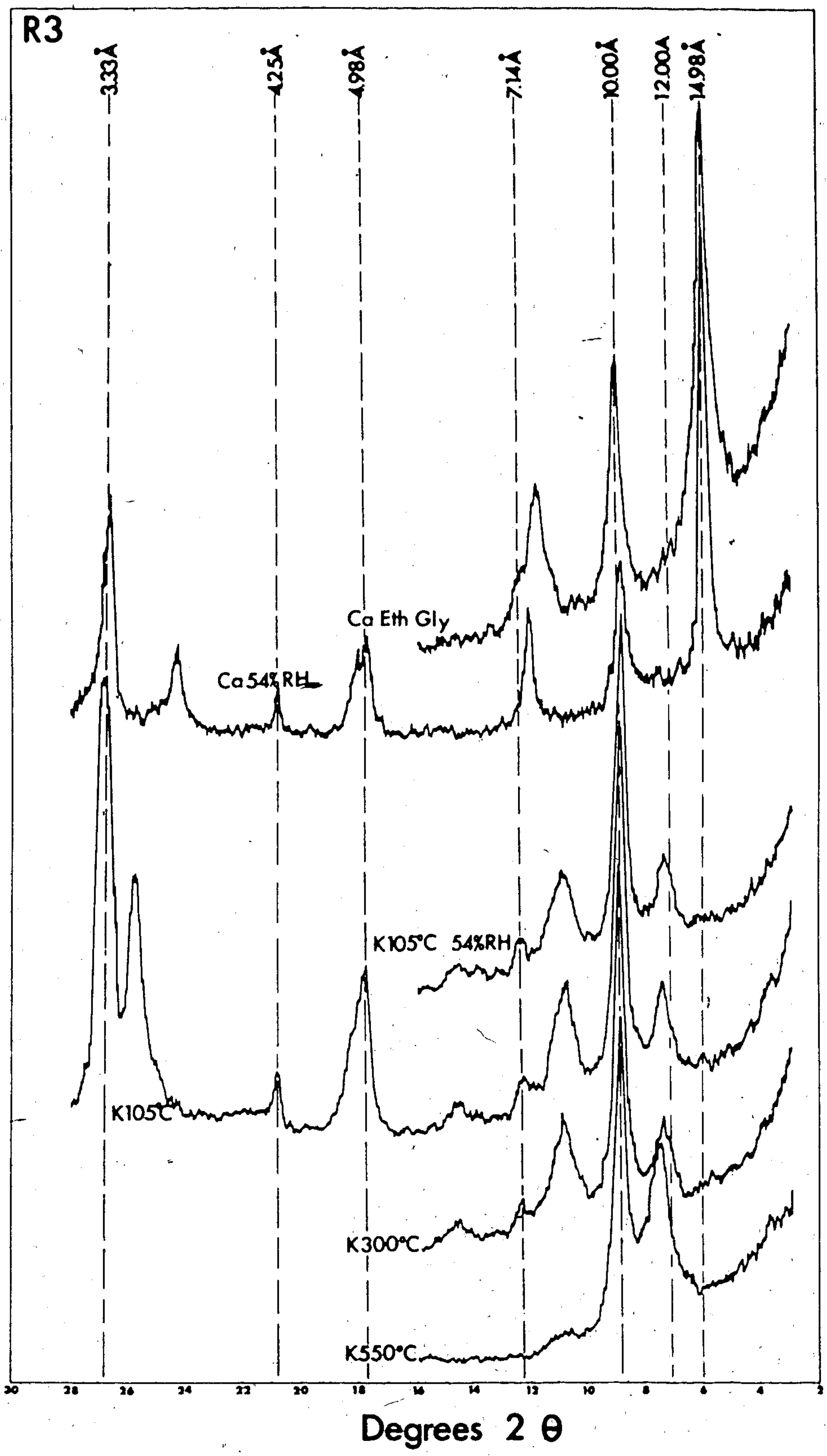

Figure 54. X-ray diffractogram of clay separate from Cloudy Ridge sample R3.

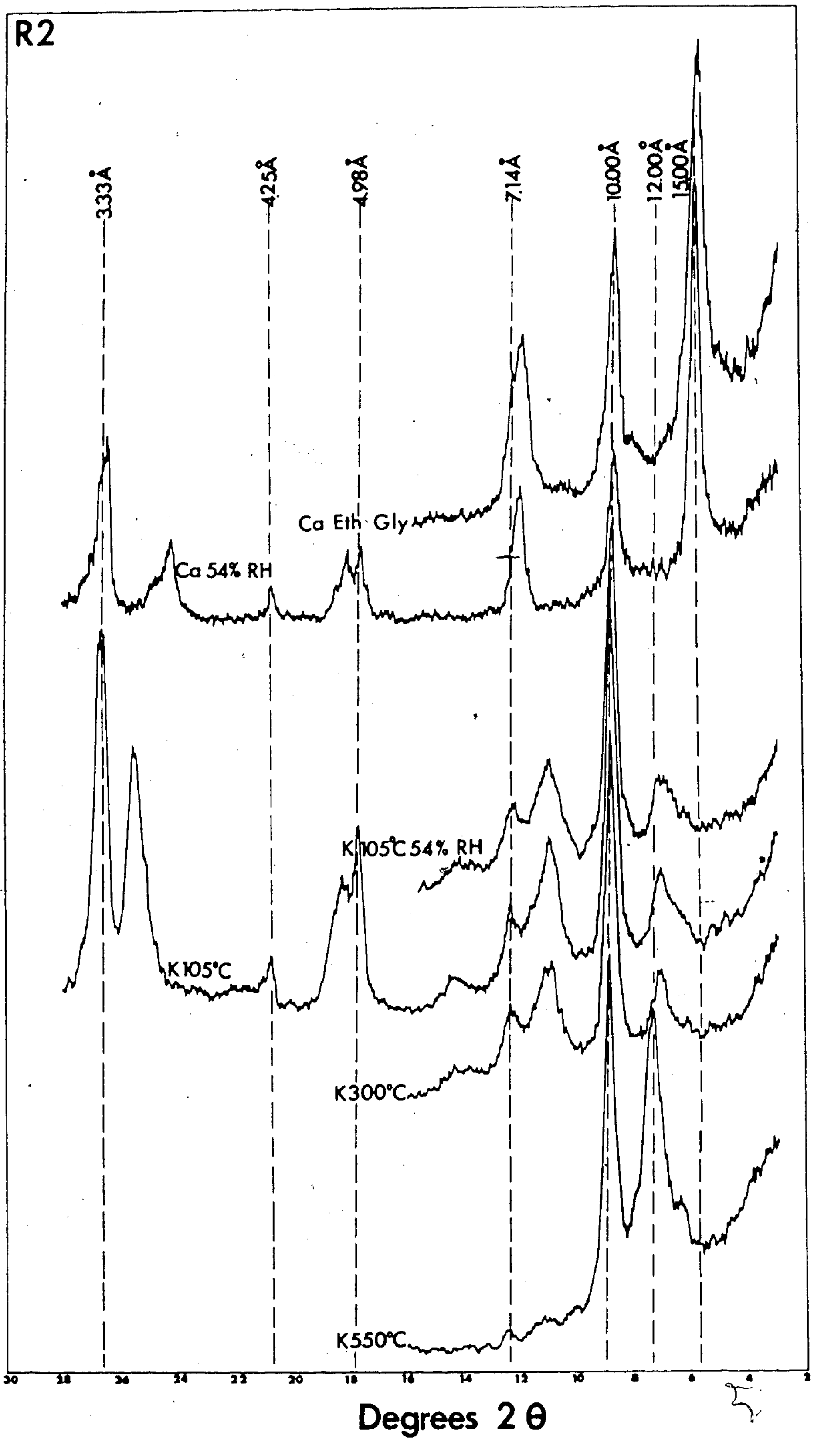

Figure 55. X-ray diffractogram of clay separate from Cloudy Ridge sample R2.

Table II. Mineral groups present in clay separates from Cloudy Ridge samples as identified by X-ray diffraction.

Sample	Mineral Groups Present	Reference
R7	i) quartz ii) mica iii) chlorite	Figure 50
R6	i) quartz ii) kaolin[1] iii) mica iv) chlorite-vermiculite[2]	Figure 51
R5	i) quartz ii) kaolin[1] iii) mica iv) chlorite-vermiculite[2]	Figure 52
R4	i) quartz ii) kaolin[1] iii) mica iv) chlorite-vermiculite[2]	Figure 53
R3	i) quartz ii) kaolin[1] iii) mica iv) chlorite-vermiculite[2]	Figure 54
R2	i) quartz ii) kaolin[1] iii) mica iv) chlorite-vermiculite[2]	Figure 55
R1	no sample	

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[1] trace amounts

[2] regularly interstratified

leaching conditions (Weaver and Pollard 1973; Sawhney 1977; April 1980). Despite the occurrence of igneous rocks in the section (Wagner 1966) and the probable source (Harrison 1976), the first explanation above is doubtful here because of the limited extent and mineralogical variability of chlorite-vermiculite so produced (April 1980). If inherited, its production by weathering prior to deposition is more probable. Chlorite-vermiculite is relatively stable in sediments (Weaver and Pollard 1973).

Alternately, the mineral may have been formed entirely within the profile. Weathering throughout it has been indicated by field and micromorphological examinations. Chlorite is present but chlorite-vermiculite absent in the overlying drift (Table 11). Assuming a similar cordilleran source for the two materials, conversion of chlorite to chlorite-vermiculite in situ is suggested for the clay mineralogy of the lower, older drift.

In either case, pedogenesis is not implicated. Processes acting on clay minerals appear to have had a nearly uniform effect throughout the section. Even assuming mineral genesis in situ, moderate acid leaching occurs more within the province of the geological weathering profile (Rutter 1969) than of the solum of soils (Canadian Society of Soil Science 1976).

Sand Separate Analyses

Feldspar analyses results are presented in Figures 56 to 58. Plagioclase values decrease upwards, which could indicate a greater degree of weathering upwards (assuming a uniform initial content). Orthoclase content is nearly uniform with depth. The distribution suggests a slight inhomogeneity of the original sediment. It is probable that processes acting on orthoclase have had a uniform effect throughout the profile.

Heavy mineral content (Fig. 59) is uniform with depth, even increasing slightly in R6, the topmost sample of Unit C. The increase could reflect an addition to the size fraction studied by grinding of rottenstone and coarse fragment "ghosts" in the upper layers by overriding ice. Alternately, it could indicate a nonuniform original sediment.

Opal was not determined because of expected low content in the presence of physical disruption and absence of any potential A horizon. Interpretation of low values would also be confounded by recent contamination, as was the case with organic compounds.

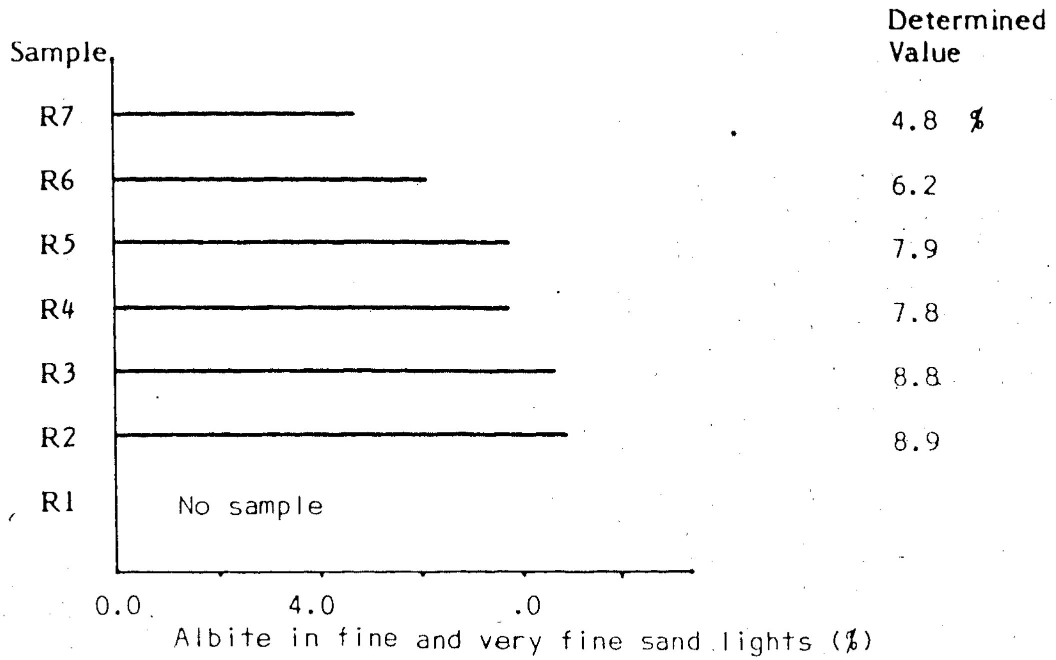

Figure 56. Percent albite (calculated from Na) in fine and very fine sand light (sp. gr. < 2.72) separates from Cloudy Ridge samples.

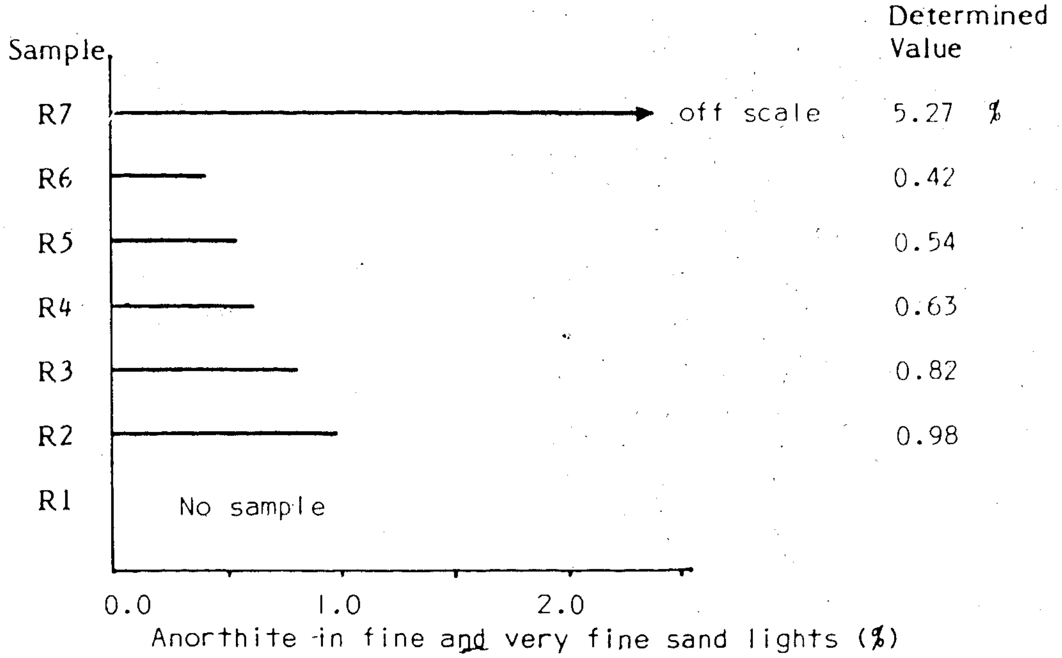

Figure 57. Percent anorthite (calculated from Ca) in fine and very fine sand light (sp. gr. < 2.72) separates from Cloudy Ridge samples.

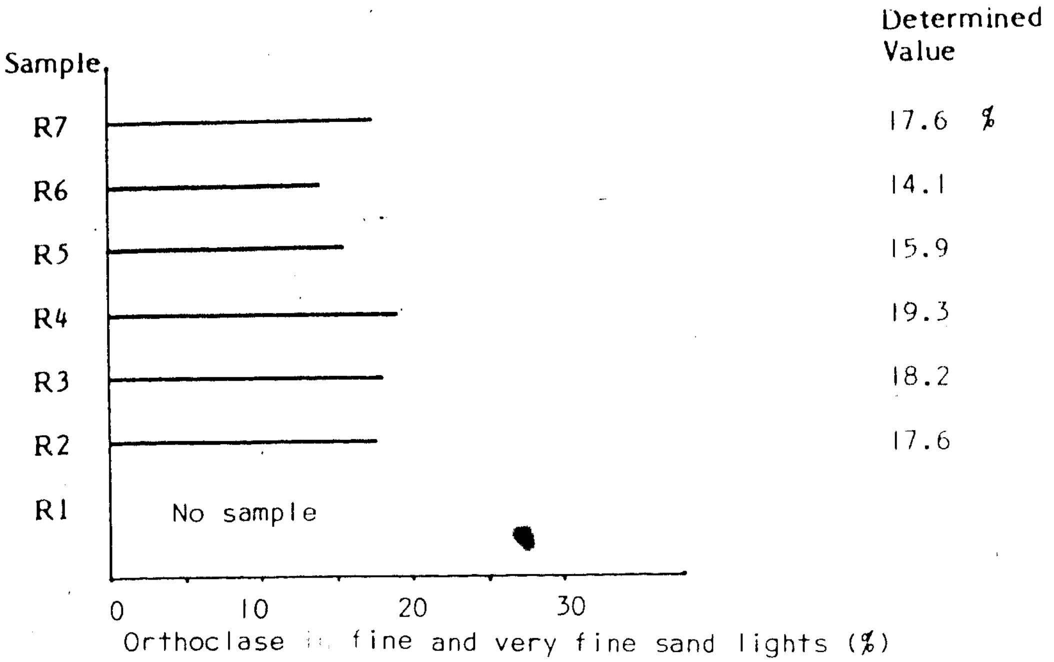

Figure 58. Percent orthoclase (calculated from K) in fine and very fine sand light (sp. gr. < 2.72) separates from Cloudy Ridge samples.

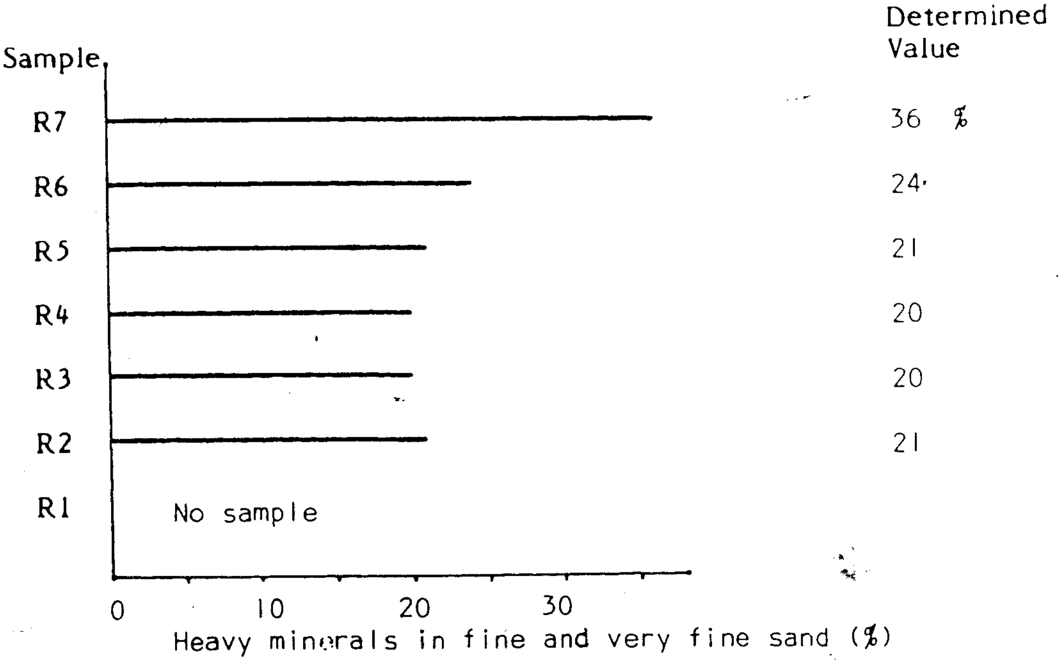

Figure 59. Percent heavy minerals (sp. gr. > 2.72) in fine and very fine sand separates from Cloudy Ridge samples.

Iron and Aluminum Analyses

It is likely that the reddish colour was the factor most responsible for the previous paleosol interpretations at the site. Results from the iron and aluminum analyses (Figs. 60-67) indicate the probable cause of the colour distribution.

Total iron (Fig. 60) is uniform throughout, while aluminum (Fig. 61) suggests slight enrichment in the upper layers or depositional varation.

Pyrophosphate iron (Fig. 62) and aluminum (Fig. 63) are very low, indicating very little is complexed with organics (C.S.S.C. 1978c). The values probably are similar to water soluble levels.

Oxalate (Fig. 64) and dithionite (Fig. 66) extractable iron indicate that colour correlates with finely divided hematite and goethite (C.S.S.C. 1978c). As with the Cypress Hills case, geochemical gradients probably have controlled the production of iron oxides.

Summary of the Cloudy Ridge Interpretation

No features indicative of paleopedogenesis were found in the physical, chemical, organic, micromorphological, or mineralogical components studied. Any paleopedological record at the Cloudy Ridge site could only be elucidated by more sophistocated techniques, if indeed any record exists at all.

The following polygenetic history is proposed to account for the layer (Unit C) that contains the soil-like features:

1) Deposition of Unit C. The process requires careful evaluation because it is likely subsequent disruption is responsible for many of the unit's current characteristics. It may be pre-Wisconsin till, but more of the features appear to be consistent with a late Tertiary or early Pleistocene fan origin;

2) A long period of physical stability during which mild geochemical processes were uniformly active throughout. Some rearrangement of clays occurred, while carbonate gradually accumulated in and cemented the coarser tectured layers. Some of the carbonate that now appears as cement probably was originally in the less resistant rocks that became "ghosts" and rottenstone. It is also possible that during this time chlorite weathered to regularly intersratified chlorite-vermiculite;

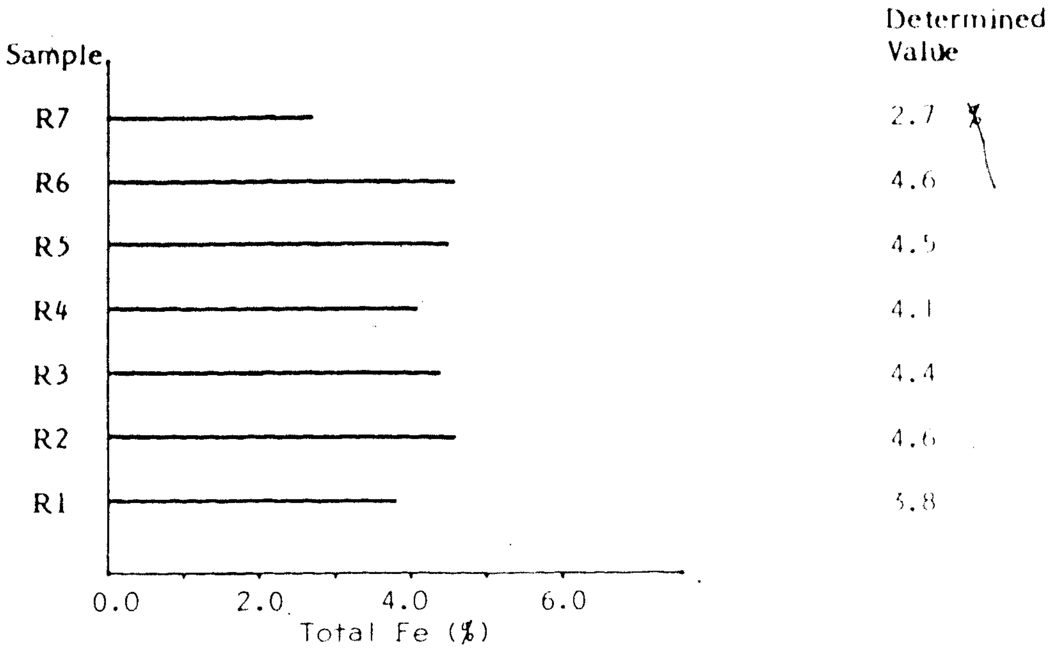

Figure 60. Percent total iron as Fe in Cloudy Ridge samples.

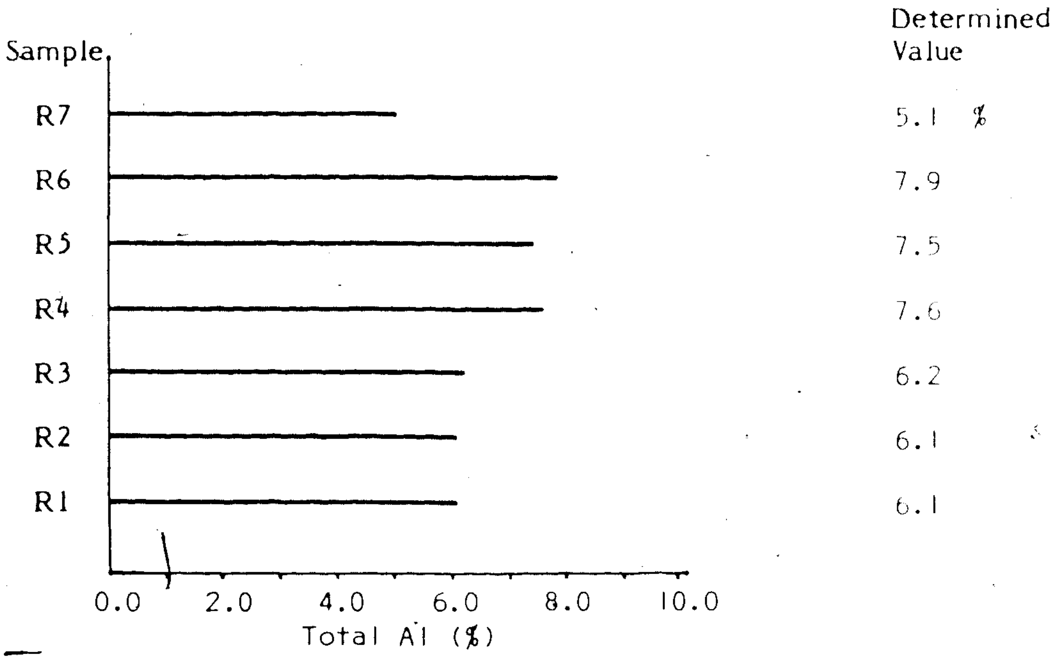

Figure 61. Percent total aluminum as Al in Cloudy Ridge samples.

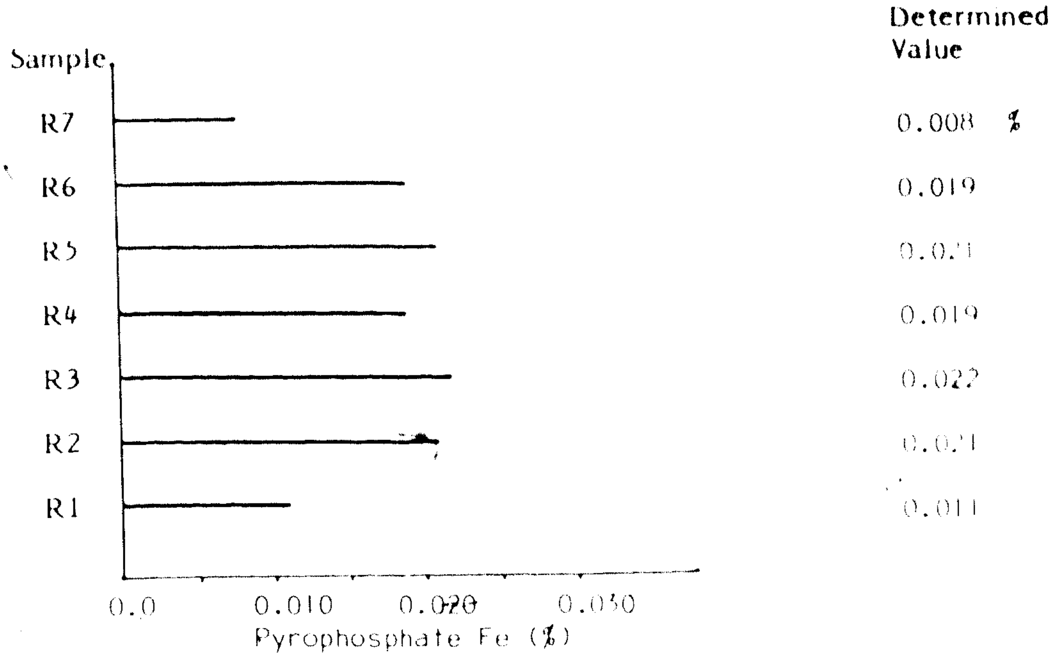

Figure 62. Percent sodium pyrophosphate extractable iron as Fe in Cloudy Ridge samples.

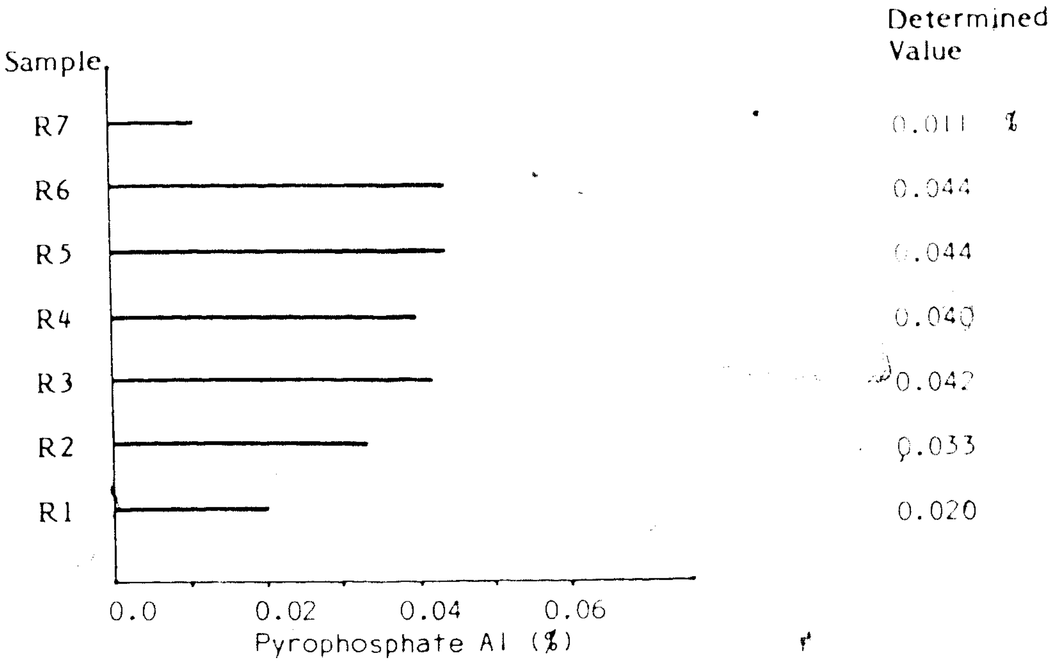

Figure 63. Percent sodium pyrophosphate extractable aluminum as Al in Cloudy Ridge samples.

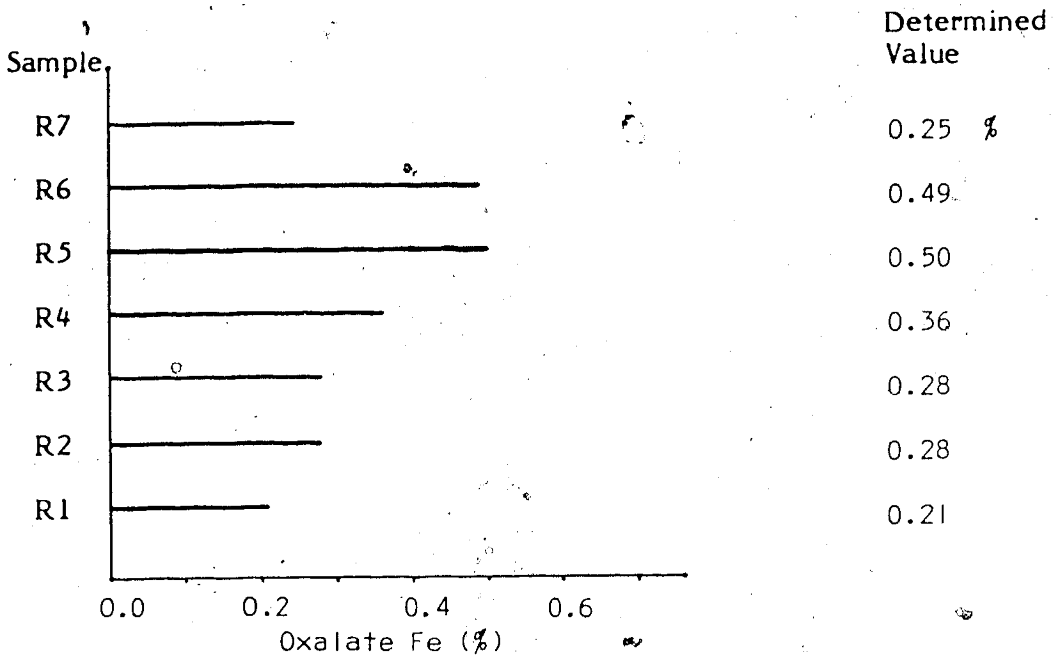

Figure 64. Percent acid ammonium oxalate extractable iron as Fe in Cloudy Ridge samples.

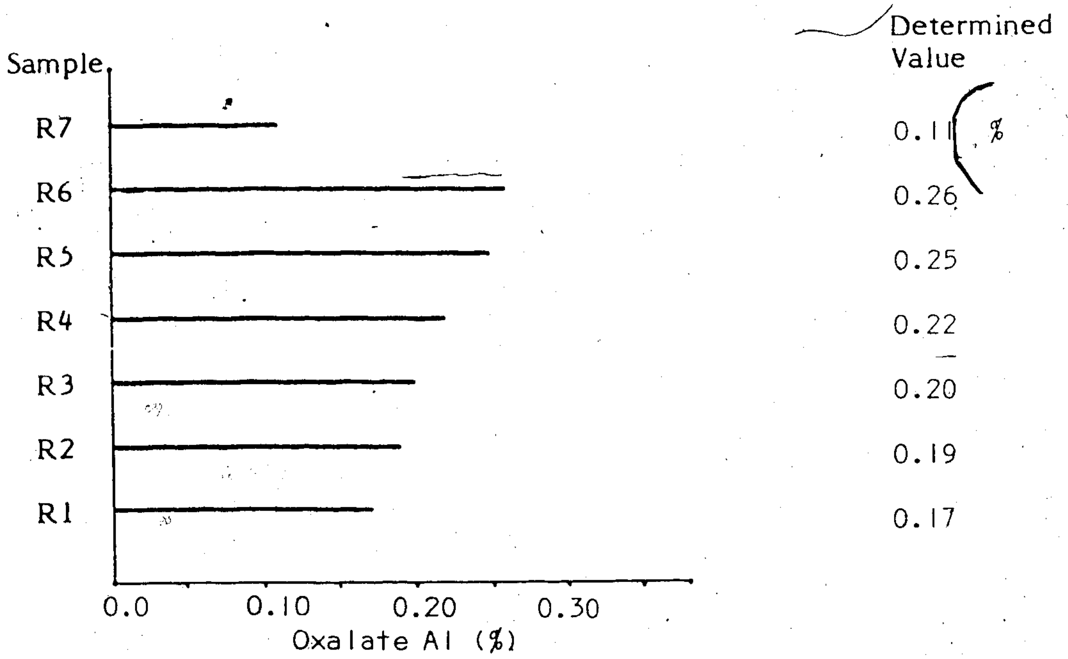

Figure 65. Percent acid ammonium oxalate extractable aluminum as Al in Cloudy Ridge samples.

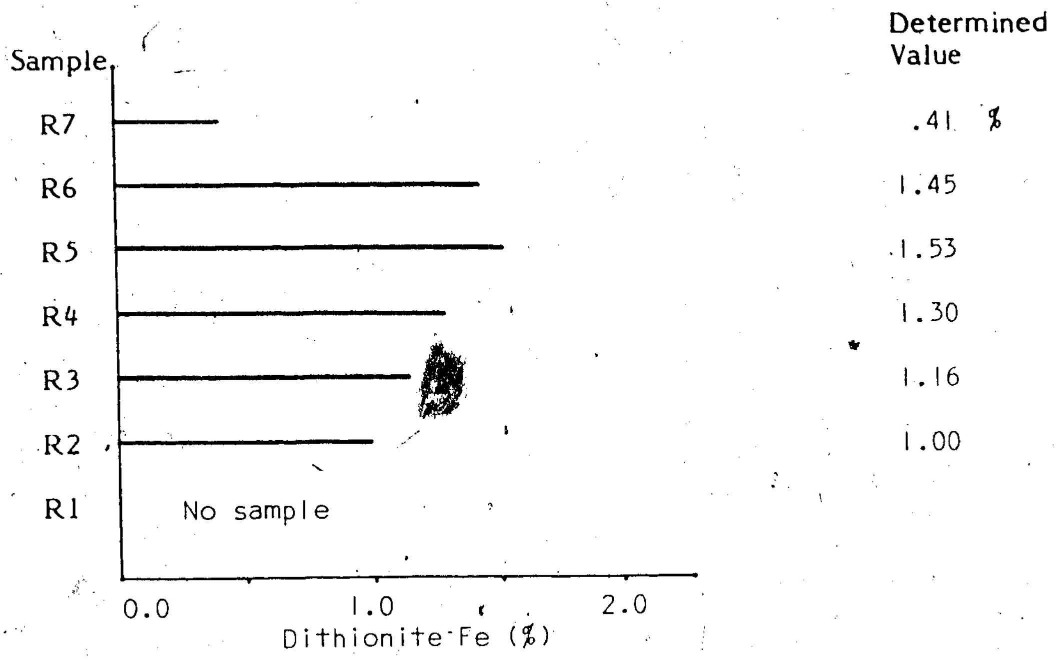

Figure 66. Percent dithionite-citrate-bicarbonate extractable iron as Fe in Cloudy Ridge samples.

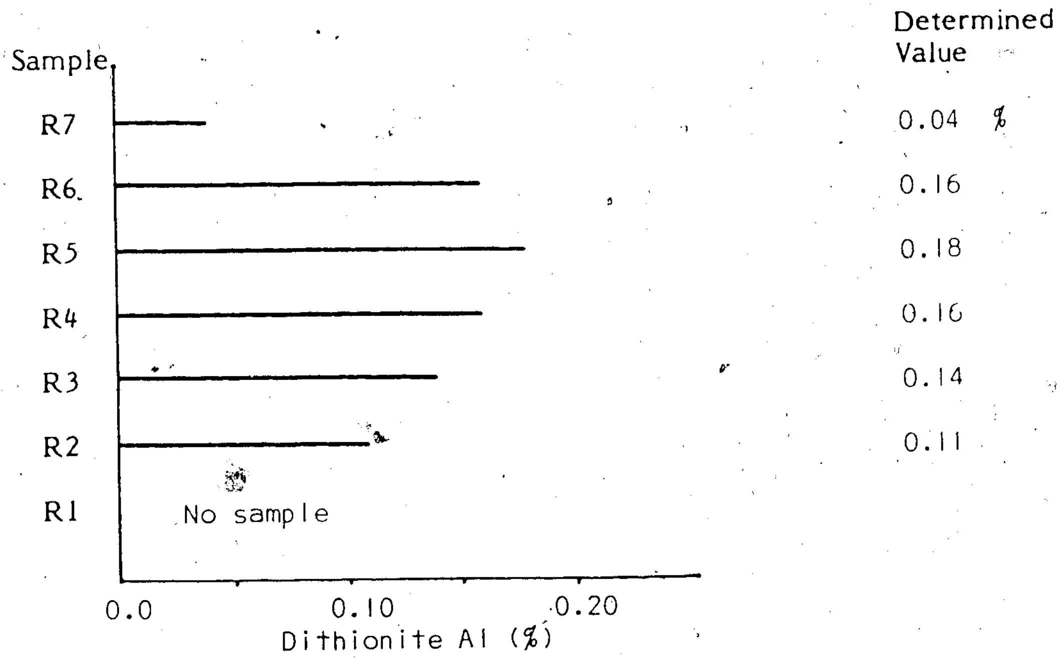

Figure 67. Percent dithionite-citrate-bicarbonate extractable aluminum as Al in Cloudy Ridge samples

3) Deformation of the (by then) incompetent material (Unit C) by overriding ice. This generated most of the current fabric and physical properties, and disrupted previous features such as clay skins and rottenstone (moreso nearest the top). An unknown thickness of surface layer could have been eroded away or mixed with lower layers, while the overlying till (Unit D) was added;

4) Addition of carbonate to Unit C by illuviation from the overlying calcareous drift, and minor rearrangement of constituents, especially nearest the top where disruption had been greatest. Small amounts of hematite produced at the time enhanced the reddish colour development.

Chapter 5

Summary and Conclusions

Cypress Hills Profile

The Cypress Hills plateau is undoubtedly somehow related to a landscape of the past. However, if the profile of the present study is typical, there seems to be little meaning (to the point of being misleading) in referring to the profiles currently on the plateau as paleosols (more correctly, the remnants of paleosols). The features that at first glance seem paleopedogenic (*e.g.* color, "clay skins") do not appear on detailed examination to have been formed by paleopedogenic agents. No features readily explainable on a paleopedogenic basis were identified, and no influence of the former landscape's surface is evident in the current features.

Many of the features in the Cypress Hills Formation have probably attained their current expression recently, but reflect the cumulative effects of processes that began shortly following deposition of the gravels during the Tertiary. One of these proposed early (pre-Pleistocene) proces[illegible]as likely the weathering of carbonates from the upper gravels, with redeposition of some of it as the cement at depth in what is now the conglomerate.

Another early event probably was the the geochemical alteration of much of the fine earth fraction in the upper gravels to smectite. This process likely raised the clay content of the deposit and was accompanied by the genesis of a considerably different fabric and set of features (*e.g.* papules of pure smectite) in the fine earth fraction than had been left by deposition. It is supposed that the neogenic clay was somewhat mobile and minor features like a few void argillans and some granular structures developed.

The Wisconsin stage of the Pleistocene seems to have brought major changes to the Cypress Hills Formation gravels in the vicinity of the profile studied. Some physical agent, probably cryoturbation or the plateau's own ice cap, or both, appears to have strongly disrupted and churned what is currently the uppermost several metres of the formation, effectively effacing its preglacial surface and creating the new current one. A mantle of unweathered drift (Wisconsin aged?) was undoubtedly in place or was emplaced over the Cypress Hills Formation during the envisioned disruption.

The features that appear to be soil-like in Cypress Hills Formation profiles probably were generated during or following the Wisconsin. The smectite clay content of the gravels' matrix is assumed to have been responsive to the stresses imposed during and following any episodes of disruption. Shrink-swell and/or freeze-thaw probably produced the granular structures, the stress-oriented surfaces of which are the features that (in hand specimen) look like "clay films."

An infusion of carbonate from the plateau's calcareous mantle(s) is believed to have contributed to the current soil-like aspect of the Cypress Hills gravels. It is assumed that the upper gravel layers were somewhat acidic prior to the Wisconsin. An infusion of bases could have had two effects. First, it might have contributed to flocculation of the clays if, as is likely, they were previously dispersed. That could have significantly aided in genesis of the granular structures. Secondly, if there was iron in solution in the gravels (*e.g.* an excess remaining from genesis of the smectite), a rise in pH could have precipitated hematite, the mineral probably responsible for the striking red color (Munsell 10R) sporadically evident about the plateau. It is suggested that hematite would have been produced most rapidly, most uniformly, and in greatest abundance where addition of carbonate was most rapid and uniform, *i.e.* near the top of the Cypress Hills Formation immediately beneath a recently added calcareous mantle, and particularly in spots where the iron was for some reason concentrated. Inhomogeneity in the factors affecting precipitation of hematite could explain the variegated redness now seen at the top of some profiles (*e.g.* Plate 9) and at greater depths throughout the entire geologic section.

Cloudy Ridge Profile

Cloudy Ridge is undoubtedly somehow related to a landscape of the past. Because of the extent to which the deposit apparently has been weathered and altered, there is some indication that the materials might have been part of a paleosol, but only in some former, considerably different expression.

Previous studies on comparable profiles may help to indicate what the degree of apparent weathering on Cloudy Ridge represents. Hunt and Sokoloff (1950) identified seventeen areas that seem comparable to Cloudy Ridge, *i.e.* areas in the Rocky Mountains with high elevation, deeply weathered pre-Wisconsin drift. The weathered medium was called till at only one location. A few were labelled as residuum, while a majority of the media were identified as Tertiary or early Pleistocene fanglomerates. Comparable weathering to that seen on Cloudy Ridge was also reported by Clague (1974) on a Tertiary (Miocene) fan. Clague's study is of paramount significance. Of the few deeply weathered profiles which have been studied in the Rocky Mountains, Clague's apparently is the only one in which deposition has been dated by a fossil assemblage rather than by more cursory stratigraphic methods.

The Cloudy Ridge deposits are likely originally to have been fan deposits from the Tertiary or early Pleistocene, *i.e.* Kennedy drift as envisioned by Willis (1902) and Daly (1912). The surface form (Plate 1), faint stratification (Plate 27), gravel ledges and lenses (Plate 27, Tables 8, 9), imbrication in the cemented gravels (Plate 30, Table 8), voids in the gravels Plate 35, Table 10), and advanced degree of weathering are less consistent with a till origin than with a fan origin when the predominance of mudflow in fans is considered.

Many of the features in the Cloudy Ridge drift have probably attained their current expression recently, but reflect the cumulative effects of processes that began shortly following deposition of the gravels. One process was likely the weathering of carbonate from the upper part of the profile, with redeposition of some of it as the cement in coarser textured fluvial beds at depth. Some reorganization of the fabric and features (*e.g.* the development of clay films) also seems to have occurred during this period.

Another early event was likely the conversion of chlorite to regularly interstratified chlorite-vermiculite throughout the section.

The Wisconsin stage of the Pleistocene probably brought major changes to the Cloudy Ridge drift. The drift apparently had become so weathered that it was incompetent to the stresses generated when Wisconsin ice overrode it. The glacier seems to have strongly disrupted, churned, and compacted the older unit, especially in the current upper layers. Direct evidence of the location of the former surface was probably completely effaced, and there is every possibility that former surface layers were scraped away.

The features that now appear to be soil-like (structure, color) were likely generated following the supposed disruption and burial during the Wisconsin. Carbonate appears to have been reintroduced into the drift, possibly flocculating previously dispersed clays and thus contributing to structure development that had been initiated by compaction. The deposit was probably already reddish because of the extent of weathering. A rise in pH, strongest in the upper layers, may have contributed to the precipitation of hematite, the mineral believed to be responsible for the color distribution in the profile.

The findings of this Cloudy Ridge study are relevant to other studies of the Tertiary and early Pleistocene history of southwestern Alberta and vicinity. They highlight the difficulty of discriminating till and fan materials in weathered, dissected settings close to the mountains. Mudflow deposits separated by bands of fluvial gravel in fans and aprons strongly resemble till from different glacial advances separated by outwash. It is suggested that on the basis of the evidence currently available, the existence of the older, weathered drift on Cloudy Ridge should not be cited as evidence for the existence of an early Cordilleran glacial stage. A reapparisal of similar deposits in the vicinity (*e.g.* Kennedy drift) in light of the possibility that some (or all?) are fan rather than till could assist in correlating a truer geological history (glacial and otherwise) of southwestern Alberta and vicinity than currently exists.

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