Investigation of Several Alleged Paleosols in the Northern Rocky Mountains

Part II: Additional Data and Analysis

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Abstract

Paleosols, "fossil soils," have been reported at several locations east of the Rocky Mountains in northern Montana, U.S.A., and southern Alberta, Canada. These alleged paleosols have been correlated between erosional remnants corresponding to the Flaxville Plain, an extensive surficial planar erosion surface. Based on correlation to magnetic reversals, a chronology of 2.6 million years has been published, supporting a uniformitarian paleogeographic and paleoclimatologic reconstruction that includes multiple glaciations. Fieldwork conducted at each of the alleged paleosol sites and laboratory analyses of selected samples of earth materials indicate that the paleosol interpretation is based on many questionable assumptions. Data are more readily interpreted from a diluvial perspective. Results of this investigation also indicate that pedostratigraphic and magnetostratigraphic "data" from other sites may need to be viewed with suspicion.

Introduction

The existence and origin of paleosols is a favorite argument of some anticreationists. But the argument is an example of a "mixed question" of both science and natural history (Klevberg et al, 2003), and its veracity is questionable. Several paleosols have been reported from the Kennedy Formation (Klevberg and Oard, 2005) and associated deposits in the northern Rocky Mountains of Montana and Alberta (Figure 1). Principles and methods of paleosol analysis (Klevberg and Bandy, 2003a, 2003b; Klevberg et al., 2003; Klevberg and Oard, 2005) render the uniformitarian interpretation even more suspect. Methods, goals, and field results of this project are described in our previous paper (Klevberg et al., 2007). Laboratory results and a discussion of the significance of both field and laboratory data are presented here.

Review of Previous (EGP) Data

Karlstrom (1988) presented a considerable number of laboratory data in support of a pedogenic origin for earth materials at the sites he investigated (see Figure 1), including X-ray analyses of clays (physils) indicating the presence of possible secondary minerals: kaolinite, chlorite, smectite, and vermiculite. While we agree that these data are probably accurate and representative of the materials sampled, results could reflect a complex history rather than a strictly pedogenic one. While secondary minerals and oxides (inferred from color) are typical of well-developed soils, they are not diagnostic of pedogenesis (Klevberg and Bandy, 2003a). Still unresolved is: (1) whether that soil formation occurred over long periods of time in superposed units and were only recently exposed in landslide scarps (Karlstrom's apparent position); or (2)

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Accepted for publication November 16, 2006

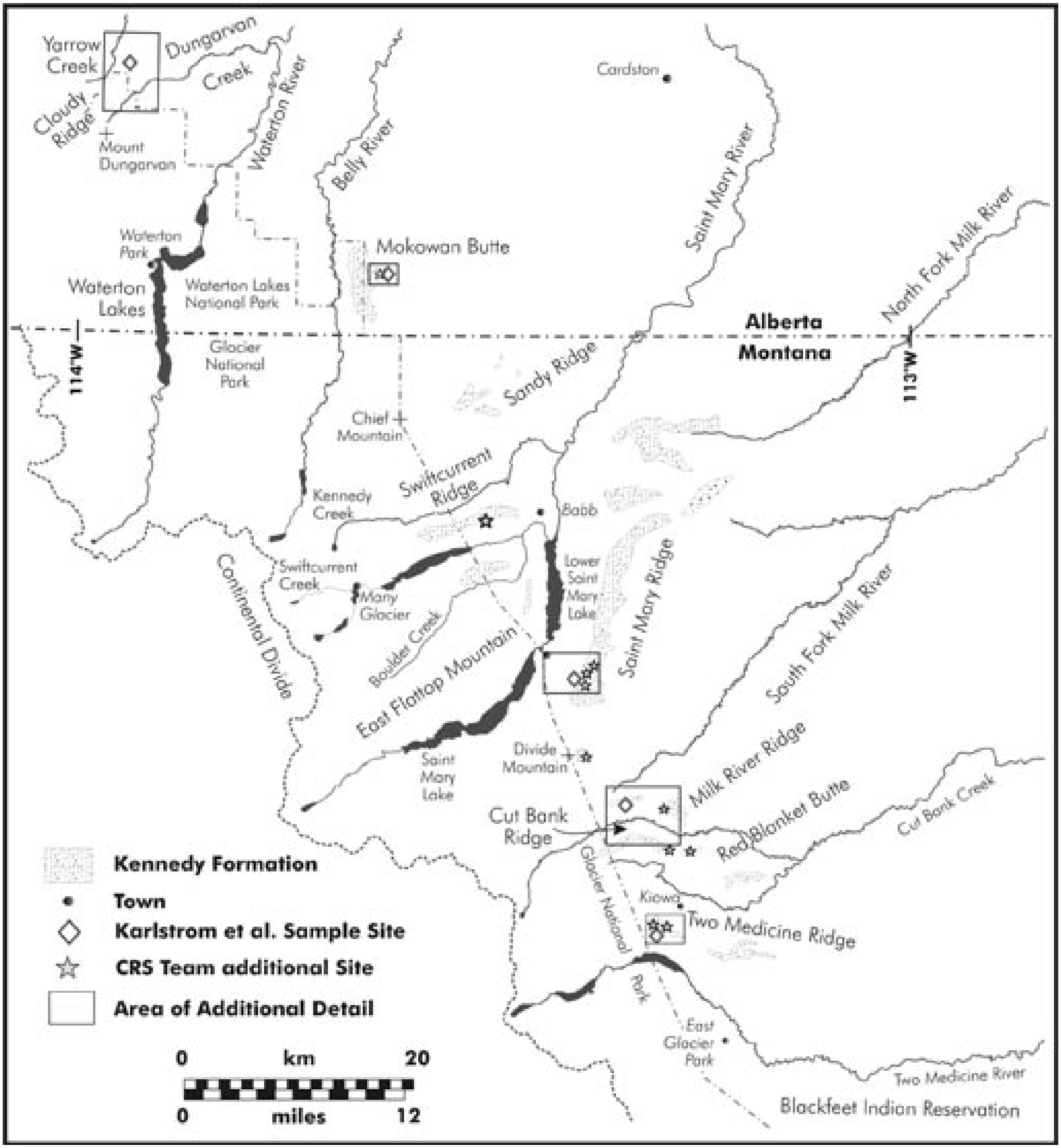

Figure 1. Map of study area.

if soil formation is actively occurring parallel to slopes simultaneously with nearby mass wasting. To resolve this question, we supplemented fieldwork with laboratory investigation.

Laboratory Results

The CRS team collected and submitted 21 samples for laboratory analysis. Vertically oriented thin sections were prepared by Continental Rocktell Services of Calgary, Alberta, and plane polarized and cross-polarized photomicrographs generated. Some samples also were photographed in reflected light and analyzed using scanning electron

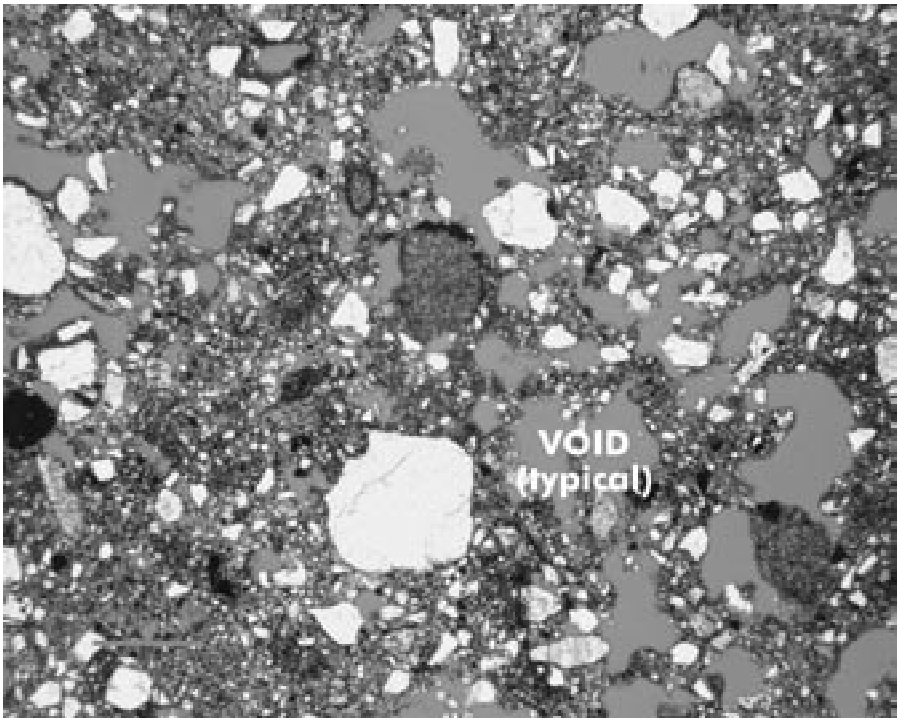

Figure 2. Photomicrograph of eluvial horizon from MR-1.

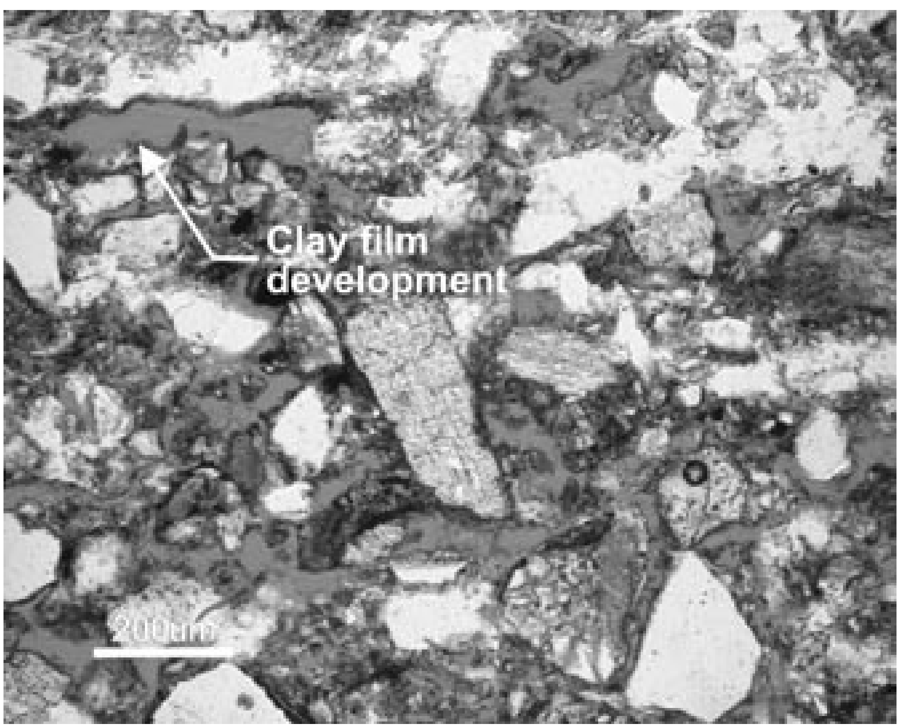

Figure 3. Photomicrograph of illuvial horizon from MR-1.

microscopy backscatter electron imaging and electron diffraction spectroscopy. These images provided information on soil microfabrics, mineralogy, the nature of mineral grains hosting remanent magnetization, the types of physils and their relation to other mineral grains, and evidence (if any) of epigenesis. Control samples were collected from soils developed in nearby stable environments. Some of these analytical data have been presented elsewhere (Klevberg and Oard, 2005).

Sample mineralogy was highly variable. Some samples consisted almost entirely of calcite, others were dominated by quartz and hematite, and some had significant clay content. Some soils that appeared well developed macroscopically appeared less well developed ("less mature") at the microscopic level.

Figures 2 and 3 are thin section images from a well-developed alfisol on Milk River Ridge (MR-1). Figure 2 shows the open structure of the eluvial horizon, with fines bridging sand grains and considerable void space. Figure 3 shows possible clay film development in voids, which corresponds with the macroscopic observation of ferroargillan accumulation indicative of the illuvial B_t (argillic) horizon. However, if the ferroargillans were indicative of long-term pedogenesis in a warmer and moister climate than at present (i.e. paleosols), then chert, feldspars, and lithic fragments should show evidence of epigenesis (chemical weathering resulting in mineral transformation), which is clearly not the case.

Figure 4 is a photomicrograph of a sample of the E horizon from a well-developed alfisol. The sample site (SM-10) is in forested terrain directly above the center scarp on Saint Mary Ridge (Figure 5). This soil is superjacent to (or partially identified with) Karlstrom's (1988) Soil 5. No argillic horizon was encountered. Instead, the percentage of rock fragments increased downward; near the bottom of the pit, the material was similar to packstone, consisting of fine sand of angular limestone fragments with small amounts of physil cement. This indicates soil formation is occurring at this site.

The other samples collected for control purposes provide equivocal evidence for pedogenesis. Figure 6 is a photomicrograph from the B_t horizon at SM-9, at about the same elevation as SM-10 but on the lee side of the ridge (Figure 5). The abrupt boundary between the B_t and C horizons in this soil indicates a geologic rather than pedologic origin. Argillic horizon samples from PH-1, near Mokowan Butte (Figure 7), and SM-7 (Figure 5) exhibit largely "fresh" lithic fragments and lack of clay film development (Figures 8 and 9), again largely controlled by parent material (i.e. geologic origin).

Several of the samples from "paleosol" slopes exhibit evidence of current soil formation. Good clay film development was evident in the B_t sample from PH-4 (Figure 10) on an unstable slope at Pole Heaven, near Mokowan Butte (Figure 7). Evidence of epigenesis is clear at TM-2 (Figure 11), though evidence of translocation is not (Figures 12 and 13). A very small amount of clay film development was evident in images from a sample collected at 90 feet in SM-2 (Figure 5).

"Petrocalcic horizons" are an important factor in the paleosol interpretation. Most of the calcite-dominated zones ("B_k horizons") were observed on Two Medicine and Saint Mary ridges. Pedogenic processes would tend to transform B_k horizons into B_t horizons above the water table in relatively moist climates, and form B_k horizons where leached carbonate encounters the base of the zone of annual wetting, or a less-permeable horizon or aquitard. Evidence of authigenic calcite was observed in thin section images from samples collected in SM-2 and SM-5. Detrital calcite grains, often in a clay matrix and geologic in origin, were observed in images from

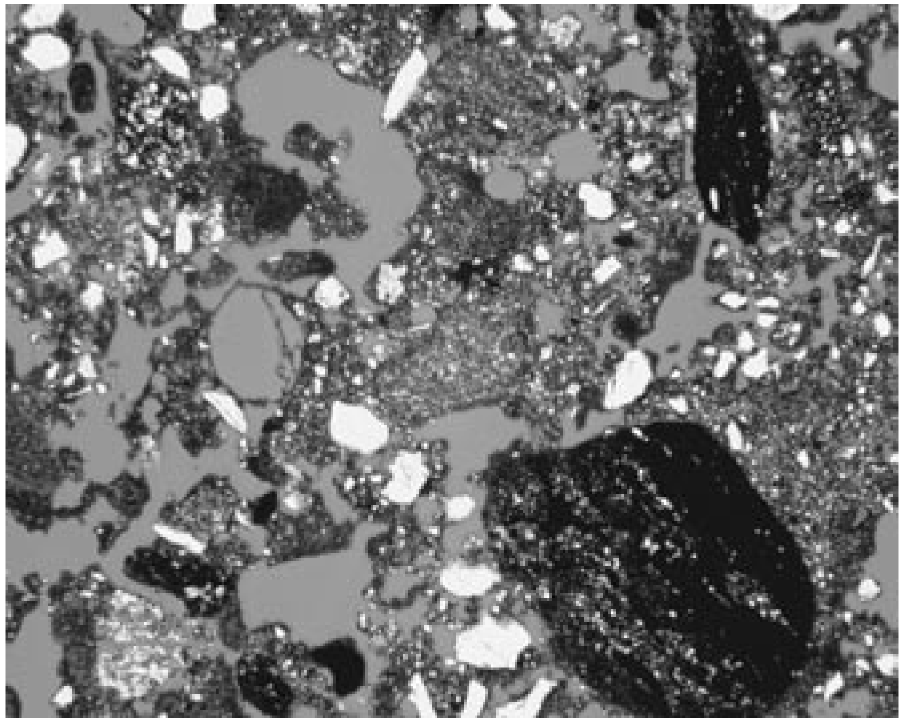

Figure 4. Photomicrograph of eluvial horizon from SM-10.

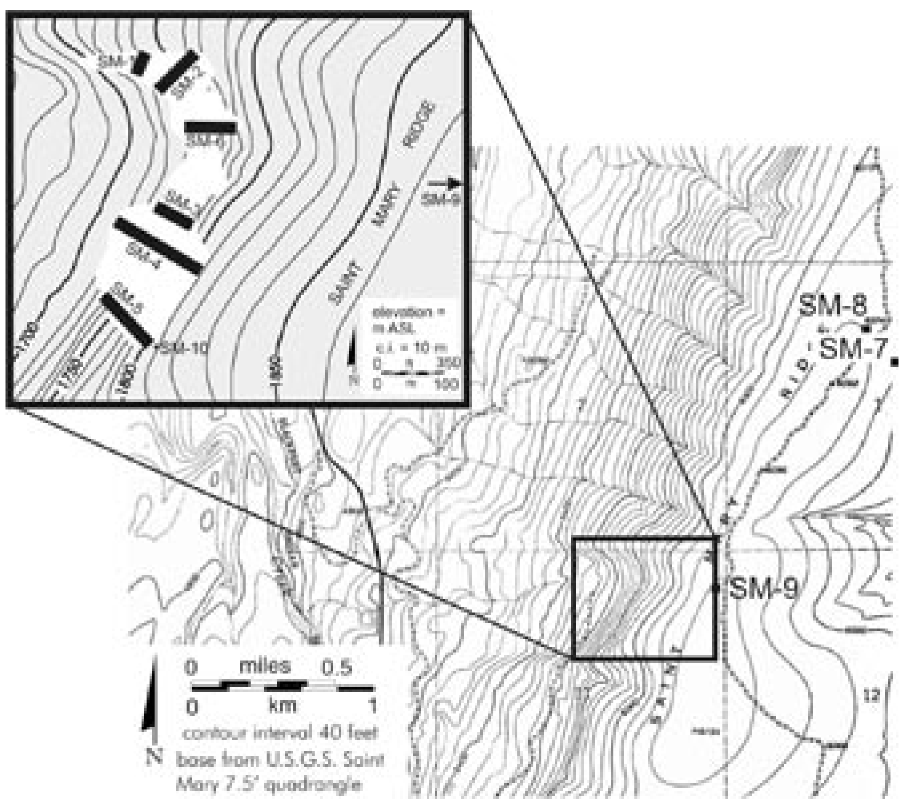

Figure 5. Saint Mary Ridge sample map. Inset shows slide area.

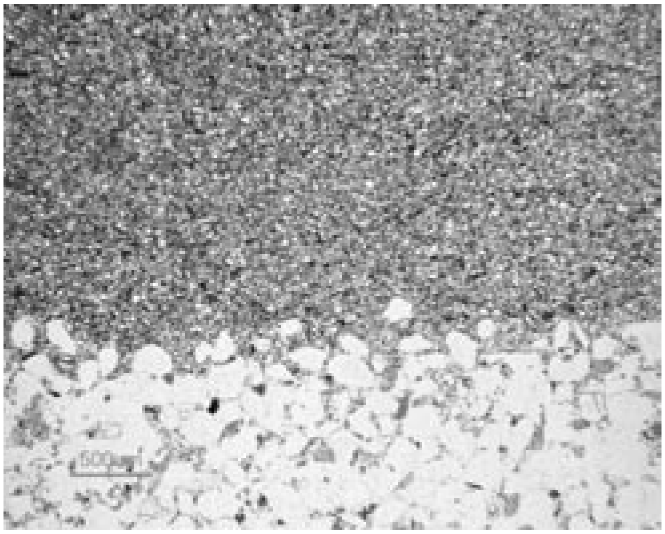

Figure 6. Photomicrograph of B_t horizon from SM-9.

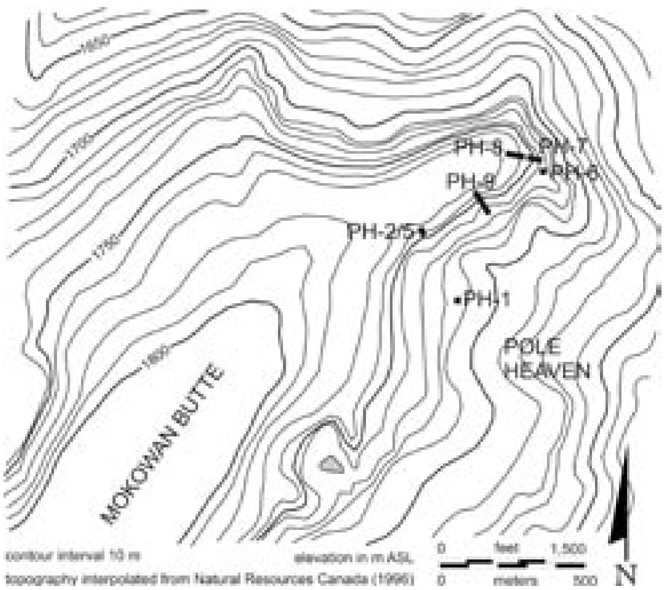

Figure 7. Mokowan Butte sample map.

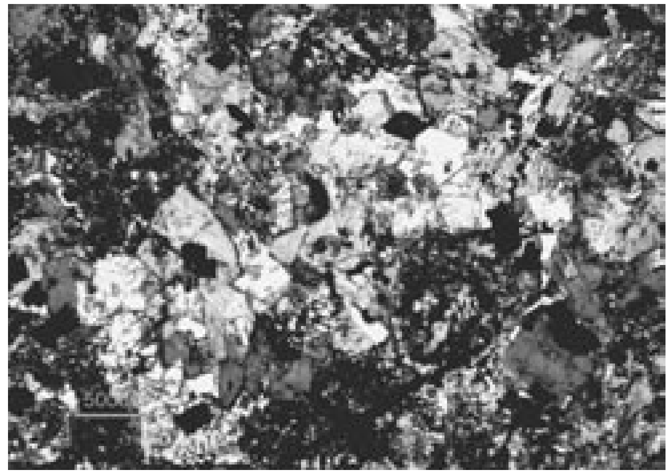

Figure 8. Photomicrograph of B_t horizon from test pit PH-1.

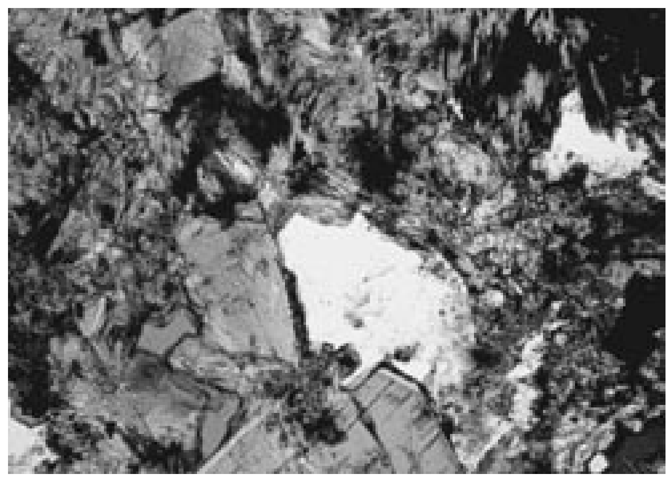

Figure 9. Photomicrograph of B_t horizon from SM-7.

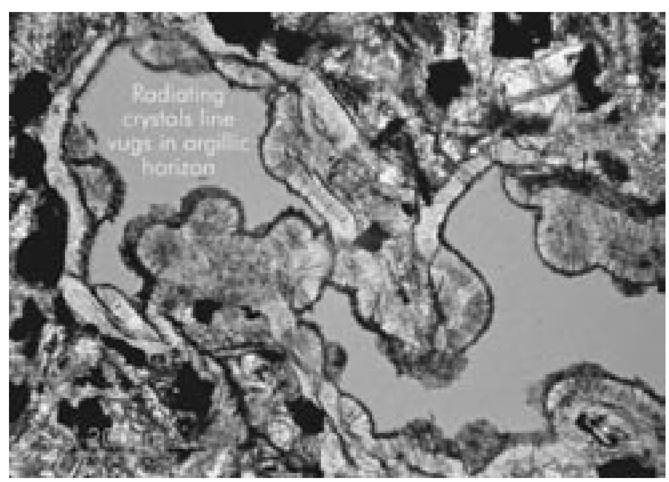

Figure 10. Photomicrograph of B_t horizon from test pit PH-4.

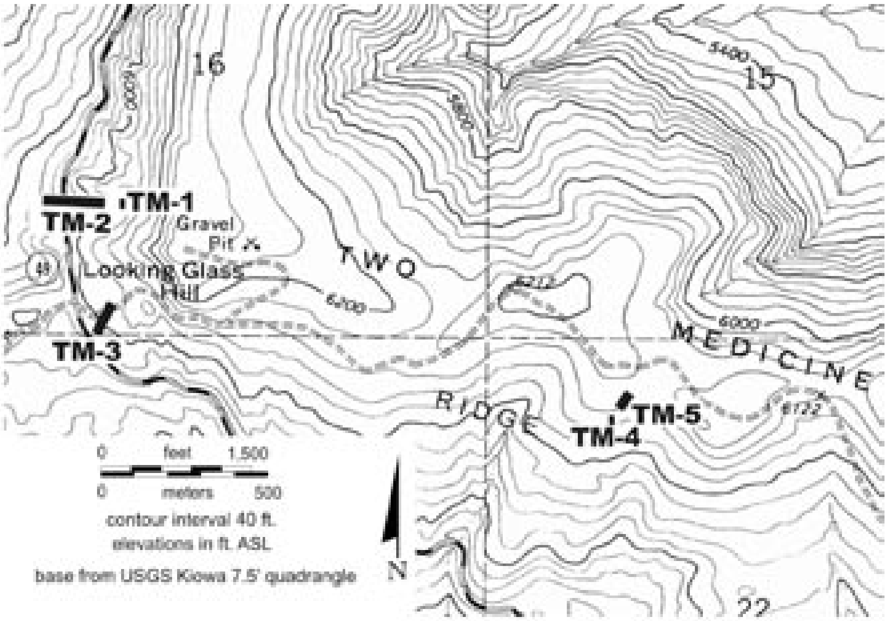

Figure 11. Two Medicine Ridge sample map.

Figure 12. Photomicrograph of A horizon from test trench TM-2.

Figure 13. Photomicrograph of B_t horizon from test trench TM-2.

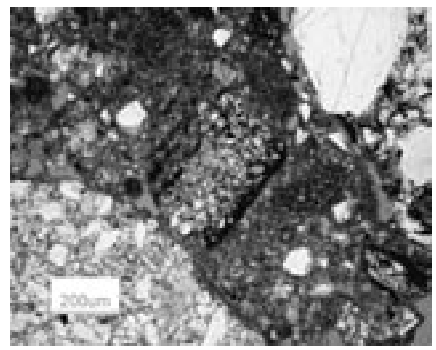

Figure 14. Photomicrograph of B_k horizon from SM-5 at 157 feet.

samples collected in SM-2, SM-4, and SM-5. The sample from SM-5 at 157 feet exhibited both authigenic and detrital calcite (Figure 14). Much of the calcite in images from Saint Mary Ridge samples was fine-grained (75 to 425 μm), well-rounded sand. Most observations from carbonate-dominated zones indicated depositional and diagenetic (i.e. geologic) rather than groundwater (i.e. pedogenic) processes.

The hypothesis of extant pedogenesis in colluvium was not supported by some thin section images. The apparent argillic horizon observed in CR-1 showed fractured, high-physil content aggregates rather than clay film development (Figure 15). Evidence of clay movement was negligible in thin section images from samples of the argillic (B_t) horizon collected in MR-2 at 10 and 20 feet.

Remanent magnetization appears primarily hosted in hematite, most of which is detrital, not authigenic (Kleverg and Oard, 2005). Physils include smectite and illite, occurring primarily as matrix between grains rather than grain coatings, films, or rinds. They probably originated through a combination of

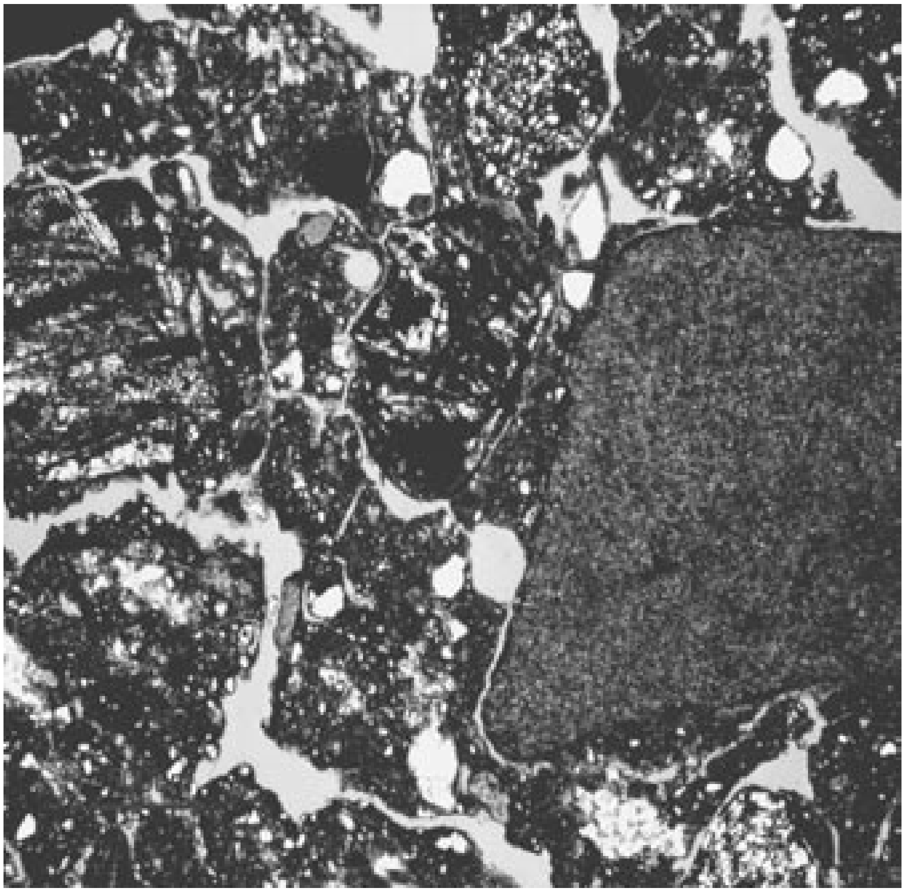

Figure 15. Photomicrograph of argillic ("paleoargillic") horizon from test trench CR-1.

geological processes and translocation (i.e. $\partial^2 S/\partial P \partial t$) during physical weathering (Klevberg and Bandy, 2003a).

Some of the thin section images show evidence of soil formation processes, while others appear to be dominated by geologic factors. Samples from TM-1, TM-4, MR-1, SM-7, SM-8, SM-9, SM-10, PH-1, and PH-4 (see Figure 1) show evidence of pedogenesis. Photomicrographs of samples from landslide scarps (in trenches of both Karlstrom and the CRS team) generally did not show evidence of clay film development or other pedogenic processes; most of these images show characteristics consonant with a colluvial origin. Very little evidence of significant chemical weathering was observed. Thus, while we found ubiquitous evidence of current soil formation, thin section data indicate that soil development in many of the sample locations is rudimentary.

Discussion

Evidence supports a case for either a paleosol interpretation or for a combination of geologic and modern pedogenic processes. Prior beliefs about natural history will likely drive conclusions.

The Case for a Paleosol Interpretation

The argument by Karlstrom and others that the field and laboratory data from the Kennedy Formation indicate the presence of paleosols is supported by evidence of pedogenesis at all of the sites. Argillic horizons are present at several, and these horizons are often relatively thick and deep, suggesting long periods of time or warmer, wetter climates than at present. Secondary minerals and organic oxide complexes (sesquioxides) also imply soil formation. Paleomagnetic studies have permitted separation of paleosol units using magnetochronostratigraphy.

As must be the case in such a natural history interpretation, the conclusions are dependent on several assumptions:

- Rates of current pedogenesis are slow enough to prevent near surface paleosols from being destroyed by ongoing soil formation.
- Rates of current pedogenesis are slow enough to prevent soil formation in landslide scarps that could be mistaken for relict soil features.
- Episodic mass wasting results in sharp landslide scarps with very thin colluvial cover.
- Minimal creep or ongoing mass wasting on the scarps prevents thickening of the colluvial mantle and enables ready removal of the colluvium, producing a clear picture of the backslope profile.
- Carbonate cement is evidence of formation of petrocalcic horizons in soils.
- Magnetic polarity calculated from remanent magnetization measurements accurately reflects the contemporary terrestrial magnetic field (i.e. normal or reversed polarity).
- Magnetochronostratigraphy provides an accurate picture of terrestrial magnetic reversals over time.
- Iron oxide (i.e. rubification) present in the Kennedy Formation is evidence of relatively warm and wet oxidizing conditions conducive to soil formation.

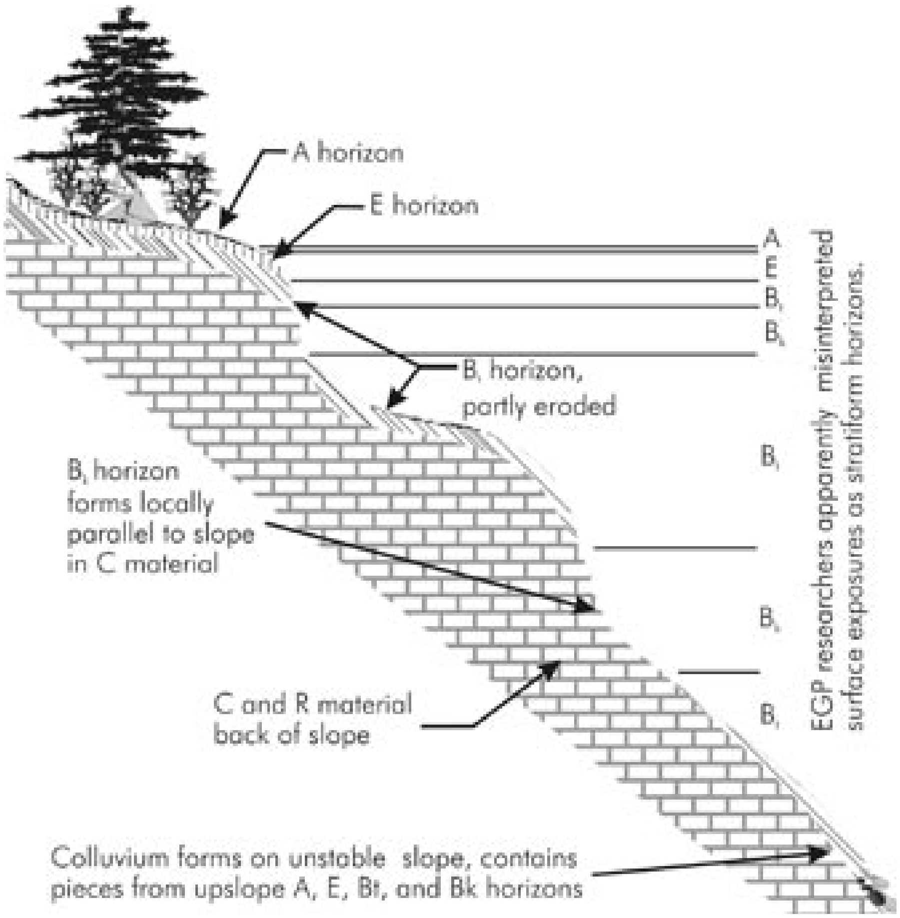

Figure 16. CRS team model. While uniformitarians have tended to interpret materials observed on scarps as representing a cross section of strata behind the face, the CRS team believes a combination of mass wasting and ongoing pedogenesis dominates.

If these assumptions are accurate, they bolster the credibility of the paleosol interpretation.

The apparent immaturity of soils from the control locations can be interpreted as evidence for slow rates of soil formation. Interpretation of the Kennedy Formation as a series of paleosols and interpretation of the "immaturity" of control soils as evidence of slow pedogenesis bolsters the old-earth position.

The Case for Ongoing Pedogenesis

Evidence for soil formation in colluvium was evident at nearly all of the sites except where carbonate was adequate to lithify the Kennedy gravel. Rudimentary A horizons were observed on unstable slopes, and better-developed A horizons on more stable slopes. Clay film development and evidence of epigenesis appeared to be related to distance from the slope surface in several locations, though other factors affecting slope stability add to the complexity of the relationship between slope stability and pedogenesis. However, features at all sites correspond equally well with ongoing pedogenesis as they do with relict paleosols.

TM-5 triggered a new model (Figure 16). Based on field evidence, we hypothesized that long-slope pedogenesis occurs contemporary with or alternately with mass wasting, producing bands or bodies of differing earth materials that could be misconstrued as paleosol horizons. Evidence of long-slope soil formation was abundant at MR-2. Even the unstable slope of the Saint Mary Ridge scarp showed that soil formation wages an incessant battle against mass wasting in Kennedy colluvium, as do data from the Pole Heaven and Cloudy Ridge. These observations fit well with our model.

While we are in substantial agreement with EGP (establishment geologic paradigm) researchers about most of the data, we believe their bias toward gradualism has led to an interpretation error, which highlights disagreements between the EGP and DGP (diluvial geologic paradigm) over the importance of different environmental factors and soil forming mechanisms (Klevberg and Bandy, 2003a; 2003b). We emphasize the role of parent material and water movement through the soil, while EGP practitioners stress climate and epigenesis. Our position is supported by high clay content horizons with relatively unweathered lithic fragments and graded bedding. We believe that pedogenesis occurs on even unstable slopes—sometimes outpacing mass wasting, sometimes succumbing to erosion. As a result, various horizons are exposed on the slope surface, sometimes mixed, and readily misinterpreted as superposed horizontal paleosol horizons.

Iron oxide is not evidence of rubification; rather, it was already present in the parent material or introduced during syndepositional processes. Hydrous iron and aluminum oxides impart the warm, bright colors of oxisols, which are believed to form from extreme, protracted weathering in tropical climates (Klevberg and Bandy, 2003a), here interpreted as "rubification." However, our thin section data indicate that minerals that should have weathered long before significant accumulation of the hydrous oxides are still present, often as angular particles. Farther east, quartzite gravels of the Cypress Hills and Flaxville Formations cover the planation surfaces that begin on the east side of Glacier and Waterton National Parks. These gravels are nearly pure quartzite, so the iron did not originate from these clasts. Instead, it appears to have originated in the solutions transporting the sediments, since the gravel clasts exhibit a ubiquitous, uniform patina (Oard and Klevberg, 1998), unlike the pattern expected from solutions leaching down through the sediments. This may also be true for the Kennedy Formation. These same iron oxide colors are also observed in entisols and mollisols on the Kootenai Formation in large parts of Glacier County and elsewhere in Montana (N.R.C.S., 2004), where parent material appears to be the source of the "rubification." Although the Kennedy Formation is not underlain by the Kootenai Formation, iron might have come either from Belt Supergroup rocks or have already been in solution. In either case, evidence for an epigenetic (i.e. pedogenic) source of the iron oxides was not observed.

The Case against a Paleosol Interpretation

All of the assumptions listed above in support of the paleosol interpretation are suspect.

- Rates of soil formation are often much higher than uniformitarian predictions (Klevberg and Bandy, 2003a; 2003b).
- Slow pedogenesis is essential to the hypothesis that landslide scarps provide an accurate cross section of buried horizons. Slope-parallel soil formation could mask the buried horizons.
- Colluvial cover and soil creep can obscure any cross section of buried horizons in landslide scarps.
- Thin section data indicate that the majority of calcium carbonate in the sampled sections is detrital and not related to pedogenesis.
- Thin section data indicate that paleomagnetic data from sampled locations may well reflect something other than the contemporary terrestrial field. Apparently normally and reversely magnetized samples may not reflect terrestrial reversals.
- Magnetochronostratigraphy includes many uniformitarian assumptions that may lead to distortion or misinterpretation of paleomagnetic data (Klevberg and Oard, 2005).
- Iron oxide in the Kennedy Formation appears to be geologic in origin, not pedogenic.

Most of the data therefore appear at variance with the paleosol interpretation, and the evidence essential to the paleosol position seems dependent merely on uniformitarian assumptions. These data are more readily explained if a complex geologic origin is assumed rather than a uniform pedogenic history.

Uniformitarian training often biases researchers toward single-sequential thinking in earth history studies. In reality, most geological deposits are probably polygenetic, most earth processes are probably complex, and our interpretations of earth history need to reflect these realities. Single-sequential thought patterns may have hampered previous researchers in understanding the important role of current pedogenesis. Their commitment to uniformitarianism has certainly been detrimental.

Is the Kennedy "Drift" Really Glacigenic?

Four decades of research have upheld the opinion of Whitcomb and Morris (1961, p. 299):

> In general, we feel the conclusion may be justified that the supposed earlier, weathered tills and other soils beneath the last glacial deposits really represent either deposits made in the last stages of the Deluge or else deposits made in the early stages of the oncoming glaciation.

Klevberg and Oard (2005) noted that arguments for a glacial origin of the Kennedy Formation are weak, and the data are more readily explained by processes expected during late diluvian and early postdiluvian time: mass wasting, traction currents, and the fluid transitional states between them. All these are capable of explaining striated clasts, rounded to angular clasts, and the often imperceptible transition between the equivocal parts of the Kennedy Formation and the clearly fluvial parts farther east.

Do Kennedy "Paleosols" Record Magnetic Reversals?

Magnetostratigraphy is essential to the distinction of some of the paleosol units described by EGP researchers (Karlstrom, 1988). However, the claim for an accurate record of terrestrial magnetic field reversal in Kennedy Formation sediments is underwhelming at best (Klevberg and Oard, 2005). At this point, we neither affirm nor deny the veracity of the paleomagnetic data collected by Karlstrom and others from the study area, but only question the adequacy of these data in the light of the variables summarized below.

Thin section images show that the hematite hosting the remanent magnetization is primarily detrital, recording the orientation of each grain at deposition rather than the orientation of the earth's magnetic field, a common problem in paleomagnetic studies of sedimentary rocks (Tarling, 1983). Thus, some of the results used by EGP researchers in support of magnetostratigraphic interpretations (Karlstrom, 1988) are probably not valid paleomagnetic data.

Isothermal remanent magnetization (IRM) can affect areas where thunderstorms are frequent (Butler, 1992), such as our study area. While Karlstrom and Barendregt (2001) mention possible "resetting" by lightning, IRM may still be a factor in some of their samples. Step-wise demagnetization is intended to account for IRM, but it is important to observe sampling locations to ascertain the likelihood of lightning strikes (Tarling, 1983). Viscous remanent magnetization (VRM) is similar but occurs over time in a logarithmic manner (Strangway, 1970), thus tending to dampen reversed paleomagnetism. It may be necessary to obtain a relatively large number of samples (at substantial time and expense) to reduce this uncertainty.

Chemical remanent magnetism (CRM) can also distort results, and the magnetite orientation that occurs when magnetite oxidizes to hematite has not been determined,[1] though the opposite reaction does acquire the contemporary field orientation, and it is likely this is generally the case with all similar reactions (Hailwood, 1989). Oxidation of magnetite or ilmenite to hematite or titanohematite appears to be occurring in sample SM5-157 (Klevberg and Oard, 2005). Self-reversal has been observed (remanent magnetization *opposite* to the contemporary magnetic field) in titanohematite, a $50\%_{mol}$ mixture of ilmenite and hematite (10% titanohematite + 90% hematite) and in the formation of hematite from maghemite (Merrill et al., 1998). Obtaining accurate paleomagnetic data requires collecting multiple samples from each horizon, very carefully located (Hailwood, 1989).

Thus, while Karlstrom and others apparently have done careful work in collecting samples for paleomagnetic analysis, many pitfalls from a complex geologic history could lead researchers to false conclusions about the history of Earth's magnetic field and the time of formation of various horizons. Indeed, magnetochronostratigraphy is based on evolutionary and other assumptions beyond the pale of science (Hailwood, 1989; Merrill et al., 1998), and erroneous assumptions compound errors during analysis.

Were the Kennedy Formation "Paleosols" Ancient Soils?

The argument for long periods of time for paleosol formation hinges on their interpretation as ancient soils. Evidence of ongoing soil formation was observed at all of the sites described by EGP researchers, as was evidence of slope instability. These sites do not reveal a cross section of superposed soil profiles, but they show soil formation within active colluvium. Mass wasting occurs as creep, sloughs, slumps, and slides. Sometimes it is episodic and infrequent enough to permit substantial soil formation, while at other locations slope instability prevents a high degree of development in soils. When soils develop, they are often subsequently carried downslope by mass wasting events, mixing with the colluvium.

Observed soil formation is primarily *parallel* to the slope, not to the horizontal, except at the top of the slopes, where conditions favorable to soil formation tend to produce well-developed alfisols. Soil development on scarps and at other locations (Klevberg and Bandy, 2003b; Klevberg et al., 2003) indicates rapid pedogenesis—a few centuries. The extent of epigenesis observed in thin sections is minimal, indicating that these soils are very youthful relative to the nonlinear curve describing pedogenesis (Klevberg et al., 2003). Disseminated iron oxide appears to be syngenetic, not authigenic, which is not surprising based on formations farther east (Oard and Klevberg, 1998) and is thus not indicative of soil formation, let alone paleoclimate. Finally, the probability of preservation of exposed paleosols is low.

Do These Deposits Really Indicate the Passage of Long Periods of Time?

Much of the argument for long ages hinges on the paleosol interpretation, since many geologic processes operate catastrophically and require very little time. Such was probably the case for the Kennedy Formation (Klevberg and Oard, 2005). Pedogenic arguments, especially those requiring great periods of time, often are equivocal (Klevberg and Bandy, 2003a; 2003b; Klevberg et al., 2003).

Physils

At least some of the physils observed in the alleged paleosols are present in Belt Supergroup source rocks or may be explained in non-pedogenic ways (Karlstrom, 1988). In contrast, sesquioxides are not typical of any known geologic environment and appear indicative of soil formation. Karlstrom (1988, p. 158) described a spodic horizon "superposed into" a "relict paleosol" at the surface of Saint Mary Ridge. This corresponds with our observations of some of the soils between SM-9 and the landslide scarp (Figure 5). However, this surficial "relict paleosol" (and the others claimed for the study area) should not have survived long enough to be recognizable, being subjected to modern pedogenic processes (Klevberg et al., 2003). Also, the "argillic" horizon subjacent to the spodic horizon also may be of geologic rather than pedologic origin.

Carbonates

Also significant is Karlstrom's (1988) observation that dolomite is abundant in some of the "petrocalcic horizons" he sampled. While dolomite can be more soluble than calcite in some groundwater environments (Raymond, 1995), experiments with limestone and dolostone for treating contaminated surface and groundwater indicate that relatively

[1] Strangway (1970, p. 49) discounts the importance of CRM on the basis of uniformitarian assumptions, which, of course, undermines the credibility of his conclusion that CRM by itself is not likely to significantly alter the direction of overall remanent magnetism.

pure dolostones are much less soluble than limestones or calcareous dolostones (Letterman et al., 1987). Groundwater in both vadose and saturated zones is more likely to dissolve calcite than dolomite, so abundant dolomite probably indicates a depositional environment much different from the present or a dolomite-rich parent material. Dolomite may dominate in seawater or mixed waters, especially warm water with a minimum of 10% seawater (Raymond, 1995, pp. 309–311). Dolostone and magnesian limestone are present in the Altyn Formation, which outcrops along the east side of Glacier National Park and as far east as Divide and Chief Mountains (Ross, 1959), the inferred source area for the Kennedy Formation. Thus, while the ratio of dolomite to calcite is likely to be low if deposited from groundwater, it could be much higher if syngenetic with the Kennedy Formation, as these data indicate.

Iron Oxides

Elevated iron (relative to the majority of rocks and unweathered sediments) is also typical of parts of the Altyn Formation (Ross, 1959) as well as much of the Belt argillite in the Kennedy Formation. Elevated iron and aluminum is typical of highly weathered sediments, but lack of silica depletion in samples collected from Two Medicine Ridge (Karlstrom, 1988) indicates that iron enrichment rather than silica depletion is responsible for relatively high iron oxide concentrations in the alleged paleosols. This also corresponds with our observations of Flaxville surface (Bench No. 1) deposits farther east (Oard and Klevberg, 1998), where the iron oxide is very likely syngenetic.

Rates of Pedogenesis

Evidence shows that soil formation occurs much more rapidly than envisioned by EGP researchers (Klevberg and Bandy, 2003b; Klevberg et al., 2003), and any practicing soil scientist would recognize ongoing pedogenesis in the study area. While soil formation is a slow process in comparison to a human life span, it is not slow in the way most geologists think of time. For example, during the Dustbowl of the 1930s, silt and fine sand often were deposited to depths of a few meters, burying fences and other structures that make identification of the previous ground surface easy. Unlike most alleged paleosols, A horizons are typically present in these buried soils. Pedogenesis often is significant in these deposits. Well-developed alfisols such as those observed in this study can readily develop in even a comparatively cool and dry climate in the space of several centuries. This would be still more likely for the permeable Kennedy Formation, though it could be expected even in finer grained materials (Klevberg and Bandy, 2003b; Klevberg et al., 2003).

Challenges in Investigating Possible Paleosols

The only way to definitively determine whether subhorizontal soil horizons exist in the subsurface would be to excavate or drill a relatively undisturbed vertical surface or sample. This would be extremely difficult in the coarse material of the Kennedy Formation. Only in the top section of the Cloudy Ridge site was the colluvium shallow enough (due to carbonate cementation) to permit adequate removal using Karlstrom's method, and it did not exhibit superposed soils. If these geologic units were not soils, then the argument for long periods of time evaporates. While soil formation can be much more rapid than EGP adherents commonly recognize, geologic processes can be—in many cases must have been—even more rapid. The size of water-rounded boulders in the Kennedy Formation implies strong currents, as do the gravels on the Flaxville surface and other surfaces (Oard and Klevberg, 1998).

Stratigraphy

In addition to the rapid formation of soils, the traditional argument also hinges on stratigraphic correlation. Suppose ten paleosols are superposed, each of which required a thousand years to form. The total time required would be in excess of ten thousand years, which would push it considerably beyond the biblical date for the Deluge. But the argument for superposition relies on pedostratigraphic correlation, which offers many pitfalls (Klevberg, 2000; Klevberg et al., 2003). Pedostratigraphy is frequently tied to magnetostratigraphy, with its own weaknesses (Klevberg and Oard, 2005).

Our examination of the study area (including Karlstrom's sites) convinced us that his correlations are dubious. Even the three "paleosols" at Saint Mary Ridge are not apparent at any scale; indeed, the fabric appears at variance with both the paleosol designations and a pedogenic origin (Klevberg and Oard, 2005). Anticreationists have it backwards: pedostratigraphy cannot cast doubt on biblical history when the preponderance of our data cast doubt on pedostratigraphy.

A Diluvial Interpretation of Kennedy "Paleosols"

While the paleosol interpretation of EGP researchers for the Kennedy Formation clearly contradicts the timescale of the Bible, its assumptions are highly suspect. The diluvial position does not deny the existence of paleosols (Froede, 1998; Klevberg et al., 2003), but the paleosol interpretation of the Kennedy Formation is not well supported. In particular:

- Field observation indicated ongoing soil formation at nearly all of the sites.
- Current pedogenesis can occur roughly parallel to slopes and becomes quite complex where unstable colluvium mixes soil materials downslope.
- Microscopic evidence supports a geologic origin for features that could be either geologic or

pedologic based on macroscopic evidence, including apparent argillic and petrocalcic horizons, pervasive iron oxides, carbonate species and distribution, and physil species.

- The apparent low degree of development of most of the soils can be interpreted as evidence for slow pedogenesis over vast periods of time. Alternatively, relatively "immature" soils may result from parent material subjected to the action of groundwater and physical weathering (Klevberg and Bandy, 2003a). Climate and epigenesis may be less important than EGP researchers have assumed. The time during which soil formation has occurred also may be much less than EGP researchers have envisioned.
- Paleomagnetic data from the Kennedy Formation must be viewed with caution, are subject to several possible interpretations, and provide an inadequate basis for stratigraphic correlation.

Conclusion

In general, we think that soil formation is effectively occurring in the Kennedy Formation, especially under forest cover. Unstable slopes in the study area are dominated by colluvium and may be subject to sloughing and creep; they do not provide unambiguous evidence for buried soil horizons. The Kennedy Formation exhibits features of both mass wasting and fluvial transport. While the surface may have been modified by glaciation, the formation as a whole is probably diluvial in origin. Rates of pedogenesis are adequate to explain the presence of the observed soil horizons within the biblical timeframe, even allowing for a postdiluvial ice age.

Since creationists have done little to investigate the scientific veracity of paleomagnetic techniques and conclusions, and since these studies are important to paleosol investigations, we suggest this as an area for extended research. Also, while pedostratigraphic correlation between Two Medicine Ridge, Milk River Ridge, Saint Mary Ridge, Mokowan Butte, and Cloudy Ridge (Figure 1) has been called into question by this study, an even more direct means of studying the veracity of the EGP correlations would be to investigate the landslide scarps on Saint Mary Ridge north and south of the scarp studied by Karlstrom and included in this study. Additional geochemical and physil identification studies could be undertaken. If these are performed, test pits or trenches for both test and control samples will be vital to a proper interpretation of the results. Pedostratigraphic analysis must be performed independently of magnetostratigraphic and other stratigraphic methods and results integrated afterward. Studies of alleged paleosols in other topographic and climatic settings could provide useful comparisons to this study.

Acknowledgements

We gratefully acknowledge the Blackfeet Nation for permission to perform research on tribal land, and our work benefited from the able assistance of Gabriel Renville, Timothy Sollid, Raymond Strom, Arden Sunwall, and David Sunwall. A significant portion of the fieldwork for this project was funded by a grant from the Creation Research Society. We benefited from the editorial assistance of John Reed and the anonymous reviewers. *Deum laudamus* (Isaiah 45:8).

Glossary

aquitard: a zone of relatively low permeability that hinders the movement of groundwater.

authigenic: said of minerals that form in place, often in pores in rocks, during diagenesis, typically as precipitates from aqueous solutions such as groundwater.

diagenetic: resulting from diagenesis, i.e. the changes occurring in a sediment after deposition but at near-surface conditions of temperature and pressure.

detrital: materials derived by physical weathering followed by transport to their place of deposition.

epigenesis: replacement of existing minerals or formation of new minerals under conditions of temperature and pressure that characterize the near-surface environment.

ferroargillan: physils containing high concentrations of iron or bonded to iron oxides; often limonite, a mixture of iron oxides and iron hydroxides, is disseminated in the physil mass.

glacigenic: having its origin in glacial processes (also spelled *glaciogenic*).

magnetostratigraphic: a conceptual scheme for the organization of units of earth materials (possibly demonstrating temporal relationship) based on remanent magnetic properties.

pedostratigraphic: stratigraphic correlation of units of earth materials based on soil profiles.

rubification: oxidation of iron in a sediment or soil horizon, resulting in a redder color; often used as an indicator of weathering in warm, moist conditions, though this is disputed (Klevberg and Bandy, 2003b, p. 110).

sesquioxides: oxides (typically of iron) that are more highly oxidized than other species (e.g. ferric oxide as opposed to ferrous oxide) and that typify soil horizons where leaching in the presence of organic acids is occurring.

syndepositional: occurring as part of the depositional process; contemporaneous with deposition.

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