Investigation of Several Alleged Paleosols in the Northern Rocky Mountains

Part I: Background and Methods

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Abstract

The existence of paleosols, "fossil soils," is a popular argument of anticreationists. Paleosols have been reported from 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, and dated by correlation to magnetic reversals. A chronology of 2.6 million years has been presented in the literature, with multiple glaciations, paleogeographic and paleoclimatologic reconstructions. The first part of this series presents background, methods, and a description of field sites where these alleged paleosols are found, including field data. The second part will present laboratory data and a discussion of field and laboratory data from both the traditional and diluvial perspectives.

The Apparent "Problem" of Paleosols

Because the traditional understanding of paleosols conflicts with the biblical timescale and history, "paleosols" are a favorite "proof" used by some anticreationists (Klevberg and Bandy, 2003a; Klevberg et al., 2003; Walker, 2003). This "proof" rests on the following claims:

- Soil formation is a slow process, requiring thousands to millions of years.
- Paleosols are present throughout the geologic column (equated to rock record)
- Successions of paleosols (vertical sequences) require in excess of the additive time for the formation of each paleosol.
- Paleosols are indicative of subaerial conditions and thus inimical to a global flood (since they occur throughout the global stratigraphic column)

The first claim is an assumption. Klevberg and Bandy (2003a; 2003b) have shown that soil formation can happen much more rapidly. Second, many horizons identified as paleosols in the rock record are very tentative (Klevberg et al., 2003). In addition, the geologic column (by definition) is a natural history paradigm, indefensible on solely scientific grounds. Equating the geologic column with the physical phenomena it is intended to interpret is a tautology and a grave error philosophically, historically, and scientifically (Klevberg, 1999; 2000a; 2000b; Reed and Oard, 2006; Woodmorappe, 1981). Therefore, the supposed distribution of paleosols through time is also open to question. Furthermore, the vast ages inferred from successions of "paleosols" depends on both the veracity of the paleosol interpretation of a horizon in the rock record and the assumption of slow pedogenesis. The fourth claim may be problematic for diluvialists. Not all soils form under dominantly subaerial conditions, but certainly most do. While not all of the earth's surface

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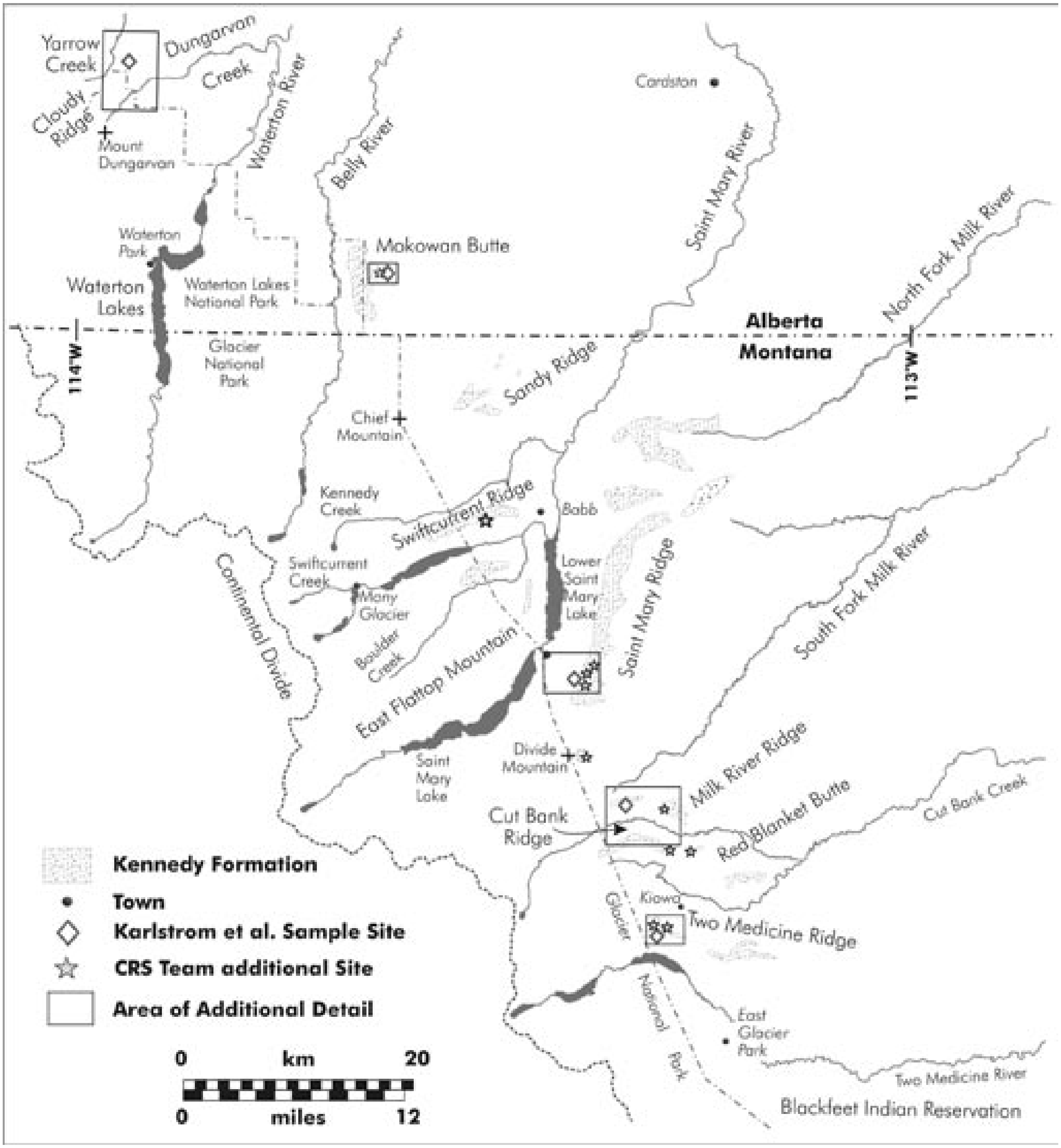


Figure 1. Map of Study Area.

would have been continuously submerged for the entire Deluge (Barnette and Baumgardner, 1994), abundant paleosols would not be expected to form during a global flood. The anti-creationist Meerts (2006) noted on a website posting that, "Obviously there is no chance for mature and thick soils to form during a global tempest such as the flood of Noah."

How can diluvialists explain paleosols? Do "paleosols" indicate the passage of vast periods of time? Do they actually provide the evidence for past climate change, geography, and biology that many establishment researchers claim? What are the scientific data, and how do they compare with expectations based on biblical presuppositions? While previous papers addressing paleosols have approached the issue in general or theoretical terms (see Froede, 1998, pp. 21–28; Klevberg et al., 2003; Oard, 1990, pp. 151–159), this series will focus on a field investigation and the interpretation of those results within opposing worldviews.

Paleosol Investigation in the Northern Rocky Mountains

Applying principles from Klevberg and Bandy (2003a, 2003b), Klevberg et al. (2003), and Klevberg and Oard (2005), we examined alleged paleosols in northern Montana and vicinity, focusing on those of the Kennedy "drift." These have been recognized for many years, have been the subject of previous investigations and many published papers, and are found within a geologic setting familiar to us (Cioppa et al., 1995; Horberg, 1956; Karlstrom, 1982; 1988; 1990; 1991; 2000; Karlstrom and Barendregt, 2001; Klevberg and Oard, 2005; Richmond, 1957; 1986). These paleosols(?) are claimed to separate "late Pliocene ice ages" up to 2.6 million years old, and lie on erosional remnants just east of Glacier National Park, Montana, and Waterton National Park, Alberta, Canada (Figure 1). We also evaluated the relationship of these deposits to other gravel-capped erosional remnants farther out on the high plains.

Since investigations into natural history are by definition mixed question (requiring multidisciplinary input from fields other than science), conclusions about paleosols are ultimately historical, not scientific (Klevberg and Bandy, 2003b; Klevberg et al., 2003). Science can constrain interpretation, but a careful distinction must be made between data and interpretation, a distinction often lacking in both evolutionist and creationist research. While evolutionists' interpretations involve a timescale incompatible with biblical history, paleosols per se are not inimical to a diluvial interpretation, and it was not our goal to "disprove" their existence. Rather, our purpose was to distinguish between data and interpretation in the work performed by previous researchers and to conduct enough field and laboratory research to test the validity of their data and elucidate remaining uncertainties.

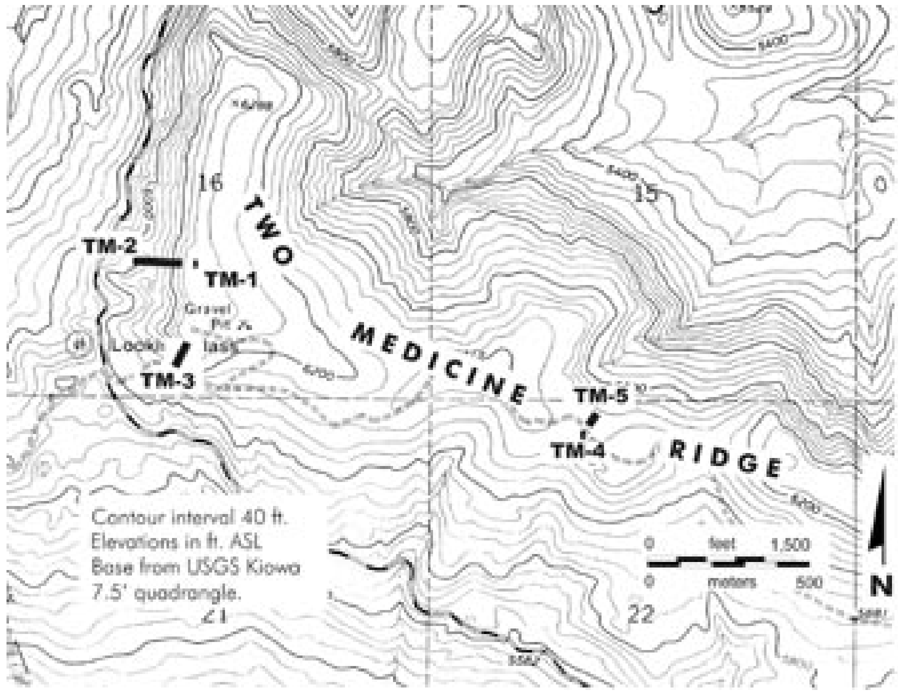


Figure 2. Two Medicine Ridge Sample Map.

The Kennedy "Drift" and "Paleosols"

Paleosols separate what are considered glacial tills on generally flat-topped interfluves east of Glacier and Waterton National Parks (Karlstrom, 1988). These interfluves are 185 to 490 m (600 to 1,600 ft) above rivers and streams draining the east slopes of the Rocky Mountains (Figure 1), and are erosional remnants of the Flaxville planation surface in northern Montana, southern Alberta, and southwestern Saskatchewan (Alden, 1932; Karlstrom, 1982). This surface was recognized by Willis (1902) and Ross (1959) as the "Blackfeet surface," but Alden (1932), working from the east, correlated it with erosional remnants he first encountered near Flaxville, Montana. The Flaxville surface is the second highest of four defined by Alden (1932), all mantled by exotic coarse gravel. The Cypress Hills surface is the highest in the area and corresponds locally to East Flattop Mountain (Figure 1). The coarse gravel caps have been transported at least 700 km (400 miles) eastward on a low slope (Klevberg and Oard, 1998; Oard and Klevberg, 1998).

The Flaxville surface shows slight disparities in summit concordance and is at a slightly lower level than East Flattop Mountain. Its gravel cap was considered fluvial by Bailey Willis (1902), but Alden (1932), who renamed the deposit the "Kennedy Drift" from Willis's "Kennedy gravels," believed it to be glacial because of striated clasts (Figure 2). He considered the deposits "old" because the surrounding area had been eroded up to 490 m (1,600 ft) since that ice age. Despite a lack of contrast between clearly fluvial and "glacial" deposits, the glacial interpretation was widely accepted (Ross, 1959) and still is. The interfluves were above the Cordilleran and Laurentide Ice Sheets (Pleistocene, see Horberg, 1956). In the diluvial framework, the glacial deposits would correspond to the single postdiluvial glaciation (Oard, 1990). The thickness of the coarse gravel ranges up to at least 75 m [250 ft] (Horberg, 1956).

With the exception of a minor amount of the "Cretaceous" sandstone below the gravel, the "drift" is composed almost exclusively of "Precambrian" Belt Supergroup rocks from the mountains to the west (Cannon, 1996; Hobbs, 1984; Roberts, 1986; Ross, 1959). The "drift" includes argillite, quartzite, limestone, dolostone with minor diorite, and possibly basalt or metagabbro from sills and dikes. Some of the "drift" is cemented by calcium carbonate, forming conglomerate (Figure 3). In general, the diamicton is considered a till, and is cemented in places.

Figure 3. The "classic slope" on Two Medicine Ridge (southwest slope).

A Tale of One-Five-Ten Paleosols

Horberg (1956) noted that the "drift" has been "weathered" to an unusual depth. He correlated the "weathered till" to the "known" climatic event of the "Yarmouth Interglacial" (Table I). He saw no evidence of a warmer and more humid climate from the weathering profile, although he noted that the "weathering profile" would have taken considerable time to develop. Later, Richmond (1957) and Karlstrom (1987; 1988; 1991) saw at least five, and possibly ten, strongly developed paleosols between five tills on two of the interfluves, and lesser numbers on the others. Furthermore, Karlstrom (1991) claimed that the paleosols represent interglacials at least 6 to 8°C warmer and 40 cm (16 in) wetter than the present climate. In contrast, the climate of each ice age was at least 10°C colder than today, based on relict periglacial features on some of the "tills" (Karlstrom, 1990). The Kennedy "drift" has been paleomagnetically dated to as old as 2.6 Ma—late Pliocene in the establishment geologic paradigm (EGP)—and is considered one of the oldest tills in North America (Cioppa et al., 1995). Magnetostratigraphy and pedostratigraphy have been used to correlate paleosols(?) between five sites over a distance of approximately 75 km (45 miles) to arrive at a more "complete" history of the area, including paleoclimate (Karlstrom, 1988).

If EGP researchers are correct in their interpretation of the Kennedy Formation, it would bolster the evolutionist-uniformitarian view of earth history. This view is incompatible with the biblical-diluvial view of earth history in several ways:

- An age of 2.6 Ma is not compatible with biblical chronology.
- Multiple ice ages fit poorly with the shorter time period indicated by biblical history.
- Multiple magnetic reversals reportedly recorded in the Kennedy Formation are not inimical to the diluvial geologic paradigm (DGP), but may fit better with the EGP.
- An age of 2.6 Ma implies soil development (pedogenesis) is relatively slow, and multiple superposed paleosols would imply a vast age.

However, these issues are merely inferences from geologic data. It is important to determine what the field data are and which geologic paradigm (if either) they may be understood to favor. Science is an invaluable tool in testing these disparate claims.

Table I. "Classical" Four Ice Age Scheme

Glacial	Years B.P.*	Interglacial
Wisconsinan	100,000–10,000	
	225,000–100,000	Sangamon
Illinoian	325,000–225,000	
	700,000–325,000	Yarmouth
Kansan	1.1–0.7 Ma	
	1.2–0.7 Ma	Aftonian
Nebraskan	1.6–1.2 Ma	

*Evolutionists differ significantly on these fictional dates.

Research Methods

Alleged paleosols have been identified at Two Medicine Ridge (Horberg, 1956; Richmond, 1957; 1986) and at four other sites (Karlstrom, 1988; 1990; 1991). To the extent feasible, both a geological engineer and a soil scientist from our group (CRS team) examined each of these sites (Figure 1). In addition, at least one member of our team examined each of 11 other Kennedy Formation sites not previously published (Figure 1). Until recently (Karlstrom and Barendregt, 2001), locations of the sites investigated by Karlstrom were not well documented, but we are confident that we located nearly all of his test trenches.

In addition to reopening his trenches, we dug additional test pits nearby. Our soil scientist described their soil profiles using U.S. Department of Agriculture nomenclature (Soil Survey Division Staff 1993; 1999). Our geologist/engineer classified unconsolidated materials using the Unified Soil Classification System (ASTM, 1992) and consolidated materials using petrologic terminology. Soil samples collected from several pits and trenches were submitted to Continental Rocktell Services of Calgary, Alberta, for thin section, petrologic, and electron microscopy analysis. Most were oriented samples. Our field research gathered and evaluated a significant quantity of data, and a detailed description of methods is presented in Appendix A. Pedologic and geologic data are displayed on test pit and slope logs in Appendix B. The following sites can be found by reference back to Figure 1.

Research Sites

Two Medicine Ridge

Two Medicine Ridge is the "original" paleosol site. The area described by previous investigators coincides with our test trench TM-3 (Figure 2). In addition to that location, we dug a series of test pits that included: TM-1, a test pit on top of the ridge; TM-2, a series of pits down the west side; TM-4, another ridge top test pit east of TM-3, and TM-5, a scarp trench farther east along the ridge. A summary of soil classifications for the materials encountered in test pits and trenches is presented in Table II. Slope logs can be seen in Appendix B. The southwest slope of Two Medicine Ridge is the only site included in this study virtually devoid of evidence of modern pedogenesis.

Table II. Two Medicine Ridge Soils

Test Pit or Trench	Classification
TM-1 (0')	Loamy-skeletal, mixed, superactive, ustic haplocryalfs
TM-2 (2')	Loamy-skeletal, mixed, superactive, ustic haplocryalfs
TM-2 (70')	Typic cryopsamments
TM-2 (148')	Sandy-skeletal, mixed, typic cryorthents
TM-2 (266')	Loamy-skeletal, mixed, superactive, ustic, typic cryorthents
TM-2 (363')	Fine-loamy, mixed, superactive, ustic haplocryalfs
TM-2 (479')	Loamy-skeletal, mixed, superactive, lithic haplocryolls
TM-3	Sandy-skeletal, mixed, typic cryorthents
TM-4	Clayey-skeletal, mixed, superactive, ustic glossocryalfs
TM-5 (2')	Clayey-skeletal, mixed, superactive, ustic glossocryalfs
TM-5 (3')	Clayey-skeletal, mixed, superactive, inceptic haplocryalfs
TM-5 (16')	Loamy-skeletal, mixed, superactive argicryolls
TM-5 (19')	Loamy-skeletal, mixed, superactive argicryolls
TM-5 (22')	Loamy-skeletal, mixed, superactive argicryolls

The soil in TM-1 was that expected for nearly level slopes or slopes without a long history of pedogenesis. The A horizon is 15 cm (6 in) deep with a B_t argillic horizon extending to a depth of at least 43 cm (17 in). This indicates a well-developed soil with a deeper moisture control section, indicative of a fairly high effective precipitation rate that would allow for deeper leaching. Downslope to the west (TM-2), we found little evidence of any kind of argillic horizon in the soil pits, as expected for steep slopes with little vegetation to slow water movement across the surface, and allow leaching. As the slope angle lessened down TM-2, the slope became more stable with more vegetation, and argillic horizons were found. This corresponds to the local climate: runoff from snowmelt and high-intensity rainfall on steep slopes increases erosion. Since soil moisture levels rarely get to the saturation point, vegetation is sparse, and organic matter that would improve fertility cannot accumulate. As the slopes decrease, less runoff and more water percolation into the soil occur. Erosion decreases, vegetation increases, fertility increases, and colonization by more climax type species occurs.

The "classic" location on Two Medicine Ridge is the scarp on the southwest side at TM-3 (Figure 3). The slope has a southwest aspect and is virtually devoid of vegetation. It is steeper than the west slope, averaging roughly 36° from the horizontal. Its surface is covered with coarse colluvium (talus) with outcrops of carbonate-cemented conglomerate of the same composition—the suite of lithologies typical of the Kennedy Formation. Bedding is sometimes evident in the conglomerate—sometimes paralleling the slope, and sometimes horizontal. Iron oxide coats some of the clasts. Evidence of soil formation near TM-3 was almost nonexistent, with an obvious lack of clay films and with material that would be considered B_k or C intermixed with boulders and coarse rock fragments. An exception was observed approximately 3.6–4.6 m (12–15 ft) vertically below the top of the ridge, where argillic material was encountered that proved to be colluvial. Further investigation disclosed an argillic (B_t) horizon approximately 2.1 m (7 ft) below the ridgetop. Both the argillic material and colluvial sand downslope exhibited red coloration; however, no evidence was apparent for a pedogenic origin of the iron oxide in the colluvium.

Figure 4. North-facing scarp on Two Medicine Ridge (test trench indicated).

TM-4 and TM-5 are 1.6 km (1 mi) east of the “classic” scarp (Figure 3). TM-5 occupies what appears to be a rather recent scarp (Figure 4). Seedlings there appeared to be no more than 3–5 years old. The slope aspect is north, and the north slope of the ridge is forested with Engelmann Spruce (*Picea engelmannii*) and Sitka Alder (*Alnus sitchensis*). The scarp was well vegetated with cow parsnip (*Heracleum lanatum*), yellow Indian paintbrush (*Castilleja sessiliflora*), and various forbs and grasses. The top of the ridge, which is exposed to more sun and wind than the north-facing slope, is entirely covered with grasses except for a few battered Whitebark Pine (*Pinus albicaulis*) along the edges of the rather flat ridge top. TM-4 showed what appeared to be a well developed alfisol with an E horizon to the bottom of the pit at 0.45 m (1.5 ft), corresponding to the profile evident in TM-5, where an argillic horizon was encountered below an A horizon and a leached E horizon 0.75 m (2.5 ft) vertically below the top of the scarp.

This site was significant in forming our ideas about the paleosols(?) in the Kennedy Formation. The argillic horizon observed in TM-5 is quite thick and deep, typical of a relatively moist, forested site with good leaching characteristics. The elevation of the site produces a cool climate with much of the moisture derived from snowmelt. Where carbonate content is low, the Kennedy Formation is quite permeable, promoting water movement and clay translocation (Klevberg and Bandy, 2003b). Trees help prevent moisture loss from the surface and allow meteoric water to penetrate, leaching organic acids from leaf litter to more rapidly produce an eluvial (E) horizon, and depositing clays (mostly physils) in the subjacent illuvial (B_t) horizon. On the slope surface in colluvium, an A horizon overlies the argillic horizon to its maximum extent below the ridge top. Material below the argillic (B_t) horizon appeared to be Kennedy Formation to a depth of approximately 8 m (25 ft), where float indicated the presence of sandstone, which resembled strata outcropping at the northwest end of Two Medicine Ridge.

Milk River Ridge (West)

Milk River Ridge is cut by a saddle into west and east halves. The scarp on the west end has a southeasterly aspect (Figure 5). While some of the CRS team members had previously performed a reconnaissance of the adjacent slope,

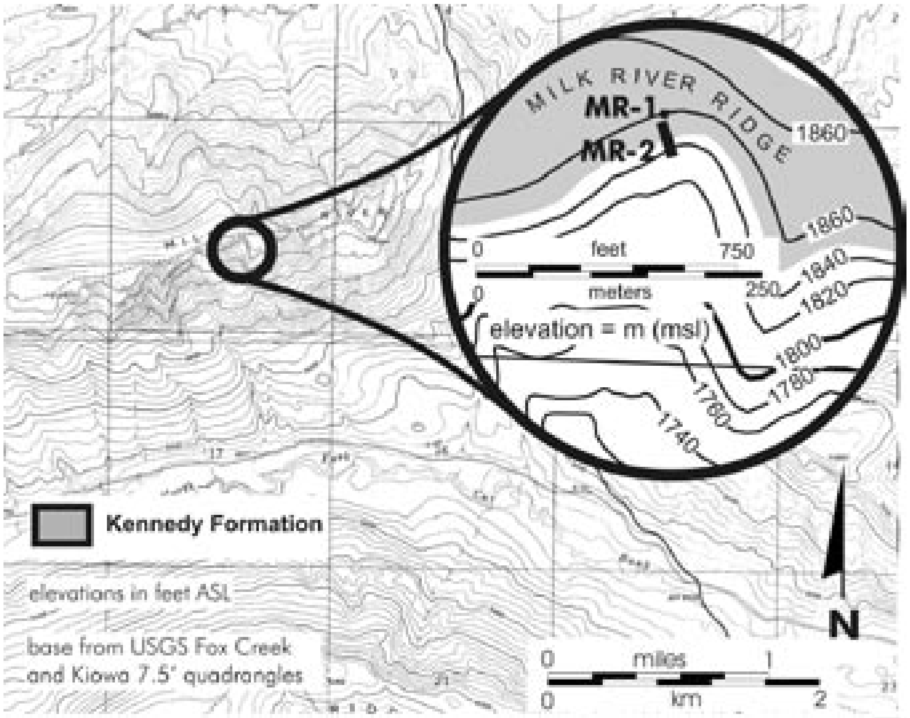


Figure 5. Milk River Ridge Sample Map. Topography from USGS Fox Creek and Kiowa 7.5' quadrangles.

Table III. Milk River Ridge (West) Soils

Test Pit or Trench	Classification
MR-1	Clayey-skeletal, mixed, superactive ustic glossocryalfs
MR-2 (5')	Clayey-skeletal, mixed, superactive ustic glossocryalfs
MR-2 (10')	Clayey-skeletal, mixed, superactive, ustic haplocryalfs
MR-2 (15')	Clayey-skeletal, mixed, superactive, ustic haplocryalfs
MR-2 (20')	Clayey-skeletal, mixed, superactive, ustic haplocryalfs
MR-2 (25')	Clayey-skeletal, mixed, superactive, ustic haplocryalfs
MR-2 (30')	Clayey-skeletal, mixed, superactive, ustic glossocryalfs
MR-2 (35')	Clayey-skeletal, mixed, superactive, ustic haplocryalfs
MR-2 (40')	Clayey-skeletal, mixed, superactive, ustic haplocryalfs
MR-2 (45')	Clayey-skeletal, mixed, superactive, ustic haplocryalfs
MR-2 (55')	Clayey-skeletal, mixed, superactive, ustic eutrocryepts
MR-2 (62')	Clayey-skeletal, mixed, superactive, ustic eutrocryepts
MR-2 (70')	Clayey-skeletal, mixed, superactive, ustic eutrocryepts
MR-2 (80')	Clayey-skeletal, mixed, superactive, ustic glossocryalfs

the information here is primarily from the scarp studied by Karlstrom (1988; 1990; 1991). In addition to reopening his test trench (our MR-2), we excavated a test pit on the ridge top near the head of the scarp (MR-1). Soil classifications for materials encountered at the landslide scarp on the south side of the west part of Milk River Ridge are shown in Table III. Soil development has occurred at a rate adequate to produce well-developed soils. The presence of a strongly developed E horizon on top of the ridge indicates an environment conducive to leaching. The ridge crest is quite flat and well forested with conifers (principally Lodgepole Pine, *Pinus contorta latifolia*). Movement of water from snowmelt and rainfall through the soil profile translocates primary minerals and clays deeper into the soil profile. This is enhanced by production of organic acids from leaf litter and other organic matter. A reduction in permeability and slowing of water movement results in deposition of clays beneath the eluvial (E) horizon, forming an argillic (B_t) horizon to a depth of at least 50 cm (20 in) in the vicinity of MR-1.

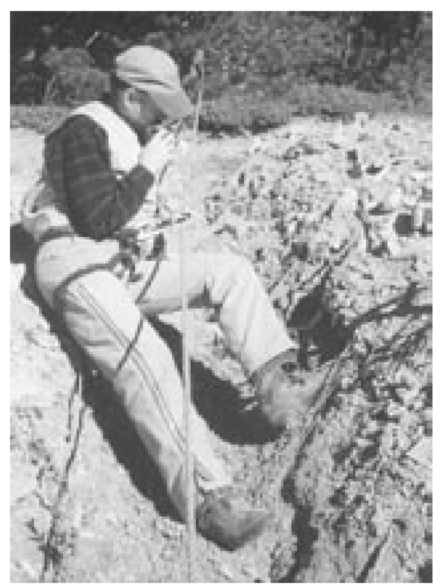


Figure 6. Dictating field notes while excavating Karlstrom's trench on Milk River Ridge (trench MR-2).

Down slope (MR-2), we encountered a relatively thick A horizon in our shallow test pits within and beside Karlstrom's trench (Figure 6), probably due to colluvial accumulation from upslope sources. These were underlain by B_t horizons approximately 25 cm (10 in) thick. At the toe of the scarp, where MR-2 entered timber, E horizons appeared above the argillic horizons, and A horizon material appeared more intact rather than colluvial. Limonite and other combinations of hydrous oxide minerals, which were evident in the near surface soil along the scarp, were not evident below the toe of the scarp.

The soils observed on the slope could be expected on a well-vegetated, stable slope, where deep leaching would promote formation of prominent argillic horizons. Loss of forest cover to disease, insects, fire, or logging may result in destabilization of the slope and soil erosion. Soil formation is ongoing on the slope, based on the cumulic A horizon and secondary minerals, though erosion on the unstable slope constantly disrupts the formation of the soil profile. A well-developed alfisol is present above and below the scarp. Slope logs can be seen in Appendix B.

Saint Mary Ridge

The largest of the sites investigated is Saint Mary Ridge. Three landslide scarps are prominent on its west side. The middle scarp was investigated by Karlstrom and was the primary focus of our investigation. However, before examining the scarp, we excavated three test pits in the forested top of the ridge (Figure 7). To the extent feasible, we located Karlstrom's previous test trenches and designated ours with Arabic numerals corresponding to his Roman numerals (e.g. his Trench V corresponds with our SM-5). Their locations are shown on the inset of Figure 7. Soil classifications are summarized in Table IV; test pit and slope logs can be seen in Appendix B.

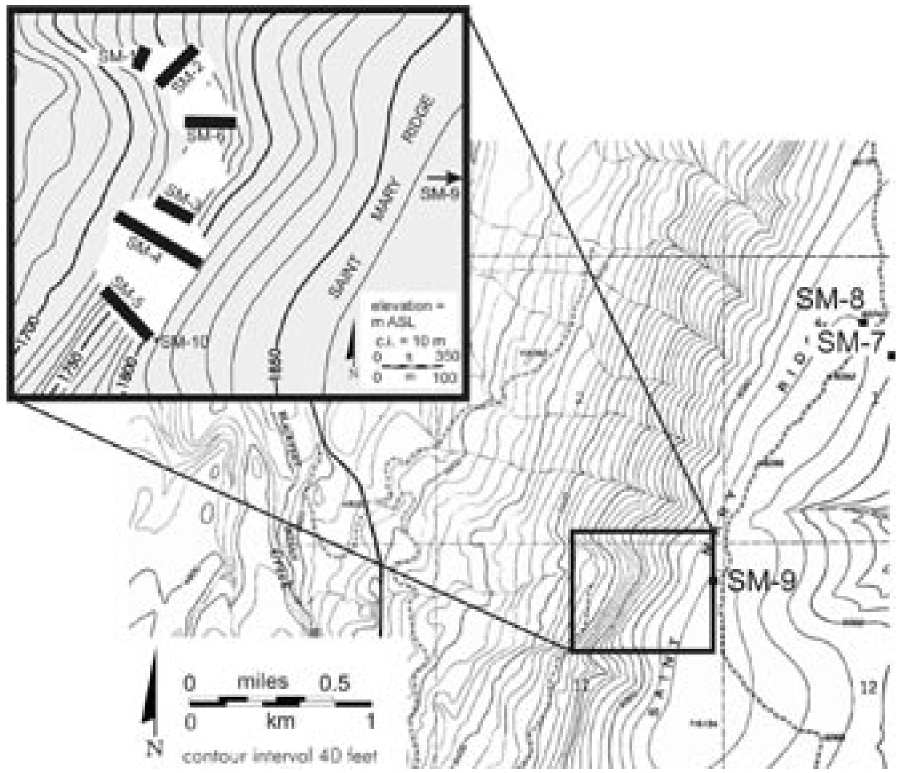


Figure 7. Saint Mary Ridge Sample Map. Base from USGS Saint Mary 7.5' quadrangle.

Before examining the test trenches, we excavated an additional test pit (SM-10) just above the top of the scarp (Figure 7). In SM-10, we found a well-developed alfisol with a 5-cm (2-in) thick O horizon atop a 75 cm (30-in) E horizon, above an argillic horizon, indicating a moist, stable environment where rainfall and snowmelt percolate into rather than erode the soil. Adequate effective precipitation; smooth, low slopes; a canopy of trees; and the soil texture combine to produce a leaching environment, effecting translocation of clay particles from the E horizon into the B_t horizon.

Downslope from SM-10, the slope becomes unstable (Figure 8). Runoff from snowmelt and rain erode the soil, minimizing vegetation, infiltration, and thus soil formation. Examination of the soil on the scarp confirmed this. Thin A horizons are present with (in most cases)

Figure 8. Unstable slope (center scarp), Saint Mary Ridge.

Table IV. Saint Mary Ridge Soils

Test Pit or Trench	Classification
SM-1	Entisol, unclassified
SM-2 (115')	Coarse-loamy, mixed, ustic, eutrocryepts
SM-3 (0')	Sandy-skeletal, mixed, ustic calcicryolls
SM-5 (5')	Clayey-skeletal, mixed, superactive, ustic glossocryalfs
SM-5 (20')	Loamy-skeletal, mixed, superactive, typic eutrocryepts
SM-5 (30')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (40')	Loamy-skeletal, mixed, superactive, ustic eutrocryepts
SM-5 (50')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (60')	Fine-loamy, mixed, superactive, ustic eutrocryepts
SM-5 (70')	Fine-loamy, mixed, superactive, ustic eutrocryepts
SM-5 (80')	Loamy-skeletal, mixed, superactive, ustic eutrocryepts
SM-5 (90')	Loamy-skeletal, mixed, superactive, ustic eutrocryepts
SM-5 (100')	Loamy-skeletal, mixed, superactive, ustic eutrocryepts
SM-5 (110')	Loamy-skeletal, mixed, superactive, ustic eutrocryepts
SM-5 (120')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (130')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (140')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (157')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (160')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (170')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (180')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (190')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (200')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (240')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (260')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (300')	Loamy-skeletal, mixed, superactive, ustic eutrocryepts
SM-5 (320')	Loamy, mixed, superactive, lithic cryorthents
SM-5 (335')	Heavy clay loam with 40–50% coarse frag., violently eff.
SM-6 (80')	Loamy, mixed, superactive, lithic cryorthents
SM-6 (180')	Loamy-skeletal, mixed, superactive, ustic eutrocryepts
SM-7	Fine-loamy, mixed, superactive, inceptic haplocryalfs
SM-8	Fine-loamy, mixed, superactive, inceptic haplocryalfs
SM-9	Fine-loamy, mixed, superactive, aquic haplocryalfs
SM-10	Clayey-skeletal, mixed, superactive, ustic glossocryalfs

a B_k or C horizon directly beneath. In only one location (SM-5 at 50 feet) did we find evidence of formation of a B_t horizon (though argillic material was occasionally present in colluvium). This escarpment showed predictable soil development. Applying the five environmental factors and four soil-forming mechanisms (Klevberg and Bandy, 2003a), the slope above the landslide scarp is a strong leaching environment where well-developed soils would be expected, while the steep and unstable slope limits soil formation. Nonetheless, with the exception of lithified portions of the scarp (Figure 9), evidence of nascent pedogenesis was observed in the unstable colluvium.

Mokowan Butte (Pole Heaven)

Pole Heaven is an area on the northeast flank of Mokowan Butte near the summit flat. In addition to the landslide scarp and road cut investigated by Karlstrom, the CRS team excavated test pits in other locations (Figure 10). Slope logs can be seen in Appendix B. Mokowan Butte is well forested, and much of Pole Heaven has been logged in recent years. Soil classifications for materials encountered are shown in Table V. The first test pit (PH-1) was in a well-vegetated area near the edge of a clear-cut. It revealed a well-developed, productive alfisol, typical of forested terrain in this climate. Test pits PH-2 through PH-5 form a test trench near the west end of a small landslide scarp near the northeast edge of the top of the butte. PH-2 was excavated in the forested edge above the scarp, and a B_t horizon was encountered at a depth of 51 cm (20 in). This indicates a stable landscape with high effective precipitation, resulting in significant leaching and physical weathering (translocation of clays), producing an argillic horizon beneath the E horizon. Based on observations of PH-1 and PH-2, we infer that well-developed alfisols can be expected on stable slopes with heavy vegetation. Since soil formation is evident on most

Table V. Mokowan Butte (Pole Heaven) Soils

Test Pit or Trench	Classification
PH-1	Fine, smectitic, superactive, alfic argicryolls
PH-2	Fine, smectitic, superactive, ustic glossocryalfs
PH-3	Fine, smectitic, superactive, ustic haplocryalfs
PH-4	Fine, smectitic, superactive, ustic haplocryalfs
PH-5	Fine, smectitic, superactive, ustic haplocryalfs
PH-6	Loamy, mixed, shallow, superactive, typic cryorthents
PH-7	Fine-loamy, mixed, superactive, ustic eutrocryepts
PH-8	Nonsoil—rock
PH-9	Fine, smectitic, ustic glossocryalfs

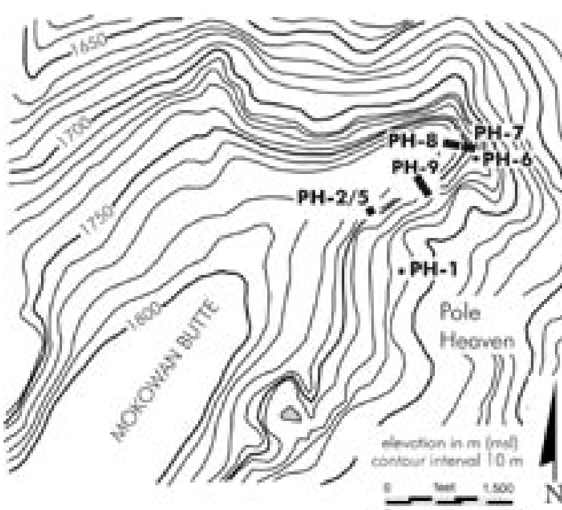


Figure 9 (*above*). North end of Saint Mary Ridge center scarp showing conglomerate outcrops.

Figure 10 (*left*). Mokowan Butte Map showing Pole Heaven sample locations.

of the slope, it may be that this area was formerly stable and well vegetated.

The argillic horizon is exposed at several sites on the slope, probably due to erosion of the A horizon and exposure of the B_t horizon. This might be more difficult to establish if the entire slope were a single B_t exposure. Where present, the E horizon, a sandy loam or loam, averages about 13 cm (5 in) thick above the B_t horizon. Presence of an E horizon indicates leaching and translocation, important soil-forming mechanisms mediated by water (Klevberg and Bandy, 2003a). The argillic horizon is about 45 to 50 cm (18 to 20 in) thick above a C horizon and is a heavy clay loam to clay in texture and quite red (5YR4/6 moist). Down slope, clay films are less evident, and the slope is covered with a veneer of angular gravel (slope wash). Downslope movement creates colluvium and inhibits pedogenesis, with the A and E horizons apparently eroded off of much of the slope.

Bedrock outcrops in a road cut at PH-6 (Figure 10). It is overlain by a C horizon, then an E horizon, and between them a possible buried soil horizon. Vegetation is present, but this section may indicate past slope instability. Because the buried horizon is within the zone of current soil formation, it is not a paleosol (Klevberg et al., 2003).

The edge of Mokowan Butte at the north end of Pole Heaven (Figure 10) revealed evidence of slope instability and formation of a considerable apron of colluvium. Test pit PH-7 exposed a 6-inch (15-cm) sandy loam A horizon over an 18-inch (46-cm) B_w horizon, with an underlying C horizon of Kennedy Formation colluvium. Up slope, colluvium and conglomerate or breccia are present and soil formation is minimal. Forest vegetation and a well-developed alfisol cover Mokowan Butte at the head of this bluff.

Between PH-2 through PH-5 on the southwest, and PH-6 through PH-8 on the northeast we found what appears to be one of Karlstrom's test trenches, our PH-9, located on the main scarp face at approximately 43° to horizontal. We found a 25 cm (10 in) E horizon (loam) overlying a heavy clay loam B_t horizon overlying a B_{tk} horizon overlying rock. Clay films were relatively thick and covered pit faces, pores, and sand grains. Carbonate increased down section, forming rock at approximately 3.6 m (12 ft) vertically below the butte's rim. The rock is a carbonate-cemented, matrix-supported conglomerate with angular clasts (i.e. breccia), with colluvium below the conglomerate. In the colluvium, we found a section of argillic material that proved to be a colluvial pocket of clay-rich material, not a B_t horizon. Slope instability appeared to be a major factor in the location and exposure of argillic material, and we found no evidence of pedogenesis in the colluvial apron.

Cloudy Ridge

Only one paleosol was alleged by Karlstrom (1988; 1990; 1991; Karlstrom and Barendregt, 2001) to have been found at Cloudy Ridge, and it was supposedly exhumed. This site (Figure 1) was unlike the others we investigated, not having a concordant summit capped by Kennedy gravel. Instead, it is a pediment surface stretching from the rugged Rocky Mountains north of Waterton National Park toward the Great Plains (Figure 11). This pediment surface is considered by some to be a paleosol (Karlstrom and Barendregt, 2001; Karlstrom, 1988, 1990, 1991) and is correlated with those of Mokowan Butte, Saint Mary Ridge, Milk River Ridge, and Two Medicine Ridge. Relief at this site is less than the other sample locations visited by EGP researchers. Our CR-1 on a southeast-facing slope coincided with Karlstrom's trench (Figures 12, 13). The slope was well vegetated with small bushes and forbs except at the eroded trench. Data are presented in Table VI and slope log CR-1 (Appendix B).

Like the other sites, particularly Two Medicine Ridge, Cloudy Ridge is close to the mountain front and experiences very strong winds. The pediment surface is armored with about 80 percent coarse fragments (pebbles and cobbles), interspersed with short grass, with a rooting medium of a mollic A horizon about 8 cm (3 in) thick, atop a B_k horizon. Approximately 1.1 m (3.6 ft) vertically below the bench, an irregular, red sandy clay loam was encountered. Clay film

Figure 11. Photograph of Cloudy Ridge pediment surface.

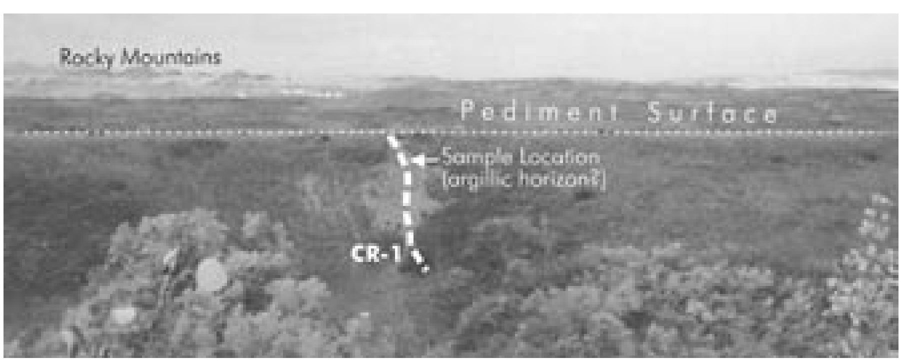


Figure 12. Cloudy Ridge Sample site photograph (trench CR-1 indicated).

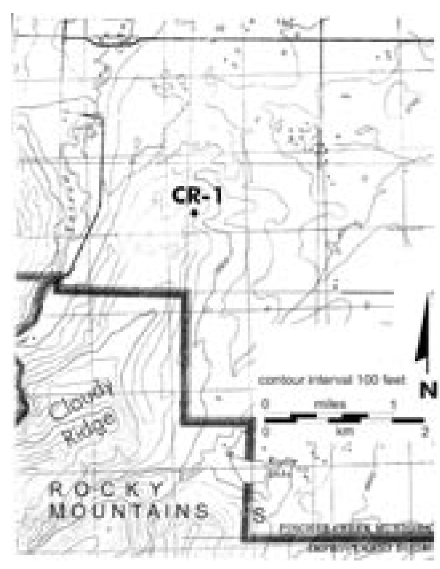


Figure 13. Cloudy Ridge Sample Map.

was present in the upper 8 cm (3 in) of soil. This may be a B_t horizon deformed by downslope movement. As at the other sites, gravel was abundant in the soil, and pebble orientation coincided with small-scale mass wasting on the unstable slope. Carbonate content was high enough to lithify the material locally, and even in lesser concentrations, it appears sufficient to stabilize other portions of the slope. A talus apron of boulders forms the toe of the slope.

Table VI. Cloudy Ridge Soils

Test Pit or Trench	Classification
CR-1 (0’)	Sandy-skeletal, mixed, typic cryorthents
CR-1 (5.5’)	Loamy-skeletal, mixed, superactive, ustic eutrocryepts
CR-1 (36’)	(not classified)
CR-1 (72’)	(not classified)

Figure 14. Cut Bank Ridge from Red Blanket Butte.

Figure 15. View from top of Red Blanket Butte toward Milk River Ridge East. Patterns of cobbles and boulders are anthropogenic.

Cut Bank Ridge

A small slump scarp was present on the east end of Cut Bank Ridge (Figure 14). Carbonate content was too low for lithification, and the entire slope is colluvial. Some vegetation has become established, but not significantly impairing erosion. However, the lack of vegetation is compensated by the highly permeable colluvium. A poorly developed A horizon was evident, but no evidence of an argillic horizon was observed.

Red Blanket Butte

Red Blanket Butte is an erosional remnant, probably the eastern continuation of Cut Bank Ridge (Figure 1). Its convex surface is like Two Medicine Ridge and Milk River Ridge, but it is lower than those larger ridges (Figure 15). It may have originally been a slight depression in the Flaxville surface that led to development of the drainages forming the North and South Forks of Cut Bank Creek (Figure 1). We found no prominent scarps on Red Blanket Butte, and the presence of culturally important anthropogenic features (graves, teepee rings) precluded excavation or other disturbance of the site. Material visible on the surface appeared to be Kennedy gravel with some notable dolostone boulders. No igneous lithologies were observed. Some large, angular boulders or blocks may have been a weathered outcrop of limestone; if so, the Kennedy Formation is very thin atop Red Blanket Butte. Soils appear to be generally alfisols, and the ground surface is covered with grass except for the north slope, which is forested with *Pinus contorta latifolia* and *Pseudotsuga* *menzesii*, with scattered trees elsewhere on the butte.

Milk River Ridge (East)

The east half of Milk River Ridge appeared to resemble the west part, but lacked the unvegetated landslide scarp noted in Karlstrom's previous investigations there. Kennedy gravel was observed on the slopes of the east part of Milk River Ridge, but most of this was slope wash over sandstone bedrock. The deposit is thicker over the center part of the ridge. Igneous boulders are rounded, as are many of the Belt clasts. A few argillite clasts exhibited striations. Deposits farther east on this ridge are not mapped as Kennedy Formation (Cannon, 1996), but the contact between these formations appears to be gradational. The slope east-northeast along the ridge crest is about four percent (2¼°). The ridge is covered with thick grass, and slopes are forested (Figure 16). No scarps were observed, but road cuts and small coulees (draws) provided some opportunity to observe soils, which appeared to be alfisols similar to TM-1 and TM-4.

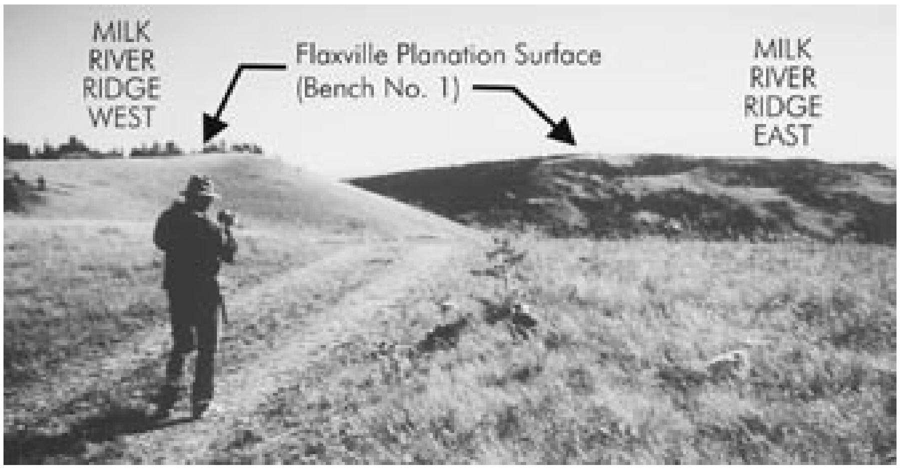


Figure 16. East end of Milk River Ridge from west end of ridge.

Swiftcurrent Ridge

The eroded top of Swiftcurrent Ridge slopes gently to the northeast and is capped by Kennedy gravel, which ap-

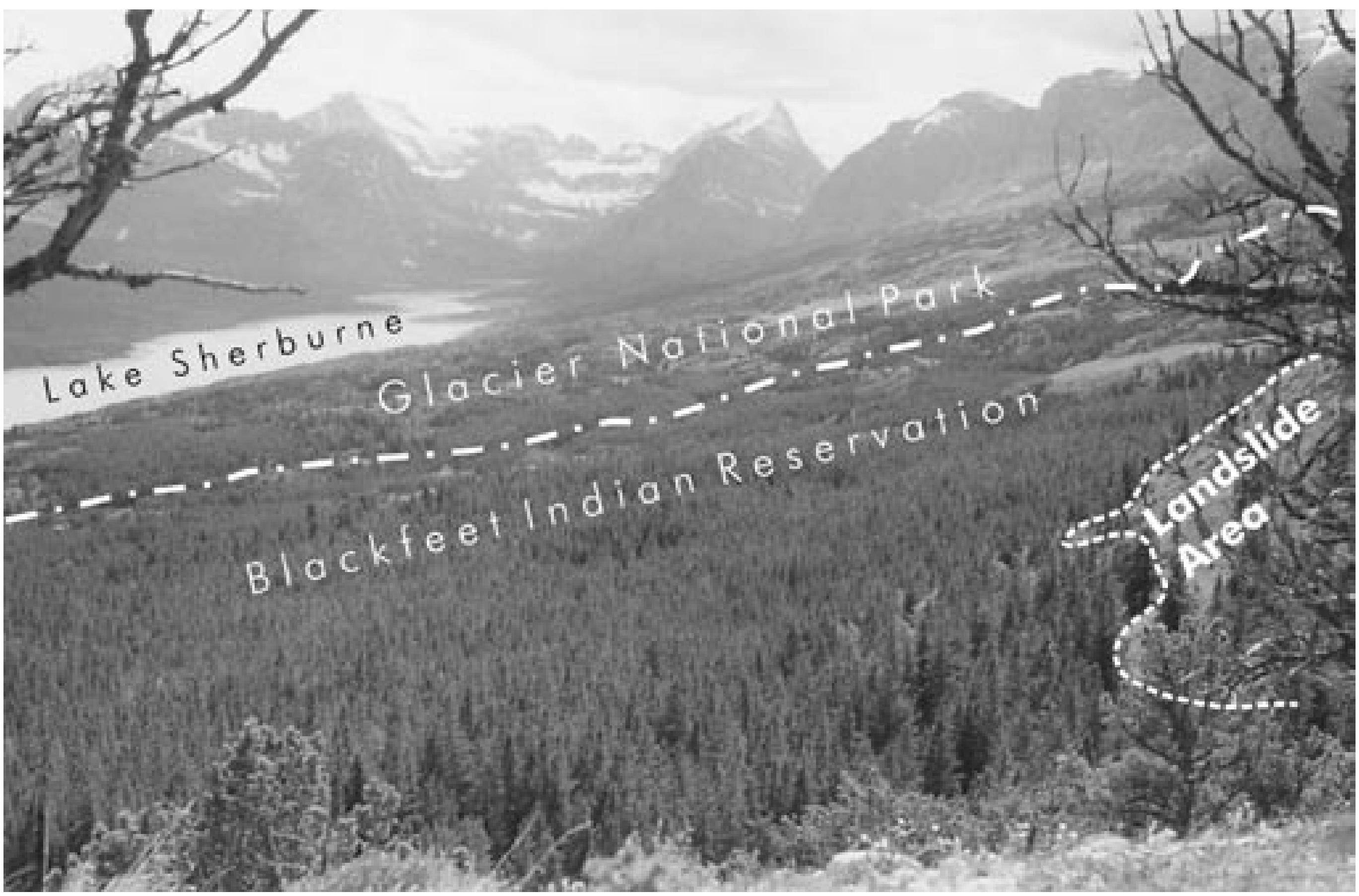


Figure 17. View west along south side of Swiftcurrent Ridge showing landslide area.

pears slightly more rounded than on Two Medicine and Saint Mary Ridges and contains cataclastic dolostone and some mafic lithologies. Relatively good soil development has occurred in the Kennedy Formation; the ridge top is well vegetated with grasses, and the slopes forested. A slump on the south side (Figure 17) exposes the Kennedy Formation, and a sandy gravel colluvium that would classify as an entisol. Elsewhere in the site vicinity, soils appeared to be alfisols. The soil on top of the ridge consists of a dark brown loam A horizon 8 cm (3 in) thick above a sandy loam E horizon with much gravel. In the slump scarp, a reddish brown argillic horizon penetrated by roots was present beneath the E horizon. Elsewhere, the slope was mantled with colluvium. Only occasionally is carbonate abundant enough to form small amounts of conglomerate.

Summary

Deposits interpreted by EGP researchers as paleosols are found in the Kennedy Formation, which is interpreted as glacial (Klevberg and Oard, 2005). Landslide scarps generally show continued slope instability. Soils observed on stable slopes were generally alfisols (Klevberg and Bandy, 2003a), characteristic of well-drained forest cover. Unstable slopes were generally mantled with entisols.

Appendix A: Research Methods

Our goal was to obtain adequate geologic and pedologic data to judge between competing natural history hypotheses. We examined sites previously published by EGP researchers as a minimum for this investigation. The majority of the sites are on the Blackfeet Indian Reservation (Figure 1), and permission for our research was graciously granted by the Blackfeet Nation. Isolated outcrops of Kennedy Formation occur inside Glacier National Park. These were observed but not sampled. Canadian residents assisted us in gaining access to sites north of the border.

Investigation of published "paleosol" trenches was essential to understand both field conditions and data used by EGP researchers. We reopened these trenches by removing loose material from their surfaces and digging shallow test pits within them to examine "intact" earth materials (Figure 6). Measured distances along each trench identified field description and laboratory sample locations (Figure 18). Slope gradients were measured with a Brunton compass to convert long-slope distances to elevations for sample log preparation and comparison with published information. To permit careful examination of earth materials and measurement along unstable slopes, we rappelled down some of the landslide scarps, especially those proximate to conglomerate outcrops (Figure 19).

We excavated additional test pits proximate to most of the original test trenches (Figure 20) to better ascertain lateral facies changes and ongoing pedogenesis. Test pits were also excavated away from unstable slopes to better evaluate local soil formation conditions. Laboratory analysis compared samples

Figure 18. Excavation of trench TM-2, steel tape used for long-slope measurement.

Figure 19. Rappelling permitted convenient and careful examination of outcrops.

Figure 20. A spade was used to hand excavate in and along previous test trenches (SM-4).

Figure 21. Field examination of test pit TM-1.

from stable and unstable slopes.

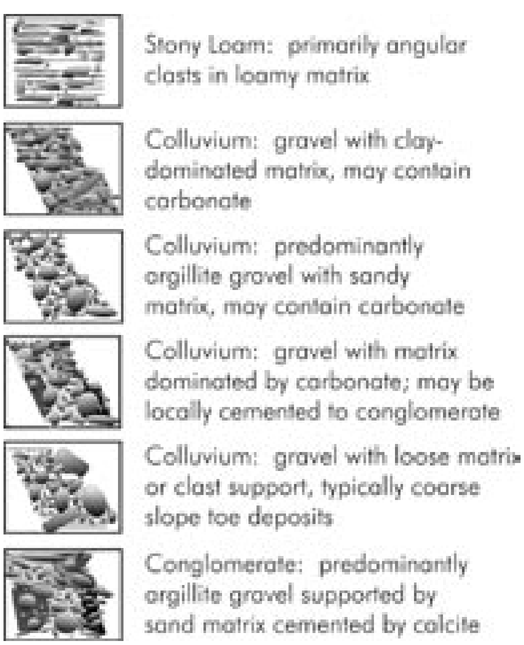
Other scarps exposing Kennedy Formation were observed to test stratigraphic interpretations and evidence for or against modern soil formation. Observation was limited to scarp surfaces and test pits; no trenches of the kind used by previous researchers were excavated, out of respect for tribal land and to minimize erosion. In addition to the creation of test pit and slope logs (presented in Part II of this series) and evaluation of laboratory data, we examined soil maps of the Blackfeet Indian Reservation sites available at the Natural Resources Conservation Service office of the U.S. Department of Agriculture.

Soil descriptions were based on standard practices (Figure 21) and used USDA nomenclature (Soil Survey Division Staff 1993; 1999). Colors are based on a Munsell color chart and are moist colors unless displayed in parentheses. To the extent feasible, soil samples were collected by excavating around the material to be collected and molding a piece of aluminum foil around it, marking the foil with a north arrow and top marking, and placing it in a sealed plastic bag. Noncohesive soils were sometimes too friable to collect oriented or "undisturbed" samples, though the same methods were used. Thin section, petrologic, and electron microscopy results were provided as high-resolution color images. Thin section images included plane polarized and cross-polarized pairs, and reflected light images, all at 400x magnification. Scanning electron microscopy (SEM) and scanning electron microscopy backscatter electron imaging (SEMBSE) were also performed. Geologic descriptions were based on field examination of gravel veneers, float, test trenches and pits, outcrops, and textural classification of unconsolidated materials using the Unified Soil Classification System (ASTM, 1992). Attitudes of clasts and larger features were measured using a Brunton compass. No additional laboratory data (e.g. sesquioxide content, physil species) were obtained. We had no reason to doubt their quality as published, nor did we think that additional chemical data would be essential in evaluating alternative natural history scenarios, since interpretation of these data is equivocal (Klevberg and Bandy, 2003b).

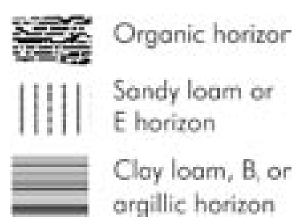
In addition to outcrop-scale investigation, we observed geomorphology and topography. Topography is particularly important in identifying true paleosols. Site orientation has a profound effect on the microclimate and thus vegetation, which in turn are significant factors in soil formation (Klevberg and Bandy, 2003a).

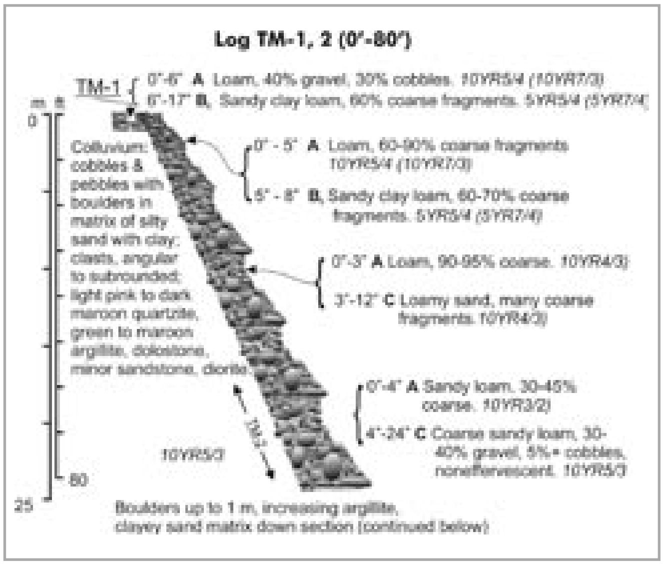
Appendix B: Slope Logs

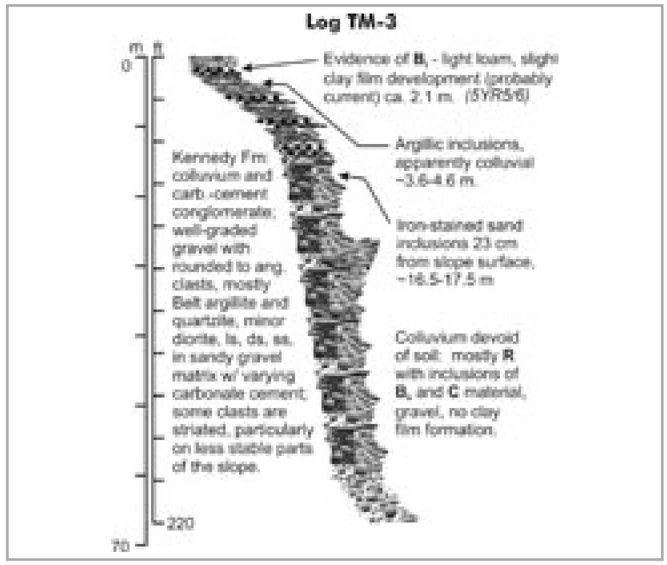
Slope log legend:

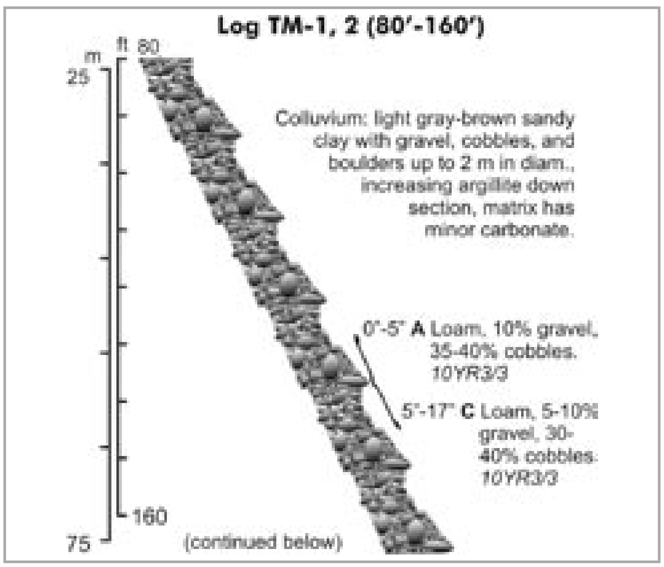


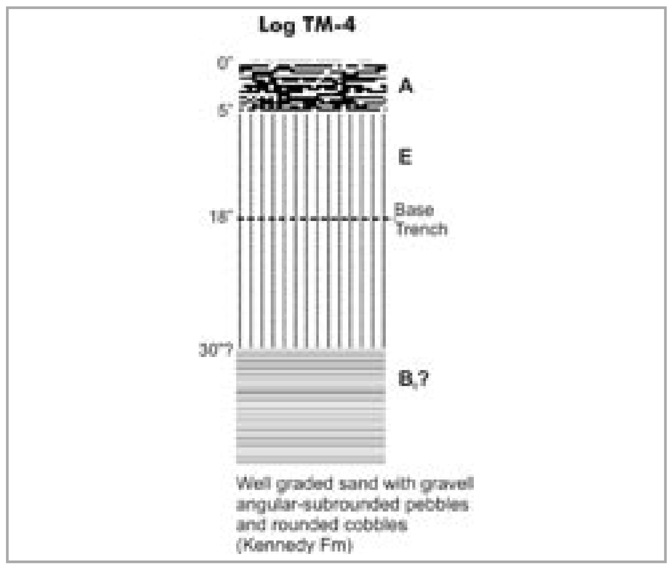
Trench log legend:

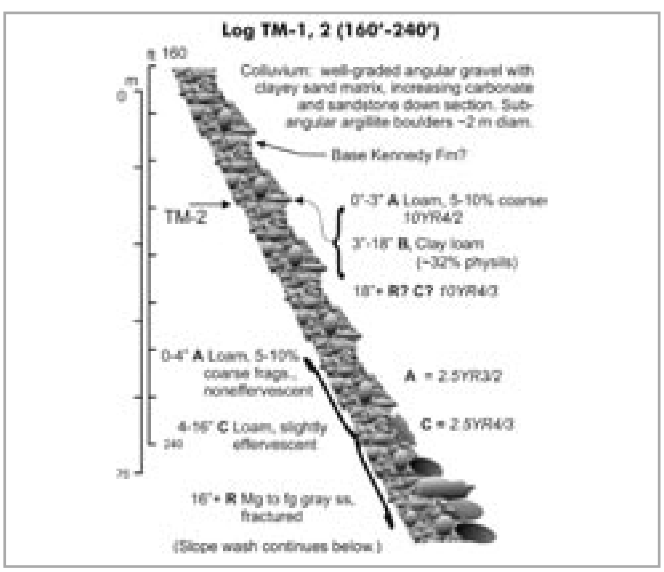


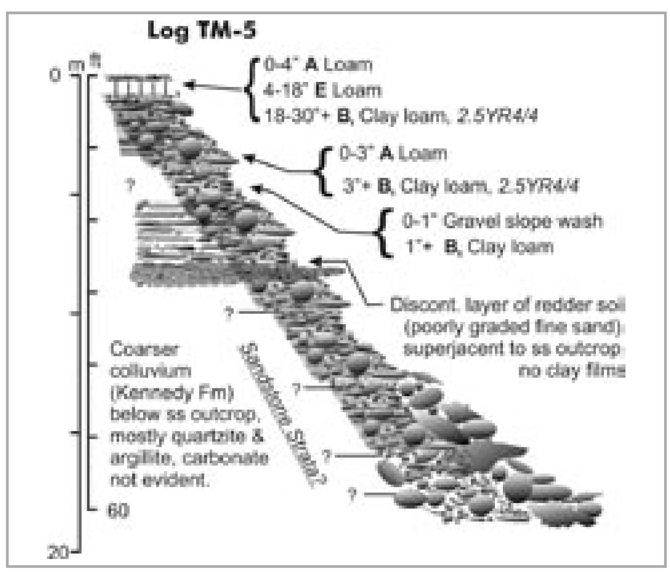

Log TM-1, 2 (0'-80')
TM-1
0"-6" A Loam, 40% gravel, 30% cobbles. 10YR5/4 (10YR7/3)
6"-17" B, Sandy clay loam, 60% coarse fragments. 5YR5/4 (5YR7/4)
m ft
0
Colluvium: cobbles & pebbles with boulders in matrix of silty sand with clay; clasts, angular to subrounded; light pink to dark maroon quartzite, green to maroon argillite, dolostone, minor sandstone, diorite
0" - 5" A Loam, 60-90% coarse fragments 10YR5/4 (10YR7/3)
5" - 8" B, Sandy clay loam, 60-70% coarse fragments. 5YR5/4 (5YR7/4)
0"-3" A Loam, 90-95% coarse. 10YR4/3)
3"-12" C Loamy sand, many coarse fragments. 10YR4/3)
0"-4" A Sandy loam. 30-45% coarse. 10YR3/2)
4"-24" C Coarse sandy loam, 30-40% gravel, 5%+ cobbles, noneffervescent. 10YR5/3
TM-2
10YR5/3
80
25
Boulders up to 1 m, increasing argillite, clayey sand matrix down section (continued below)

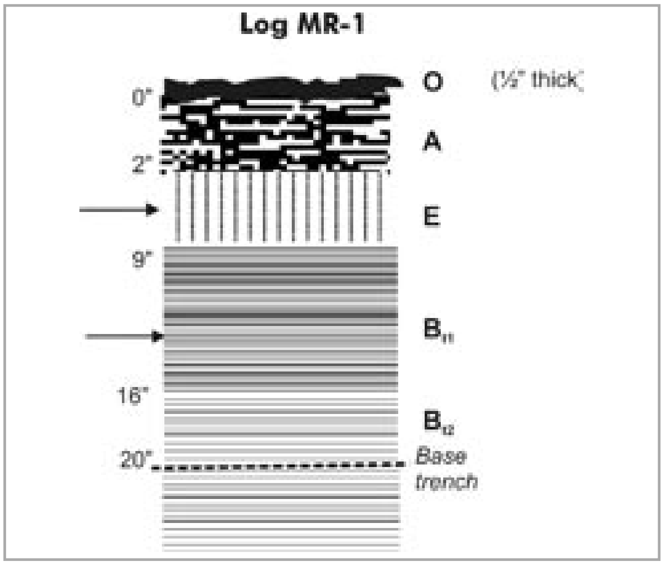

Log TM-3
m ft
0
Evidence of B, - light loam, slight clay film development (probably current) ca. 2.1 m. (5YR5/6)
Argillic inclusions, apparently colluvial ~3.6-4.6 m.
Kennedy Fm: colluvium and carb.-cement conglomerate; well-graded gravel with rounded to ang. clasts, mostly Belt argillite and quartzite, minor diorite, ls, ds, ss, in sandy gravel matrix w/ varying carbonate cement; some clasts are striated, particularly on less stable parts of the slope.
Iron-stained sand inclusions 23 cm from slope surface, ~16.5-17.5 m
Colluvium devoid of soil: mostly R with inclusions of B, and C material, gravel, no clay film formation.
220
70

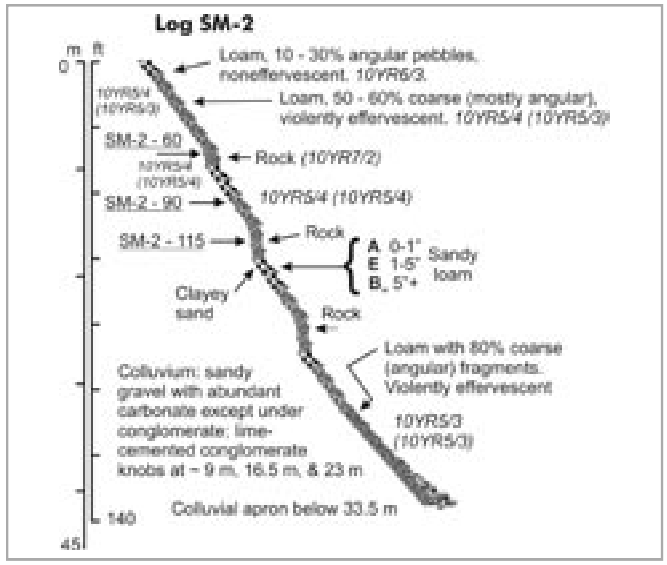

Log TM-1, 2 (80'-160')
m ft 80
25
Colluvium: light gray-brown sandy clay with gravel, cobbles, and boulders up to 2 m in diam., increasing argillite down section, matrix has minor carbonate.
0"-5" A Loam, 10% gravel, 35-40% cobbles. 10YR3/3
5"-17" C Loam, 5-10% gravel, 30-40% cobbles. 10YR3/3
160
75
(continued below)

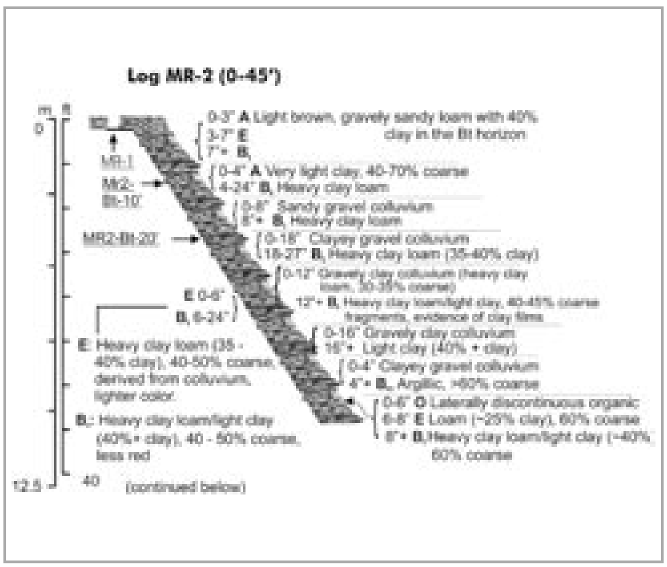

Log TM-4
0"
A
5"
E
18"
Base Trench
30"?
B,?
Well graded sand with gravel angular-subrounded pebbles and rounded cobbles (Kennedy Fm)

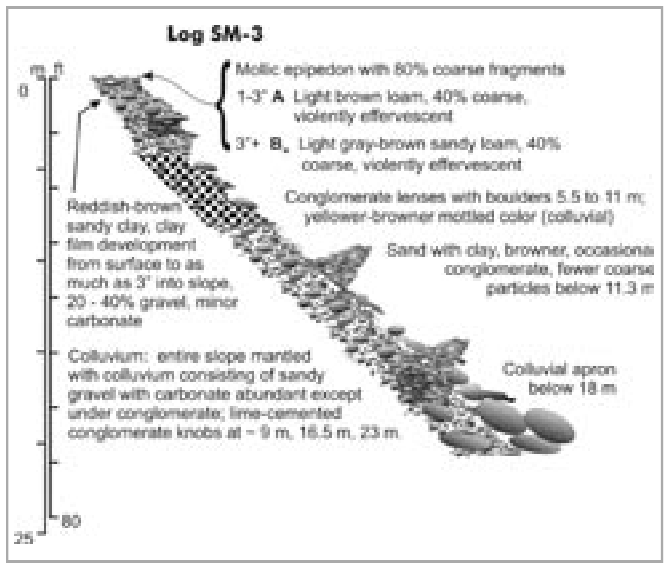

Log TM-1, 2 (160'-240')
ft 160
m
0
Colluvium: well-graded angular gravel with clayey sand matrix, increasing carbonate and sandstone down section. Sub-angular argillite boulders ~2 m diam.
Base Kennedy Fm?
TM-2
0"-3" A Loam, 5-10% coarse 10YR4/2
3"-18" B, Clay loam (~32% physils)
18"+ R? C? 10YR4/3
0-4" A Loam, 5-10% coarse frags., noneffervescent
A = 2.5YR3/2
4-16" C Loam, slightly effervescent
C = 2.5YR4/3
240
75
16"+ R Mg to fg gray ss, fractured
(Slope wash continues below.)

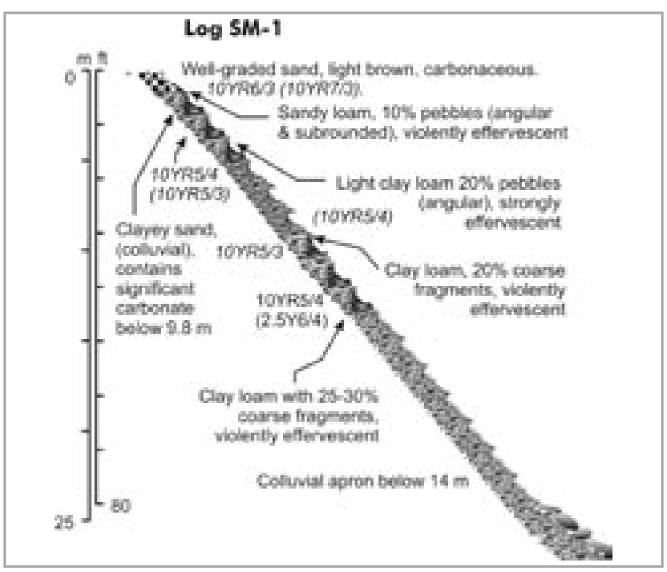

Log TM-5
0 m ft
0-4" A Loam
4-18" E Loam
18-30"+ B, Clay loam, 2.5YR4/4
0-3" A Loam
3"+ B, Clay loam, 2.5YR4/4
0-1" Gravel slope wash
1"+ B, Clay loam
Discont. layer of redder soil (poorly graded fine sand); superjacent to ss outcrop; no clay films
Coarser colluvium (Kennedy Fm) below ss outcrop, mostly quartzite & argillite, carbonate not evident.
Sandstone Strata?
60
20

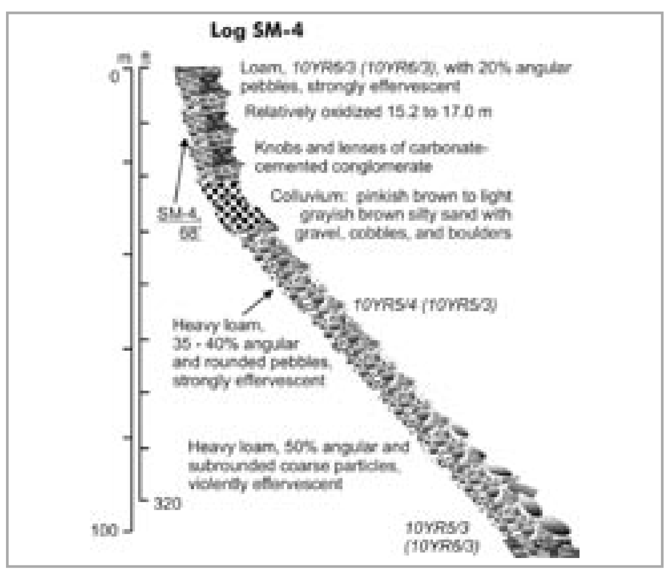

Log MR-1
0"
2"
9"
16"
20"
O
(½" thick
A
E
B_{t1}
B_{t2}
Base trench

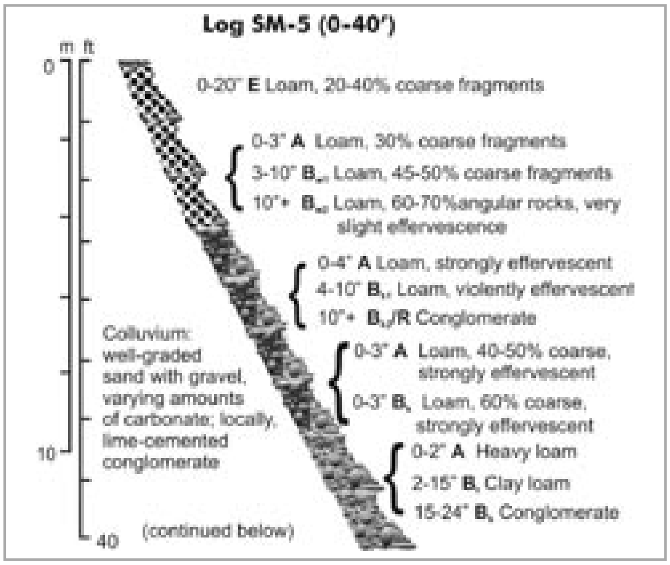

Log SM-2
m ft
0
Loam, 10 - 30% angular pebbles, noneffervescent. 10YR6/3.
10YR5/4 (10YR5/3)
Loam, 50 - 60% coarse (mostly angular), violently effervescent. 10YR5/4 (10YR5/3)
SM-2 - 60
Rock (10YR7/2)
10YR5/4 (10YR5/4)
SM-2 - 90
10YR5/4 (10YR5/4)
SM-2 - 115
Rock
A 0-1"
E 1-5"
B_t 5"+
Sandy loam
Clayey sand
Rock
Loam with 80% coarse (angular) fragments. Violently effervescent
Colluvium: sandy gravel with abundant carbonate except under conglomerate; lime-cemented conglomerate knobs at ~ 9 m, 16.5 m, & 23 m
10YR5/3 (10YR5/3)
Colluvial apron below 33.5 m
140
45

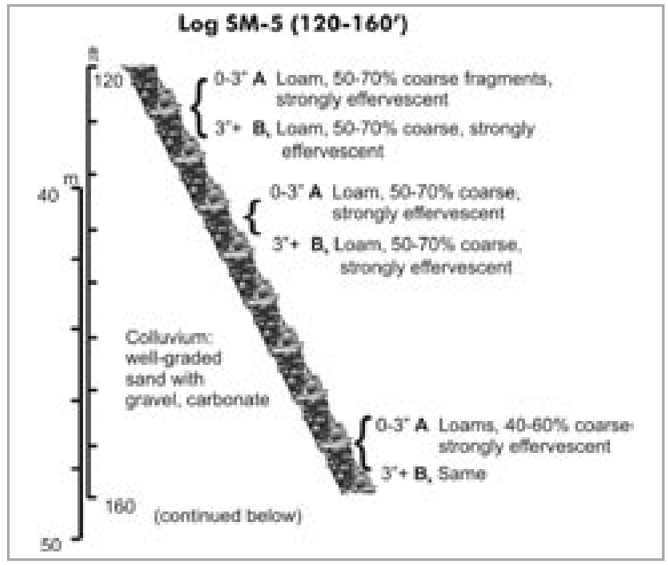

Log MR-2 (0-45')
m ft
0
0-3" A Light brown, gravely sandy loam with 40% clay in the Bt horizon
3-7" E
7"+ B_t
MR-1
0-4" A Very light clay, 40-70% coarse
4-24" B_t Heavy clay loam
Mr2-Bt-10'
0-8" Sandy gravel colluvium
8"+ B_t Heavy clay loam
MR2-Bt-20'
0-18" Clayey gravel colluvium
18-27" B_t Heavy clay loam (35-40% clay)
0-12" Gravely clay colluvium (heavy clay loam, 30-35% coarse)
12"+ B_t Heavy clay loam/light clay, 40-45% coarse fragments, evidence of clay films
E 0-6"
B_t 6-24"
E: Heavy clay loam (35 - 40% clay), 40-50% coarse, derived from colluvium, lighter color.
B_t: Heavy clay loam/light clay (40%+ clay), 40 - 50% coarse, less red
0-16" Gravely clay colluvium
16"+ Light clay (40% + clay)
0-4" Clayey gravel colluvium
4"+ B_t, Argillic, >60% coarse
0-6" O Laterally discontinuous organic
6-8" E Loam (~25% clay), 60% coarse
8"+ B_t Heavy clay loam/light clay (~40%, 60% coarse
12.5
40
(continued below)

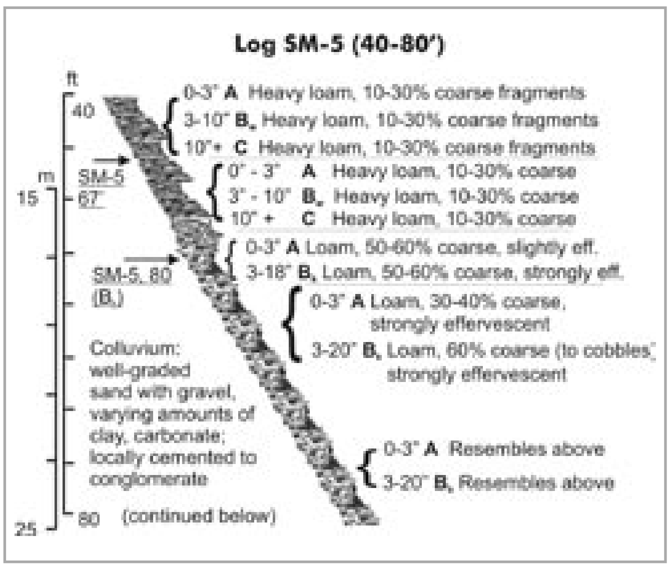

Log SM-3
m ft
0
Mollic epipedon with 80% coarse fragments
1-3" A Light brown loam, 40% coarse, violently effervescent
3"+ B_t Light gray-brown sandy loam, 40% coarse, violently effervescent
Conglomerate lenses with boulders 5.5 to 11 m; yellower-browner mottled color (colluvial)
Reddish-brown sandy clay, clay film development from surface to as much as 3" into slope, 20 - 40% gravel, minor carbonate
Sand with clay, browner, occasional conglomerate, fewer coarse particles below 11.3 m
Colluvium: entire slope mantled with colluvium consisting of sandy gravel with carbonate abundant except under conglomerate; lime-cemented conglomerate knobs at ~ 9 m, 16.5 m, 23 m
Colluvial apron below 18 m
80
25

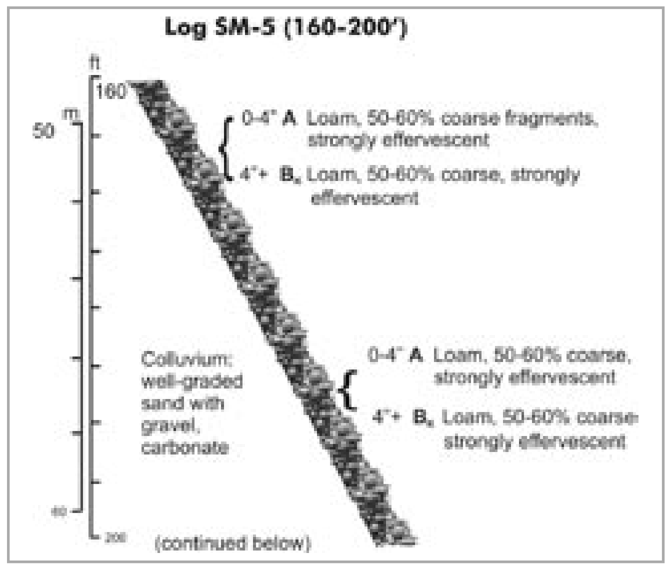

Log SM-1
m ft
0
Well-graded sand, light brown, carbonaceous. 10YR6/3 (10YR7/3).
Sandy loam, 10% pebbles (angular & subrounded), violently effervescent
10YR5/4 (10YR5/3)
Light clay loam 20% pebbles (angular), strongly effervescent
(10YR5/4)
Clayey sand, (colluvial), contains significant carbonate below 9.8 m
10YR5/3
Clay loam, 20% coarse fragments, violently effervescent
10YR5/4 (2.5Y6/4)
Clay loam with 25-30% coarse fragments, violently effervescent
Colluvial apron below 14 m
80
25

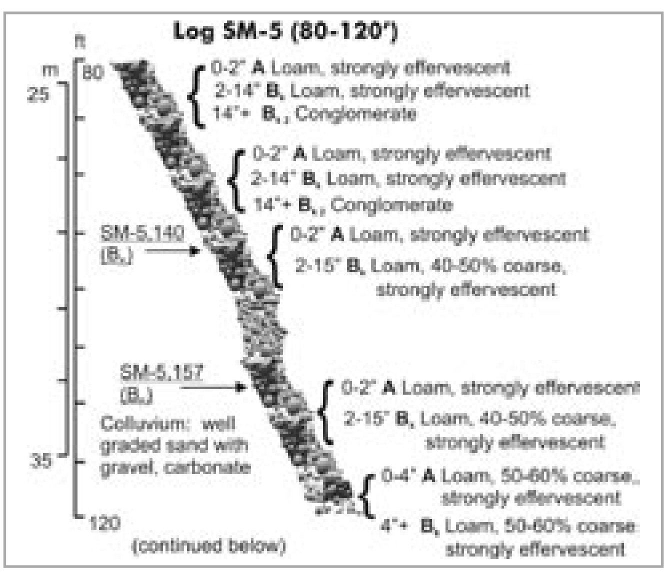

Log SM-4
m ft
0
Loam, 10YR6/3 (10YR6/3), with 20% angular pebbles, strongly effervescent
Relatively oxidized 15.2 to 17.0 m
Knobs and lenses of carbonate-cemented conglomerate
SM-4, 68'
Colluvium: pinkish brown to light grayish brown silty sand with gravel, cobbles, and boulders
10YR5/4 (10YR5/3)
Heavy loam, 35 - 40% angular and rounded pebbles, strongly effervescent
Heavy loam, 50% angular and subrounded coarse particles, violently effervescent
320
100
10YR5/3 (10YR6/3)

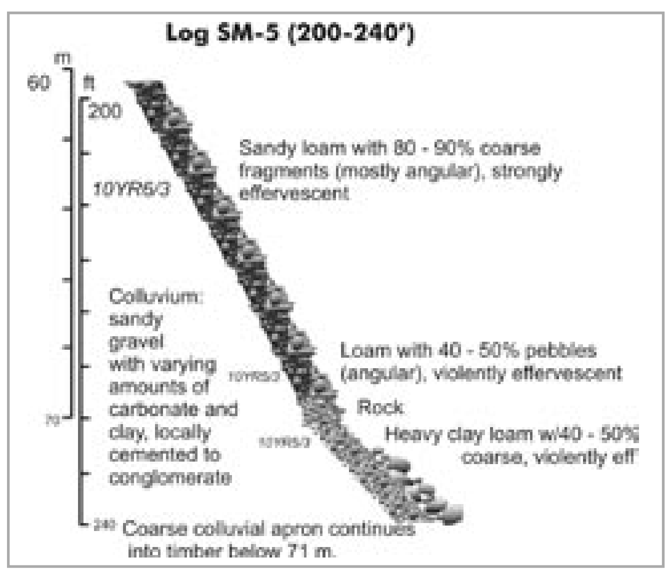

Log SM-5 (0-40')
m ft
0
0-20" E Loam, 20-40% coarse fragments
0-3" A Loam, 30% coarse fragments
3-10" B Loam, 45-50% coarse fragments
10"+ B Loam, 60-70%angular rocks, very slight effervescence
0-4" A Loam, strongly effervescent
4-10" B Loam, violently effervescent
10"+ B/R Conglomerate
Colluvium: well-graded sand with gravel, varying amounts of carbonate; locally, lime-cemented conglomerate
0-3" A Loam, 40-50% coarse, strongly effervescent
0-3" B Loam, 60% coarse, strongly effervescent
0-2" A Heavy loam
2-15" B Clay loam
15-24" B Conglomerate
10
40 (continued below)

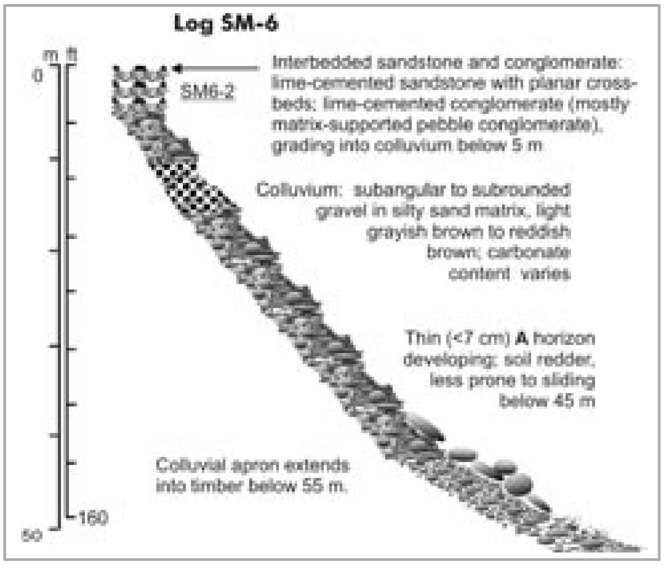

Log SM-5 (120-160')
ft
120
0-3" A Loam, 50-70% coarse fragments, strongly effervescent
3"+ B Loam, 50-70% coarse, strongly effervescent
40 m
0-3" A Loam, 50-70% coarse, strongly effervescent
3"+ B Loam, 50-70% coarse, strongly effervescent
Colluvium: well-graded sand with gravel, carbonate
0-3" A Loams, 40-60% coarse strongly effervescent
3"+ B Same
160 (continued below)
50

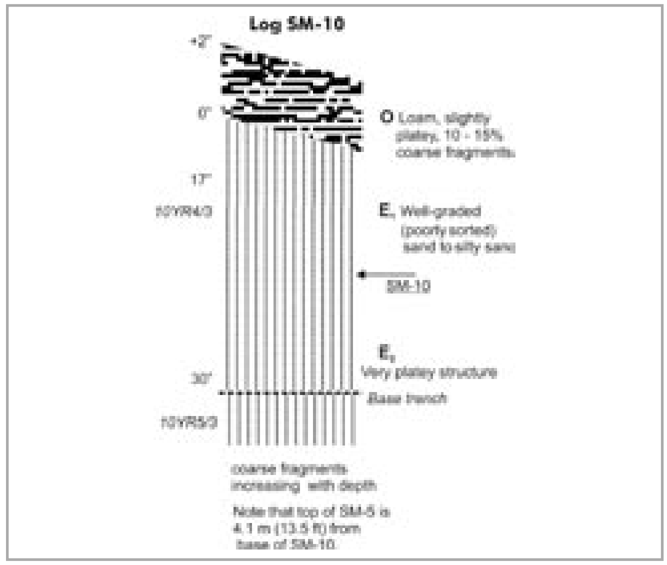

Log SM-5 (40-80')
ft
40
0-3" A Heavy loam, 10-30% coarse fragments
3-10" B Heavy loam, 10-30% coarse fragments
10"+ C Heavy loam, 10-30% coarse fragments
m SM-5 67'
15
0" - 3" A Heavy loam, 10-30% coarse
3" - 10" B Heavy loam, 10-30% coarse
10" + C Heavy loam, 10-30% coarse
0-3" A Loam, 50-60% coarse, slightly eff.
3-18" B Loam, 50-60% coarse, strongly eff.
SM-5, 80 (B)
0-3" A Loam, 30-40% coarse, strongly effervescent
3-20" B Loam, 60% coarse (to cobbles) strongly effervescent
Colluvium: well-graded sand with gravel, varying amounts of clay, carbonate; locally cemented to conglomerate
0-3" A Resembles above
3-20" B Resembles above
25 80 (continued below)

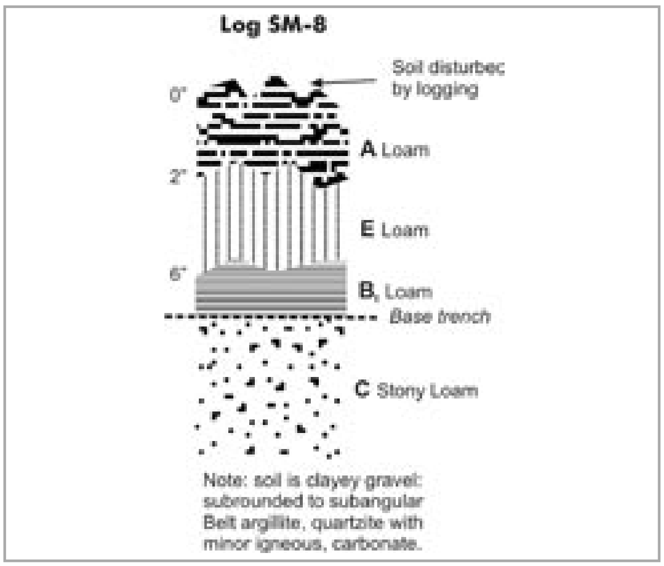

Log SM-5 (160-200')
ft
160
50 m
0-4" A Loam, 50-60% coarse fragments, strongly effervescent
4"+ B Loam, 50-60% coarse, strongly effervescent
Colluvium: well-graded sand with gravel, carbonate
0-4" A Loam, 50-60% coarse, strongly effervescent
4"+ B Loam, 50-60% coarse strongly effervescent
(continued below)

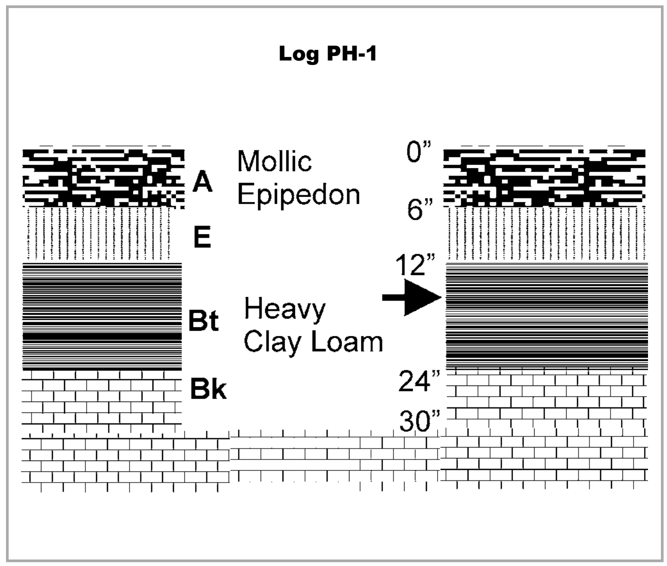

Log SM-5 (80-120')
ft
m 80
25
0-2" A Loam, strongly effervescent
2-14" B Loam, strongly effervescent
14"+ B Conglomerate
0-2" A Loam, strongly effervescent
2-14" B Loam, strongly effervescent
14"+ B Conglomerate
SM-5,140 (B)
0-2" A Loam, strongly effervescent
2-15" B Loam, 40-50% coarse, strongly effervescent
SM-5,157 (B)
Colluvium: well graded sand with gravel, carbonate
0-2" A Loam, strongly effervescent
2-15" B Loam, 40-50% coarse, strongly effervescent
35
0-4" A Loam, 50-60% coarse, strongly effervescent
4"+ B Loam, 50-60% coarse strongly effervescent
120
(continued below)

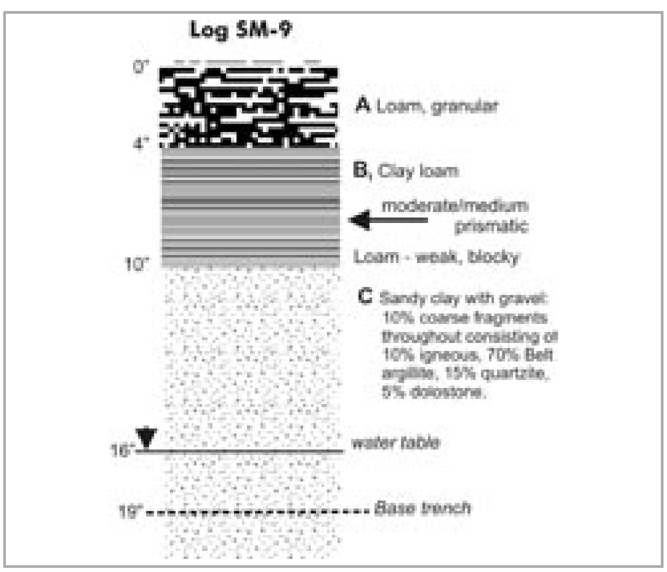

Log SM-5 (200-240')
m
60 ft
200
10YR5/3
Sandy loam with 80 - 90% coarse fragments (mostly angular), strongly effervescent
Colluvium: sandy gravel with varying amounts of carbonate and clay, locally cemented to conglomerate
Loam with 40 - 50% pebbles (angular), violently effervescent
Rock
Heavy clay loam w/40 - 50% coarse, violently eff
240 Coarse colluvial apron continues into timber below 71 m.

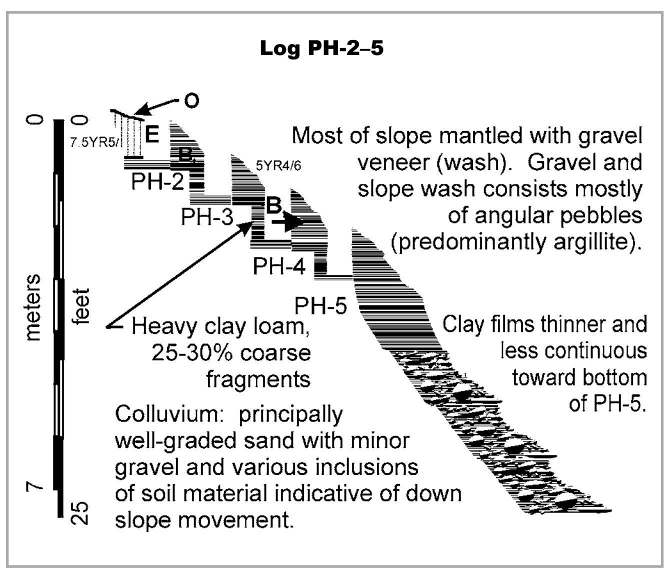

Log SM-6
m ft
0
SM6-2
Interbedded sandstone and conglomerate: lime-cemented sandstone with planar cross-beds; lime-cemented conglomerate (mostly matrix-supported pebble conglomerate), grading into colluvium below 5 m
Colluvium: subangular to subrounded gravel in silty sand matrix, light grayish brown to reddish brown; carbonate content varies
Thin (<7 cm) A horizon developing; soil redder, less prone to sliding below 45 m
Colluvial apron extends into timber below 55 m.
160
50

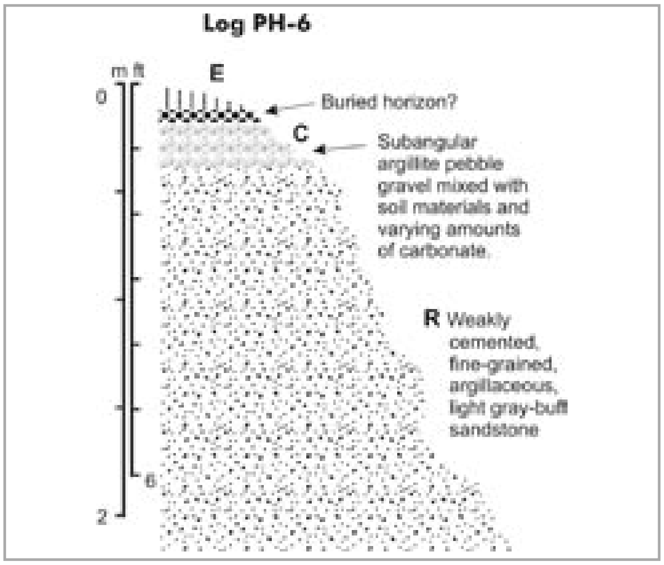

Log SM-10
+2"
0"
O Loam, slightly platey, 10 - 15% coarse fragments
17"
10YR4/3
E, Well-graded (poorly sorted) sand to silty sand
SM-10
E
Very platey structure
30"
Base trench
10YR5/3
coarse fragments increasing with depth
Note that top of SM-5 is 4.1 m (13.5 ft) from base of SM-10.

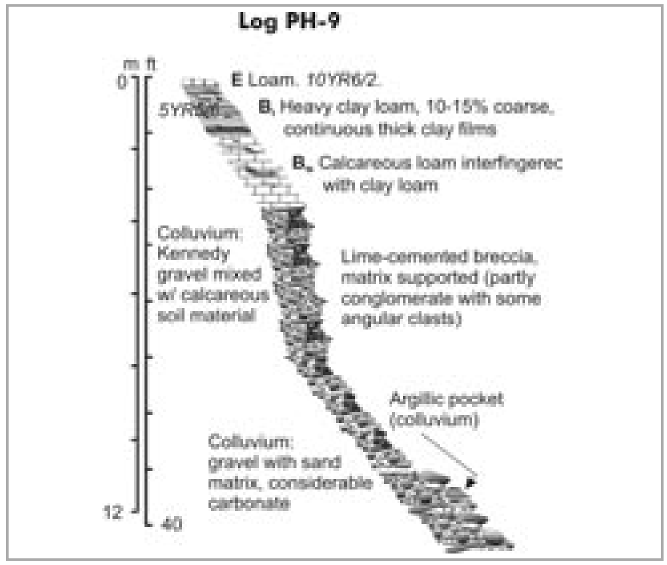

Log SM-8
Soil disturbed by logging
0"
A Loam
2"
E Loam
6"
B Loam
Base trench
C Stony Loam
Note: soil is clayey gravel: subrounded to subangular Belt argillite, quartzite with minor igneous, carbonate.

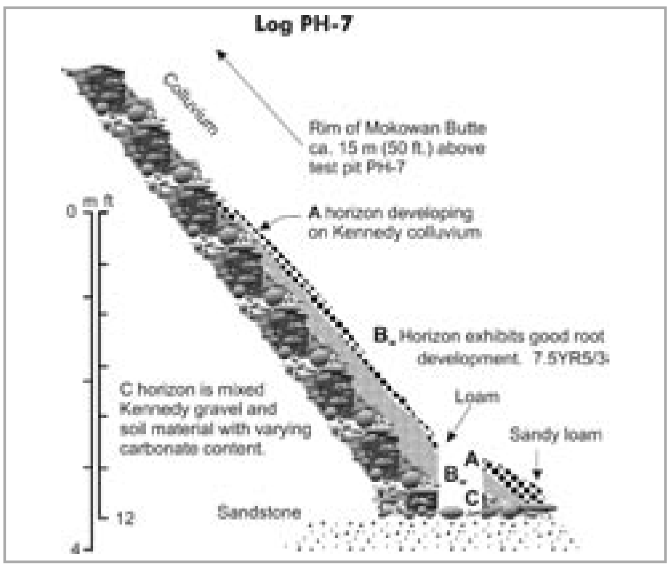

Log PH-1
A
Mollic Epipedon
E
Bt
Heavy Clay Loam
Bk
0"
6"
12"
24"
30"

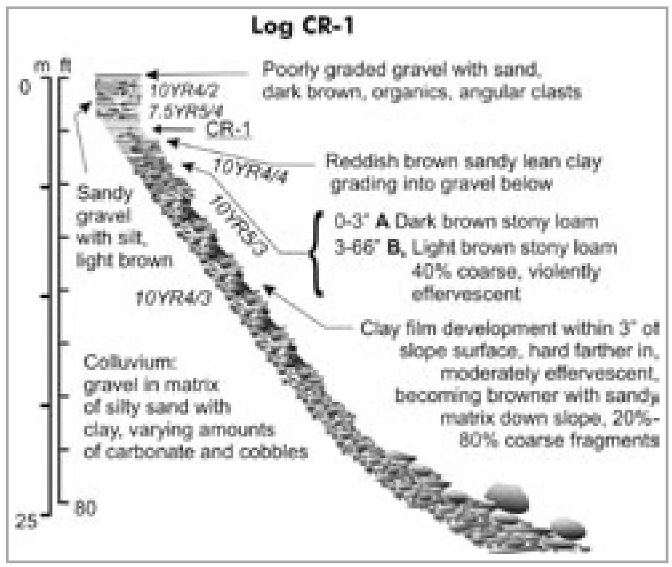

Log SM-9
0"
A Loam, granular
4"
B Clay loam
moderate/medium prismatic
Loam - weak, blocky
10"
C Sandy clay with gravel: 10% coarse fragments throughout consisting of 10% igneous, 70% Belt argillite, 15% quartzite, 5% dolostone.
16"
water table
19"
Base trench

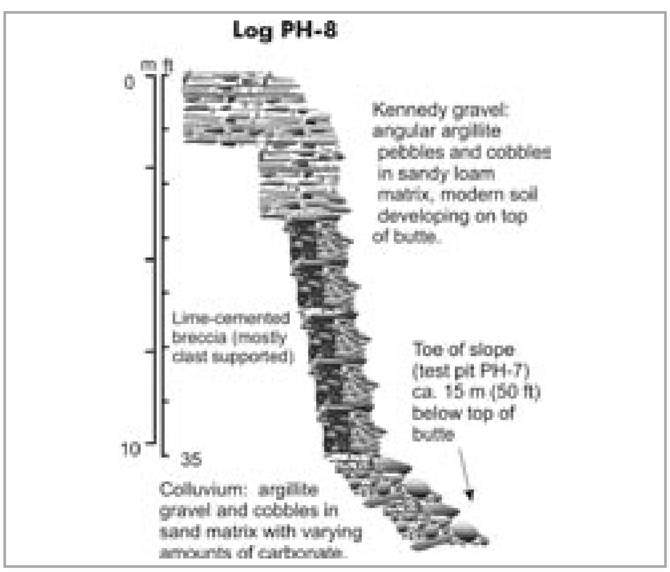

Log PH-2–5
meters
0
7
feet
0
25
O
7.5YR5/
E
B
PH-2
5YR4/6
PH-3
B
PH-4
PH-5
Most of slope mantled with gravel veneer (wash). Gravel and slope wash consists mostly of angular pebbles (predominantly argillite).
Heavy clay loam, 25-30% coarse fragments
Clay films thinner and less continuous toward bottom of PH-5.
Colluvium: principally well-graded sand with minor gravel and various inclusions of soil material indicative of down slope movement.


Log PH-6
m ft
0
6
2
E
Buried horizon?
C
Subangular argillite pebble gravel mixed with soil materials and varying amounts of carbonate.
R Weakly cemented, fine-grained, argillaceous, light gray-buff sandstone


Log PH-9
m ft
0
12
40
E Loam. 10YR6/2.
5YR
Bt Heavy clay loam, 10-15% coarse, continuous thick clay films
Bk Calcareous loam interfingered with clay loam
Colluvium: Kennedy gravel mixed w/ calcareous soil material
Lime-cemented breccia, matrix supported (partly conglomerate with some angular clasts)
Argillic pocket (colluvium)
Colluvium: gravel with sand matrix, considerable carbonate


Log PH-7
Colluvium
Rim of Mokowan Butte ca. 15 m (50 ft.) above test pit PH-7
m ft
0
12
4
A horizon developing on Kennedy colluvium
Bk Horizon exhibits good root development. 7.5YR5/3
C horizon is mixed Kennedy gravel and soil material with varying carbonate content.
Loam
Sandy loam
A
Bk
C
Sandstone


Log CR-1
m ft
0
25
80
10YR4/2
7.5YR5/4
Poorly graded gravel with sand, dark brown, organics, angular clasts
CR-1
10YR4/4
Reddish brown sandy lean clay grading into gravel below
10YR5/3
Sandy gravel with silt, light brown
0-3" A Dark brown stony loam
3-66" Bk Light brown stony loam 40% coarse, violently effervescent
10YR4/3
Clay film development within 3" of slope surface, hard farther in, moderately effervescent, becoming browner with sandy matrix down slope, 20%-80% coarse fragments
Colluvium: gravel in matrix of silty sand with clay, varying amounts of carbonate and cobbles


Log PH-8
m ft
0
10
35
Kennedy gravel: angular argillite pebbles and cobbles in sandy loam matrix, modern soil developing on top of butte.
Lime-cemented breccia (mostly clast supported)
Toe of slope (test pit PH-7) ca. 15 m (50 ft) below top of butte
Colluvium: argillite gravel and cobbles in sand matrix with varying amounts of carbonate.

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. Finding some of the sites and the individuals who assisted us was clearly providential. *Deum laudamus* (Proverbs 16:9).

Glossary

alfisol: the soil order characterized by a subsurface diagnostic horizon in which silicate clay has accumulated by illuviation; this clay-rich horizon is only moderately leached, and its cation exchange capacity is more than 35% saturated with base-forming cations. Alfisols formed under a forest canopy typically have a leached, light-colored E horizon subjacent to the A horizon.

argillic: said of a soil horizon high in argillaceous matter, typically a B_t horizon or illuvial horizon.

colluvial: dominated by earth material transported primarily by gravity.

eluvial: said of a soil horizon (E horizon) characterized by leaching of physils, bases, cations, and other relatively transportable materials, eventually leaving a horizon dominated by quartz and hydrous aluminosilicates: minerals consisting primarily of aluminum, silicon, and oxygen. Physils or clay minerals are aluminosilicates. Hydrous aluminosilicates are the most stable minerals, most resistant to leaching and weathering, in the surficial environment and thus dominate highly leached or weathered soil horizons.

entisol: the soil order characterized by nascent soil development without distinct development of soil horizons.

interfluve: a topographic high of lesser or greater relief between two drainages.

natural history: as used in this paper, *natural history* refers to the history of nature or earth history.

paleopedology: the study of paleosols.

paleosol: a soil horizon preserved through burial or other processes beyond the reach of current soil forming processes.

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TJ: *Technical Journal*

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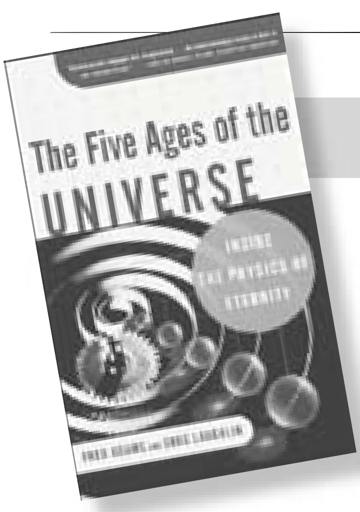

Book Review

The Five Ages of the Universe

by Fred Adams and Greg Laughlin

Touchtone by Simon & Schuster, New York, 1999, 251 pages, $14.00.

The authors are astrophysicists and active members of the Big Bang cosmology establishment with long lists of research publications. Adams is professor of physics at the University of Michigan and Laughlin is a researcher at Lick Observatory. Their book purports to be a detailed biography of the universe from its moment of beginning over 10 billion years ago until its projected death in the distant future. According to the authors, "The Big Bang theory