# Drifting Interpretations of the Kennedy Gravel

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## Abstract

**Poorly stratified deposits of coarse gravel cover Kennedy Ridge and several other planation surfaces east of Glacier National Park in north-central Montana, U.S.A., and adjacent Alberta, Canada. These gravel deposits, commonly called "Kennedy drift" and classified as glacial drift, are composed primarily of lithologies identical to Belt Supergroup rocks observed in the Rocky Mountains immediately to the west. In recent years, the Kennedy gravel has been described as a series of tills containing paleosols documenting several glacial and interglacial episodes over the course of approximately two million years. Fabric measurements and paleomagnetic surveys have been taken and the evidence interpreted in support of the multiple till interpretation. However, these data are far from unequivocal, and alternative genetic interpretations may be superior to the multiple till interpretation.**

## Introduction

The Kennedy "drift" or Kennedy Formation is a discontinuous body of diamict[1], generally poorly sorted (well graded) gravel, that caps the relatively flat tops of high ridges east of Glacier and Waterton National Parks in Montana and Alberta (Figure 1). While the dominant lithology is quartzite (high grade, various colors and patterns, mostly identifiable as Belt Supergroup), argillite (mostly green and maroon Belt Supergroup) is common. Diorite and carbonate clasts (mostly dolostone) constitute up to about ten percent of the total mass, while subjacent lithologies are poorly represented. Although sometimes obscured, subjacent lithologies do outcrop at or near all of the study sites. These outcrops appear properly mapped (Cannon, 1996, Sheet 2) and consist of weak sandstones and mudrocks. The quartzites, argillites, carbonates, and diorite all outcrop in the rugged mountains of Glacier Park to the west. This implies transport, and the mystery then becomes how and when that transport occurred.

Genetic interpretations of the deposit by establishment geologists have evolved over the past century. Recently, the Kennedy Formation has been interpreted as a stratigraphically significant sequence of glacial tills and paleosols. Magnetostratigraphy and fabric analyses have been used to develop a stratigraphic column. "Paleosol" characteristics have been used to infer paleogeographic and paleoclimatologic conditions. Some believe portions of the Kennedy Formation represent "…some of the oldest glacial deposits in North America"(Karlstrom, 2000, p. 1496).

The climate of the area is quite variable with warm, short summers and long, cold winters. The average temperature is about 4°C (Horberg, 1956, pp. 202–203). Annual precipitation is about 75 cm (30 in), half of which falls as snow. It is extremely windy east of Glacier Park, especially on the ridges where the Kennedy "drift" is located. Winds in excess

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[1] Important terms are included in the glossary near the end of this paper.

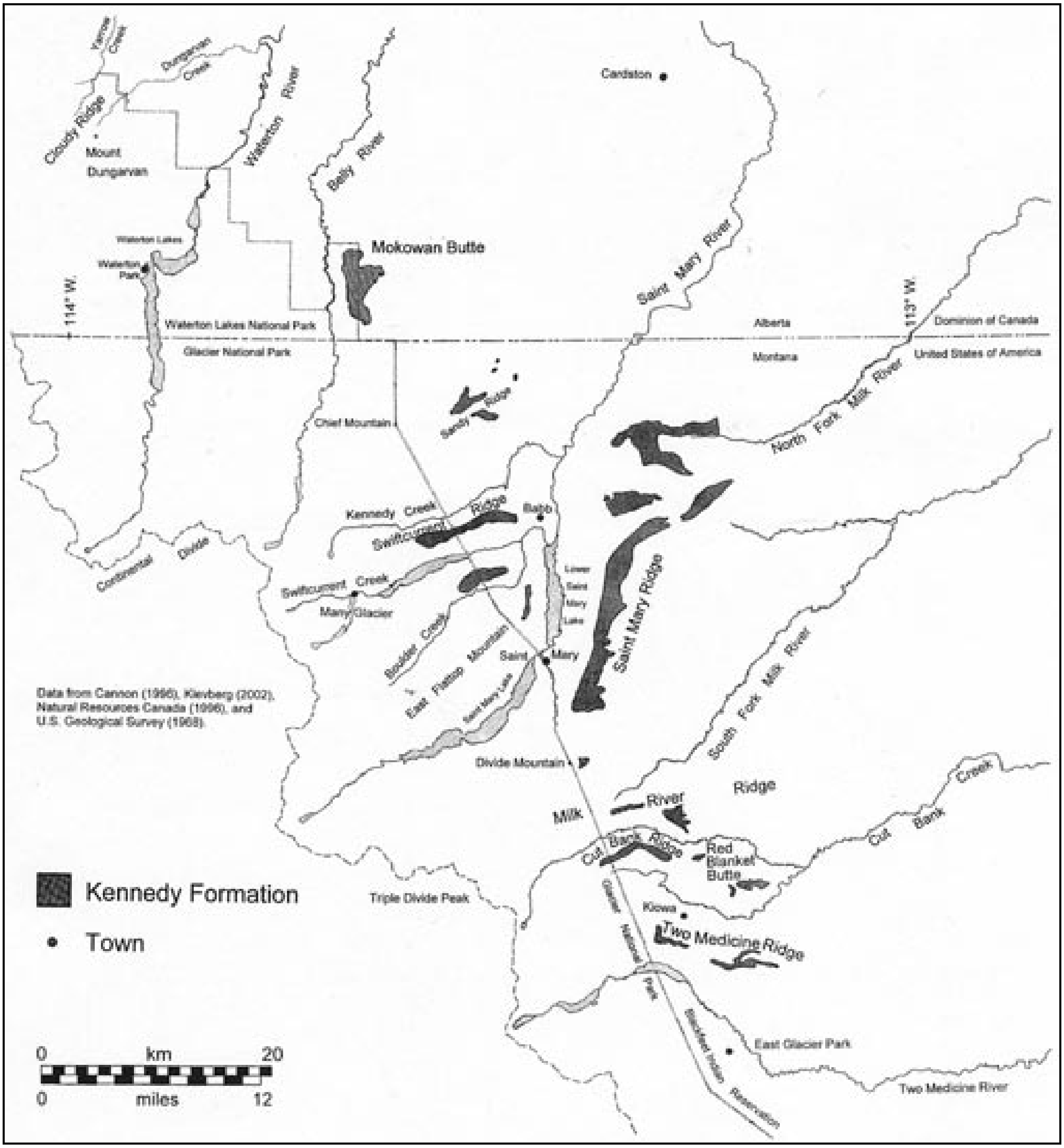


**Figure 1. Map of study area showing Kennedy gravel distribution.**

of 50 m/s (110 mph) occur every winter (Oard, 1993).

The Kennedy "drift" caps the western edge of remnants of planation surfaces that begin just east of Glacier and Waterton National Parks and continue eastward for hundreds of kilometers (Oard and Klevberg, 1998, p. 422, Figure 1). A planation surface or erosion surface is defined as: "A land surface shaped and subdued by the action of erosion, especially by running water. The term is generally applied to a level or nearly level surface" (Bates and Jackson, 1984, p. 170). The reason water is included in this definition is


**Figure 2. Striated clasts, Two Medicine Ridge.**

because the planation surface is usually capped by rounded or subrounded rocks indicative of water action. Thus, it is apparently the action of water that planes the surface. It is likely that the original planation surface was widespread east of the parks, the original planation surface having been dissected and leaving isolated, generally flat-topped ridges (Alden, 1932). The summits are 185 to 490 m (600 to 1,600 ft) above present drainage in the study area (Horberg, 1956, p. 204).

The gravel cap on the planation surfaces east of the park was at first considered fluvial by Bailey Willis (1902). Based on striated rocks (Figure 2), Alden (1932, pp. 31–40) believed that the gravel cap was laid down by glaciers debouching out of Glacier Park. He called the gravel capping the planation surfaces the Kennedy drift, *drift* being a term for any glacial deposit[2]. Most workers since Alden have considered the gravels glacigenic. Horberg (1956) saw what he thought were deep weathering profiles in the Kennedy "drift." Such a deep weathering profile is generally thought to have developed over a long period of time. So Horberg (1956) dated the Kennedy "drift" as from the Yarmouth interglacial stage, within the now-defunct four-ice-age scheme of the Pleistocene. The Yarmouth interglacial stage is the middle of the three postulated interglacials and was considered about 440,000 years old within the uniformitarian time scale. He saw no evidence of a warmer, more humid climate than at present.

Richmond (1957) later recognized what he thought were three buried paleosols within the Kennedy "drift" and so subdivided the gravel into three tills. Based on normal paleomagnetism, he considered all three tills younger than 0.78 Ma (Karlstrom, 2000, p. 1496). Karlstrom (1982; 1987; 1988; 1991; 2000) has since revised Richmond's chronology, recognizing gravel of "reversed paleomagnetism." He has postulated at least seven superposed till/paleosol units dated as old or older than about 2 million years. He believes it is possible that the oldest "till" on Mokowan Butte is 3.7 to 2.7 million years old (Karlstrom, 2000, p. 1505). Whereas Horberg could see no evidence of a warmer climate in the "paleosols," Karlstrom (1991) concludes the paleosols represent interglacial periods with a mean annual temperature and precipitation at least 6–8$^{\circ}$C warmer and 40 cm (16 in) wetter than today.

## Geomorphology

The planation surfaces just east of Glacier and Waterton National Parks have been correlated by William Alden (1932, p. 31) to the Flaxville Plain (planation surface) in north central and northeast Montana. While Alden may not have been first to recognize these plateaus as planar erosion surfaces, he was apparently the first to perform a systematic, published study of them. The Flaxville Plain is Alden's second from the highest planation surface (and the first he encountered) in northern Montana and adjacent Canada. He called it the Number 1 bench. He followed this planation surface to the Rocky Mountains, showing that the accordant summits defined a roughly exponential profile clear to the Front Range. The highest planation surface, the Cypress Hills of southeastern Alberta and southwestern Saskatchewan (Klevberg and Oard, 1998; Oard and Klevberg, 1998), since it was discovered later, was named the Number 0 bench. Alden also described two lower planation surfaces in the region: the Numbers 2 and 3 benches. The Number 2 bench includes the 120-km-long Fairfield Bench north of Great Falls, Montana, which stretches from just east of the Rocky Mountain Front to Fort Benton. The eastern end of the Fairfield Bench is the area that especially inspired William Morris Davis to develop his idea of the "cycle of erosion" or "geographical cycle" in 1883 that became so popular for more than half a century (Chorley, Beckinsale, and Dunn, 1973, p. 160). Davis's scheme has mostly been rejected since the 1960s, although it still appears in some textbooks and college courses.

The Cypress Hills and Flaxville planation surfaces are especially noteworthy for their cap of well-rounded quartzite cobbles and boulders. Quartzite does not outcrop on the high plains. Based on paleocurrent indicators, this coarse

[2] The term is genetic; thus, it is historiographic, not scientific. That genetic definitions belong to the realm of history and not science has been amply demonstrated elsewhere (Adler, 1965; Klevberg, 1999; 2000a; 2000b; Reed, 2000; 2001).

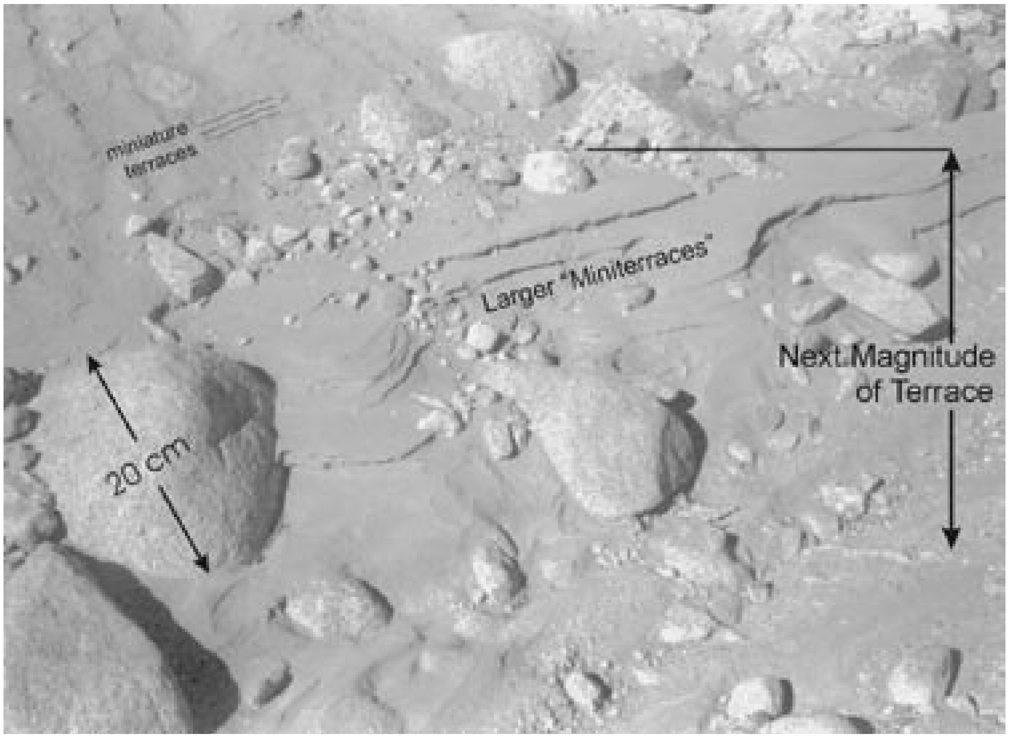


**Figure 3. Terrace formation at various scales in a dry wash (Fish Creek Wash, Anza Desert, Southern California). The "miniterraces" occur in the sides of other "miniterraces" roughly an order of magnitude larger.**

gravel originated from the Rocky Mountains or central Idaho (Oard and Klevberg, 1998). In the western and central Cypress Hills, the cobbles and boulders are mostly massive and about 30 m (100 ft) thick. The rocks have been transported distances of at least 700 km (400 mi) (Oard and Klevberg, 1998). Percussion marks, semicircular cracks on the rock surface, are found on at least half of the rocks in the Cypress Hills. These percussion marks likely represent the banging of rocks against each other while falling from suspension in a fast, turbulent water flow[3]. Based on open flow channel equations, the minimum velocity was estimated at 30 m/s (65 mph) and the minimum depth of flow at 55 m (180 ft) deep (Klevberg and Oard, 1998). Since the Cypress Hills average about 15 km (9 mi) wide, the gravel cap represents a current at least 15 km wide and 55 m deep rushing off the Rocky Mountains. Based on concordant and similar erosional remnants north and south, it seems likely the Cypress Hills planation surface was continuous north and south; the current, therefore, would have been hundreds of kilometers wide. Currents traveling over 30 m/s are very erosive, so it is reasonable that the original huge area of the Cypress Hills planation surface was quickly eroded, leaving the Cypress Hills as a prominent erosional remnant. A similar sequence can be postulated for the lower three planation surface remnants.

Multiple planation surfaces lead naturally to the inference of multiple events. However, we have become increasingly aware of contrary evidence to this intuitive bias (which one of us previously shared). Continuous drawdown in reservoirs and rivers frequently produces distinct terraces (Figure 3) (Williams, 1988). Benches, even when distinct over long distances, are observed to ramp into each other at scattered locations (e.g. Judith Basin, Judith Mountains, Sweetgrass Hills). Thus, we recognize that the inference of multiple events is subject to question in tectonically inactive eastern Montana. Tectonic explanations in the Kennedy gravel study area are possible, though most faults are inferred stratigraphically (Cannon, 1996, Sheet 2), and the exponential concavity of the summit planation surfaces often results in concordance farther east from the mountain front.

## Fabric Analysis

Identification of fabrics in clastic sediments is a fundamental part of paleocurrent analysis (Potter and Pettijohn, 1977). These fabrics are often the basis for inferring the degree of energy in the depositional environment. However, interpretation of these fabrics can be equivocal. Plane beds, for example, can develop at very low current speeds and at very high speeds, but not at intermediate speeds (Julien, 1995, pp. 138–146). Diamict, with a very poorly developed fabric, can result from glacial, mass wasting, and turbidity current

[3] One of us is doing additional research on formation of percussion marks. It is possible (if unlikely) that percussion marks can be formed by cavitation but, if anything, this would probably imply even stronger currents than those estimated using traditional paleohydraulic assumptions.

processes (Oard, 1997). Subtle differences can sometimes be discerned using macroscopic, microscopic, and statistical analyses that can suggest that one possible depositional mechanism is more likely than others.

Karlstrom (2000) claims that fabrics in the Kennedy Formation are indicative of a glacial origin for the deposit. He collected long axis (a-axis) orientation data for 50 prolate pebbles per "paleosol" at 17 locations on Two Medicine Ridge, Milk River Ridge, Saint Mary Ridge, Mokowan Butte, and Cloudy Ridge (Figure 1). He concluded that the fabrics could generally correspond to what might be expected for basal till, deformed or undeformed lodgement till, or glacigenic sediment gravity flows, but argued for a glacial till explanation. He rejected the sediment flow explanation: "Thus, fabric and sedimentological properties, as well as the distance of the Mokowan Butte and Saint Mary Ridge sections from the nearest mountain (5–10 km), seem to rule out a strictly colluvial origin. Mudflow deposits, by contrast, could be expected to include fewer lithologies and more angular clasts and to be less extensive horizontally and vertically" (p. 1505). We find his arguments most unpersuasive for the following reasons:

- The sampling program was very limited and highly selective.
- The eigenvalue ranges for various depositional fabrics are not very distinct.
- Eigenvalue ranges for nonglacial depositional fabrics were not used for comparison.
- Karlstrom's dismissal of gravity flow mechanisms exhibits a profound uniformitarian bias.

Karlstrom's method is derived from previous work by others (Dowdeswell and Sharp, 1986; Hart, 1994) that includes modern and historic glacial deposits in Iceland and elsewhere. This is understandable, not only from practical considerations, but also because of his hypothesis that these deposits represent till (or at least drift). Nonetheless, to reach this conclusions, Karlstrom's sampling program appears somewhat arbitrary and possibly at variance with accepted statistical analyses (ASTM, 1993; Koch and Link, 1980), not least because of the single data set collected from each assumed paleosol. Although the eigenvector method of determining preferred orientation and the strength of this development is very useful, much more information is needed to determine the extent to which these results are applicable to the deposit as a whole or inferred trends across the deposit. For nonglacial deposits, the c-axis orientation of oblate pebbles could be expected to provide more information than the a-axis orientation of prolate pebbles, and the oblate clasts should, at a minimum, have their a-axis orientations compared with those of the prolate clasts. These data should be considered within the context of a grain-size distribution, and variations of the grain-size distribution should be investigated vertically and laterally. Angularity and aspect ratio would also bear investigation, and a large number and diversity of historic deposits should be examined to provide control. To do justice to the type of statistical analysis attempted by Karlstrom and others would require an enormously labor intensive data acquisition effort to determine clast orientation for all sizes larger than granules in an adequate sample population. "Adequate sample population" means enough data to generate confidence intervals "tighter" than the relatively small differences observed between different fabrics such as those studied by Dowdeswell and Sharp (1986) and Lawson (1981). This must be done meter-by-meter vertically and horizontally across each scarp, avoiding the ubiquitous effects of colluvial (down slope) movement. Photogrammetric methods might be useful, but the data are needed in three dimensions, probably requiring at least partial excavation. It would be a daunting task for the most statistically minded

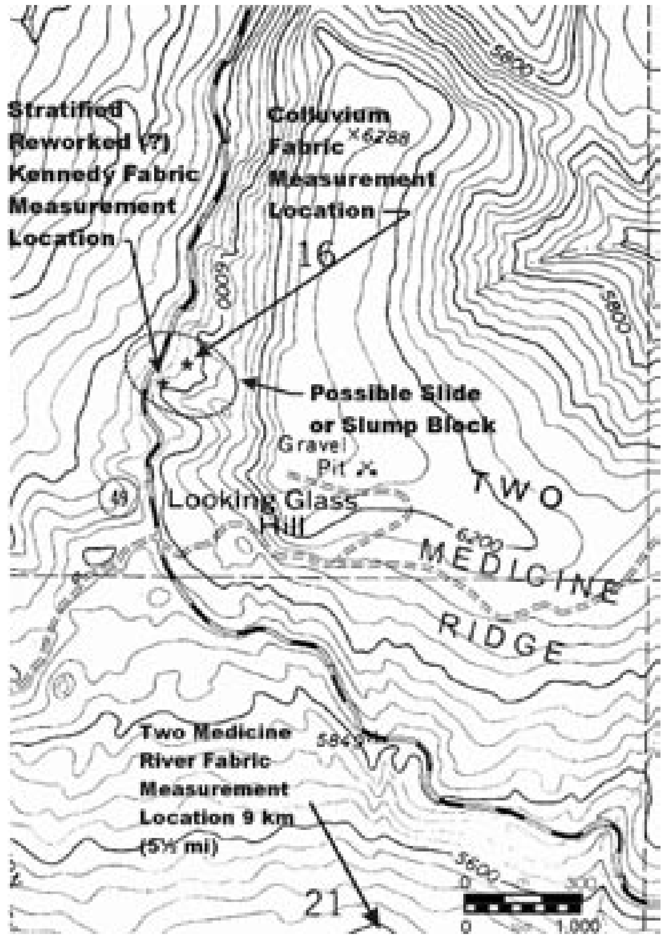


**Figure 4. Map of Two Medicine Ridge area showing control sample locations. Contour interval is 40 ft (12.2 m). U.S.G.S. Kiowa 7.5' quadrangle map base.**

**Figure 5. Photograph of colluvium fabric measurement location, northwest side of Two Medicine Ridge.**

**Figure 6. Photograph of folded strata of Kennedy composition (inferred slide or slump block), northwest side of Two Medicine Ridge.**

researcher. Hence, Karlstrom has—as would virtually any other researcher—approached the fabric study only semiquantitatively.

To evaluate the applicability of the method employed by Karlstrom to the Kennedy deposits, eigenvalue ranges for clearly nonglacigenic sediments in the same area (viz. Two Medicine Ridge) were measured and analyzed in accordance with the specific technique of Mark (1973) and ordinary eigenvector analysis (Anton, 1981; Danielson, 1997; Koch and Link, 1980, pp. II:119–150; Pipes and Harvill, 1970, pp. 104–106). Since this method (Dowdeswell and Sharp, 1986) was developed specifically for glacial sediments, data from nonglacigenic deposits were necessary to provide controls for Karlstrom's data. One data set was collected from seasonally generated colluvium consisting of Kennedy gravel on the northwest side of Two Medicine Ridge (Figures 4 and 5). Carbonate cement provides a relatively solid base upon which colluvium up to half a meter thick moves during the warmer months, particularly during the spring thaw. The second control sample location was from a single gravel stratum within a dramatic outcrop adjacent to the colluvial slope (Figures 4 and 6). This outcrop consisting of gravel and silt-dominated alternating strata (rhythmic bedding), is weakly consolidated, and may represent part of a slide or slump block composed primarily of stratified Kennedy Formation (redeposited Kennedy?) as illustrated in Figures 7 and 8. A rhythmic sequence such as that observed at this location bespeaks turbulent deposition in a fluvial environment (Berthault, 1986). The strata have been "righted" in Figure 8 to their approximate inferred initial attitude, and the approximate orientation of the primary fabric eigenvector ($S_1$) does resemble a typical fluvial attitude for this stratum. The third control sample was measured from a cut bank deposit of the Two Medicine River in the valley bottom upstream from Two Medicine Canyon (Figure 4). Soil formation in the upper half meter or less of the gravel floodplain deposit was ignored and prolate clasts for the entire profile included in the measurements (Figure 9).

**Figure 7. Stratified "slide" or "slump block," northwest side of Two Medicine Ridge. Field crew chief points at gravel fabric sample stratum.**

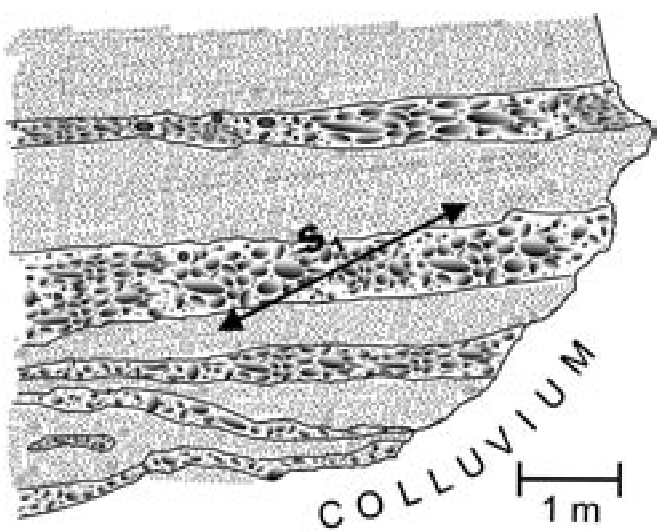


**Figure 8. Diagram of sand and gravel rhythmite interpreted as stratified reworked Kennedy Formation. Section has been "righted" to inferred orientation at deposition. Approximate orientation of primary fabric axis ($S_1$) indicated for stratum measured in this study.**


**Figure 9. Photograph of Two Medicine River fabric measurement location. Protruding prolate clasts are more likely to fall from bank, potentially skewing orientation data.**

Two hypothetical data sets were included for comparison. The first represents a traction current or bed load deposit such as could be expected to form along a stream bed, and the second represents prolate pebbles deposited from suspension. Fifty orientation data were generated for each set using a random number generator and assuming a Gaussian normal distribution for each variable (Moore and McCabe, 1993). The traction current data were generated using a mean a-axis azimuth of 090°/180° with σ equal to 15° and a plunge of 0° with σ equal to 15° from the horizontal. The suspended deposition data set was generated using a mean plunge of 60° from the horizontal and no preferred azimuth; the value of σ was 15°. Eigenvalue analysis was performed on these coordinate data in the same manner as the field data to generate major and minor orientation axes (S1 and S3, respectively). The ratio of these is also listed in Table I and is the primary value used to judge fabric strength[4].

As shown on Figure 10 and in Tables I and II, the eigenvalue ranges for measured fabrics in a variety of glacigenic and nonglacigenic sediments differ far less from each other than the variation within each depositional environment, and the persuasive value of Karlstrom's results is underwhelming. The colluvium and cyclic reworked Kennedy show poorer fabric development (based on the method of

[4] Minor discrepancies between the value of S1/S3 and the quotient of the separate values in the table are indicative of rounding error.

## Table I
## Comparison of Several Depositional Fabrics

| Depositional Process | Fabric Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | $S_1$ | | $S_3$ | | Mean $S_1/S_3$ | Refer-ence | Remarks |
| | mean | σ | mean | σ | | | |
| Basal melt-out till | 0.820 | 0.045 | 0.035 | | 23.43 | 1 | |
| Undeformed lodgement till | 0.687 | 0.060 | 0.078 | 0.040 | 8.81 | 1 | |
| Deformed lodgement till | 0.588 | 0.090 | 0.119 | 0.040 | 4.94 | 1 | |
| Glacigenic sediment flow | 0.570 | 0.050 | 0.126 | | 4.52 | 1 | |
| Mean lodgement and ploughed till | 0.837 | | 0.030 | | 27.90 | 2 | |
| Mean high strength fabric soft bed till | 0.768 | | 0.057 | | 13.47 | 2 | |
| Mean intermediate strength fabric soft bed till | 0.686 | | 0.076 | | 9.03 | 2 | |
| Mean low strength fabric soft bed till | 0.532 | | 0.122 | | 4.36 | 2 | |
| Mean soft bed till | 0.641 | | 0.101 | | 6.35 | 2 | A |
| Cloudy Ridge | 0.677 | 0.051 | 0.080 | 0.019 | 8.42 | 3 | B |
| Mokowan Butte | 0.574 | 0.051 | 0.088 | 0.022 | 6.51 | 3 | C |
| Milk River Ridge | 0.637 | 0.110 | 0.074 | 0.008 | 8.67 | 3 | D |
| Saint Mary Ridge | 0.602 | 0.055 | 0.086 | 0.026 | 6.98 | 3 | E |
| Two Medicine Ridge | 0.588 | 0.086 | 0.117 | 0.034 | 5.02 | 3 | F |
| Kennedy colluvium | 0.499 | | 0.198 | | 2.52 | 4 | G |
| Cyclic reworked Kennedy | 0.443 | | 0.262 | | 1.69 | 4 | H |
| Floodplain gravel | 0.667 | | 0.094 | | 7.06 | 4 | I |
| Hypothetical traction carpet | 0.709 | | 0.077 | | 9.25 | 4 | J |
| Hypothetical suspended load | 0.521 | | 0.046 | | 11.27 | 4 | J |

Shading indicates insufficient data.

References:

1 Dowdeswell and Sharp, 1986; Lawson, 1979. Also cited in Hart, 1994; Karlstrom, 2000.

2 Hart, 1994.

3 Karlstrom, 2000; data composited by Klevberg for each site (cf. Table II)

4 Klevberg, 2002.

A “not very meaningful” (Hart, 1994)

B Northeast gully

C Pole Heaven

D South slope

E Central scarp

F South outcrop

G Two Medicine Ridge

H Two Medicine slump

I Two Medicine River

J Prolate clasts

## Table II
## Fabric Data For Kennedy Formation
## Karlstrom (2000)

| "Unit" | $S_1$ | $S_3$ | $S_1/S_3$ | "Unit" | $S_1$ | $S_3$ | $S_1/S_3$ |
|---|---|---|---|---|---|---|---|
| *Cloudy Ridge* | | | | *Saint Mary Ridge* | | | |
| 1 (Bt) | 0.757 | 0.070 | 10.81 | 5 | 0.651 | 0.085 | 7.66 |
| 1 (Bk) | 0.618 | 0.111 | 5.57 | 4 | 0.693 | 0.055 | 12.60 |
| 1 (b) | 0.655 | 0.600 | 10.92 | 3 (a) | 0.614 | 0.096 | 6.40 |
| **Comp.*** | **0.677** | **0.080** | **8.42** | 3 (b) | 0.606 | 0.063 | 9.62 |
| *Mokowan Butte* | | | | 2 (a) | 0.564 | 0.124 | 4.55 |
| 5 | 0.671 | 0.073 | 9.19 | 2(b) | 0.515 | 0.135 | 3.81 |
| 4 | 0.573 | 0.116 | 4.94 | 1(a) | 0.530 | 0.068 | 7.79 |
| 3 | 0.508 | 0.119 | 4.26 | 1(b) | 0.645 | 0.064 | 10.08 |
| 2 | 0.532 | 0.062 | 8.58 | **Comp.*** | **0.602** | **0.086** | **6.98** |
| 1 | 0.588 | 0.071 | 8.28 | *Two Medicine Ridge* | | | |
| **Comp.*** | **0.574** | **0.088** | **6.51** | 4 | 0.695 | 0.109 | 6.38 |
| *Milk River Ridge* | | | | 3 | 0.665 | 0.062 | 10.56 |
| 2 | 0.772 | 0.064 | 12.06 | 2 | 0.462 | 0.167 | 2.77 |
| 1 | 0.502 | 0.083 | 6.05 | 1 | 0.529 | 0.130 | 4.07 |
| **Comp.*** | **0.637** | **0.074** | **8.67** | **Comp.*** | **0.588** | **0.117** | **5.02** |

Data from Karlstrom (2000), p. 1499

*Composite result calculated by Klevberg from Karlstrom's data by treating these as multiple data from a single composite section, not separate units.

Dowdeswell and Sharp) than both glacial and Kennedy Formation values. This is certainly not surprising in the case of the colluvium, which could be expected to provide minimal fabric development[5]. One could expect maximum fabric development from a well-sorted traction carpet or bed load deposit. Note, however, that the method of Dowdeswell and Sharp (1986) may not provide a clear indication of such fabric development. The Two Medicine flood plain fabric strength is slightly less than the hypothetical traction carpet fabric strength; these values compare favorably with both the glacigenic and Kennedy Formation fabric strengths. The Two Medicine floodplain deposit exhibits a fabric strength less than the composite values for Cloudy Ridge and Milk River Ridge, greater than the composite values for Mokowan Butte and Two Medicine Ridge, and approximately equal to the composite value for Saint Mary Ridge. The hypothetical traction carpet and suspended load fabric strengths fall near the middle of the range of undeformed glacigenic sediment values.

The composite values are averages of all of Karlstrom's data from a given outcrop and treat the Kennedy Formation as a single unit with multiple samples. Karlstrom sampled inferred units from each outcrop singly. These data are presented in Table II, where the wide variations in fabric values are apparent. These variations may result from greatly different depositional processes for the individual units distinguished by Karlstrom, they may reflect natural variation in clast attitudes ("noise"), or they may be data collection artifacts. The differences between the values of the various data sets from each outcrop are expressed as standard deviation units in Table I.

If the c-axis of oblate pebbles had been measured instead of the a-axis of prolate pebbles, a measure of imbrication could have been made. This could be expected to be a minimum for the colluvium and a maximum for the traction carpet deposit. Without additional data such as these, separation of glacigenic from nonglacigenic sediments on the basis of fabric strengths is impossible. We therefore conclude that the fabric strengths of Kennedy Formation outcrops determined by Karlstrom using the method of Dowdeswell and Sharp lack persuasive value relative to the question of a glacial origin for the Kennedy Formation. Karlstrom (2000, p. 1499) himself admits that fabric data alone are not diagnostic. Some researchers have demonstrated that the data collection stage itself introduces systematic errors when measurements are made from outcrops, that preferential weathering introduces errors, and that even an eigenvalue analysis of many data can produce meaningless results (Benn and Ringrose, 2001; Bennet et al., 1999; Dreimanis, 1999; Klein, 2002; Millar and Nelson, 2001). It may be possible that measurement of all three axes from all coarse

[5] Domack and Lawson (1985) argue for an ice-rafted origin for a diamicton on Whidbey Island, Washington. This diamicton exhibits extremely weak fabric strength similar to the Two Medicine colluvium and rhythmite gravel stratum.

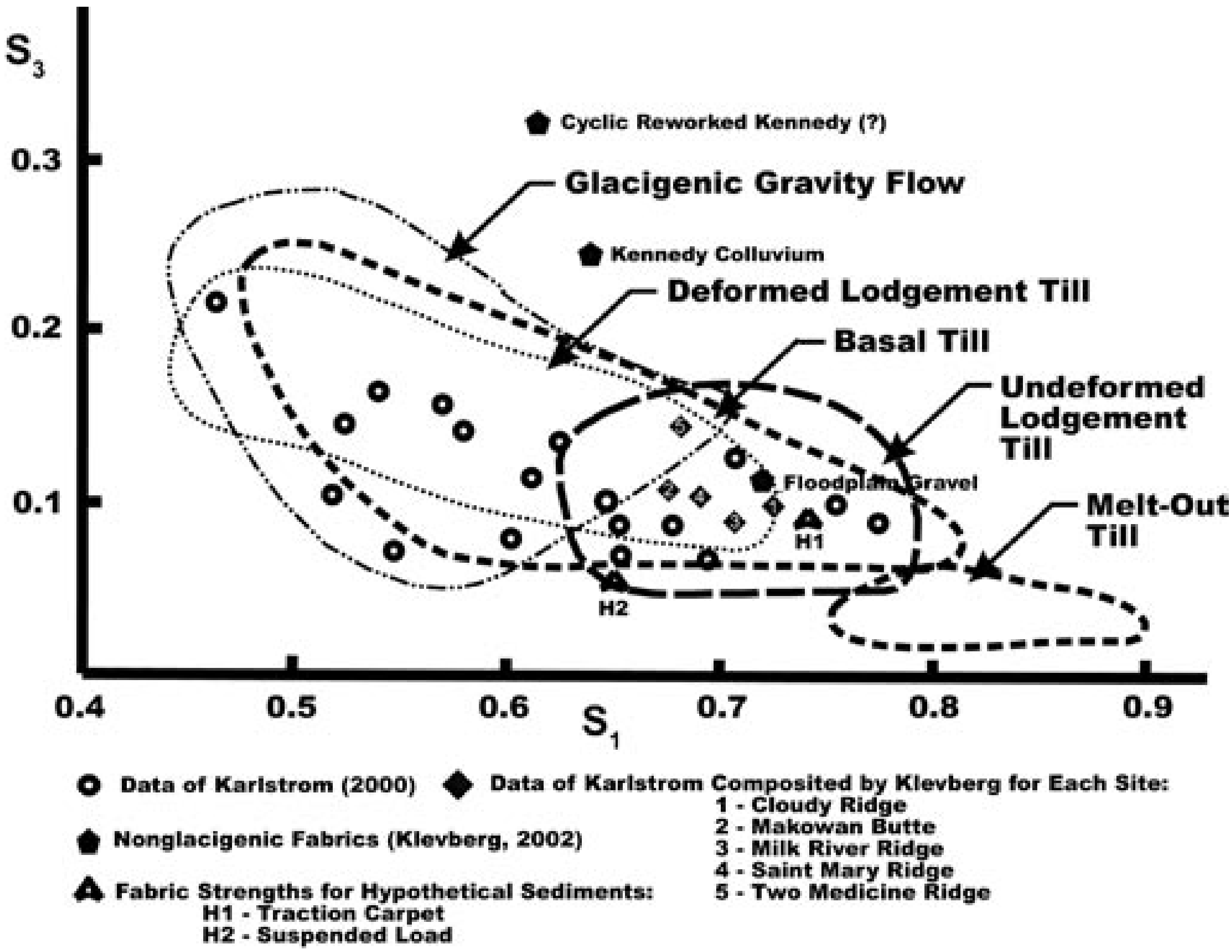


**Figure 10. Plot of fabric data. The strongest fabric development is at the lower right of the diagram, and the weakest fabric development is at the upper left.**

particles in randomly selected but uniformly sized volumes (not areas) of a formation may obviate at least some of these errors, but the immensity of this task intimidates the vast majority of geologists. The result is no conclusive standard by which to evaluate these fabric data.

Karlstrom's dismissal of the possibility of a debris-flow origin for the Kennedy Formation bespeaks the depth of his uniformitarian bias. Examination of the data in Tables I and II shows that variability in S1/S3 values is too great to convincingly argue that a glacial sediment flow or non-glacial mechanism can be discounted based on the S1/S3 values from the Kennedy Formation. As pointed out by Dowdeswell and Sharp (1986), among others, there is also a paucity of data. Fabrics in mudflows may develop rapidly and cycle through phases of greater and lesser fabric development. The final degree of development is determined by the state at the instant the flow "freezes," and the final fabric can be indistinguishable from a till (Lindsay, 1968). Karlstrom (2000) argues that the sheer scale of the Kennedy Formation makes a debris-flow origin impossible. This is crass uniformitarianism. We find this argument much more weakly developed than the Kennedy Formation fabrics themselves.

Figure 11 shows fabric in lime-cemented conglomerate on a landslide scarp on the northwest slope of Saint Mary Ridge (Figure 1). The nearly random orientation of clasts is apparent. From a distance (Figure 12), gross stratification is evident in parts of the Kennedy Formation, and this is also present on a submeter scale in zones dominated by sand. A few planar cross-beds can even be found in the

**Figure 11. Lime-cemented conglomerate on a landslide scarp on the northwest slope of Saint Mary Ridge. Note rounded boulders. Soil scientist is 180 cm (6 ft) tall.**


**Figure 13. Planar cross-beds and sand interbeds in sandy gravel zones of Kennedy Formation exposed on central landslide scarp, Saint Mary Ridge.**

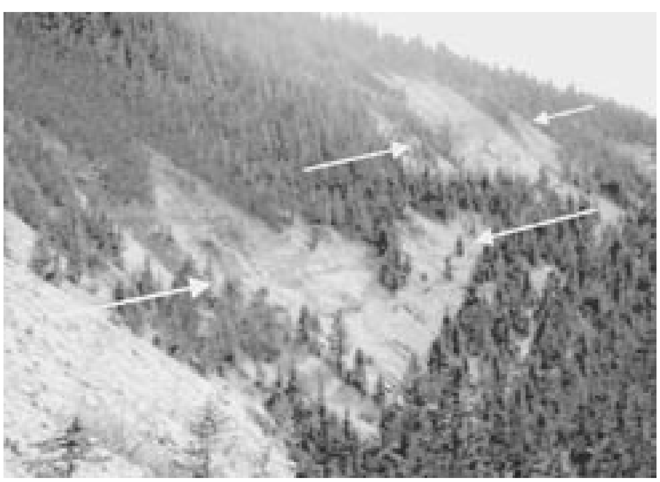

**Figure 12. Gross stratification (indicated by arrows) evident in parts of the Kennedy Formation exposed on Saint Mary Ridge.**

sand-dominated zones (Figure 13). Figure 14 shows fabric in soil exposed in a gully in the northeast side of Cloudy Ridge (Figure 1). Stratification, cross-bedding or preferred clast orientation is not apparent. Table III compares the properties of these outcrops with characteristics typical of several depositional processes. While tills can display fabrics similar to those of Saint Mary and Cloudy Ridges, these fabrics are far from diagnostic of tills (i.e. only formed as debris deposited by glacial ice). On the other hand, the limited stratification that is evident on Saint Mary Ridge appears more likely to favor a fluvial or fluid debris flow depositional mechanism.

## Evidence Favors Deposition by Water

It is doubtful that the Kennedy "drift" represents till left over from any glaciation, ancient or modern. The so-called till lies fairly flat on the planation surface remnants (Figures 15 and 16) and slopes eastward, tapering to the other planar erosion surfaces farther out on the plains (Alden, 1932). This was noted long ago by Willis (1902, pp. 328–329), who considered this evidence for a fluvial mechanism:

> The typical occurrence of Kennedy gravels is illustrated [end plates]. There one may note the size and form of the constituent boulders and pebbles, the incoherent water-washed nature of the gravel shown by the slopes, *the level top which falls into the horizon line of the Plains*, and the elevated position of the gravel mass…the high-level gravels of the Plains and the Kennedy formation are *alike* in genesis and derivation from the Lewis Range" [emphasis added].

This smoothness contrasts with normal glacial deposits that form end, lateral and ground moraines with relief (Figures 17, 18, and 19). Glacial outwash, on the other hand, usually has a planar surface (Figure 20), but outwash is usually clast supported with rounded clasts. The texture of the Kennedy "drift" is mostly matrix supported. The clasts near the surface of the deposit are generally angular (Figure 21). There are also rounded clasts disseminated throughout the deposit. Karlstrom (2000, p. 1501) admits that locally such clasts can predominate and possibly indicate fluvial deposition.

Are not the striated rocks positive proof[6] of glaciation? The answer to this question is a clear, No! Striated and even

## Table III

### Depositional Characteristics of Sediment Transport Processes and Kennedy Formation

| Transport Processes / Depositional Characteristics | Fluvial/Traction Current | Turbidity Current | Glacial Drift | Mudflow/Debris Flow | Fluidized Sediment Flow/ Hyperconcentrated Flow | Grain Flow/Debris Flow | Falls/Slides | Soil | Kennedy Formation (observed) |
|---|---|---|---|---|---|---|---|---|---|
| Stratification | (shaded) | (diagonal) | | | (diagonal) | | | (shaded) | (diagonal) |
| Grading* | (shaded) N | (diagonal) N R | | (diagonal) R | (diagonal) N | | | | |
| Sorting | (shaded) | (diagonal) | | | | | | | |
| Imbrication | (shaded) | | | | | | | | |
| Cross-Bedding | (shaded) | (shaded) | | | | | | | (shaded) |
| Rounding | (shaded) | | | | ? | | | | (diagonal) |
| Angular or FacetedClasts | | (shaded) | (shaded) | (shaded) | ? | | | | (shaded) |
| Striated Clasts | | (shaded) | (shaded) | (shaded) | ? | ? | | | (shaded) |
| Clast-Supported Fabric | (shaded) | | (diagonal) | ? | (shaded) | (shaded) | | | |
| Matrix-Supported Fabric | (diagonal) | (shaded) | (shaded) | (shaded) | (shaded) | (shaded) | (shaded) | (shaded) | (shaded) |
| Downstream Fining | (shaded) | | | | | | | | (diagonal) |
| Boulder Pavement or Stone Line | ? | (shaded) | (diagonal) | | (shaded) | | (shaded) | (shaded) | ? |

Shading indicates process produces deposits exhibiting given attribute.

Diagonal line indicates process sometimes produces deposits exhibiting given attribute (or is sometimes observed) depending on other variables.

*N - normal grading (fining upward)

*R - reverse grading (coarsening upward)

References:


1 Blatt, Middleton, and Murray, 1972; Julien, 1995; Selley, 1976; Tucker, 1990.

2 Carter, 1975; Ghibaudo, 1992; Lowe, 1979; 1982; Middleton, 1993; Nardin et al., 1979; Pierson and Costa, 1987.

3 Dowdeswell and Sharp, 1986; Hart, 1994; Karlstrom, 1990; 1991;2000; Lawson, 1979; Oard, 1997; Tarbuck and Lutgens, 1984.

4 Hampton, 1979; Iverson, 1997; Pierson and Costa, 1987; Smith, 1986.

5 Beverage and Culbertson, 1964; Costa, 1984; Hampton, 1979; Iverson, 1997; Pierson and Costa, 1987; Pierson and Scott, 1985; Smith, 1986.

6 Costa, 1984; Hampton, 1979; Iverson, 1997; Major, 1997; Pierson and Costa, 1987; Smith, 1986.

7 Coussot and Meunier, 1996; Tarbuck and Lutgens, 1984;Tschebotarioff, 1951.

8 Brady, 1974; Birkeland, 1974; 1984; Klevberg and Bandy, 2003.

9 Cioppa et al., 1995; Horberg, 1956; Karlstrom, 1982; 1987; 1988; 1990; 1991; 2000; Karlstrom and Barendregt, 2001; Klevberg, 2002.

**Figure 14. Fabric in soil exposed in a test trench in the northeast side of Cloudy Ridge. Scale is marked in tenths of a foot.**

faceted rocks can form under a variety of circumstances (Oard, 1997, pp. 41–47). A common mechanism for forming striated and faceted clasts is mass movement (Schermerhorn, 1974). Apparently many geologists have ignored these other mechanisms and hence indiscriminately have defined "ancient glaciations" within the rocks:

> To repeat the most important point, great caution is urged in the use of striated stones as glacial pointers. It is a point that has been stressed time and again by many stratigraphers, without apparently leaving much impression (Schermerhorn, 1974, pp. 681–682).

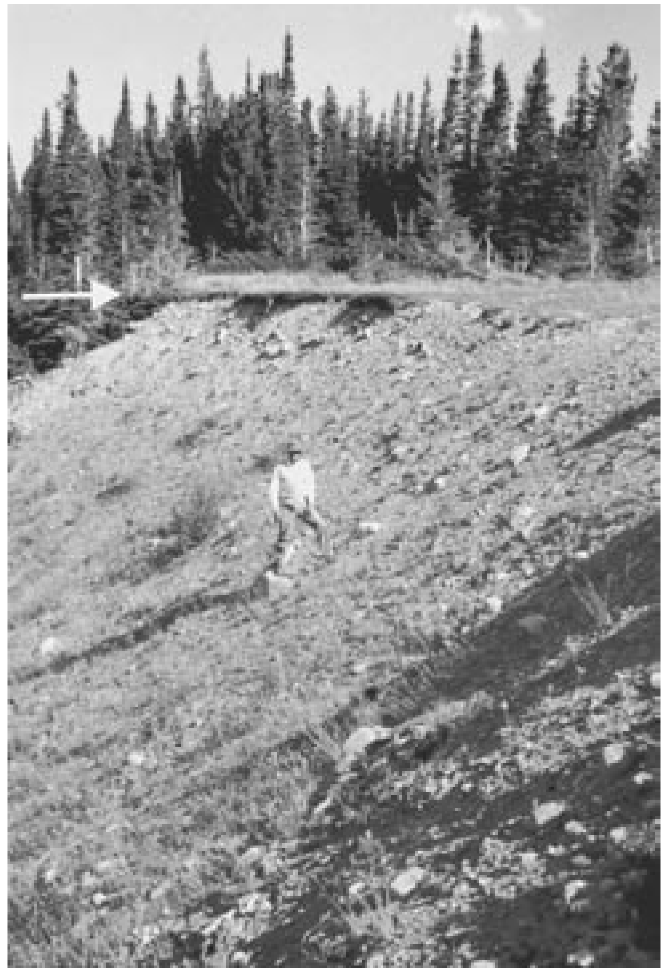

**Figure 15. Exposure of Kennedy Formation on north side of Two Medicine Ridge. Note planarity of upper (depositional) surface.**

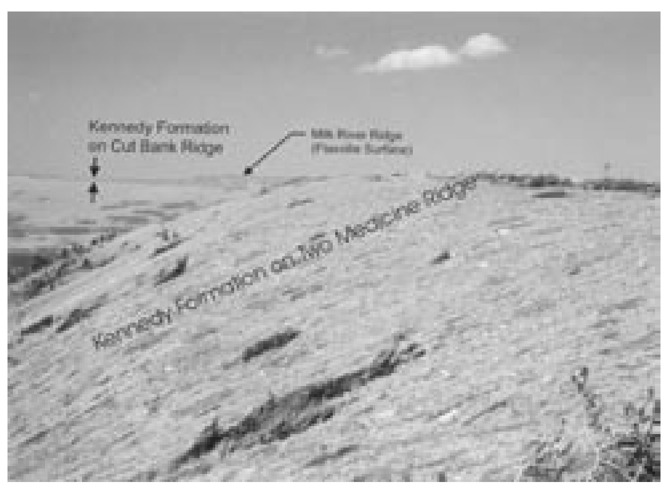


**Figure 16. View north from west end of Two Medicine Ridge toward Milk River Ridge showing tabular geometry of Kennedy Formation conforming to Flaxville erosion surface.**

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[6] We use this term facetiously, recognizing that "scientific proof" is an oxymoron and that the striation issue is a mixed question.


**Figure 17. Primarily glacial deposits from the Athabaska Glacier, Alberta, Canada.**


**Figure 19. End moraine complex, Skeiðarárjökull, Iceland.**


**Figure 18. Athabaska Glacier: the sign marks the extent of ice in 1890; deposits between sign and glacier terminus in distance were formed after 1890.**

**Figure 20. Skeiðarársandur, Iceland, an active glacial outwash plain.**

Karlstrom (2000) also points to a boulder pavement in an outcrop on Saint Mary Ridge and bullet-shaped boulders in the Kennedy "drift" as further proof of glaciation. We thoroughly searched the outcrop on Saint Mary Ridge and did not find a boulder pavement. Bullet-shaped rocks, on the other hand, are sometimes found (Figure 22). Boulder pavements and bullet-shaped rocks are associated with modern and ice age glaciers. Researchers then assume that they are diagnostic of glaciation, that they form only in glacial environments. However, glacial geologists do not know how glaciers form these features, and they have been found in nonglacial deposits (Oard, 1997, pp. 45, 54–56). It is likely that both boulder pavements and bullet-shaped clasts can form in debris flows, and stone lines (of which boulder pavements are a type) can form diagenetically and pedologically (Birkeland, 1974, pp. 193, 194; Paton, Humphreys, and Mitchell, 1995). This is yet another example of the widespread tendency to seize upon one *possible* explanation and lose sight of other possibilities (Klevberg, 2001).

The so-called Kennedy drift has an appearance and geomorphology not greatly different from other gravel caps on the planation surfaces that are so common in Montana east of the continental divide and vicinity (Alden, 1932; Klevberg and Oard, 1998; Oard and Klevberg, 1998). As shown in Figure 23, the Kennedy gravel-capped planation surface

**Figure 21. Angularity of Kennedy gravel—picture from Two Medicine Ridge. Scale is 16 cm (6 in) long.**

**Figure 23. View northeast from Cut Bank Ridge, showing the smooth transition from surfaces capped by the Kennedy Formation (at left) to extensive remnants of the Flaxville Plain (at right).**

**Figure 22. "Bullet-shaped" rock observed in Kennedy Formation, Saint Mary Ridge. Lens cap is approximately 6 cm (2.5 in) in diameter.**

blends smoothly with the Flaxville erosion surface farther east, a fact previously noted and admitted by Willis (1902) and Alden (1932, pp. 31–40). The gravel is thicker in the Kennedy Formation than on the planation surfaces farther east. Clasts farther out on the plains are more rounded. The Kennedy gravel is more matrix supported than the typical gravel cap farther out on the plains, which one might expect if its source were just to the west in the Rocky Mountains. However, we have also noted patches of matrix-supported gravel and conglomerate on the Cypress Hills. Even farther east, in the Flaxville Formation near Turner, Montana, statistical analysis of gravel samples suggests the effects of current winnowing (Klevberg and Oard, 1998, p. 372), as

**Figure 24. Typical unstable slope with carbonate-cemented erosional knob, southwest side of Two Medicine Ridge.**

**Table IV**
**Comparison of Kennedy Formation Genetic Arguments**

| Characteristic | Argument for Glacial Origin | Alternative Explanation |
|---|---|---|
| Striated Clasts | Striations commonly form from glacial movement. | Striations form from many mechanical processes, including mass wasting. |
| Diverse lithologies | Varied lithologies are evidence of glacial transport. | Varied lithologies may result from lithologically diverse source areas or polygenetic histories. |
| Primarily angular clasts but with some rounded | Mudflows should produce all angular, fluvial deposits all rounded, but glacial deposits may have both. | The source area may have contained some rounded clasts; soft lithologies may round even during mass wasting, while hard lithologies transported short distances fluvially may remain angular. |
| Fabric Strength | Fabric strengths observed fall into range observed for glacigenic and inferred glacigenic sediments. | Fabric strengths are not diagnostic; same values may be obtained for nonglacigenic deposits. |
| Faceted clasts | Faceted clasts result from glacial transport. | Faceted clasts are known to form from mass wasting processes and can even form in certain fluvial environments. |
| Bullet-shaped clasts | Bullet-shaped clasts result from glacial transport. | The manner in which bullet-shaped clasts form is not known and may also result from mass wasting or debris flow processes. |
| Matrix support | Matrix support is indicative of deposition as glacial till. | Matrix support is typical of debris flows and other mass wasting processes and sediment-laden fluvial processes. |
| Boulder pavements | A horizon of boulders and cobbles is indicative of a glacial origin. | Similar nonglacial features ( stone lines) are known; boulder pavements can be formed by certain mass wasting processes.* |

*The authors have not been able to confirm the existence of a boulder pavement in the Kennedy Formation.

does the average pebble size in the Cypress Hills Formation from west to east.

Arguments for a strictly glacial origin of the Kennedy Formation are not strong. Evidence against a glacial origin is considerable. Glacigenic arguments and alternatives to these are summarized in Table IV.

## Multiple Ice Ages?

Another problem with the Kennedy "drift" being left over from a "late Pliocene" ice age is that only one glaciation is now recognized over much of southern and central Alberta (Young et al., 1994; Oard, 1995). This glaciation is dated within the uniformitarian time frame as late Wisconsinan, which is the youngest. It is true that the supposed glaciation that laid the Kennedy "drift" would have come from the vicinity of today's Glacier and Waterton National Parks. However, this area represents the southeast edge of the Cordilleran Ice Sheet, and it is doubtful that this area would have been glaciated without a Laurentide Ice Sheet in southern Alberta.

Furthermore, there are supposed to be at least seven separate glaciations that laid down the supposed alternating till-paleosol sequence. Glaciers are highly erosive of soft, unconsolidated sediments. How could any of these paleosols survive even one attack of an ice sheet coming off the mountains from the west? Even the supposed till would have been reworked by each glacier. Each glacial advance should churn any supposed previous till-paleosol sequence into chaotic debris. This reworking and destruction of previous supposed ice age deposits is employed as the typical uniformitarian excuse for why most formerly glaciated areas show evidence for only one ice age. They say the last ice sheet churned up all the evidence of previous ice ages. This is the reason researchers appeal to oxygen isotope ratios from deep-sea cores to infer the "real" number of ice ages, which is claimed to be around 30 in the late "Cenozoic" (Oard, 1990). One might argue that this would not apply if the glacier were frozen to its bed, but if the ground had been frozen, we would expect to see evidence for permafrost features: ice wedge casts, sharply demarcated boulder pavements with striated clasts, patterned ground, etc. We have not seen such features in the Kennedy "drift."

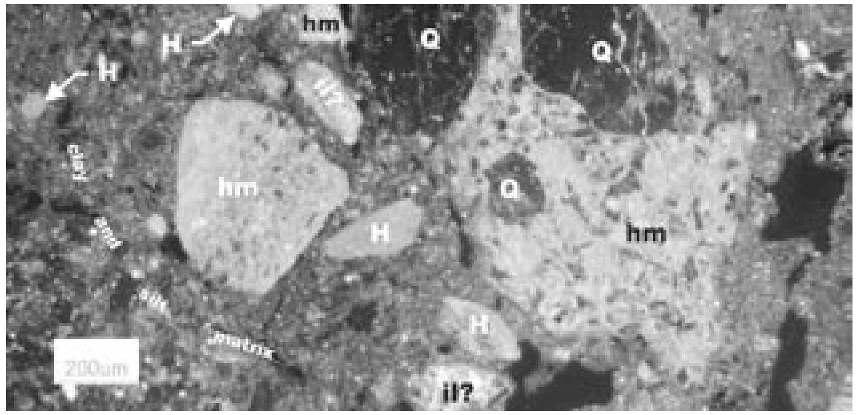



**Figure 25. False color photomosaic of reflected light micrographs of Kennedy Formation from trench SM-5, Saint Mary Ridge (sample SM5-157), showing detrital grains containing hematite and smaller inclusions of hematite that may be authigenic. Hematite is indicated by light color.**

## Paleomagnetism

Paleomagnetism provides a potentially powerful argument for the passage of significant time in the formation of these sections of unconsolidated sediments. This has not escaped the attention of previous establishment researchers (viz. Richmond and Karlstrom). There are at least three possibilities:

- If magnetochronostratigraphy[7] is valid, and the alleged paleosol horizons can be matched to these "chrons," then the ages Karlstrom has assigned these "paleosols" apply, whether or not his paleosol interpretation of their genesis is accurate. This would "disprove" the biblical chronology.
- If magnetochronostratigraphy is in error, but the remanent magnetization measurements are accurate, then the potential remains to match the lithologic section with reversals of the Earth's magnetic field through the course of Earth history. Such reversals may have been rapid (Brown, 1989; Humphreys, 1987; 1990; 2002) and, if so, may not be in conflict with biblical chronology.
- If the remanent magnetization measurements are not valid, they are irrelevant to both the multiple-event question and the question of how much time was required to deposit the Kennedy Formation. Spurious magnetic data neither affirm nor deny the multiple glaciation theory or, for that matter, biblical chronology.

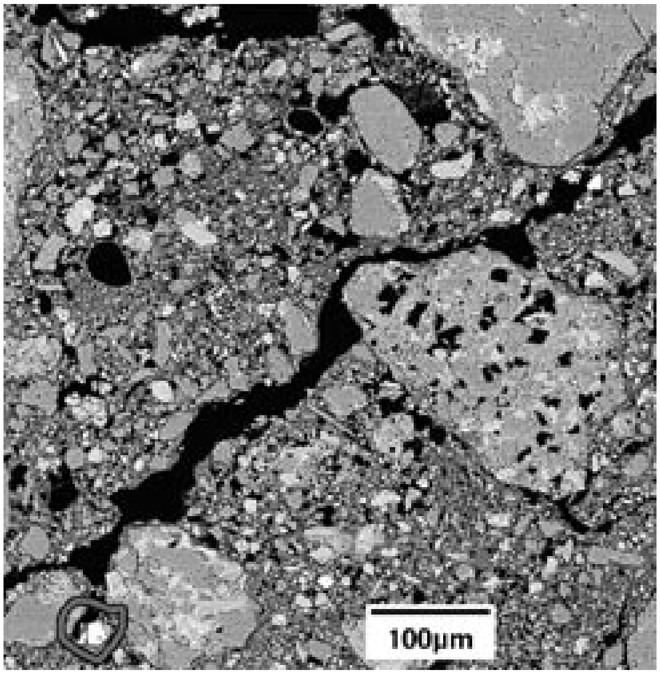
We suspect that the discrepancy between Richmond (1957) and Karlstrom (2000, p. 1496; 1982; 1987; 1988; 1991) may result from at least four complications faced by those attempting remanent magnetization measurements in the Kennedy Formation:

- All of the slopes evince significant instability (Figure 24). All are blanketed by colluvium, some to considerable thicknesses. Calcium carbonate is also abundant, allowing the sediments to be recemented when conditions permit. Both random and systematic errors in mineral grain orientation can result, and thin section analysis suggests that this has, in fact, occurred in at least some outcrops of the Kennedy Formation (Figure 25).
- The statistical method of dealing with paleomagnetic data is similar to that employed in analyzing glacigenic fabrics, though it is not prone to the same degree of difficulty (Koch and Link, 1980, pp. II:132–150). Nevertheless, paleomagnetic data may exhibit small signal-noise ratios and present some difficulty in obtaining a "standard deviation" for the data set. One must be cautious in accepting paleomagnetic "data" without the qualification of a confidence interval. Such "data" are not "raw," and one cannot be sure of just how they were "cooked." They may not, in reality, be representative of actual in situ remanent magnetization.

However, measures of statistical strength are presented by Karlstrom (2000, pp. 1502, 1504) graphically. They appear quite weakly developed to us, especially those for reversed magnetization, though they do seem to at least indicate that few of the samples had been tilted toward the vertical. Measurements by Cioppa et al. (1995) appear to be good, direct measurements, but we lack full confidence in efforts to eliminate results of "overprinting." More recent work by Karlstrom and Barendregt (2001) has addressed some of these problems.

- Statistical strength of inferred paleomagnetism from paleomagnetic data is also dependent on the quantity of data collected. Insufficient data result in large deviations. However, the number of data collected by Karlstrom (2000, p. 1496), a total of

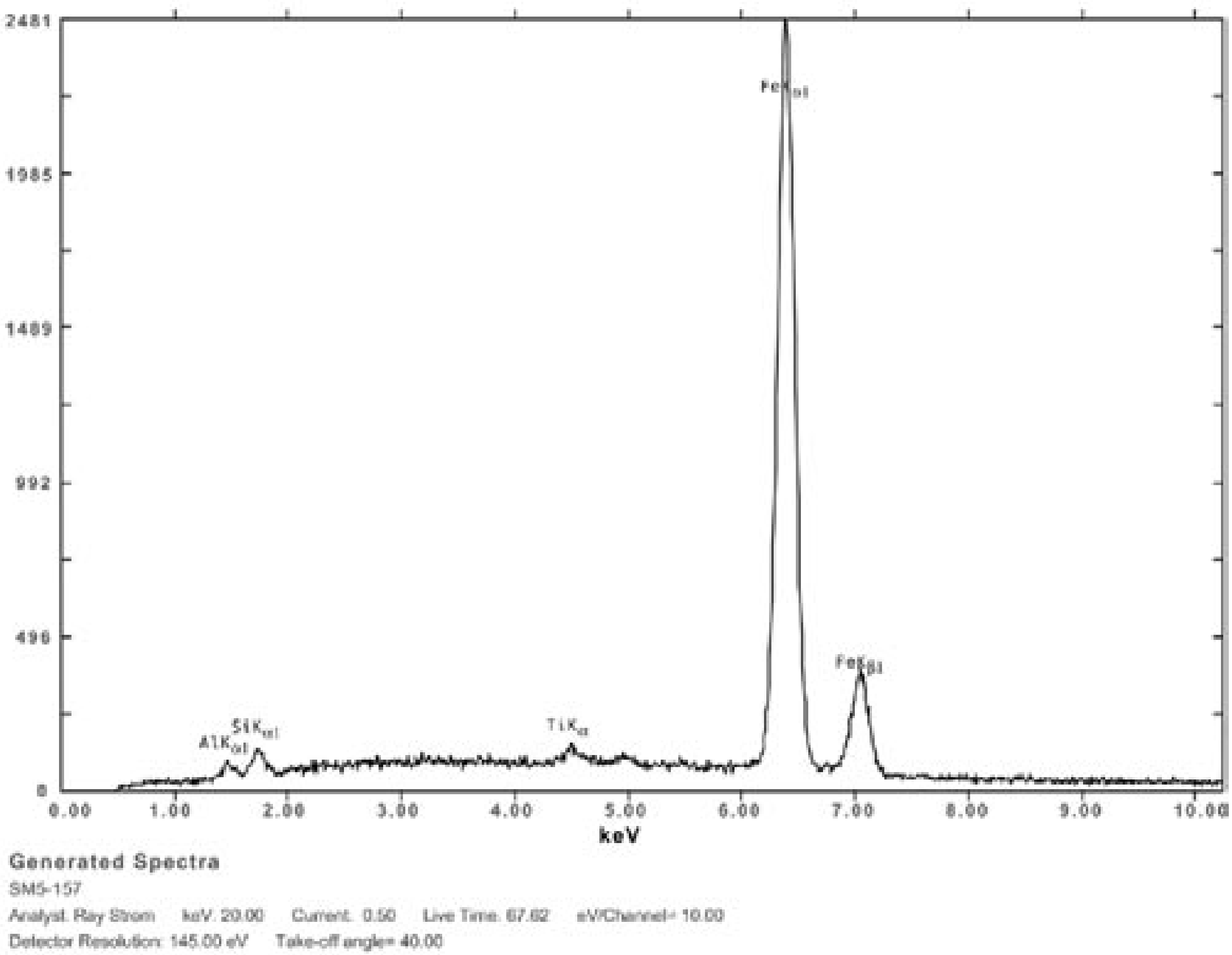
[7] Magnetochronostratigraphy is not a scientific stratigraphic method, since it begins with a scheme for the history of the Earth's magnetic field and fits the data into this scheme.




34 from Saint Mary Ridge and 246 from Mokowan Butte, appears adequate.

- Cioppa et al. (1995) determined that much of the remanent magnetization resides in hematite in the matrix of the Kennedy Formation and stated that the strength and directionality of the measured remanent magnetization were often poor. The poor quality of these data is probably a reflection of the actual situation rather than a result of the mineralogy (see Appendix A).
- Cioppa et al. (1995) inferred that the hematite hosting most of the remanent magnetization of

**Figure 26. Backscatter scanning electron micrograph with electron diffraction spectrum of circled grain. Spectrum is indicative of magnetite, probably with ilmenite, which is likely detrital. The micrograph also shows hematite incorporated into detrital grains.**



the Kennedy Formation was syndepositional and therefore representative of the contemporary terrestrial magnetic field, but it is also possible that it is diagenetic or authigenic, or that it represents a more complex history. It is known that remanent magnetism in sediments can reflect the terrestrial magnetic field accurately in some cases, while reflecting depositional current directions in others (Rouse, 1983a, p. 32).

## Evaluating Remanent Magnetism in the Kennedy Formation

Most readers are probably familiar with the general concept of thermoremanent magnetization, whereby a ferromagnetic mineral forms from magma or lava and inherits the orientation of the local magnetic field. This also assumes that minerals below the Curie point are not reoriented by lava or magmatic motions or geomechanical effects. This does not apply to the Kennedy Formation, of course, since it is sedimentary. However, the terrestrial magnetic field will have been one of the force fields that acted on particles transported by whatever fluid deposited the Kennedy Formation, and hematite formed since deposition (i.e. diagenetic or authigenic) would presumably have inherited the orientation of the contemporary terrestrial magnetic field. It is therefore important to closely examine the Kennedy Formation for evidence of diagenetic or other factors that may affect the orientation of magnetic minerals.

Paleomagnetic measurements were not collected as part of this investigation and, as stated above, we have a reasonable degree of confidence in the data of Cioppa et al. (1995) and Karlstrom and Barendregt (2001). Instead of duplicating these earlier efforts, we collected oriented samples from several locations on landslide scarps where these researchers had collected their samples: Cloudy Ridge, Milk River Ridge, Mokowan Butte, Saint Mary Ridge, and Two Medicine Ridge (Figure 1). These samples were submitted to Continental Rocktell Services of Calgary, Alberta, for analysis. Approximately 160 thin-section images were produced from 21 samples, many of which exhibit detrital characteristics and microfabric evidence of grain rotation and fracture propagation indicative of soil creep. Of particular relevance to this paper is sample SM5-157, which was collected from approximately halfway down the south side of the middle landslide scarp on Saint Mary Ridge (Karlstrom's Trench V, 1988). This sample corresponds to the "B horizon" of Karlstrom's Soil 3 (or possibly Soil 2), which is reversely magnetized.

Sample SM5-157 was further analyzed in several vertical sections using reflected light, transmitted plane light, transmitted light with crossed polars, scanning electron microscopy back scatter electron imaging (SEMBSE), and electron diffraction spectroscopy (EDS) to locate and characterize the ferromagnetic minerals in the sample. Figure 25 is a reflected light image of sample SM5-157. Small inclusions of hematite may be detrital or authigenic (or diagenetic), while the larger particles are clearly incorporated into detrital grains of the sedimentary matrix. Thus, the majority of remanent magnetization is contained in detrital particles that represent not the terrestrial magnetic field at the time of deposition of the Kennedy Formation, but the present orientation of hematite crystals in grains that may have been deposited with attitudes very different from their original orientations. This may explain why Cioppa et al. (1995) considered their paleomagnetic data to be of poor quality: while eigenvector calculations resulted in a "reversed" principal direction for these data, such a result could easily be obtained by chance. Figure 26 is a SEMBSE image with EDS spectrum for the most iron-rich grain in the image field. The spectrum indicates this is probably magnetite with some ilmenite, both of which have much larger magnetic susceptibilities than does hematite. Note that this also more closely resembles a detrital grain than a crystal that has grown since deposition of the Kennedy Formation.

## Stratigraphic Agreement?

As presented elsewhere (Klevberg, Oard, and Bandy, 2003), while stratigraphic methods that agree may both be wrong, methods that do not agree cannot both be correct. Some popular stratigraphic methods are not descriptive (i.e. scientific), either, which means they cannot provide an independent source of data for comparison with paleopedologic interpretations[8]. Magnetochronostratigraphy is one such unscientific stratigraphic method (Klevberg, 2000a) and is very popular among paleopedologists. Magnetochronostratigraphy begins with a global chronological scheme. It should be possible to measure remanent magnetism without reference to this scheme and create a stratigraphic section based on paleomagnetic properties, which would produce a

[8] Several papers have been published which elucidate the important distinctions between scientific and nonscientific approaches to stratigraphy (Froede, 1998; Froede and Reed, 1999; Klevberg, 1999; 2000a; 2000b; Reed and Froede, 2000; 2003; Reed, Froede, and Bennett, 1996; Woodmorappe, 1981; 1996). Readers who fail to see the importance of this distinction would benefit greatly from these papers.

scientifically valid magnetostratigraphic section. Such a section may or may not coincide with a paleopedologic section from the same outcrops or magnetochronostratigraphy[9].

Adherence to magnetochronostratigraphy requires a faith commitment which we are not prepared to make. Nor are we convinced that there is an unequivocal correspondence between paleomagnetic measurements and the various paleosols claimed by Karlstrom. As we have summarized above, remanent magnetism measurements can be problematic, and some of the results for Kennedy Formation samples are ambiguous or interpreted as displaying overprinting (Cioppa et al., 1995). The lack of completely random or near-vertical paleomagnetic data can be expected if most magnetic grains were deposited in a relatively fluid medium and not subjected to significant cryoturbation. Research on debris flow fabrics and paleomagnetism has shown considerable variability, with most particles oriented parallel to the inferred paleoslope (thus flow direction), and with fewer sites showing transverse orientation and some neither (Gravenor, 1986). While magnetite has an octahedral crystal habit that would tend to form equant grains, if it (and possibly hematite) were contained in prolate and oblate agglomerations or clasts, its final orientation might be related to whatever forces determined the final orientation of these agglomerations. Syndepositional magnetite in debris flow deposits may therefore indicate paleocurrent direction, not the contemporary direction of the earth's magnetic field. If some of the hematite in the matrix of the Kennedy Formation is syndepositional, it may also be oriented with paleocurrent directions. Thus there is clearly no "solid" case for a trustworthy paleomagnetic dating scheme for the Kennedy Formation. In the light of the technical difficulties outlined above, we leave it to the reader to determine whether compromise of the historically attested biblical chronology is warranted based on magnetochronostratigraphic speculation.

While we decry the naturalistic inconsistencies of magnetochronostratigraphy, we do not dismiss paleomagnetic data as spurious or unimportant. While some creationists have argued against terrestrial reversals from a few exceptional cases (Barnes, 1973; Brown, 1989; Rouse, 1983b), many diluvialists believe that the Earth's magnetic field has reversed direction multiple times, probably during the year-long global flood cataclysm (Brown, 1989; Humphreys, 1986; 1988; 1990; 2002) and perhaps some time thereafter (Appendix B). If one assumes that the remanent magnetization data published for the Kennedy Formation are valid, and that these data are actually representative of the contemporary terrestrial magnetic field, then such magnetic field reversals provide a reasonable explanation for reversed polarity in some of the Kennedy Formation units. Diluvialists following this line of reasoning would not face the establishment geologic paradigm (EGP) temptation to constantly expand the chronology to accommodate ever increasing numbers of chrons.

One could expect a relatively small number of reversals which might make correlation of many geomagnetic and archaeomagnetic data possible (however, see Appendix B for reservations). The reversals would dissipate the terrestrial dipole field strength, and should therefore show decreasing strength of magnetization (holding all other variables constant) the more recent the date of magnetization (Humphreys, 2002, p. 5), assuming such measurements are possible[10]. It may be that paleohydrologic or other methods can be applied to the Kennedy Formation to estimate minimum or maximum times for deposition; if so, it may be possible to estimate the rapidity of magnetic field reversals. All of this analysis hinges, of course, on the veracity of the remanent magnetization data as terrestrial magnetic field indicators and some solid historical data to pin the measurements to.

If the remanent magnetization measurements are accurate but do not represent the contemporary terrestrial magnetic field, then they are just as irrelevant to the multiple-event question and the time question as are spurious data. Remanent magnetization data that are not indicative of the terrestrial field neither affirm nor deny the multiple glaciation theory or biblical chronology. Data helpful to determining the likelihood of paleohydraulic influences on remanent magnetization may help to clarify this question. In light of the laboratory evidence presented here, alternative explanations for the paleomagnetic data appear not only

[9] Typically, if fossils are present, the presumed evolutionary succession is used to "date" everything else. Since many alleged paleosols do not contain fossils, magnetostratigraphy is often the only other method used in comparison with pedostratigraphy. Unfortunately, instead of using magnetostratigraphy as a geophysical method to look for physical boundaries between units, it is typically used to reference the local section to a magnetochronostratigraphic column, i.e. a presumed magnetic history of the Earth, similar to the manner in which fossils are used to "date" units.

[10] While some show confidence in efforts to measure paleointensity (Rouse, 1983b, p. 78), paleointensity can be very difficult to measure with any accuracy (Barnes, 1973), and some of the classic measurements have been shown to be statistically meaningless (Smith and Smith, 1993).

possible, but likely. It therefore behooves diluvialists not to blindly accept assertions about paleomagnetic directions for given formations. The skepticism with which geologists should consider the even more tenuous inferences of terrestrial field reversals during distinct stages of earth history should go without saying.

## Conclusions

Based on the evidences presented above, we conclude the following:

- Early research on the Kennedy Formation by EGP geologists resulted in disparate explanations for the deposit, including fluvial and glacial mechanisms, genesis during an interglacial, and as the result of multiple glaciations. Arguments against a debris flow origin hinge on the lateral extent and volume of the formation.
- The extensive, planar erosion surfaces on which the Kennedy Formation rests are continuous with surfaces stretching far east onto the Great Plains. These vast planation surfaces are almost certainly diluvial (Klevberg and Oard, 1998; Oard and Klevberg, 1998). The scale and magnitude of the event necessary to produce these surfaces would have been more than adequate to erode, transport, and deposit the Kennedy Formation.
- The lithologies contained in the Kennedy Formation correspond with those observed in the Rocky Mountains to the west and were probably derived from them. The mixture of rounded and more angular clasts indicates a combination of transport mechanisms over a relatively short distance, which fits well with the Rocky Mountain source area inference.
- Analysis of depositional fabric based on observations of Karlstrom, Klevberg, and others is inconclusive. While fabric strengths do not rule out a glacial origin, neither do they rule out mass wasting or fluvial transport mechanisms.
- Evidence for multiple glaciations hinges on paleosol and paleomagnetic interpretations. Both of these are mixed questions, not strictly scientific issues, and they are hampered by a number of technical difficulties.
- Remanent magnetism measurements vary greatly in quality. Magnetochronostratigraphy has been used by previous researchers to create an interpretive framework which the data are insufficient to support. Paleomagnetism does not provide unequivocal evidence for the amount of time or the various soil-forming intervals Karlstrom and others espouse. It may, in fact, indicate rapid deposition of the Kennedy gravel during a time of wildly fluctuating terrestrial magnetism. Paleomagnetism is a field as yet poorly researched by diluvialists.
- Laboratory analysis of 21 samples from five landslide scarps indicated that a wide variety of microfabrics is present, many of which are indicative of soil creep. Additional analysis of sample SM5-157, from a reportedly magnetically reversed stratum, showed that most of the mineral grains hosting the remanent magnetism are detrital, not authigenic, and are present as randomly oriented inclusions within randomly oriented sedimentary grains. The reverse magnetism of this stratum therefore appears to be a statistical artifact and probably unrelated to the contemporary terrestrial magnetic field.

## Speculations Regarding the Origin of the Kennedy Formation

We believe the evidence indicates a combination of debris flows and traction flows coming off the Rocky Mountains as a sheet when the Flaxville surface was one continuous plain abutting the mountains. Following the sheet erosion and deposition of the gravel, increasingly channelized flows eroded the areas between, leaving the erosional remnants high above the surrounding area. Streams–both of water and of ice–would naturally flow in the lowest areas. This scenario is typical of the Abative (sheet flow) and Dispersive (channelized flow) Phases of the Recessive Stage of the Genesis Flood (Walker, 1994; Oard and Klevberg, 1998; Oard, 2001a; 2001b; see Appendix C). Following the Deluge, the short-lived Ice Age (Oard, 1990) would have placed a veneer of till with moraines in the valleys surrounding the erosional remnants. The erosional remnants themselves appear to have been nunataks, high remnants sticking out of the ice that moved out of Glacier Park during the postdiluvial ice age. We believe this natural history scenario corresponds considerably better with the data than does Karlstrom's or the uniformitarian scenarios that preceded it.

## Appendix A

By far the most important magnetic mineral on earth is, naturally, magnetite. Ilmenite is also ferromagnetic, though weaker than magnetite, and hematite (with which ilmenite is often associated) is not listed by some mineralogists as a ferromagnetic mineral (Dietrich and Skinner, 1979, pp. 70–73), while others describe it as "weakly magnetic"

| *Event/Era* | *Stage* | *Duration* | *Phase* |
|---|---|---|---|
| Postdiluvian Era | | 4,000 years | Modern |
| | | 300 years | Residual |
| The Deluge | Recessive | 220 days | Dispersive |
| | | | Abative |
| | Inundatory | 110 days | Zenithic |
| | | | Ascending |
| | | 40 days | Eruptive |
| Antediluvian Era | | 1,700 years | Antediluvial |
| The Creation Event | Formative | 2 days | Biotic |
| | | 2 days | Derivative |
| | Foundational | 2 days | Ensuing |
| | | 0 days | Primordial |

**Figure 27. Walker's geochronologic paradigm as revised by Oard and Klevberg**

(Nesse, 1991, p. 129). However, Strangeway (1970, p. 31) states:

> The most interesting point about hematite in rock magnetism is that it has a very high coercive force. The fine-grained material with no ferromagnetism develops a TRM [thermoremanent magnetization] which is extremely stable. The coarser-grained material with superimposed ferromagnetism has a definite hysteresis with a coercive force of several thousand oersteds. Either type of remanent magnetization shows extreme stability when compared with most other magnetic materials. It is for this reason that hematite, although weakly magnetic, has considerable significance in paleomagnetism.

The techniques used by Cioppa et al. (1995) and Karlstrom and Barendregt (2001) included collection of oriented samples, measurement of remanent magnetization using a spin magnetometer, and step-wise demagnetization. While there is inevitably room for error in each of these steps, we do not find fault with this procedure and retain confidence in their remanent magnetization data. Differing opinions between researchers as to the precision of the data may result primarily from the eigenvalue analysis and interpretation of the strength of trends expressed by the eigenvectors.

While several possible causes for reversed remanent magnetization besides the terrestrial magnetic field have been identified (Barnes, 1973), the terrestrial field remains the most compelling explanation for many of these data. The actual conditions responsible for the formation of the remanent magnetization in the past are, of course, matters of historical speculation and far from certainty.

## Appendix B

Humphreys (1990; 2002) suggests migration of flux loops outside the core into the mantle as a means of generating reversed magnetism. Evolutionists are wont to argue that exchange of energy between Earth's dipole field and nondipole field explains the apparent decrease in the terrestrial dipole field so much in conflict with the evolution worldview and so strongly emphasized by Barnes (1973). However, if enough energy were actually transferred to the nondipole field, the temporarily strong quadripole and octopole fields could result in a temporarily reversed regional rather than global magnetic field. This might also result from Humphreys' proposed flux loops. If the reversed field were stronger than the normal field over part of the Earth's surface, then normally magnetized rocks could be formed in one region, reversed in another. The ramifications of this possibility for magnetostratigraphy should be obvious!

## Appendix C

Various researchers have proposed diluvial chronostratigraphic outlines, probably the best known being Froede's (1995) and Walker's (1994). We have here used Oard's and Klevberg's modification of Walker's geochronologic paradigm (Oard, 2003) as illustrated (Figure 27), which closely reflects previous work by the authors of this paper and ideas introduced long before (Whitcomb and Morris, 1961).

Oard's and Klevberg's changes are relatively minor. We have altered slightly the duration of the phases to conform as strictly as possible to the historic account in the Bible. We have also altered some of Walker's terms. We have replaced Walker's "Lost World Era" and "New World Era" with their traditional time designations, asserting that the former sounds much like a popular movie, while the latter term has been consistently applied to the Western Hemisphere for many decades (e.g. "Old World warblers," "New World flora," *New World Symphony*). The word "flood," or even "Flood," may be too weak and general (potentially confused with other floods), while "mabbul" (the Hebrew word in the Old Testament for this unique event) is probably too obscure; "Deluge" seems a suitable and traditionally employed compromise. The use of widely understood words such as "antediluvian" and "Deluge" is also consistent with Walker's other terms, nearly all of which are derived from Latin ("zenithic" is Greek). This also serves to make the terms less anglocentric, which is a good thing in Klevberg's opinion. Otherwise, the framework used here is very close to Walker's original timescale, which is a logical and practical one. Readers interested in studying historical geology and diluvial paradigms further should consult Walker (1994), Froede (1995), and an important recent paper by Barrick and Sigler (2003).

## Glossary

**authigenic:** grown in place; formed in situ.
**chron:** an interval of earth history during which the earth's magnetic field had a particular orientation, i.e. normal or reversed polarity.
**chronostratigraphy:** a geochronologic paradigm or natural history timescale used to organize geologic data into a stratigraphic relationship. It is important to note that chronostratigraphy begins with an assumed historical scenario and fits the scientific data into this historical construct.
**Curie point:** the temperature below which permanent magnetization is possible.
**Deluge:** the global Flood cataclysm during Noah's time as described in Genesis 6–8.
**detrital:** resulting from physical weathering and transport; not formed in situ.
**diagenetic:** resulting from processes acting on a geologic unit subsequent to deposition.
**diamict:** any heterogeneous, unstratified sediment; the term is descriptive (scientific), not genetic (historical), and includes till and debris flow deposits.
**diluvial:** formed by or during the Deluge.
**diluvialist:** one who interprets geologic history in terms of the primacy of the Deluge.
**drift:** a general term for all glacial deposits, including various kinds of till.
**magnetic susceptibility:** the property of a material that measures its tendency to acquire a permanent magnetic orientation.
**magnetostratigraphy:** stratigraphic correlation based on remanent magnetization patterns.
**paleomagnetism:** remanent magnetic properties preserved in earth materials.
**rounded and subrounded:** the degree to which edges of a clast are smooth and subdued. It differs from shape designations, e.g. a slate boulder that is quite flat could be well rounded if the edges were smooth, free from projections or sharp profiles.
**syndepositional:** contemporary with and resulting from the processes responsible for deposition of a geologic unit.

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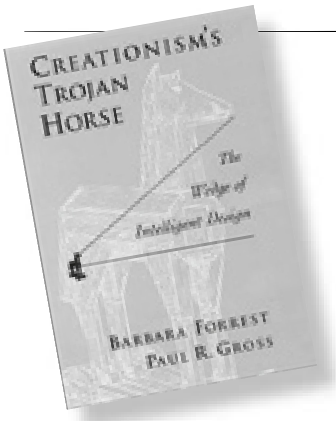


## Book Review

### *Creationism's Trojan Horse: The Wedge of Intelligent Design* by Barbara Forrest and Paul R. Gross
### Oxford University Press, New York, 2004, 401 pages, $40.00.

From time to time I read books and articles from the pro-evolution camp. I do not particularly enjoy this but I think it is important to know what the other side is saying and how they think. *Creationism's Trojan Horse* was a somewhat painful, yet at the same time fascinating, read. It purports to tell the history of the modern intelligent design (ID) movement, albeit from the perspective of writers who are members of the Darwinian choir. Throughout the book Forrest and Gross use the term "Wedge" for the ID movement. The Wedge is really a strategy, not the ID movement itself, but that is a fairly minor point.

The father of the ID movement is law professor Phillip Johnson who started the modern discussion of design with his book *Darwin on Trial* in 1991. Johnson also coined the term "Wedge." *Trojan Horse* describes the Discovery Institute in Seattle as the key player in the movement's growth over the past ten years or so. Forrest and Gross go into some detail about a number of the Wedge's key contributors—particularly Johnson, Michael Behe, William Dembski, and Jonathan Wells. These and other ID theorists are skewered mercilessly and unfairly throughout the book, but I will not go into detail here.

Forrest and Gross have three major themes they keep hammering on. One aim is to convince the reader that ID is really a religious movement, not a scientific one. They refer to ID as "an upgraded form of the religious fundamentalist creationism long familiar to America" (p. 6). Their purpose in using this tactic is to try to persuade the reader that ID is something to be feared and stamped out since its "ultimate goal is to create a theocratic state" (p. 11).

Forrest and Gross are concerned that "the Wedge is associated with some of the most extreme factions of the Religious Right network" (p. 273). They point out, for example, that the movement is supported by such "theocratic extremists" (p. 270) as James Dobson, D. James Kennedy, and Beverly LaHaye. (These are people I have always admired!) Forrest and Gross may fear a takeover by people of faith; I am more concerned about a takeover by people *without* faith (*i.e.*, supporters of naturalism).

A second theme echoed throughout the book is that ID has no scientific evidence to back it up. Forrest and Gross claim the movement has "produced no original scientific data" (p. 39) and that the Wedge has had a "total failure in scientific productivity" (p. 314).

A lot of space is devoted to the fact that ID scientists have not published their work in peer-reviewed science journals. According to Forrest and Gross, "It is *not* hard to get a hearing in regular science journals for ideas like ID" (p. 39). The implication is that if ID had anything important to offer, then the journals would rush to publish it. It is painfully obvious that this is just not true. The reason you do not see pro-ID articles in the journals is that the editors and reviewers will not permit it. They censor ID because it is not naturalistic. Forrest and Gross make no mention of this detail.

Evidence is in the eye of the beholder. *Trojan Horse* discusses in very negative terms such major ID tenets as the sudden appearance of new species and the lack of transitional forms in the fossil record, irreducible complexity at the cellular level, making design inferences based on