The Big Sky Paving Gravel Deposit, Cascade County, Montana

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Abstract

Gravel-capped buttes, benches, and pediments are common in Montana east of the continental divide. One such gravel deposit near Great Falls, Montana, has been extensively mined by Big Sky Paving, Inc. Gravel fabric, sorting, bedding, load structures, and an associated clay rhythmite unit within the gravel deposit are described in this paper. A brief summary of traditional genitive explanations is presented. However, the characteristics of the Big Sky Paving deposit appear to be at variance with these uniformitarian explanations. A biblical approach to earth history provides superior explanations for the depositional features of this deposit.

Introduction

Traditional views of earth history have been severely challenged by data acquired during recent decades from surficial deposits east of the continental divide in Montana and adjacent areas (Crickmay, 1972, 1974, 1975; Shaw, Rains, Eyton and Weissling, 1996). A notable example is the Big Sky Paving gravel deposit near Great Falls, Montana (Figure 1). The gravel pit is located in the southeast corner of Section 32, Township 21 North, Range 3 East, northwest of the City of Great Falls in Cascade County, Montana, at an elevation of approximately 1,082 m above mean sea level (3,550 ft ASL). The site is the summit of a flat-topped hill or butte forming an erosional remnant of an extensive bench or plateau (Figure 2). The valley of the Sun River bounds the south side of the hill and is approximately 65 m (200 feet) lower than the hill and adjacent bench.

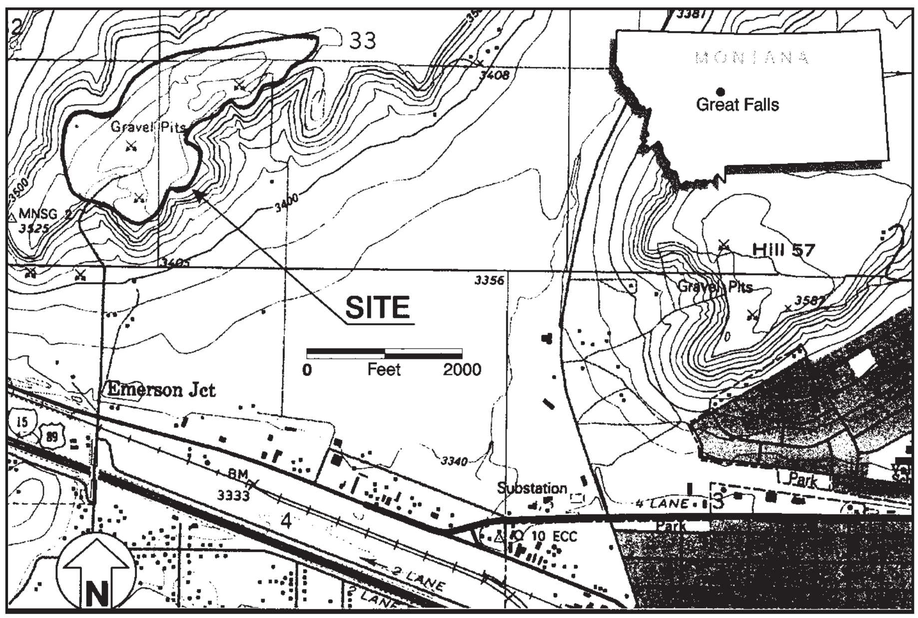

Figure 1. Site location map of Big Sky Paving gravel pit, Cascade County, Montana. From USGS 7.5' Great Falls NW Quad.

This gravel pit is typical of economic gravel deposits in the Great Falls area. Many of the other gravel mining operations in the area are located on the benches bounded by the valleys of the Missouri and Sun Rivers. Such gravel-capped benches are common in Cascade County (Soil Conservation Service, 1982). They are usually referred to as "stream terraces," with the gravels purportedly transported from the Rocky Mountains and deposited over long periods of time by ordinary fluvial processes. No consensus has been reached on whether these processes of transport and deposition included stream capture, lateral corrasion, braided streams, or other fluvial or glaciofluvial processes (Collier and Thom, 1917; Fields, Rasmussen, Tabrum and Nichols, 1985; Hyndman, Alt and Sears, 1988; Ritter, 1967). With the exception of the Sun River Valley, alluvial gravel deposits at elevations lower than the "stream terrace" bench deposits are very uncommon.

The deposit mined by Big Sky Paving (and most local mining operations), labeled the "older Pleistocene gravel," is described by Lemke and Maughan (1977):

> Poorly sorted deposit consisting of abundant, well-rounded gravel, cobbles, and boulder-size rocks of quartzite and argillite, and lesser chert, limestone, and sandstone in a silty sand matrix. High to moderate permeability and well-drained. Rocks are coated with

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Figure 2. View northwest toward bench from northwest side of Great Falls. Big Sky Paving gravel deposit caps bench in background. Location of active mining in 1995-1997 indicated by arrow.

> caliche, especially in upper part of the deposit, and locally are cemented. Unit lies on bedrock and in most places predates the glacial deposits. Generally between 5 feet (1.5 m) and 20 feet (6 m) thick.

The author interviewed Mr. Bill Pfleger, owner of Big Sky Paving, regarding the deposit. He said the deposit has been mined by various companies for at least 20 to 30 years (Pfleger, 1996). Stratification (e.g. separation of clast-supported gravel and sand interbeds) was not common in the deposit according to Mr. Pfleger. Further, he was not aware of structures elsewhere in the pit resembling the load casts observed by the author.

Description of Deposit

The Big Sky Paving deposit originally covered approximately 33 hectares (80 acres) with an average thickness of 3 to 4 m (9 to 12 feet) (Pfleger, 1996). The area described here is primarily the southwest-central portion of the deposit (Figure 1), which was investigated by the author on March 29, 1995, and February 19 and 23, and August 29, 1997. Thin overburden consisting of discontinuous patches of very dark brown to mottled fat clay or silty topsoil roughly 0.1 to 0.5 m (4 to 18 inches or 0.3 to 1.5 feet) overlies the gravel and generally grades abruptly into it. The deposit is underlain by bentonitic shale of the Taft Hill member of the Blackleaf Formation (Lemke and Maughan, 1977). Appendix I has more information about this formation. The gravel-bedrock contact is reportedly unconformable, an assertion substantiated by the irregular base of the pit. Though the contact is generally obscured, maroon bentonitic shale appears to underlie the gravel.

The deposit consists primarily of well sorted (poorly graded) gravel with some interbedded sand. Sand beds up to 1 m (3 feet) thick were common in the 1995 working face but are uncommon elsewhere in the pit. Stratification is weak in most of the deposit, but evident in exposed faces, especially to the east. Since much of the deposit has already been mined, a quantitative assessment of stratification is not possible. Much of the gravel is clast-supported, with easily observed voids between cobbles and large pebbles. The presence of carbonate precipitates ("caliche,") in roughly the upper 0.5 to 1.5 m (1.5 to 4.5 feet) of the deposit provides a weak cement which bonds the clasts and enables near vertical slopes to be maintained in the upper part of most of the pit (calcic or petrocalcic horizons—Soil Conservation Service, 1975). In the west-central part of the pit, soft sediment deformation features, including load casts and contorted bedding, were present (Figure 4). This part of the pit constituted the working face at the time of a site visit by the author on March 29, 1995. These soft-sediment deformation features are the focus of this article.

The majority of clasts observed (roughly 70%) were bladed or oblate, well-rounded, red to tan quartzite. Other lithologies observed were sandstone, limestone, argillite, chert, and trachyandesite. The largest clast observed by the author was a prolate, well-rounded red banded quartzite cobble with a median diameter of 23 cm (9 in). With the exception of the sandstone (apparently from the subjacent Blackleaf Formation), the lithologies observed are presently exposed in the Rocky Mountains a minimum of 95 km (60 miles) to the west.

Channel deposits, cross-bedding, and pervasive imbrication were not observed in 1995 or 1997. With one exception, imbrication was limited to a few locations on a scale of approximately one meter, and appeared to conform to deformational features. Only one portion of the deposit exhibited strong imbrication. This was the south working face observed during a site visit on February 19, 1997, located approximately 100 m (300 feet) south-southeast of the March, 1995, working face (center of south end of deposit, Figures 1 and 2). Oblate pebbles and cobbles in the 1997 working face exhibited northwest to southwest dip directions, indicating transport from the west (Figure 3). Maximum dip observed was 25° to the west with an inferred paleocurrent direction of 080° (N80E).

A few minor soft sediment deformation structures were observed in most of the pit, being absent in those areas

Figure 3. View of 1997 south working face showing imbrication.

Figure 4. View of 1995 working face showing sand interbeds and load casts. Length of scale is one meter. Snow covers slough from working face.

nearly devoid of sand interbeds. In the west-central part of the pit (1995 working face), sand interbeds between gravel strata displayed load casts and contorted or convolute laminations (Figures 4–11). Load casts were present, though not abundant, in the north working face observed in February, 1997, located approximately 15 m south of the 1995 working face (Figure 12). Sand was abundant in the 1997 north working face and contained randomly oriented oblate and bladed pebbles up to 6 cm (2.5 inches) median diameter.

A thin clay deposit roughly 25 cm (10 inches) thick at the east end of the 1995 working face (located slightly to the left of the area shown in Figure 4) was observed which formed the overburden over an area approximately 3 m (10 ft) in diameter (Figure 13). This small deposit of fine-grained sediment consisted of laminated silty clay and fat clay overlying clast-supported gravel (Figure 14). The laminations were deformed, broken, or absent in the upper part of the clay unit. Cobbles were present in the upper part of the clay, possibly representing disturbance during removal of other overburden nearby, or more likely the average annual wetting depth and resulting blending of the clay and gravel units to achive a less ordered, lower energy state. Laminations were intact in the lower half of the clay unit. Laminations were approximately 1 cm (0.5 in) thick. Deposits of this sort are typically called "varves" and assumed to represent annual layers in proglacial lakes (Gilbert, 1975; Bates and Jackson, 1984; Oard, 1992a). The Big Sky Paving pit lies outside glacial deposits and Glacial Lake Great Falls according to Lemke (1977) and Lemke and Maughan (1977).

Similar dark clay was observed in February, 1997, forming overburden along part of the 1997 south working face but lacked laminations. By August, 1997, mining had exposed a clay rhythmite across approximately 30 m of the working face. This corresponded spacially with the clay observed in February, 1997. The rhythmite constituted an interbed between gravel strata and dipped toward the northeast. This appears consistent with proximal imbrication and with the attitude of other stratified parts of the deposit. A zone of disturbed laminae containing pebbles and cobbles formed the top of the unit, similar to that observed in the 1995 working face.

Elsewhere, dark clay interbedded with silt, sand, and fine gravel (granules and pebbles) was observed in 1997 at the southeast edge of the deposit. One fine-grained, stratified interbed (Figure 15) was observed with progradation indicating flow in a direction approximately 090° (N90E). Imbrication of small gravel in the nearby face (Figure 16) was quite variable, but oblate pebbles generally dipped east-northeast. The strike of stratification in this face was measured at 095° (N95E), dipping to the south at 7°. Lime cementation was present in two seams of coarse gravel in the southeast corner of the pit. These zones (petrocalcic horizons) were stratiform for a distance of roughly 50 m, becoming more weakly cemented to the east and more strongly cemented but irregular in form to the north.

Depositional Environment

Soft sediment deformation features provide clues to the depositional environment. Load casts, contorted bedding, and highly deformed or convolute laminations are often observed where sandstones overlie mudrocks. Selley (1976, p. 227) attributed them to a variety of ancient and modern depositional environments, including turbidite, deltaic, and fluvial facies. Tucker states:

> Load structures are formed through differential sinking of one bed into another. Load casts are common on the soles of sandstone overlying mudrock, occurring as bulbous, rounded structures, generally without any preferred elongation or orientation (Tucker, 1982, p. 70).

These inferred depositional processes are time-dependent because fluid pore pressure in the lower stratum, a critical variable, is dependent on the permeability of the upper stratum and loading experienced by the sediment. Load casts are indicative of the rapidity of deposition of the overlying stratum and hydroplastic nature of the underlying

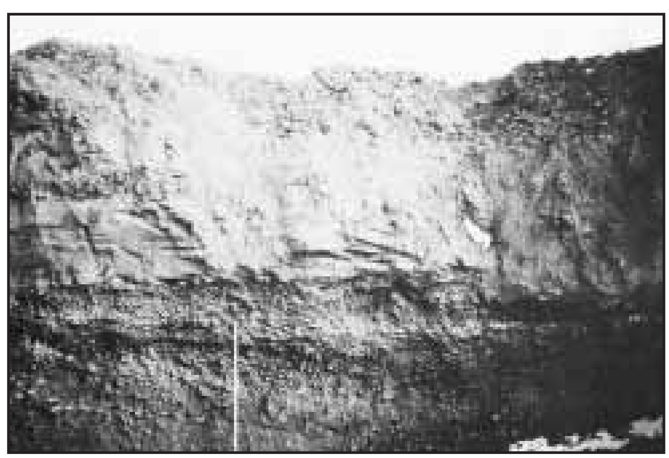

Figure 5. Massive sand interbed in clast-supported gravel. Length of scale is one meter.

Figure 6. Convolute lamination or contorted bedding in sand interbed. Length of scale is one meter.

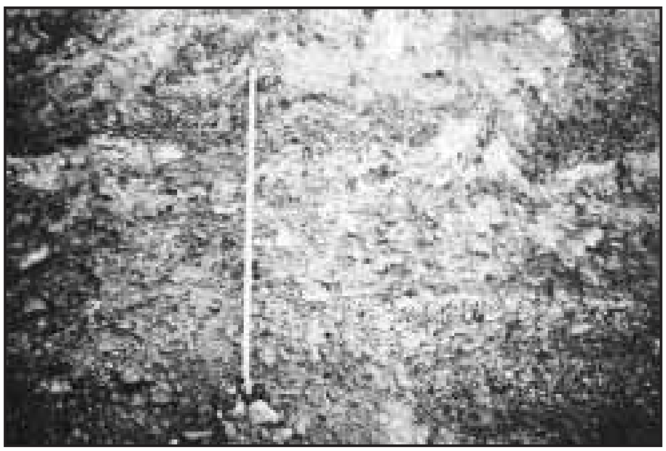

Figure 7. Close-up view of load structures to left of meter stick in Figure 4. Note that fabric cuts across gravel-sand interface at left side of load cast. Length of scale is one meter.

Figure 8. Zone of extensive mixing of poorly graded (uniform particle size) gravel, sand with gravel, and well-graded (poorly sorted) gravel. Note that bedding plane visible in lower right of photograph disappears to left. Length of scale is one meter.

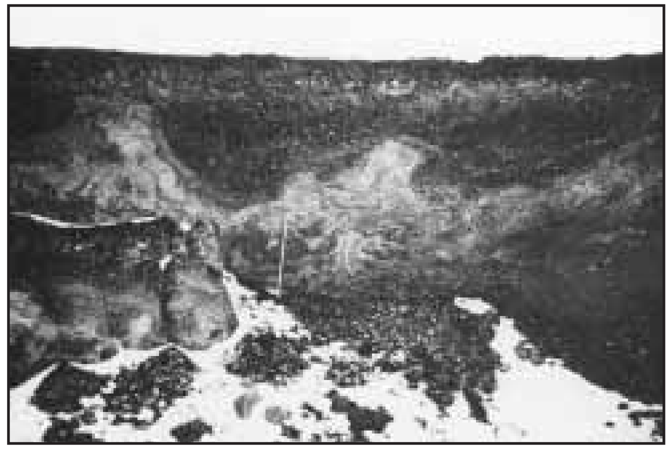

Figure 9. Closer view of load structures near meter stick in Figure 4. Both contorted laminations and load casts are evident in sand interbed. Length of scale is one meter.

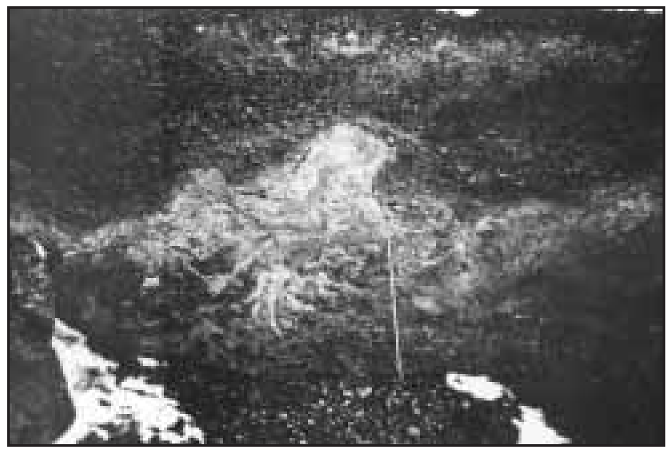

Figure 10. Closer view of Figure 9. Note clast-supported gravel beneath sand body. Length of scale is one meter.

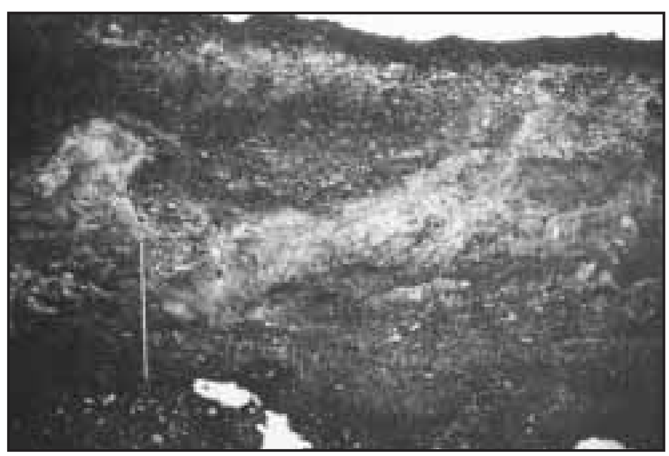

Figure 11. View to right of Figure 10. Note coarse, poorly-graded gravel above deformed sand interbed, sandy gravel below interbed, and mixing of units at right. Length of scale is one meter.

stratum, not of a unique depositional environment (Potter and Pettijohn, 1977, p.200).

Experimentation by various researchers has provided theoretical explanations for load casts and other soft sediment deformation phenomena. "There is general agreement that these structures are generated by the differential loading of a waterlogged sand on an unconsolidated mud" (Selley, 1976, p.227). The instability that produces the deformation results from a reverse density gradient (Blatt, Middleton, and Murray, 1972, pp. 173,174). As stated by Blatt, Middleton, and Murray (1972, pp. 174,175), the presence of pore fluids is an important factor in the deformation of the unconsolidated sediments:

> In a sediment where the increase in effective pressure is produced rapidly (e.g. by fast sedimentation), the compression of the sediment at some time t will be less than the ultimate compression that would take place if enough time were to be allowed for the pore water to escape. The degree of consolidation is defined as the ratio between the compression at t and the ultimate compression. At any stage short of ultimate compression, part of the pressure of the sediment must be transmitted to the pore fluid so that the pore fluid pressure exceeds hydrostatic by an amount equal to the excess pore pressure. Sediments with excess pore pressures are described as underconsolidated.
>
> The response of a sediment to shearing depends on the angle of internal friction (ϕ) and the cohesion of the sediment (c). Suppose the shear stress is τ and the total normal pressure is σ, then the effective pressure (σ-u), where u is the pore pressure; the relation between these pressure and stress variables is given by:
>
> $$\tau = c + (\sigma - u)\tan\phi. \qquad (1)$$
>
> Deformation of the sediment may therefore be facilitated by reducing the cohesion c, by reducing the coefficient of internal friction $\tan\phi$ (e.g. by altering the packing of the sediment), or by increasing the pore pressure u. In the previous section it was remarked that most soft-sediment deformation structures in sands are restricted to coarse silt to fine sand grades. The reason for this is now clear. These size grades are the ones where the cohesion is not large, where rapid deposition from suspension and an unstable packing are possible, and where the permeability is low enough to prevent rapid loss of pore fluids. Consequently, the fine sands are those most likely to undergo loss of strength and at least partial liquefaction.

Contorted bedding and convolute lamination can be produced by a variety of causes. McKee, Crosby and Berryhill (1967) attributed convolute laminations in fluvial sand to quicksand conditions (zero intergranular pressure) at the conclusion of flooding (p. 840).

> Deformed bedding can arise from a number of processes. Shearing by currents on a sediment surface and frictional drag exerted by moving sand are thought to cause some convolute bedding and overturned cross-bedding. Dewatering processes such as fluidization and liquefaction (often induced by earthquake shocks) give rise to convolutions, contortions and disruptions (Tucker, 1982, pp.68,69).

The deformation structures at the Big Sky Paving pit differ from these classic cases in that the sediments are gravel overlying sand rather than sand overlying mud. Although the features observed in the Big Sky Paving deposit are similar in form to load casts and deformed bedding commonly seen in fine-grained sediments, the properties of the sediments differ, as summarized in Table I.

Cohesion is generally low in granular soils and may be negligible in poorly graded (well sorted) ones consisting of well-rounded particles, such as the upper gravel stratum in the 1995 working face (Figures 4, 5, 8, 10, and 11). This would favor development of load structures following deposition. Rapid deposition from suspension is not commonly considered in studies of gravel deposits because of the energy required to transport large pebbles and cobbles in this mode. However, transport via intermittent suspension and rolling would tend to produce channel and bar deposits, which are not observed at the Big Sky Paving pit. The general lack of imbrication also suggests that the deposit was not formed by typical fluvial processes. Imbrication is common in fluvial deposits, but would not be expected if the

Table I. Salient Implications of Deformation Features at Big Sky Paving Gravel Deposit, Cascade County, Montana.

Observation	Implication	Conclusion
Poorly graded, well rounded clasts	Cohesion relatively low	Favorable condition for development of load structures following deposition
Lack of channel and bar deposits	Transport via intermittent suspension and rolling unlikely; migrating channels unlikely	Transport via suspension probable; possibly sheet flow rather than channelized flow
Coarse-grained sediments	Relatively large energy level required for transport	Catastrophic deposition, not typical fluvial deposition
General lack of imbrication	Deposit probably not formed by typical fluvial processes	Clasts probably deposited from suspended rather than bed load
High permeability	Water could escape rapidly from sediments during deposition	Time required to form deformation structures brief and transport energy high

Figure 12. View of 1997 north working face.

clasts were deposited from suspended rather than bed load. The permeabilities of sand and gravel are obviously much greater than permeabilities typical of fine-grained sediments, suggesting that pore fluids would be lost relatively rapidly from the Big Sky Paving deposit immediately upon deposition. If the role of fluid pore pressure is of primary importance in the formation of load structures, then the time required to form them must have been very short in light of the permeability of these coarse-grained sediments. If the role of fluid pore pressure is not of primary importance in forming load structures, then the transport energy must have been high to deposit coarse gravel atop the sand stratum.

Stratification does not imply a depositional hiatus or change in flow regime. Stratified deposition of fine-grained sediments has been documented by Berthault (1986), Carey and Roy (1985), and others, and some quantitative descriptions of the fluid mechanics processes have been developed. Whether similar processes occur in coarse-grained sediment deposition (dominated by inertial forces) is unclear; however, Shaw and Kellerhals (1977) documented segregated sand and gravel deposits which provided evidence for contemporaneous transport of the sand and gravel fractions.

Assuming equant quartzite particles (for simplicity) and fluid properties approximating those of "clean water," the terminal velocity of the suspended particles can be balanced with the drag force resulting from current turbulence using the empirical relation that the transverse component of velocity is approximately eight percent of the component of velocity in the direction of transport (Blatt, Middleton, and Murray, 1972, p. 100). This results in the following restriction on the minimum average current speed u_{min} (time rate of change of position in the direction of transport):

$$u_{min} \geq 12.5\sqrt{(2F_D / (C_D A\rho))}, \qquad (2)$$

where F_D is the drag force, C_D is the drag coefficient relative to turbulence (i.e. counteracting gravity), A is the particle area normal to the gravitational gradient, and ρ is fluid density. Note that u_{min} refers to the magnitude of the current transporting the suspended sediment and may differ from the average speed of the current as a whole, which may have been greater. The calculation is iterative, the drag coefficient being determined from a figure for axisymmetric bodies (Roberson and Crowe, 1985).

Using the above relations and a median clast diameter of 64 mm (2.5 in), a minimum current speed in excess of 11 m/s (36 fps or 24 mph) is required to maintain the clast in suspension. For 100 mm diameter (4-inch) cobbles (common in some of the coarse gravel bodies addressed here), this equates to a minimum mean current speed of 14 m/s (46 fps or 30 mph). For bladed 64 mm (2.5-inch) clasts, the estimates are less precise due to likely rotation of particles in the current and resulting changes in values of A and C_D; however, a reasonable estimate is u_{min} in excess of 17 m/s (56 fps or 38 mph). For the occasional 150 mm (6-inch) bladed cobble, the value of u_{min} required to maintain transport in suspension would be approximately 30 m/s (98 fps or 68 mph). The average current speed at the time of deposition could have been any value in excess of u_{min} to maintain sediment in suspension. Interaction of particles in sediment-laden water might be expected to reduce the requisite value of u_{min} somewhat, while simultaneously increasing the requisite energy for fluid transport. Lower power (time rate of energy) levels are required for transport of coarse sediments as bed load than as suspended load. Since the largest clast (230 mm or 9 inches) was not observed in situ, it may not have been associated with the load casts and may have been transported as bed load. Most paleohydraulic equations applicable to coarse sediments address bed load transport. These equations are based on hydrodynamic theory or empirical data for the limited range of conditions encountered in certain modern streams (Williams, 1984). Maizels (1983) evaluated open channel flow equations commonly used in engineering calculations for application to coarse sediment transport. Church, Wolcott and Maizels (1990) provided corrections to Maizels' article, showed the basic equivalence of the various methods, and recommended use of the Keulegan Equation. Unfortunately, the Keulegan Equation, like most open channel flow equations, requires knowledge of flow depth. Flow depth may be known for modern streams through gauging or channel depth, but is not generally accessible in paleohydraulic analyses.

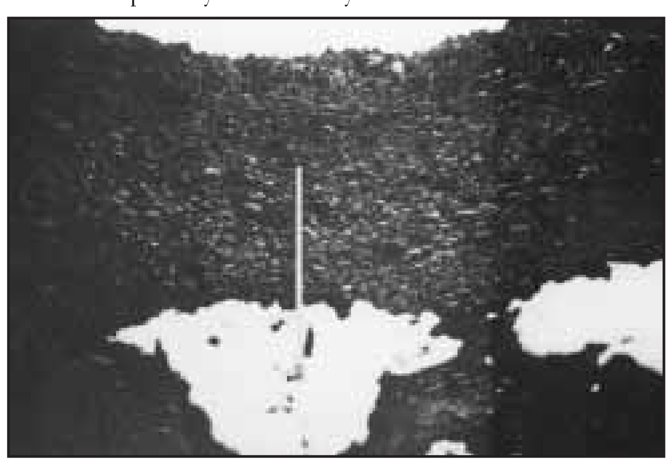

Figure 13. Laminated clay atop clast-supported gravel. Length of scale is one meter.

Figure 14. Closer view of laminated clay. Upper part of clay unit probably corresponds with the average annual wetting depth. Scale graduated in feet.

Costa (1983) compared two theoretical methods (turning moments of Helley and drag-lift-friction) and two empirical methods (least squares regression and U.S. Bureau of Reclamation) for velocity and depth estimation from coarse sediment transport to nine watersheds in the Colorado Front Range. He found that discharge estimates for historic flash floods based on an arithmetic average of the four methods differed by less than 76 percent from values obtained by the slope-area method traditionally used to estimate ungauged stream discharges. Similarly, Williams (1983) presented an empirical relation for minimum current speed based on intermediate particle diameter. Although large velocity fluctuations typical of turbulent flow may exceed the threshold velocity for incipient motion, transport of coarse bedload requires a minimum mean current speed somewhat greater than the threshold velocity, since the threshold velocity is defined by incipient motion.

Slope is somewhat difficult to estimate from the erosional remnants west and east of the Big Sky Paving deposit, and actually appears adverse in relation to Hill 57 (Figure 1). The depositional surface slope based on the surface of the Blackleaf Formation outcropping on various erosional remnants as much as 30 km (20 miles) west of the site (Lemke, 1977) is less than 0.0010 and closer to 0.0001. The streams studied by Costa, which generally had slopes in excess of 0.05, may make poor analogues for the Big Sky Paving deposit, which has a much smaller slope. However, the data he used in developing his equations included some streams with slopes of 0.001 or less. Based on the maximum observed clast size and the method of Costa, the magnitude of the threshold velocity necessary to transport the gravel as bedload would have been 2.6 m/s (8.5 fps or 6 mph). The method of Williams yields a minimum current speed of 1 to 7 m/s (3 to 23 fps, or 2 to 16 mph). This indicates that the minimum current speed required for the suspended sediment load to produce load casts is greater than that required for transporting the largest observed clast as bed load.

Genitive Inferences

The characteristics of the Big Sky Paving gravel deposit suggest that a powerful current deposited the sand and gravel rapidly from suspension. The location of the load structures in the west part of the deposit; imbricated pebbles and cobbles near the center; and stratified, finer, more variable material to the east may indicate a loss of competence across the deposit, possibly due to irregularities or obstructions in the bed. It may also indicate overloading of the current with sediment. Obstructions might shelter sand, preventing removal by the current transporting the pebbles and cobbles; however, other studies indicate that sand and gravel may be deposited together (Shaw and Kellerhals, 1977) or that relatively large, heavy bodies may be deposited above sand in upper flow regime fluvial deposits (McKee, et al., 1967). A local loss of competence might also result from transient turbulent processes or fluctuations in the current. Increased variability in sediment type, a general decrease in grain size, and variability in inferred paleocurrent directions in the southeast part of the deposit may have resulted from

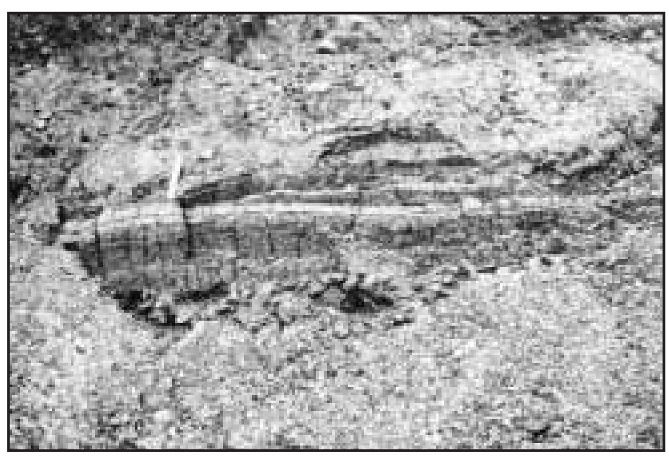

Figure 15. Fine-grained interbeds in southeast corner of deposit. Scale is 6 inches (15 cm). Mottled appearance from snow.

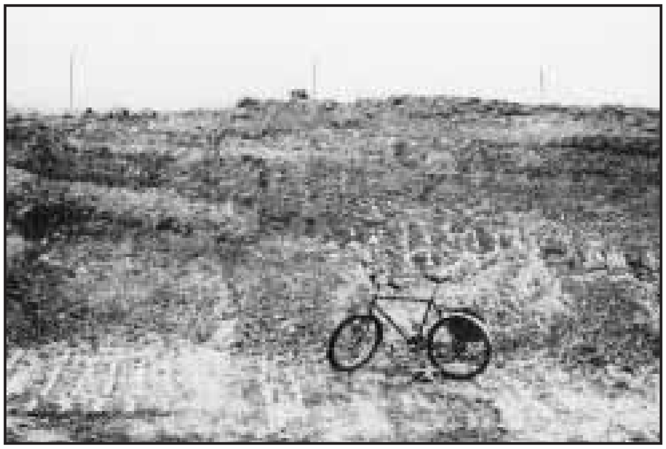

Figure 16. East face in southeast corner of deposit showing gravel strata. Pebbles dip east-northeast. Stratification strikes 095° (S85E), dipping south at 7°.

eddies, episodic deposition, or development of the Sun River channel to the south. The close association of these features attributed, respectively, to transport as suspended load and transport as bed load may indicate that the actual current speed was not significantly greater than the minima estimated above.

Historical Analysis

According to the establishment geologic paradigm, the Big Sky Paving deposit and related gravel deposits are traditionally viewed as stream terrace deposits. They are widely believed to have formed in the early "Pleistocene Epoch" as individual streams transported gravel eroded from the Rocky Mountains eastward across the plains, or as flash floods transported gravel across alluvial fans or bajadas. Laminated clay deposits are typically thought to be "varves," representing annual depositional cycles in proglacial lakes or older lacustrine environments.

The features observed at the Big Sky Paving gravel pit appear to require a catastrophic event in the relatively recent past. Load casts and deformed bedding observed in this gravel deposit indicate depositional instability caused by a reversed density gradient. The general lack of imbrication, absence of channel and bar deposits, and the abundance of clast-supported gravel do not support a traditional fluvial interpretation of the deposit. The deformation features observed in the deposit are expected where sediment has been transported as suspended rather than bed load. The characteristics of this gravel deposit appear most consistent with very rapid, high energy deposition and syndepositional deformation.

The paucity of overburden and presence of clast-supported gravel are not compatible with an age of many thousands of years of exposure. Based on the presence of large aeolian deposits elsewhere in the area (Lemke and Maughan, 1977), aeolian transport alone might have been sufficient to deposit considerably more than the average 25 cm of fine-grained material, and a particle size gradient should be evident as sand and smaller particles migrate downward through the gravel. The presence of relatively pure carbonate cement is not indicative of a gradual, ongoing process. Multiple, distinct horizons and irregular boundaries between lime-cemented and lime-deficient gravel may indicate that the carbonate is syndepositional. Multiple caliche layers would not be expected to form, since layers formed earlier would be destroyed by dissolution. The abundance of limestone in the presumed source area suggests that the limestone may have been the source of the carbonate minerals cementing the gravel and may have been deposited with the quartzite pebbles and cobbles.

The gravel deposit shows evidence of energetic deposition (as do similar deposits in the area). Historically, vast, highly energetic currents capable of transporting cobbles and boulders great distances over large areas can be expected to have occurred during the Deluge (Genesis 6:13,14; 7:11,18-24; 8:1-5). Such phenomena might correspond to the Dispersive Phase of Walker's geochronologic paradigm (Walker, 1994) or the Upper Flood Division of Froede (Froede, 1995). As pointed out by Reed, Froede, and Bennett (1996, p.100), the end of the Deluge may be difficult to identify in the geology of a locale due to a gradual decline in the rate of energy expended in geologic processes. The historical setting for the formation of the Big Sky Paving deposit, as an example of a remnant of a laterally extensive, high energy process, is therefore most likely very late diluvian or very early postdiluvian time. The probability of such a geologic process declines with increasing time since the Deluge.

Another possibility would be catastrophic glaciofluvial events. Although continental glaciation would be grossly improbable from a uniformitarian standpoint, catastrophic glaciation could well have resulted from the Deluge (Oard, 1990). Catastrophic melting and outburst flooding (jökulhlaup) could explain many features inexplicable by present processes. Such a genitive mechanism would correspond to the Residual Phase of Walker's geochronologic paradigm (Walker, 1994) or the Upper Ice Age Division of Froede (Froede, 1995). However, the fact that the Big Sky Paving deposit is part of a vast sheet deposit 65 m above the valley of the underfit Sun River and at a considerable distance from the source area does not appear to support a glaciofluvial explanation.

The presence of laminated clay atop clast-supported gravel and as an interbed within gravel strata is not consistent with gradual deposition in a lacustrine or glaciolacustrine environment. The lack of clay-size particles in the subjacent gravel supports neither gradual deposition nor extended time since deposition. Since moisture adequate to permit natural mixing of the clay and gravel by gravity alone appears to be affecting the upper portion of the clay deposits, it appears probable that even slightly more moisture than experienced in the present arid climate would be sufficient to induce mixing of the clay and subjacent gravel. This is not consistent with the idea of a gradual retreat of glaciers and concomitant climate change. Vast periods of time virtually imply climate change.

Formation of laminated deposits of some fine-grained sediments has been observed to be independent of current velocity (Berthault, 1986). Many clay and silt rhythmites have been shown to result from hyperpycnal flows such as turbidity currents rather than the traditional "varve" mechanism (Lambert and Hsü, 1979; Oard, 1992a,b). The clay was probably deposited rapidly. The discontinuous nature of the clay deposits may result from partial erosion of the rhythmite, or it may indicate that various rhythmite units formed in a relatively heterogeneous depositonal milieu.

Conclusions

The Big Sky Paving deposit is unusual in the prevalence of load casts and related soft-sediment deformation structures in sand beds beneath gravels. These features are typical of deposition from suspension, requiring energetic currents. The changes in particle size, imbrication, and bedding across the deposit are consistent with an eastward paleocurrent direction, possibly with a decelerating or variable current. The lithologies are typical of rocks outcropping in the Front Range of the Rocky Mountains 95 km (60 mi) or more to the west. These features are consistent with genitive speculations invoking transport via highly energetic sheet flow. The presence of laminated clay above largely clast-supported gravel is consistent with neither glaciolacustrine deposition nor a long time period since deposition. The inferred depositional environment is not consistent with the historical framework of the establishment geologic paradigm. The inferred genitive history of the deposit is compatible with the diluvial geologic paradigm and probably corresponds to late diluvian or early postdiluvian time. Although the Deluge appears to be the only reasonable explanation for the geologic conditions necessary to form the deposit, greater precision in historical placement of the deposit than that presented here does not appear justified by the scientific data is is probably unwise. Other surficial gravel deposits in the region should be examined and the geologic data compared with traditional interpretations (including alleged age). Recognition of biblical authority provides a superior approach to both the scientific study of this deposit and its implications for earth history. The same may be expected elsewhere (Matthew 5:18).

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Glossary

aeolian—Deposited primarily by wind.
alluvial—Unconsolidated detrital sediments, usually deposited by streams along their courses.
bentonite—Clay composed primarily of montmorillonite, with minor amounts of other smectite minerals.
bladed—Shaped like a flattened cylinder or elongated disk.
caliche—A soil type in which grains are cemented by calcium carbonate.
clast—An individual rock particle, including sand grains, pebbles, cobbles, and boulders.
cobble—A rock with median diameter of 64 mm to 256 mm (2.5 to 10 inches), intermediate in size between pebble and boulder.
corrasion—Abrasion, ablation, and attrition.
deltaic—Typical of deposits formed where running, sediment-laden water enters still water.
Deluge—The global, catastrophic flood that occurred during the lifetime of Noah.
diluvian—Occurring during the Deluge.
equant—Roughly spherical.
fabric—Grain orientation in a deposit.
fat—Said of clay having a plasticity index of 50 or greater; indicates high moisture sensitivity and domination by smectite minerals.
fluvial—Typical of deposits formed by streams.
geochronologic—Pertaining to the history of events molding the Earth's surface.
glaciofluvial—Typical of deposits formed by streams emanating from glaciers.
imbrication—The shingle-like orientation or fabric of bladed or oblate particles. The particles usually dip into the current.
lacustrine—A lake environment; typical of deposits formed in lakes.
load cast—A bulbous or irregular projection of an overlying bed into an underlying bed, inferred to be a soft sediment deformation feature.
oblate—Disk shaped.
paleohydrology—Estimation of possible past flow parameters from sediment characteristics, erosional and depositional features.
pediment—A gently sloping erosion surface projecting from a steep mountain front.
permeability—The rate at which water can migrate through a sediment under a given pressure (head).
petrocalcic horizon—A soil science term for a lime-cemented conglomerate, i.e. earth material in which calcium carbonate fills spaces between mineral particles and cements them.
progradation—Differential deposition of sediments (e.g. sand, silt, then clay), resulting in movement of an inclined depositional surface in the current direction.
prolate—Roller shaped or roughly cylindrical.
rhythmite—A banded sediment in which sediment types alternate.

syndepositional—Occurring during a depositional process.
terminal velocity—The velocity at which the drag force opposing particle motion equals the weight of the particle, resulting in constant speed downward through the fluid.
turbidite—Characteristic of deposits formed by turbidity currents (hyperpycnal flows or bodies of heavily sediment laden fluid that move along the bottom of water bodies, often at great speeds or for great distances).

Appendix I—The Blackleaf Formation

According to Lemke and Maughan (1977), the Blackleaf Formation consists of two members, the Taft Hill Member and the Flood Member. The basal Flood Member consists of three units: a basal flaggy sandstone interbedded with shale [claystone?] approximately 6 m (20 ft) thick; a dark shale unit approximately 15 m (50 ft) thick; and an upper massive sandstone unit approximately 20 m (65 ft) thick. The upper Flood Member sandstone forms prominent bluffs, including the base of the bench on which the Big Sky Paving deposit rests. The Taft Hill Member forms the upper portion of the Blackleaf Formation. It consists of many thin strata and laminae of bentonitic shale, bentonite, siltstone, and glauconitic sandstone. Roughly the basal 30 m (100 ft) of the approximately 73 m (240 ft) thick member is present beneath the Big Sky Paving deposit. The Taft Hill Member weathers rapidly and is easily eroded.

According to the establishment geologic pardigm, the Blackleaf Formation is "Upper Cretaceous." It overlies the Kootenai Formation, a highly variable "continental" deposit included in the "Colorado Shale" group. The Big Sky Paving gravel is labeled "early Pleistocene." Virtually identical gravel 9 km (5 mi) east of the Big Sky Paving site is labeled "upper Pleistocene" due to stratigraphic relations with presumed glacial deposits. An unconsolidated silty fine sand (glaciolacustrine) unit containing fossil snails in places follows the base of the bench on which the gravel deposit is located.

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Book Review

After the Flood: The Early Post-Flood History of Europe Traced Back to Noah by Bill Cooper

New Wine Press. Chichester; England. 1995. 256 pages. Paper £7.99.

Reviewed by Pete J. Williams*

Though records such as those of Nennius (eighth century AD) and Geoffrey of Monmouth (twelfth century AD) are generally regarded by scholars as of little historical value for consideration of the pre-Roman period in Britain, Cooper believes that these and other sources of similar date make it possible to reconstruct the history and succession of kings in Britain for over a thousand years before Caesar's conquest of Britain. In addition these records preserve striking independent confirmation of the genealogical material found in the Table of Nations in Genesis 10 and 11 since six royal houses in Britain, as well as the Danish, Norwegian, and Irish Celtic kings trace their descent from Noah. In addition to arguing for the general historicity of the genealogical records, Cooper also argues that many records of monsters from this period are in fact records of dinosaurs. This is argued at length in respect of Grendel, the monster of the *Beowulf* epic.

Creationists cannot assume that the conclusions of evolutionists about a document can be accepted unaltered, and Cooper is surely right to bring the sources he does to our attention for evaluation. However, he presents his readers too often with the choice of either believing that such sources are pious fiction or that they preserve historical records of early post-Flood history independent of the Bible. The reader is quickly convinced that we are not dealing with fraud or fiction, and so is left with the suggested solution that some of the descendants of Japheth reliably recorded their genealogies for well over two thousand years. However, the large time-scale involved allows the genealogical records to have arisen at a period sufficiently distant from the medieval scribes to exonerate them from dishonesty, and yet not sufficiently close to the figures of Genesis 10 and 11 to provide historical confirmation of their existence.

Furthermore the independence from the Bible of the genealogical records cited by Cooper is highly debatable. The fact that the manuscripts involved come from areas where the Bible had been available to scribes for hundreds of years, and the way that Nennius (see Appendix 5) contains a genealogy relating Biblical figures to characters from Vergil's *Aeneid* (the best known Latin epic) witnesses against the independence of the genealogies.

The first three of the fourteen appendices are useful in providing extra-Biblical attestations of the names of the descendants of Shem, Ham, and Japheth recorded in Genesis 10 and 11. These suggested attestations, which are of mixed value, come from a much wider variety of sources than the northwest European sources which constitute the bulk of the book. Cooper is not so familiar with these sources, and thus one reads seven times of the "Armana tablets" when one should read of the "Amarna tablets."

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