



Sedimentary evolution of the Miocene-Pliocene Camp Davis basin, northwestern Wyoming  
by Timothy John Olson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in  
Earth Sciences

Montana State University

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Abstract:

The late Miocene to early Pliocene Camp Davis Formation of northwestern Wyoming consists of conglomeratic lower and upper members separated by lacustrine limestone, siltstone, and tuff of the middle member. Detailed lithofacies analyses show the lower member (75 to 100 meters) to consist primarily of massive to horizontally stratified pebble to cobble gravel (Gm) and trough cross-stratified granule to pebble gravel (Gt). Deposition occurred in a Scott-type braided stream system characterized by development and aggradation of diffuse gravel sheets and longitudinal bars (Gm) and filling of shallow channel scours (Gt). Paleocurrent data and presence of reworked Precambrian quartzite clasts and distinctive, yet previously unrecognized, Tertiary intrusive clasts suggest deposition by a south to southeastward flowing axial-parallel fluvial system (ancestral Snake River).

The upper member (1500 meters) is dominated by muddy, clast-supported, massive to horizontally stratified pebble to boulder conglomerates (Gm/Dcm and Gm/Dcm-Dmm) deposited by streamflow, sheetflood, hyperconcentrated flood flows and high-strength plastic debris flows. Matrix-supported conglomerate (Gms/Dmm) is typically massive, may be inversely graded, and represents deposition by high-strength plastic debris flows. Low-angle trough crossbedded gravel (Gt) accumulated during shallow scour infilling within shallow bed-load streams and during periods of unconfined sheet-flood. Collectively, these lithofacies suggest deposition on the proximal portion of a hyperconcentrated flood flow-dominated alluvial fan. Clast imbrication measurements indicate a southwestward paleoflow direction. Clasts include Paleozoic and Mesozoic sedimentary and Precambrian crystalline rocks derived from the Hoback and Gros Ventre ranges to the northeast.

The lower and middle members are interpreted to have been deposited in an incipient Camp Davis basin prior to major movement on the Hoback listric normal fault. Upper member deposition was in response to major motion along the Hoback fault which may have occurred later and over a shorter period of time than previously thought.

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A thesis submitted in partial fulfillment  
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of

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Earth Sciences

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**APPROVAL**

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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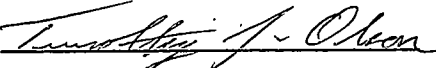
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## ABSTRACT

The late Miocene to early Pliocene Camp Davis Formation of northwestern Wyoming consists of conglomeratic lower and upper members separated by lacustrine limestone, siltstone, and tuff of the middle member. Detailed lithofacies analyses show the lower member (75 to 100 meters) to consist primarily of massive to horizontally stratified pebble to cobble gravel (Gm) and trough cross-stratified granule to pebble gravel (Gt). Deposition occurred in a Scott-type braided stream system characterized by development and aggradation of diffuse gravel sheets and longitudinal bars (Gm) and filling of shallow channel scours (Gt). Paleocurrent data and presence of reworked Precambrian quartzite clasts and distinctive, yet previously unrecognized, Tertiary intrusive clasts suggest deposition by a south to southeastward flowing axial-parallel fluvial system (ancestral Snake River).

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## INTRODUCTION

### Purpose

Late Tertiary extension, associated with development of the Basin-and-Range structural province, was superimposed upon older thrust terranes of the Sevier orogenic belt in portions of the Cordillera of western North America. Many of the preexisting thrust ramps were reactivated as listric normal faults in response to this extension, forming rapidly-subsiding basins which filled with thick sedimentary sequences (Royse and others 1975; Constenius, 1982). The deposits of these listric normal fault-bounded basins, especially coarse-grained basin margin facies, are generally poorly exposed, thereby preventing detailed stratigraphic, sedimentologic, and provenance studies. Hence, understanding of the depositional and tectonic histories of such basins is typically poor.

This study provides an example from northwestern Wyoming of the potential depositional and tectonic complexities which may exist in late Tertiary basins of the northern Rocky Mountain region. Excellent northeast dipping exposures of the late Miocene to early Pliocene Camp Davis Formation are present along the west flank of the Hoback Range in northwestern Wyoming (Figure 1). These exposures provide a unique opportunity to study in detail the sedimentology, stratigraphy, and provenance of late Tertiary coarse-grained basin-fill, in order to gain a better understanding of the tectonic and sedimentary evolution of a

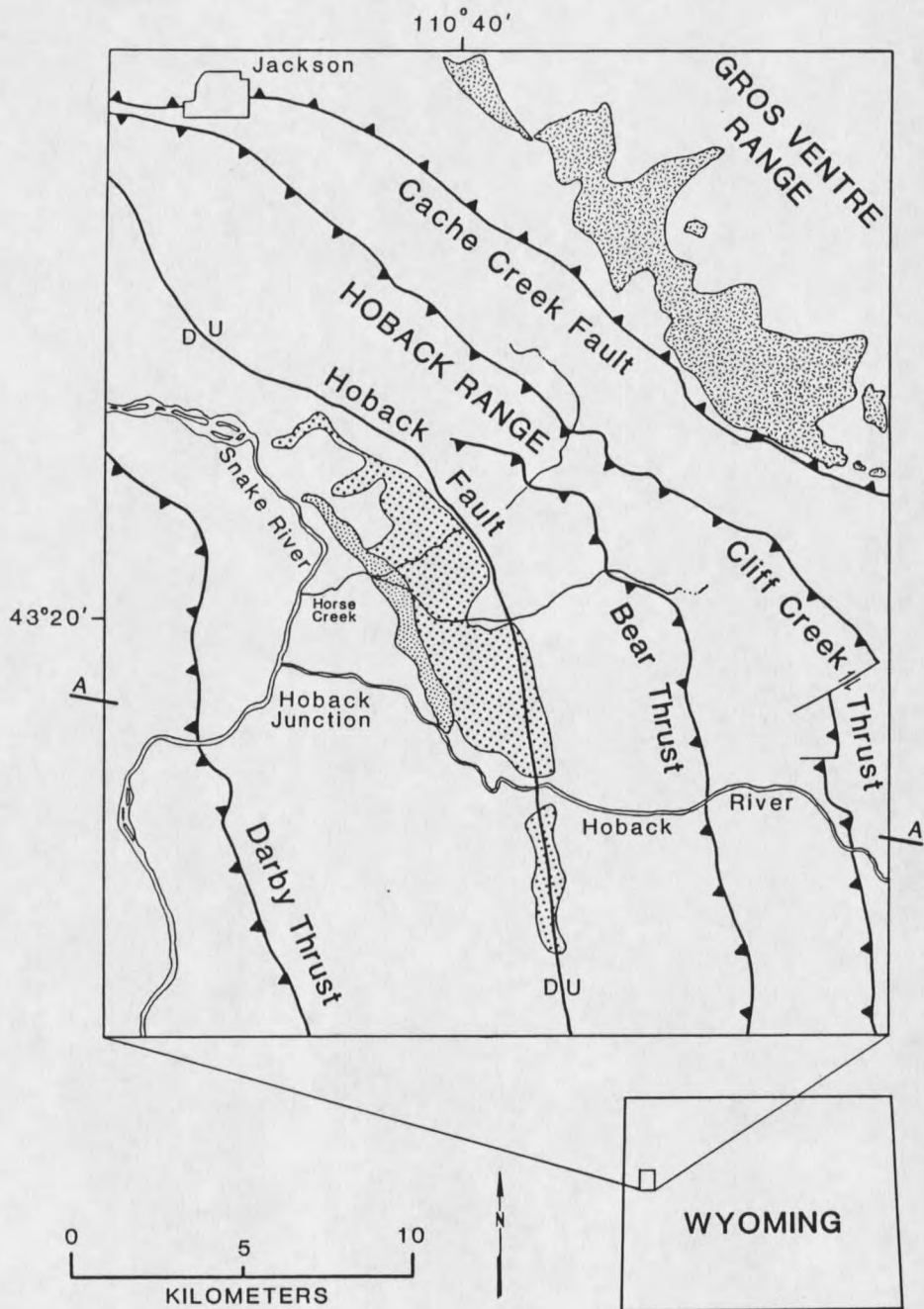


Figure 1. Location map showing the distribution of lower and middle members (fine-stippled pattern) and upper member (coarse-stippled pattern) of the Camp Davis Formation in northwestern Wyoming and relation to Mesozoic and Tertiary structural features. Dip of the Camp Davis is to the northeast. Area of dashed pattern in Gros Ventre Range denotes exposures of Precambrian crystalline rock.

listric normal fault-bounded basin. Specifically, in order to clarify our understanding of the history of the Camp Davis basin, this study addresses the following questions.

1. In which depositional environment(s) were the conglomerates of the Camp Davis Formation deposited?
2. What is the provenance of the two conglomeratic members of the Camp Davis Formation?
  - a. From what direction(s) were the coarse clastics transported?
  - b. What lithologies, or more specifically, which stratigraphic units were eroded to provide the coarse clastic fraction of the conglomerates?
3. What do the sedimentologic and provenance data from the lower and upper member conglomerates tell us about the tectonic evolution of the Camp Davis basin?

From a more general perspective, this study also emphasizes the importance of detailed lithofacies and sedimentologic investigations for obtaining a more complete picture of the history of an evolving sedimentary basin.

#### Study Area

The study area is located approximately 19 kilometers south of Jackson, Wyoming and is entirely on the Camp Davis, Wyoming 7.5 minute quadrangle. Although the Camp Davis Formation has been mapped for 25 kilometers on the west flank of the Hoback Range (Dorr and others, 1977, Figure 2), outcrops in much of that area are nonexistent to poor. Consequently, outcrops were examined only in the Hoback Junction area between Horse Creek to the north and the Hoback River to the southeast. Lower member conglomerates are well exposed in prominent light gray cliffs east and north of the Snake and Hoback rivers, respectively

(Figures 1 and 2). The upper member is exposed in reddish-brown cliffs on the north side of Horse Creek (Figures 1 and 3). All outcrops are accessible by foot from either U.S. Highway 187-189 or a private dirt road along Horse Creek.

#### Geologic Setting

The Camp Davis Formation was deposited in a narrow basin on the downthrown block of the Hoback listric normal fault. Blackwelder (1911) first recognized the Hoback fault, which was later named and mapped by Nelson and Church (1943). Eardley and others (1944) extended the trace of the fault about 32 kilometers south of the Hoback River. Love and Albee (1972) mapped the approximated trace of the fault north to the southern flank of Boyles Hill southwest of the town of Jackson.

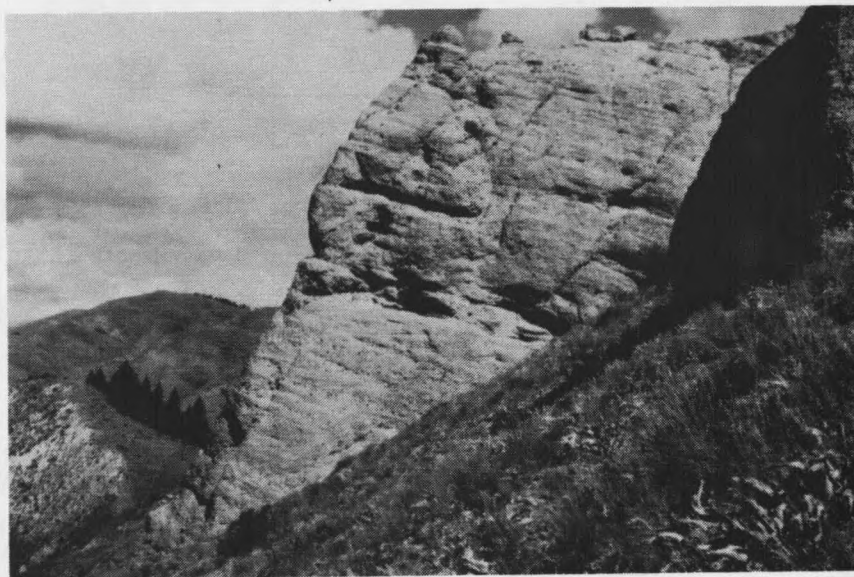


Figure 2. Typical exposures of the lower member conglomerates located north of the Hoback River along U.S. Highway 187-189. Unit strikes northwest and dips northeast due to rotation toward the Hoback listric normal fault.

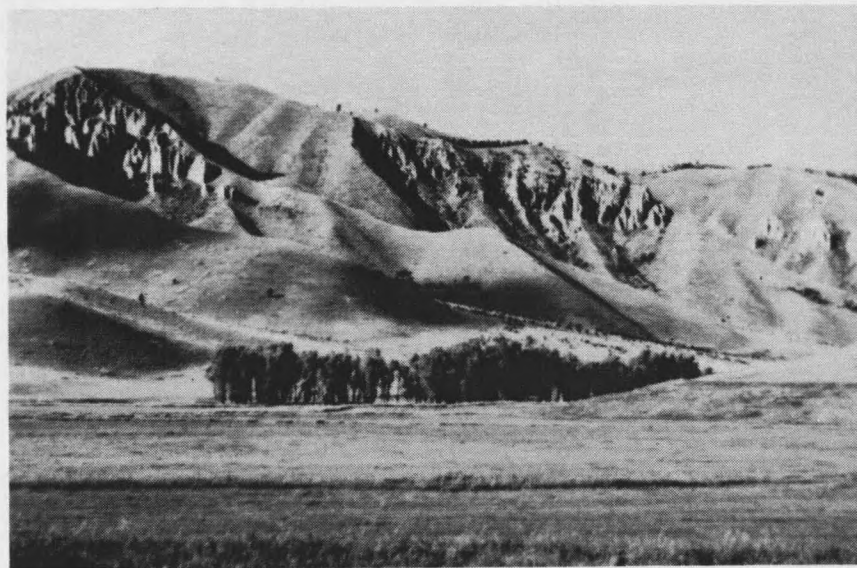


Figure 3. Outcrops of the upper member conglomerates exposed north of Horse Creek.

The Hoback fault's location and character are directly related to structures within the frontal portion of the Idaho-Wyoming thrust belt. Specifically, the position of the Hoback fault (Figure 4) is controlled by a ramp of the Bear thrust, a minor imbricate splay of the Cliff Creek thrust. Seismic evidence indicates that the Hoback fault is steep at the surface, but flattens at depth where it merges with the plane of the Bear thrust (Royse and others, 1975). Coincidence of the normal fault plane and the older thrust ramp indicates reactivation, in the opposite sense, of the fault segment during late Tertiary Basin and Range extension. Other major extensional faults in the area which exhibit similar relationships to older Sevier thrust ramps include those bounding the east sides of Grand Valley and Star Valley, which both contain thick, eastward-dipping sequences of Pliocene coarse clastic strata. (Royse and others, 1975).



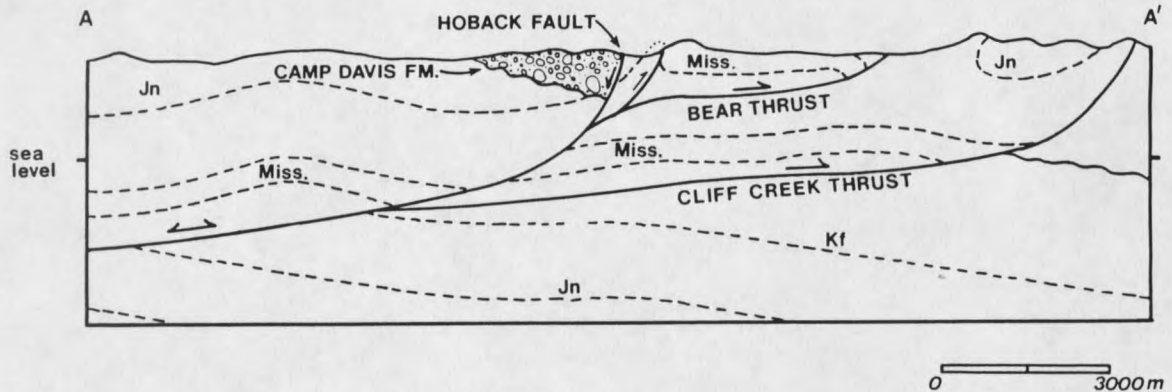


Figure 4. Structural cross-section through the Camp Davis basin showing relationship of the Hoback listric normal fault to the older Bear thrust. Modified from Royse and others (1975). Exact location of cross-section is denoted in Figure 1.

#### Methods

Lithofacies analysis of the Camp Davis conglomerates included detailed measurement and description of stratigraphic sections using a Jacob's staff. Four sections were measured in the lower member and, due to limited exposures, one composite section was measured for the upper member. Lithofacies analysis methods for coarse-grained deposits described by Mia11 (1977, 1978) and subsequently refined by Rust (1978), Mia11 (1985), Shultz (1984), Nemec and Steel (1984), and Smith (1986) were used. Paleocurrent analyses were based on data collected from imbricated pebbles and cobbles in massive conglomeratic lithofacies at regular intervals in each section. Poles to imbricated planes were plotted on an equal area stereonet and correction for tectonic tilt was completed using the method outlined by Potter and Pettijohn (1977). Summary rose diagrams depicting paleoflow directions

with calculated vector means (Potter and Pettijohn, 1977) were plotted for each measured section. Clast composition counts were also made at regular intervals in each section to determine compositional variation of the Camp Davis conglomerates. A grid system was used to randomly select clasts to be included in the counts.

### CAMP DAVIS FORMATION STRATIGRAPHY

The Camp Davis Formation was first named by Eardley and others (1944). Previously, Schultz (1914) and Nelson and Church (1943) mapped it as part of the Eocene Almy conglomerate. More complete descriptions were provided by Love (1956a; 1956b), Wanless and others (1955), Dorr and others (1977) and Giardinelli (1979). These workers have recognized three members in the Camp Davis Formation including: 1) a lower conglomeratic member, 2) middle limestone and tuffaceous member, and 3) upper conglomeratic member (Figure 5).

The lower member, best exposed in cliffs north of U.S. 187-189 and the Hoback River, consists of approximately 75-100 meters of well-cemented, light-gray, calcareous cobble and pebble conglomerate and associated sandstone (Figure 2). In the same area, the middle member consists of 15 to 60 meters of light-gray claystone, tuff, siltstone, and micritic limestone. The upper member is best exposed as reddish, steep cliffs of conglomerate along the north side of Horse Creek, approximately 3 kilometers north of the Hoback River (Figure 3). It grades upward through a 300 meter thick interval from poorly-exposed basal claystone and sandstone into a 1200 meter thick section of cobble to boulder conglomerate, with individual clasts as large as 1.6 meters in diameter. The upper member also contains several gravity-slide blocks of Mesozoic rock as large as 1 kilometer across (Dorr and others 1977).

# CAMP DAVIS FORMATION

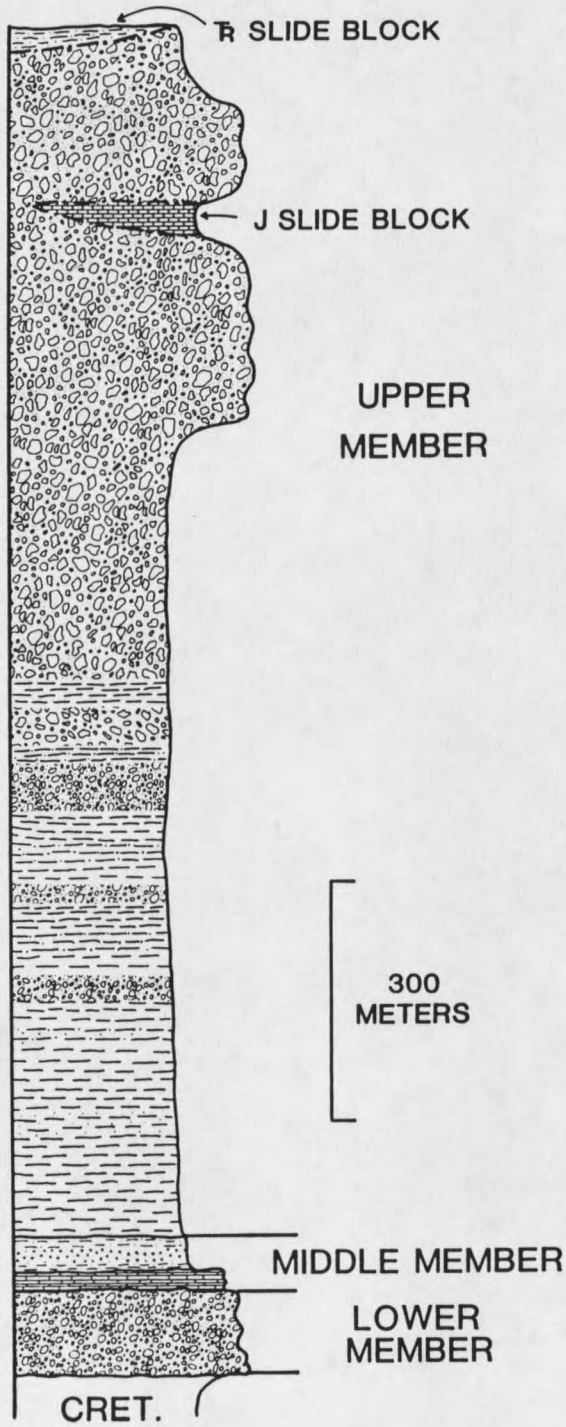


Figure 5. Generalized stratigraphic column for the Camp Davis Formation in northwestern Wyoming.

The age of the Camp Davis Formation is not well-constrained, but is thought to be either late Miocene or early Pliocene based upon the occurrence of a single Plihippus tooth within the middle member. Since this fossil was found relatively low in the formation, the basal portion may be as old as late Miocene and the upper portion early Pliocene or younger (Dorr and others 1977).

The bulk of the Camp Davis Formation, because of its coarseness and prismatic geometry, has been interpreted to represent the deposits of a series of alluvial fans (Dorr and others, 1977). The pebble and cobble conglomerate of the lower member was interpreted by Giardinelli (1979) to be deposited by high-energy braided streams which existed along the medial to distal portion of alluvial fans prograding southwestward into the Camp Davis basin from the scarp of the uplifted Hoback fault block. Middle member limestone and tuffaceous mudrock were deposited during a period of tectonic quiescence and slow basin subsidence when a shallow-water, temperate, carbonate-producing lake occupied the Camp Davis basin (Dorr and others 1977; Davis and Wilkinson, 1983). The lake was subject to periodic settling of fine-grained volcanic ash raining from ash clouds created by volcanic activity far to the west. Coarse conglomerates of the upper member of the Camp Davis are thought to indicate renewed progradation of alluvial fans into the Camp Davis basin during a final period of renewed motion along the Hoback fault and concomitant rapid basin subsidence (Dorr and others, 1977). Giardinelli (1979) interpreted the coarse upper member conglomerates as deposits of southwestward flowing braided streams and sediment-laden sheetfloods on coalescing alluvial fans.

The focus of this study involves a detailed reexamination of the sedimentology and provenance of the conglomeratic lower and upper members of the Camp Davis Formation in order to ascertain whether the above scenario for the evolution of the Camp Davis basin is justified.

Knowledge concerning coarse-grained lithofacies and sedimentary processes on alluvial fans and in braided fluvial systems has advanced considerably since Giardinelli's (1979) study of the Camp Davis Formation. No detailed sedimentologic study of strata in any of the numerous late Tertiary basins in northwest Wyoming, southeast Idaho or southwest Montana has ever been completed. Good exposures of the Camp Davis provide an excellent opportunity to increase our understanding of processes of sedimentation in these types of basins. In addition, the provenance of the Camp Davis conglomerates was addressed because the unroofing sequence suggested by Dorr and others (1977) is not well documented. Even upon casual observation, occurrence of Cambrian sandstone clasts in the lower member and coexistence of Precambrian crystalline and Triassic sedimentary clasts in the upper member are readily apparent. Both suggest that simple unroofing of the source area did not occur.

### LOWER MEMBER LITHOFACIES

Lithofacies analysis of the conglomeratic lower member of the Camp Davis Formation involved establishment of the lithofacies present and detailed documentation of their lateral and vertical distribution. Lithofacies types were distinguished on the basis of texture, fabric, sedimentary structures, and unit geometry.

#### Massive to Crudely Stratified Conglomerate (Gm)

##### Description

This lithofacies comprises approximately 80 percent of the lower member and is characterized by poorly-sorted, subangular to well-rounded pebbles and cobbles which are clast-supported with a well-sorted sand matrix. Clast imbrication is poorly developed because of the lack of platy- or discoid-shaped clasts. Horizontal stratification defined by changes in clast size, sorting and packing is dominant (Figure 6). Normally graded pebbly beds occur only rarely. Bedding planes are indistinct to distinct and are planar or irregularly scoured. Individual beds of crudely stratified conglomerate typically range from several centimeters to 2 meters thick and are frequently truncated laterally by gravel-filled trough-shaped erosional scours. As in all lower member lithofacies, calcite cement is ubiquitous.

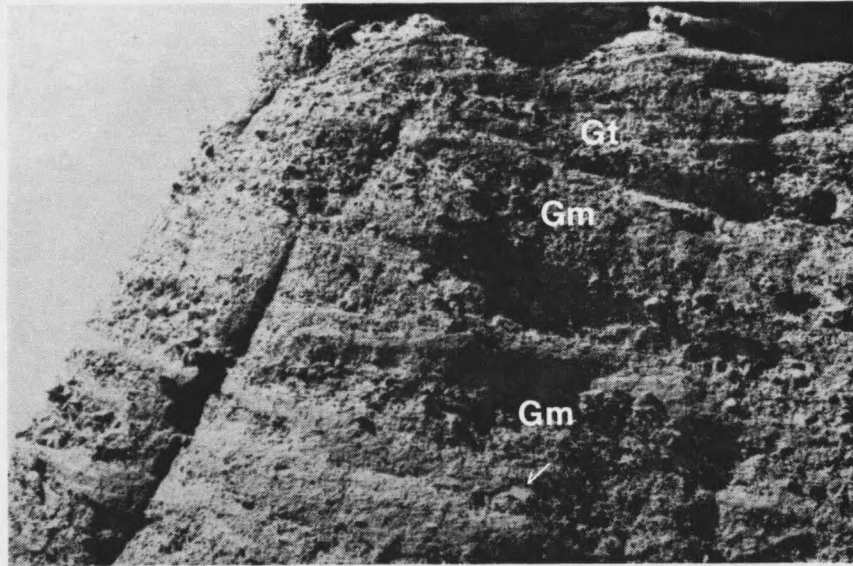


Figure 6. Exposure of lower member showing dominance of massive to crudely horizontally stratified conglomerate (Gm) and trough cross-stratified conglomerate (Gt). Note field notebook in lower center of photograph for scale and note tangential nature of foreset toes in upper most labeled Gt set. Outcrop located along U.S. 187-189 near Hoback River canyon.

#### Interpretation

Massive to crudely horizontally stratified pebble and cobble conglomerate was deposited as diffuse gravel sheets and low-amplitude longitudinal or diagonal bars lacking well-developed foresets (Boothroyd and Ashley, 1975; Rust, 1978). These bedforms develop and migrate only during periods of peak flow and can act as nuclei for further bar growth during subsequent high-flow intervals. The lack of well-developed foresets suggests that discharge and sediment load were quite high and that the rate of downstream migration of the bedforms exceeded the rate of vertical accretion. Coarse bedload was swept quickly downstream and did not accrete vertically into true bar forms with well-developed foresets (Hein and Walker, 1977). Erosional



contacts between individual units indicate modification by subsequent high stage flow (Rust, 1978). Massive conglomerates above trough-shaped scour surfaces were deposited as channel lags (Miall, 1977). Well-sorted sand matrix probably infiltrated into the coarse gravel framework during periods of lower velocity flow (Smith, 1974). The rarity of normal grading suggests that the magnitude of flow deceleration necessary to deposit the sandy matrix was small (Rust, 1984).

#### Trough Cross-Stratified Conglomerate (Gt)

##### Description

Intervals of trough cross-stratified pebble to cobble conglomerate comprise roughly 15 percent of the lower member. Clast size is generally smaller, but clast shape, sorting and matrix are similar to those in lithofacies Gm. Individual trough sets range from several centimeters up to 2.5 meters thick and up to 9 meters wide (Figure 7). Cosets comprised of 2 to 3 trough sets are present, but individual sets in association with crudely bedded to massive conglomerate (Gm) are most prevalent (Figure 6). Trough-set lower bounding surfaces are typically immediately overlain by a coarse pebble to cobble lag. Also, individual foresets usually have the largest clasts concentrated at their toes. Trough-filling strata generally conform to the trough shape of the basal scour surface (Figure 8), but some merge tangentially with the lower bounding surface (Figure 6). Ramos and others (1986) term this transverse-fill cross-stratification.

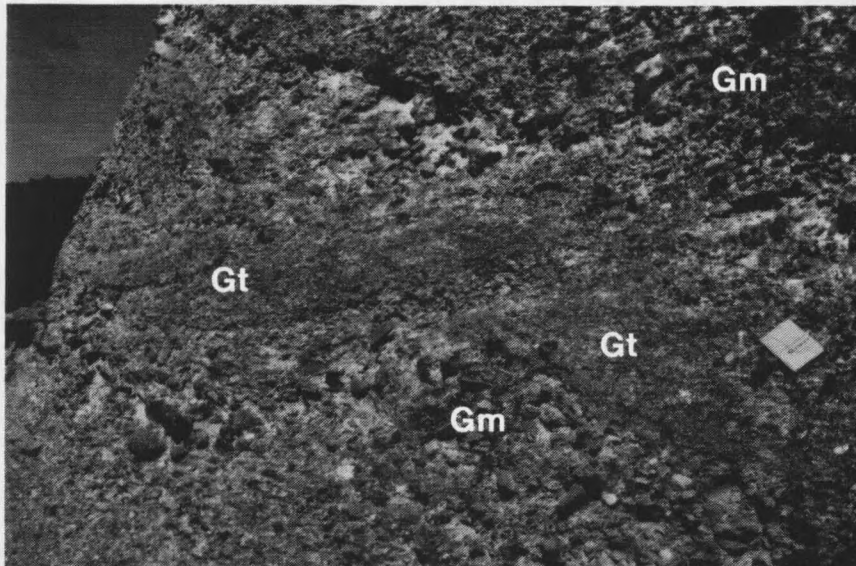


Figure 7. Coset comprised of individual, truncated trough cross-stratified conglomerate sets (Gt) overlain and underlain by massive conglomerate (Gm). Note lower bounding surfaces of trough sets truncating underlying massive conglomerate. Outcrop located in Hoback River canyon.

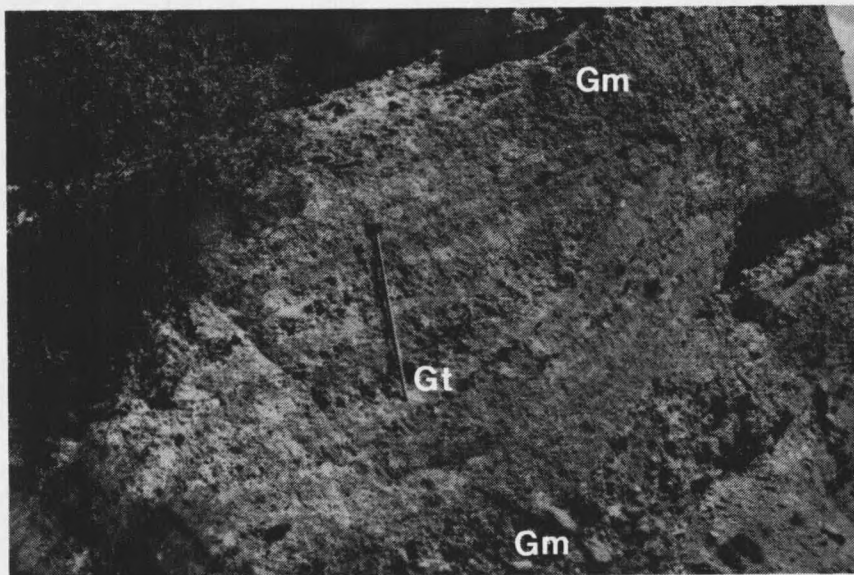


Figure 8. Trough cross-stratified conglomerate (Gt) set erosionally truncating and overlain by crudely horizontally stratified conglomerate (Gm). Note that trough-filling strata conform to the trough shape of the set's lower bounding surface. Jacob's staff is 1.5 m long

### Interpretation

Single trough cross-stratified conglomerate sets are generally interpreted to represent gradual infilling of active channel forms, scour pools or troughs (McGowen and Garner, 1970), and bar top scours (Miall, 1977) by migrating gravel sheets during flood and falling-water stages. Stratification of the fill parallel to the basal surface (Allen's (1963) eta-cross-stratification) suggests deposition under plane bed conditions, probably in the upper flow regime (Miall, 1977). Channel-fill complexes or cosets may also represent deposition during periods of rapid channel switching (Kraus, 1984) and/or by migrating gravel bedforms during flood stage (Rust, 1978). Such bedforms would probably resemble the fine gravel dunes identified by Fahnestock and Bradley (1973) using echo sounding in the Knik River, Alaska, or the crescentric gravel bedforms recognized by Galay and Neill (1967) in the North Saskatchewan River.

### Planar Cross-Stratified Conglomerate (Gp)

#### Description

Planar cross-stratified conglomerate occurs only rarely in the lower member of the Camp Davis Formation. The nature of the clasts and matrix is similar to that observed in the other conglomerate lithofacies. Typical 1 to 1.5 meter thick, solitary sets have planar bases and planar or irregularly scoured upper bounding surfaces. Adjacent lithofacies usually consist of conglomerates Gm or Gt, but sand lenses occasionally lie above and below planar cross-stratified intervals. Lateral extent of the planar cross-stratified conglomerates

varies from a few to about 10 meters. Individual sets are usually truncated by erosional scours or grade laterally into massive to crudely stratified conglomerate.

### Interpretation

The rarity, poor development and close association with lithofacies Gm suggest that this lithofacies is probably not a result of migration of individual linguoid or transverse bars. Rather, as Rust (1978) suggests, planar cross-stratified conglomerates with the above characteristics usually reflect falling stage, lateral modifications of longitudinal bars. At such times, flow over the bar diverges away from the bar axis and the remaining bedload material is deposited as avalanche foresets at lateral bar margins. Alternatively, the planar cross-stratified conglomerates may have been deposited on foresets when a longitudinal bar migrated into deeper water (Hein and Walker, 1977; Miall, 1977). Boothroyd and Nummedal (1978) only rarely observed longitudinal bar slipfaces consisting of planar cross-stratified gravels in proglacial braided outwash. They speculate that the rarity of such deposits reflects small maximum discharges in channels too shallow for flow separation processes to develop over gravel bars. The best examples of planar cross-stratified gravels in proximal, proglacial outwash were observed in southern Iceland's Skeidara river system, which is subject to high maximum discharges associated with glacier burst flooding (Boothroyd and Nummedal, 1978).

Trough Cross-Stratified and Scour-Fill Sandstone (St/Ss)Description

Trough cross-stratified sandstone (St) and scour-fill sandstone (Ss) are relatively rare in the lower member. They are grouped together here because trough cross-stratified sandstone cosets do not occur, causing distinction of solitary sets of each lithofacies from one another to be impossible. The lithofacies consist of fine- to very coarse-grained, calcite cemented, lithic sandstone, which is poorly- to moderately well-sorted and occasionally pebbly (Figure 9). Sets range from 8 to 40 centimeters thick, 0.6 to 2 meters wide, and are commonly truncated laterally by erosional scours. Basal surfaces of these sandstone units are trough-shaped and generally underlain by massive or horizontally stratified sandstone (Sm/Sh). Upper bounding surfaces are



Figure 9. Solitary set of pebbly trough cross-stratified sandstone in the lower member. Note the overlying conglomerate above an irregular erosional base.

either planar or irregularly scoured. Additional associated lithofacies include ripple cross-laminated sandstone (Sr), siltstone (F1), and conglomerate lithofacies Gm and Gt.

### Interpretation

Trough cross-stratified sandstones (St) are generally interpreted to represent deposition by migrating sinuous-crested dunes under lower flow regime conditions (Miall, 1977; Harms and others, 1982). In gravel dominated fluvial systems, sandy bedforms probably only develop in channels and on bar tops during falling stage (Boothroyd and Ashley, 1975). The rarity of well-developed, identifiable cosets of trough cross-stratified sandstone in the lower member suggests that either this process was insignificant, or that such deposits did not survive subsequent flood events (Rust, 1978). The more common solitary trough-shaped sandstone sets are probably better interpreted as scour or channel-fill deposits (lithofacies Ss), which commonly develop on bar surfaces during waning flow conditions (Miall, 1977; Rust, 1972).

### Massive to Horizontally Stratified Sandstone (Sm/Sh)

#### Description

The composition, grain size and sorting characteristics of this lithofacies are similar to those described above for lithofacies St/Ss. These massive to horizontally stratified sandstone units range in thickness from 4 to 75 centimeters and in width from 0.6 to 15 meters. The lithofacies usually overlies lithofacies Gm or Gt above a planar basal surface and is commonly overlain by other sandstone or fine-grained lithofacies (St, Sr, F1)(Figure 10).

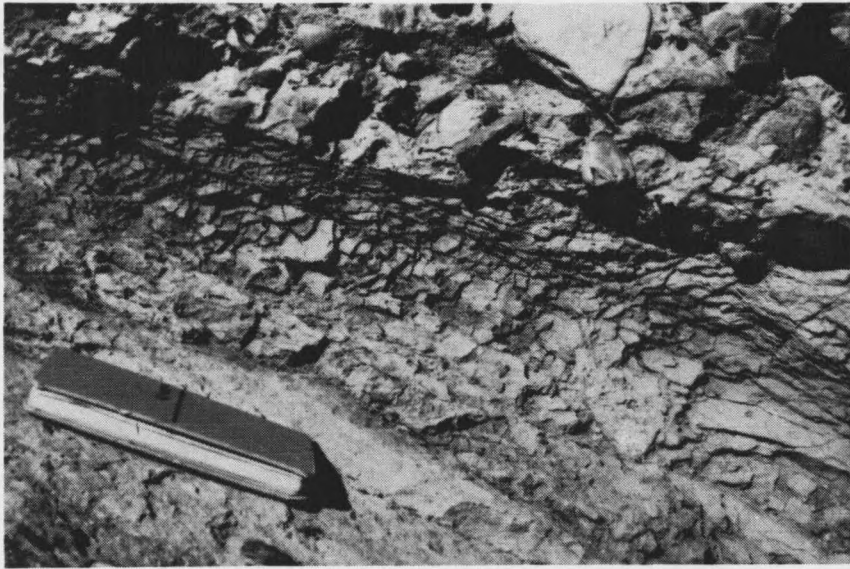


Figure 10. Massive to horizontally stratified sandstone with overlying laminated siltstone and mudrock.

#### Interpretation

Massive, structureless sandstone (Sm) is commonly the result of intense bioturbation or water escape, but the lack of any burrows, mottling, or fluid escape structures precludes such an interpretation here. Processes not involving traction transport, such as very rapid sedimentation from suspension or deposition from highly concentrated sediment dispersions produce massive bedding of primary origin (Blatt and others, 1980, p.136). It is also possible that the sandstones are actually stratified, but that it is not apparent in outcrop.

Horizontally stratified sandstones were likely deposited under plane bed conditions shortly after the onset of falling stage flow over bar tops or in shallow channels. Harms and others (1982) note that horizontal stratification in sands can form under both lower and upper flow regime conditions, but suggest that association of this lithofacies with trough cross-stratified sandstones may indicate upper

flow regime conditions. Unfortunately, current or parting lineation, which would also indicate upper flow regime conditions, were not observed. Shallow flow in channels or over bar tops, even during falling stage, could have maintained upper flow regime conditions. Shallow flow is also suggested by the generally thin, lenticular character of these sandstone units and their association with lithofacies St, Sr and F1 (DeCelles and others, 1987). Harms and others (1982) also point out that in very shallow flows carrying poorly-sorted mixtures of sand and pebbles, the formation of ripples is suppressed and bedload is transported on planar surfaces over a wide range of flow velocities.

#### Ripple Cross-Laminated Sandstone (Sr)

##### Description

Ripple cross-laminated sandstone is a very minor lithofacies in the lower member of the Camp Davis Formation. It consists of moderately well-sorted, fine to coarse grained, lithic sandstone beds, which are generally only 5 to 10 centimeters thick and less than a meter wide. This lithofacies always overlies lithofacies St/Ss or Sm/Sh along a planar basal surface. Asymmetric ripple crests are preserved only locally and upper bounding surfaces are commonly scoured and overlain by conglomerate lithofacies.

##### Interpretation

Ripple cross-laminated sandstones represent deposition, probably in minor channels on bar surfaces, during late stage, shallow waning flow, lower flow regime conditions (Miall, 1977; Rust, 1972).



Laminated Siltstone and Mudrock (F1)Description

This minor lithofacies consists of tan to reddish-brown, laminated lenses of sandy siltstone and shale, which range in thickness from a few to 20 centimeters and extend laterally for up to several meters (Figure 10). These fine-grained lenses always overlie sandstone and are generally overlain along a planar to scoured surface by lithofacies Gt or Gm.

Interpretation

Lithofacies F1 represents deposition during very low-velocity flow conditions and the settling out of suspended fines from standing water in bar top swales, inactive channels, and abandoned overbank areas (Miall, 1977). The rarity of such deposits, as well as all other sandstone lithofacies, suggests that preservation potential of fine-grained lithofacies was quite low.

**LOWER MEMBER DEPOSITIONAL SYSTEM**Depositional Model

The preponderance of massive to crudely horizontally stratified (Gm) and trough cross-stratified (Gt) conglomerate in the lower member of the Camp Davis Formation, illustrated schematically in the vertical lithofacies profile of Figure 11, strongly suggests that deposition occurred in a high-energy, gravelly, braided fluvial system similar to the Scott River braided fluvial model (Boothroyd and Ashley, 1975; Miall, 1978). The lower member fluvial system was characterized by extensive development and aggradation of gravelly longitudinal bars and diffuse gravel sheets during periods of peak-flow. As flow waned, longitudinal gravel bars and interbar channel areas were subject to local erosion. Consequently, trough-shaped scours formed which were subsequently filled by migrating gravel sheets, generating trough cross-stratified conglomerate (Gt). Minor sandstone (St, Ss, Sr, Sm, Sh) and fine-grained (Fl) lithofacies accumulated on bar tops and in channels during falling flow stages.

The lower member conglomerates differ from modern, proximal braided stream deposits in that they contain significantly more trough cross-stratified units (Gt). Rust (1978; 1984) notes that modern proximal braided outwash gravels are dominated by lithofacies Gm and that cross-stratified gravels of any type are conspicuously absent. Common occurrence of lithofacies Gt in the lower member may indicate

# LOWER MEMBER

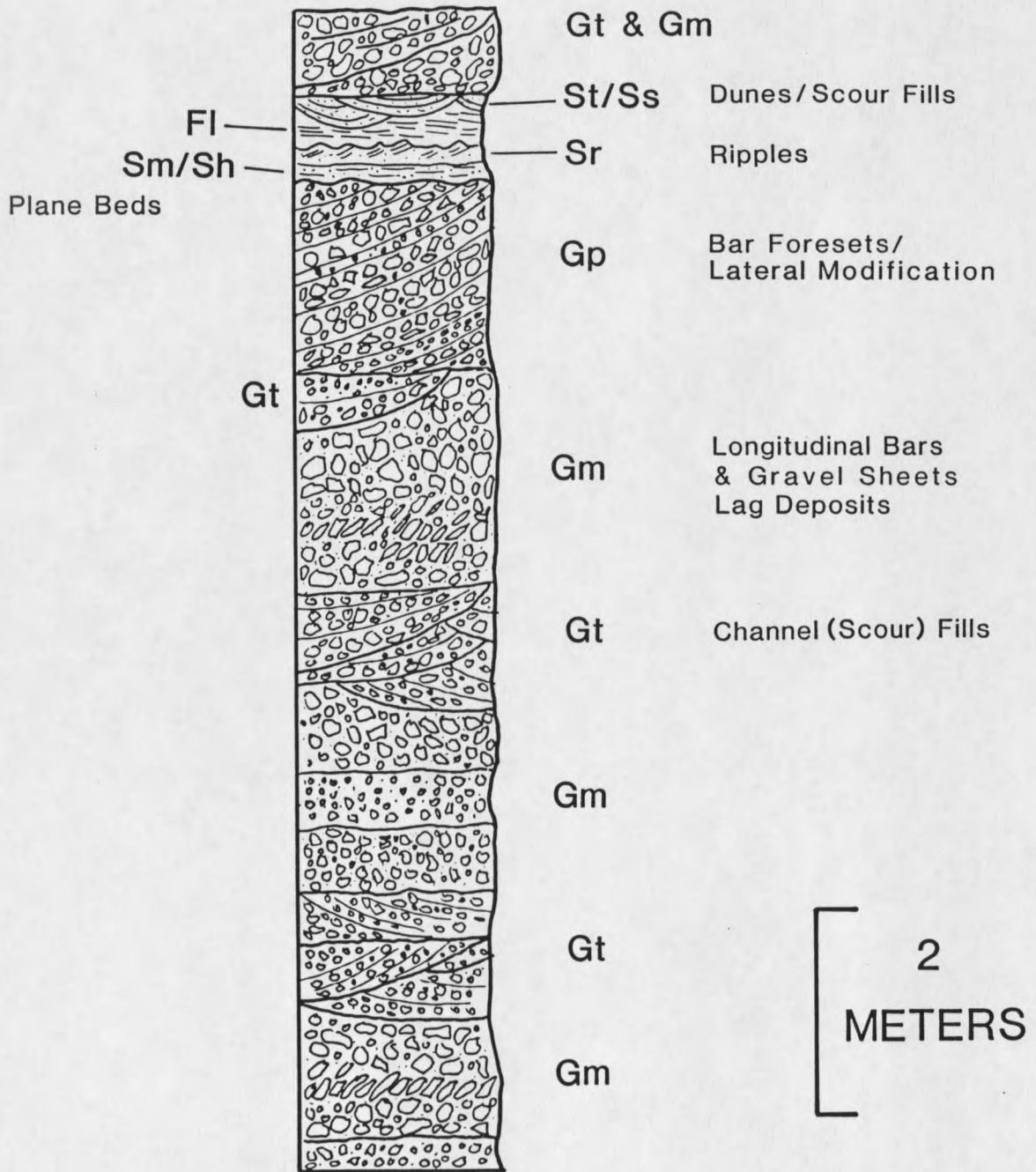


Figure 11. Generalized vertical lithofacies profile for lower member of Camp Davis Formation. Note preponderance of Gm and Gt lithofacies.

deposition in the medial portion of a braided stream complex. Boothroyd and Ashley (1975) note that the midfan portion of the Scott outwash fan, Alaska is characterized by abundant longitudinal bars within low-stage channels. These bars, comprised of finer gravels (up to 10 centimeters) and sands, are dissected by numerous shallow channels and are more readily subject to growth and modification during lower intensity flows. Boothroyd and Ashley (1975) do not discuss the occurrence of trough cross-stratified gravels, but the medial portion of a braided stream system seems a likely analog for lower member deposition. Williams and Rust (1969) observed the common occurrence of cross-stratified fine gravels and sands in the middle reaches of the Donjek River in the Yukon Territory, Canada. In addition, the same authors note the rarity of true transverse bars and associated planar cross-stratified fine gravels and sands, which are more common in distal portions of sandy braided streams (Smith, 1970; Boothroyd and Nummedal, 1978). The lack of such deposits in the lower member indicates that deposition did not occur in a distal braided stream system.

#### Paleocurrents

Paleocurrent indicators based upon imbricated clast orientations in massive to crudely stratified conglomerate (Gm) show a consistent south to southeastward paleoflow trend (Figure 12). This suggests that paleoflow in the lower member braided fluvial system was parallel to the trace of the Hoback normal fault, rather than away from it as interpreted by Giardinelli (1979), and implies that the high-energy,

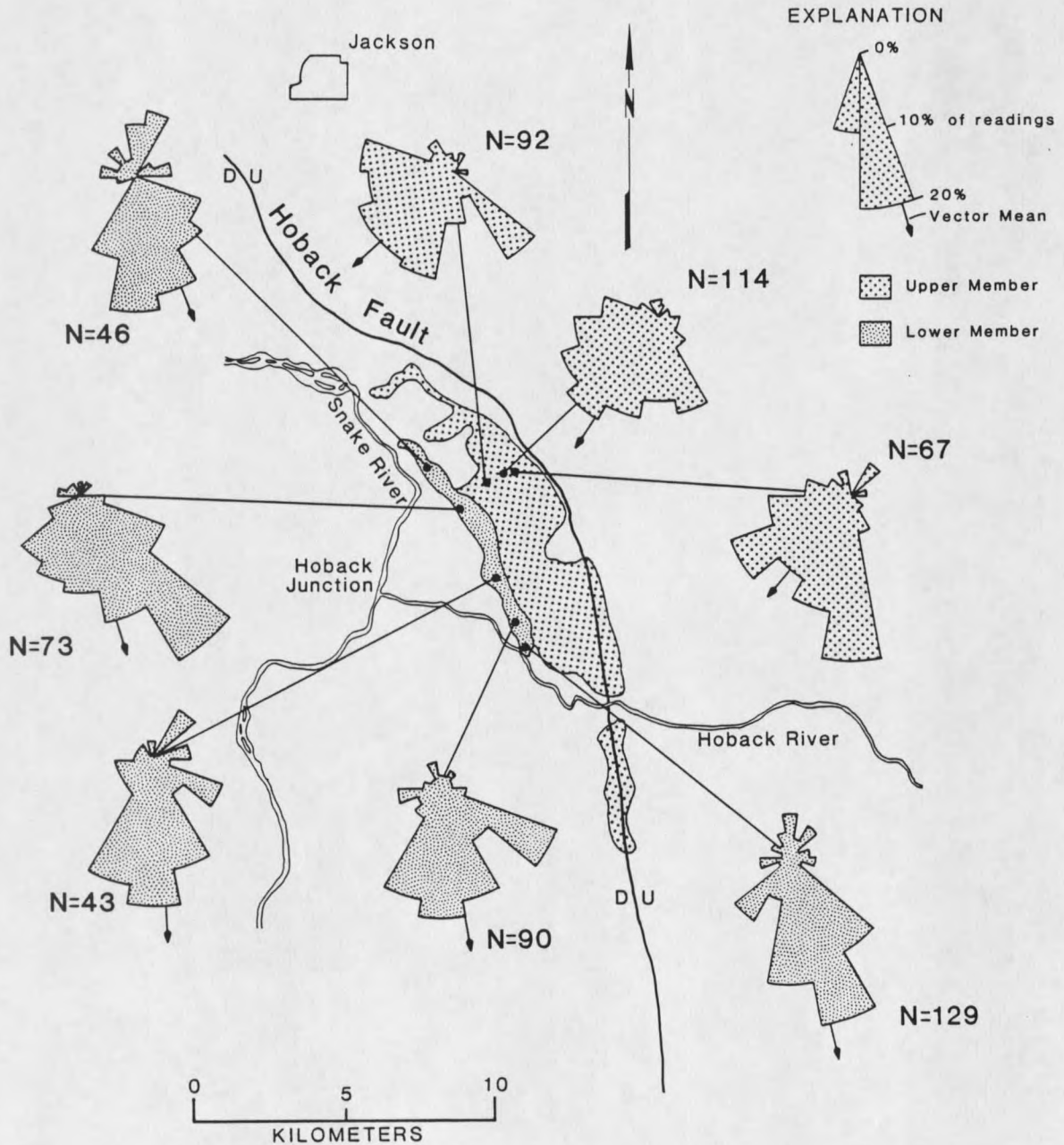


Figure 12. Composite paleocurrent data from lower and upper members of Camp Davis Formation. Data derived from measurements of imbricated clasts in Gm lithofacies.

gravelly braided stream system which deposited the lower member actually flowed parallel to the axis of the newly evolving Camp Davis basin. Clast provenance data discussed below corroborate this interpretation. Interestingly, the high-energy, gravelly nature of the lower member braided streams and the southeastward paleoflow direction are characteristics shared by the modern Snake River in the Jackson Hole area. Although speculative, it is conceivable that the lower member fluvial system may represent the ancestral Snake River. Giardinelli (1979) suggested this as well, but attributed Camp Davis deposition solely to southwest flowing tributary drainages. Dorr and others, (1977) suggest that the Snake River was well established in essentially its present location by late Pliocene-early Pleistocene time. In any case, the lower member braided stream system was not related to medial to distal deposition on alluvial fans prograding southwestward into the Camp Davis basin from the uplifted block of the Hoback fault, as previously suggested.

### UPPER MEMBER LITHOFACIES

Lithofacies analysis of the upper member of the Camp Davis Formation was performed in the same manner as that for the lower member. However, because of the bimodal, muddy nature of many upper member conglomerates, the diamictite lithofacies codes of Shultz (1984) were utilized in conjunction with the conglomerate codes of Miall (1978).

#### Massive to Crudely Stratified, Clast-Supported Conglomerate/Diamictite (Gm/Dcm)

##### Description

This lithofacies dominates the upper member of the Camp Davis Formation. Clasts range from granule to boulder size, but pebble to large cobble sizes are most common. Typically, clasts are subangular to well-rounded, exhibit a wide variety of shapes, and form a clast-supported framework. Matrix texture varies considerably, but generally consists of a poorly sorted mixture of sand and mud with enough mud-sized material to be easily detected in the field (Figure 13). In rarer cases, the matrix consists only of either poorly-sorted sand or mud with minor sand.

Horizontal stratification in these conglomerates varies from poorly- to moderately well-developed (Figure 14), where it is defined by differences in clast size, sorting, and packing. However, some intervals possess no stratification. Clast imbrication is locally



Figure 13. Close-up of crudely stratified conglomerate (Gm/Dcm) from upper member showing poorly-sorted and muddy nature of matrix.

well-developed (Figure 15) in both cobble and boulder dominated stratified intervals. Normal grading is generally absent, except for rare crude development in more well-stratified intervals. Inverse grading was not observed. Bedding planes range from indistinct to distinct and are generally planar to slightly irregular. Indistinct bedding planes often make it difficult to discern bed thickness and lateral continuity. Deeply scoured bounding surfaces and infilled channel forms are rare. Individual beds, where visible, range in thickness from 0.5 to 2 meters, from 20 to 25 meters in lateral extent,



and have well-defined planar to slightly-scoured bounding surfaces. Intervals which possess crude stratification comprise the bulk of this lithofacies and are typified by a disorganized fabric containing large cobbles and boulders in a clast- to locally mud matrix-supported arrangement.

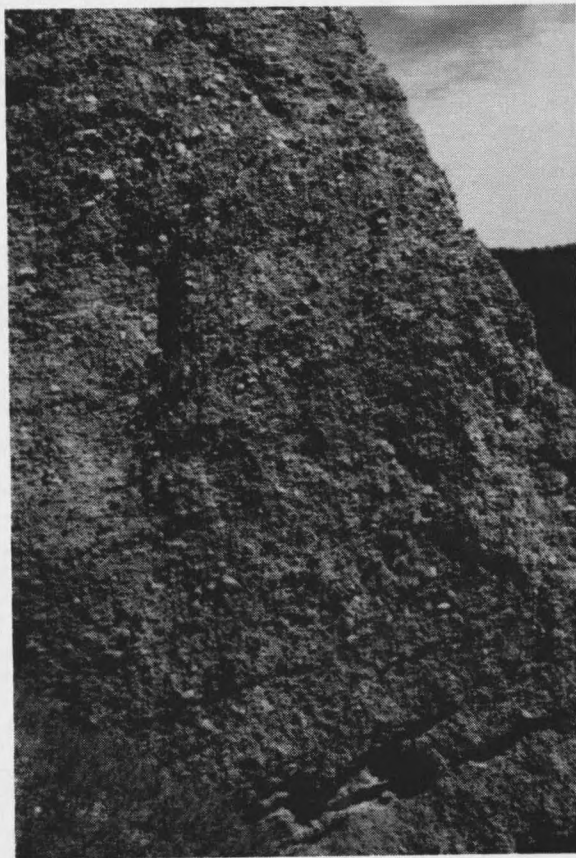


Figure 14. Crudely stratified pebble to cobble, clast-supported conglomerate (Gm/Dcm) exposed in upper member along Horse Creek. Note the difficulty inherent in determining location of individual bedding planes of sedimentation units. Outcrop is approximately 20 meters high.



Figure 15. Well developed imbrication of platy clasts in Gm/Dcm lithofacies. Top of field notebook is parallel to orientation of stratification in conglomerate.

Well-stratified intervals comprise only a small portion of the Gm/Dcm lithofacies. They are comprised mostly of pebbles and cobbles with a sandy matrix, and are commonly found with thin (0.1 to 1 meter) intervals of trough cross-stratified gravel (Gt), trough cross-stratified and scour-fill sandstone (St/Ss), and massive and horizontally stratified sandstone (Sm/Sh) as described below. Bedding surfaces in these conglomerates are generally poorly-defined, but where visible they are planar. Clast imbrication is often well-developed.

Although the differences described above between the poorly- and well-stratified intervals of this lithofacies may justify separating them into two distinct lithofacies, they are grouped together here because of a continuum of variation between the two. Those described represent the end-members of the Gm/Dcm lithofacies continuum. In fact, some intervals contain combinations of features of both end-

members, such as abundant sand and mud in the matrix. Subtle variation along this continuum is observed laterally and vertically within the Gm/Dcm lithofacies of the upper member.

### Interpretation

Deposition of the Gm/Dcm lithofacies can be interpreted in terms of the well-stratified, sandy and crudely-stratified, muddy end-members described above.

The well-stratified, sandy pebble and cobble conglomerates are interpreted to represent either streamflow deposition in shallow, shifting braided channels, or unchannelled sheetflood deposition which commonly occurs below the intersection point of alluvial fans (Bull, 1972; Gloppen and Steel, 1981; Ballance, 1984). The absence of deeply-scoured bounding surfaces is especially diagnostic of such fan settings (Wells, 1984). Deposition from migrating gravel sheets, or as low-amplitude longitudinal bars during periods of high-velocity flow likely occurred in shallow channels or on the fan surface.

In contrast, the more disorganized, crudely-stratified, clast-supported, muddy, cobble and boulder conglomerate intervals represent deposition by flood flows with extremely high sediment concentrations. Smith (1986, p.2) uses the term hyperconcentrated flood flow to describe high discharge flows intermediate in character between streamflow and debris flow, in which "neither turbulence is the lone sediment support agent nor in which deposition occurs en masse". Such flows represent extreme, short-term flood events in which sediment is transported and deposited from a hyperconcentrated dispersion (Smith, 1986). Beverage and Culbertson (1964) empirically defined

hyperconcentrated suspensions as those with sediment concentrations between 40 and 80 weight percent. Similar deposits, which indicate depositional processes intermediate between streamflow and debris flow, have been described by a number of workers including Bull (1963; 1964; 1972), Wasson (1977), Ballance (1984), Nemeč and Steel (1984), Shultz (1984), and DeCelles and others (1987). In particular, the deposits described here closely resemble the "flashy" alluvial deposits discussed by Nemeč and Steel (1984, p.8) and the proximal sheetflood conglomerates of Ballance (1984, p.345) and Wells (1984, p.139). The very poor sorting and clast-supported fabric suggest rapid traction and suspension deposition of the sediment mass, including the finer component of mud, sand and pebbles between the cobble and boulder framework. Much of this matrix material is too coarse to have later infiltrated between the larger clasts (Smith, 1986). Well-developed imbrication of clasts (b-axis type) and crude normal grading (rare) indicate that turbulence was the main support mechanism and that clasts moved freely by traction transport (Gloppen and Steel, 1981; Ballance, 1984; Nemeč and Steel, 1984; Smith 1986). Clast interaction (dispersive pressure) within these high-concentration dispersions may also have acted as a clast-support mechanism (Bagnold, 1955; Beverage and Culbertson, 1964). Pierson and Scott (1985) suggest that high suspended sediment concentrations suppress turbulence and that dispersive pressure must play a significant role in hyperconcentrated flows. Finer-grained material held in suspension above the bed typically acts to increase flow viscosity and specific weight of the sediment dispersion. This probably aided support of larger clasts and

acted to decrease particle fall velocities (Simons and others, 1963). As a consequence, less turbulence than required during streamflow was needed to support the large clasts (Beverage and Culbertson, 1964; Smith, 1986).

Absence of scoured bounding surfaces or channel-fill structures suggests deposition by unconfined, sheet-like hyperconcentrated flood flow events. Like the water-laid sheetflood deposits discussed above, deposition occurred in very shallow braided channels, or on the fan surface below the intersection point.

Massive, Chaotic, Clast- to Matrix-Supported  
Conglomerate/Diamictite (Gm/Dcm-Dmm)

Description

Several intervals within the upper portion of the upper member are dominated by this lithofacies, which is distinctly different than that discussed above. The best examples are located immediately above the brecciated slide block of Jurassic Twin Creek Limestone (Figures 3 and 16). The lithofacies consists of clast- to matrix-supported, pebble to large boulder (up to 1.6 meters) conglomerate. This is the coarsest lithofacies present in the upper member. Typically, the matrix consists of poorly sorted, sandy mud. Where planar to slightly scoured bounding surfaces are well defined, individual units range in thickness from 1.5 to 5 meters and extend laterally for up to 25 meters. Some exposures, which are probably too thick to represent one sedimentation unit, exhibit no distinct bounding surfaces. Internally the lithofacies is distinctively chaotic and lacks stratification, grading

or fabric (Figure 16). Elongate and disc-shaped clasts are commonly found in a variety of orientations, including vertical.



Figure 16. Massive, Chaotic, clast- to matrix-supported conglomerate (Gm/Dcm-Dmm). Note local matrix-support, vertically oriented clasts and extreme coarseness of conglomerate. The brecciated slide block of Jurassic Twin Creek Limestone is exposed in the lower third of the photo. Portion of Jacob's staff at base of photo is about 1.3 meters long.

#### Interpretation

The polymodal nature, lack of stratification, grading or fabric, and planar (nonerosive) to slightly scoured bounding surfaces of this lithofacies all suggest deposition by cohesive debris flows which possessed shear strength (Nemec and Steel, 1984). Disorganized or

chaotic clast fabric probably indicates "non-sheared (high strength) "plug" flow, or only weakly sheared (high viscosity) flow" (Nemec and Steel, 1984, p. 13). The lack of preferred clast orientations suggests the same. Preferred clast orientation parallel to bedding was not observed in this lithofacies, but is generally interpreted as an indication of flow by laminar shear (Nemec and Steel, 1984; Wells, 1984). However, the presence of vertically oriented clasts suggests that at least parts of these debris flows were turbulent (Wells, 1984). Laminar flow is generally considered to be the normal transport mechanism for debris flows (Shultz, 1984), but Pierson (1980) has observed the transition to turbulent flow in high velocity surges of some debris flows. Pierson and Scott (1985) conclude that lahars (volcanic debris flows) produced by the March 19, 1982 Mt. St. Helens eruption were transformed into hyperconcentrated flows due to progressive downstream dilution of the flow masses, particularly by the incorporation of streamflow which the lahars overrode. Although turbulence in these hyperconcentrated flows was significantly damped by high sediment concentrations, large standing waves and antidune waves were observed (Pierson and Scott, 1985). Dominant clast support mechanisms active during the deposition of this chaotic lithofacies probably included significant plastic yield strength and buoyancy (Lowe, 1982; Shultz, 1984). Deposits similar to these chaotic, clast-supported conglomerates have been described by Wells (1984, p.139) from Cretaceous age conglomerates on the South Orkney Islands, Antarctica.

Massive Matrix-Supported Conglomerate/Diamictite (Gms/Dmm)Description

This minor lithofacies is identifiable in only a few upper member outcrops. It is characterized by obvious matrix-support (Figure 17) and mud-rich matrix, which contains only a minor sand fraction (Figure 18). Clasts range from granules to medium boulders, but most are pebbles and cobbles. Sorting is extremely poor. Clasts are angular to subrounded and their shape varies considerably. Stratification,



Figure 17. Massive matrix-supported conglomerate (Gms/Dmm) from upper member exposure along Horse Creek. Note pebble- to cobble-sized clasts floating in a predominantly muddy matrix. Hammer in foreground for scale.





Figure 18. Close-up of massive matrix-supported conglomerate (Gms/Dmm) showing abundance of mud matrix and floating clasts.

sedimentary structures, and clast imbrication are conspicuously absent. In some outcrops, poorly developed inverse grading is present near the base of the bed. Beds comprised of this lithofacies represent single sedimentation units ranging in thickness from 10 centimeters to 2 meters. Bedding planes are well defined and nonerosive. Some thin beds of this lithofacies are sheetlike and have planar bedding surfaces; however, one 2 meter thick bed was noted which extends laterally for 20 to 25 meters, is lenticular, and may represent a broad channel-fill (Figure 17). Within this bed, abundance and size of

clasts increase laterally toward the bed margins. These deposits are interbedded with and grade laterally into other conglomeratic lithofacies including Gm/Dcm and rarely, Gt.

### Interpretation

The bimodal nature, matrix-support, and nonerosive bases characteristic of this lithofacies indicate en masse deposition by high-strength (cohesive) plastic debris flows (Shultz, 1984). Low clast concentration and disorganized fabric suggest that laminar, viscous, "plug" flow (non-sheared) was the dominant transport mechanism (Shultz, 1984; Nemec and Steel, 1984). Lack of both imbrication and well-developed grading indicates that free clast movement was inhibited by the viscous transport medium (Gloppen and Steel, 1981). The dominant clast support mechanisms active during transport included cohesive matrix strength of the medium and buoyancy. Crude, basal inverse grading is probably the result of dispersive pressure limited to that portion of the flow (Smith, 1986).

### Minor Lithofacies

#### Description

Lithofacies of minor abundance in the upper member include: trough cross-stratified conglomerate (Gt), trough cross-stratified and scour-fill sandstone (St/Ss), massive to horizontally stratified sandstone (Sm/Sh), ripple cross-laminated sandstone (Sr), and laminated sandy siltstone and shale (F1).

Trough cross-stratified conglomerate (Gt) occurs more commonly in the upper 50 meters of the upper member. Isolated troughs consist of























































