

Braided stream deposition and provenance of the Upper Cretaceous-Paleocene(?) Canaan Peak Formation, Sevier foreland basin, southwestern Utah

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ABSTRACT

The Upper Cretaceous to Paleocene(?) Canaan Peak Formation of southwestern Utah consists of approximately 100 m of cobble conglomerate and subordinate sandstone. Coarse-grained lithofacies include massive to very crudely stratified pebble to cobble conglomerate (Gm) and trough cross-stratified conglomerate (Gt). Minor associated lithofacies include trough (St) and planar (Sp) cross-stratified sandstone and scour-fill sandstone (Ss). Gravel deposition occurred during high-discharge periods within a Scott/Donjek-type perennial braided fluvial system on longitudinal bars (Gm) and sinuous-crested transverse bars (Gt), and as a product of longitudinal bar-top and interbar channel scour filling (Gt). Sand accumulated under lower flow-velocity conditions through migration of interbar channel dunes and transverse bars (St/Sp) and development of scour and fill deposits (Ss).

Clast imbrication and trough-axis orientation measurements indicate east to northeast paleoflow directions. Gravel-sized clasts are predominantly resistant lithologies including Upper Precambrian-Cambrian quartzite, fossiliferous Paleozoic chert, and some silicified middle Jurassic volcanic rocks; less resistant Paleozoic limestone clasts are only locally abundant.

Canaan Peak Formation detritus was derived from erosion of highlands created by Cretaceous Sevier-style thrust-fault development to the west in southeastern Nevada and western Utah and distributed across an extensive gravel-dominated braidplain complex. However, it is not possible to determine whether Canaan Peak deposition records active uplift or is postorogenic. Sediment was transported eastward a minimum distance of 45 to 60 km and was subject to continuous high-energy reworking within the Canaan Peak fluvial system, resulting in destruction of all but the most stable clast lithologies.

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INTRODUCTION

The Cretaceous to Eocene Sevier orogenic belt of west-central Utah is characterized by major eastward-directed thrust faults that place thick sections of Upper Precambrian, Paleozoic, and lower Mesozoic miogeoclinal strata upon equivalent, thinner shelf and cratonic sequences (Armstrong, 1968; Fleck, 1970; Burchfiel and Davis, 1975; Villien and Kligfield, 1986). In response to periods of thrust movement, synorogenic clastic sediments were shed eastward off uplifted mountainous terrain of the thrust allochthons into the subsiding Sevier foreland basin (Spieker, 1946; Armstrong, 1968; Jordan, 1981). Provenance and stratigraphic analyses of foreland basin deposits in the Wyoming-Idaho-Utah salient of the Sevier orogenic belt have been used in reconstruction of the timing and sequence of major thrust development there (Royse and others, 1975; Wiltshko and Dorr, 1983). Similar provenance studies of foreland basin clastic sequences in the central Utah segment of the Sevier foreland basin include Jefferson (1982), Lawton (1985), and Schwans (1988).

The purpose of this investigation is to determine the depositional environments and provenance of the Upper Cretaceous to Paleocene(?) Canaan Peak Formation of southwestern Utah (Fig. 1) in order to evaluate the paleogeographic and paleotectonic significance of this coarse-grained unit. Specific goals of this study include determination of the following parameters: (1) lithofacies present and their lateral and vertical relations; (2) depositional environments, (3) composition of Canaan Peak conglomerates and associated sandstones, (4) paleocurrents, and (5) provenance.

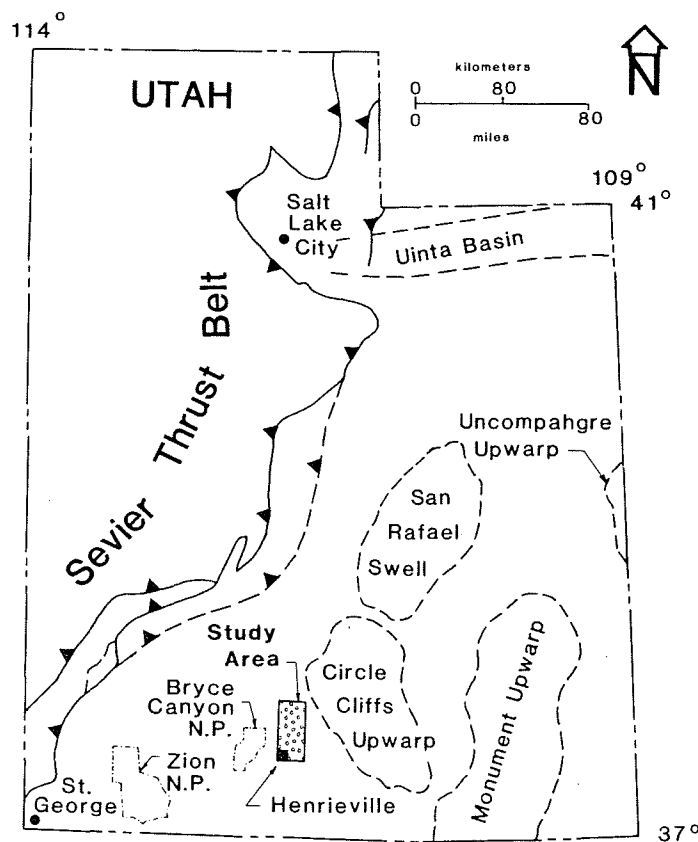


Figure 1. Map showing location of Canaan Peak Formation study area. Solid lines with teeth are exposed thrust faults; dashed lines with teeth are inferred thrust faults. Teeth are on hanging wall of thrust faults.

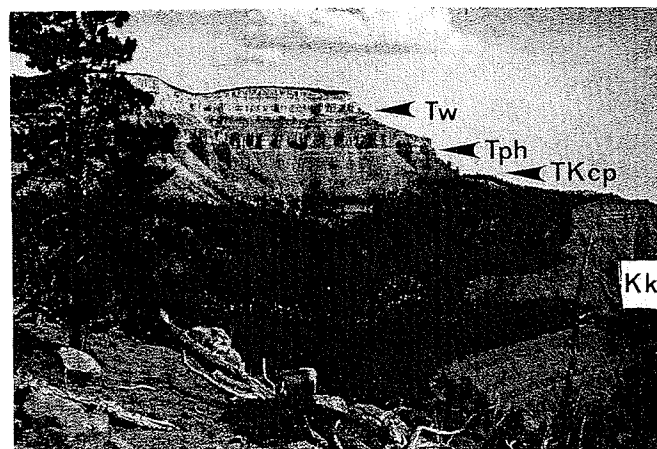


Figure 2. West side of Table Cliff Plateau, view toward the southeast. Stratigraphic succession includes the Kaiparowits (Kk), Canaan Peak (TKcp), Pine Hollow (Tph), and Wasatch (Tw) formations (See Fig. 5).

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CANAAN PEAK FORMATION

The Canaan Peak Formation consists of approximately 10 m of interbedded conglomerate and sandstone and crops out over an area of 160 km² around the southern margin of the Table Cliff Plateau (Fig. 2) and at Canaan Peak on the Kaiparowits Plateau near Bryce Canyon National Park in southwestern Utah (Fig. 3) (Bowers, 1972, 1973; Hackman and Wyant, 1973; Sargent and Hansen, 1982). Other exposures of the Canaan Peak Formation not addressed in this chapter, occur along the southern Paunsaugunt Plateau and in the eastern Pine Valley Mountains (Goldstrand, 1989, in preparation). The type section is located at the head of Wahweap Creek on the south side of Canaan Peak (Fig. 3) (Bowers, 1972). Canaan Peak Formation strata include intervals of massive to poorly stratified, granule to boulder conglomerate interbedded with moderately to well-stratified, fine- to coarse-grained, and silty fine-grained sandstone (Fig. 4). Thin discontinuous lenses of fine-grained sandy siltstone are rare. The Canaan Peak rests unconformably upon gray to blue-gray fine-grained sandstone and mudrock of the Upper Cretaceous Kaiparowits Formation (Fig. 5). The base of the Canaan Peak Formation was placed by Bowers (1972) at the base of the first conglomerate overlying the finer-grained Kaiparowits strata. This stratigraphic horizon is invariably a sharp erosional surface. The Canaan Peak Formation is unconformably overlain by conglomerate, sandstone, siltstone, and bentonitic claystone of the Paleocene Pine Hollow Formation (Fig. 5) (Goldstrand, in preparation).

Palynomorphs collected from exposures in the Kaiparowits Plateau region indicate that the upper portion of the Kaiparowits and lower portion of the Canaan Peak Formations are early to middle Campanian in age (Lohrengel, 1969; Bowers, 1972; Fouch and others, 1983). Diverse terrestrial faunas collected from the Kaiparowits Formation suggest a middle to late Campanian age (Eaton, 1987; Eaton and Cifelli, 1988). It is likely that palynomorphs collected from the lower part of the Canaan Peak Formation have been reworked (Eaton, this volume). To date, the upper portion of the Canaan Peak and the entire Pine Hollow Formation have failed to yield palynomorphs.

During the course of this investigation, several large (30 to 40 cm) dinosaur bone fragments were found within the upper 2 m of the Kaiparowits Formation. Numerous smaller fragments were collected from weathered slopes near the Kaiparowits–Canaan Peak contact near the Pine Lake locality. These bone fragments have been identified as ankylosaur tail vertebrae and are indicative only of a Cretaceous age (J. Horner, 1987, personal

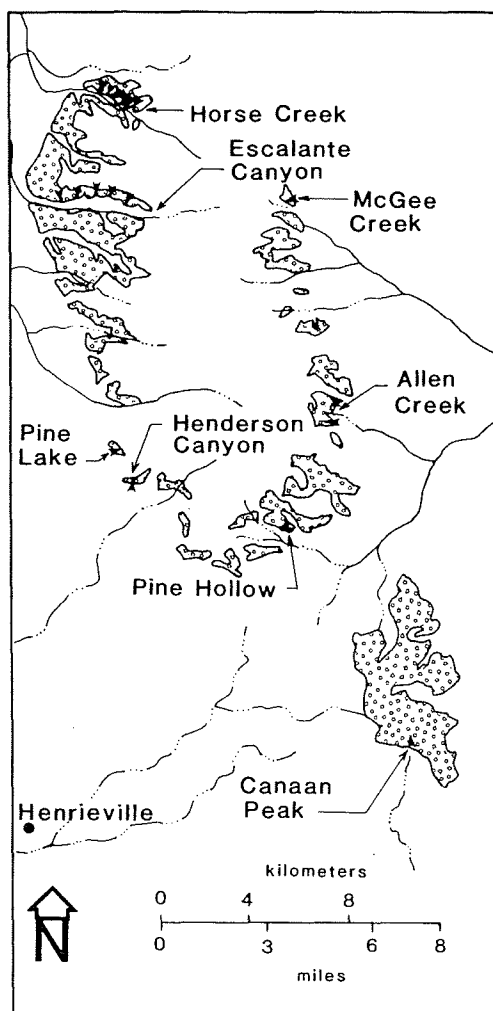


Figure 3. Location of 18 measured sections of the Canaan Peak Formation. Stippled pattern indicates Canaan Peak outcrops. Measured sections are denoted by small arrows. Modified from Bowers (1972) and Hackman and Wyant (1973).

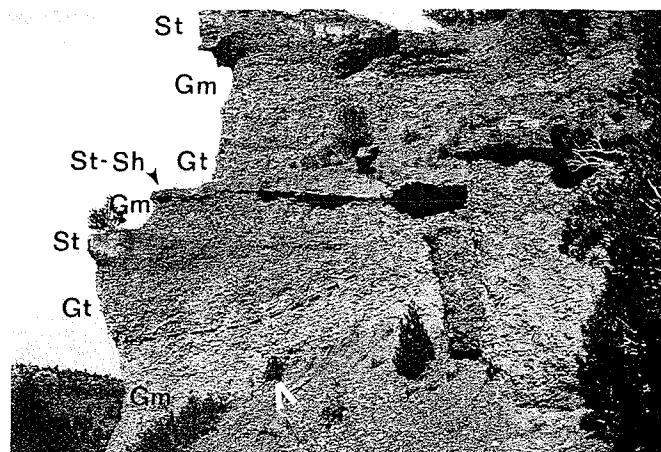


Figure 4. Typical exposure of Canaan Peak Formation strata along southern margin of Table Cliff Plateau. Nonstratified to crudely stratified (Gm) and trough cross-stratified (Gt) lithofacies are dominant. Less common trough cross-stratified (St) and horizontally stratified (Sh) sandstone are generally more resistant than conglomerate, typically occurring as cap-rock surfaces or over-hanging ledges. Note backpack (arrow) for scale.

communication). DeCourten and Russell (1985) described dinosaur leg- and foot-bone elements approximately 200 m below the Kaiparowits–Canaan Peak contact in an area between Pine Hollow and Henrieville, Utah (Fig. 3). These have been identified as Ornithomimid or ostrich dinosaur fragments and are late Cretaceous in age.

METHODS OF INVESTIGATION

Eighteen stratigraphic sections within the Canaan Peak Formation were measured, and lithofacies were described in detail. Seventeen sections are located around the southern margin of the Table Cliff Plateau and one at Canaan Peak (Fig. 3). Clast imbrication and trough axis orientation measurements were made at all localities. These data were plotted on rose diagrams. Paleocurrent trends and statistical significance were evaluated utilizing the Tukey chi-square statistical test (Middleton, 1965).

Clast composition counts were performed on gravel-sized material in order to ascertain any vertical or lateral changes in conglomerate composition. More than 140 clasts were identified at each measured section; clasts were selected by using a movable grid. Twenty-seven thin sections were prepared from samples of Canaan Peak sandstones and point-counted utilizing a petrographic microscope; the results were plotted on QFL and QmFLt ternary diagrams. In addition, 16 thin sections of various conglomerate clast varieties were prepared to aid in identification of clast lithologies and to make comparisons with potential source-rock units.

LITHOFACIES

Lithofacies present in the Canaan Peak Formation were defined on the basis of differences in grain size, texture, and types of sedimentary structures. The lithofacies terminology used herein

is that first proposed for coarse-grained fluvial deposits by Miall (1977) and later refined by Miall (1978) and Rust (1978a). Hydrodynamic interpretations of lithofacies are based on comparisons with numerous modern alluvial fan and fluvial systems.

The Canaan Peak Formation consists of two dominant lithologies: conglomerate and sandstone. Specific lithofacies present include: (1) massive to very crudely horizontally stratified (Gm), trough cross-stratified (Gt), and planar cross-stratified (Gp) conglomerate; (2) trough (St) and planar-tabular (Sp) cross-stratified sandstone; (3) scour-and-fill sandstone (Ss); and (4) massive to thinly laminated sandstone (Sh). Rarely, mudrock composed of massive to laminated siltstone (Fm/FI) and ripple cross-laminated, fine-grained sandstone (Sr) are present. Detailed descriptions of Canaan Peak lithofacies are provided in Table 1.

Conglomerate

Conglomerate typically occurs as moderately to highly resistant, 1.5- to 17-m-thick clast-supported beds containing sub-angular to subrounded, small granule and pebble to boulder-sized clasts (2 mm to 31 cm). Average gravel clast size is approximately 10 to 15 cm. Conglomerates are poorly to moderately sorted; individual beds may be massive, normally graded, horizontally stratified or trough cross-stratified. Specific conglomerate lithofacies include massive to crudely horizontally stratified (Gm) (Fig. 6), planar (Gp), and trough cross-stratified conglomerate (Gt) (Fig. 7).

Sandstone

Sandstone dominates the nonconglomeratic facies of the Canaan Peak Formation. Discrimination between these facies was based primarily on variations in grain size and cross-stratification. Four sandstone lithofacies were recognized. Trough cross-stratified sandstone (St) (Figs. 6 and 7) is dominant; planar cross-stratified sandstone (Sp) (Fig. 8) is present only locally. Horizontally stratified (Sh) (Fig. 6) and scour-and-fill (Ss) (Fig. 9) sandstone are rare.

Facies St and Sp occur more commonly in cosets than as solitary sets. Cosets consist of as many as seven sets and are up to 3.5 m thick and 6 m long. In general, sandstone lithofacies are laterally and vertically truncated by conglomerate lithofacies. Locally there is an apparent up-section increase in sandstone bed thickness and abundance.

Sandstone facies are composed of very fine- to coarse-grained sand, are typically well sorted, and possess angular to well-rounded grains. Individual beds commonly fine upward from thin pebble lag horizons. They are typically interbedded with both conglomerate lithofacies (Gm/Gt) (Fig. 7).

Mudrock

Lenses of massive to very finely laminated sandy siltstone and very fine-grained sandstone (Fm/FI) are found rarely interbedded with facies Gm and Gt. These mudrock lithofacies com-

monly form a sediment drape upon underlying coarse-grained facies.

LITHOFACIES INTERPRETATIONS

Development of longitudinal gravel bars and in-filling of shallow channel scours by diffuse gravel sheets were dominant processes in the Canaan Peak fluvial system. Clast-supported, massive to crudely horizontally stratified, gravelly longitudinal bars (lithofacies Gm) (Fig. 10) developed by downstream progradation and vertical accretion of channel bed load (Ore, 1964; Williams and Rust, 1969; Boothroyd and Ashley, 1975; Rust,

SERIES	UNIT
TERTIARY	Volcanic Rocks (undifferentiated)
	Wasatch Formation
	Pine Hollow Formation
UPPER CRETACEOUS	Canaan Peak Formation
	Kaiparowits Formation
	Wahweap Formation
	Straight Cliffs Formation
	Tropic & Dakota Formations
UPPER JURASSIC LOWER (?) CRETACEOUS	Morrison & Entrada Formations

Figure 5. Stratigraphic chart for Upper Jurassic through Tertiary rocks in vicinity of the Table Cliff and Kaiparowits plateaus and the Straight Cliffs, south-central Utah. Modified from Bowers (1972, 1973), Hackman and Wyant (1973), and Peterson (1969).

TABLE 1. DETAILED DESCRIPTION OF CANAAN PEAK FORMATION LITHOFACIES

Lithofacies Description	Geometry
Gm Massive to crudely horizontally stratified, poorly sorted pebble to boulder conglomerate (organized conglomerate of DeCelles and others, 1987); clast supported.	Individual sets include thin sheet, lens, and scoop shapes—a few cm to 1.5 m thick and 0.5 to 5 m in lateral extent. Lower and upper bounding surfaces are erosional and defined by irregular, planar to sub-planar and slightly concave-upward contacts. Clast imbrication is common. Occur as cosets of as many as five stacked sets; interfinger laterally with lithofacies Gt, St, and Sp.
Gt Trough cross-stratified pebble to cobble conglomerate.	Sets characterized by arcuate concave-upward lower bounding surfaces; upper bounding surfaces typically sub-planar to concave upward. May occur as cosets or individual sets which are vertically interbedded with lithofacies Gm and St. Individual sets range from several cm to 1.5 m in thickness and from 4 m in width to 7 m in length.
Gp Planar cross-stratified pebble to cobble conglomerate.	Occurs as cosets which range from 0.5 to 3 m in total thickness. Upper and lower bounding surfaces are slightly concave upward. Reactivation surfaces are common. Associated with lithofacies Gt and Gm; typically laterally gradational with Gm.
St Trough cross-bedded sandstone.	Occurs as solitary sets (several to 55 cm thick) or cosets (as many as 4 to 7 sets which measure as much as 3.5 m in thickness). Set bounding surfaces are arcuate and smooth with little relief. Foreset toes are tangential to basal scour surface.
Sp Planar cross-stratified sandstone.	Found only at Canaan Peak locality as cosets as thick as 1 m separated by discontinuous horizons of granule to pebble conglomerate (Gm). Individual sets are 5 to 35 cm thick. Foreset toes display angular contact with set lower bounding surfaces.
Sh Horizontally stratified fine- to medium-grained sandstone.	Individual beds less than 12 cm thick and extend laterally from 0.5 to 1 m. Commonly overlies and is crudely gradational with Gm, St, or Sp.
Ss Scour-and-fill medium- to coarse-grained and pebbly sandstone.	Fills: 1) short, shallow scoop-shaped depressions, 2) elongate, straight to sinuous asymmetrical V-shaped scours, and 3) relatively deep cylinder-shaped potholes. Elongate scour fills are 20 to 50 cm long and 10 to 15 cm deep; pothole deposits are as much as 22 cm deep and 6 to 35 cm in diameter.
Fm/FI Massive and laminated mudrock (primarily sandy siltstone).	Occur as relatively thin (8 to 30 cm) intervals that range from 0.5 to 1.5 m in lateral extent. Base of units conforms to topography of underlying surface; upper contacts are erosional, irregular, subplanar, and of little relief. Usually interbedded with Gm and Gt. Overlying conglomerate clasts commonly protrude downward into uppermost surface of this lithofacies.

1978b; Ethridge and others, 1984; Kraus, 1984). Rust (1978b, p. 614–615) suggested that gravelly longitudinal bars equilibrate under high velocity flow conditions and are most stable during peak flood stages, when all bed load is in motion. Facies Gm initially developed as small nuclei of the coarsest bed-load clasts. These clasts accumulated within the deepest portions of active channels under traction, or plane-bed flow (upper flow regime), conditions (Leopold and Wolman, 1957), forming cluster bed forms (Brayshaw, 1984, Fig. 2). Other clasts became stacked, or imbricate, upon and downcurrent from the cluster bed-form nuclei.

Deposition of longitudinal gravel bars typically occurs on planar to subplanar, or slightly concave-upward, channel scour surfaces (Harms and Fahnestock, 1965; Smith, 1970; Brayshaw, 1984; DeCelles and others, 1987). The fabric-supported character results from gravel bed-load deposition by aqueous flow ca-

pable of moving very coarse-grained (cobble to boulder size) material, which keeps sand and smaller particles in suspension. A reduction in flow velocity during Canaan Peak deposition resulted in late-stage infiltration and grading of interstitial sand within some Gm/Gt units.

Migration of transverse bars during flood stage may be represented by lithofacies Gp (Miall, 1977, 1985). Also, Gp within the Canaan Peak Formation possesses numerous reactivation surfaces and may represent delta-like growth of a bar into a relatively deep channel (Miall, 1977).

Lower flow regime modifications to longitudinal bars occurred as water levels dropped, resulting in current-velocity adjustments. Longitudinal bar surfaces became exposed, and flow directions diverged from bar axis trends (Fig. 10) (Smith, 1970; Rust, 1978b; Harms and others, 1982). Elongate, trough-shaped,

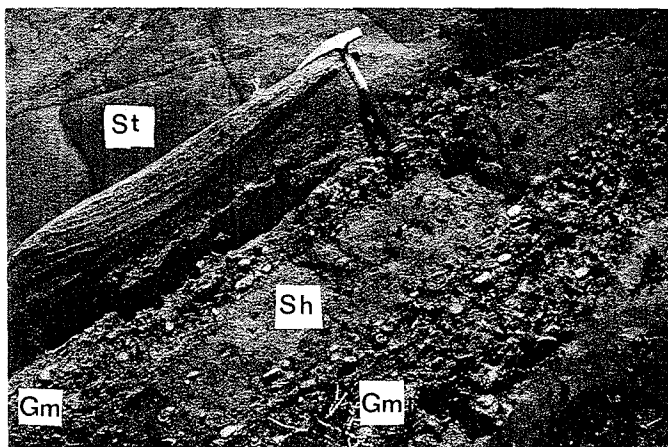


Figure 6. Outcrop exhibiting horizontally stratified sandstone (Sh) interbedded with trough cross-stratified sandstone (St) and massive to crudely bedded conglomerate (Gm).

shallow-channel scours developed adjacent to, and obliquely away and downstream from, longitudinal bar axes. Consequently, migration of coarse- and fine-grained material into large channel scours formed trough crossbeds (lithofacies Gt, St). They developed as solitary or sinuous-crested transverse gravel and/or sand dunes migrated into the shallow scours. Gt sets with low-angle foresets ($<20^\circ$) probably formed by filling of shallow in-channel scours by successive migration of diffuse gravel sheets (Middleton and Trujillo, 1984). Planar (Sp) cross-strata resulted from migration of sinuous to straight-crested sand waves (transverse bars) across slightly scoured, subplanar to planar surfaces (Ore, 1964; Harms and Fahnestock, 1965; Rust, 1978b). Miall (1977) notes that trough (Gt, St) and planar (Sp) foreset development results from simultaneous erosion and deposition. Turbulent backflow immediately upstream of the slip face initiated scouring by flow-separation eddies as water passed over a bar- or dune-crest, followed by grain saltation and bed-form progradation. Trough scours (St) began to fill by repeated avalanching of material over longitudinal bar crests and down the adjacent dune slip face (Middleton and Trujillo, 1984).

Shallow-water deposition within minor scours and potholes produced massive to horizontally stratified (Sh) and scour-and-fill (Ss) sandstone and pebbly sandstone facies during upper flow regime (plane-bed) conditions. Their development is a function of water depth and current velocity and of the relief of bed forms upon which they are deposited. During deposition, decelerating current velocities are no longer capable of transporting gravel bed load (larger than pebble size), but plane-bed flow conditions are maintained, thus transporting fine- to coarse-grained sand and small-pebble sizes when available. Although plane-bed flow conditions may exist locally, the presence of facies Sh on bar-top or dune surfaces indicates reduced water depths. Harms and others (1982) suggest lithofacies Sh forms in shallow water during low flow or peak flood-stage conditions.

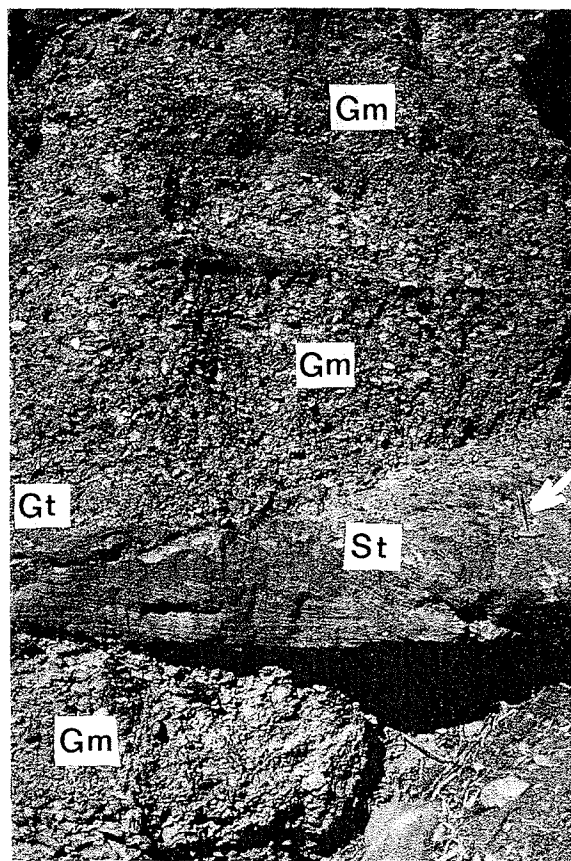


Figure 7. Sequence of the three most abundant lithofacies in the Canaan Peak Formation: Gm—massive to very crudely stratified conglomerate, Gt—trough cross-stratified conglomerate, and St—trough cross-stratified sandstone. Note rock hammer (arrow) for scale.

Unlike development of trough stratification, the cutting and filling episodes of scour-and-fill (Ss) facies are separate events (Miall, 1977). Depression hollows, or potholes, form from strong-separation eddies, similar to bar-crest dissection discussed above. In addition, local vortices may develop around stationary obstructions (e.g., larger-than-average clasts, intertwined tree trunks or branches), creating relatively deep, small-diameter potholes. Subsequent in-filling occurs either during upper (plane-bed) or lower flow-regime conditions in relatively shallow water (Allen, 1963; Miall, 1977).

Rare, massive to faintly laminated, lens-shaped facies Fm/FI developed within shallow bar-top scours during waning current flow under low flow-regime conditions. Very fine-grained suspended sediment settled by vertical accretion from standing water as bar surfaces emerged, isolating small bar-top pools.

DEPOSITIONAL SYNTHESIS

Lithofacies associations, coupled with sediment texture and fabric in the Canaan Peak strata, provide evidence for sedimentation under seasonally humid (high precipitation, frequent flood-

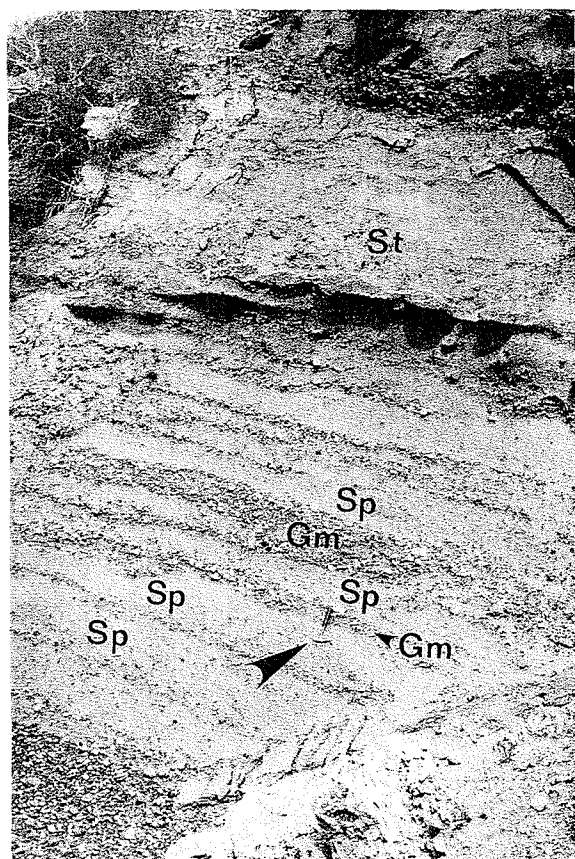


Figure 8. Planar-tabular cross-stratified sandstone (Sp) underlain by lithofacies Gm and overlain by lithofacies St. Tabular sets are commonly truncated by and interbedded with facies Gm. Note rock hammer (arrow) for scale.

ing) climatic conditions within a perennial braided fluvial system. Deposition probably occurred along relatively straight reaches of a broad, unconfined braid-plain with a moderate paleoslope, hydrodynamically similar to that of modern Alaskan proglacial braided fluvial systems (Fig. 11).

Lithofacies recognized in the Canaan Peak Formation document deposition within a high-energy fluvial system composed of numerous adjacent, subparallel active channels. Based on lithofacies associations and paleocurrent data discussed below, deposition occurred primarily within a transitional, east-to-northeast-trending medial braided fluvial system. Lithofacies sequences resemble portions of proglacial gravelly braided facies models of both the Scott type (southeast Alaska) of Miall (1977, 1978) and facies G_{II} of the Donjek type (Yukon Territories, Canada) of Rust (1978b). Comparable ancient analogs are portions of the Scanlan Conglomerate (Middleton and Trujillo, 1984, Facies Sequence 2), central Arizona; the Malbaie Formation (Rust, 1978b, 1984), eastern Gaspé, Canada; and the Unicoi Formation (Simpson and Eriksson, 1989, Facies Association B), south-central Virginia.

Lateral and vertical transitions from longitudinal bar (Gm)

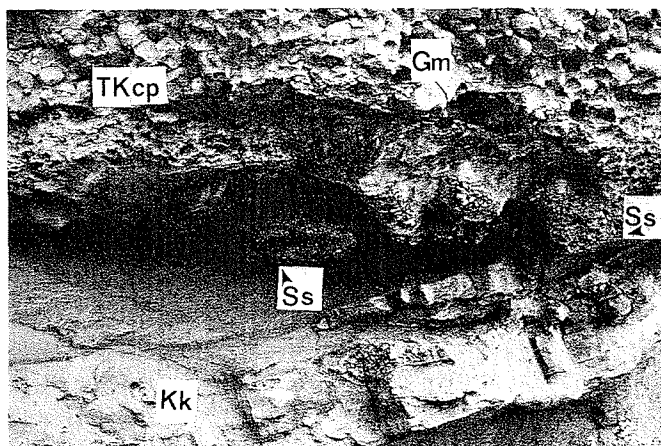


Figure 9. Weathered basal contact of Canaan Peak Formation (TKcp) with underlying sandstones of the Kaiparowits Formation (Kk). Scour-and-fill sandstone facies (Ss) occur as positive-relief features on the bottom of the Canaan Peak conglomerate bed (arrows).

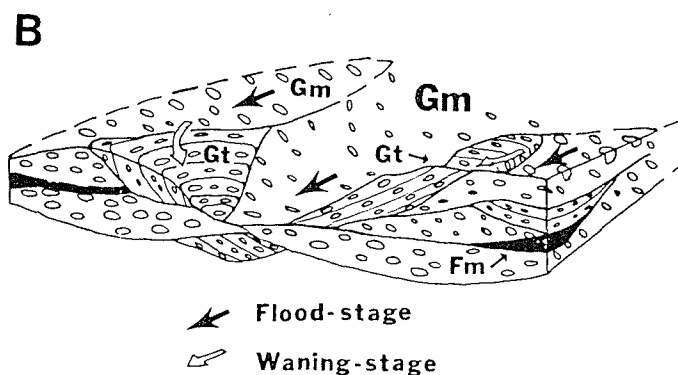
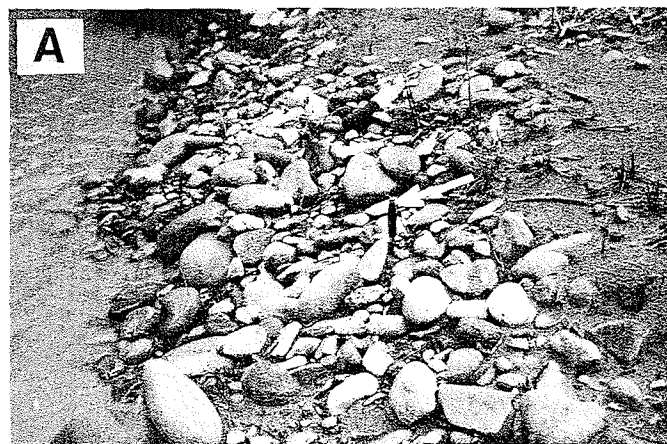


Figure 10. (A) Exposed margin of gravel longitudinal bar in channel of the Virgin River, Utah, showing a variety of different orientations of imbricated, platy clasts. Flow is from top to bottom of photograph. Note knife in middle of photograph for scale (arrow). (B) Diagram showing flow trends (large arrows) across longitudinal bar (Gm) during flood- and waning-stage flow. Rare vertical accretion facies (Fm) are also shown. Modified from Rust and Koster (1984).

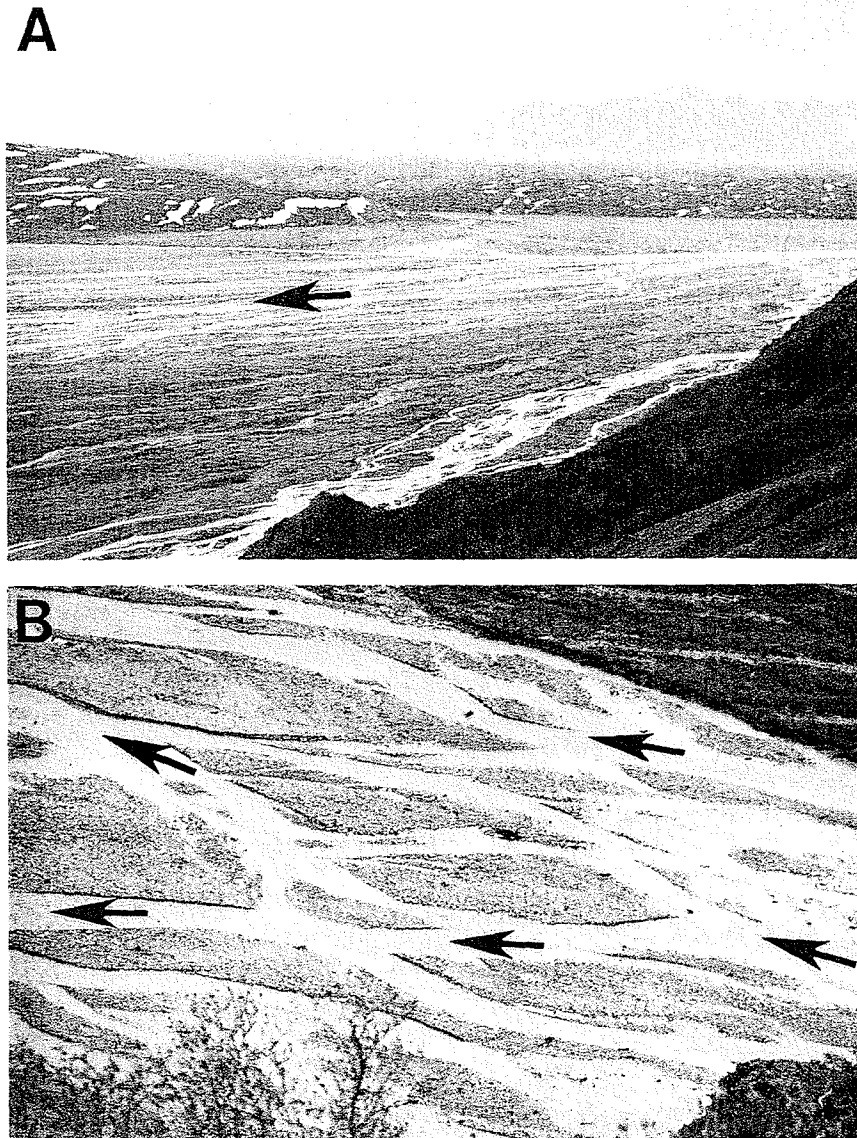


Figure 11. (A) Braided glacial outwash fluvial system (Teklanika River, Alaska) hydrodynamically similar to the Canaan Peak fluvial system. Active fluvial deposition and erosion occur on only a small portion of the braid-plain complex between flood flow stages. Dominant flow direction is right to left (arrow). Note orientation of intersecting channels at confluence of tributary drainage in upper middle portion of photograph; incoming flow trends from this tributary network can be as much as 90 degrees from the dominant, main channel trend, thereby complicating the resulting paleocurrent patterns preserved in the fluvial deposits. (B) Photograph showing longitudinal gravel bars and variable channel trends developed within active fluvial braid-plain of the Teklanika River during waning flood-flow stage. Arrows indicate flow direction. Photographs taken by F. W. Bachhuber.

facies into trough (Gt, St) or planar (Sp) cross-stratified facies characterize the Canaan Peak Formation (Figs. 4 and 12) and are documented in numerous studies of modern and ancient braided fluvial deposits for both semiarid alluvial fan and proglacial outwash deposits (Ore, 1964; Denny, 1965; Miall, 1977, 1978; Boothroyd and Nummedal, 1978; Rust, 1978b, 1984; Kraus, 1984; Middleton and Trujillo, 1984; DeCelles, 1986; DeCelles

and others, 1987). The abundance of coarse-grained, fabric-supported, imbricated conglomerate deposited as longitudinal bars; the relatively uniform sediment texture and coarse grain size; and the general lack of interbedded fines or matrix-supported conglomerate horizons indicate that river flow conditions were characterized by relatively high, consistent flow velocities. Interbedded Gm and Gp facies associations would

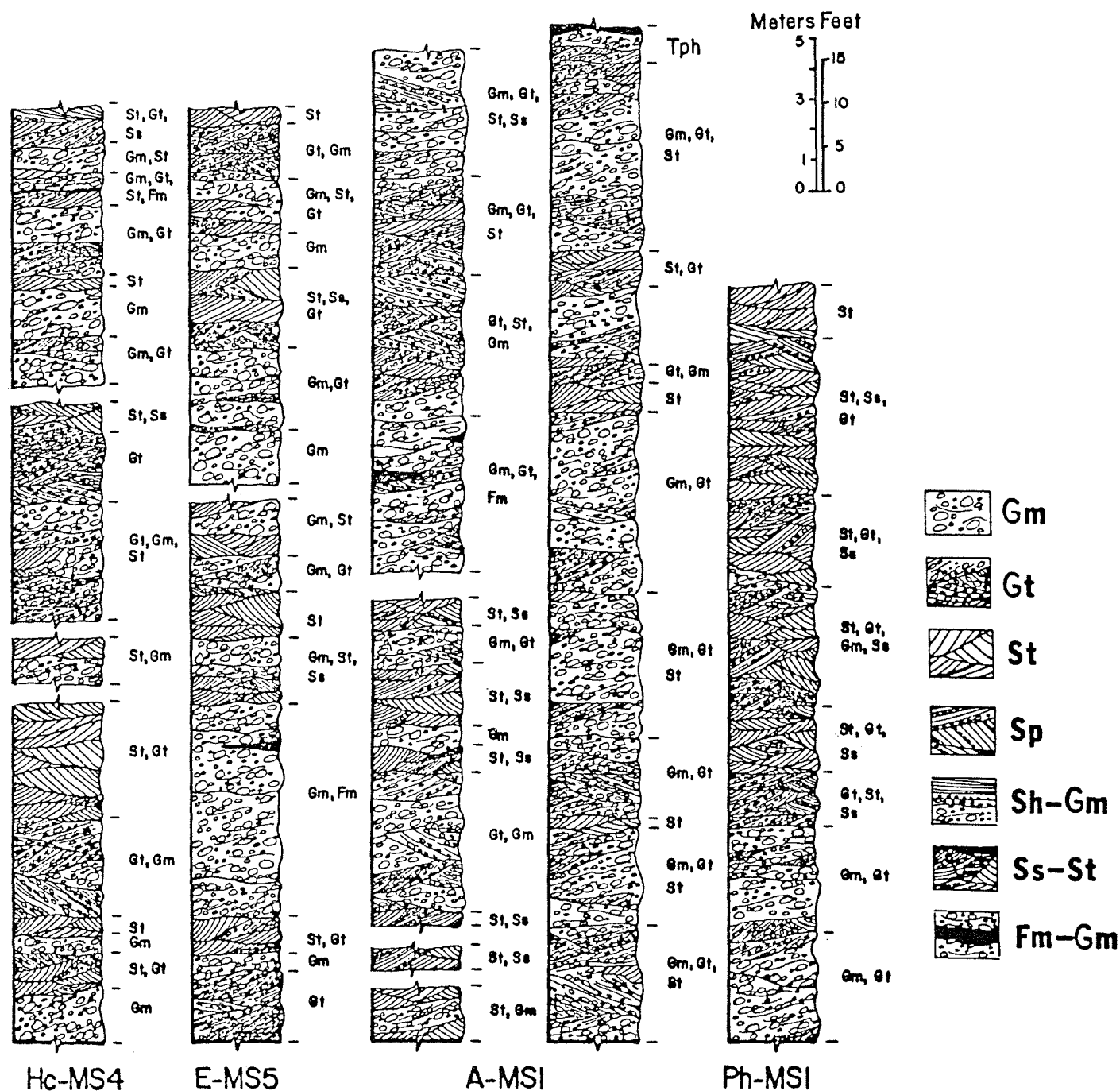


Figure 12. Selected representative lithofacies profiles of measured sections in the Canaan Peak Formation. Section locations are: Hc-MS4 = Horse Creek; E-MS5 = Escalante Canyon; A-MS1 = Allen Creek; Ph-MS1 = Pine Hollow. Detailed locality descriptions are included in the Appendix.

imply deposition along proximal, relatively high-gradient braided reaches and great water depths, with an abundance of very coarse-grained bed load (Smith, 1970; Rust, 1978b); however, lack of Gp suggests relatively low stream gradients and shallow water depths.

Consistent current flow was important in the Canaan Peak

fluvial system for vertical accretion and downstream progradation of facies Gm and Gt. Flow stages were capable of transporting and molding the dominant coarse-grained cobble-sized bed load. The prominence of facies Gm indicates that high-volume flow, necessary for longitudinal gravel bar development and maintenance, was persistent.

Water depths decreased in response to flow fluctuations, exposing bar tops and forcing flow to diverge around and away from existing longitudinal bars, thus promoting channel switching (Ore, 1964; Rust, 1978a). Subsequent erosion resulted in bar surface and margin dissection, channel widening, and development of shallow scours (Miall, 1977). Lower flow stage enhanced fine-grained sediment deposition (facies St, Sh, or Fm) as water levels dropped below bar top, isolating and pooling suspended sediment. Concurrently, deposition occurred within channels (Gm, Gt) and on the lee margins of preexisting channel bars (Gt, St, Sp). These facies associations typically develop when falling water and flow stage cause disequilibrium between preexisting bed forms and adjacent currents (Miall, 1977; Middleton and Trujillo, 1984; DeCelles and others, 1987). Deposits resulting from episodic, high-magnitude flood events, such as matrix-supported debris flows (Gms of Rust, 1978b; DeCelles and others, 1987) or hyperconcentrated flood flows (Smith, 1986), are absent, suggesting a perennial fluvial depositional setting.

PALEOCURRENTS

Paleocurrent data for the Canaan Peak Formation include measured trough-axis orientations in lithofacies Gt and St, and clast imbrication in lithofacies Gm and possibly Gt(?). Data collection was hampered by the verticality and covered character of many outcrops. Where possible, data were obtained from two- and three-dimensional exposures.

Imbricate clasts are typically oriented with their long (a) axes transverse (t) or oblique (o) to flow directions, while their intermediate (b) axes are inclined, or imbricate (i), upstream (Harms and others, 1982). Clast imbrication is common in lithofacies Gm within the Canaan Peak Formation and is, in part, a reflection of the abundance of platy or bladed, pebble-sized to small boulder-sized clasts. Clast imbrication data for this study were obtained by measuring the dip angle and azimuths of the b-axis of clast. From these data, preferred paleocurrent trends were determined (Gvo, Table 2). Adjustments for structural tilt were not performed (DeCelles and others, 1983) because of the relatively shallow stratal dip of the Canaan Peak Formation.

Two different statistical methods were used to analyze paleocurrent data from the Canaan Peak Formation. The Tukey chi-square test (Pincus, 1956; Middleton, 1965) was applied to determine grand vector orientation (Gvo), grand vector magnitude (Gvm), and chi-square (X^2) values (Table 2). For a selected data set, Gvo is a measure of the dominant directional trend; Gvm is a measure of its range of scatter, or dispersion. A Gvm value of 1 indicates no scatter, whereas a decrease in the Gvm value from 1 to 0 indicates a more random trend. The chi-square (X^2) value indicates the significance at the 90 percent confidence level of the measured orientation vector. If X^2 values are greater than 4.61, their orientation vector is significant (Table 2). Non-significant X^2 values (i.e., less than 4.61) are not included in Table 2 and were not used for interpreting or supporting paleoflow trends. In addition, the Rayleigh test of significance (at the

TABLE 2. STATISTICAL ANALYSES OF PALEOCURRENT DATA OBTAINED FOR CLAST IMBRICATION AND TROUGH AXIS ORIENTATIONS FROM CANAAN PEAK FORMATION MEASURED SECTIONS

Measured Section	Gvo* (°)	Gvm†	X^2 §	n**
Clast Imbrication				
Hc-MS3	18	0.16	5.0	100
Hc-MS4	63	0.29	16.4	100
Hc-MS5	49	0.23	10.0	100
Hc-MS6	151	0.49	46.6	100
E-MS1a	45	0.18	7.3	100
E-MS2	26	0.40	31.6	100
E-MS3	120	0.33	22.0	100
E-MSF	0	0.34	22.6	100
E-MS5	107	0.48	45.2	100
P-MS1	201	0.31	19.2	104
H-MS1	247	0.18	6.5	100
A-MS1	95	0.28	15.0	100
A-MS2	207	0.28	15.0	100
Mc-MS1	55	0.30	17.4	100
Trough Axis Orientation				
Hc-MS1-Hc-MS6	85	0.77	68.0	58
E-MS1-E-MS5	56	0.69	113.2	123
H-MS1	47	0.63	5.4	7
Ph-MS1	35	0.47	6.8	16
A-MS1	341	0.71	18.6	19
Mc-MS1	31	0.97	9.3	5
C-MS1	347	0.75	6.8	14

*Gvo = Grand vector orientation.

†Gvm = grand vector magnitude—a measure of variance.

§ X^2 = chi-square—a measure of significance at the 90 percent confidence level.

**n = total number of measurements obtained.

90 percent level) was applied to paleocurrent trends with significant X^2 values to determine if they represent random data (Graham, 1988). These trends were plotted on a Betschelet chart to estimate the amount of dispersion, suggesting a range of flow trends that bracket Gvo (Graham, 1988). The Rayleigh-test results indicate a measure of confidence in paleocurrent data comparable to that determined by the chi-square (X^2) analysis. Use of the Betschelet chart assumes a circular normal data distribution—that is, only one distributional mode—and may be misleading when applied to polymodal data like that acquired from the Canaan Peak Formation. Consequently, paleocurrent data, current rose diagrams, and statistical values for all clast imbrication and trough-axis orientation represent results determined only from the Tukey chi-squares test and can be found in Table 2.

Although paleoflow trends for the Canaan Peak fluvial system are variable, the data suggest an apparent *preferred* paleoflow direction (expressed by Gvo, Table 2) ranging from

southeast to north (Figs. 13 and 14). Dispersion in the Canaan Peak paleocurrent data is greater (i.e., G_{vm} closer to 0 than 1) for clast imbrication than for trough-axis trends (Table 2). Dispersion values for trough-axis trends may be attributed to their orientation superposed upon other, perhaps larger, bed forms (i.e., longitudinal bars) subparallel to the dominant channel trend. In addition, dispersion may indicate a localized change in paleoflow direction resulting from channel margin back-eddy currents; these currents may range up to 180° different from the main flow trend. Dispersion for clast orientation may reflect uncertainty in the a-b plane position of a clast within bed forms, that is, imbrication ($a[t]b[i/o]$) within longitudinal bars or lying parallel ($a[t]b[p]$) to foreset surfaces. Because of difficult outcrop access (vertical, two-dimensional cliff exposures), it is difficult to consistently distin-

guish truly imbricated clasts in lithofacies Gm (a-b planes dipping up-current [$a(t/o)b(i)$]) from those resting upon shallow-dipping foreset surfaces in lithofacies Gt (a-b planes inclined down current [$a(t/o)b(p)$]). This inability to discriminate conglomerate fabrics of vastly differing hydrodynamic origins likely contributed to the highly variable paleoflow directional data obtained.

Typically, clast imbrication is a more reliable indicator of true current flow than trough-axis orientation (Miall, 1977). Clast imbrication within developing longitudinal bars can vary from base to top and from the center outward (Hein, 1984). Initial deposition may orient the a-b planes of clasts transverse to paleoflow (Brayshaw, 1984, Figs. 1 and 2). Following bar development, the "preferred" clast orientation may be modified as flow stage diminishes from well-defined imbrication ($a[t]b[i]$) to less

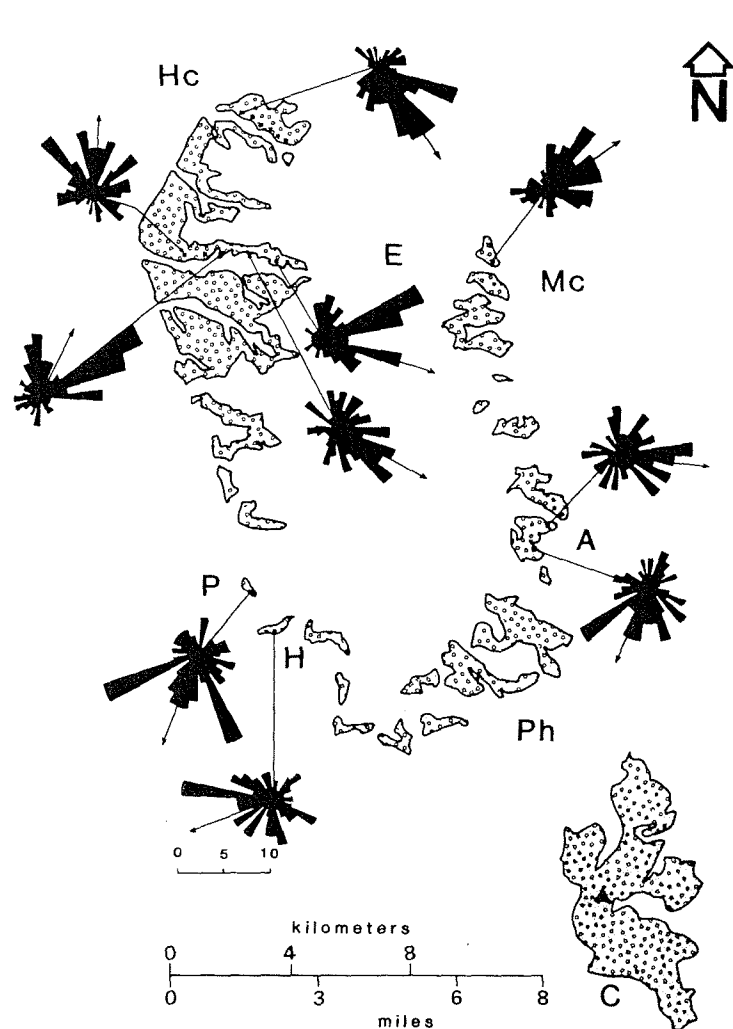


Figure 13. Study area index map showing paleoflow trends determined from measurements of imbricated clasts in the Canaan Peak conglomerates. Solid arrows indicate preferred paleocurrent trend (G_{vo}). Only trends with significant X^2 values (>4.62) are plotted. Refer to Table 2 for statistical data. Locations are: Hc = Horse Creek; E = Escalante Canyon; Mc = McGee Creek; P = Pine Lake; H = Henderson Canyon; Ph = Pine Hollow; A = Allen Creek; C = Canaan Peak.

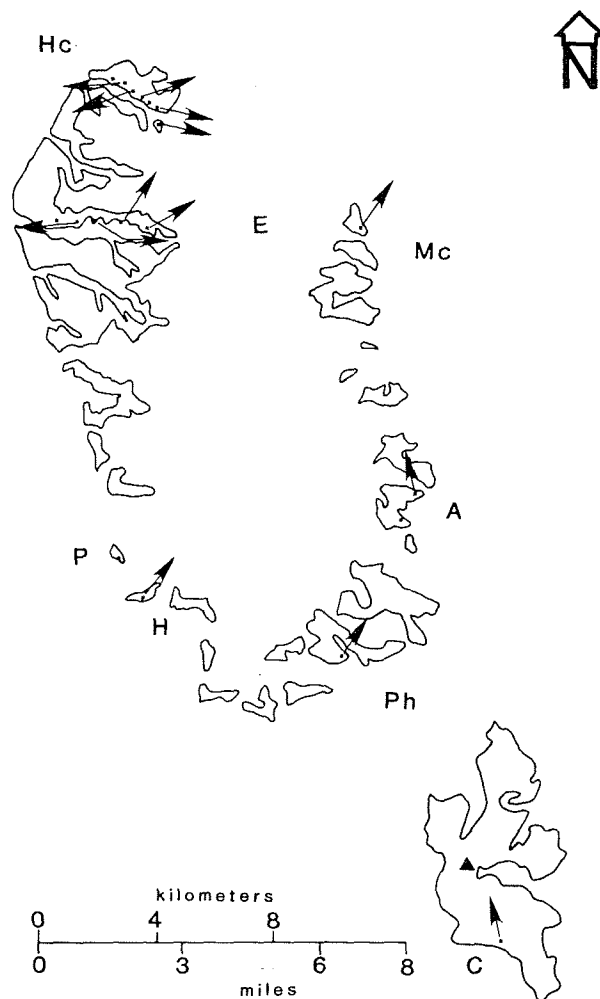


Figure 14. Study area index map showing paleoflow trends determined from trough axis orientations of cross-stratified conglomerate and sandstone lithofacies. Solid arrows indicate preferred paleocurrent trends (G_{vo}). Only trends with significant X^2 values (>4.61) are plotted. Refer to Table 1 for statistical data. Locations are: Hc = Horse Creek; E = Escalante Canyon; Mc = McGee Creek; P = Pine Lake; H = Henderson Canyon; Ph = Pine Hollow; A = Allen Creek; C = Canaan Peak.

direct flow-normal imbrication (a[o]b[i]). Consequently, clast positions influenced by dissection of the bar or trough foreset surface, or margins, may still be imbricate, but their dips (a-b plane) can change, and they may become oriented more obliquely to bed-form axis and paleoflow than before (Fig. 10). This clast reorientation, relative to a bar's vertical profile, likely reflects reworking of bed-form surfaces and margins during high-velocity flow stages prior to subsequent bar emergence and channel switching.

Trough scours typically develop adjacent and oblique to longitudinal bars and channel margins, and to primary flow directions (Miall, 1977; DeCelles and others, 1987). Their axes are subparallel to those of longitudinal bars, which develop parallel to localized channel flow (Rust, 1978b; DeCelles and others, 1983; Rust and Koster, 1984) (Fig. 10). In addition, active fluvial channel trends can vary up to 90° across a braided river tract or braid plain, but trends from 30° to 45° are most common (DeCelles and others, 1983) (Fig. 11). This is mainly a function of flow stage, which controls the level of development of channel sinuosity and subsequent low-flow channel switching (Ore, 1964; Harms and Fahnestock, 1965; Cant, 1978).

CONGLOMERATE PETROGRAPHY

Composition

Conglomerates of the Canaan Peak Formation are composed of a high proportion of resistant lithologies. Chert and quartzite lithologies are dominant. Volcanic and carbonate clasts (limestone, dolostone) are locally abundant. Sandstone (quartzarenite), conglomerate, and vein quartz clasts are minor.

Chert clasts are subrounded to well rounded and range up to medium-sized cobbles (15 cm). Varieties are gray, black, tan-brown, green, yellow, and red. Fossils recognized within chert clasts include poorly preserved rugose coral, brachiopod, bryozoan, crinoid, fusulinid, and abundant unidentified shell fragments. Some chert clasts are concentrically banded (cannonball variety); others are massive. Rarely, chert clasts have a distinctly thin, weathered rind around them.

Quartzite clasts are white, tan, dark gray, and variegated shades of tan and purple. Quartz grains within individual clasts range from fine to coarse sand, are subangular to very well rounded, and are moderately to well sorted. Planar stratification and ripple cross-lamination are present within some clasts. Quartz appears to be the only interstitial cement. Numerous grains have subangular to subround, reworked primary overgrowths.

Volcanic clasts identified include yellow, yellow-green, light and dark green, purple, red, reddish-brown, and light- to dark-gray varieties. Rhyolite and andesite flow rocks, rhyolite ash-flow tuffs (dominant), and rhyodacite and dacite breccia (E. I. Smith, 1986, personal communication) are subround to round, and friable to well indurated. Quartz-rich, gray-green volcanoclastic clasts are rare. Aphanitic and porphyritic textures have quartz as

the dominant phenocryst. Flow banding and flattened pumice fragments are present in some clasts. Accessory components include orthoclase and plagioclase, volcanic glass(?), hornblende, and biotite.

In thin sections of Canaan Peak Formation volcanic rock clasts, volcanic glass forms a patchy, finely acicular to cryptocrystalline (devitrified) groundmass that is colorless, gray, or reddish-brown in plain light. Flow banding, where present, occurs as very thin, quasi-continuous layers. Plagioclase was observed only in andesite flow rocks; grains are somewhat blocky and deformed (flattened) or have narrow lath shapes. Polysynthetic twinning is well developed.

Sandstone (moderately indurated quartzarenite) clasts are a minor component. They are reddish-brown to rust colored and, rarely, tan. Clasts are composed of well-sorted, subangular to subround, fine to medium sand-sized quartz grains. Small-scale trough cross-stratification and ripple cross-laminations occur. Examination of rock slabs and thin sections reveals interstitial calcite and hematite or clay cements.

Limestone and dolostone clasts are predominantly dull to flat black; gray and tan clasts with brown and tan laminations are also present. Clasts are very fine to coarsely crystalline; they become coarser grained and less equigranular with an increase in the degree of apparent dolomitization. Banded clasts contain a significant amount of very fine-grained terrigenous sand- and silt-size detritus. Fossils similar to those found within chert clasts occur but are a minor constituent.

Rare chert conglomerate clasts are well lithified and generally exhibit medium- to dark-gray mottled tones. These clasts contain black, gray, green, pink, red, orange, and tan medium sand- to pebble-sized grains of chert (dominant) and quartz. To a lesser extent, quartzite, fine-grained sandstone, carbonate, and siltstone fragments are also present.

Clast composition modes

Conglomerate clast lithologies and their abundances were determined from clast counts. Figure 15 indicates composite clast counts per measured section and their general locations around the Table Cliff Plateau. Clast counts were made to determine (1) dominant lithologies present in the study area, (2) lateral and vertical compositional variations, and (3) probable source-area lithologies. Of these, lateral and vertical compositional changes are least definable because of a lack of stratal continuity between measured sections across the study area.

Chert and quartzite clasts are found throughout the Canaan Peak strata. Overall, they account for more than half of all clast lithologies described. Chert is the most abundant (24 to 48 percent) and is more uniformly distributed. Quartzite clast abundance (14 to 67 percent) is more variable than chert and locally more abundant. Volcanic lithologies are present in all but three measured sections, reach a maximum 33 percent in Horse Creek Canyon (Hc-MS4), and are otherwise laterally persistent. Sandstone clasts (2 to 13 percent) occur in each measured section but are a minor component.

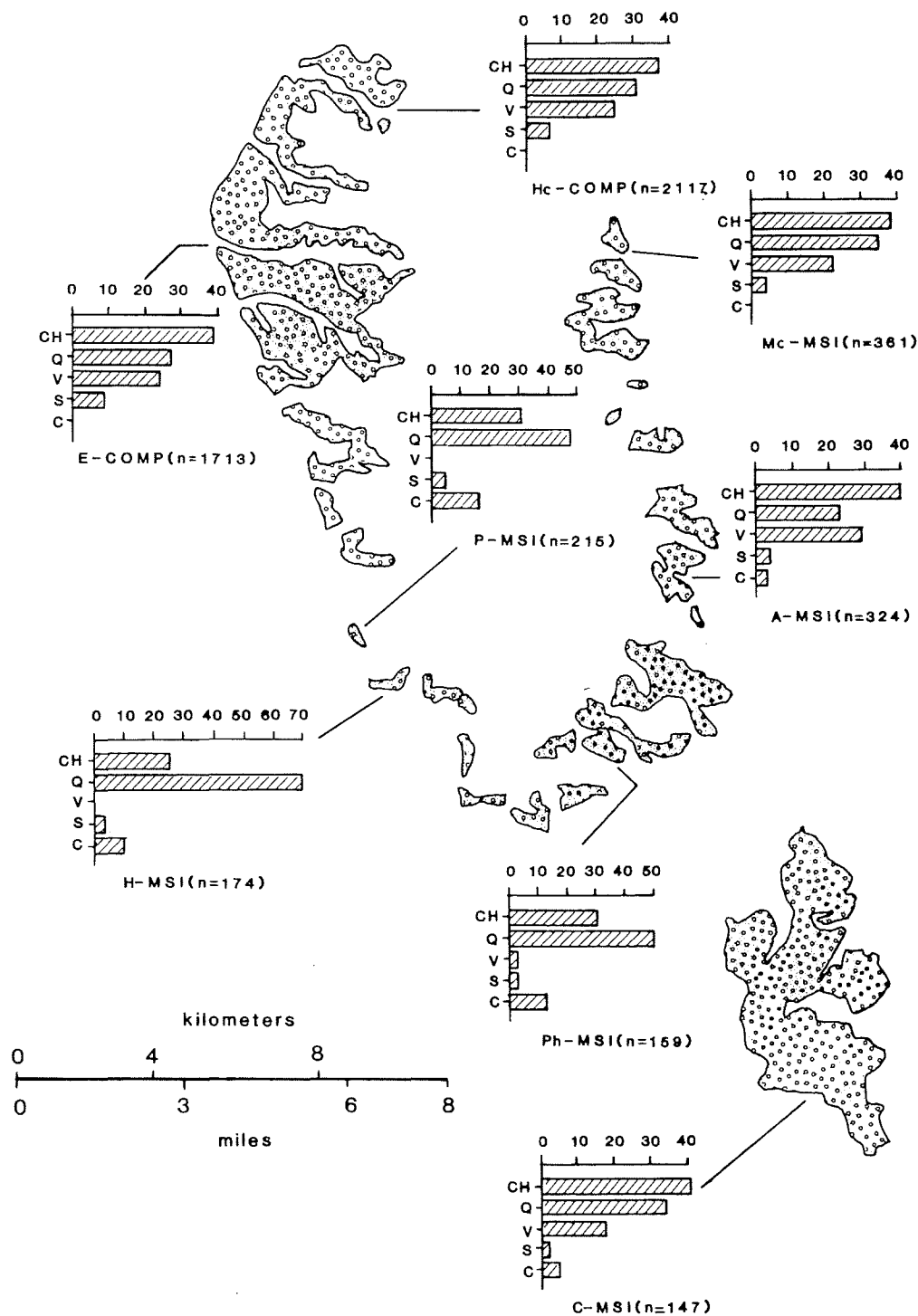


Figure 15. Index map showing locations of Canaan Peak measured sections (grouped) and associated conglomerate clast composition histograms. Composition abundance in percent plotted on X-axis; composition plotted on Y-axis. n = total number of clasts identified. C = carbonate, S = sandstone, V = volcanic, Q = quartzite, CH = chert. E-COMP and Hc-COMP histograms represent composite measured sections at the Escalante and Horse Creek localities, respectively. Data from other localities compiled from denoted measured sections (see Appendix). Mc = McGee Creek; P = Pine Lake; H = Henderson Canyon; Ph = Pine Hollow; A = Allen Creek; C = Canaan Peak.

Absence of volcanic or carbonate clasts is the most distinctive difference between measured sections. In contrast to other lithologies, carbonate clasts were encountered in only seven measured sections (reaching 16 percent at P-MSI) and appear more concentrated in the southern portion of the study area (Fig. 15). Although lateral continuity between sections cannot be precisely determined, there appears to be a general decrease upward in carbonate clast abundance, in contrast to observations of Bowers (1972); volcanic clast content, however, appears consistent. Where volcanic clasts occur in abundance, carbonate clasts are negligible to absent. The converse is true for the Pine Hollow, Pine Lake, and Henderson Canyon measured sections (Fig. 15). Recent petrofacies mapping by Goldstrand (1989, in preparation) suggests that the volcanic-rich and carbonate-rich conglomerates represent two different fluvial systems. The carbonate-rich fluvial system deposits overlie and locally contain clasts of the older volcanic-rich fluvial conglomerates (Goldstrand, 1989, in preparation).

SANDSTONE PETROGRAPHY

Sandstones are compositionally immature to mature (feldspathic litharenite to chertarenite). Compositions were determined from analysis of 27 thin-section point counts. They consist primarily of monocrystalline (Qm) and polycrystalline (Qp) quartz; lithic fragments (L), such as carbonate, siltstone, and volcanic rock fragments; and feldspar (F). Muscovite, chloritized clay, zircon, apatite, glauconite(?), and glass shards are negligible.

Texture

Sandstones are texturally immature to mature and very poorly to very well sorted. Sandstones are grain supported; grains are very angular to very well rounded and range from very fine silt (0.01 to 0.06 mm) to very coarse sand (2.0 mm); medium to coarse sand (0.25 to 0.5 mm) is dominant.

Sandstone is cemented by a combination of calcite, clay, hematite, and rare ferroan dolomite(?). Calcite cement is dominant (15 to 20 percent total volume) and is present within pore spaces and along grain fractures where it occurs either as poikiloplastic crystals or as a mosaic of twinned intergranular interlocking crystals (drusy). Some detrital grains are floating within calcite cement. Clay and hematite cement appear as flakes and grain surface coatings.

Dolomite, in some cases, is euhedral to subhedral; its rhombohedral shape indicates an authigenic origin. It occurs predominantly within interstitial calcite cement but is found rarely within calcite-filled grain embayments. Dolomite grains are colorless to translucent tan-brown, similar to the ferro-magnesian brown of Tucker (1981, p. 143).

Framework grains

Primary framework grains include monocrystalline (Qm) and polycrystalline (Qp) quartz, feldspar (F), and lithic fragments (L). The total quartz abundance (Q) was determined from the

sum of monocrystalline and polycrystalline quartz; total lithics (Lt) is the sum of polycrystalline quartz and lithic fragments.

Monocrystalline quartz (Qm). Monocrystalline quartz (Qm) is dominant in Canaan Peak sandstones. Single-crystal quartz exhibits straight to slightly undulose extinction. Well-rounded and reworked detrital quartz, with poorly to well-defined angular authigenic grain overgrowths, occurs but is not common. Some microlites consist of calcite or quartz crystals or of sericitized muscovite or feldspar; vacuoles are also present.

Polycrystalline quartz (Qp). Polycrystalline quartz (chert and composite quartz) occurs as a mosaic of equidimensional microcrystalline quartz crystals. Grains resemble quartz referred to by Pettijohn and others (1973) as resulting from "cold working" (grains being slowly strained, yielding a suture-like boundary). In the Canaan Peak sandstone, silty chert and chalcedonic chert are the most common polycrystalline quartz varieties. Carnelian or jasperoid (massive, opaque, mixed colors) chert and composite quartz were also recognized. Polycrystalline quartz grains are very angular to very well rounded. Sponge spicules(?), detrital quartz, and dolomite rhombs were noted within some chert grains.

Lithic fragments (L). Carbonate grains are distinguished by their very fine-grained, homogeneous character. They commonly contain quartz, chert, and silicified fossil fragments. Many nonsilicified fossil fragments are masked and unidentifiable because of diagenetic recrystallization. Some may be an artifact of multiple replacement episodes by calcite cement. Siltstone fragments are less common and may contain quartz and fossil fragments. Volcanic rock fragments consist of felsitic and microlitic grains with laths of feldspars and quartz. Devitrified flow structures are present in some grains.

Feldspar (F). Untwinned orthoclase grains were identified in only a few thin sections, based primarily on grain dispersion. However, oversize pores now infilled by large patches of coarsely crystalline sparry calcite cement suggest that abundant orthoclase was present but was subsequently nearly completely replaced by calcite during diagenesis. Contained within them are small flecks of feldspar that have escaped calcite replacement. Plagioclase, microcline, and untwinned orthoclase are persistent components of Canaan Peak sandstones.

Sandstone composition modes

Using the classification scheme of Folk (1982), sandstone compositions range from quartzarenite to litharenite and feldspathic litharenite. Quartzarenite is dominated by monocrystalline quartz (Qm 90 percent); sublitharenite is characterized by abundant monocrystalline quartz and moderate amounts of total lithics (polycrystalline quartz and sedimentary and volcanic rock fragments); litharenite is primarily chertarenite and is dominated by polycrystalline quartz. Feldspathic litharenites contain both plagioclase and orthoclase in addition to sedimentary and volcanic rock fragments.

Relative percentages of sandstone framework grain parame-

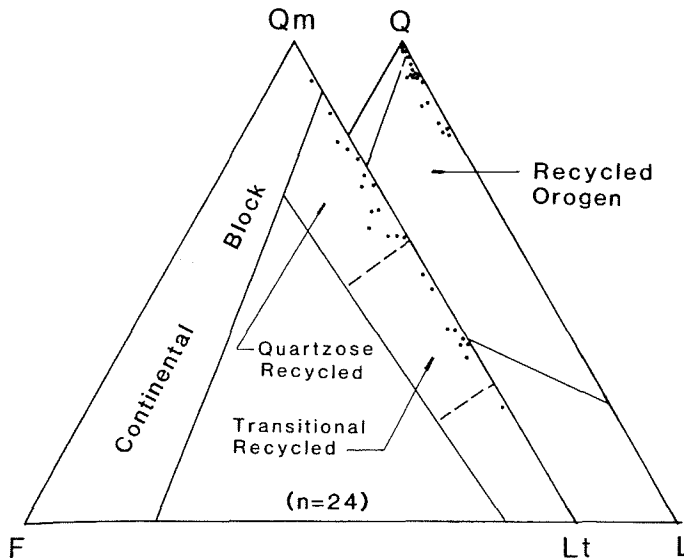


Figure 16. QmFLt and QFL ternary plots of Canaan Peak sandstone composition. After Dickinson and others (1983).

ters discussed above were plotted on QmFLt and QFL compositional ternary diagrams after Dickinson and others (1983) (Fig. 16). They plot as linear clusters and suggest that sandstones of the Canaan Peak Formation were derived predominantly from quartzose-transitional (craton margin) and recycled orogen (thrust belt) provenances consisting primarily of preexisting sedimentary rocks.

Discussion

As noted earlier, carbonate clasts are not abundant in the Canaan Peak Formation (Fig. 15). Humid climatic conditions, subaerial channel margin exposure, and periodic submergence and transport by flood flow would render carbonate clasts susceptible to chemical and mechanical weathering. Some chert clasts have a discolored, weathered rind, possibly similar to those described elsewhere by Varley (1984) and attributed to extensive subaerial exposure under humid environmental conditions. Chert, quartzite, and felsic volcanic lithologies are more resistant than carbonate and mafic volcanic lithologies through time and distance of transport (Abbott and Peterson, 1978). Consequently, a relatively great transport distance, or extensive recycling of detritus, would result in destruction of all but the most resistant clast lithologies present. The abundance of chert, quartzite, and felsic volcanic lithologies, and the paucity of carbonate lithologies therefore support significant and continuous recycling of detritus far down the Canaan Peak fluvial paleoslope.

PROVENANCE AND TECTONIC IMPLICATIONS

Synthesis of paleocurrent and compositional data suggests that the source area for Canaan Peak deposits was located in highlands of the Sevier fold-and-thrust belt west of the present-

TABLE 3. PROVENANCE OF CLASTS FROM CANAAN PEAK FORMATION CONGLOMERATES

Clast Type	Source Areas
Quartzite	Southwest Utah, upper plate of Wah Wah, Blue Mountain thrusts—Precambrian Prospect Mountain Quartzite, Ordovician Eureka Quartzite
Chert and carbonate	Upper and lower plates along entire length of thrust belt, southeast Nevada—southwest Utah—Paleozoic carbonate rocks
Volcanic rocks	Middle Jurassic Delfonte Volcanics of southern Spring Mountains, southeastern California
Red chert	Southwest Utah, lower plate of Blue Mountain thrust—Triassic Shinarump and Jurassic Morrison Formations
Sandstone	Southwest Utah, lower plate of Blue Mountain thrust—Jurassic Navajo Sandstone
Conglomerate	Southwest Utah, lower plate of Blue Mountain thrust—Triassic Shinarump and Jurassic Morrison Formations

day Table Cliff and Kaiparowits plateaus. Paleoflow data from this study, and Peterson (1969a), show an overall east to north-east sediment transport direction for Late Cretaceous fluvial systems in this region.

Consideration of Canaan Peak conglomerate compositions suggests that rocks exposed in thrust plates of the Sevier orogenic belt to the west were likely sources. Table 3 provides some probable source rocks and areas for Canaan Peak detritus. The closest uplifted thrust plates that could have provided detritus to the Canaan Peak fluvial system are now approximately 110 to 160 km to the west and include the Wah Wah, San Francisco (Frisco), and Blue Mountain thrusts (Fig. 17). Upper plate rocks include upper Precambrian–Lower Cambrian quartzite through upper Paleozoic quartzite and chert-rich carbonate; other exposed strata include Cambrian or lower mid-Paleozoic cherty carbonate rocks (East, 1966; Miller, 1966, Figs. 11–12). Lower plate rocks include lower Paleozoic carbonate or lower mid-Mesozoic terrigenous clastic rocks (East, 1966; Miller, 1966; Tschanz and Pampeyan, 1970; Morris, 1983). Presence of distinctive red chert pebbles, which first appear locally in the Campanian Wahweap Formation (Miller, 1966; Peterson, 1969), indicate that uplift and erosion of the red chert-bearing Triassic Shinarump and Jurassic Morrison formations continued into latest Cretaceous time. Volcanic clasts found in the Canaan Peak deposits are similar in composition to the middle Jurassic Delfonte Volcanics and may have been recycled from volcanic cobble and boulder conglomerates, exposed beneath the Contact thrust plate in the southern Spring Mountains, which contain Delfonte Volcanics clasts.

The presence of Upper Precambrian–Cambrian and lower Paleozoic quartzite and of Paleozoic chert and carbonate clast populations in the Canaan Peak conglomerate suggests that significant uplift occurred by latest Cretaceous time along parts of the southwestern Utah segment of the Sevier thrust belt (Fig. 17). However, it is not possible to relate deposition of Canaan Peak detritus to displacement along any particular thrust plate since

none contain unique, diagnostic lithologies. Indeed, complex clast suites in foreland basin conglomerates typically indicate erosional dissection of major portions of the adjacent, complexly folded and faulted thrust orogen (DeCelles and others, 1987; Steidtmann and Schmitt, 1988). For example, erosion of interior ramp-supported uplifts in the core of fold-thrust orogens may occur during periods of active frontal thrusting (DeCelles, 1988; Schmitt and Steidtmann, 1990). Dispersal of eroded detritus from interior sources may be accomplished by major antecedent fluvial systems that cut across the structural fabric of the fold-thrust belt (Steidtmann and Schmitt, 1988).

Rethinking of the significance of gravel dispersal in foreland basins has led to the hypothesis that some coarse-grained sedimentation reflects tectonic quiescence rather than uplift (Heller and others, 1988; Blair and Bilodeau, 1988) and calls into question many interpretations of thrust plate uplift and concomitant coarse clastic sediment deposition. Paola (1988) indicates that rapid proximal subsidence results in selective deposition of gravel along the active basin margin and hence an areally restricted

conglomerate geometry. When rates of erosion in actively uplifted source areas and concomitant sediment supply dominate adjacent basin subsidence, gravel sheets may be distributed across larger portions of the basin. Burbank and others (1988) illustrate this principle with an example of gravel progradation into the northwestern Himalayan foreland basin during active thrusting. In this case, the durability and volume of detritus supplied to the subsiding foreland basin result in basin overfilling, even during a period of relatively rapid subsidence. Thus, it is apparent that the controls on gravel dispersal within sedimentary basins are complexly related to rates and processes of sediment supply balanced against rates of basin subsidence.

Given the poor constraints on the timing and sequence of thrusting in the southwestern Utah thrust belt and the lack of biostratigraphic and chronostratigraphic resolution within the Cretaceous to early Tertiary nonmarine foreland basin section in the region, it is difficult to ascertain the tectonic signature of the Canaan Peak coarse-grained detritus. Conceivably, the Canaan Peak could record active uplift in the Sevier thrust belt to the west. Alternatively, Canaan Peak detritus may record the post-orogenic dissection of highlands created by earlier thrust-related uplift during a phase of relative tectonic quiescence (Fig. 18).

Regardless of the exact timing of uplift, it is important that thrust faulting in the southwestern Utah region did result in development of mountainous terrain during latest Cretaceous time and that erosion of those highlands contributed detritus to the Canaan Peak fluvial system. The question of which particular thrust was active when is not answerable from sedimentologic and provenance studies of the Canaan Peak Formation. To answer this question will require detailed structural mapping and stratigraphic studies within the thrust belt itself.

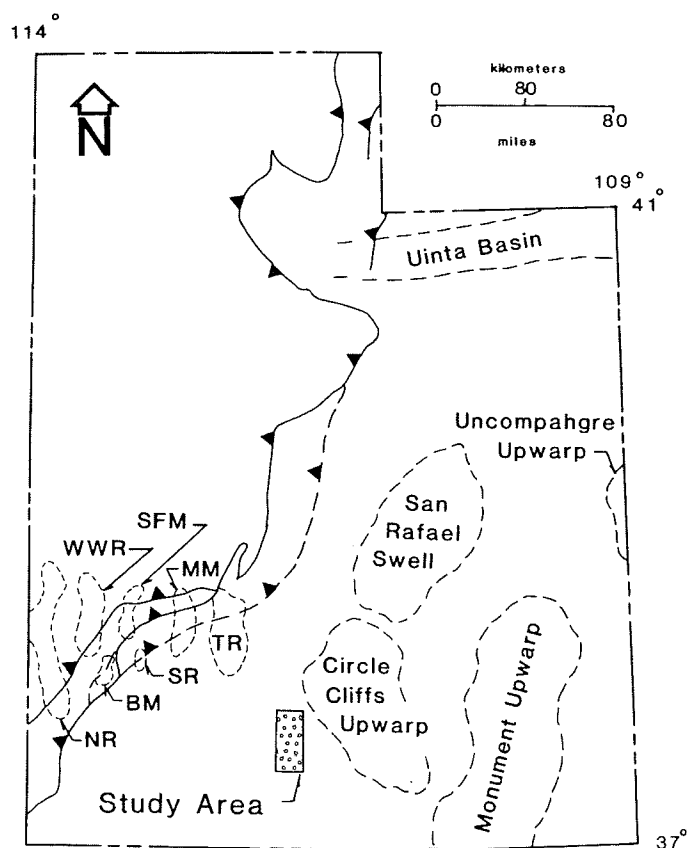


Figure 17. Locations of Sevier thrust fault exposures in southwestern Utah. The three major thrusts exposed there are, from east to west, the Blue Mountain, San Francisco, and Wah Wah thrusts. Mountain ranges where these thrusts are exposed include the Star Range (SR), Blue Mountains (BM), Mineral Mountains (MM), Needles Range (NR), Wah Wah Range (WWR), and San Francisco Mountains (SFM). TR denotes the Tushar Range where easternmost thrust is inferred to be buried beneath Cenozoic volcanic rocks.

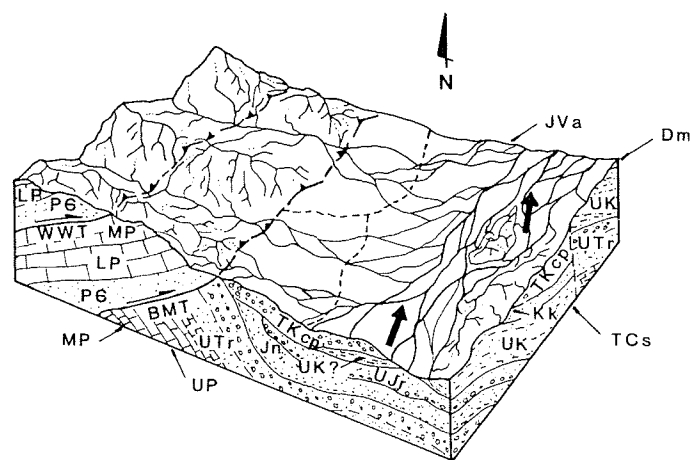


Figure 18. Schematic block diagram illustrating the paleogeographic and inferred paleotectonic setting for the Canaan Peak fluvial system. Stratigraphic units include: PC = Precambrian-Lower Cambrian; LP = Lower Paleozoic; MP = Middle Paleozoic; UP = Upper Paleozoic; UTr = Shinarump, Chile, and Moenkopi formations; Jn = Navajo Sandstone; UJr = San Rafael Group, Morrison Formation; UK = Dakota, Tropic Straight Cliffs, and Wahweap formations; Kk = Kaiparowits Formation; TKcp = Canaan Peak Formation. Structural features include: BMT = Blue Mountain thrust; WWT = Wah Wah thrust; Dm = Dutton monocline; TCs = Table Cliff syncline; JVa = Johns Valley syncline.

APPENDIX. MEASURED SECTION LOCALITIES

Base Sources:

1. USGS 7.5' Topographic Quadrangles—Lower left, upper right corner latitude/longitude values given for each topographic base map used.
 - (a) Sweetwater Creek, Utah: 38°45'N. Lat/120°0'00"W. Long; 37°52'30" N. Lat/111°52'30"W. Long.
 - (b) Pine Lake, Utah: 37°37'30"N. Lat/112°0'00"W. Long; 37°45'00"N. Lat/111°52'30"W. Long.
 - (c) Canaan Peak, Utah: 37°30'00"N. Lat/111°52'30"W. Long.; 37°37'30"N. Lat/111°45'00"W. Long.
 - (d) Upper Valley, Utah: 37°37'30"N. Lat/111°52'30"W. Long.; 37°45'00"N. Lat/111°45'00"W. Long.
2. Geologic Maps
 - (a) Bowers, 1973
 - (b) Hackman and Wyant, 1973
3. U.S.F.S., Dixie National Forest: Powell, Escalante, and Teasdale Ranger Districts, Utah (1:48,000 scale), 1982.

Measured Section Localities

Horse Creek Canyon: Easiest access via USFS road through local private property from paved Utah State Highway 22 on the USGS Grass Lakes 7.5' Topographic Quadrangle. Exit from highway approximately 4.5 miles north-northeast of Widsloe.

Hc-MS1—Center, SE 1/4, SW 1/4, NW 1/4, Sec. 8, T34S, R1W: Base—8,080' elevation.

Hc-MS2—NW 1/4, SW 1/4, NW 1/4, SW 1/4, Sec. 8, T34S, R1W: Base—8,040' elevation.

Hc-MS3—NW corner, NW 1/4, SE 1/4, NW 1/4, NE 1/4, Sec. 7, T34S, R1W: Base—8,000' elevation.

Hc-MS4—NE corner, SE 1/4, SW 1/4, SW 1/4, Sec. 6, T34S, R1W: Base—7,910' elevation.

Hc-MS5—NW 1/4, NE 1/4, SW 1/4, SW 1/4, Sec. 6, T34S, R1W: Base—7,930' elevation.

Hc-MS6—SW 1/4, NE 1/4, SE 1/4, NE 1/4, SW 1/4, Sec. 1, T34S, R2W: Base—7,860' elevation.

Escalante Canyon: Access via USFS road from Utah State Highway 22. Turn right (east) at junction of highway and Escalante-Main Canyon Road (USFS road FH17) at Widsloe.

E-MS1—NE 1/4, SW 1/4, SE 1/4, SE 1/4, SW 1/4, Sec. 24, T34S, R2W: Base—8,640' elevation.

E-MS2—SE corner, SE 1/4, SW 1/4, SE 1/4, SW 1/4, SE 1/4, Sec. 24, T34S, R2W: Base—8,080' elevation.

E-MS3—North center, SW 1/4, NW 1/4, SE 1/4, SW 1/4, SW 1/4, Sec. 24, T34S, R2W: Base—7,980' elevation.

E-MS4—Northeast corner, NW 1/4, SE 1/4, SW 1/4, SE 1/4, SE 1/4, Sec. 23, T34S, R2W: Base—7,900' elevation.

E-MS5—SW 1/4, NW 1/4, NW 1/4, SW 1/4, SE 1/4, Sec. 23, T34S, R2W: Base—7,800' elevation, approximately 70' east of western USFS boundary.

Pine Lake: Access via Utah State Highway 22 to USFS road 132 toward Pine Lake. Take USFS road 282 west and south of Pine Lake approximately 1.25 miles.

P-MS1—330' due east of T35S, R2W-R1W boundary. 450' due north SE corner Sec. 25, T35S, R2W: Base—8,495' elevation.

Henderson Canyon: Same access as for Pine Lake section. Reach end USFS road 282, turn right (west), drive approximately 0.5 miles west. Section is approximately 0.5 miles to south.

H-MS1—2,080' due east of T35S, R2W-R1W boundary, 740' due north of SW corner Sec. 36, T35S, R2W: Base—8,685' elevation.

Pine Hollow: Access via Utah State Highway 12 to USFS road 144. Drive north-northwest approximately 2.25 miles.

Ph-MS1—3.9 miles due east, 3,280' south of SE corner Sec. 36, T35S, R2W: 2 miles west-northwest along Pine Hollow from SW corner Sec. 7, T36S, R1E (R1W-R1E boundary), along west margin of Sec. 12: Base—8,400' elevation.

Canaan Peak: Access via Utah State Highway 12 to USFS road 461 south and east toward head of Shurtz Bush Creek and Canaan Peak.

C-MS1—SE corner SE 1/4, SE 1/4, NE 1/4, NE 1/4, NE 1/4, Sec. 16, T37S, R1E: Base—8,020' elevation.

Allen Creek: Access same as for Pine Hollow or USFS road 147.

A-MS1—NE corner NE 1/4, SW 1/4, SE 1/4, SE 1/4, NW 1/4, Sec. 19, T35S, R1E: Base—8,140' elevation.

A-MS2—610' due south, 240' due west of SW corner, Sec. 19, T35S, R1E: Base—8,145' elevation.

McGee Creek: Access via Main Canyon road approximately 5.5 miles northwest of junction with Utah State Highway 12.

Mc-MS1—NW corner SW 1/4, SW 1/4, NE 1/4, NE 1/4, NW 1/4, Sec. 25, T34S, R1W: Base—7,970' elevation.

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