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Braided stream deposition and provenance of the Late Cretaceous-Paleocene(?) Canaan Peak Formation, Table Cliff and Kaiparowits Plateaus, southwestern Utah

David Allen Jones

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Braided stream deposition and provenance of the Late Cretaceous-Paleocene (?) Canaan Peak Formation, Table Cliff and Kaiparowits Plateaus, southwestern Utah

Jones, David Allen, M.S.
University of Nevada, Las Vegas, 1989
BRAIDED STREAM DEPOSITION AND PROVENANCE OF THE LATE CRETACEOUS-
PALEOCENE(?) CANAAN PEAK FORMATION, TABLE CLIFF AND
KAIPAROWITS PLATEAUS, SOUTHWESTERN UTAH

by

David Allen Jones

A thesis submitted in partial fulfillment
of the requirements for the degree of

Master of Science

in

Geology

Department of Geoscience
University of Nevada, Las Vegas
August, 1989
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University of Nevada, Las Vegas
August, 1989

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ABSTRACT

The Late Cretaceous to Paleocene (?) Canaan Peak Formation of southwestern Utah is comprised 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, scour-fill (Ss) sandstone, and massive to finely laminated silt- and sandy siltstone (Fm). Gravel deposition occurred during high-discharge periods within a Scott-type, perennial, braided fluvial system as longitudinal (Gm) and sinuous-crested transverse (Gt) bars, and as a product of longitudinal bar-top and inter-bar channel scour filling (Gt). Sand accumulated under lower flow velocity conditions through migration of inter-bar channel dunes and transverse bars (St/Sp) and development of scour-and-fill deposits (Ss). Siltstone (Fm) deposition resulted from vertical accretion on bar tops during waning flow conditions.

Clast imbrication and trough axis orientation measurements indicate east to northeast paleoflow directions. Gravel-sized clasts are comprised predominantly of resistant lithologies including Upper Precambrian-Cambrian quartzite, Paleozoic chert, and distinctive Jurassic red chert; Upper Cretaceous (?) volcanic rocks and 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 faulting to the west in southeastern Nevada and western Utah and was distributed across an extensive gravel-dominated braid-plain complex. Sediments represent multiple-cycle deposits that were transported eastward a minimum distance of 70 to 80 km. They were subjected to multiple episodes of continuous, high-energy fluvial recycling that resulted in the destruction of all but the most stable clast lithologies.
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I am grateful to my thesis committee for their contribution to the completion of this manuscript. Fred Bachhuber's participation in the field area, as well as his long distance communication, was quite helpful. A special thanks is extended to the folks with the Clark County Department of Comprehensive Planning, Las Vegas and with the Water Resources Division of the U.S. Geological Survey, Carson City, Nevada for their encouragement and support.

When the project was at a low ebb, my spirits were lofted by the support to continue from many wonderful friends; they will always be remembered. To Linda S. and Susan R., Susan P. and Susan H., Jerry C., Matthew B., and Kent W. - I'm here when you need a lift; to the Hunts (of Las Vegas, not Texas), the Bloomers, the Harrisons, and others - THANKS!!

Mentioned last, but really at the top of the list is MOM. You played a big role - you taught me early on about humility, respect, honesty with oneself, and how to fight on through against seemingly insurmountable odds; you taught me how to persevere. We did it, finally, huh?!

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INTRODUCTION

During the development of the Sevier orogenic belt, synorogenic clastic sediments were shed from highland source areas created by major eastward-directed thrust plates into an adjacent subsiding foreland basin (Speiker, 1946; Armstrong, 1968; Fleck, 1970; Burchfiel and Davis, 1975). The latest stages (middle Cenomanian-early Maastrichtian) of thin-skinned, Sevier-style thrusting were coeval with Laramide-style, basement-involved foreland uplift and associated basin formation across central Utah (Fig. 1), into western Colorado, and northward into Montana and Wyoming (Armstrong, 1968; Dorr and others, 1977; Lawton, 1983; DeCelles, 1987; Dickinson and others, 1988). Provenance and stratigraphic analyses of late Cretaceous to early Tertiary foreland basin deposits in the Wyoming-Idaho-Utah segment of the Sevier orogenic belt have enabled a detailed reconstruction of the timing and sequence of major thrust development (Wiltscho and Dorr, 1983) as well as a clear picture of the influence of Laramide structures on foreland basin sedimentation (Dickinson and others, 1988). Provenance studies of similar-aged foreland basin clastics in the central Utah segment of the Sevier thrust belt include those by Jefferson (1982), Fouch and others (1983), and Lawton (1983, 1985, 1986). In addition, these studies also have provided information concerning the nature of fluvial systems within the evolving Sevier foreland basin. Detailed sedimentologic and provenance investigation of Cretaceous to early Tertiary foreland basin deposits, however, have not been conducted in southwestern Utah.

The purpose of this study was to determine the depositional environments and provenance of the conglomeratic Upper Cretaceous-Paleocene (?) Canaan Peak Formation of south-central Utah (Fig. 1). More specific research objectives included determination of (1) lithofacies present and their lateral and vertical relationships; (2) composition of Canaan Peak conglomerate and associated
Figure 1. Map showing location Canaan Peak Formation study area (enlarged in Fig. 2) in southcentral Utah, approximate trace of the Sevier thrust belt, and major Laramide-style basement-cored uplifts, Utah. Map adapted from Armstrong (1968), Stewart (1980), Lawton (1983, 1985), Peterson (1986), Dickinson and others (1988).
sandstone; and (3) provenance of the conglomerate as determined from the identification of source rocks and paleocurrent indicators. Synthesis of these findings suggests that deposits of the Canaan Peak Formation represent sediments subjected to multiple cycles of reworking, downstream transport, and redeposition within a medial-to-distal fluvial braid-plain depositional environment. These sediments appear to have been removed, temporally and spatially, from any influences of active tectonism along the Sevier fold-thrust belt to the west, from west-central Utah to southeast Nevada.

**Canaan Peak Formation**

The type section of the Upper Cretaceous-Paleocene (?) Canaan Peak Formation is located at the head of Wahweap Creek on the south side of Canaan Mountain near Bryce Canyon National Park (Bowers, 1972) (Fig. 1; 2). The formation crops out sporadically over an area of 160 km² (100 mi²) around the base of the Table Cliff Plateau and at Canaan Mountain on the Kaiparowits Plateau (Bowers, 1972; Hackman and Wyant, 1973) (Fig. 2). Exposures are generally poor and, where stratigraphic sections were measured, consist of alternating intervals of non- to poorly resistant colluvial slopes and moderately to highly resistant ledges and cliffs of conglomerate and sandstone (Fig. 3).

The Canaan Peak Formation unconformably overlies the Upper Cretaceous Kaiparowits Formation which is dominated by massive to well-stratified, gray to blue-gray, fine- to very fine-grained sandstone and subordinate mudstone (Lohrengel, 1969; Peterson, 1969a; Bowers, 1972) (Fig. 4). Rare lenses of a sandy silt-pebble conglomerate occur in its upper 20 m at the Henderson Canyon measured section locality (Fig. 2). The basal contact of the Canaan Peak Formation was designated by Bowers (1972) as the base of the first major conglomerate overlying the Kaiparowits Formation, and is invariably a sharp, irregular erosional surface. It consists of alternating intervals of
Figure 2. Index map of 18 measured sections (solid-fill squares) of the Canaan Peak Formation (TKcp, stippled). Shown from northwest to southeast are 8 major localities including: Horse, McGee, and Allen Creeks; Escalante, Pine Lake, and Henderson Canyons; and Pine Hollow and Canaan Mountain. Canaan Peak (solid-fill triangle) denoted as "cp". The town of Henriville, Utah is in extreme southwest corner. Modified from Bowers (1972), and Hackman and Wyant (1973).
Figure 3. West side of Table Cliff Plateau, view is toward the southeast. Stratigraphic succession shown (indicated in Fig. 4) includes the Kaiparowits (Kk), Canaan Peak (TKcp), Pine Hollow (Tph) and Wasatch (Tw) Formations. Arrows indicate approximate base of formation(s). Conifer tree in lower left of photo is growing on Kaiparowits strata.
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<tr>
<td></td>
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<td>Wasatch</td>
</tr>
<tr>
<td></td>
<td>Tph</td>
<td>Pine Hollow</td>
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<tr>
<td></td>
<td>TKcp</td>
<td>Canaan Peak</td>
</tr>
<tr>
<td>UPPER CRETACEOUS</td>
<td>Kk</td>
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<td></td>
<td>Kwa</td>
<td>Wahweap</td>
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<td></td>
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<td>Tropic &amp; Dakota</td>
</tr>
<tr>
<td>UPPER CRETACEOUS</td>
<td>Jm</td>
<td>Morrison</td>
</tr>
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Figure 4. Stratigraphic and age relationships for some rock units 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 (1969a).
massive to poorly stratified granule to boulder conglomerate that are interbedded with moderately to well-stratified, pebbly coarse-grained and coarse- to fine-grained sandstone. Thin lenses of sandy siltstone are rare. The formation grades upward and laterally into sandstone, siltstone, and bentonitic clay of the conformably overlying and intertonguing Paleocene Pine Hollow Formation. The lower Pine Hollow Formation is composed predominantly of thinly bedded to massive, variegated red to purple-gray, fine-grained siltstone and mudstone that are interbedded with fine-grained limestone and calcareous siltstone horizons near its top (Bowers, 1972).

Vertebrate fossils from the Kaiparowits Formation have provided little biostratigraphic control other than establishing a middle to late Cretaceous age (Decourten and Russell, 1985; J.G. Schmitt, 1986, personal commun.; D. Gillette, 1987, personal commun.). Palynomorphs collected from the uppermost part of the Kaiparowits and lower half of the Canaan Peak Formations indicate ages ranging from early to middle Campanian (Lohrensegel, 1969; Peterson, 1969a; Bowers, 1972, pg. B19, Table 1). The upper half of the Canaan Peak and entire overlying Pine Hollow Formations have not yet yielded age-diagnostic fossils. Consequently, full age range of the Canaan Peak Formation presently is unknown. Fouch and others (1983), in agreement with Bowers (1972), suggested that the age of the formation may extend from middle to late Campanian. Regrettably, precise biostratigraphic correlations of the Kaiparowits-Canaan Peak strata with other temporally equivalent strata nearby is unlikely until more extensive biostratigraphic studies are completed.

Methodology
Field Methods

Eighteen stratigraphic sections within the Canaan Peak Formation were measured and described. Seventeen sections are located around the base of the
Table Cliff Plateau, one is located at Canaan Mountain (Fig. 2). Selection of measured section sites was based primarily on outcrop accessibility and the spatial relationship, overall, to the aerial extent of the formation. In order to recognize and describe sedimentary facies and structures using criteria of Miall (1977), vertical and lateral outcrop continuity was a prerequisite. Approximately 100 clast composition counts also were performed at each measured section upon sub-vertical to vertical two-dimensional and, rarely, three-dimensional exposures. Data were obtained from a pre-determined grid-size based on the largest clast within the area counted, so as not to count a clast more than once. Clast compositions and their lateral or vertical variation between measured sections was determined. Results were then plotted as horizontal-bar histograms. Various clast types were collected at each measured section for petrographic analysis and provenance determination. Representative sandstones were also collected for petrographic analysis. Clast imbrication and cross-strata axis orientations were obtained at each measured section where exposures were accessible. Preferred paleocurrent trends and statistical significance for these data were determined by a computer program using the Tukey Chi-squares method provided by E.I. Smith. Results are plotted as grand vector orientations and circular rose diagrams.

Laboratory Methods

A total of 24 petrographic thin sections were analyzed and point counted to determine compositional framework modes. Compositions were then plotted on ternary compositional and provenance diagrams (Dickinson and others, 1983). Conventional rock-slab, staining techniques (Morris, 1985) were used for comparing relative orthoclase feldspar percentages with those determined from thin-section analysis.
LITHOFACIES

Conglomerate and sandstone are the two major lithotypes occurring within the Canaan Peak Formation. Conglomerate is dominant, with lesser amounts of interbedded sandstone and rare siltstone. Lithotypes are subdivided, following the terminology of Miall (1977, 1978) and Rust (1978a), on the basis of sediment fabric and sedimentary structures into seven lithofacies. These consist of two conglomerate (Gm, Gt), four sandstone (St, Sp, Sh, Ss), and one siltstone (Fm) lithofacies (Table 1).

Canaan Peak strata crop out as moderately to highly resistant vertical and subvertical ledges and cliffs (1.5-17 m thick) (Fig. 5). Facies change quickly and no recognizable marker horizons exist. Lithofacies identified could not be correlated between measured sections because they lack lateral continuity; however, sections were traced as far as outcrops permitted, locally up to several hundred meters. Examination of lateral changes between sections indicate some general trends discussed in the following sections. Thus, generalized stratigraphic sections are illustrated in Figure 6 to facilitate discussion and to document vertical lithofacies relationships.

**Conglomerate Lithofacies**

Coarse-grained conglomerate was subdivided into two lithofacies: massive, non- to very crudely horizontally stratified (Gm) and trough cross-stratified (Gt) conglomerate (Figs. 5, 7). Lithofacies discrimination was based on textural characteristics, clast imbrication, cross-stratification (if any), and outcrop geometry. Due to poorly defined stratification, concise lithofacies differentiation was not always possible. Nevertheless, facies Gm appears to be dominant. Facies Gt is only locally more abundant (Fig. 6).
Table 1. Summary of lithofacies defined on the basis of texture and sedimentary structures present and hydrodynamic interpretations for the Canaan Peak Formation. After Miall (1977, 1978), Middleton and Trujillo (1984), and DeCelles (1987). Some typical facies associations within the Canaan Peak sediments are illustrated.

<table>
<thead>
<tr>
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<th>STRUCTURES</th>
<th>INTERPRETATION</th>
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<td><strong>Conglomerate</strong> - clast supported, pebble- boulder-size clasts</td>
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<tr>
<td>Gm -</td>
<td>massive to crudely bedded, poorly sorted</td>
<td>non- to horizontal bedding, clast imbrication, graded interstitial fines</td>
<td>longitudinal bars, mid- to lateral channel development: upper flow regime</td>
</tr>
<tr>
<td>Gt -</td>
<td>poorly to well stratified and sorted</td>
<td>low-angle, small-large scale trough cross-stratified, incipient clast imbrication, graded interstitial fines</td>
<td>lateral bar and shallow channel scour deposits: lower-upper flow regime transition</td>
</tr>
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<td><strong>Sandstone</strong> - fine- to coarse-grained sandstone, pebbly sandstone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St -</td>
<td>poorly to well stratified, moderately graded</td>
<td>small-large scale trough cross-stratification</td>
<td>shallow scour, bar-top and dune deposit: lower flow regime</td>
</tr>
<tr>
<td>Sp -</td>
<td>poorly to well stratified, moderately graded</td>
<td>moderate scale planar-tabular cross-stratification</td>
<td>shallow scour, bar-top and transverse/linguid bar deposit: lower flow regime</td>
</tr>
<tr>
<td>Sh -</td>
<td>non- to poorly stratified, non- to moderately graded</td>
<td>massive to horizontally stratified,</td>
<td>channel margin/bar-top sand sheet deposit: plane bed, upper flow regime</td>
</tr>
<tr>
<td>Ss -</td>
<td>non- to poorly stratified, moderately graded</td>
<td>crude horizontal or trough cross-stratified, elongate, sinuous channel or cylindrical pothole shape</td>
<td>channel floor scour deposits: turbulent, upper flow regime</td>
</tr>
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<td><strong>Siltstone</strong> - very fine-grained sandy siltstone</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Fm -</td>
<td>non- to poorly stratified, well sorted, non-graded</td>
<td>massive to finely laminated, drape characteristics</td>
<td>very shallow-water, channel margin/bar-top deposits: lower flow regime; standing water, vertical accretion</td>
</tr>
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Figure 5. Vertical and subvertical cliffs of the Canaan Peak Formation. Non- to crudely stratified (Gm) and trough (Gt) cross-stratified conglomerate are dominant. Less abundant trough (St) cross-stratified and rare horizontally (Sh) stratified sandstone are generally more resistant than the conglomerate, typically occurring as cap-rock surfaces or overhanging ledges. Note backpack (arrow) for scale along middle-left cliff base.
Figure 6. Generalized stratigraphic columns from some representative measured sections of the Canaan Peak Formation. Indicated are the selected measured section and their vertical lithofacies associations. The base of each section is a different elevation, therefore some apparent lateral similarities are only coincidental, and correlations are not intended. Arrows along column margins indicate possible complete lithofacies depositional cycles (i.e., Gm-Gt-St; Gm-Fm). Refer to Table 1 (pg. 10) for explanation, and Appendix A2 for additional information.
Figure 7. Outcrop photograph and interpretive sketch showing the 3 most dominant facies of the Canaan Peak Formation: Gm - massive to very crudely horizontally stratified conglomerate; Gt - trough cross-stratified conglomerate; St - trough cross-stratified sandstone. Note rock hammer (arrow) for scale on lower right margin of St facies.
Conglomerate facies (Gm, Gt) are intimately interbedded with each other and, to a lesser extent, with finer-grained facies. Facies Gm occurs as solitary beds, or poorly defined multi-story sequences consisting of three to five individual beds. Facies Gt occurs as solitary sets, or cosets of up to four sets. Conglomerate bed dimensions are variable; individual beds are up to 1.5 m thick and 5 to 7 m long.

Bed geometries include thin, sheet-like (a few clasts thick), and lens- and scoop-shaped deposits. Most lower bounding contacts are erosional and sharp. Some small-scale, fine-grained conglomerate beds grade upward from basal contacts from facies Gm to Gt. Erosional surfaces are irregular (slightly dissected), planar to subplanar, and concave- or convex-upward showing little relief.

Conglomerate facies are clast supported throughout and commonly well indurated. Poorly-cemented horizons occasionally permit easy clast removal. Beds in each conglomerate facies are non- to normally graded and are poorly to well sorted. Interstitial medium- to coarse-grained sand is non-stratified, non- to normally graded, and poorly to well sorted. Clasts are generally subround to well rounded with smooth surfaces. Depending on mineralogy, some are highly weathered and pitted (rhyolite), while others exhibit only crescent-shaped fractures or surface indentations (quartzite and chert). Clasts vary in size from pebble to small boulder (-0.2-31 cm) although very coarse granules to small cobbles (-3.2-14 cm) are dominant. Clasts larger than pebble-size are commonly elongate (oblate- or blade-shaped), while those smaller are more equant. Elongate, flattened clasts express incipient to well-defined imbrication in some beds; long (a) axes are transverse (t) or oblique (o) to paleoflow trends, while intermediate (b) axes are imbricate (i) (terminology from Harms and others, 1982, Figure 6-2) and dipping as steeply
as 60° in an upstream direction. The long (a) and intermediate (b) axes of some clasts appear parallel (p) to foresets, with intermediate (b) axes also parallel to paleoflow direction.

Massive To Crudely Stratified Facies (Gm)

Lithofacies Gm is recognized by its massive, non-stratified, poorly-sorted character, and its clast imbrication (organized conglomerate of DeCelles and others, 1987) (Figs. 5, 7). Stratification, where present, is crudely horizontal and generally truncated at low angles by overlying beds. Facies Gm is typically interbedded with trough cross-stratified conglomerate (Gt) and sandstone (St) (Fig. 6). Rare interbedded lenses of sandy siltstone (Fm) occur locally. Clast imbrication is prominent in facies Gm dipping from 4° to vertical, but most commonly 20°-60°. Lower bounding surfaces are erosional, planar to subplanar, and exhibit very slight convex- or concave-upward contacts with little relief. Some Gm beds are gradational with overlying trough cross-stratified conglomerate (Gt) or sandstone (St) intervals.

Trough Cross-stratified Facies (Gt)

Lithofacies Gt is recognized by its trough-shaped cross-stratification and arcuate-shaped, concave-upward, low relief basal erosion surface (Fig. 7). Poorly to well-defined cross-stratification permit distinction from facies Gm. Upper bounding surfaces are sub-planar or concave-upward. Some facies Gt sets are gradational from non-stratified, coarse-grained facies Gm; others are gradational with overlying trough cross-stratified (St), or massive to horizontally stratified (Sh) sandstone.

Facies Gt foreset inclination is generally low, ranging between 4°-28°. The orientation of flattened, elongate clasts lying parallel to foresets
accentuates stratification. Conversely, some clasts appear to represent incipient to well-defined imbrication, oblique and normal to foreset inclination. However, this seems to be relatively uncommon in trough crossbeds (J.G. Schmitt, 1987, personal commun.).

Facies Gt commonly occurs as single sets, which interfinge laterally and are interbedded vertically with facies Gm and St. They also occur in cosets of up to four sets. Set thicknesses range from a few centimeters for small-pebble horizons up to 1.5 m for cobble dominated intervals; sets are up to 7 m long and 4 m wide.

**Fine-grained Lithofacies**

Sandstone dominates the non-gravel facies of the Canaan Peak Formation. Discrimination between these facies was based primarily on grain size and cross-stratification. Four sandstone and one siltstone facies were recognized. Trough cross-stratified sandstone (St) is dominant, while planar cross-stratified sandstone (Sp) is present only locally. Horizontally stratified (Sh) and scour-and-fill (Ss) sandstone, and massive to finely laminated sandy siltstone (Fm) facies are rare. Cross-stratification within the sandstone facies is more easily recognized than that within the conglomerate facies.

Facies St and Sp occur more commonly in cosets than as solitary sets. Cosets consist of up to seven sets, and are up to 3.5 m thick and 6 m long. In general, sandstone facies are laterally and vertically discontinuous with the conglomerate facies. Locally there is an apparent up-section increase in sandstone bed thickness and overall volume.

Sandstone facies are composed of very fine- to coarse-grained sand (0.06-2 mm), are typically well sorted, and possess angular to well-rounded grains. Sandstone beds commonly fine upward from thin pebble lag horizons. They are
typically interbedded with both conglomerate lithofacies (Fig. 6).

**Trough Cross-stratified Sandstone (St)**

Facies St occurs singly and as multi-story assemblages and are interbedded with conglomerate facies Gm and Gt (Figs. 5-7). Solitary sets range from a few to 55 cm thick, often fining upward from small-granule to pebble (16-2 mm) lag horizons into coarse- to medium-grained sandstone (0.25-0.1 mm). Cosets (4-7 sets) measure up to 3.5 m thick. Sand grains are subangular to well-rounded, fine to very coarse, and poorly to well sorted.

Set bounding surfaces are arcuate-shaped (concave-upward), erosional and smooth, and show little relief (Fig. 7). Foreset inclination is commonly as steep or steeper than that in facies Gt, with foreset dips of 3°-28°. Toe- and bottomsets are tangential (onlap of Miall, 1977) to the basal scour surface. Erosional surfaces commonly truncate underlying cross-stratified sets.

**Planar Cross-stratified Sandstone (Sp)**

Well-defined, fine- to coarse-grained planar cross-stratified sandstone (Sp) was observed only at the Canaan Mountain measured section (Fig. 3). There, the base of facies Sp overlies facies Gm. The outcrop surface is approximately 8 m wide and 7 m high. The sequence is locally gradational with and overlain by crudely horizontally stratified (Sh) and small-scale trough cross-stratified (St) pebbly sandstone (Fig. 8).

Facies Sp cosets are tabular (up to 1 m thick) and separated by thin (up to 25 cm thick), discontinuous horizons of granule to pebble conglomerate (Gm). Lower set and coset bounding surfaces are erosional, slightly irregular, and subparallel to one another (Fig. 8). Set thicknesses range from 5-35 cm. Foresets dip 8°-20° and are parallel to subparallel. Toesets
Figure 8. Outcrop photograph and interpretive sketch showing planar-tabular (Sp) sandstone bounded by underlying facies Gm and overlying facies St. Thin, pebbly foreset slip-faces define Sp cosets within tabular bodies. Tabular sets are commonly truncated by and interbedded with facies Gm. Note rock hammer (arrow) in lower middle of view for scale.
display a non-tangential, sharply angular relationship to their basal depositional surface. Thin granule-pebble lag horizons (a few grains thick, 0.15-2 cm) are common along some foreset avalanche slip-faces, and fine upward along foreset surfaces.

**Horizontally Stratified Sandstone (Sh)**

Fine- to medium-grained, moderately sorted, poorly developed massive to horizontally stratified (Sh) sandstone is rare. It overlies and is crudely gradational with facies Gm, St or Sp. More often, it grades upward from a thin, small-pebble lag horizon (Fig. 9). Individual beds do not exceed 12 cm in thickness and are approximately 0.5-1.0 m wide.

**Scour-and-fill Sandstone (Ss)**

Facies Ss is defined by medium- to coarse-grained sandstone and pebbly sandstone. In the Canaan Peak Formation, as well as in descriptions by Miall (1977), it may include thin basal granule-pebble lag horizons. In the study area, Ss is best exposed along the base of the Canaan Peak Formation (Fig. 10). Deposits include fine- to very coarse-grained sandstone and pebbly, very coarse-grained scour-and-fill sandstone (Fig. 6). Massive to trough cross-stratified, and non- to normally graded sequences are intimately associated. Some Ss deposits are crudely horizontally stratified. Figure 10 illustrates facies Ss expressed in negative relief; the scoured upper surface of the underlying Kaiparowits Formation sandstone represents a mold surface upon which lithofacies Ss was deposited. Lithofacies Ss are represented by (1) short, shallow scoop-shaped depressions, (2) elongate, and straight to sinuous asymmetrical V-shaped channels, and (3) relatively deep cylinder-shaped potholes (Fig. 10). Elongate, channelized facies Ss deposits are 20-50 cm long and 10-15 cm deep; pothole deposits are up to 22 cm deep and 6-35 cm in
Figure 9. Outcrop photograph and interpretive sketch of small-scale massive to horizontally stratified (Sh) sandstone and pebbly sandstone interbedded with facies St and Gm. Isolated, small pebbles are locally abundant in an otherwise sand-sized grain population. They suggest deposition under upper flow regime conditions. Note rock hammer (arrow) in upper middle for scale.
Figure 10. Outcrop photograph and interpretive sketch of scour-and-fill (Ss) deposits defined by medium- to coarse-grained sandstone and pebbly sandstone. In addition to basal foreset deposits, Ss also occurs as pothole and shallow, elongate channel deposits; these result from excessive turbulence during the transition between lower and upper flow regime conditions. Scale-bar (lower right of photo) approximately 15 cm. TKcp and Kk denote Canaan Peak and Kaiparowits Formations, respectively.
Massive To Laminated Fine-grained Siltstone (Fm)

Lenses of massive to very finely laminated sandy siltstone and very fine-grained sandstone (Fm) are found rarely interbedded between facies Gm and Gt (Fig. 11). Deposits are 0.45-1.5 m wide and 8-30 cm thick. Lower bounding surfaces are erosional and concave-upward. Facies Fm commonly form a sediment drape upon underlying coarse-grained facies. Upper bounding surfaces are erosional, irregular, subplanar, and of modest relief. Overlying conglomerate clasts (facies Gm or Gt) commonly protrude downward into the upper-most surface of lithofacies Fm (Fig. 11).
Figure 11. A rare lens of massive to finely laminated sandy siltstone and very fine-grained sandstone (Fm). It typically forms a sediment drape overlying coarser grained sediment (Gm-Gt). Both lower and upper surfaces of facies Fm are irregular. The upper surface of facies Fm commonly has overlying, imbricate conglomerate clasts protruding into it; note clast orientation immediately above and nearby hammer handle (arrow).
DEPOSITIONAL ENVIRONMENT

Lithofacies recognized in the Canaan Peak Formation document deposition within a high-energy fluvial system composed of numerous adjacent, sub-parallel active channels. Deposition occurred primarily within a transitional, medial braided fluvial system. Strata resemble portions of proglacial gravelly braided facies models of the Scott type (southeast Alaska) of Miall (1977, 1978) and facies G$_{II}$ of the Donjek type (Yukon Territories, Canada) of Rust (1978b). Although the Canaan Peak Formation does not compare closer to one type than the other, valid comparisons can be made between apparent processes that produced the Canaan Peak facies assemblages and those of other similar ancient and modern fluvial deposits. Portions of the Scanlan Conglomerate (Middleton and Trujillo, 1984, Facies Sequence 2), central Arizona, the Malbaie Formation (Rust, 1978b, 1984), eastern Gaspe’, Canada, and the Unicoi Formation (Simpson and Eriksson, 1989, Facies Association B), south-central Virginia provide comparable ancient analogs.

**Interpretation**

Development of longitudinal gravel bars and in-filling of shallow channel scours by diffuse gravel sheets were dominant processes of the Canaan Peak fluvial system. Fabric supported, massive to crudely horizontally stratified, imbricate gravelly longitudinal bars (lithofacies Gm) (Figs. 12, 13) develop by downstream progradation and vertical accretion of channel bedload (Ore, 1964; Williams and Rust, 1969; Boothroyd and Ashley, 1975; Rust, 1978b; Ethridge and others, 1984; Kraus, 1984). Rust (1978b, p.614-615) suggests that gravelly longitudinal bars equilibrate under high velocity flow conditions and are most stable during peak flood stages, when all bedload is in motion. Facies Gm initially develop as small nuclei of the coarsest bedload clasts. These nuclei
Figure 12. A. Examples of flow direction and its effect on clast orientation. Exposed margin of longitudinal bar along Virgin River, Utah indicating orientations of various flattened clasts. Note knife (arrow, middle view) for scale. Flow direction from top to bottom. B. Diagram showing flow trends (arrows) across longitudinal bar (Gm) and trough cross-stratified (Gt) gravel surfaces, and rare vertical accretion (Fm) facies association(s). Modified from Rust and Koster, 1984.
Figure 13. Longitudinal gravel bars and variable channel trends developing within active fluvial braided-plain of the Teklanika River, Alaska during waning flood-flow stage; arrows indicate flow direction. Bar-scale (lower right) approximately 3 m (F.W. Bachhuber photo).
form within the deepest portions of active channels under traction, or plane-beded, flow (upper flow regime) conditions (Leopold and Wolman, 1957) forming cluster bedforms (Brayshaw, 1984, Fig. 2). Other clasts become stacked, or imbricate, upon and downcurrent from cluster bedform nuclei.

Deposition of gravel occurs on planar to subplanar, or slightly concave-upward channel scour surfaces (Harms and Fahnstock, 1965; Smith, 1970; Brayshaw, 1984; DeCelles and others, 1987). The fabric supported character results from gravel bedload deposition by aqueous flow capable of moving very coarse-grained (cobble-boulder sized) material, which keeps sand and smaller particles in suspension. A reduction in flow velocity during Canaan Peak deposition resulted in the late-stage infiltration and grading of interstitial sand within some of the gravel component of Gm units.

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 (Smith, 1970; Rust, 1978b; Harms and others, 1982) (Figs. 12, 13). Elongate, trough-shaped 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 (facies Gt, St). They developed as solitary or sinuous-crested transverse dunes migrated into the shallow scours. Alternatively, Gt sets with low-angle foresets ( <20°) could also form 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 Fahnstock, 1975; Rust, 1978b). Miall (1977) notes that trough (Gt, St) and planar (Sp) foreset development result
from simultaneous erosion and deposition. Turbulent backflow immediately upstream of the slip-face initiates scouring by slow-separation eddies as water passes over a bar- or dune-crest, followed by grain saltation and bedform progradation. Trough scours began to fill by repeated avalanching of material over longitudinal bar crests and down the adjacent dune slip-face (Middleton and Trujillo, 1984). The presence of thin, granule-pebble lag horizons, particularly along the erosional base, and some foresets, of facies St and Sp (Fig. 9), indicate a localized increase in flow regime preceded their deposition. A subsequent decrease in flow regime followed with sand deposition.

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 (Figs. 9, 10). Their development is a function of water depth and current velocity, and of the relief of bedforms upon which they are deposited. During deposition, current velocities are no longer capable of transporting gravel bedload (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, presence of facies Sh on bar-top or dune surfaces indicate reduced water depths. Harms and others (1982) suggest lithofacies Sh form in shallow water during low flow or peak flood-stage conditions. 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 (i.e., larger-than-average clasts, inter-twined tree trunks or branches) creating relatively deep, small-diameter potholes. Subsequent infilling occurs either during upper (plane-bed) or lower
flow-regime conditions and relatively shallow water (Allen, 1963; Miall, 1977).

Rare, massive to faintly laminated, lens-shaped facies Fm developed within 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 became emergent, isolating small bar-top pools. Some basal facies Fm layers formed a drape-like cover upon underlying coarser-grained material (Fig. 11).

Discussion

Lithofacies associations, coupled with sediment texture and fabric, clast lithologies recognized in the Canaan Peak sediments, and palynology data provide evidence for their development under humid (high precipitation, frequent flooding) climatic conditions within a perennial braided fluvial system. Deposition occurred along low-sinuosity reaches of a broad, unconfined braid-plain with a moderate paleoslope (Fig. 14).

Lateral and vertical transitions from longitudinal bar (Gm) facies into trough (Gt, St) or planar (Sp) cross-stratified facies are documented in numerous studies of modern and ancient braided fluvial deposits for both semi-arid 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 grain size, and general lack of interbedded fines or matrix-supported gravel horizons indicate river flow conditions were characterized by relatively consistent flow velocities. Interbedded Gm and Gp facies would imply deposition along proximal, relatively high-gradient braided reaches and great water depths, with an abundance of very coarse-grained bedload (Smith, 1970; Rust, 1978b). The lack
Figure 14. Braided fluvial depositional system (Teklanika River, Alaska) probably hydrodynamically similar to that for Canaan Peak Formation. Alluvial fan deposition was not a local factor in Canaan Peak sediment dispersal. Active fluvial deposition and erosion is occurring across a relatively small portion of the braid-plain complex between flood flow stages. Dominant flow direction (arrow) right to left. Note orientation of intersecting channels at confluence of tributary drainage upper middle of photograph; incoming flow trends from this tributary network can be up to nearly 90° different from the dominant, main active channel trend. Bedform axis trends from incoming tributary channels add to complexity of developing drainage patterns and subsequent interpretation of current-flow indicators (F.W. Bachhuber photo).
of gravel facies Gp suggests stream gradients and water depths were not sufficient for their development.

Consistent current flow was important in Canaan Peak fluvial processes 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 bedload. The prominence of facies Gm indicates high-volume flow was necessary for longitudinal gravel bar development and, to maintain bar character. Harms and Fahnstock (1975) note that when fluid discharge and sediment abundance are relatively high, longitudinal bars will grow faster downstream than they will accrete vertically. These conditions may increase the potential for horizontal stratification to develop. Since lithofacies Gm and Gt recognized in the Canaan Peak Formation are massive- to very poorly horizontally stratified, it is suggested that relatively low but consistent stream flow discharges promoted more rapid vertical accretion over downstream progradation. Coarse-grained bedload was abundant in more proximal reaches of the Canaan Peak fluvial system (Claron Formation(?), southwest Utah) and was being rigorously reworked and transported downstream, but without the addition of much new detritus.

Water depths decreased as minor flow fluctuations occurred, exposing bar-tops and forcing flow to diverge around and away from existing longitudinal bars, 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 drop below bar-tops, isolating and pooling suspended sediment. Concurrently, deposition occurred within channels (Gm, Gt) and on the lee margins of pre-existing channel bars (Gt, St, Sp). These facies associations typically develop when falling water
and flow-stage cause disequilibrium between pre-existing bedforms and adjacent currents (Miall, 1977; Middleton and Trujillo, 1984; DeCelles and others, 1987). Sorted, stratified (Gt, St, Sp) units support current flow reductions most likely resulting from fluctuating seasonal precipitation. Ultimately, fine-grained, non-stratified material infiltrates into clast intersticies as current flow continues to wane. 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 lacking and support a perennial fluvial depositional setting.

Proximal braided river deposits form in response to major tectonic or steep gradient flood-stage events (Rust and Koster, 1984). Initially, major thrusting events can provide a variety of clast lithologies to the fluvial depositional environment. However, continued tectonic control would be indicated by several factors or combinations of factors. With abundant sediment supply, deposition of coarsening upward cycle(s) of heterogeneous composition in response to source area unroofing of successively older strata is common; each cycle may be overlain by more homogeneous, reworked sediment layers indicating episodic tectonic activity (Miall, 1981; Burbank and others, 1988). Repeated fining- or coarsening-upward cycles of reworked proximal fluvial sediments may also indicate fluctuating tectonic pulses. The common occurrence of alluvial fan facies (i.e., Gms, Gp), and a greater abundance of larger clast sizes and texturally more immature deposits are typically used to suggest proximity to tectonically active zones (Denny, 1965; Rust and Koster, 1984; DeCelles, 1986; DeCelles and others, 1987; Heller and others, 1988). The absence of these characteristics, or combinations of them, in the Canaan Peak detritus indicate that deposition did not occur along a tectonically active fault-bounded uplift, but rather on a more distal, coarse-grained braided fluvial plain. The
influence of individual tectonic episodes is diminished or lost completely as detritus is transported farther away from tectonically influenced alluvial fans (Rust and Koster, 1984).

**PALEOCURRENT TRENDS**

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 most outcrops. Where possible, data were obtained from two- and three-dimensional exposures.

The ab-planes of imbricate clasts are typically oriented such that their long (a) axes are transverse (t) or oblique (o) to flow direction, 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 a reflection of the abundance of platy or bladed, pebble- to small boulder-sized clasts. Clast imbrication data for this study was obtained by measuring the dip and dip direction of the clast’s ab-plane; actual paleoflow direction differed from collected data by 180°, and was subsequently corrected for statistical applications. Adjustments for structural tilt were not performed (DeCelles and others, 1983) due to the relatively shallow stratigraphic dips overall of the Canaan Peak Formation.

The Tukey chi-squares test (Pincus, 1956; Middleton, 1975) was applied to corrected paleoflow data to statistically determine grand vector orientation (Gvo), grand vector magnitude (Gvm) and chi-square ($X^2$) values (Table 2). Gvo is a measure of the dominant directional trend for a selected data set; Gvm is a measure of their range of scatter, or dispersion. A 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% 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 95% level) was applied to paleocurrent trends with significant $X^2$ values to determine if they represented random data (Tucker, 1988). Only those determined to be significant were then plotted on a Betschelet chart (Tucker, 1988) to estimate the amount of dispersion, indicating a range of flow trends bracketing the grand vector orientation (Gvo).

### CLAST IMBRICATION

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### TROUGH AXIS ORIENTATION

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Table 2. Statistical analyses of paleocurrent data obtained for clast imbrication and trough axis orientations from Canaan Peak Formation measured sections. Grand vector orientation (Gvo - given in degrees), grand vector magnitude (Gvm - a measure of variance), and chi-square ($X^2$ - a measure of significance at the 90% confidence level) values were determined; (n) equals the total number of measurements obtained; R equals Rayleigh significance test at 95% level (R-random, S-significant); D equals +/- degrees of scatter bracketing Gvo (Appendix B).
of the Rayleigh test (R) and the Betschelet plots (D) are shown in Table 2 and Appendix B. Where the Rayleigh test (at 95% level) indicated possible randomness these data were omitted from Table 2. However, for comparison the Rayleigh test of significance was also applied at the 90% level for all data with previously determined significant $X^2$ values. These results indicate a comparable measure of confidence in the same data as originally suggested by the $X^2$ analysis. Use of the Betschelet chart assumes a circular normal data distribution, i.e., only one distributional mode (Smith, 1989, personal commun.). Consequently, the range of dispersion indicated by the D values (Table 2; Appendix B) at the 90% and 95% confidence levels determined from the Canaan Peak paleocurrent polymodal data may be misleading. Measured paleocurrent data, current rose diagrams, and statistical values for all clast imbrication and trough axis orientations can be found in Appendix B.

Although paleoflow trends for the Canaan Peak fluvial system are variable, data provide an apparent preferred paleoflow direction (Gvo, Table 2; Appendix B) ranging from southeast to north. Truly imbricated clasts were difficult to distinguish from clasts resting upon poorly defined foreset surfaces within conglomerate lithofacies in lateral or vertical juxtaposition of one another. Insufficient discrimination between conglomerate fabrics of differing hydrodynamic origins may contribute, in part, to variable paleoflow data obtained from clast imbrication.

With few exceptions, dispersion in the Canaan Peak paleocurrent data is greater (Gvm closer to 0 than 1; +/- D values) for clast imbrication than for trough axis trends (Table 2). Dispersion within clast data reflect the ab-plane's orientation within bedforms, i.e., imbrication [a(t)b(i/o)] (dipping upstream) within longitudinal bars (lithofacies Gm) or lying parallel [a(t)b(p)] (dipping downstream) to foreset surfaces (lithofacies Gt).
Dispersion for trough axis trends may be attributed to their orientation superposed upon other, perhaps larger bedforms (i.e., longitudinal bars), and their occurrence 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 back-eddy currents may range up to 180° different from the main flow trend. Subsequent scatter in paleoflow trends may indicate vertical or lateral changes in the degree of channel sinuosity, dispersal patterns, and flow conditions during development of the Canaan Peak fluvial system.

Typically, clast imbrication is a more reliable indicator of true current flow than trough axis orientation (Miall, 1977, 1983; Davis, 1984). Clast imbrication within developing longitudinal bars can vary from base to top, and from the center outward (Hein, 1974). Initial deposition may orient clasts transverse or oblique to paleoflow (Brayshaw, 1984, Figs. 1 & 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 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 (ab-plane) can be more steep or oriented more oblique to bedform axis and paleoflow than before dissection occurred (Fig. 12). This clast re-orientation, relative to a bar's vertical profile, likely reflects reworking of bedform surfaces and margins during high-velocity flow stages prior to subsequent channel switching and bar emergence.

Trough scours typically develop adjacent and oblique to longitudinal bars, channel margins, and to primary flow directions (Miall, 1977; DeCelles and others, 1987). Their axes are sub-parallel to those of longitudinal bars which develop closely parallel to localized channel flow (Rust, 1978b;
DeCelles and others, 1983; Rust and Koster, 1984) (Fig. 12). In addition, active fluvial channel trends can vary up to 90° across a braided river tract or braid-plain but, trends from 30°-45° are most common (DeCelles and others, 1983). 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).

Clast imbrication was measured mostly from 2-dimensional exposures (Fig. 5); rarely, crude 3-dimensional longitudinal bar complexes were located (Fig. 11). Dips [a(t/o)b(i)] and paleoflow directions of flattened clasts were measured at each section (Appendix B). For this study, clast imbrication trends are more variable than those for trough axes; overall, most clast imbrication trends suggest a preferred eastward (dominant range is southeast to northeast) orientation (Gvo, Table 2; Fig. 15).

Most trough axis measurements were obtained from 3-dimensional sandstone exposures. Sandstone troughs were more easily recognized and accessible than gravel troughs. With some exceptions, trough axis trends determined from conglomerate and sandstone beds also show paleoflow was generally eastward (dominant range is east to northeast) (Gvo, Table 2; Fig. 16). Measurements on 2-dimensional surfaces were estimated and, ascribing to the methods of DeCelles and others (1983), are likely to be accurate to within 25° of actual paleoflow direction.
Figure 15. Study area index map indicating paleoflow trends determined from measurements of imbricated, coarse-grained conglomerate clasts of the Canaan Peak Formation. Solid arrows indicate preferred paleocurrent trend (Gvo) determined from data collected at each measured section (solid-fill squares) indicated by letters (refer to Fig. 2). Only trends with significant X² values (> 4.62) are plotted. Refer to Table 2 and Appendix B for numerical and current rose data. Solid-fill triangle indicates Canaan Mountain summit.
Figure 16. Study area index map indicating paleoflow trends determined from trench axis orientation measurements of cross-stratified conglomerate and sandstone lithofacies from the Canaan Peak Formation. Solid arrows indicate preferred paleocurrent trends (Gvo) determined from data collected at each measured section (solid-fill squares) indicated by letters (refer to Fig. 2). Only trends with significant X² values (> 4.62) are plotted. Refer to Table 2 and Appendix B for numerical and current rose data. Solid-fill triangle indicates Canaan Mountain summit.
PETROGRAPHY

Conglomerate

Composition

Conglomerate lithotypes of the Canaan Peak Formation are composed of a high proportion of resistant lithologies. Chert and quartzite lithologies are dominant. Volcanic and carbonate clasts are locally abundant; however, overall their abundance is consistent. Sandstone (quartzarenite), conglomerate, vein quartz, and carbonate (limestone, dolostone) clasts are minor. Fossils recognized within chert and carbonate clasts include poorly-preserved rugose coral, brachiopod, bryozoan, crinoid, fusilinid, and abundant unidentified shell fragments.

Chert clasts are sub- to well-rounded, and range up to medium-sized cobbles (15 cm). Varieties are gray, black, tan-brown, green, yellow and red. Some chert clasts are concentrically banded (cannonball variety) while others are massive. Rarely, chert clasts have a thin, distinctly-weathered rind around them.

Quartzite (well-cemented quartzarenite) clasts are white, tan, dark gray, and variegated shades of tan and purple. Quartz grains within individual clasts range from fine to coarse sand size, are subangular to very well-rounded, and are moderately to well-sorted. Horizontal stratification and ripple cross-lamination are present within some clasts. Quartz appears to be the only interstitial cement. Numerous grains have sub-angular 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 commun.) are
subround to round, and friable to well-indurated. Quartz-rich, gray-green volcaniclastic 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 boitite. Volcanic clasts in the Canaan Peak Formation are similar in composition to highly-altered Cretaceous(?) andesite flows and tuffs of eastern Lincoln County, Nevada described by Tschanz and Pampeyan (1970, p.65). These volcanic rocks are characterized by sericitized plagioclase and chloritized or completely destroyed mafic minerals.

In thin sections of Canaan Peak Formation volcanic rock clasts, volcanic glass forms a patchy, finely acicular to cryptocrystalline (devitrified) groundmass which 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 flows; grains are somewhat blocky and deformed (flattened), or have narrow lath shapes. Polysynthetic twinning is well-developed.

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 dominate.

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 apparent increase in the degree of dolomitization.
Banded clasts contain a significant amount of very fine-grained terrigenous sand- and silt-sized 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 17 indicates composite clast counts per measured section and their general locations around the Table Cliff Plateau (refer to Fig. 2). Clast counts were made to determine (a) dominant lithologies present in the study area, (b) lateral and vertical compositional variations, and (c) probable source area lithologies. Of these, lateral and vertical compositional changes are least definable due to 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 (24-48%) and is more uniformly distributed. Quartzite clast abundance (14-67%) is more variable than chert, and locally more abundant. Volcanic lithologies are present in all but three measured sections, reach a maximum 33% in Horse Creek Canyon (Hc-MS4, Appendix C) and, is otherwise laterally consistent through the formation. Sandstone clasts (2-13%) occur in each measured section but are a minor component.

Presence of volcanic or carbonate clasts is the most distinctive difference between measured sections. In contrast to other lithologies,
Figure 17. Index map showing locations of Canaan Peak Formation measured sections (some grouped) and associated clast composition (Y-axis) histograms. Composition abundance in percent (X-axis), (n) equals total number of clasts identified (C-carbonate, S-sandstone, V-volcanic, Q-quartzite, CH-chert) at measured section(s) shown. E-COMP and Hc-COMP histograms represent composite values for those groups of measured sections (refer to Fig. 2 and Appendix C).
carbonate clasts were encountered in only seven measured sections (reaching 16% at P-MS1) and appear more concentrated in the southern portion of the Table Cliff Plateau (Fig. 17). Although lateral continuity between sections cannot be precisely determined, there appears to be a general decrease upward in carbonate clast abundance, contrasting with observations of Bowers (1972), while volcanic clast content appears consistent. Allen Creek (A-MS1) is the only measured section where there is an apparent upward increase in carbonate clasts. 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. 17; Appendix C).

**Sandstone**

Sandstones are compositionally immature to mature (chert- to quartzarenite). Compositions were determined from analysis of 24 thin section point counts. They consist primarily of mono- (Qm) and polycrystalline (Qp) quartz, and lithic fragments (L), such as carbonate, siltstone and volcanic rock fragments. Muscovite, chloritized clay, zircon, apatite, glauconite(?), glass shards, and feldspar (F - plagioclase, orthoclase) are negligible. Sandstone thin-section slabs were stained for orthoclase feldspar using sodium cobalt nitrate solution. Plagioclase was observed in only one sandstone thin section.

**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 (0.01-0.06 mm) to very coarse sand (2.0 mm); medium to coarse sand (0.25-0.5 mm) is dominant.

Sandstone is cemented by a combination of calcite, clay, hematite, and
rare ferroan dolomite(?). Calcite cement is dominant (~15-20% total volume) and is present within pore spaces and along grain fractures where it occurs either as poikilotopic 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 is indicative of 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).

Framework Grains

Primary framework grains recognized include mono- (Qm) and polycrystalline (Qp) quartz, feldspar (F) and lithic fragments (L). The total quartz abundance (Q) was determined from the sum of mono- 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 poor to well-defined angular authigenic grain overgrowths, occur but are not common. Some microlites consist of calcite or quartz crystals, or 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 and chalcedonic
chert are the most common polycrystalline quartz varieties. Carnelian or jasperoid (massive, opaque, mixed colors) chert and composite quartz are also recognized. Polycrystalline quartz grains are very angular to very well rounded. Sponge spicules (?) and detrital quartz 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 non-silicified 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 are rare.

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 calcite cement suggest that orthoclase was present but was subsequently replaced during diagenesis (J.G. Schmitt, 1986, personal commun.); plagioclase, untwinned orthoclase, and perthite were also identified from sandstones collected at the Canaan Mountain type locality (Fig. 2). Schmitt (1986, personal commun.) describes feldspar as being almost completely replaced by patches of coarse sparry calcite, within which are small flecks of feldspar that seem to have escaped calcite replacement.

Sandstone Composition Modes

Sandstone compositions range from quartzarenite to litharenite, but are dominated by quartz-rich sublitharenite. Quartzarenite is dominated by monocrystalline quartz (Qm > 90%); 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. Feldspar occurs in only two sandstone samples. With the exception of the Canaan Mountain samples, plagioclase is virtually non-existent; orthoclase is negligible and comprises only about 1% of the grain population.

Relative percentages of sandstone framework grain parameters discussed above were plotted on QmFLt and QFL compositional ternary diagrams after Dickinson and others (1983) (Fig. 18). 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 pre-existing sedimentary rocks.

Discussion

As noted earlier, carbonate and volcanic clasts are not abundant overall in the Canaan Peak Formation (Fig. 16). Humid climatic conditions, subaerial channel margin exposure, and periodic submergence and transport by flood-flow would render carbonate and felsic volcanic clasts susceptible to chemical and mechanical weathering. Some chert clasts have a discolored, weathered rind, possibly similar to those described elsewhere by Varley (1984). He attributes the rinds to extensive subaerial exposure under humid environment conditions, which lends support to a humid Canaan Peak depositional environment. Chert and quartzite lithologies are more resilient than carbonate and some 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. Therefore, the abundance of chert and quartzite, and lack of carbonate and felsic volcanic lithologies
Figure 18. Ternary compositional (QmFLt) and tectonic (QFL) discrimination diagrams showing Canaan Peak Formation sandstone composition data (open circles) plotting as linear clusters within the quartzose and transitional recycled fields, respectively, of Dickinson and others (1983); (n) equals total number of thin sections studied.
support significant and continuous recycling of detritus far down the Canaan Peak fluvial paleoslope.

TECTONIC IMPLICATIONS

Geologic Setting

Regional

Sevier-style deformation from southeastern Nevada through western Utah was characterized by eastward directed thrusting. Uplift provided debris for eastward fluvial transport and deposition into the adjacent foreland basin (Armstrong, 1968). The late Cretaceous Price River and Canaan Peak Formations are two such foreland-basin deposits in west- and south-central Utah, respectively (Miller, 1966; Fouch and others, 1983; Lawton, 1983; Morris, 1983). Thrusting occurred along this segment of the Sevier thrust belt from late Cenomanian to middle Campanian (93-78 Ma) time and may have extended into the Eocene (Fouch and others, 1983; Picha, 1986). Explosive volcanism occurred sporadically from middle-late Turonian through latest Campanian (90-75 Ma) within and west of southeast Nevada-southwest Utah (Lohrengel, 1969; Peterson, 1969a; Tschanz and Pampeyan, 1970; Elder, 1988). Peterson (1969a) suggested this igneous activity coincided with the initiation, locally, of Sevier-style uplift. Associated north-south trending folds and normal faults developed during this period in the foreland-basin from west- to south-central Utah; they are east of and trend subparallel to the thrust belt (Robison, 1966; Peterson, 1969a, 1969b, 1986; Bowers, 1972; Fouch and others, 1983; Lawton, 1983, 1985).

Provenance and palynologic data provide Fouch and others (1983) and Morris (1983) with evidence for two and probably four pulses of late Cretaceous, Sevier-related orogenic events in western Utah. Similar data derived from the Kaiparowits and Table Cliff Plateaus (Figs. 1, 2) suggest Sevier-style tectonism and foreland basin deposition occurred at least during middle to late Campanian
(78-75 ma) (Lohrengel, 1969; Peterson, 1969a; Bowers, 1972). These data record the beginning of the last major pulse of thrusting along the west-central to southwest Utah segment of the Sevier thrust belt (Peterson, 1969a; Bowers, 1972; Fouch and others, 1983; Lawton, 1985).

Laramide-style deformation was contemporaneous with late stages of thrusting (78-73 ma). Basement-cored, domal uplifts and adjacent, internally-drained basins formed east of the Sevier orogenic belt within the foreland basin from central Utah to Colorado, and northward into central Montana (Fouch and others, 1983; Lawton, 1983, 1985; Dickinson and others, 1988). Uplift continued well into the early Tertiary (Paleocene-early Eocene, 66-52 Ma; Armstrong, 1968; Peterson, 1969a; Bowers, 1972; Dickinson and others, 1988). Basement-cored uplift typically influenced the development of new fluvial drainage patterns and changes in associated detrital compositional suites (Lawton, 1985; DeCelles, 1986; DeCelles and others, 1987; Dickinson and others, 1988).

Deposition of sediments derived from Laramide-style uplift was generally restricted to one or more associated, isolated basins. As paleo-drainage patterns became disrupted and re-directed, the unroofing of adjacent, uplifted source terrains commonly provided individual basins a heterogeneous sediment mixture. Adjacent basins often received compositionally vastly dissimilar sediment input from lithologically distinctive marginal uplifts, adding to the complexity of accurately determining pre-existing provenance and sediment dispersal patterns (Lawton, 1985).

Provenance and paleo-drainage influences exerted by Laramide-style uplift during deposition of the Canaan Peak Formation could have similarly altered well established paleo-flow trends and provenance characteristics. Based on the geological and structural characteristics of and surrounding the study area, uplift of local terrain might have exposed finer grained Upper Cretaceous units,
possibly including the Dakota Sandstone through the Kaiparowits Formation (Fig. 3). Depending on locations of domal uplifts, dissection of these units could have resulted in the interfingering of re-cycled, fine-grained Upper Cretaceous detritus with the marginal distribution of dominantly coarse-grained Canaan Peak sediments. Continued or renewed uplift of the pre-existing Circle Cliffs upwarp (Peterson, 1969, 1985; Dickinson and others, 1988), may have exerted some control on the development of the Dutton monocline and Straight Cliffs positive structures, influencing a change, locally, from an eastward to westward directed paleoflow trend; data obtained by Goldstrand (1989) is supportive of the above interpretation.

Table Cliff and Kaiparowits Plateaus

Within the study area (Fig. 19), structural limits of the Canaan Peak Formation are the north-south trending east limb of the Johns Valley anticline, and the west limb of the Dutton monocline (Bowers, 1972, 1973). The axial trend of the centrally located Table Cliff syncline is northwest-southeast. The Canaan Peak Formation lies with angular unconformity on the Kaiparowits Formation, locally with up to three meters of relief (Bowers, 1972). Canaan Peak sediments are conformably overlain by and interfinger with the Pine Hollow Formation. According to Bowers (1972, 1973) the Canaan Peak and Pine Hollow Formations depositionally pinchout where they locally lap against the Dutton monocline and Johns Valley anticline. The folded, dissected upper surface of the Kaiparowits Formation, and the laterally thinned margins of the Canaan Peak and Pine Hollow Formations are all locally truncated by the overlying Wasatch Formation (Bowers, 1972). Pollen identified from the upper levels of the Kaiparowits Formation date the latest phase of folding of the Table Cliff-Kaiparowits Plateaus as latest Campanian and continuing through deposition of the lower Wasatch Formation conglomerate (Eocene) (Armstrong, 1968; Peterson,
Figure 19. Study area index map showing local, generalized geologic structure (bold lines) of the Table Cliff Plateau. Axial traces of the Johns Valley anticline (JVa), the Table Cliff syncline (TCs), and the west limb of the Dutton monocline (Dm) may have partially influenced control of developing paleo-drainage patterns during Canaan Peak Formation deposition. The fault in the northwest portion of the study area is downthrown on west (shown by bars). Modified from Bowers (1973). Solid-fill triangle indicates Canaan Mountain summit; solid-fill squares represent study area measured sections.
1969a; Bowers, 1972). Along the northwest margin of the Table Cliff Plateau, a northern segment of the north trending Paunsaugunt fault juxtaposes the Cretaceous Kaiparowits and Eocene Wasatch Formations (Bowers, 1972; Lindquist, 1977) (Fig. 19). This boundary fault results from younger post-Eocene faulting within the Sevier and Paunsaugunt fault zones.

Provenance

Paleoflow data from Peterson (1969a), Goldstrand (1989), and this study indicate, in part, east to northeast directed sediment transport occurred within the Canaan Peak depositional system (Table 2). These trends support probable latest Cretaceous source areas within and west of the southeastern Nevada-southwestern Utah segment of the Sevier thrust belt. Table 3 indicates probable first generation source areas for Canaan Peak Formation detritus. Several major

<table>
<thead>
<tr>
<th>Clast Type(s)</th>
<th>Source Area(s)</th>
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<tbody>
<tr>
<td>- Quartzite</td>
<td>Southwest Utah: upper plate of Wah Wah, Blue Mountain thrusts; Precambrian</td>
</tr>
<tr>
<td></td>
<td>Prospect Mountain Quartzite, Devonian Eureka Quartzite.</td>
</tr>
<tr>
<td>- Chert and carbonate</td>
<td>Upper and lower plates along entire length of fold-thrust belt, southeast</td>
</tr>
<tr>
<td></td>
<td>Nevada-southwest Utah: Paleozoic carbonate rocks.</td>
</tr>
<tr>
<td>- Volcanic rocks</td>
<td>Sevier highlands(?): west of southeast Nevada (Lincoln County)-southwest</td>
</tr>
<tr>
<td></td>
<td>Utah thrust belt.</td>
</tr>
<tr>
<td>- Red chert (jasper)</td>
<td>Southwest Utah: lower plate of Blue Mountain thrust; Triassic Shinarump,</td>
</tr>
<tr>
<td></td>
<td>Jurassic Morrison Formation.</td>
</tr>
<tr>
<td>- Sandstone</td>
<td>Southwest Utah: lower plate Blue Mountain thrust; Jurassic Navajo Sandstone</td>
</tr>
<tr>
<td></td>
<td>(Aztec Sandstone, southeast Nevada).</td>
</tr>
<tr>
<td>- Conglomerate</td>
<td>Southwest Utah: lower plate Blue Mountain thrust; Triassic Shinarump Formation, Jurassic Morrison Formation(?).</td>
</tr>
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frontal thrusts and minor thrust traces are exposed from southeast Nevada through southwest Utah (Longwell and others, 1965; Armstrong, 1968; Burchfiel and others, 1974; Bohannon, 1983). The closest of these uplifted source areas that could have initially provided detritus to the Canaan Peak fluvial system are ~110-160 km distant from the study area and include the Wah Wah, San Francisco (Frisco), and Blue Mountain thrusts (Fig. 20). Although, palinspastic restoration of extended terrane along the Basin and Range-Colorado Plateau transition zone (trace of Sevier thrust belt, southwest Utah; Fig. 1, 20) may significantly reduce the presently observed distance between the thrust belt and the Canaan Peak Formation. Some basal, upper plate rocks include Upper Precambrian-Lower Cambrian quartzite through Paleozoic, quartzite and chert-rich carbonate strata; others expose Cambrian or lower-middle Paleozoic, chert-rich carbonate strata (East, 1966; Miller, 1966, Figs. 11-12). Upper plate rocks rest on lower Paleozoic carbonates or lower-middle Mesozoic terrigenous clastic rocks (East, 1966; Miller, 1966; Tschanz and Pampeyan, 1970; Morris, 1983).

Precambrian-Cambrian quartzite, and Paleozoic quartzite, chert and carbonate clast populations in Canaan Peak strata suggest that significant uplift occurred along parts of the southwest Utah thrust segment. However, it is not possible to relate deposition of Canaan Peak conglomerates to uplift along any particular thrust, 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 belt (DeCelles and others, 1987; Steidtmann and Schmitt, 1988). For example, erosion of interior ramp uplifts in the core of fold-thrust orogens may occur during periods of active frontal thrusting (DeCelles, 1988). Dispersal of eroded detritus from interior sources may be by major antecedent fluvial systems which cut across the structural fabric of the fold-thrust belt.
Figure 20. Index map indicating general locations of Sevier thrust fault exposures in southwestern Utah. Locations of Laramide foreland basin uplifts, southern Utah, indicated. Those most likely to have supplied detritus for Canaan Peak deposition occur within the Blue (BM) and Mineral Mountains (MM), and the Star Range (SR). Other thrust trace exposures occur in the Needles (NR), Wah Wah (WWR), and Tushar (TR) Ranges, and the San Francisco Mountains (SFM). Adapted from Bowers (1972), Smith and Bruhn (1984), Dickinson and others (1988).
(DeCelles, 1988; Steidtmann and Schmitt, 1988. Consequently, resultant east to north-eastward directed dispersal of coarse- and fine-grained sediment led to deposition of the Canaan Peak Formation in a folded and faulted subsiding foreland-basin in west- to south-central Utah (Fig. 21).

Elder (1988) indicates volcanism was active during late Cretaceous time within the Nevada-Utah-Arizona region. Bentonite horizons present in the Kaiparowits Formation suggest that volcanism was, in part, coeval with thrusting. Volcanic clasts occurring within Canaan Peak sediments are similar in composition to highly-altered Cretaceous(?) andesite flows and tuffs of eastern Lincoln County, Nevada described by Tschanz and Pampeyan (1970, p.65). This similarity suggests volcanism was associated, at least, with uplift prior to, and perhaps coeval with, Cannan Peak deposition. Volcanic clasts similar to those within the Canaan Peak Formation are lacking in older Cretaceous-aged rocks (Albian-lower Campanian) of the Kaiparowits region, but those within the late Cretaceous(?) Claron Formation of southwestern Utah appear similar (Peterson, 1969a, 1969b; Bowers, 1972; J.G. Schmitt, 1986, personal commun.). Although, Chapman (1989) describes rhyolite ignimbrite boulders within fluvial deposits of the Middle Jurassic Carmel Formation, southwestern Utah and suggests their probable source was within the Jurassic volcanic arc stretching across parts of Nevada-California-Arizona. An igneous source area for Canaan Peak volcanic clasts is still only speculative, but assuming its location some distance west of the Sevier fold-thrust belt, the Canaan Peak volcanic clast abundances suggest that they were more resistant to attrition than were carbonate clasts. It is unlikely that volcanic source areas provided a greater volume of detritus than the thick Paleozoic carbonate sequence presently exposed within the fold-thrust belt.

Distinctive red chert pebbles first appear in local Cretaceous strata in the
Stratigraphy

TKc - Claron Fm.
TKcp - Canaan Peak Fm.
Kk - Kaiparowits Fm.
UK - Dakota, Tropic, Straight Cliffs, Wahweap Fms.
Kv - Volcanic rocks undifferentiated
UJr - San Rafael Group, Morrison Fm.
Jn - Navajo Fm.
UTr - Shinarump, Chinlee, Moenkopi Fms.

UP - Upper
MP - Middle
LP - Lower
PC - Precambrian-Lower Cambrian

Structures

JVa - Johns Valley anticline
TCs - Table Cliff Syncline
Dm - Dutton monocline
WWT - Wah Wah thrust
BMT - Blue Mountain thrust

Figure 21. Interpretive sketch depicting Canaan Peak Formation depositional environment within the folded and faulted foreland-basin of southwestern and southcentral Utah during the Campanian(?) (~80 Ma). In this model, thick arrows suggest possible preferred paleoflow trends; contributing drainage patterns would vary significantly, probably ranging from east- to west-trending, but primarily northward. Adapted from DeCelles (1986).
medial Campanian-aged Wahweap Formation (Miller, 1966; Peterson, 1969a) (Fig. 4). Their presence, and that of conglomerate clasts, within the Canaan Peak sediments indicate that uplift and exposure of the Triassic Shinarump and Jurassic Morrison Formations containing this red chert variety, was well under way to the west along the Wah Wah and Blue Mountain thrusts (Peterson, 1969a).

Thrust-related regional folding in the Table Cliff and Kaiparowits Plateau areas was well established prior to, and was coeval with, late Cenomanian dissection of the upper Kaiparowits Formation that preceeded Laramide-style, basement-involved uplift. Paleocurrent patterns forming during middle Campanian in the study area were controlled by these structures (Peterson, 1969a). Canaan Peak detritus was initially shed eastward from proximal foreland basin areas, and down the distally complex, foreland basin paleoslope. The Table Cliff syncline, as a local depocenter (Bowers, 1972) for the Canaan Peak sediments, and uplifts including the Johns Valley anticline and Dutton monocline, possibly influenced the development of eastward and westward directed paleo-drainage patterns. Interfingering of coarse- and fine-grained beds within the upper levels of the Canaan Peak Formation along the east part of the study area suggest eastern structural elements (Dutton monocline, Circle Cliffs upwarp) were becoming better established.

Local structural grain (Fig. 19), and petrographic and paleocurrent data obtained from Canaan Peak strata (Table 2) suggest Laramide-style uplift had little influence on developing paleo-drainage patterns during early stages of Canaan Peak deposition, as it did for deposits elsewhere in the foreland-basin (Lawton, 1985; Dickinson and others, 1988). Although, subsequent reactivation of the Dutton monocline, and Circle and Straight Cliffs uplifts (Peterson, 1969b, 1986; Dickinson and others, 1988) east of the Canaan Peak fluvial system may have continued to influence earlier, pre-established positions of Canaan
Peak paleo-drainage patterns. However, local paleocurrent trend variability may indicate the development of topographic irregularities to the east, suggesting Laramide-style influences were present during later stages of Canaan Peak deposition.

Southerly(?) directed headward erosion or dissection of the Mogollon highlands, northern Arizona may have initiated development of some north flowing paleo-drainage trends (I. Luchitta, 1987, personal commun.; Dickinson and others, 1988). These streams could have provided sediment for some early late Cretaceous(?) through Eocene deposits, especially the arkosic Dakota, Wahweap, and Kaiparowits formations (Fig. 3), and possibly contributing later to the development of the Canaan Peak fluvial environment.

Characteristics and distribution of Canaan Peak coarse-grained deposits resemble modern and ancient perennial, fluvial braid-stream sediments (Miall, 1977; Rust, 1978b). Two recently proposed models (Burbank and others, 1988; Heller and others, 1988) for tectogenically derived deposits (Steidtmann and Schmitt, 1988) from within thrust faulted terrains point out some potential foreland basin deposit complexities that may exist while trying to decipher depositional histories.

Heller and others (1988) suggest that during active thrusting coarse-grained, synorogenic sedimentation occurs predominantly within proximal areas of the foreland-basin. When thrusting ceases, reduced thrust-plate loading due to erosional retreat of the thrust-front stimulates rapid post-thrust isostatic uplift, or rebound, of the proximal foreland-basin axial trough. This rebound initiates rapid dissection of proximal foreland-basin sediments. The result is distinctive post-thrusting, coarsening-upward deposition of second-cycle detritus onto finer grained, distal foreland-basin sediments. Heller and others (1988) add that if rebound of proximal foreland-basin sediments is faster than
erosional retreat of the thrust front a conspicuous unconformity will form across that rebounding proximal surface.

In contrast to Heller and others (1988), Burbank and others (1988) suggest that when provided with ample coarse-grained, thrust-derived detritus synorogenic sedimentation will occur rapidly within and across the foreland basin. In addition, Burbank and others (1988, p. 1146) also indicate that syn-thrusting vs. post-thrusting (as in Heller and others, 1988) downstream gravel progradation is a function of local "rates of sediment erosion and transport, thrusting and of subsidence", and that parameters existing within specific thrust regions will be unique.

At present, data is insufficient to support either model discussed above. Although, Canaan Peak sediments could have been post-tectonically derived and distributed similarly to that described by Heller and others (1988). In their model, the Canaan Peak strata would represent dispersal during a period of relative tectonic quiescence in the Sevier fold-thrust belt. This is supported, in part, by the relatively consistent clast sizes and the vertical distribution of clast lithologies within the Canaan Peak Formation. In the model of Burbank and others (1988), Canaan Peak deposits would suggest a correlation with a period of major thrust plate development in the adjacent Sevier fold-thrust belt. However, in either case, the lack of unique lithologies in the Canaan Peak clast population precludes determination of the timing and duration of movement along a specific thrust (Fig. 20).

CONCLUSION

Sedimentologic and provenance analyses of the late Cretaceous(?) - Paleocene Canaan Peak Formation in southwestern Utah support the following conclusions concerning foreland basin depositional environment, paleogeography, and tectonic setting.
1. Conglomerate and sandstone lithofacies associations and thicknesses, and sediment textures suggest the Canaan Peak Formation developed within a perennial, low-sinuosity, high-energy braided fluvial complex. Braided channel deposits were dominated by coarse-grained longitudinal bar and trough scour-fill development. Sediment transport was dominated by movement of coarse-grained bedload material within low-sinuosity channels. During normal-flow stages interchannel areas were broad, and active channel flow occupied only a minor portion of the braid-plain surface; flood-stage water levels extended widely across the braid-plain. The frequency of flooding and active channel switching, and continuous reworking of bedload detritus prevented extensive development of overbank and bar-top fines.

2. Non-volcanic conglomerate clast populations indicate source areas consisted of highlands created by Sevier-style deformation in southwestern Utah and possibly southeastern Nevada. The presence of red chert pebbles and conglomerate clasts suggest derivation from the Shinarump Conglomerate; the closest exposure is presently within the Blue Mountain autochthon. The minor abundance of Paleozoic chert-rich carbonate rocks within the Canaan Peak Formation suggests that these less stable clasts were destroyed by chemical and mechanical weathering, and multiple recycling during transport within the high-energy Canaan Peak fluvial system. Volcanic source areas were probably west or southwest of the southwest Utah segment of the Sevier fold-thrust belt. Volcanic clast abundance suggests that they were more resistant to attrition than carbonate clasts.

3. Although paleocurrent trends obtained from the Canaan Peak Formation are wide ranging, they suggest the depositional system's preferred transport direction ranged from southeastward to northward. The eastward component of paleoflow is, in part, supported by the formations proximity to the fold-
thrust belt. Early-stage eastward and, less conspicuous, late-stage westward
directed antecedent drainage patterns may have influenced these developing
paleoflow trends. The northward component is supported by the north-south
trending thrust-related fold structures which may have influenced, locally, some
stages of late Cretaceous deposition. Canaan Peak deposits resulted from
consistent downstream recycling of thrust derived detritus eroded from proximal
foreland basin synorogenic deposits (Claron Formation ?, southwest Utah) which
were initially derived from upper Precambrian through Mesozoic strata exposed in
the Sevier fold-thrust belt.

4. Canaan Peak Formation sedimentation occurred, at least, coeval with
late, or waning stages of thrust-related folding. During this time thrust-
front erosion, dissection, and retreat possibly led to thrust unloading and
associated uplift along the proximal foreland basin margin. Subsequently, the
eroded detritus was recycled and transported farther down the paleoslope and
deposited upon distal, finer-grained strata. Deposition occurred upon the
folded and dissected Kaiparowits Formation surface. The regionally developing
Laramide-style domal uplift and basin formation does not appear to have
influenced the early-stage development of paleoflow trends or detrital
compositional suites of the Canaan Peak fluvial system. However, less
conspicuous westward directed paleoflow trends may reflect incipient Laramide-
style uplift from the pre-existing Dutton monocline to the Circle Cliffs upwarp,
east of and during the late stages of development of the Canaan Peak fluvial
system.
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APPENDIX A

CANAAN PEAK FORMATION MEASURED SECTIONS
Appendix A1. -- Measured Section Localities

Basemap 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: 37°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 Mountain, Utah:
   (d) Upper Valley, Utah:

2. **Geologic Maps** -
   (a) Bowers, 1973
   (b) Hackman and Wyant, 1973


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 Widtsoe.

- **Hc-MS1** -- Center, SE1/4, SW1/4, NW1/4, SECT. 8, T34S, R1W: Base-8080' elev.
- **Hc-MS2** -- NW1/4, SW1/4, NW1/4, SW1/4, SECT. 8, T34S, R1W: Base-8040' elev.
- **Hc-MS3** -- NE Corner, NW1/4, SE1/4, NW1/4, NE1/4 SECT. 7, T34S, R1W: Base-8000' elev.
- **Hc-MS4** -- NE Corner, SE1/4, SW1/4, SE1/4, SW1/4 SECT. 6, T34S, R1W: Base-7910' elev.
- **Hc-MS5** -- NW1/4, SW1/4, NE1/4, SW1/4, SW1/4 SECT. 6, T34S, R1W: Base-7930' elev.
- **Hc-MS6** -- SW1/4, NE1/4, SE1/4, NE1/4 SW1/4 SECT. 1, T34S, R2W: Base-7860' elev.

**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 Widtsoe.

- **E-MS1** -- NE1/4, SW1/4, SE1/4, SE1/4, SW1/4 SECT. 24, T34S, R2W: Base-8640' elev.
- **E-MS2** -- SE Corner, SW1/4, SE1/4, SW1/4, SE1/4 SECT. 24, T34S, R2W: Base-8080' elev.
- **E-MS3** -- North Center, SW1/4, NW1/4, SE1/4, SW1/4, SW1/4 SECT. 24, T34S, R2W: Base-7980' elev.
- **E-MS4** -- Northeast Corner, NW1/4, SE1/4, SW1/4, SE1/4 SECT 23, T34S, R2W: Base-7900' elev.
- **E-MS5** -- SW1/4, NW1/4, NW1/4, SW1/4, SE1/4 SECT 23, T34S, R2W: Base-7800' elev., 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 1-1/4 miles.
P-MS1 -- 330’ DUE East of T35S,R2W-R1W boundary, 450’ DUE North SE Corner
SECT.25,T35S,R2W: Base-8495’ elev.

Henderson Canyon: Same access as for Pine Lake section. Reach end USFS road 282, turn right (west), drive approximately 1/2 mile west. Section is approximately 1/2 mile to south.

H-MS1 -- 2080’ DUE East of T35S,R2W-R1W boundary, 740’ DUE North of SW Corner SECT.36,T35S,R2W: Base-8685’ elev.

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

Ph-MS1-- 3.9 mile DUE east, 3820’ DUE south of SE Corner SECT.36,T35S,R2W; 2 mile WNW along Pine Hollow from SW corner Sect. 7, T36S, R1E (R1W-R1E boundary), along west margin of Section 12: Base-8400’ elev.

Canaan Mountain: 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 SE1/4,SE1/4,NE1/4,NE1/4,NE1/4 SECT.16,T37S,R1E:
Base-8020’ elev.

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

A-MS1 -- NE Corner NE1/4,SW1/4,SE1/4,SW1/4 SECT.19,T35S,R1E:
Base-8140’ elev.

A-MS2 -- 610’ DUE south, 240’DUE west of SW Corner SECT.19,T35S,R1E:
Base-8145’ elev.

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

Mc-MS1-- NW Corner SW1/4,SW1/4,NE1/4,NE1/4,NE1/4 SECT.25,T34S,R1W:
Base-7970’ elev.
Appendix A2. -- Measured Stratigraphic Sections

Graphic representations of 18 measured stratigraphic sections follow. The legend provided below indicates lithofacies symbology used and a brief description of each (refer to Table 1). Measured section names and their approximate basal elevations are provided. Locations of conglomerate clast composition counts (CC), and clast imbrication measurements (CI) are indicated adjacent to the respective measured section; Gvo values and directional arrows (top = north or 0°) for CI are also listed. Arrows along left margin of each stratigraphic column indicate possible single cycle depositional event. Refer to Figure 3, Table 2, and Appendix A1 for measured section location and associated paleocurrent data indicated.

- Massive to very crudely horizontally stratified gravel; longitudinal bar deposits.
- Poor to well defined trough cross-stratified gravel; coarse-grained dune and sinuous-crested transverse bar deposits.
- Poor to well defined trough cross-stratified sandstone; fine-grained dune and sinuous- to straight-crested transverse bar deposits.
- Poor to well defined planar-tabular stratified sandstone; straight-crested transverse bar deposits.
- Massive to horizontally stratified sandstone and coarse, pebbly sandstone; channel margin/bar-top deposits.
- Non- to poorly stratified sandstone and coarse, pebbly sandstone; channel floor pothole/scour deposits.
- Massive to very finely laminated mud and siltstone, and sandy siltstone; channel margin/bar-top vertical accretion deposits.
Horse Creek Canyon: Total of six measured sections.

Hc-MS6, Hc-MS5 --
Hc-MS2, Hc-MS1 --
Escalante Canyon: Total of five measured sections.

E-MS5, E-MS4, E-MS3 --
Pine Lake and Henderson Canyon: Total of two measured sections.

P-MS1, H-MS1 --
Canaan Mountain: One measured section.

C-MS1 --
Allen Creek, Pine Hollow: Total of two measured sections. A-MS2, Ph-MS1 --
McGee and Allen Creeks: Total of two measured sections.

Mc-MS1, A-MS1 --
APPENDIX B

CANAAN PEAK FORMATION PALEOCURRENT DATA
APPENDIX B1. -- CLAST IMBRICATION

Dip direction and dip (i.e., N28W/59) for clast imbrication are indicated by quadrant and degrees. Current rose diagrams indicate paleoflow direction, which is 180 degrees opposite dip direction. \((n = \) ) is the total number of orientations measured, that fall within each 10 degree increment field. Scale-bar length is incremented into \((n)\) number of measurements grouped within each 10° interval. \(Gvo, Gvm, X^2, \) and \(D\) values given (refer to Table 2). Thin arrow indicates \(Gvo\), thick arrow indicates mean \((m)\); mean \((m)\) is given only when it is not equivalent to \(Gvo\) (based on circular normal distribution). Measured section localities are indicated in Figure 2; clast count position within measured sections are shown in Appendix A1.
Measured Section: Hc-MS6
(n = 100)

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X² = 46.6

D = ± 15°
Gvo = 151°
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(n = 100)

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S77W/74  N78E/33  S80W/44  N45E/35  S81W/40  N19E/53
N56W/42  S86W/28  S54E/83  S70W/53  S43E/71  S08E/21
N52E/50  S78W/27  S72W/57  S18E/35  S53W/32  S40E/30
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S77W/14  S33E/25  N35W/26  N77E/47  N56E/81  N77E/71
S43E/32  S22W/58  S77W/19  S45E/09  N75W/41  S69W/45
S43W/33  N54W/46  S02E/25  S24W/65

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\[ Gvo = 63^\circ \]

\[ Gvm = 0.29 \]

\[ X^2 = 16.4 \]
Measured Section: Hc-MS3
(n = 100)

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\[ Gvo = 18^\circ \]
\[ Gvm = 0.16 \]
\[ X^2 = 5.0 \]
Measured Section: Hc-MS2  
(n = 100)

| N86E/29 | S78E/19 | S22E/30 | N53E/14 | S68W/22 | N28E/18 |
| N62E/28 | N58W/12 | S75E/11 | S84E/16 | S55W/18 | S39W/17 |
| S27E/22 | N47W/39 | S47E/31 | N43E/55 | S10E/13 | S43W/21 |
| N86W/37 | S73E/60 | N62E/52 | N80E/69 | S80W/34 | S39E/15 |
| S24W/35 | S22E/37 | S48E/49 | S74E/08 | S66E/05 | N18E/52 |
| S25W/30 | S89E/56 | S06E/38 | S54W/65 | N86W/42 | S08E/27 |
| N25W/35 | N14W/34 | N86W/19 | S53E/30 | N35W/36 | N80W/55 |
| S52W/36 | S12W/21 | N17E/53 | N61E/52 | N82E/73 | S07E/24 |
| N49E/39 | S37W/82 | N85E/30 | S85E/18 | N30W/11 | N38W/24 |
| S24W/42 | N42W/53 | S16W/25 | S01E/29 | N36E/19 | S64E/31 |
| S79W/27 | N08E/17 | S27E/46 | N50W/27 | N66W/46 | S73E/29 |
| S04W/51 | N53W/37 | S32E/46 | N56W/22 | S42W/60 | S65W/56 |
| S28E/23 | N08W/22 | S82E/22 | S02W/14 | S54E/48 | S84W/23 |
| S71W/33 | N07E/38 | S82W/44 | S23E/33 | S19W/31 | S87E/30 |
| N13W/44 | N67W/40 | N16W/24 | N74W/55 | N85E/14 | N83E/48 |
| N85W/16 | S32W/22 | S54W/35 | N80E/23 |   |

\[ G_{vo} = 265^\circ \]

\[ G_{vm} = 0.02 \]

\[ X^2 = 0.1 \]

0 \[ \quad \] 5
**Measured Section: Hc-MS1**

(n = 94)

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**Gvm = 0.13**

**X² = 2.9**

**Gvo = 183°**
Measured Section: E-MS5
(n = 100)

N17E/19  N18W/16  N33W/31  N86W/55  N65W/12  S24W/45
N62W/18  N76W/63  N62W/64  N04W/34  N16W/17  N02E/37
N78W/41  N48W/41  S77W/34  S57W/54  N84W/49  N80W/46
S29E/39  N70W/51  N28W/40  N80W/10  N28W/11  N38W/28
N72W/72  N74W/60  S44W/70  N42W/26  S28E/11  N55W/39
N14W/31  N71E/03  S35W/67  N87W/02  N09E/38  S63E/14
S16W/40  S29W/41  N75W/32  S07E/35  S30W/28  S24W/78
S43W/18  N85E/12  S44W/42  S31W/60  S66W/13  N52W/30
S86W/45  S61W/41  N87W/45  N74W/25  S65W/25  N87W/16
N05W/87  S53W/26  S42W/32  S85W/26  N54W/09  S88W/24
S79E/38  N09W/35  S35W/32  N40W/46  N70W/56  S35E/35
S45E/26  N10W/15  N50E/03  S49W/48  N59E/46  S56W/46
N48W/37  N89W/52  N38W/03  S38W/19  N23W/30  N43W/33
N84W/42  N29W/10  N42W/23  N44E/38  S67W/52  N25W/47
N85W/64  N46W/79  N81W/55  S80W/47  N76W/49  N46W/61
N33W/19  N15W/40  N87W/30  N40W/58

\[ G_{vm} = 0.48 \]
\[ \chi^2 = 45.2 \]

Gvo = 107°
D = ±15°
Measured Section: E-MS4
\( (n = 100) \)

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\[ Gvo = 0^\circ \]
\[ Gvm = 0.34 \]
\[ X^2 = 22.6 \]
Measured Section: E-MS3  
(n = 100)

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\[
G_{vm} = .33 \\
X^2 = 22.0 \\
D = \pm 24^\circ \\
G_{vo} = 120^\circ \\
\]

\[0\quad 5\quad 10\]
Measured Section: E-MS2
\( (n = 100) \)

\[ \begin{align*}
S69W/23 & \quad S23W/54 & \quad S70W/43 & \quad S63W/42 & \quad N85E/45 & \quad 811W/60 \\
S15W/25 & \quad S64W/16 & \quad S67W/27 & \quad S71W/10 & \quad S56E/45 & \quad S79E/26 \\
S55W/41 & \quad N85E/22 & \quad S83W/13 & \quad S87W/15 & \quad S52W/17 & \quad N55E/29 \\
N78W/14 & \quad S49W/39 & \quad S85W/28 & \quad N48W/27 & \quad S55W/33 & \quad S59W/60 \\
S12E/45 & \quad S18W/33 & \quad S20W/70 & \quad S55W/23 & \quad S04W/48 & \quad S55W/45 \\
S25W/39 & \quad S04E/41 & \quad N85W/26 & \quad S19W/25 & \quad S52W/37 & \quad S10W/24 \\
S02W/31 & \quad S50W/28 & \quad S90W/32 & \quad S20E/67 & \quad S35W/16 & \quad S52W/17 \\
N37W/37 & \quad S80W/26 & \quad N60E/13 & \quad S04E/33 & \quad S56W/22 & \quad N28E/50 \\
S48W/27 & \quad S60W/21 & \quad S00W/35 & \quad N26E/33 & \quad N05E/41 & \quad N05E/35 \\
S68W/35 & \quad N62E/32 & \quad S30E/13 & \quad N72E/37 & \quad S40W/35 & \quad S02E/47 \\
S56W/13 & \quad S15E/15 & \quad S60W/11 & \quad S80W/24 & \quad S61W/36 & \quad S22W/54 \\
S70W/02 & \quad N10E/12 & \quad S39W/38 & \quad S71W/16 & \quad N62E/31 & \quad N36W/19 \\
S07E/53 & \quad S03E/61 & \quad S61W/35 & \quad S25E/28 & \quad N62W/28 & \quad S10E/29 \\
S26E/33 & \quad S89E/66 & \quad S85W/16 & \quad N49E/52 & \quad S19E/48 & \quad S06W/37 \\
S13E/45 & \quad N83E/22 & \quad N62E/64 & \quad S15E/45 & \quad S55E/28 & \quad S89E/50 \\
S44E/53 & \quad S68E/54 & \quad N52W/32 & \quad S65W/28 & \quad S54E/29 & \quad S51W/36 \\
N45W/14 & \quad S07E/27 & \quad S42E/42 & \quad S61E/29 & & \\
\end{align*} \]

\( G_m = 0.4 \)

\( \chi^2 = 31.6 \)
Measured Section: E-MS1
(n = 99)

N32W/27  N28W/59  S03W/30  S05W/12  N53E/38  S19E/20
N03W/38  S68W/30  N46W/35  N70E/30  N40E/23  S08E/19
N25W/29  N88W/42  S05E/26  N15W/31  N01E/09  N03E/34
N07E/11  S83E/18  N25W/42  S59E/24  N08W/37  N84E/14
S76E/64  N46E/38  S51E/55  N40W/30  S54W/38  S03W/38
S25W/44  S26E/41  N10W/35  N50W/25  N06W/37  N50E/43
N69E/18  S45W/11  N55W/28  S68W/39  S81W/14  N72E/56
S39E/11  N05E/61  N70E/42  S57W/29  S60E/58  N46E/29
S21E/21  S35E/27  N50W/22  S85W/11  S32W/33  S60E/46
S15W/12  S07E/25  S83W/10  S35E/24  N28E/34  S25E/27
S16W/42  S41E/23  S35E/28  S14E/11  S45E/28  S48W/38
N56E/14  S64E/42  S82W/25  S05W/24  S15W/30  S13W/40
N40E/30  N75W/16  S63W/09  S10W/23  S33E/16  S10E/53
S37W/05  S16E/21  S27W/24  S65W/23  S08W/25  N23W/18
S01E/21  S60W/24  N65W/10

$X^2 = 0.1$
$G_{vm} = 0.03$
$m = 322^\circ$

$Gvo = 142^\circ$
Measured Section: P-MS1
(n = 104)

<p>| | | | | | |</p>
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<td>N65E/13</td>
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</tbody>
</table>

0 5 10

Gvm = 0.31

X² = 19.2

Gvo = 201°
Measured Section: H-MS1
(n = 100)

\[ Gvm = 0.18 \]
\[ X^2 = 6.5 \]

\[ Gvo = 247° \]
Measured Section: Ph-MSl
(n = 100)

\[ G_{vm} = 0.1 \]
\[ X^2 = 2.0 \]
\[ G_{vo} = 195^\circ \]
Measured Section: A-MS2

\[ (n = 100) \]

\[
\begin{align*}
\text{S90E/22} & \quad \text{S31E/15} & \quad \text{N04E/16} & \quad \text{S25W/73} & \quad \text{N06W/15} & \quad \text{N23E/34} \\
\text{N60E/14} & \quad \text{N02E/22} & \quad \text{N13E/14} & \quad \text{N01W/19} & \quad \text{S06W/28} & \quad \text{N17W/38} \\
\text{N45W/25} & \quad \text{N09E/33} & \quad \text{S20W/17} & \quad \text{N27W/71} & \quad \text{N49E/21} & \quad \text{S28W/09} \\
\text{N11W/64} & \quad \text{S19E/38} & \quad \text{S47W/29} & \quad \text{S13E/08} & \quad \text{N17W/33} & \quad \text{N73W/16} \\
\text{N56E/69} & \quad \text{N28E/06} & \quad \text{N24E/21} & \quad \text{S73E/12} & \quad \text{N19W/21} & \quad \text{S85E/37} \\
\text{S17E/14} & \quad \text{N43E/19} & \quad \text{S79W/33} & \quad \text{S85E/42} & \quad \text{N20E/30} & \quad \text{S67W/24} \\
\text{S31W/03} & \quad \text{S50E/30} & \quad \text{N79E/35} & \quad \text{S74E/63} & \quad \text{N47W/44} & \quad \text{N36E/42} \\
\text{N60E/46} & \quad \text{S34W/09} & \quad \text{N55E/29} & \quad \text{N16E/39} & \quad \text{S74E/10} & \quad \text{N54W/21} \\
\text{S26W/21} & \quad \text{S25W/17} & \quad \text{N71E/55} & \quad \text{N23E/29} & \quad \text{N55E/60} & \quad \text{N79E/29} \\
\text{N35E/30} & \quad \text{N67W/19} & \quad \text{S37E/53} & \quad \text{N16W/32} & \quad \text{S40E/32} & \quad \text{N56E/04} \\
\text{N72W/35} & \quad \text{N25W/31} & \quad \text{S41W/35} & \quad \text{N43E/35} & \quad \text{S03W/03} & \quad \text{N47W/15} \\
\text{S63W/13} & \quad \text{N18E/32} & \quad \text{S65E/16} & \quad \text{N19W/28} & \quad \text{N07W/45} & \quad \text{N51W/37} \\
\text{S80E/13} & \quad \text{S61W/24} & \quad \text{N52E/46} & \quad \text{N25E/21} & \quad \text{N09W/19} & \quad \text{N11E/31} \\
\text{N53W/61} & \quad \text{N03E/21} & \quad \text{N27W/44} & \quad \text{N60W/61} & \quad \text{S40W/47} & \quad \text{N48W/29} \\
\text{N42W/16} & \quad \text{S65E/48} & \quad \text{N88E/53} & \quad \text{S74E/63} & \quad \text{S62E/32} & \quad \text{N55E/52} \\
\text{N62W/20} & \quad \text{N66E/58} & \quad \text{S09W/17} & \quad \text{N68W/24} & \quad \text{N52E/37} & \quad \text{N23E/35} \\
\text{N31E/28} & \quad \text{N89E/33} & \quad \text{N20E/44} & \quad \text{N71E/33} & \quad & \\
\end{align*}
\]

\[
Gvm = 0.28 \\
X^2 = 15.0
\]
**Measured Section: A-MS1**

(n = 100)

<table>
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<th>Point 3</th>
<th>Point 4</th>
<th>Point 5</th>
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</tbody>
</table>

\[ G_{vm} = 0.28 \]

\[ X^2 = 15.0 \]
Measured Section: Mc-MS1  
(n = 100)

<table>
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\[ G_{vm} = 0.3 \]
\[ X^2 = 17.4 \]

\[ G_{vo} = 55^\circ \]
\[ D = \pm 26^\circ \]

\[ 0 \quad 5 \]
Appendix B2. -- Trough Axis Orientation

Trough axis trends indicated by quadrant and degrees (i.e., N23E) for sandstone and conglomerate lithofacies of the Canaan Peak Formation. Where trough foreset inclination was determined, foreset dip and dip direction (i.e., /13SE ) were noted. All directional measurements are from sandstone bedforms unless stated otherwise (i.e., [Gt]). Refer to text Figure 2 and Appendix A1. for measured section location. (n - ) is the total number of orientations measured, that fall within each 10° increment field, for a given section. Current rose diagrams are cumulative plots and the measured sections represented are listed adjacent to plot. In addition, Gvo, Gvm, X2, and D values are listed (refer to Table 2).

Measured Section: Hc-MS6
(n = 4)
S85E/32SW N85E S82E/23NE N84E/19NW

Measured Section: Hc-MS5
(n = 5)
N74E/20NW S74E/07NE S53E/37NE N61E S69E/33NE

Measured Section: Hc-MS4
(n = 2)
S90E/19N N58E/17SE

Measured Section: Hc-MS3
(n = 10)
N88E/16NW N79E/19NW N36E/04NW S10E/14NE N67E/13NW N49E/31NW N49E/31NW N09E N70E/17NE S05E/07NE N59E/13NW N05E N81E

Measured Section: Hc-MS2
(n = 4)
N48E N26E/08NW N55E/35SE S36E/20NE
The following directional measurements were obtained along an outcrop traverse between measured sections Hc-MS1 and Hc-MS2.

(n = 16)

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<th>Direction</th>
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<th>Direction</th>
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<th>Direction</th>
<th>Direction</th>
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</thead>
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<td>S40E</td>
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<tr>
<td>N51E/08SE</td>
<td>S73E/15NE</td>
<td>N75E</td>
<td>S37E [Gt]</td>
<td>S23W</td>
<td>N05E/05SE</td>
</tr>
<tr>
<td>N45E/16NW</td>
<td>S37E [Gt]</td>
<td>S52E [Gt]</td>
<td>N42E/12SE</td>
<td>[Gt]</td>
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</tr>
</tbody>
</table>

Measured Section: Hc-MS1
(n = 15)

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<th>Direction</th>
<th>Direction</th>
<th>Direction</th>
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</thead>
<tbody>
<tr>
<td>N85E/12NW</td>
<td>S68E/17NE</td>
<td>S80E/15NE</td>
<td>N48E/16SE</td>
<td>N35E</td>
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<tr>
<td>S30E/25SW</td>
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</table>

\[ \text{Gvm}=0.77 \]
\[ X^2=68.0 \]

Gvo= 85°

D=±10°
Measured Section: E-MS5  
(n = 12)

S83E/09NE S67E/13NE N74E/06NW S65E/19NE S69E/30NE N55E/14NW  
N72E/35NW S90E/53N S61E/28NE N30E/18NW N85E N53E/34NW

Measured Section: E-MS4  
(n = 5)

S38E/21NE N54E/12NW N55E/17NW S23E/07SW N18E/17SE

Measured Section: E-MS3  
(n = 11)

N72E/20NW S86E/24SW N28E/24NW N81E/26NW N53E/36NW N63E/28NW  
S81E/06NE S45E/10SW S54E S49E/22NW N23E/14NW

The following directional measurements were obtained from outcrop traverse between measured sections E-MS2 and E-MS3.

(N = 16)

N71E/08NW N48E/34NW S78E S83E/10NE N39E/14NW N74E  
S80E/12NE N85E/07NW N25E/12NW N43E/13NW N76E S74E/21NE  
N57E/15SE S60E/15NE S33E N81E

Measured Section: E-MS2  
(n = 49)

N39E N11E N19E/07SE N08E N18E N22E  
N51W N50E N54E N22E N65W N48E  
N16W N35E N38E N33E N68E N24E  
N16E N68E N80W N36W N08E N47E  
N74W N18E N78E N32W N22E N45E  
N07E N40E N85E [Gt] N12W N03W N06E  
N04E N12W N41E N10E N78E N48W  
N51W

The following directional measurements were obtained from measured section E-MS2.

(n = 24)

S64E/08SW N36E/19NW N41E/14NW N80E/12NW N61E/07NW N25E/21NW  
N64E/04NW S58E/08NE S10E/10NE N52E/05SE N62E/21NE N87E/12NW  
S04E/17NE S50E N40E/16SE S55E/15NE S62E N74E/15NW  
N45E/28NW N68E/17NW N82E N62E/26NW N85E/36SE N62E
Measured Section: E-MS1
(n = 6)


\[ G_{vm} = 0.69 \]

\[ X^2 = 113.2 \]

\[ G_{vo} = 56^\circ \]

\[ D = \pm 9^\circ \]
Measured Section: H-MS1
(n = 7)

\[
\begin{align*}
\text{Gvm} &= 0.63 \\
X^2 &= 5.4
\end{align*}
\]

Gvo = 47°

Measured Section: Ph-MS1
(n = 16)

\[
\begin{align*}
\text{Gvm} &= 0.47 \\
X^2 &= 6.8
\end{align*}
\]

Gvo = 35°
Measured Section: A-MS1
(n = 19)

N33W/08SW N67W/25NE N10E/08NW N61E/12NW N30W/14NE N65W/15NE
N57W/14NE N50W/08NE N10W/26SW N55W/11SW N90W/19N N52E/08NW
N72E/15NW N42E/14NW N20W/18SW N06W/23SW N20W N24W/22SW

Gvm = 0.71
X² = 18.6

Gvo = 341°

D = ± 21°

Measured Section: Mc-MS1
(n = 5)

N42E/32NW N42E/17NW N15E/24SE N40E/16NW N11E/22NW

Gvm = 0.97
X² = 9.3

Gvo = 31°
APPENDIX C

Canaan Peak Formation Lithology
Appendix C1. -- Conglomerate Clast Composition

The following histograms illustrate conglomerate clast compositions identified from the Canaan Peak Formation. Where accessible, clast composition counts were conducted at each measured section except A-MS2; a minimum of 100 clasts were counted during each session. All measured sections:
Measured sections Hc-MS1 -- Hc-MS6:
Measured sections E-MS1 -- E-MS5:

- **E-MS1 (n = 388)**
  - Ch
  - Q
  - V
  - S
  - C

- **E-MS2 (n = 321)**
  - Ch
  - Q
  - V
  - S
  - C

- **E-MS3 (n = 511)**
  - Ch
  - Q
  - V
  - S
  - C

- **E-MS4 (n = 311)**
  - Ch
  - Q
  - V
  - S
  - C

- **E-MS5 (n = 182)**
  - Ch
  - Q
  - V
  - S
  - C
Measured sections P-MS1, H-MS1, Ph-MS1, C-MS1, Ph-MS1, A-MS1, Mc-MS1:
Appendix C2. -- Sandstone Grain Composition

The following table documents sandstone grain populations determined from 24 thin section point counts. The total number of compositionally distinct grains identified and their relative percentages are indicated, as well as the overall total grain point count (n). Sample Loc. includes measured section and approximate level (meters) where collected. Qm = monocrystalline quartz; Qp = polycrystalline quartz; Li = total lithics; F = feldspar (orthoclase and plagioclase) (terminology after Dickinson and others, 1983).

<table>
<thead>
<tr>
<th>Sample Loc.</th>
<th>Qm</th>
<th>Qp</th>
<th>Li</th>
<th>F</th>
<th>Total (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-MS1/1 (base)</td>
<td>138/38%</td>
<td>218/60%</td>
<td>8/2%</td>
<td>0</td>
<td>364/100%</td>
</tr>
<tr>
<td>A-MS1/4 (61m)</td>
<td>167/41%</td>
<td>245/59%</td>
<td>0</td>
<td>0</td>
<td>412/100%</td>
</tr>
<tr>
<td>A-MS2/1 (1.5m)</td>
<td>284/71%</td>
<td>116/29%</td>
<td>0</td>
<td>0</td>
<td>400/100%</td>
</tr>
<tr>
<td>P-MS1/1 (base)</td>
<td>80/26%</td>
<td>202/65%</td>
<td>31/9%</td>
<td>0</td>
<td>313/100%</td>
</tr>
<tr>
<td>P-MS1/2 (10m)</td>
<td>69/29%</td>
<td>137/57%</td>
<td>36/14%</td>
<td>0</td>
<td>242/100%</td>
</tr>
<tr>
<td>Me-MS1/3 (8.3m)</td>
<td>140/37%</td>
<td>237/62%</td>
<td>4/1%</td>
<td>0</td>
<td>381/100%</td>
</tr>
<tr>
<td>H-MS1/1 (3m)</td>
<td>249/75%</td>
<td>60/18%</td>
<td>25/7%</td>
<td>0</td>
<td>334/100%</td>
</tr>
<tr>
<td>H-MS1/4 (12.5m)</td>
<td>331/92%</td>
<td>27/8%</td>
<td>0/0%</td>
<td>0</td>
<td>358/100%</td>
</tr>
<tr>
<td>E-MS1/5 (22.3m)</td>
<td>238/62%</td>
<td>115/31%</td>
<td>23/6%</td>
<td>1/&lt;1%</td>
<td>377/100%</td>
</tr>
<tr>
<td>E-MS2/1 (19m)</td>
<td>251/79%</td>
<td>46/14%</td>
<td>21/7%</td>
<td>0</td>
<td>318/100%</td>
</tr>
<tr>
<td>E-MS3/1 (8.5m)</td>
<td>8/2%</td>
<td>284/79%</td>
<td>69/19%</td>
<td>0</td>
<td>361/100%</td>
</tr>
<tr>
<td>E-MS3/5 (14m)</td>
<td>129/38%</td>
<td>137/40%</td>
<td>74/22%</td>
<td>0</td>
<td>340/100%</td>
</tr>
<tr>
<td>E-MS4/1 (3m)</td>
<td>210/64%</td>
<td>47/15%</td>
<td>70/21%</td>
<td>0</td>
<td>327/100%</td>
</tr>
<tr>
<td>Hc-MS1/1 (7m)</td>
<td>238/77%</td>
<td>65/21%</td>
<td>7/2%</td>
<td>0</td>
<td>310/100%</td>
</tr>
<tr>
<td>Hc-MS2/1 (3.7m)</td>
<td>158/41%</td>
<td>157/40%</td>
<td>74/19%</td>
<td>0</td>
<td>389/100%</td>
</tr>
<tr>
<td>Hc-MS3/1 (3m)</td>
<td>271/60%</td>
<td>117/26%</td>
<td>62/14%</td>
<td>0</td>
<td>450/100%</td>
</tr>
<tr>
<td>Hc-MS3/5 (26m)</td>
<td>240/55%</td>
<td>170/39%</td>
<td>29/6%</td>
<td>0</td>
<td>439/100%</td>
</tr>
<tr>
<td>Hc-MS4/1 (10.4m)</td>
<td>328/66%</td>
<td>134/27%</td>
<td>38/7%</td>
<td>0</td>
<td>500/100%</td>
</tr>
<tr>
<td>Hc-MS5/6 (14.3m)</td>
<td>276/82%</td>
<td>42/12%</td>
<td>16/5%</td>
<td>1/&lt;1%</td>
<td>335/100%</td>
</tr>
<tr>
<td>Hc-MS5/7 (17.7m)</td>
<td>201/48%</td>
<td>184/44%</td>
<td>32/8%</td>
<td>0</td>
<td>417/100%</td>
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<tr>
<td></td>
<td>Hc-MS6/1 (15.3m)</td>
<td>259/58%</td>
<td>144/33%</td>
<td>40/9%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Hc-MS6/2 (16.8m)</td>
<td>215/69%</td>
<td>78/25%</td>
<td>19/6%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Ph-MSl/1 (12.8)</td>
<td>178/52%</td>
<td>157/46%</td>
<td>9/2%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Ph-MSl/4 (25.3m)</td>
<td>228/71%</td>
<td>74/23%</td>
<td>17/6%</td>
<td>0</td>
</tr>
</tbody>
</table>