BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

GEOLOGICAL SOCIETY OF AMERICA

FIELD TRIP GUIDE BOOK

1997 ANNUAL MEETING • SALT LAKE CITY, UTAH

PART 2 TWO

EDITED BY PAUL KARL LINK AND BART J. KOWALLIS

VOLUME 42 • 1997

MESOZOIC TO RECENT GEOLOGY OF UTAH

Edited by
Paul Karl Link and Bart J. Kowallis

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

Volume 42, Part II, 1997

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A Publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published by the Department of Geology. This publication consists of graduate student and faculty research within the department as well as papers submitted by outside contributors. Each article submitted is externally reviewed by at least two qualified persons.

Cover photos taken by Paul Karl Link.

Top: Upheaval Dome, southeastern Utah.
Middle: Lake Bonneville shorelines west of Brigham City, Utah.
Bottom: Bryce Canyon National Park, Utah.

ISSN 0068-1016
9-97 700 23870/24290

Preface

Guidebooks have been part of the exploration of the American West since Oregon Trail days. Geologic guidebooks with maps and photographs are an especially graphic tool for school teachers, University classes, and visiting geologists to become familiar with the territory, the geologic issues and the available references.

It was in this spirit that we set out to compile this two-volume set of field trip descriptions for the Annual Meeting of the Geological Society of America in Salt Lake City in October 1997. We were seeking to produce a quality product, with fully peer-reviewed papers, and user-friendly field trip logs. We found we were bucking a tide in our profession which de-emphasizes guidebooks and paper products. If this tide continues we wish to be on record as producing "The Last Best Geologic Guidebook."

We thank all the authors who met our strict deadlines and contributed this outstanding set of papers. We hope this work will stand for years to come as a lasting introduction to the complex geology of the Colorado Plateau, Basin and Range, Wasatch Front, and Snake River Plain in the vicinity of Salt Lake City. Index maps to the field trips contained in each volume are on the back covers.

Part 1 "Proterozoic to Recent Stratigraphy, Tectonics and Volcanology: Utah, Nevada, Southern Idaho and Central Mexico" contains a number of papers of exceptional interest for their geologic synthesis. Part 2 "Mesozoic to Recent Geology of Utah" concentrates on the Colorado Plateau and the Wasatch Front.

Paul Link read all the papers and coordinated the review process. Bart Kowallis copy edited the manuscripts and coordinated the publication via Brigham Young University Geology Studies. We would like to thank all the reviewers, who were generally prompt and helpful in meeting our tight schedule. These included: Lee Allison, Genevieve Atwood, Gary Axen, Jim Beget, Myron Best, David Bice, Phyllis Camilleri, Marjorie Chan, Nick Christie-Blick, Gary Christenson, Dan Chure, Mary Droser, Ernie Duebendorfer, Tony Ekdale, Todd Ehlers, Ben Everitt, Geoff Freethey, Hugh Hurlow, Jim Garrison, Denny Geist, Jeff Geslin, Ron Greeley, Gus Gustason, Bill Hackett, Kimm Harty, Grant Heiken, Lehi Hintze, Peter Huntoon, Peter Isaacson, Jeff Keaton, Keith Ketner, Guy King, Mel Kuntz, Tim Lawton, Spencer Lucas, Lon McCarley, Meghan Miller, Gautam Mitra, Kathy Nichols, Robert Q. Oaks, Susan Olig, Jack Oviatt, Bill Perry, Andy Pulham, Dick Robison, Rube Ross, Rich Schweickert, Peter Sheehan, Norm Silberling, Dick Smith, Barry Solomon, K.O. Stanley, Kevin Stewart, Wanda Taylor, Glenn Thackray and Adolph Yonkee. In addition, we wish to thank all the dedicated workers at Brigham Young University Print Services and in the Department of Geology who contributed many long hours of work to these volumes.

Paul Karl Link and Bart J. Kowallis, Editors

Stratigraphy and structure of the Sevier thrust belt and proximal foreland-basin system in central Utah: A transect from the Sevier Desert to the Wasatch Plateau

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ABSTRACT

The Sevier orogenic belt in central Utah comprises four north-northwest trending thrust plates and two structural culminations that record crustal shortening and uplift in late Mesozoic and early Tertiary time. Synorogenic clastic rocks, mostly conglomerate and sandstone, exposed within the thrust belt were deposited in wedge-top and foredeep depozones within the proximal part of the foreland-basin system. The geologic relations preserved between thrust structures and synorogenic deposits demonstrate a foreland-breaking sequence of thrust deformation that was modified by minor out-of-sequence thrust displacement. Structural culminations in the interior part of the thrust belt deformed and uplifted some of the thrust sheets following their emplacement.

Strata in the foreland basin indicate that the thrust sheets of central Utah were emplaced between latest Jurassic and Eocene time. The oldest strata of the foredeep depozone (Cedar Mountain Formation) are Neocomian and were derived from the hanging wall of the Canyon Range thrust. The foredeep depozone subsided most rapidly during Albian through Santonian or early Campanian time and accumulated about 2.5 km of conglomeratic strata (Indianola Group). The overlying North Horn Formation accumulated in a wedge-top basin from the Campanian to the Eocene and records propagation of the Gunnison thrust beneath the former foredeep. The Canyon Range Conglomerate of the Canyon Mountains, equivalent to the Indianola Group and the North Horn Formation, was deposited exclusively in a wedge-top setting on the Canyon Range and Pavant thrust sheets.

This field trip, a three day, west-to-east traverse of the Sevier orogenic belt in central Utah, visits localities where timing of thrust structures is demonstrated by geometry of cross-cutting relations, growth strata associated with faults and folds, or deformation of foredeep deposits. Stops in the Canyon Mountains emphasize geometry of late structural culminations and relationships of the Canyon Range thrust to growth strata deposited in

the wedge-top depozone. Stops in the San Pitch Mountains illustrate deposits of the foredeep depozone and younger, superjacent wedge-top depozone. Stops in the Sanpete Valley and western part of the Wasatch Plateau examine the evolution of the foreland-basin system from foredeep to wedge-top during growth of a triangle zone near the front of the Gunnison thrust.

INTRODUCTION

The Sevier orogenic belt is part of a linear zone of late Mesozoic thin-skinned deformation that extends northward from the vicinity of Las Vegas, Nevada, through the Canadian Rocky Mountains, and into northern Alaska. Although the term, Sevier orogenic belt, has been applied to fold-and-thrust deformation as far north as Montana (e.g., Schmitt et al., 1995), the name was originally proposed by Armstrong (1968) for that part of the deformed belt, consisting of thrust faults and related folds, that lies between southern Nevada and the northern boundary of Utah. Armstrong (1968, p. 451) recognized that the thin-skinned deformation was primarily a Cretaceous event and therefore older than basement uplifts of the Laramide orogeny that began to form near the end of the Cretaceous. He intended that the term discriminate, both temporally and kinematically, the thrust-related deformation at the eastern edge of the Basin and Range from the basement-involved structures of the central Rocky Mountains. The exact timing of initiation of thrusting remains somewhat controversial (e.g., Heller et al., 1986; DeCelles and Currie, 1996), and there is significant overlap in age of late thrust movement and Laramide basement uplift to the east (e.g., Lawton and Trexler; 1991; Lawton et al., 1993); however, the Sevier orogeny was a major, distinct episode of crustal shortening recorded both by its structural geometry and by the stratigraphic record of the Cretaceous foreland (e.g., Kauffman, 1977).

Since the general geologic community's most recent visit to the Sevier orogenic belt in central Utah in 1982 (Nielson, 1982 and papers therein), a tremendous amount of field research has taken place in central Utah. In addition, thrust belts and foreland basins have enjoyed a scientific renaissance; general concepts have blossomed and advanced greatly in the last 17 years. Tools and concepts applied universally today that were nascent or nonexistent in the early 1980s include balanced cross sections (e.g., Dahlstrom, 1969; Woodward and Boyer, 1985), geometric models for thrust belts (e.g., Bally et al., 1966; Boyer and Elliott, 1982), critical-wedge theory (Davis et al., 1983), provenance modeling (Graham et al., 1986; DeCelles, 1988), subsidence of foreland basins as a result of flexure (Beaumont, 1981; Jordan, 1981), and growth-stratal analysis (Riba, 1976; Suppe et al., 1992). Application of these tools has advanced our understanding of thrust timing and foreland-basin origins, both in the Cordilleran fold-and-thrust belt and elsewhere in the world. The trip through the central Utah part of the Sevier orogen will examine some aspects of the thrust belt and proximal foreland basin that were unknown in 1982.

Geologic Setting

Four thrust sheets and two structural culminations, the Sevier and Canyon Range culminations, are presently defined in the central Utah segment of the Sevier orogenic belt (fig. 1.). The thrust belt to be visited on the field trip represents only a frontal zone of imbricate thrusts that lies cratonward of the Sevier culmination. The Sevier culmination is a stack of basement blocks inferred to lie mostly in the subsurface of the Sevier Desert beneath a Miocene basin, although it is partly exposed in the House and Confusion ranges (DeCelles et al., 1995; Coogan and DeCelles, 1996). In the Late Cretaceous, the Sevier culmination constituted a strong wedge of competent Precambrian crystalline basement and Proterozoic strata, dominantly quartzite, at the rear of the orogen (fig. 1; DeCelles et al., 1995; Mitra, in press). The upper part of the culmination that was available for erosion during the Cretaceous probably consisted of Paleozoic and Mesozoic strata. The Canyon Range culmination lies roughly 5–10 km to the west of the frontal trace of the Canyon Range thrust and caused uplift and stripping of much of the frontal part of the Canyon Range thrust plate (fig. 2; Sussman and Mitra, 1995).

Three exposed thrust plates overlie the Canyon Range, Pavant, and Gunnison thrusts, from west to east. The Canyon Range thrust emplaces Proterozoic sedimentary rocks above Cambrian through Devonian strata and the Cretaceous Canyon Range Conglomerate (Christiansen, 1952; Millard, 1983; Holladay, 1984). The Pavant thrust structurally underlies the Canyon Range thrust and emplaces Cambrian through Ordovician strata over Jurassic strata (Burchfiel and Hickox, 1972; Millard, 1983; Hintze, 1991a). The Gunnison thrust is a frontal detachment in Jurassic evaporite east of a ramp that emplaces Paleozoic over lower Mesozoic strata (Standlee, 1982; Lawton, 1985; Coogan et al., 1995). A wedge-top or piggyback basin developed on the Gunnison thrust sheet during latest Cretaceous and Paleogene time (Lawton and Trexler, 1991). Some workers infer the presence of an additional thrust, the Paxton thrust, in the subsurface based on analysis of stratigraphy and structure in boreholes (fig. 1; Royse, 1993; Coogan et al., 1995; Mitra, in press). The thrust structure of the central Utah part of the Sevier orogenic belt terminates at a structural cross-strike discontinuity at Leamington Canyon (Morris, 1983). North

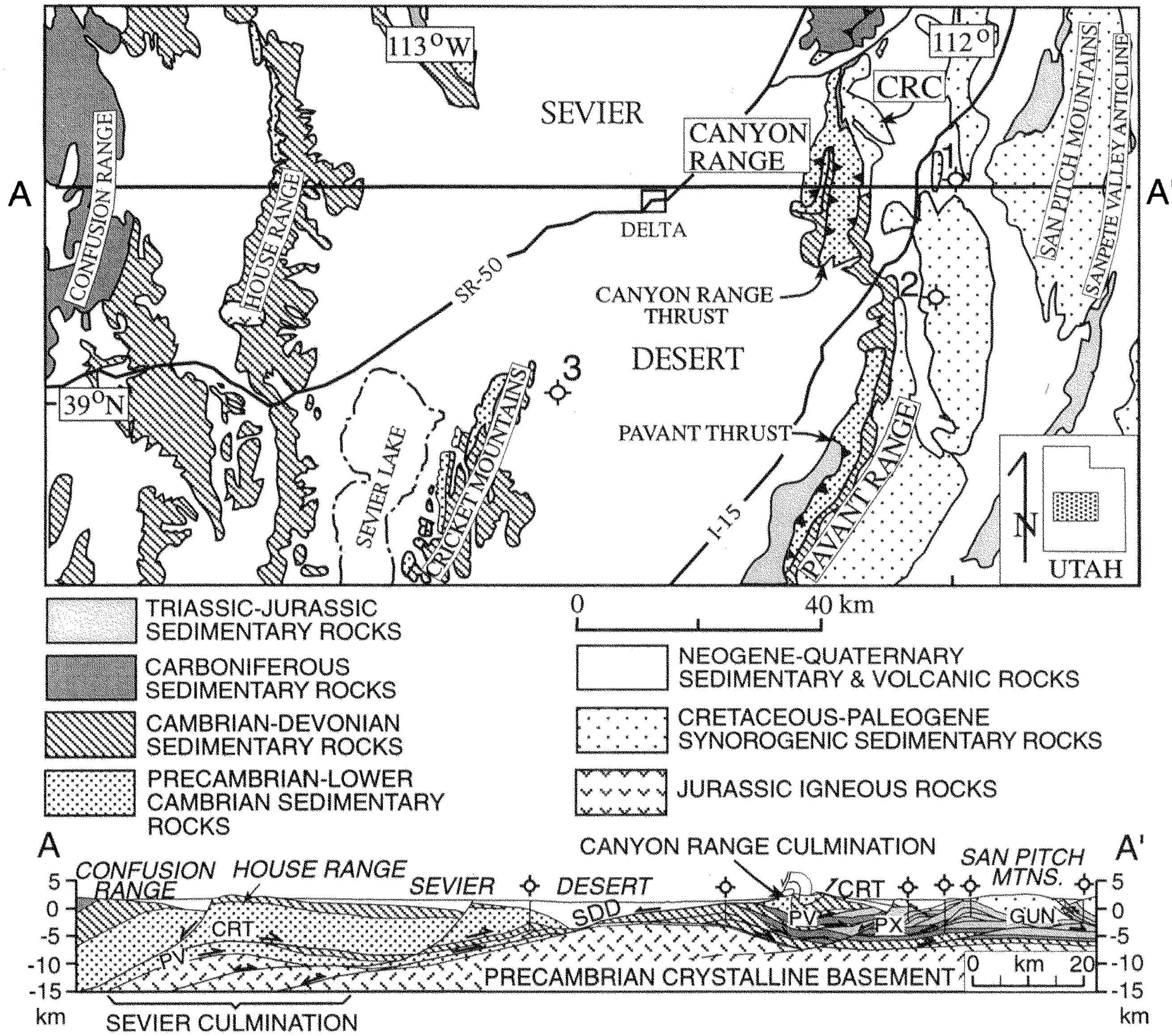


Figure 1. Generalized geologic map of central Utah, after Hintze (1980) and cross section through Sevier orogenic belt (Coogan et al., 1995). Boreholes: 1, Placid WXC Barton1; 2, Placid WXC USA 1-2; 3, Cominco American #2 Beaver River. CRC indicates Canyon Range Conglomerate. Major structures: CRT, Canyon Range thrust; PV, Pavant thrust; SDD, Sevier Desert detachment fault, PX, Paxton thrust; GUN, Gunnison thrust. The Leamington structural cross-strike discontinuity parallels the highway at the north end of the Canyon Range (Canyon Mountains of this text). From Decelles et al., (1995).

of the Leamington cross-strike discontinuity are thrust plates with different hanging-wall stratigraphies and kinematic histories (Mitra, in press).

Thrust faulting is generally believed to have followed a foreland-breaking progression (fig. 4; Lawton, 1986; DeCelles et al., 1995; Mitra, in press), although alternative scenarios have been proposed (Villien and Kligfield, 1986; Schwans, 1995). Recent detailed work on proximal foreland-basin stratigraphy and consideration of cross-cutting and refolding relationships among thrusts has shown that minor out-of-sequence thrusting was common (DeCelles et al., 1995; Mitra and Sussman, 1997; Mitra, in press). For example, the Canyon Range Conglomerate rests unconformably on both the Canyon Range and Pavant thrust sheets along the east flank of the Canyon Mountains and in the Pavant Range (fig. 1; Millard, 1983; Holladay, 1984; Hintze, 1991a). Prior to deposition of the Canyon Range Conglomerate, significant uplift of the Canyon Range sheet was caused by displacement on underlying thrusts, including the Pavant thrust (fig. 1; Lawton 1986). The Canyon Range Conglomerate was

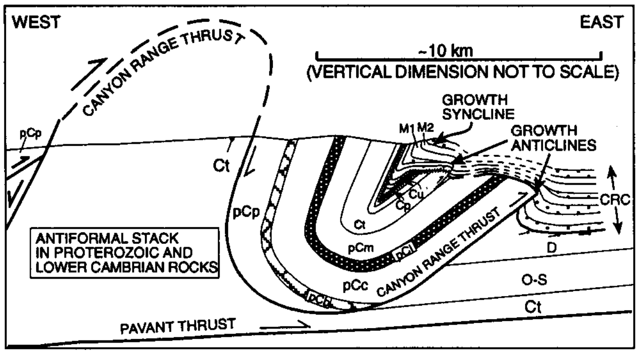


Figure 2. Schematic, generalized cross section through northern Canyon Mountains, showing relationships of Canyon Range thrust, Canyon Range culmination (antiformal stack exposed beneath thrust), and Canyon Range conglomerate (CRC). Stippled units in conglomerate are quartzite petrofacies; unpatterned units are carbonate and mixed (M1, M2) petrofacies. Stratigraphic units: pCp, Pocatello Group; pCb, Black Rock Canyon Limestone; PCc, Caddy Canyon Quartzite; pCi, Indom Formation; pCm, Mutual Formation; Ct, Tintic Quartzite; Cp, Pioche Formation; Cu, Cambrian undifferentiated (limestone, shale and dolostone); O-S, Ordovician and Silurian carbonates and siliciclastics; D, Devonian carbonates.

deposited on the Canyon Range and Pavant thrust sheets and subsequently was overthrust several hundred meters by the Canyon Range thrust sheet, although the amount of thrust displacement was minor compared with initial displacement of the Canyon Range thrust that emplaced Precambrian strata over Devonian strata (see additional discussion in text at stop 3). Thus, the Canyon Range thrust experienced a small amount of out-of-sequence displacement following emplacement of the Pavant thrust (Villien and Kligfield, 1986; DeCelles et al., 1995).

Thrust-related uplift contributed detritus to a foreland basin that lay immediately east of the orogen. Even before the structural characteristics of the Sevier belt were understood, the presence of coarse-grained Cretaceous deposits west of the Wasatch Plateau lead early workers to postulate the presence of orogenic uplift to the west. On the evidence of conglomeratic deposits and angular unconformities, Spieker (1946) defined three orogenic events in western Utah during Cretaceous and early Tertiary time. He termed these orogenic episodes the mid-Cretaceous movement of early Late Cretaceous age, the early Laramide movement of latest Cretaceous age, and the pre-Flagstaff movement of Paleocene age. In defining these events, he recognized the temporal separation of Sevier and Laramide deformation. Spieker (1949; p. 21) was also first to recognize an unroofing sequence, consisting of abundant Paleozoic limestone clasts in the lower part of the conglomeratic section and abundant quartzite clasts in the upper part, in the stratigraphy of the foreland basin. The source of the clasts in western Utah was delineated by Harris (1959), who recognized that Mesozoic and some Paleozoic formations corresponding to clast types in the conglomerate are absent beneath Tertiary volcanic strata of the Basin and Range. He termed this uplifted terrane the Sevier arch (Harris, 1959), the source of the term subsequently employed by Armstrong (1968).

The stratigraphic record of thrusting in the proximal part of the foreland basin, or that part of the basin lying between the Canyon Mountains and the Wasatch Plateau (fig. 5), consists primarily of conglomeratic strata that range in age from Neocomian through Paleocene (figs. 5, 6). Synorogenic strata of the foreland basin include five major stratigraphic units (fig. 6): The Cedar Mountain Formation; the Indianola Group; the South Flat Formation, a fine-grained unit of sandstone, shale, and minor conglomerate generally excluded from the Indianola Group (Hunt, 1954); the Price River Formation; the North Horn Formation. Based on physical correlation and unpublished palynomorph data (G.L. Waanders, written communications, 1981, 1982, 1983, 1991, 1992, 1993, 1994), the Canyon Range Conglomerate of the Canyon Mountains is interpreted as equivalent to all or part of these units (e.g., Stolle, 1978). Ages of these units are interpreted primarily from a few localities where palynomorphs have been recovered, coupled with regional correlation. Correlation is difficult and involves interpretations of physical stratigraphic sequence and clast population (e.g., DeCelles et al., 1995; Schwans, 1995). Recent regional work on the proximal stratigraphy has yielded a preliminary correlation of units in the foreland basin between the Canyon Mountains and Castle Valley, east of the Wasatch Plateau (fig. 6). Considered in terms of the foreland-basin system of DeCelles and Giles (1996), these rocks were deposited in the wedge-top and foredeep depozones. The wedge-top depozone includes basins, such as piggyback basins, formed on thrust sheets of the orogen. The foredeep depozone represents the thick deposits of the basin immediately adjacent to the tip of the thrust wedge. The Canyon Range Conglomerate, deposited directly on the Canyon Range and Pavant sheets, represents deposits of the wedge-top depozone. Strata of the Indianola Group in the San Pitch Mountains were deposited in the foredeep depozone, whereas strata of the North Horn Formation at the same locality are wedge-top deposits that accumulated on the hanging wall of the Gunnison thrust after it propagated beneath the former foredeep. Correct interpretation of the relationships among these proximal strata and the thrust faults is essential to understanding the evolution of the thrust belt, both in terms of kinematics and timing.

Each thrust sheet of the Sevier orogenic belt contains a stratigraphic section originally deposited in the Proterozoic-early Mesozoic Cordilleran miogeocline. Although parts of the miogeoclinal stratigraphy are common to all thrust

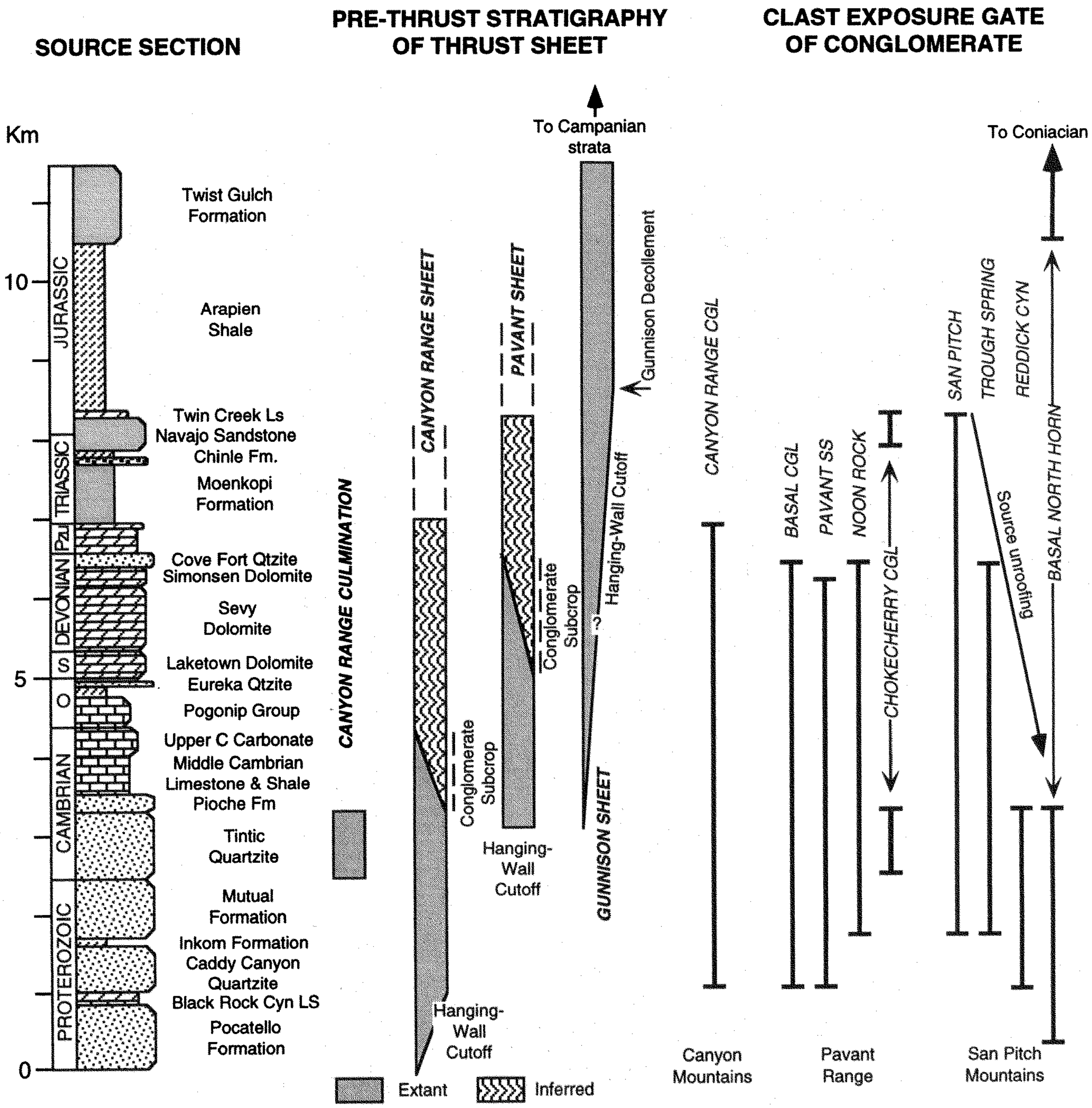


Figure 3. Stratigraphic section present in thrust sheets of the Sevier orogenic belt in central Utah and its relationship to clast populations in synorogenic conglomerate of the proximal foreland-basin system. Left column depicts stratigraphic section present in thrust belt (after Hintze, 1988). Central bars indicate ranges of formations that are present (extant) and postulated to have been present in the Cretaceous (inferred) in each of the three exposed thrust sheets and the Canyon Range culmination. At the initiation of its displacement, the Gunnison sheet included strata as young as Campanian. Vertical lines on right indicate range of clasts present in selected conglomeratic formations of the Canyon Mountains, Pavant Range, and San Pitch Mountains. The range of clasts indicates the exposure gate, or stratigraphic interval available for erosion, during deposition of a particular conglomeratic formation (Graham et al., 1986; DeCelles, 1988). Successively younger conglomeratic units of the San Pitch Mountains (names explained in figure 17) record progressive unroofing of the source section (Lawton, 1986). In the San Pitch Mountains, the basal member of the North Horn Formation contains clasts with a bimodal age distribution because it was derived from both thrust sheets to the west and the rising Sevier-Sanpete Valley antiform above the tip of the Gunnison thrust (Lawton et al., 1993).

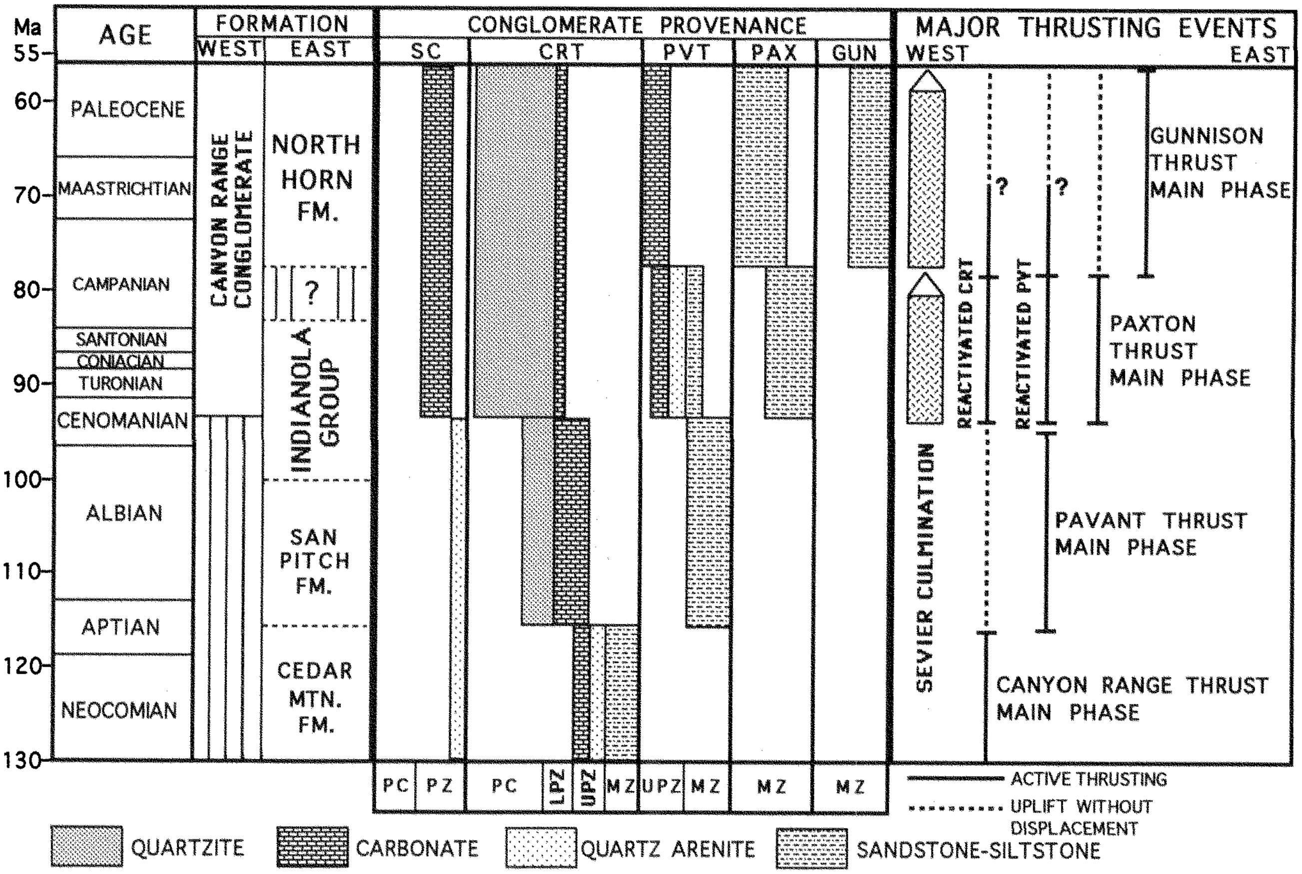


Figure 4. Provenance of Cretaceous-Paleocene conglomeratic units and proposed sequence of Sevier thrust faulting in central Utah (DeCelles et al., 1995). Conglomerate provenance panel shows likely source stratigraphic units (ages of units are along bottom of panel) and lithologies, indicated by patterns, divided among five principal souce terranes: SC, Sevier culmination; CRT, Canyon Range sheet; PVT, Pavant sheet; PAX, Paxton sheet; GUN, Gunnison sheet. Ages of conglomerate source-rock units: PC, Proterozoic; PZ, Paleozoic; LPZ, lower Paleozoic; UPZ, upper Paleozoic; MZ, Mesozoic.

sheets, some parts are unique to a given thrust plate (figs. 3, 4). This is particularly true if the stratigraphy is considered in terms of what parts of each sheet were exposed in the Cretaceous and early Tertiary during thrusting. Stratigraphic units still extant in some thrust plates never produced detritus for synorogenic deposits of the foreland basin, whereas they were prodigious contributors from other thrust sheets. For example, lower Paleozoic strata of the Canyon Range sheet in the House Range and in the Canyon Mountains south of Leamington Canyon contributed abundant clasts (DeCelles et al., 1995); on the other hand, the lower Paleozoic section of the Pavant sheet was never exposed to erosion (figs. 1, 3). In addition, only the Canyon Range sheet contains Precambrian strata that were ever exposed to erosion (fig. 1); therefore, essentially all first-cycle Proterozoic quartzite clasts and lower Paleozoic quartzite clasts in the central Utah part of the proximal foreland basin were derived from the hanging wall of the Canyon Range thrust.

Field Trip Road Log and Stops

The field trip traverses the central Utah part of the Sevier orogenic belt from west to east, beginning in the Canyon Mountains and proceeding to the San Pitch Mountains and Sanpete Valley (fig. 5). Stops in the Canyon Mountains illustrate the structure of the Canyon Range culmination and thrust sheet, superb examples of growth strata deposited during folding (e.g., Suppe et al., 1982), depositional facies in the proximal conglomerate and the nature of the Leamington cross-strike discontinuity where the Sevier River crosses between the Gilson and Canyon mountains (fig. 5). Stops in the western San Pitch Mountains illustrate deposits of the foredeep depozone and the temporal transition between foredeep and wedge-top depozones. Stops in and near the Sanpete Valley illustrate early foreland-basin stratigraphy and interaction of syntectonic foreland-basin deposition with an actively growing frontal triangle zone.

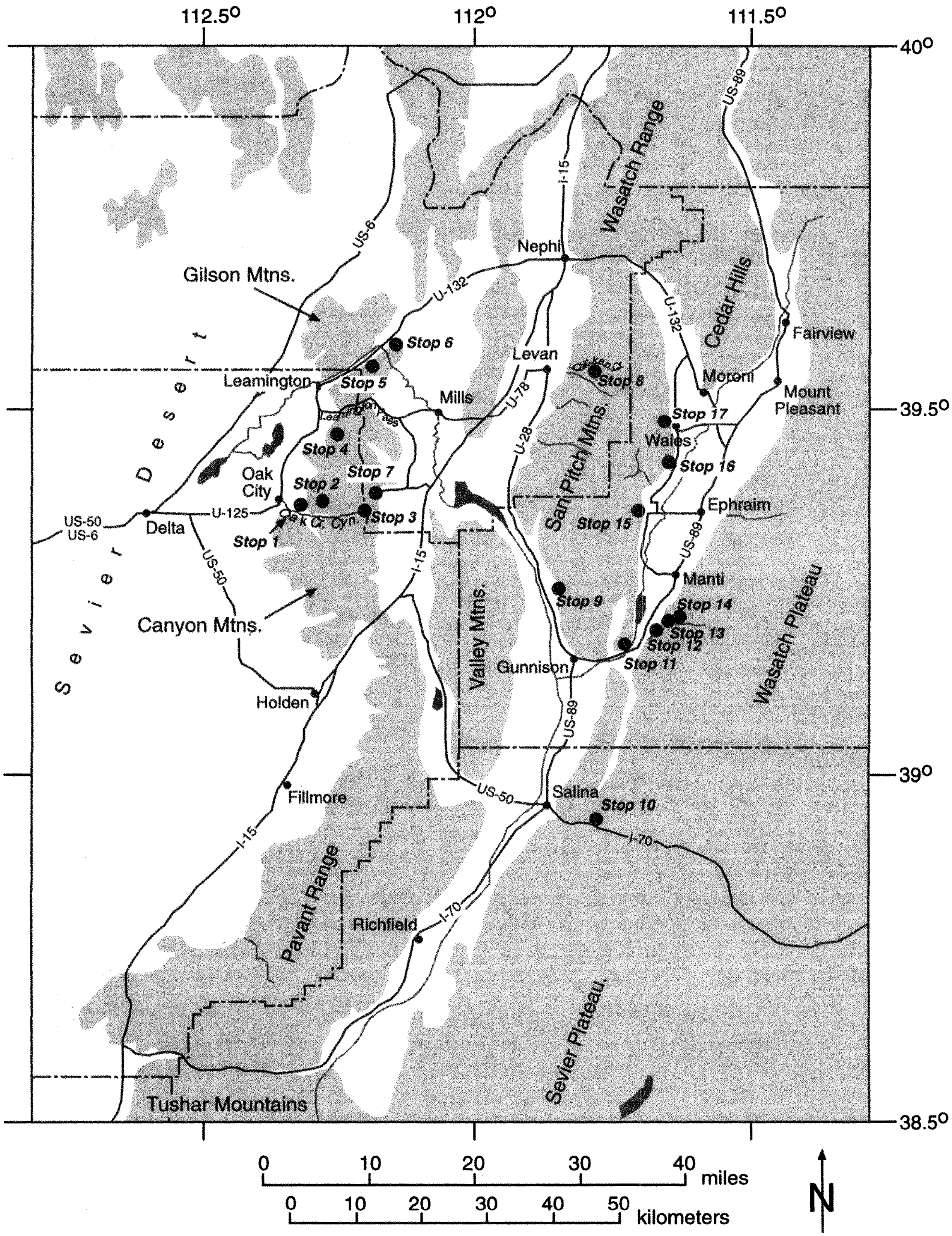


Figure 5. Location map of central Utah, showing field trip stops.

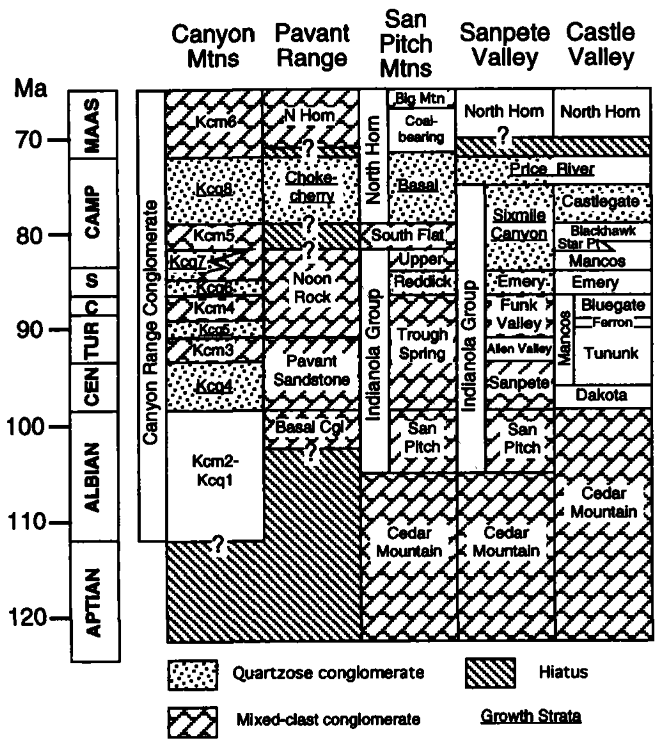


Figure 6. Correlation of strata in proximal part of foreland basin between the Canyon Mountains and Colorado Plateau (Castle Valley). Correlations based on palynology, stratigraphic sequence, and petrographic characteristics of conglomerate. Patterns indicate if conglomerate of a particular is composed only of quartzite clasts (quartzose conglomerate) or quartzite and carbonate clasts (mixed-clast conglomerate). Unpatterned units are of uncertain composition, except in Canyon Mountains, where lack of pattern indicates undifferentiated conglomerate units. Formations that contain growth strata are underlined.

<u>Note on geographic nomenclature</u>: The Canyon Mountains of current topographic maps were formerly known as the Canyon Range, and the San Pitch Mountains were formerly named the Gunnison Plateau. The names Canyon Range and Gunnison Plateau are more commonly encountered in the geologic literature than the current cartographic names.

Geologic maps of field trip stops in the Canyon Mountains are available in open-file form at a scale of 1:24,000 (Hintze, 1991b, 1991c) from the Utah Geological Survey. Published geologic maps of field trip stops in the San Pitch Mountains and San Pete Valley area are available at a scale of 1:100,000 (Witkind et al., 1987; Witkind and Weiss, 1991). Geologic coverage of the stop in Salina Canyon (stop 10) is available at a scale of 1:24,000 (Willis, 1986).

The field trip and road log begin at the Best Western Hotel on U.S. Highway 6 in Delta, Utah. Numbers in parentheses indicate mileage: bold face, cumulative distance; plain text, distance since previous comment. Stops are shown on figure 5.

Day 1. Canyon Range.

(**0.0**) Depart Best Western Motel in Delta, Utah. Right (south) on U.S. Highway 6.

(**0.1**, 0.1) Left (east) on U.S. Highway 50.

(**3.6**, 3.5) Intersection of U.S. Highway 50 and Utah Route 125. Continue straight east on Utah Route 125. Canyon Mountains are straight ahead at 12:00; Pavant Range is to the southeast at 1:00–3:00; Gilson Mountains, north of Leamington Canyon, are to the northeast at 10:00. The Sevier River enters the Sevier Desert basin by way of Leamington Canyon. The Sevier Desert basin has been interpreted as a supradetachment basin above the low-angle Sevier desert detachment (Allmendinger et al., 1983; Coogan and DeCelles, 1996), which may intersect the surface along the west side of the Canyon Mountains and Pavant Range (Otton, 1995); however, the connection between the range-bounding fault and a low-angle detachment at depth has been questioned (Anders and Christie-Blick, 1994).

(**8.2**, 4.7) Barchan dunes to south of road. Whereas most of the dunes in the basin are vegetated and inactive, some dunes such as these are locally active.

(**11.9**, 3.7) Entering Oak City.

(**12.5**, 0.6) Right (east) on Center Street. Upon departing Oak City, outcrops of the Miocene Oak City Formation are visible on both sides of the road.

(**13.5**, 1.0) **Stop 1. Brief orientation, west flank of Canyon Range.**

Outcrops are visible on the low ridge to the south immediately after leaving town. These are made up of highly brecciated beds of Cambrian Tintic, Cambrian Pioche, and Cambrian carbonate rocks. The beds are extensively fractured but nevertheless preserve cohesive internal stratigraphy. The attitudes of beds indicate an upsection decrease in dips eastward along the ridge, interpreted as progressive rotation of beds above a curved normal fault. Older second-order fold hinges are also preserved in these rocks. These beds, which have been previously mapped as part of the Miocene Oak City Formation (Otton, 1995), are actually brittlely deformed hanging-wall rocks in the breakaway zone of the Sevier Desert detachment. They record extensional unroofing of the Canyon Mountains during westward displacement of the upper plate of the Sevier Desert detachment. Apatite fission-track data from the western part of the range suggest rapid uplift and denudation of the Canyon Mountains at 18 Ma, possibly as a result of exhumation by a major low-angle detachment (Stockli and Linn, 1996).

Closer to the mouth of Oak Creek Canyon and north of the road, the front of the range is defined by fault scarps, expressed as small triangular facets, that represent segments of a steeply west-dipping normal fault system (Otton, 1995; Sussman and Mitra, 1996). The normal faults have downdropped the folded Canyon Range thrust so that it is not exposed anywhere along the western flank of the range (figs. 7, 8; Sussman and Mitra, 1995). Gently dipping Proterozoic Pocatello Formation in the hanging wall of the Canyon Range thrust is exposed on low hills west of the normal fault trace. Beyond and east of the break in slope, the footwall of the normal fault preserves a connecting splay duplex antiformal stack that developed in the footwall of the Canyon Range thrust and resulted in folding of the thrust (Mitra and Sussman, 1997). The duplex contains repeated slices of Proterozoic Mutual through Cambrian carbonate rocks; some repeated slices of the Cambrian Tintic Formation can be seen from here. Also visible near the top of the ridge is the western end of Paul's Meadow, the location of Stop 2.

(**15.8**, 2.3) Cattleguard, not far beyond Fishlake National Forest sign on right, marks entrance to National Forest.

(**17.4**, 1.6) Limekiln Canyon. Turn left (north) on Forest Road 419. This road requires high clearance and four-wheel drive. It is narrow, locally rough, and turnaround spots are few after the first half-mile.

(**19.4**, 2.0) **Stop 2. Canyon Range culmination and Canyon Range syncline**. Two mile strenuous walk uphill, approximately 3 hours round trip.

From the end of the road, climb northward (up the valley) to Paul's Meadow at the gap between the Cambrian Tintic quartzite ridge to the west and the Cambrian carbonate ridge to the east. From Paul's Meadow, climb to the top of the carbonate ridge to the east. Here we are in the footwall of the folded Canyon Range thrust.

The knob immediately east of this point along the east-west ridge is made up of Proterozoic Pocatello Formation in the hanging wall of the Canyon Range thrust. The thrust dips to the east here, and hanging-wall rocks have been transported to the east. The eastward dips are seen in the west limb of the Canyon Range syncline which has folded the entire Canyon Range thrust sheet; Proterozoic Pocatello through Cambrian Tintic formations are exposed on the west limb. The far end of the east-west ridge is Fool

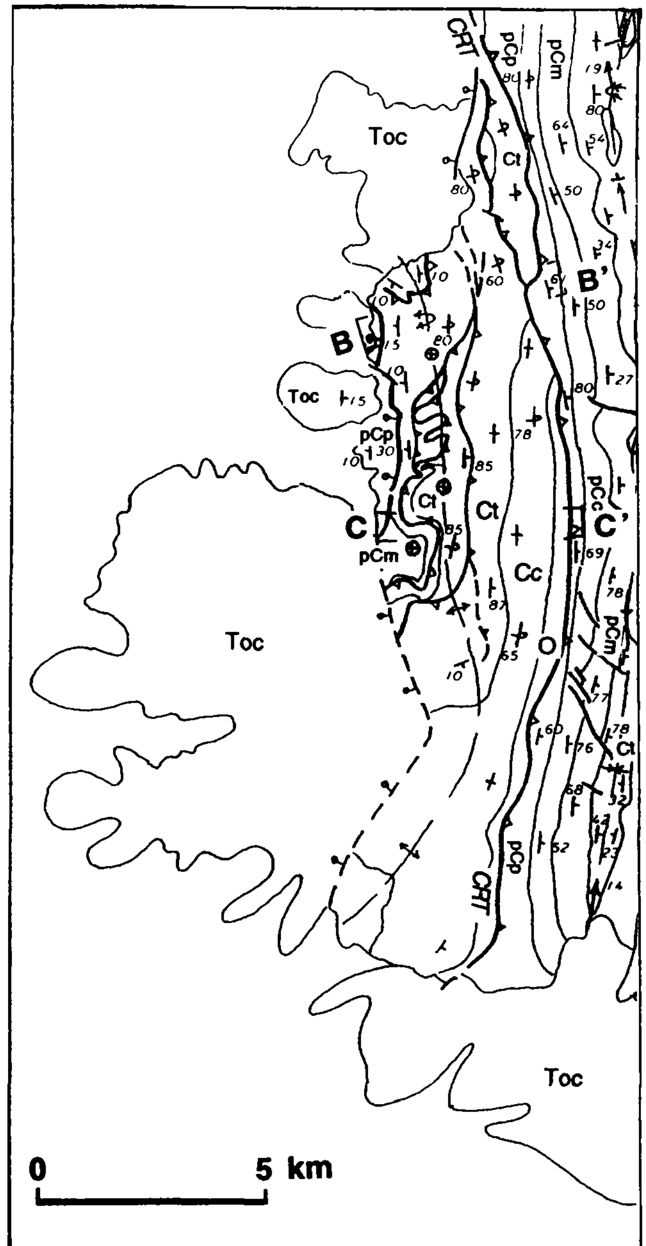


Figure 7. Map of part of west flank of Canyon Mountains, showing thrust slices that form the antiformal stack in the footwall of the Canyon Range thrust. Explanation: pCp, Pocatello Formation; pCm, Mutual Formation; Ct, Tintic Quartzite, Cc, Cambrian carbonate rocks, undifferentiated, O, Ordovician rocks, Toc, Oak City Formation. CRT, Canyon Range thrust.

Creek Peak whose west face is a dip slope composed of Canyon Range Conglomerate overlying Cambrian Tintic Formation in the east limb of the Canyon Range syncline.

Looking north, we see that the west limb of the syncline becomes progressively steeper and eventually overturned

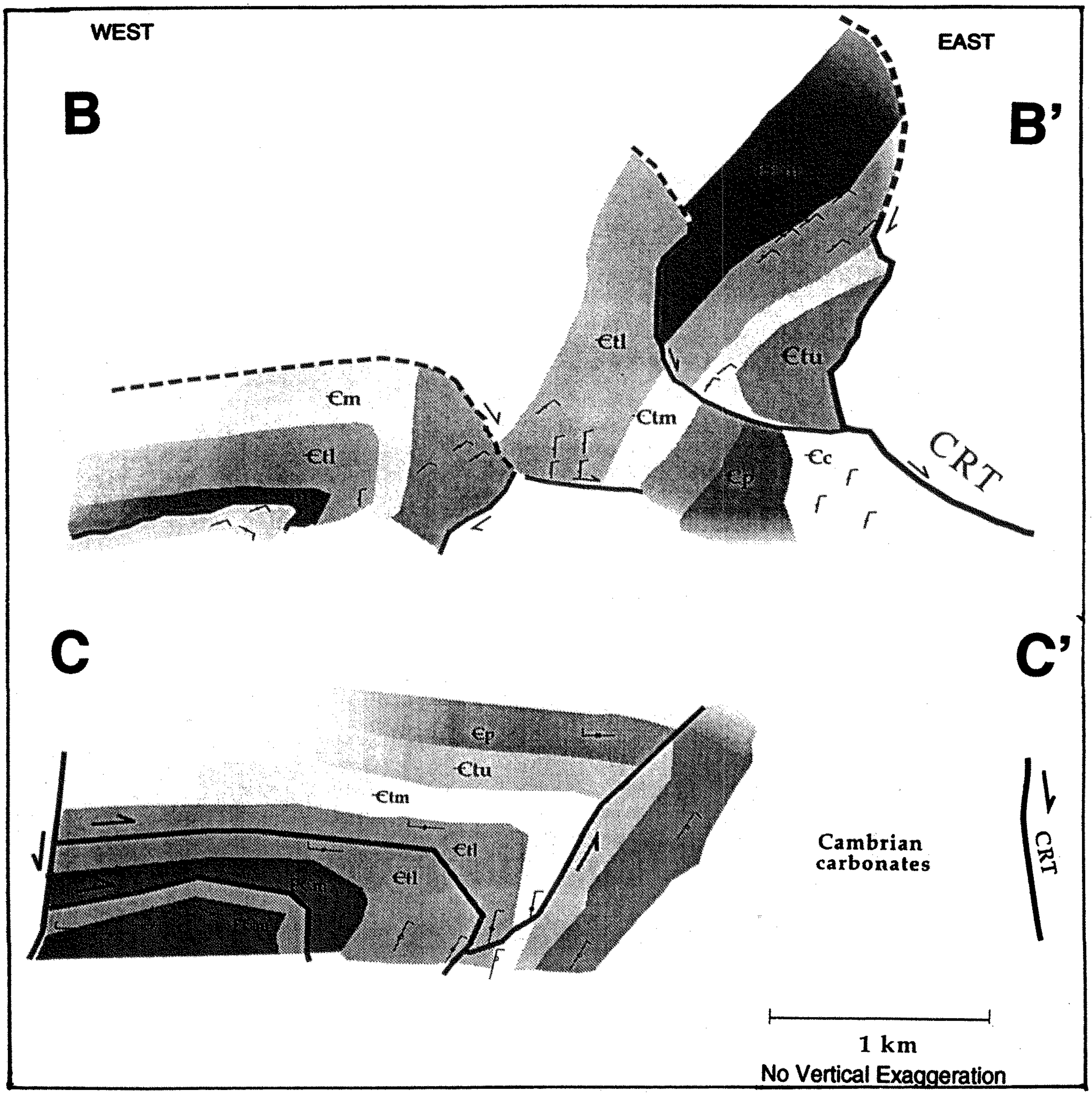


Figure 8. Down-plunge projections through the antiformal stack in the footwall of the Canyon Range thrust exposed on the west side of the Canyon Mountains. Explanation: PCm, Mutual Formation; Ct, Tintic Quartzite, divided into lower (Ctl), middle (Ctm), and upper (Ctu) members; Cp, Pioche Formation. CRT, Canyon Range thrust.

(fig. 9a). At the northern end of the range, bedding strike swings northeastward at Leamington Canyon, which separates the Canyon Mountains from the Gilson Mountains. The east limb of the syncline has uniform dips, shown by dip slopes of the Caddy Canyon, Mutual and Tintic quartzites. The core of the syncline exposes folded Canyon Range Conglomerate, which we will visit at Stop 4. The west limb of the syncline also exposes the east-dipping Canyon Range thrust and its footwall. The footwall exposes the core of the Canyon Range anticlinal culmination made up of an antiformal stack that repeats Proterozoic and Cambrian quartzites (fig. 7); one of the faults repeating the Cambrian Tintic

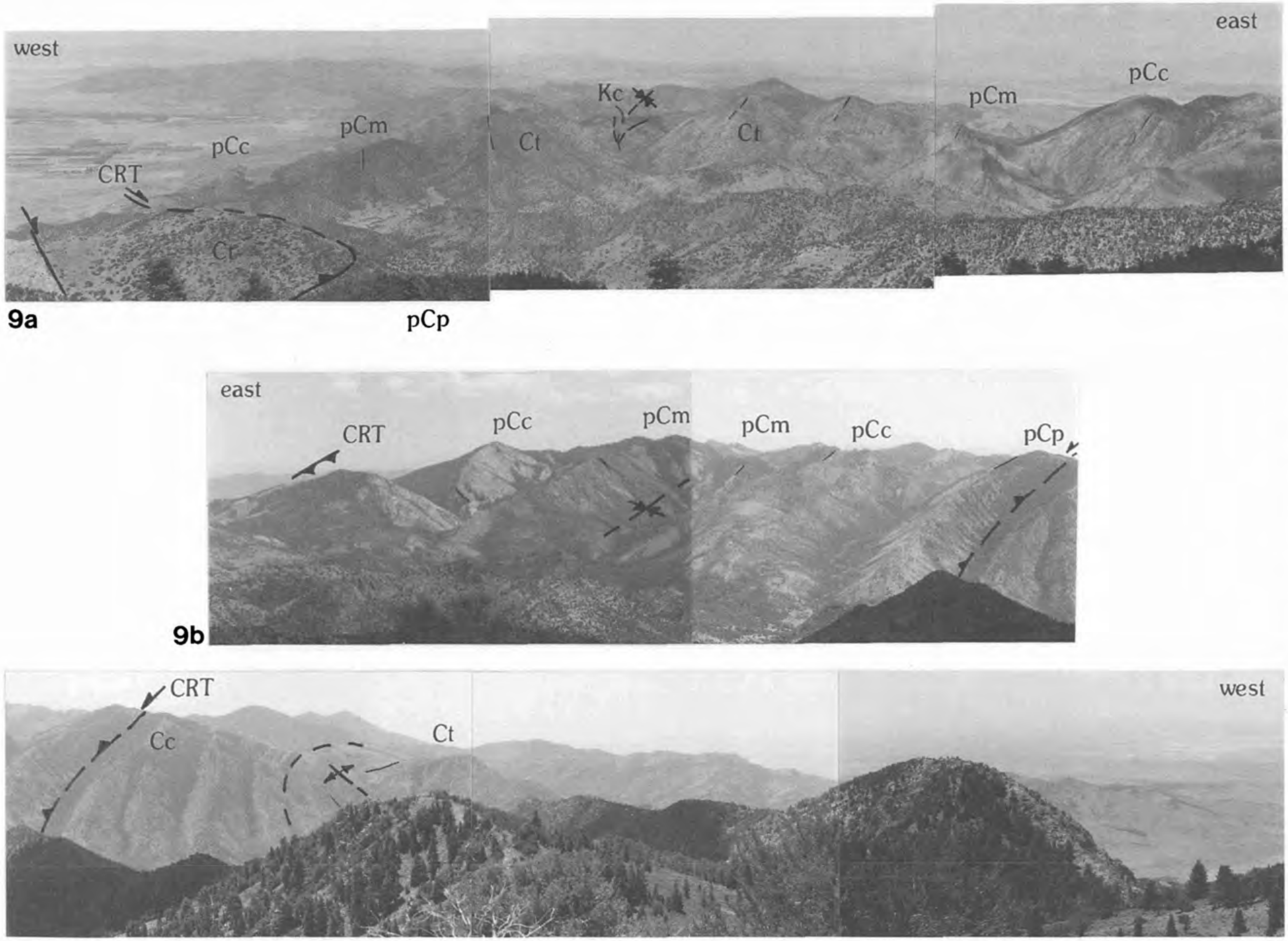


Figure 9. Panoramas from Paul's Meadow of Canyon Range thrust, Canyon Range culmination, and Canyon Range syncline. A. View north. B. View south. Symbols as in figure 7 with following additions: pCc, Caddy Canyon Quartzite; Kc, Canyon Range Conglomerate. Lower two panels overlap at Canyon Range thrust, which is duplicated on adjacent photos.

stratigraphy is clearly visible on the east-west ridge immediately north of here (fig. 9a).

Looking south (fig. 9b), we see the southward-plunging closure of the antiformal culmination defined by the Limekiln Canyon slice of the antiformal stack, on which we are standing. The underlying slices of the stack are all exposed west of the Tintic ridge to our right (west). East of the anticline is the Canyon Range syncline made up of hanging-wall rocks of the Canyon Range thrust. The west limb of the syncline exposes Proterozoic Pocatello through Mutual formations. The east limb of the syncline contains Proterozoic Blackrock Canyon through Mutual formations, with the Blackrock Canyon and Caddy Canyon formations emplaced above Devonian rocks and Cretaceous conglomerate along the Canyon Range thrust, which we will visit at Stop 3.

Return to road in Oak Creek Canyon.

(**21.4**, 2.0) Turn left (east).

(**22.8**, 1.4) South Walker Canyon on right. Cross western exposure of Canyon Range thrust, which emplaces Proterozoic Pocatello Formation of the hanging wall on Ordovician Pogonip Group of the footwall (fig. 10; Millard, 1983).

(**23.0**, 0.2) Contact of Proterozoic Caddy Canyon Quartzite and Proterozoic Blackrock Canyon Limestone exposed on north side of canyon.

(**23.3**, 0.3) Picnic area. Proterozoic Inkom Formation, a shale unit above the Caddy Canyon Quartzite, crosses the canyon here.

(**24.1**, 0.8) Dark red exposures are of Proterozoic Mutual Formation in core of syncline in hanging wall of Canyon Range thrust.

(**24.4**, 0.3) Inkom strike valley at Lyman Creek (south of road). *Canyon Range Conglomerate caps Fool Creek Peak to the north (9:00), where it overlies Cambrian Tintic Quartzite in the core of the syncline.*

(**24.6**, 0.2) End of road.

Stop 3. Canyon Range thrust and Canyon Range Conglomerate. Three mile walk (round trip). The first part is leisurely on good trails to Oak Creek summit where views are available; after that the walk is moderately strenuous south to a vantage point on a sloping meadow in the Blackrock Canyon Limestone, where views are extraordinary. Approximately 2.5 hours.

The view northward from the high meadow at stop 3 (fig. 11) encompasses the entire Canyon Range syncline, *the frontal trace of the Canyon Range thrust, and growth* structures in the Canyon Range Conglomerate. The summit of Fool Creek Peak is located near the axis of the syncline and is occupied by a quartzite-boulder conglomerate facies of the Canyon Range Conglomerate resting in angular unconformity upon gently west-dipping beds of the Lower Cambrian Tintic Quartzite. A minor out-of-the syncline thrust cuts the Tintic Quartzite and the conglomerate (fig. 10), but the conglomerate also overlaps the thrust. This thrust thus developed during deposition of the conglomerate. East of Fool Creek Peak, the 30° west-dipping eastern limb of the Canyon Range syncline comprises the Tintic, Mutual, Inkom and Caddy Canyon formations. The eastern limb of the folded Canyon Range thrust is visible in the foreground, where it places Caddy Cayon Quartzite on top of the Canyon Range Conglomerate. Beds in the lower part of the conglomerate are tightly folded beneath the thrust, but stratigraphically higher beds overlap the thrust. Several hundred meters of eastward displacement is visible along the thrust. A closer inspection of the conglomerate above the thrust tip reveals a prominent growth anticline in the east limb of which bedding dip decreases progressively upsection. This is an example of a "progressive syntectonic unconformity" (Riba, 1976). These relationships indicate *that the Canyon Range Conglomerate was deposited during* late-stage reactivation of the Canyon Range thrust; however, it is important to remember that the conglomerate in the footwall rests on Devonian strata. This means that the Canyon Range thrust must have had an earlier, major phase of displacement that juxtaposed Proterozoic strata with Paleozoic strata at this location. Subsequently, both the hanging wall and footwall must have been deeply eroded. The footwall alone must have been stripped of several kilometers of middle Paleozoic to Jurassic strata (Royse, 1993; DeCelles et al., 1995). The uplift needed to sustain this major erosional event probably took place during the emplacement of underlying thrust sheets such as the Pavant, Paxton, and Gunnison thrusts. Although we have no firm handle on when the Canyon Range thrust sheet was initially emplaced, regional provenance data from the Cedar Mountain Formation (figs. 4, 6) indicate that lower Paleozoic and upper Proterozoic rocks were exposed by Early Cretaceous time. J.K Linn (personal communication, 1996) recently reported an apatite fission-track age of 146 Ma from the Tintic Formation in the hanging wall of the Canyon Range thrust at the north end of the Canyon Mountains, near stop 6. Thus, the relationships in the Canyon Mountains in combination with regional stratigraphic data suggest that the Canyon Range thrust experienced its main phase of displacement during Early Cretaceous or latest Jurassic time and was subsequently folded and reactivated during emplacement of younger, underlying thrusts during Late Cretaceous-Paleocene time (fig. 4).

A west-trending oblique ramp in the Pavant thrust, termed here the Oak Creek ramp, crosses the range at this point. South of the ramp, Proterozoic rocks in the hanging wall structurally overlie Devonian dolostones of the footwall (Millard, 1983). Northward from the ramp, the Canyon Range Conglomerate is preserved beneath Proterozoic

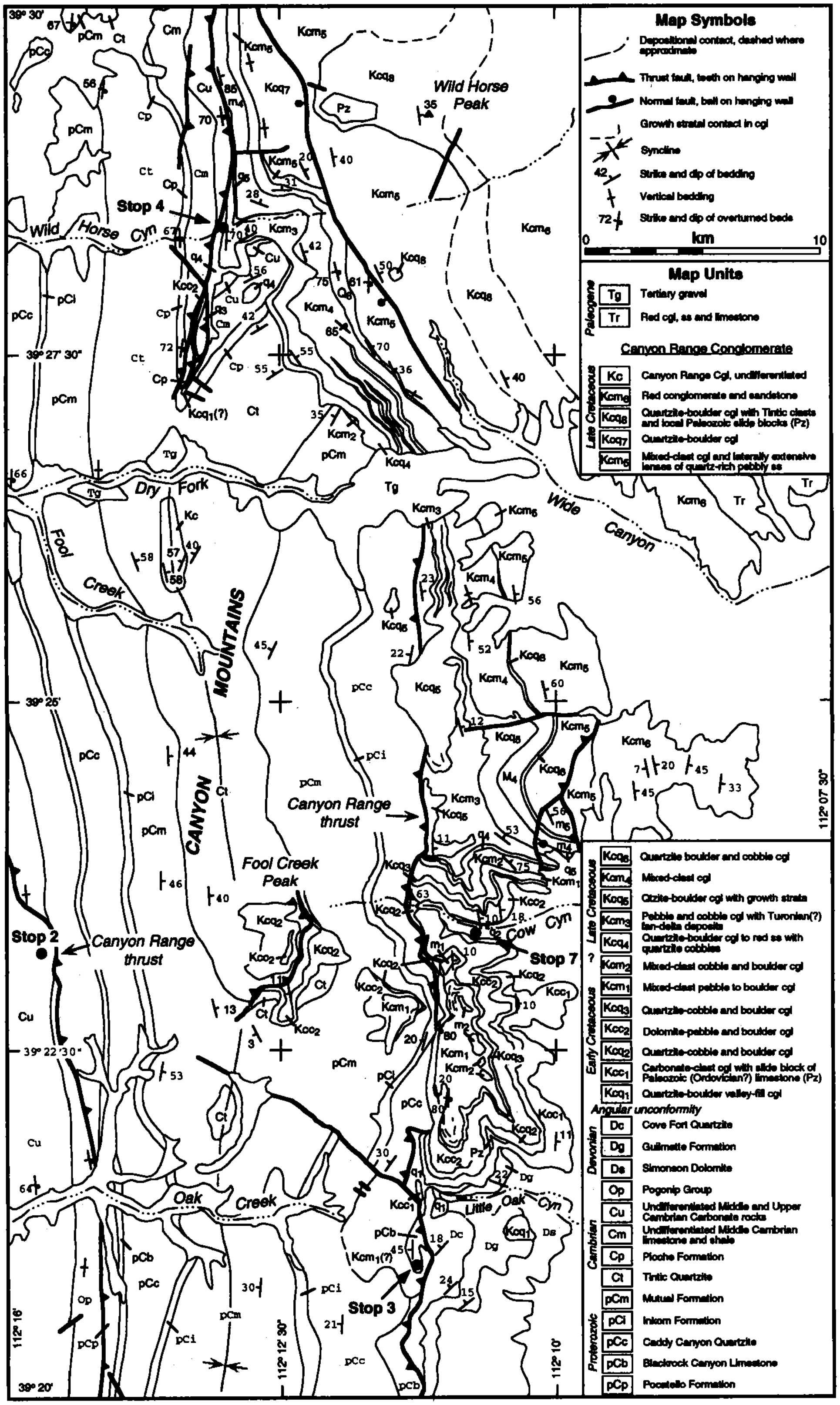


Figure 10. Geologic map of the northern part of the Canyon Mountains. Pre-Cretaceous geology modified from Millard (1983), Holladay (1984) and Hintze (1991 b, c).

hanging-wall rocks and unconformably overlies Devonian strata in the footwall (Millard, 1983). The leading edge of the Canyon Range thrust descends in elevation from south to north, but is less deformed than footwall rocks, which dip north as much as 60° at the ramp. Structural relationships thus indicate the ramp formed prior to late emplacement of the Canyon Range thrust over the conglomerate.

Retrace route to vehicle and return west down Oak Creek Canyon.

(**32.7**, 8.1) Center and Main (Utah Route 125) Streets, Oak City. Turn right (north) on Utah Route 125.

(**37.5**, 4.8) Intermountain Power Plant in the Sevier Desert at 9:00 (west). The flats in near distance are Pleistocene Lake Bonneville beds dotted with partially vegetated dunes.

(**39.6**, 2.1) Low hills at 3:00 (east) are underlain by Oak City Formation (Miocene).

(**40.3**, 0.7) Dirt road to Fool Creek Canyon on right.

(**42.1**, 1.8) Leamington Pass road (gravel). Turn right (east). Red strata of Mutual Formation form the base of the Canyon Mountains north of Pass Canyon.

(**43.3**, 1.2) Cattle guard at entrance to Fishlake National Forest (Forest Road 086). Strike ridge at 3:00 (south) is Proterozoic Caddy Canyon Quartzite. A gravel pit is present to the southwest in the alluvial fan at the mouth of Pass Canyon. All clasts in this fan are Precambrian and Paleozoic lithic types derived from the nearby Canyon Mountains, demonstrating that the Sevier River, which transports volcanic clasts, has never flowed through Leamington Pass.

(**43.6**, 0.3) Turn right on Forest Road 425 (dirt) and proceed south along the strike valley in Inkom Formation.

(**44.1**, 0.5) Bear left (south) at Y intersection formed by power line road.

Figure 11. Panorama of Canyon Range thrust (CRT) and progressive syntectonic unconformity in Canyon Range conglomerate (Kc) at stop 3, Little Oak Canyon. Thrust, carrying Caddy Canyon Quartzite (pCc) in its hanging wall, cuts lower part of conglomerate in center of photo, but younger part of conglomerate is folded to form a tip anticline over thrust (center skyline). Canyon Range conglomerate on Fool Creek Peak (upper left) unconformably overlies Tintic Quartzite (Ct) in core of Canyon Range syncline. Conglomerate on Fool Creek Peak is duplicated by a minor out-of-the-syncline thrust (fig. 10). Mutual Formation (pCm) is in east flank of Canyon Range syncline.

(**45.2**, 1.1) Bear right (south) at small side canyon. Passing outcrops of the Mutual Formation on the left (east).

(**45.7**, 0.5) Left at T intersection at mouth of Wild Horse Canyon. Proceed east.

(**46.4**, 0.7) Gate. Crossing contact between Proterozoic Mutual Formation and Cambrian Tintic Quartzite.

(**47.0**, 0.6) Contact of Tintic Quartzite and Lower Cambrian Pioche Formation is exposed in the saddle on the right. In the next 0.3 mile, ridges of Middle Cambrian limestone formations alternate with strike valleys composed of eroded, poorly exposed shale formations. Beds are vertical, with stratigraphic tops to the east. The succession above the Pioche Formation is Howell Limestone, Chisholm Formation, Dome Limestone, Whirlwind Formation, and Swasey Limestone (fig. 12). The Paleozoic section on the west limb of the Canyon Range syncline in the main drainage of Wild Horse Canyon is truncated above the Swasey Limestone where it is thrust over the Canyon Range Conglomerate (figs. 10, 12). North of the the main drainage, the Middle Cambrian Wheeler and Pierson Cove formations are present in the hanging wall of the thrust (fig. 12).

(**47.3**, 0.3) **Stop 4. Canyon Range syncline, Wild Horse Canyon.** Moderately strenuous one-half mile walk up ridge to south, approximately 1 hour.

Units of the Canyon Range Conglomerate at stop 4 are compositionally distinct with sharp contacts, making it possible to confidently differentiate units acording to their clast populations (fig. 12). Red-weathering, quartzite-cobble conglomerate (Kcq4) dominated by Tintic and Pioche clasts forms the basal conglomerate of the Canyon Range Conglomerate at the stop. Pioche clasts are purplish-red and contain muscovite and glauconite; Tintic clasts are tan and white. The overlying conglomerate (Kcm3) contains limestone and dolostone pebbles mostly from Devonian and Mississippian formations, but Cambrian units of mottled gray and tan limestone are present as well. This unit forms an upward-coarsening succession with wave ripples and hummocky cross stratification interpreted by DeCelles et al., (1995) as a fan-delta deposit. This unit is postulated to represent deposits of the Turonian sea-level high stand in the Western Interior, an interpretation supported by physical correlation with Cenomanian-Turonian strata present in the subsurface of the Valley Mountains and Pavant Range to the southeast of this locality (figs. 5, 6). Follow the carbonate

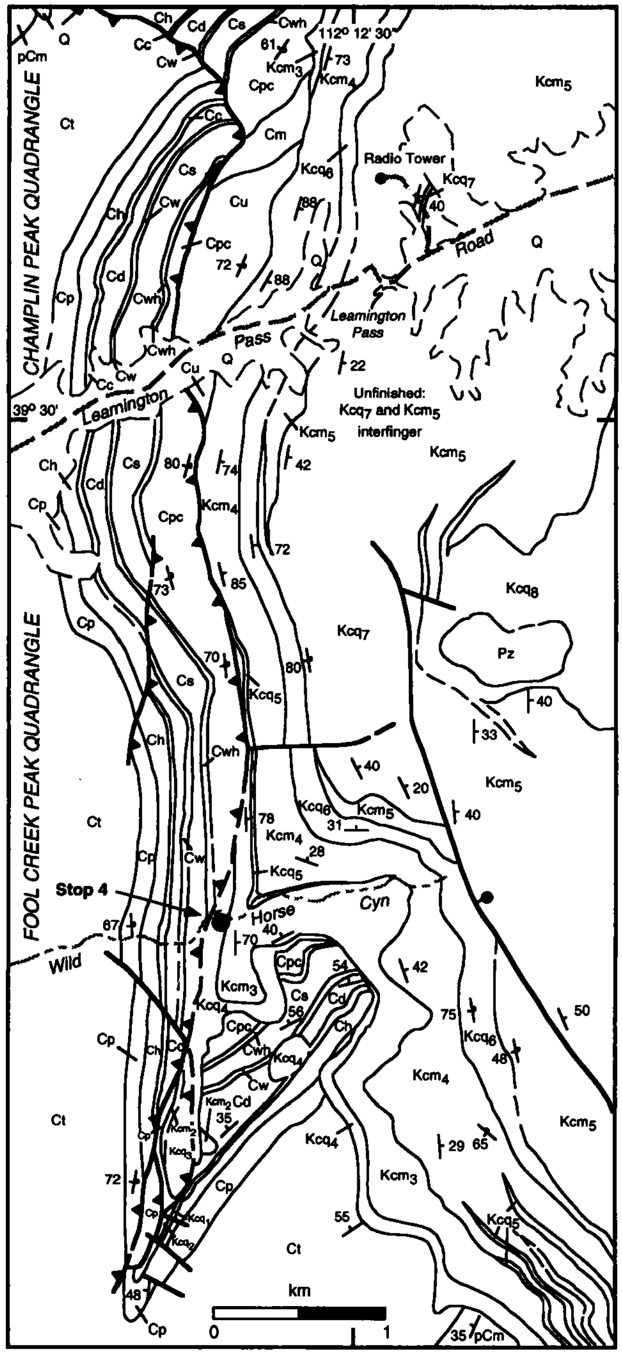


Figure 12. Geologic map of Canyon Mountains in vicinity of stop 4, Wild Horse Canyon to Pass Canyon. Explanation; pCm, Mutual Formation; Ct, Tintic Quartzite; Cp, Pioche Formation; Ch, Howell Limestone; Cc, Chisholm Formation; Cd, Dome Limestone; Cw, Whirlwind Formation; Cs, Swasey Limestone; Cwh, Wheeler Formation; Cpc, Pierson Cove Formation; Cm, undifferentiated Middle Cambrian rocks; Cu, undifferentiated Upper Cambrian rocks. Pz, undifferentiated rock-avalanche deposits composed of lower Paleozoic rocks; Q, undifferentiated surficial deposits. Units of Canyon Range Conglomerate are in figure 10 explanation. Geology of Paleozoic units modified from Holladay (1984) and Hintze (1991b).

conglomerate exposures upslope to a saddle for views of the Canyon Range syncline.

The syncline at this locality consists of a vertical to overturned west limb and a moderately dipping east limb. Older conglomerate beds are more deformed that younger beds; on the ridge north of Wild Horse Canyon, bedding dips decrease within a quartzite-boulder conglomerate (Kcq7) in the hinge of the syncline (fig. 12). These features indicate that conglomerate was deposited during tightening of the syncline. The fold in the Canyon Range Conglomerate plunges northward at Wild Horse Canyon, with plunges decreasing in progressively younger units (fig. 13). The plunge is inferred to result from an oblique ramp in the Canyon Range thrust (Pequera et al., 1994), termed the Wild Horse ramp. At this point, the Canyon Range and Pavant thrusts apparently dip northward, resulting in preservation of progressively younger strata northward in the hanging wall of the Canyon Range thrust. As a result of the northward dip of the thrusts, the region between here and Leamington Canyon to the north was the structurally lowest part of the thrust belt. Fluvial conglomerate was transported through this zone from the interior part of the thrust belt (Lawton et al., 1994; DeCelles et al., 1995). Imbrication in fluvial facies of the Canyon Range Conglomerate indicates southeast dispersal in this region (Lawton, unpublished data).

Retrace route to Utah Route 125.

(**52.4**, 5.1) Right (north) on Utah Route 125. For the next 1.2 miles, the road traverses Fool Creek Flats, a surface on Pleistocene Lake Bonneville beds.

(**53.6**, 1.2) Descending terrace into valley of Sevier River cut to post-Pleistocene level of Sevier Lake.

(**54.9**, 1.3) Turn right (west) on Utah Route 132, pass through downtown Leamington, and return to Delta via Lynndyl, approximately 21 miles. End of Day 1 road log.

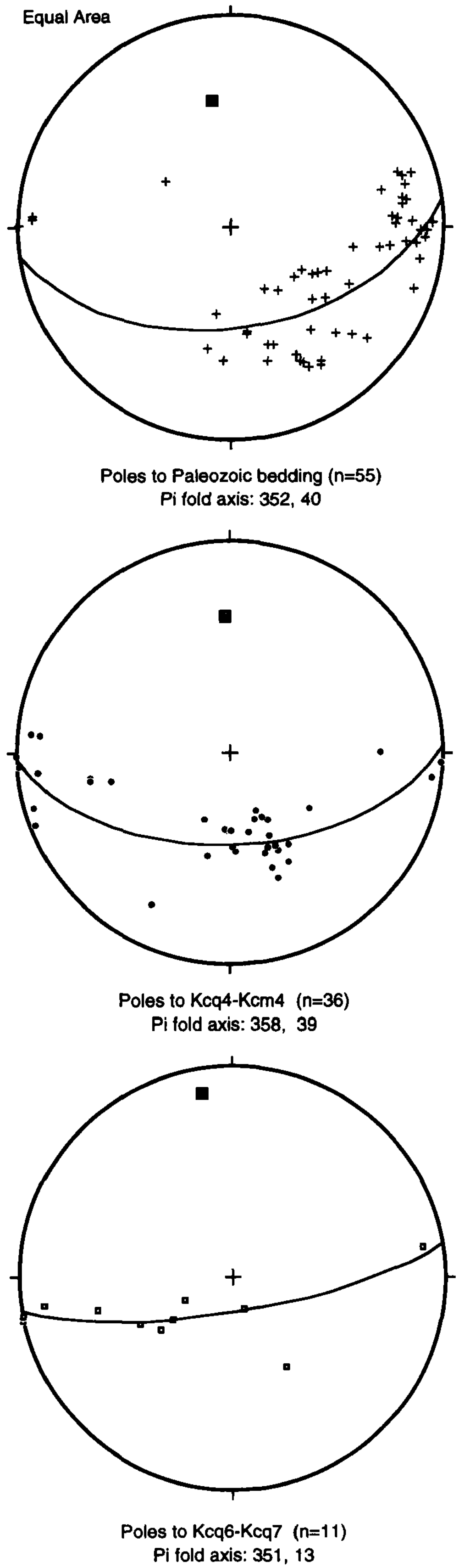


Figure 13. Equal area stereonet plots of bedding poles and pi axes of stratigraphic units in syncline at Wild Horse Canyon. Pi axes are coincident for upper two plots that summarize poles to bedding for Paleozoic strata and lower four conglomerate units exposed in Wildhorse Canyon. Pi axis for younger conglomerate beds (bottom plot) has approximately 20o shallower plunge, indicating that ramp affected Paleozoic strata and older conglomerate equally, whereas younger conglomerate was affected less, probably as a result of deposition during ramp formation.

Day 2. Leamington cross-strike discontinuity, Cow Canyon, Western San Pitch Mountains. Road log begins at junction of Utah Routes 132 and 125 immediately east of Leamington.

(0.0)	Depart junction with Utah Route 125, heading east on Utah Route 132.
(0.9, 0.9)	Steeply dipping Caddy Canyon Quartzite at 9:00 (north of Sevier River) is in hanging wall of the Canyon Range thrust.
(1.4, 0.5)	Charcoal-making ovens on left side of road.
(2.0, 0.6)	Saddle at 4:00 contains Inkom Formation; brown hill on left is Caddy Canyon Quartzite. Exposures of the Mutual Formation are on the left (red exposures).
(3.3, 1.3)	Millard County line. Lake Bonneville beds in roadcut on right. On right immediately ahead, bedding surfaces of vertical Tintic beds and Mutual-Tintic contact are exposed.
(4.5, 1.2)	Passing under cement conveyor. Ash Grove Cement Company quarries Swasey Limestone from vertical beds to the south.
(5.5, 1.0)	Pull over on right onto old highway right-of-way. Vertical beds of Tintic Quartzite face south.

Stop 5. Canyon Range Conglomerate at Leamington Canyon. Easy one-half mile climb up hillside. Approximately 1 hour.

Boulder conglomerate with abundant Caddy Canyon, Mutual, Tintic, and Pioche clasts overlies Tintic Quartzite at this locality (fig. 14). This clast assemblage is typical of conglomerate derived from the hanging wall of the Canyon Range thrust, which contains the only nearby exposures of Proterozoic strata. Angular unconformities within the conglomerate cause northward thinning here and nearer the cement plant, and suggest that these are growth strata. These quartzite-clast conglomerates rest on Paleozoic strata at this locality, but lateral equivalents of these units overlie mixed-clast conglomerate west of the cement plant (fig. 14), nearer the axis of the Canyon Range syncline. The boulder conglomerate represents alluvial-fan deposits locally sourced from rocks in the hanging wall of the Canyon Range thrust. The alluvial-fan deposits interfinger westward with imbricated pebble conglomerate composed of lower Paleozoic limestone and dolostone clasts derived from the strata now exposed in the House Range to the west (DeCelles et al., 1995). Large slide blocks and debris-avalanche deposits of Cambrian limestone are present in the zone of interfingering with the fluvial strata. We tentatively correlate one of these units (Kcq4; fig. 14) with the Dakota Sandstone of the Colorado Plateau (fig. 6). Angular unconformities between conglomerate beds, coarse grain size of the conglomerate facies, and slide blocks in conglomerate along strike indicate that the steep attitudes associated with the Leamington cross-strike discontinuity began to form early in the depositional history of the Canyon Range Conglomerate, perhaps at the beginning of the Late Cretaceous; therefore, this cross-strike discontinuity is not a late feature in the history of thrust kinematics in central Utah. We infer that folding associated with the formation of the Leamington cross-strike structural discontinuity took place during the deposition of the quartzite-clast conglomerate at Stop 5.

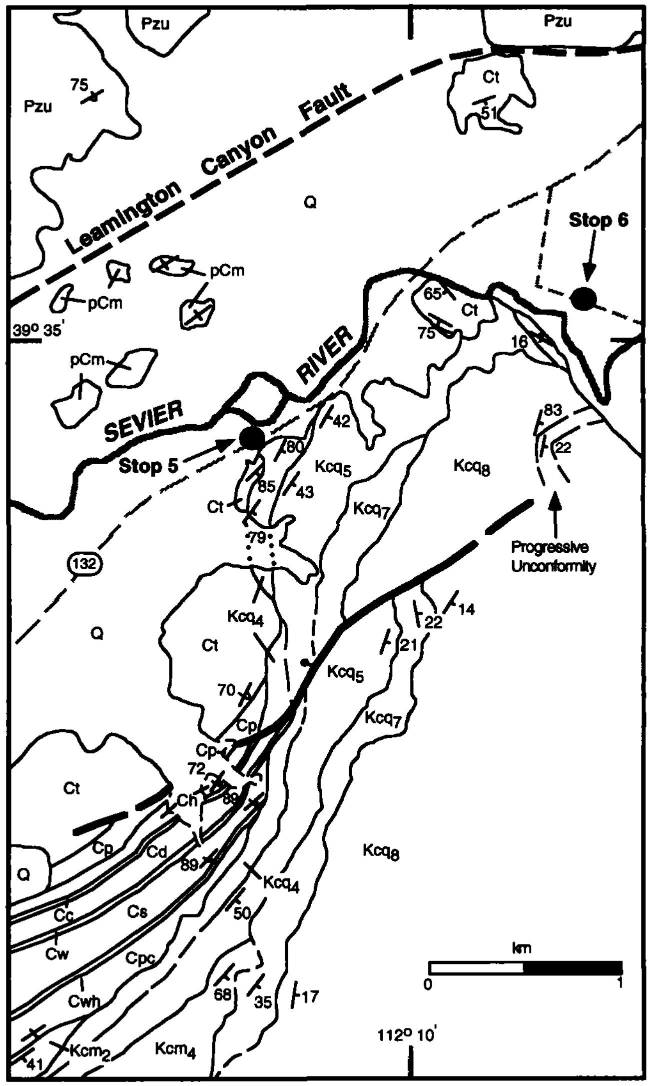


Figure 14. Geologic map of Leamington Canyon area, vicinity of stops 5 and 6. Pre-Cretaceous units and surficial deposits modified from Higgins (1982). See figure 12 for explanation of map units. Additional unit: Pzu, upper Paleozoic sedimentary rocks.

The Leamington cross-strike discontinuity is probably the Canyon Range thrust folded to a near-vertical attitude.

The structural discontinuity is expressed as a juxtaposition of northeast-striking Proterozoic and Cambrian strata with Upper Paleozoic strata of the Gilson Mountains (fig. 14). North of stop 5, across the Sevier River, vertical, south-facing beds of the Mutual Formation are in fault contact with Pennsylvanian Oquirrh Group strata (Higgins, 1982). The fault has a steep southward dip in Leamington Canyon (Higgins, 1982). This structure was interpreted as a transcurrent fault by Morris (1983); however, Precambrian, Cambrian, and Cretaceous strata south of the fault change strike to north-south near the western flank of the Canyon Mountains, and are continuous with strata in the hanging wall of the Canyon Range thrust throughout the Canyon Mountains, indicating the likelihood that this fault is contiguous with the Canyon Range thrust. If one accepts that the fault in Leamington Canyon is indeed the Canyon Range thrust, three conclusions may be drawn: 1) The Leamington cross-strike discontinuity is a folded hanging-wall ramp in the Canyon Range thrust that cuts upsection eastward from the Caddy Canyon Quartzite (west of figure 14) to the Tintic Quartzite (fig. 14); 2) there is a footwall ramp north of Wild Horse Canyon on which the Canyon Range thrust rises from Precambrian to Pennsylvanian strata; 3) the Canyon Range thrust was folded and uplifted by propagation of a deeper thrust during deposition of the alluvial-fan deposits at stop 5.

Continue east on Utah Route 132.

(**6.6**, 1.1) Bridge over Sevier River. Quarry on south bank in vertical beds of Tintic Quartzite, facing west. J.K. Linn (personal communication, 1996) reported an apatite fission-track age of 146 Ma from the quartzite at this locality.

(**6.9**, 0.3) Turn right (south) on dirt road. Bear left after 0.3 mile and proceed upstream for 0.2 mile.

Stop 6. Progressive unconformity at Sevier River.

Northeast-dipping and -thickening beds of conglomerate are present across the river at this point (fig. 15). Similar features consisting of wedge-shaped, unconformity-bounded bodies of conglomerate that thin onto the flanks of folds or basement uplifts in the Ebro basin of Spain were termed progressive syntectonic unconformities by Riba (1976) and interpreted by him to have formed as a result of deposition during on-going deformation and uplift. These conglomerate beds are part of the youngest coarse quartzite-clast conglomerate lithosome (Kcq8) in the the Canyon Mountains (fig. 14). At Leamington Pass to the south, near the axis of the Canyon Range syncline, Kcq8 overlies a very thick interval of mixed-clast conglomerate (Kcm5) of fluvial origin (figs. 10, 12, 14). The base of Kcq8 cuts down section to the northeast, causing this distinctive, orange-weathering, Tintic-clast conglomerate to rest on somewhat older conglomerate (Kcq7) at Leamington Canyon (fig. 14). The deformation that caused this angular discordance was likely displacement of the leading edge of the Canyon Range thrust or a related splay. North of the progressive unconformity, overturned mixed-clast conglomerate dips shallowly westward, and appears to be beneath Tintic Quartzite exposed northward along the river and at the quarry near the highway bridge (fig. 14). We interpret these exposures as Tintic thrust above overturned conglomerate and onlapped by younger conglomerate (Kcq5) derived from the hanging wall of the Canyon Range thrust. This may be the northernmost exposure of the leading edge of the Canyon Range thrust. Similar relationships are better exposed at the next stop.

Figure 15. Progressive unconformity in the Canyon Range Conglomerate along the Sevier River, north end of the Canyon Mountains at stop 6. Conglomerate beds on light-gray face in center of photo dip steeply toward viewer; beds on left thin onto older conglomerate and decrease in dip upsection.

Return to highway and retrace route westward to Utah Route 125 at Leamington.

(**13.8**, 6.9) Turn left (south) on State Route 125.

(**16.3**, 2.5) Turn left (east) at Leamington Pass road (gravel).

(**17.4**, 1.1) West-vergent, out-of-syncline reverse fault at 3:00 (south) emplaces Howell Limestone over Pioche Formation.

(**18.9**, 1.5) Leamington Pass. Leaving Fishlake National Forest. The road descends a valley north of Wild Horse Peak, which is underlain by Tintic-clast conglomerate (Kcq8) of Stop 6. Red conglomeratic beds on the east flank of Wild Horse Peak have been assigned to the upper member of the Canyon Range Formation (Holladay, 1984). The road winds through Flagstaff Limestone beveled by a pediment surface that was graded to the Sevier River when it flowed into Pleistocene Lake Bonneville.

(**26.2**, 7.3) Cuesta straight ahead to the northeast is underlain by North Horn Formation (red) and Flagstaff Limestone (white). Mt. Nebo, composed of Paleozoic strata, is slightly to the left and beyond the cuesta.

(**27.6**, 1.4) Intersection with road to Mills, Utah. Proceed straight (south).

(**28.4**, 0.8) Ascend grade through Sevier River delta of Lake Bonneville highstand. Top of grade at elevation 1520 m. Pebbles of this gravel accumulation include silicic welded tuffs, intermediate volcanic rocks, subordinate dark gray chert, sandstone, and oolitic chert. Provenance is Tertiary Marysvale volcanic field and Mesozoic and Tertiary strata exposed in the upper drainage basin of the Sevier River to the south.

(**29.1**, 0.7) Pass road to Wide Canyon on right (west). Continue straight.

(**33.1**, 4.0) Turn right (west) at fenceline.

(**33.6**, 0.5) Crossing from Lake Bonneville deposits to alluvial-fan deposits. The lake beds form bottomless dust or mud, depending upon time of year. Quaternary fans are graded to this level. In wet years in the spring, this grassland is a vast expanse of green. It is common to see Ferruginous Hawks and Long-Billed Curlews migrating through.

(**33.7**, 0.1) Bear left (west). Road to right goes to Wide Canyon, by way of a gate that is nearly impossible to close. A gate is also present on the field trip route in 0.1 mile. Be sure to leave gates as they are found, whether open or closed.

(**35.8**, 2.1) Gate at Fishlake National Forest Boundary. Folded Canyon Range Conglomerate on ridge to north. Road becomes increasingly steep as it climbs the proximal part of the Cow Canyon alluvial fan.

(**36.9**, 1.1) Turn right at 3-way intersection deep in Gambel Oak thicket.

(**37.2**, 0.3) Park at watering trough on left (south side of road).

Stop 7. Cow Canyon: Footwall Canyon Range Conglomerate, Canyon Range thrust. Walk uphill to the north, approximately 1 mile. 2 hours.

At Cow Canyon (fig. 10), quartzite-boulder conglomerate derived from the the Canyon Range sheet is interbedded with mixed-clast conglomerate of interior thrust belt provenance. Conglomerate lithosomes are easily differentiated by composition, and paleosols are developed on the tops of most lithosomes, particularly on the mixed-clast conglomerates at this locality. Alluvial-fan lithosomes, represented by the quartzite-boulder units, can be traced to paleovalleys eroded into the hanging wall. These paleovalleys were backfilled with conglomerate, and folded over the tip of the thrust during its late phases of displacement (fig. 10). The alluvial-fan lithosomes have along-strike dimensions of 5–10 km; their edges break up and interfinger to the north with the more distal, fluvial conglomerates. To the northwest, Caddy Canyon Quartzite of the hanging wall overrides the quartzite-clast lithosomes, and mixed-clast units thin toward the thrust (fig. 16). Each of three folded alluvial-fan deposits on the north side of Cow Canyon has a separate, distinct axial surface, indicating that fold growth was spatially discontinuous and may have involved both kink-band migration and progressive limb rotation.

From a vantage point on the ridge north of Cow Canyon, the conglomerate on the south side of the canyon can be seen to steepen from 10o east dips to form a fold that probably represents a tip anticline, possibly on a splay of the Canyon Range thrust. As discussed at stop 3, the impressive exposures here record only late and minor (several hundred meters) displacement on the Canyon Range thrust. Prior to deposition of the Canyon Range Conglomerate, Proterozoic rocks were emplaced on strata as young as Devonian, and both the hanging wall and the footwall of the Canyon Range thrust (the latter being also the hanging wall of the Pavant thrust) were deeply eroded. Conglomerate was then deposited on Devonian strata of the footwall. The conglomerate in the footwall is approximately 600 m thick on the ridge north of Cow Canyon. We tentatively correlate this conglomerate with middle to late Albian beds, also unconformable on Devonian strata of the hanging wall of the Pavant thrust, that were encountered in drill holes, including the Placid WXC USA 1-2 (fig. 1), on the west side of the Valley Mountains, visible to the southeast. The late Albian age of these subsurface beds is inferred from their stratigraphic position beneath strata that contain Cenomanian to Turonian palynomorphs (Pavant Sandstone of figure 6; G.L. Waanders, written communications, 1982, 1993). These stratigraphic relations indicate that much of the hanging wall of the Pavant thrust was buried by the end of the Albian and probably did not subsequently serve as an important source of first-cycle detritus.

Return to vehicles and proceed back down Cow Canyon road.

(**37.5**, 0.3) Turn right at 3-way intersection in oak thicket. High clearance required for the next mile.

(**38.8**, 1.3) Bear left at junction. Road to right ends in 0.9 mile at a flagstone quarry in a lacustrine fan-delta unit at the base of a carbonate-clast conglomerate (Kcc2 of figure 10). Footwall conglomerate, dipping homoclinally 11 degrees east, is exposed to the west along the front of Canyon Mountains. Flatirons on upper slopes

Figure 16. View of north wall of Cow Canyon, looking north. Homoclinal, east-dipping conglomerate is folded beneath Canyon Range thrust (arrow). Thrust emplaces Caddy Canyon Quartzite (pCc) over alluvial-fan lithosomes Kcq2 through Kcq5 of the Canyon Range Conglomerate (fig. 10).

are the same beds folded over the front of the Canyon Range thrust.

(**39.7**, 0.9) Gate at east boundary of Fishlake National Forest. The road descends the gentle slope of a sage brush-covered grassland, home of Lark and Vesper Sparrows, Horned Larks, Sage Thrashers and Western Meadowlarks.

(**43.8**, 4.1) Gate at frontage road, west side of I-15. Turn left (north) on frontage road. You should have passed four gates since leaving the National Forest. From here, there is a view westward of the Oak Canyon lateral ramp in the hanging wall of the Pavant thrust (fig. 10). On the south side of the ramp, the Canyon Range thrust emplaces Proterozoic over Devonian strata, which dip steeply northward at the ramp. The Canyon Range thrust descends from south to north as well, but not as steeply as footwall beds. North of the ramp, the Canyon Range thrust overrides footwall Canyon Range Conglomerate. Basal conglomerate (Kcq1) also dips steeply northward at the ramp to form discontinuous exposures on Devonian beds south of Little Oak Creek Canyon. These relationships show that late movement of the Canyon Range thrust largely postdates development of the ramp in the hanging wall of Pavant thrust.

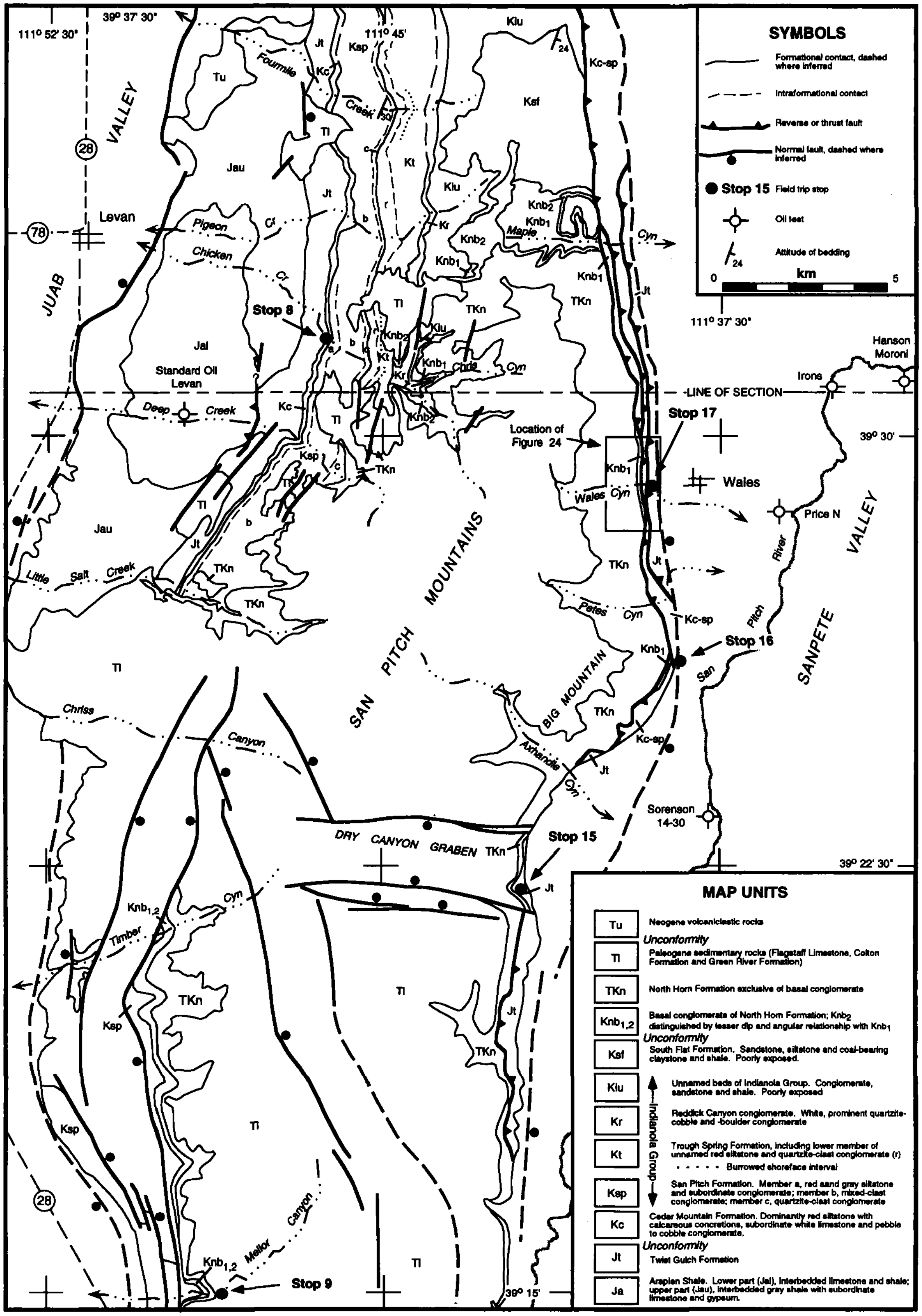
(**50.5**, 6,7) Cross overpass (Interchange 202, Yuba Lake) to east side of I-15 and enter interstate heading north. Views of Canyon Mountains to the west. Highest point is Fool Creek Peak, composed of Tintic Quartzite overlain by Canyon Range Conglomerate.

(**54.4**, 3.9) Exit I-15 at Interchange 207. Turn right (east) on Utah Route 78 toward Levan.

(**63.3**, 8.9) Junction Utah Routes 78 and 28. Turn right (south) on Utah Route 28.

(**63.5**, 0.2) Turn left (east) on First South Street in Levan. Directly ahead are outcrops of Jurassic Arapien Shale that forms the western foothills of the San Pitch Mountains. The Arapien is folded and faulted, and oil wells drilled in this belt to the south indicate that the Jurassic Navajo Sandstone beneath the Arapien is duplicated (figs. 17, 18; Ritzma, 1972). This belt of deformation has been interpreted as a duplex zone associated with a ramp in the Gunnison thrust (Standlee, 1982; Lawton, 1985) and as an antiformal stack or triangle zone above the tip of the Paxton thrust (Coogan et al., 1995).

Figure 17. Geologic map of the San Pitch Mountains. Geology modified from Mattox (1987), Witkind et al., (1987), Auby (1991), Witkind and Weiss (1991), Fong (1995), and Lawton and Weiss (in press).


SYMBOLS
Formational contact, dashed where inferred
Intraformational contact
Reverse or thrust fault
Normal fault, dashed where inferred
Stop 15 Field trip stop
Oil test
Attitude of bedding
0 km 5
MAP UNITS
Tu Neogene volcaniclastic rocks
Unconformity
Tl Paleogene sedimentary rocks (Flagstaff Limestone, Colton Formation and Green River Formation)
TKn North Horn Formation exclusive of basal conglomerate
Knb1,2 Basal conglomerate of North Horn Formation; Knb2 distinguished by lesser dip and angular relationship with Knb1
Unconformity
Ksf South Flat Formation. Sandstone, siltstone and coal-bearing claystone and shale. Poorly exposed.
Indianola Group
Klu Unnamed beds of Indianola Group. Conglomerate, sandstone and shale. Poorly exposed
Kr Reddick Canyon conglomerate. White, prominent quartzite-cobble and -boulder conglomerate
Kt Trough Spring Formation, including lower member of unnamed red siltstone and quartzite-clast conglomerate (r)
Burrowed shoreface interval
Ksp San Pitch Formation. Member a, red aand gray siltstone and subordinate conglomerate; member b, mixed-clast conglomerate; member c, quartzite-clast conglomerate
Kc Cedar Mountain Formation. Dominantly red siltstone with calcareous concretions, subordinate white limestone and pebble to cobble conglomerate.
Unconformity
Jt Twist Gulch Formation
Ja Arapien Shale. Lower part (Jal), interbedded limestone and shale; upper part (Jau), interbedded gray shale with subordinate limestone and gypsum.
39° 37' 30"
111° 52' 30"
111° 45'
111° 37' 30"
39° 30'
39° 22' 30"
39° 15'
Levan
Standard Oil Levan
Hanson Moroni
Irons
LINE OF SECTION
Stop 17
Location of Figure 24
Wales
Price N
Stop 8
Stop 16
Stop 15
Stop 9
Sorenson 14-30
JUAB VALLEY
SANPETE VALLEY
SAN PITCH MOUNTAINS
BIG MOUNTAIN
DRY CANYON GRABEN
Fourmile Creek
Pigeon Cr
Chicken Cr
Maple Cyn
Chris Cyn
Deep Creek
Wales Cyn
Little Salt Creek
Petes Cyn
San Pitch River
Chriss Canyon
Axhandle Cyn
Timber Cyn
Mellor Canyon

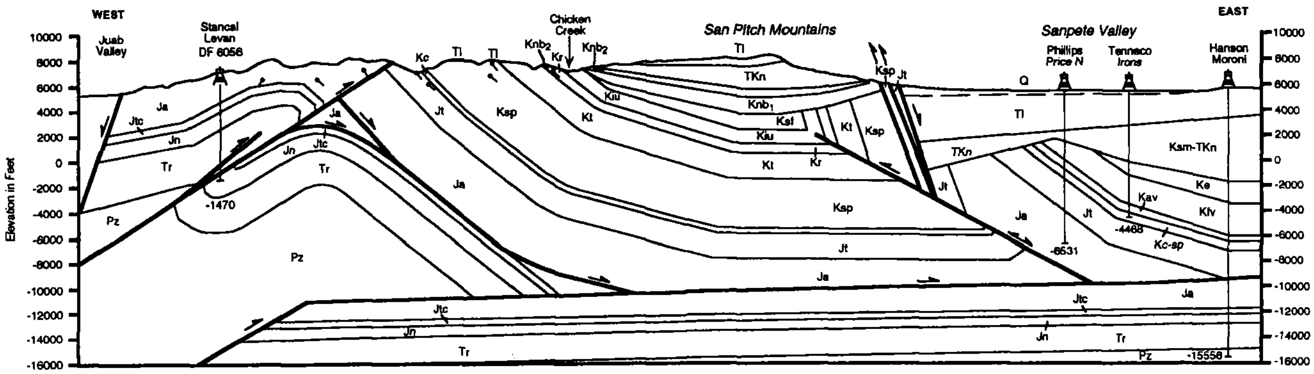


Figure 18. Geologic cross section of San Pitch Mountains. Unit symbols are the same as in figure 17 with the following additions and modifications: Pz, Paleozoic rocks; Tr, Triassic rocks; Jn, Navajo Sandstone; Jtc, Twin Creek Likestone; Ja, Arapien Shale. Campanian and Maastrichtian strata of Knb1, Knb2 and TKn represent fill of wedge-top, or piggyback, basin (Lawton and Trexler, 1991; Lawton et al., 1993). Location of cross section is shown in figure 17.

(**64.9**, 1.4) Right (south) at T intersection, Chicken Creek Road (gravel).

(**65.5**, 0.6) Quarry operation in gypsum on right (south).

(**66.9**, 1.4) Folded limestone beds in lower part(?) of Arapien Shale.

(**67.8**, 0.9) Cattle guard at entrance to Uinta National Forest. Gray and pink weathering shales of upper part of Arapien Shale on both sides of road.

(**68.4**, 0.6) Contact of Arapien Shale with overlying, red-weathering Upper Jurassic Twist Gulch Formation. This part of the road is dirt and can be impassable after a significant rain.

(**69.1**, 0.7) Chicken Creek Campground on right (south). Contact of Jurassic Twist Gulch Formation with Lower Cretaceous strata of San Pitch Formation.

Stop 8. Early Cretaceous foredeep depozone, Chicken Creek. Approximately 2 hours. We will stop at several points along the Chicken Creek Road to study Cretaceous conglomerate of the Indianola Group (fig. 17).

Cretaceous beds along the western flank of the San Pitch Mountains dip homoclinally eastward. This is the limb of a fault-bend fold above the Gunnison thrust (fig. 18). Lower Cretaceous strata here comprise nearly one-half of the synorogenic section of the foreland basin. Considered undifferentiated Indianola Group by Spieker (1949), these strata were assigned to the Pigeon Creek Formation, and removed from the Indianola Group, by Schwans (1988). Because of their genetic relationship to the Indianola Group that overlies them, we will refer to the Lower Cretaceous conglomerate in Chicken Creek Canyon, and elsewhere on the field trip, as San Pitch Formation, a term recommended by Sprinkel et al., (in review). Lower Cretaceous strata of the Cedar Mountain and San Pitch Formation are 1140 m thick here and range in age from Neocomian(?)-late Albian. This represents the maximum thickness of Lower Cretaceous strata in the region and marks the foredeep depozone of the foreland-basin system at that time. Beds low in the San Pitch Formation within 50 m of the Cedar Mountain Formation are middle Albian (G.L. Waanders, written communication, 1992). Clasts of Paleozoic limestone and dolostone and Mesozoic sandstone were derived primarily from the hanging wall of the Pavant thrust, whose tip lay only a few km to the west; subordinate quartzite clasts were derived from the hanging wall of the Canyon Range thrust.

(**69.7**, 0.6) Beds of cobble conglomerate of the San Pitch Formation alternate with red sandy siltstone beds as much as several tens of meters thick. Furrows on the bases of beds indicate northeast or southwest sediment dispersal, parallel to the foredeep. Although the thick parts of foreland basins are commonly referred to as foredeeps (e.g., DeCelles and Giles, 1995), this stratigraphic section, composed entirely of fluvial deposits, illustrates that foredeeps need not be bathymetrically deep.

(**70.6**, 0.9) Higher in the section, shallow-marine deposits of probable Turonian age are exposed along the road. These deposits represent the maximum transgression into the region of the San Pitch Mountains and probably correlate with the fan-delta deposits in the Canyon Range syncline at Stop 4.

(**71.0**, 0.4) Massive boulder conglomerate of the Reddick Canyon Conglomerate (Santonian?) at Reddick Canyon represents the initial incursion of alluvial-fan deposits into this part of the basin. Although the conglomerate is primarily clast supported, abundant boulder clusters adjacent to boulder-filled channels are interpreted as debris-flow levees. Sediment dispersal was eastward, indicated by measured orientations of channels filled with sandy siltstone and furrows on bases of conglomerate beds. The Reddick Canyon Conglomerate pinches out gradually to the north. There is no apparent angularity at the basal contact; in fact, the unit appears to coarsen upward from wave-rippled conglomerate and sandstone, and may have begun as a fan delta. This unit also has been interpreted as an incised valley-fill succession (Schwans, 1995). We regard it instead as a major alluvial-fan lithosome.

(**71.3**, 0.3) At Chris Canyon, quartzite-boulder conglomerate overlies a series of paleosols and shows a progressive decrease in dip upsection. Massive conglomerate contains fluid-escape and slump structures. The angular discordance at this point in the section causes removal of Campanian and Santonian beds from north to south along the range (fig. 17). Schwans (1995) has termed this unit the Chris Canyon Conglomerate. We consider it equivalent to beds recently assigned to the basal North Horn on the east side of the range (fig. 17; Lawton et al., 1993). The changing dip upsection and slump features indicate that this interval is a progressive unconformity formed by deposition concomitant deposition with growth of the fault-bend fold in the western San Pitch Mountains. Progressive unconformities are also present on the east side of the range in the basal North Horn Formation (Lawton and Trexler, 1991; Lawton et al., 1993), associated with west-vergent thrusting above the decollement of the Gunnison thrust. These features record the initiation of the Axhandle basin, a wedge-top basin filled with fluvial and lacustrine deposits above the Gunnison thrust in middle to late Campanian time (Lawton et al., 1993). The Axhandle basin occupies most of the San Pitch Mountains, and is flanked by an antiformal duplex or fault-bend fold on the west side of the range and a west-vergent fault-propagation fold on the east side.

Retrace route to Levan.

(**79.1**, 7.8) Turn left, (south) on Utah Route 28.

(**80.1**, 1.0) Utah Route 28 runs along the east side of Juab Valley, paralleling the Levan segment of the Wasatch fault system.

(**80.8**, 0.7) Fanhead fault scarp (just below Juniper trees) in small alluvial fan on left (east). Scarps are also exposed on the heads of alluvial fans for the next few miles. Tan-weathering beds of the Eocene Green River Formation are exposed low along the flank of the range

(**82.0**, 1.2) Deep Creek Canyon on left (east). The Standard Oil of California Levan well was drilled in this canyon in 1959. It spudded in the Jurassic Arapien Shale, penetrated an upright section of the Jurassic Navajo Sandstone and Triassic redbeds, and bottomed in the Navajo Sandstone (fig. 18; Ritzma, 1972).

(**88.6**, 6.6) Skinner Peaks at 10:00 (southeast). Caprock dipping WSW is Green River Formation. Arapien Shale underlies the Green River Formation and forms the lower slopes. This is probably a diapiric piercement structure, circular in plan view, but the Green River Formation is depositional on the Arapien Shale. Red, white, and orange beds in the vicinity are volcaniclastic Goldens Ranch Formation (Oligocene)

(**91.9**, 3.3) Golden's Ranch Formation (Oligocene volcaniclastics) form the hills to west of highway. These strata are in the hanging wall of the Wasatch normal fault system

(**92.9**, 1.0) Sanpete County Line; begin descent into Sevier Valley.

(**96.6**, 3.7) Crags at 9:00 (east) are San Pitch Formation of the Indianola Group, dipping west, in vicinity of Hells Kitchen Canyon (fig. 17). The north-trending Chriss-Mellor graben system of Mattox (1987) separates the west-dipping strata from east-dipping strata on the east side of graben. The graben system marks the crest of a fault-bend fold in the hanging wall of the Gunnison thrust system. Exposures of the San Pitch Formation continue for 3.5 mi along range front. West of the conglomerate exposures, the Fayette segment of Wasatch fault zone is expressed as scarps in dissected alluvium.

(**102.5**, 5.9) Mellor Canyon road. Turn left (east) at gate.

(**103.0**, 0.5. Cross Fayette fault. First exposures along mountain front are west-dipping panels of Flagstaff Limestone (Paleocene-Eocene).

(**103.5**, 0.5) Entering Chriss-Mellor graben system. Conglomerate of the Indianola Group is exposed on both sides of road.

(**104.2**, 0.7) White-weathering exposures of Mellor Canyon Conglomerate on left (north).

Stop 9. Progressive unconformity in Mellor Canyon Conglomerate. One-half mile walk up hillside to the north. Approximately one hour.

The Mellor Canyon Conglomerate, dominated by Tintic clasts, is exposed in Mellor Canyon east of the Chriss-Mellor graben system (fig. 17). The conglomerate contains dewatering and slump structures related to deformation coeval with deposition (Balcer, 1992). Concurrence of sedimentation and folding here is also indicated by progressive decrease in bed dip upsection through the unit; bed dips continue to shallow upsection through the red-weathering North Horn Formation and Flagstaff Limestone. The Mellor Canyon Conglomerate rests unconformably on conglomeratic strata equivalent to the San Pitch Formation (fig. 17). The subjacent conglomerate contains a population of mixed carbonate and quartzite clasts. The San Pitch Formation was lithified prior to deposition of the Mellor Canyon, indicated by fissures extending downward from the contact and steep-walled segments of the unconformity. The Mellor Canyon Conglomerate is equivalent to the conglomerates at Stop 8 in Chris Canyon. The soft-sediment deformation here signifies development of the fault-bend fold on the west side of the San Pitch Mountains as the Gunnison thrust propagated beneath this locality in the Campanian, the same event recorded by soft-sediment deformation at Chris Canyon.

Flat-bedded sandstone at the top of the main conglomerate unit bevels and fills in topography developed on the underlying conglomerate by slumping. Pebbly sandstone above the main part of the formation is capped by a major rootlet horizon formed during uplift. The Mellor Canyon Conglomerate thins westward and pinches out adjacent to the crest of the fault-bend fold. This relationship is consistent for 13 km northward to Timber Canyon, where the formation is covered by Tertiary strata (fig. 17). Paleocurrents are generally southeastward, down structural dip.

Retrace route to Utah Route 28.

(**105.9**, 1.7) Turn left (south) at Utah Route 28.

(**112.4**, 6.5) Intersection of Utah Route 28 and U.S. Highway 89. Entering Gunnison. Continue straight (south) on U.S. Highway 89.

(**113.9**, 1.5) Entering Centerfield. Valley Mountains are to the west, with the Pavant Range forming the southwestern skyline behind them. Sevier Plateau looms over the southeast flank of Sevier Valley. Tushar Mountains (fig. 5) of the Tertiary Marysvale volcanic field are to the far south.

(**120.0**, 6.1) Steeply dipping hogbacks at 10:00–11:00 composed of Eocene Green River Formation, depositional on Eocene Colton Formation, or locally, Arapien Shale in core of anticline.

(**121.3**, 1.3) Sevier County line.

(**123.2**, 1.9) Redmond Hills are composed of Quaternary sediment on the Arapien Shale, with salt mines locally, at 3:00 (west). Hills of the Arapien Shale to the south are capped by dark gray Oligocene volcanic rocks.

(**126.4**, 3.2) Entering Salina. End day 2 road log.

Day 3. Salina Canyon and Sanpete Valley: Structure and sedimentation associated with Sevier-Sanpete Valley antiform. Road log begins at Mom's Cafe, at Center and Main Streets in downtown Salina.

(**0.0**) Proceed east on Main Street.

(**0.2**, 0.2) Turn right on 300 East. Proceed south.

(**0.7**, 0.5) Hills of member E of Arapien Shale of Hardy (1952) on both sides of road.

(**2.6**, 1.9) Member D of Arapien Shale overlain by volcaniclastics of formation of Black Cap Mountain (late Oligocene) and Osiris Tuff (early Miocene) at 9:00 (north) (Willis, 1986).

(**3.0**, 0.4) Pavement becomes intermittent, continue straight on gravel road.

(**3.4**, 0.4) Arapien Shale on left (north) overlain by Green River Formation dipping west on flank of Wasatch monocline.

(**3.7**, 0.3) Steep beds of Twist Gulch Formation on the left are overlain by gently west-dipping redbeds of the Eocene Flagstaff and Colton formations (Willis, 1986).

(**3.8**, 0.1) Bear left onto spur road just west of underpass beneath I-70.

(**4.0**, 0.2) Pass gate and take first right at fork of dirt road. Angular unconformity above vertical beds of the Twist Gulch Formation is exposed to north.

(**4.2**, 0.2) Park at base of slope where tan sandstone is exposed in a steep road cut up the slope. This sandstone is in the Twist Gulch Formation and is equivalent to the base of the Jurassic Curtis Formation of the Colorado Plateau (Willis, 1986; Lawton and Willis, 1987).

Stop 10. Salina Canyon. Early foreland basin stratigraphy at tip of thrust belt. Two mile round-trip walk, east along base of hillslope. Approximately 1.5 hour. This traverse is described in detail by Lawton and Willis (1987).

Jurassic and Cretaceous strata beneath the unconformity with Tertiary strata in Salina Canyon are the most accessible and most eastern exposures of late Mesozoic strata in the thrust belt. This locality is an important link between thrust belt and Colorado Plateau stratigraphy (fig. 6). Steep dips here represent the east flank of the Sevier-Sanpete Valley antiform, a fold in the hanging wall of the Gunnison thrust formed above a decollement in shale and salt of the Arapien Shale (Standlee, 1982; Lawton, 1985).

Beds of the Twist Gulch Formation to the north are recognizable as the upper part of the San Rafael Group, including the Entrada Sandstone, Curtis Formation and

Summerville Formation (Imlay, 1980; Lawton and Willis, 1987). The Summerville Formation is overlain by gray mudstone from which Doug Sprinkel has recently recovered Late Jurassic pollen. Above the mudstone is a chert-pebble conglomerate that contains poorly rounded clasts of silicified wood. Above the conglomerate are white sandstone with crossbeds and gray mudstone beneath drab smectitic mudstone of the Cedar Mountain Formation. The nonmarine section between the Twist Gulch Formation and overlying Lower Cretaceous strata is on the order of 15 m thick and may be the Morrison Formation. Overlying strata are correlative with the Cedar Mountain Formation, indicated by Albian to Cenomanian zircon and apatite fission-track ages (ranging from 85 ± 5 to 105 ± 10 Ma; Willis, 1986; Willis and Kowallis, 1988). The steeply dipping beds crop out as ribs of conglomeratic sandstone and pink and gray siltstone with micrite nodules. The Cedar Mountain Formation is 188 m thick and is overlain by 84 m of conglomeratic strata of the San Pitch Formation, earlier assigned to the upper member of the Pigeon Creek Formation by Schwans (1988). A prominent chert-pebble conglomerate forms the base of the San Pitch Formation (fig. 20). Palynomorphs collected from the top of the San Pitch Formation at this locality include *Tigrisporites scurrandus*, with a middle to late Albian range (G.L. Waanders, written communication, 1992).

The base of the Upper Cretaceous section is a prominent, white-weathering quartzite-clast conglomerate about 10 m thick (fig. 20). It is exposed on both the north and south sides of Salina Canyon. The clast assemblage consists of Tintic Quartzite (70%), very fine grained white quartzite that may be Proterozoic Caddy Canyon Quartzite (25%), red pebbly quartzite of the Mutual Formation (5%), and a trace of pale green quartz arenite with glauconite (Pioche Formation). This conglomerate locally forms the base of the Sanpete Formation, which is equivalent to the Dakota Formation of the Colorado Plateau (Lawton and Willis, 1987; Schwans, 1995). A retrogradational succession overlies a flooding surface on top of the conglomerate. A fine-grained, mottled white sandstone with vertical and horizontal burrows above the conglomerate is overlain by very fine grained tan sandstone with ripples and in turn by brown mudstone. The succeeding three sandstone bodies are 2–3 m thick, with cross beds and burrowed tops, and may be estuarine deposits. The overlying part of the Sanpete Formation consists of tan-weathering sandstone beds with pebble lags that include quartzite, carbonate and chert clasts. Interbedded siltsone is poorly exposed. The uppermost part of the Sanpete Formation consists of an assemblage of burrowed, upward-coarsening shoreface deposits, channelform sandstone beds, and oyster-bearing sandstone. The Sanpete Formation is 380 m thick in Salina Canyon. Overlying the Sanpete is the Allen Valley Shale, composed of gray shale and siltstone beds that contain the middle Turonian ammonite, *Collignoniceras woollgari* (Lawton, 1982). The Sanpete Formation and Allen Valley Shale correlate with the Dakota Formation and Tununk Member of the Mancos Shale, respectively, on the east side of the Wasatch Plateau (fig. 6). The lower member of the Funk Valley Formation, equivalent to the Ferron Sandstone to the east (fig. 6), crops out beneath Tertiary strata south of Interstate 70.

These Lower to Upper Cretaceous strata constitute the relatively distal equivalents of the coarse conglomerates exposed in the Canyon Mountains and San Pitch Mountains. Unlike their western, more proximal counterparts, these distal facies lack any evidence of syndepositional, progressive deformation. This absence of progressive deformation distinguishes these rocks as foredeep deposits, in contrast to the wedge-top deposits visited during Days 1 and 2.

Retrace route to vehicles. If you choose to walk along the interstate, be careful of coal trucks descending the grade. Retrace route to downtown Salina.

(8.4, 4.2)	Corner of Main and Center Streets, Salina. Turn right (north) onto U.S. Highway 89.
(22.4, 14.0)	Turn right (east) on U.S. Highway 89 just north of Gunnison. Colored beds to the right are the upper Eocene Crazy Hollow Formation resting on the Green River Formation.
(23.3, 0.9)	Light gray exposures at 2:00–3:00 are outcrops of Arapien Shale in core of Sevier-Sanpete antiform.
(25.1, 1.8)	Pass cuesta of upper Green River Formation on left (north). The strike valley to the northeast is underlain by Colton Formation (Eocene), which is statigraphically beneath the Green River.
(26.1, 1.0)	Pickup truck on light gray cuesta of Flagstaff Limestone on left.
(26.9, 0.8)	Stop at milepost 213, U.S. Highway 89.

Stop 11. Christianburg. Lower Cretaceous foredeep stratigraphy.

This locality is on the west flank of a large boxlike anticline with faulted flanks and core that underlies Sanpete Valley. Although the base of the Cretaceous section is faulted (figs. 21, 22), this is one of the most complete exposures of the Cedar Mountain and San Pitch formations in the southern part of the San Pitch Mountains (fig. 5). A west-vergent syncline in Cretaceous units is onlapped from the west by Tertiary beds of the North Horn Formation, which forms a progressive unconformity on the flank of the anticline in Sanpete Valley.

Here, beds assigned to the Cedar Mountain (Witkind et al., 1986) or lower member of the Pigeon Creek Formation (Schwans, 1988) consist dominantly of mudstone with abundant calcareous nodules and subordinate sandstone and light gray limestone. The mudstone represents floodplain deposits, the calcareous nodules represent paleosol carbonate, and the limestones with oncolites were deposited in freshwater ponds (Schwans, 1988). Soil horizons within the section appear to be composite or stacked, and thus suggest slow deposition punctuated by unconformities.

The base of the upper member of the Pigeon Creek Formation (Schwans, 1988) is at the lowermost conglomerate in the section. Sprinkel and coworkers (in review) suggest the term San Pitch Formation for this section of Lower Cretaceous conglomerate (fig. 22). Conglomerate beds are on the order of 10 m thick and broadly lenticular. They are interbedded with red siltstone and mudstone. Clasts within the lower 57 m include green quartzite clasts of the Proterozoic Dutch Peak Formation, as well as sandstone clasts derived from Jurassic and Triassic Formations. The Dutch Peak Formation is exposed in the Sheeprock Mountains northwest of the San Pitch Mountains, and the Mesozoic clasts were presumably derived from the Pavant thrust sheet to the west. These diverse lithologies were contributed in part by a large Early Cretaceous drainage network that departed the thrust belt at an embayment in the mountain front (Lawton et al., 1994). Overlying conglomerate beds in an interval 96 m thick contain boulders and cobbles of both quartzite and carbonate (mostly dolostone). Interbedded mudstone is reddish orange and silty. The upper 44 m consists of reddish-brown to gray silty mudstone (fig. 22). It is unconformably overlain by a striking quartzite-boulder conglomerate that marks the base of the Sanpete Formation, which is equivalent to the Dakota Sandstone (fig. 6).

Continue north on U.S. Highway 89.

(**27.9**, 1.0) Overturned, east-dipping beds of Arapien Shale at 9:00 (north). Ridge is formed by member C, the middle of five members in the Arapien Shale (Weiss, 1994). Member C consists of thin-bedded calcareous shale and mudstone with subordinate thin beds of fossiliferous micrite. Member B, bluish gray and red gypsiferous shale with local halite, is exposed to the right of the highway and on the east flank of the ridge. Exposures of the Arapien Shale are continuous from here southward past Salina and form the core of the Sevier-Sanpete Valley antiform. Two kilometers to the south, all members of the Arapien Shale are exposed in a zone of imbricate reverse faults with west vergence. The decollement of the Gunnison thrust system (fig. 1) apparently lies in evaporite and shale near the base of member A, which is above a Jurassic limestone succession equivalent to the Twin Creek Limestone of northern Utah (Sprinkel, 1982). Member A overlies some thrust faults in the structural culmination of the Sevier-Sanpete Valley antiform, but older limestone is not exposed.

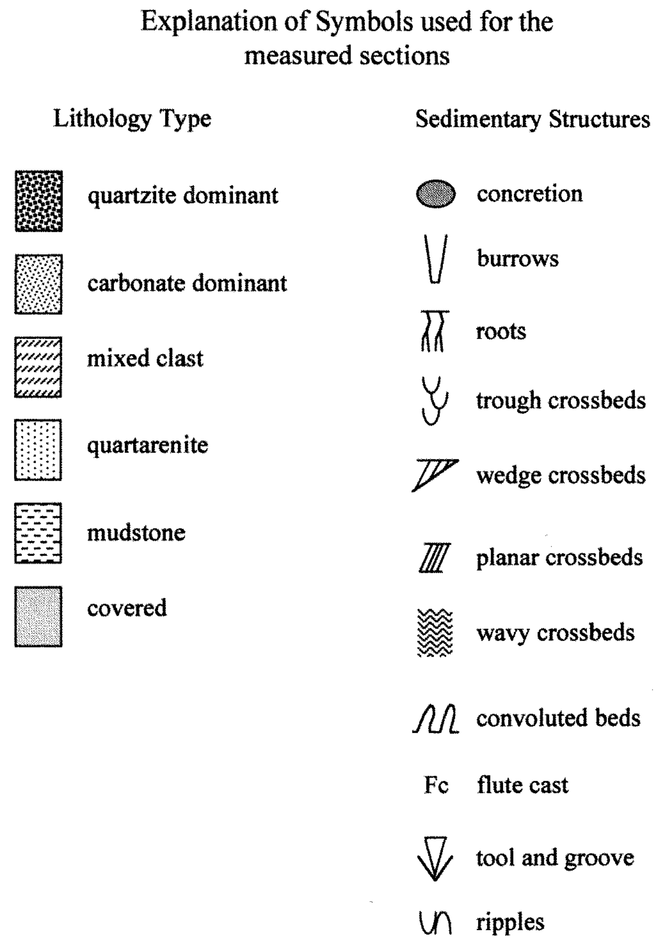


Figure 19. Explanation of symbols for measured sections in figures 20 and 22.

(**30.2**, 2.3) Entering Sterling, Utah.

(**30.9**, 0.7) Turn right (east) on road to Palisade Lake State Park.

(**31.6**, 0.7) Stop at turnout on left (north side of road), directly east of dirt road to the north.

Stop 12. Overview of type Indianola Group. Fifteen minutes

North-striking strata of the Indianola Group form ridges and valleys to the north of the road. This is the locality at which formations of the group were first defined (Spieker, 1946). These rocks were determined to be Late Cretaceous in age on the basis of marine fossils present in the section here (Spieker and Reeside, 1926; Spieker, 1946). Spieker (1946, 1949) also recognized that these strata coarsen westward to conglomeratic equivalents in the western part of the San Pitch Mountains and postulated a western source

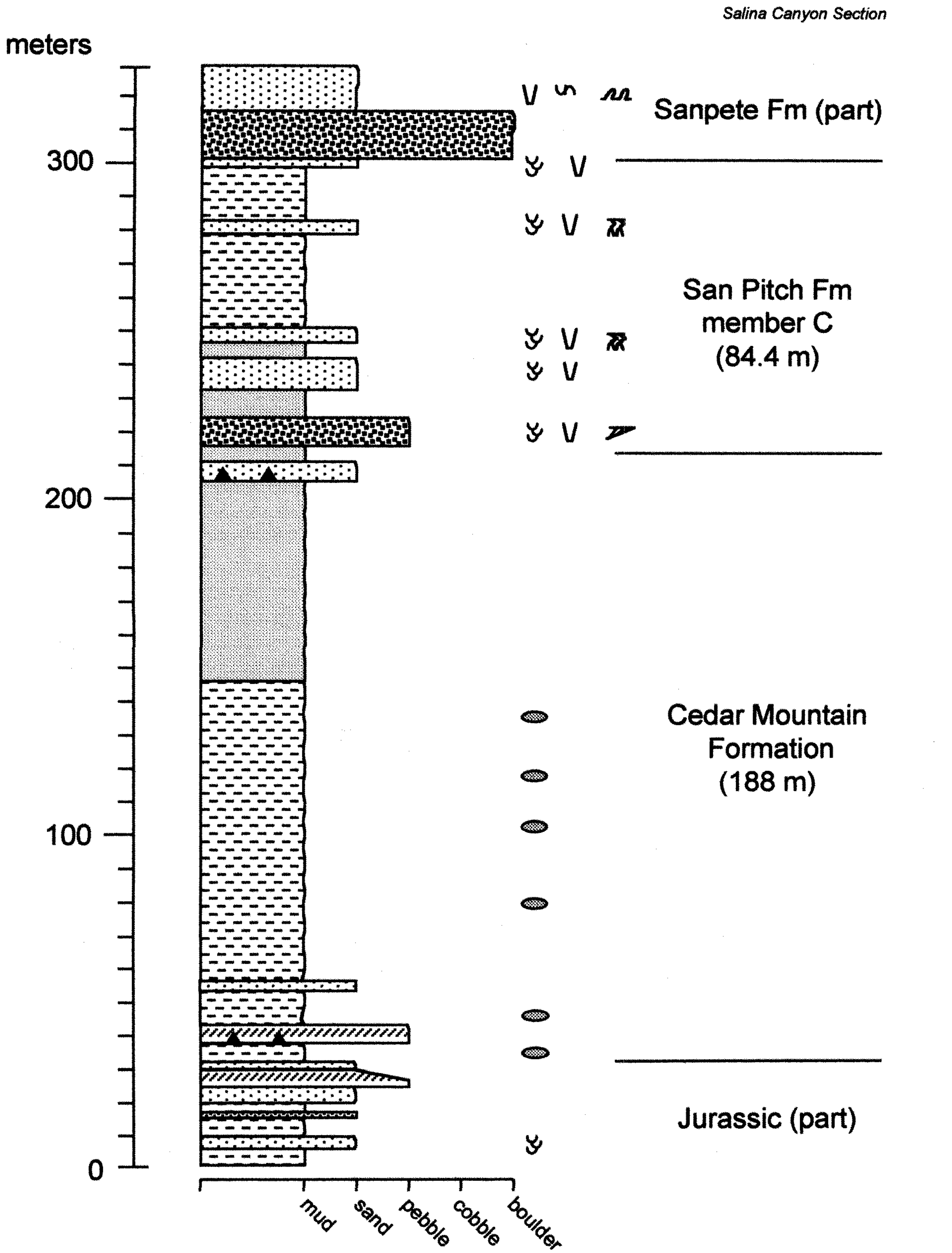


Figure 20. Measured section of Lower Cretaceous strata in Salina Canyon . Base of Cedar Mountain Formation is an unconformity with Jurassic strata, possibly Morrison Formation. See figure 19 for explanation of symbols.

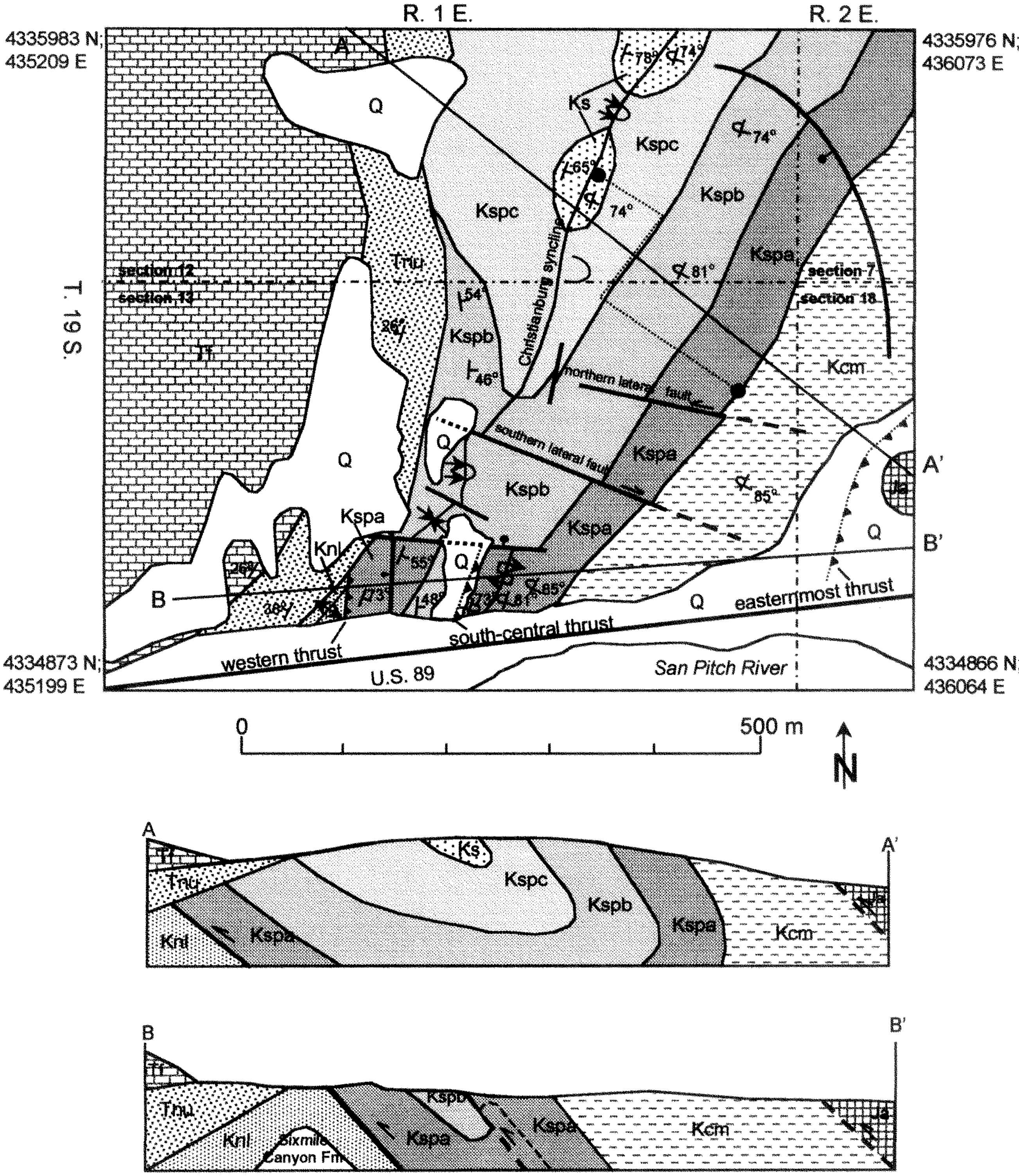


Figure 21. Generalized geologic map and diagramatic cross sections of the Christianburg area.

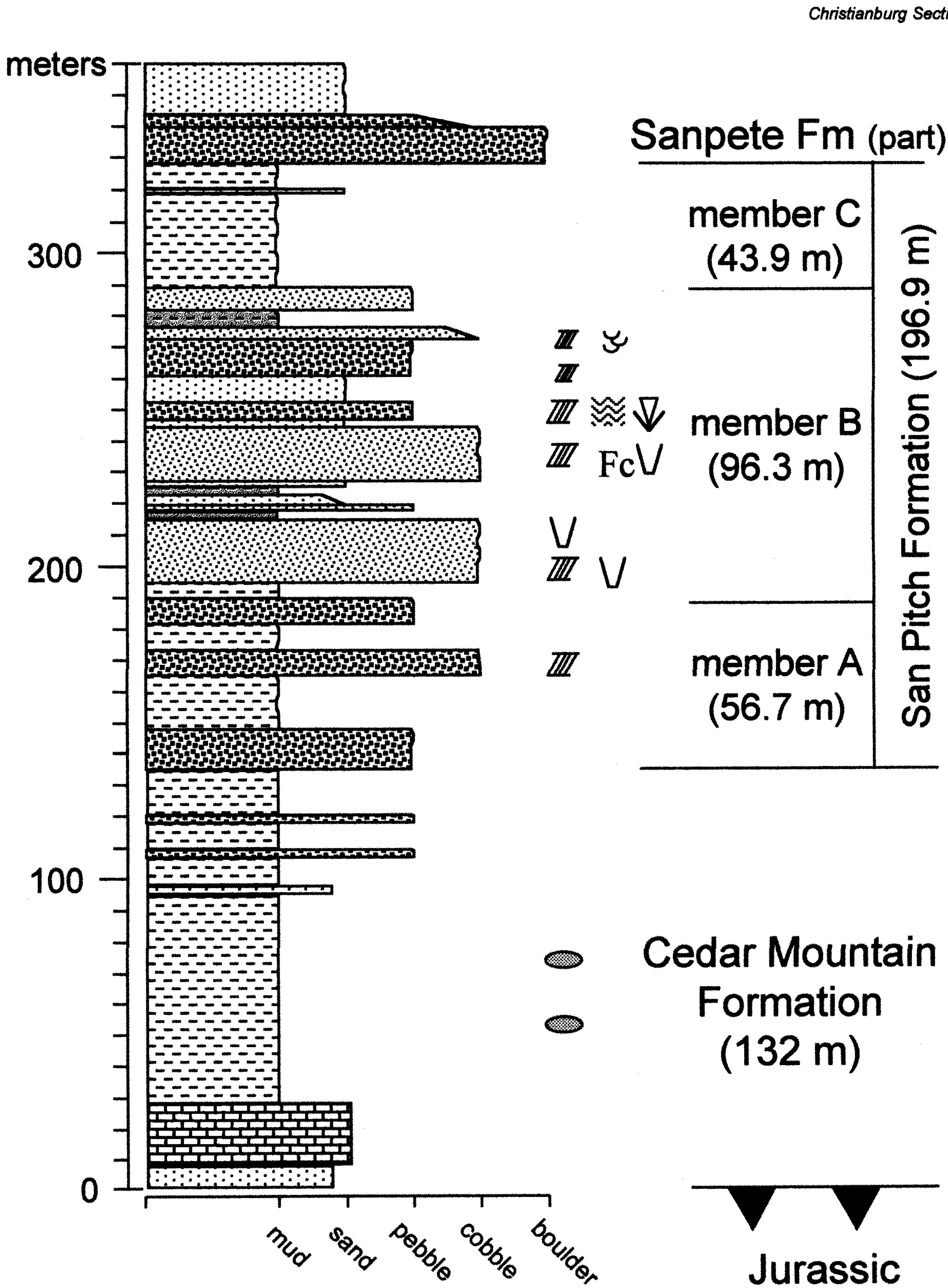


Figure 22. Measured section of Lower Cretaceous strata at Christianburg. Base of the Cedar Mountain Formation is a thrust fault with Jurassic Arapien Shale. See figure 19 for explanation of symbols.

for the clastic material. Ridge to the north is underlain by Sanpete Formation (Cenomanian-Turonian); strike valley mostly covered with alfalfa fields is underlain by the Allen Valley Shale (middle Turonian). Shoreface deposits of lower Funk Valley Formation (Turonian) are exposed in ridge to the east of Allen Valley Shale.

(**33.1**, 1.5) Park in golf course parking lot at end of paved road.

Stop 13. Indianola-Flagstaff angular unconformity. Fifteen minutes.

Excellent views to the north of steeply dipping shoreface deposits in upper part of Funk Valley Formation (Coniacian) overlain by flat-lying Flagstaff Limestone (Paleocene), which postdates local shortening. Prior to onlap by the Flagstaff Limestone, the Mesozoic rocks formed an island in Eocene Lake Flagstaff, termed Sterling Island by Weiss (1994). Comparison of the Funk Valley section with wells to north in Sanpete Valley indicates that much of the unit is missing from here, apparently cut out by a thrust fault near the east flank of the ridge west of the golf course. Along this trend, upright, east-dipping beds are thrust over steeply west-dipping, overturned beds.

(**33.9**, 0.8) Retrace route on paved road to Sixmile Canyon road (dirt). Turn left.

(**34.3**, 0.4) Flagstaff Limestone unconformably overlies the lower member of the Campanian Sixmile Canyon Formation at 9:00 (north). The Sixmile Canyon Formation is the uppermost unit of the Indianola Group (Spieker, 1946). Light gray, thick pebbly sandstone beds of the lower member are unconformable on the Funk Valley Formation.

(**35.6**, 1.3) Road to Manti on left (north). Continue east up Sixmile Creek.

(**35.7**, 0.1) Turn right, downhill into turnoff and park. **Do not** attempt to drive over bridge. Walk across bridge and climb trail 5095 to a bench for a view of the north wall of Sixmile Canyon (approximately 150 meters from bridge).

Stop 14. Progressive unconformity in Campanian strata, Sixmile Canyon.

Fluvial strata on north side of Sixmile Canyon (fig. 5) contain several unconformities that converge in a westward direction, causing the stratigraphic section to thicken to the east. Unconformity-bounded successions of sandstone are discordant in the west, but become concordant in a short distance eastward. The most obvious truncation is beneath beds assigned to the Price River Formation (Spieker, 1946; Lawton, 1982; Weiss, 1994). From its westernmost exposure, the Price River Formation may be traced eastward from an angular unconformity with underlying beds of the upper member of the Sixmile Canyon into an apparently concordant succession of strata (fig. 23). With a little imagination, one can also make out subtle truncations in the underlying Sixmile Canyon Formation. Bedding dip decreases upsection through the unconformity-bounded successions. Campanian pollen have been reported from the middle member of the Sixmile Canyon Formation at the coal prospect to the west (Schwans, 1995) and late Campanian pollen were found in the Price River Formation to the east in the southwest corner of section 30, where it is traversed by the Sixmile Canyon road (Fouch et al., 1983). These strata, which appear to be genetically related, were deposited during incremental rotation in a short period of time during the Campanian.

This progressive unconformity lies on the east flank of the Sevier-Sanpete Valley antiform and indicates that growth of the antiform, and thus movement on the Gunnison thrust, took place late in the Campanian. Lawton et al., (1993) have reported similar relations in Campanian strata on the west flank of the structure; therefore, equivalent growth strata on both sides of Sanpete Valley record structural growth.

West-dipping Tertiary strata on the west flank of the Wasatch Plateau are also visible from this vantage point. This structure is termed the Wasatch monocline (Spieker, 1946). Beds of the lower to middle Eocene Green River Formation are folded, indicating that the monocline is a late Eocene-early Oligocene structure (Weiss, 1994).

Retrace route down Sixmile Canyon and proceed west on paved road toward Sterling.

(**37.5**, 1.8) Turn right (north) on dirt road. After 0.8 mile this road merges with a north-trending paved road that parallels a strike ridge of Sanpete Formation. After 1.4 miles on the pavement, the road crosses the strike ridge and the contact of the Sanpete and Allen Valley formations. Shoreface deposits of the Lower Funk Valley Formation are exposed at 3:00 (east) beyond the alfalfa field.

(**40.3**, 2.8) Turn right (northeast) on U.S. Highway 89.

(**43.1**, 2.8) Turn left (west) on 5th North Street on the north side of Manti, across from the Mormon temple, which is built of limestone blocks quarried from the upper part of the Green River Formation just east of the Temple. Temple Hill is a synclinal toreva block composed of Green River and Crazy Hollow (late Eocene) formations emplaced over a cuesta of limestone in the Green River Formation.

(**45.8**, 2.7) Cross San Pitch River. River knolls on left (southwest) are composed of late Tertiary gravels that dip 50° west. These gravel deposits were tilted by diapirism of Arapien Shale, which also deflected the course of the river to the east.

(**49.7**, 3.9) On east side of the San Pitch Mountains, vertical conglomerate beds of the North Horn Formation rest depositionally on overturned, east-dipping Twist Gulch Formation. The vertical beds form the east limb of a broad, asymmetric syncline in the footwall of a thrust that carries Arapien Shale in its hanging wall. West-vergent folds and reverse faults are exposed discontinuously along the base of the eastern part of the San Pitch Mountains (fig. 17). This zone of reverse faulting is part of the faulted forelimb of a west-vergent fault-propagation fold that underlies Sanpete Valley (fig. 18; Lawton and Weiss, in press).

(**53.0**, 3.3) Turn left (west) at T intersection. Proceed west 1.3 mile to a sharp right (north) turn. West-vergent structures are visible in Big Mountain to the north. After 0.4 mile, turn left (west) and proceed toward mouth of Dry Canyon. Proceed straight 0.5 mile, then bear left on dirt road. Road ends in another 0.2 mi.

(**55.4**, 2.4) End of road in Dry Canyon.

Stop 15 (optional). Fold in Flagstaff Limestone. Walk up the canyon several hundred meters to the fold.

At Dry Canyon (fig. 17), a west-vergent anticline-syncline pair in the Paleocene-Eocene Flagstaff Limestone indicates that some shortening took place following early Eocene time. The Flagstaff is unconformable on overturned, east-dipping Twist Gulch Formation; folding appears to be related to reverse faults that propagated along bedding in the Twist Gulch Formation.

Retrace route to main dirt road on west side of Sanpete Valley.

(**57.8**, 2.4) Proceed straight (east) at T intersection.

(**58.2**, 0.4) At ranch buildings, turn left (north) on west-side road (dirt).

(**58.8**, 0.6) Sharp left turn.

(**58.9**, 0.1) Sharp right turn (north) to follow main road.

(**61.4**, 2.5) On the left (9:00–11:00) west-vergent reverse faults in Cretaceous strata are visible at foot of range in the vicinity of Coal Canyon. Chevron fold in upper San Pitch and Sanpete formations is present north of Coal Canyon. Beds of the North Horn Formation in the footwall of the reverse faults occupy a growth syncline and were deposited intermittently during shortening.

(**63.3**, 1.9) Sheep pens on left. Pull off road on left (west).

Figure 23. Panorama of Campanian strata in upper part of Sixmile Canyon. Upper Member of Sixmile Canyon Formation (Ks) is truncated by unconformatiy beneath Price River Formation (Kp). North Horn Formation (T?n) thins to the west above Price River Formation and beneath Flagstaff Limestone (Tf). Late Campanian pollen were reported by Fouch et al., (1983) from the Price River Formation at the east end of the panel (asterisk).

Stop 16. Progressive unconformity in basal North Horn (Upper Cretaceous), Lambs Canyon. Fifteen minutes.

Beds in the basal part of the North Horn Formation visible on the south side of Lambs Canyon form several unconformity-bound sequences that are truncated eastward by convergence of the unconformities. Bedding attitudes decrease upsection. Clasts within the conglomerate record an unroofing sequence derived from the rising structure to the east: Indianola clasts in the middle part of the section are overlain in succession by conglomerate, limestone, and sandstone clasts derived from Lower Cretaceous and Jurassic beds (Lawton et al., 1993). The basal North Horn Formation here is late Campanian in age (Talling et al., 1994) and correlates with the Sixmile Canyon and Price River formations at stop 14.

(**63.8**, 0.5)	Cottonwoods at 10:00 (west) grow at springs on the main normal fault at the foot of the range. Stratigraphic offset on this fault is about 640 m (Lawton and Weiss, in press). The fault reactivated an older west-vergent thrust fault (Standlee, 1982).
(**66.6**, 2.8)	Entering Wales, Utah.
(**67.3**, 0.7)	Left (west) on Wales Canyon Road.
(**68.2**, 0.9)	Park on right (north) side of road, east of prominent hogback.

Stop 17. Wales Gap. Axhandle wedge-top basin and Wales thrust system.

Vertical and overturned strata exposed at the narrow portal called Wales Gap display discordant relationships created by both thrust faults and angular unconformities (fig. 24). The prominent hogback consists of cobble to boulder conglomerate that dips 90o and faces west. It represents the lowermost unit in the fill of the Axhandle piggyback, or wedge-top basin, which contains as much as 1100 m of strata in its thickest part (Lawton et al., 1993). The strata of the basin, comprising the North Horn Formation and Flagstaff Limestone, thin eastward onto the belt of folding and faulting, known informally as the Wales thrust system, along the eastern base of the San Pitch Mountains. The prominent conglomerate was considered by Spieker (1946, 1949) as Price River Formation, but Lawton et al., (1993) termed it the basal conglomerate member of the North Horn Formation to emphasize its genetic link with overlying North Horn strata of the wedge-top basin. This conglomerate correlates with conglomeratic strata seen yesterday at Chris Canyon on the other side of the range, west northwest of here. On the south side of the creek, the basal conglomerate overlies overturned, east-dipping Sanpete Formation with angular discordance. Beds of the Sanpete Formation depositionally overlying the San Pitch Formation are also exposed on the south side of the creek. To the east, a reverse fault emplaces Jurassic Twist Gulch Formation

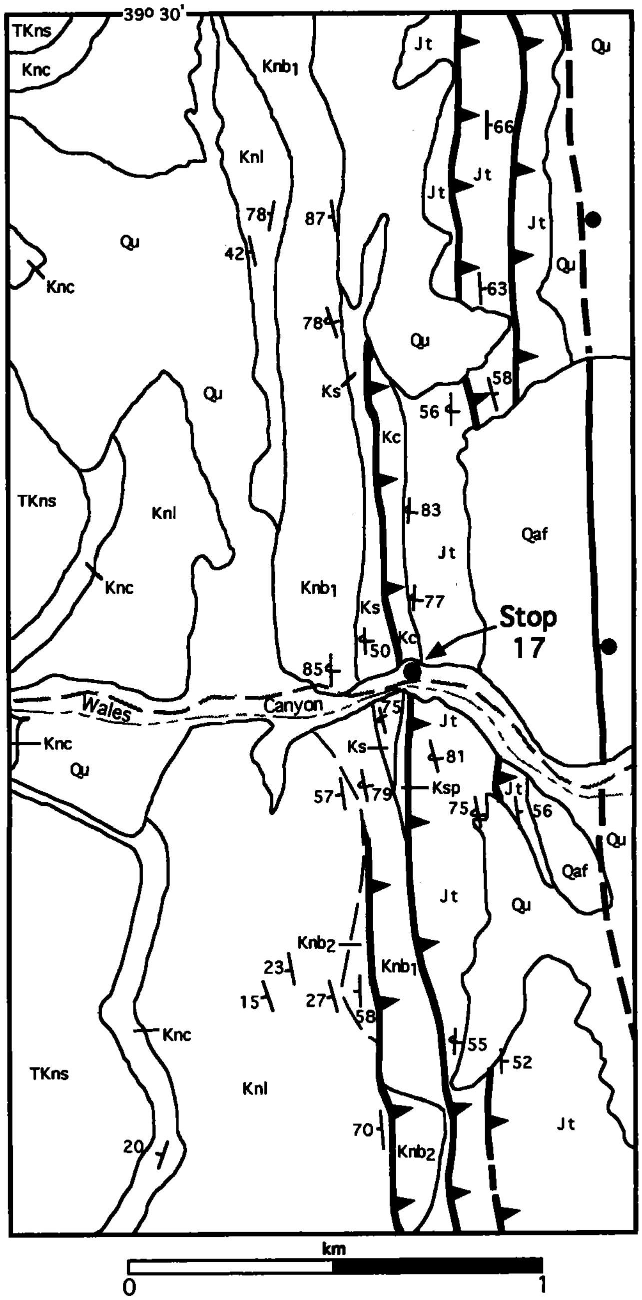


Figure 24. Geologic map of Wales Gap and vicinity of stop 17 on the east flank of the San Pitch Mountains (Lawton and Weiss, in press). Explanation: Jt, Twist Gulch Formation; Kc, Cedar Mountain Formation; Ksp, San Pitch Formation, Knb1, Knb2, basal members of North Horn Formation; Knl, lower redbed member of North Horn Formation; Knc, coal-bearing member of North Horn Formation; TKns, upper siltstone member of North Horn Formation; Qaf, alluvial-fan deposits; Qu, undifferentiated surficial deposits. Location of map is shown on figure 17.

above the San Pitch Formation. To the north, the thrust cuts upsection in the hanging wall and footwall, juxtaposing the Cedar Mountain Formation with the Sanpete Formation north of Wales Creek (fig. 24). Beds within the North Horn Formation west of the hogback have progressively lower dips upsection, partly as a result of the geometry of the syncline and parly a result of angular unconformities in the lower part of the section.

Wales gap displays structures typical of the Wales thrust system. The steep western forelimb of the Sevier-Sanpete Valley antiform formed the structural margin of the Axhandle basin in which the North Horn Formation was deposited (Lawton and Trexler, 1991; Lawton et al., 1993; Talling et al., 1995). The late Campanian onset of deposition in the piggyback, or wedge-top, basin marks major movement of the Gunnison thrust.

End road log. Retrace route to Wales, turn left (north) at Wales Ward Chapel and proceed north on Utah Route 177 to Fountain Green (12 miles). Then turn left on Utah Route 132 to Nephi and Interstate 15.

ACKNOWLEDGMENTS

We thank Lehi Hintze for careful review of the Canyon Range map and for discussions of both Paleozoic and Cretaceous stratigraphy, Phyllis Camilleri and Paul Link for constructive reviews of the manuscript, and Tommy Delgado for help with drafting. Partially supported by National Science Foundation grants EAR-9316700 (to DeCelles) and EAR-9205411 (to Lawton), and by a grant from the Donors of the Petroleum Research Fund (ACS-PRF #25163-AC2) administered by the American Chemical Society (to Mitra).

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