The Confusion Range, west-central Utah: Fold-thrust deformation and a western Utah thrust belt in the Sevier hinterland

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ABSTRACT

The Confusion Range in west-central Utah has been considered a broad structural trough or synclinorium with little overall shortening. However, new structural studies indicate that the Confusion Range is more accurately characterized as an east-vergent, fold-thrust system with ~10 km of horizontal shortening during Late Jurassic to Eocene Cordilleran contractional deformation. For this study, four balanced and retrodeformable cross sections across the Confusion Range and adjacent Tule Valley were constructed using existing mapping and new field data, and these were tied with a fifth strike-parallel section. Ramp anticlines and anticlinal duplexes characteristic of strong Lower Paleozoic carbonate units are balanced by faulted and rotated detachment folds in more ductile Upper Paleozoic strata. The apparently synclinal aspect results from two different sets of thrust structures that uplift and expose Lower Paleozoic rocks on the flanks of the range. Fold-thrust structures are continuous southward for more than 130 km, forming a thrust belt of regional extent herein named the western Utah thrust belt. This thrust belt is comparable in length and magnitude of shortening to the central Nevada thrust belt, and both merge southward with the Sevier frontal thrust belt. Together, these and related fold-thrust zones in eastern Nevada indicate significant, broadly distributed Mesozoic shortening in the Sevier hinterland. The Cordilleran thrust belt in eastern Nevada and western Utah thus consists of a frontal zone—the Sevier frontal thrust belt—where major thrust faults with 50–100 km of displacement breach the surface, and a hinterland zone, characterized by a number of distributed fold-thrust belts, each accommodating on the order of 10 km of shortening.

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INTRODUCTION

The Confusion Range is a collection of ridges and small ranges that together form a low mountain range in western Utah, between the more imposing Snake Range on the west and House Range on the east (Figs. 1 and 2). The range is named for its "rugged isolation and confusing topography" (Van Cott, 1990). The Confusion Range exposes ~5000 m of Ordovician through Triassic strata in what has been considered a broad structural trough or synclinorium (e.g., Hose, 1977; Anderson, 1983; Hintze and Davis, 2003; Rowley et al., 2009). Hintze (*in* Hintze and Davis, 2003) described the envisioned synclinorium as a structural feature 130 km long, up to 24 km wide, and extending the entire length of western Millard County, with the Confusion Range comprising approximately the northern half.

Complex near-surface structures have been recognized in the Confusion Range since the mapping of Richard Hose, Lehi Hintze, and others in the 1960s and 1970s, (e.g., Hose and Ziony, 1963; Hose and Repenning, 1963; Hose, 1965a, 1974a; Hintze, 1974a). These previous structural interpretations have generally featured complicated and variable internal deformation, but with little overall shortening (e.g., Hose, 1977).

In contrast to early interpretations of synclinoria, more recent work (Dubé and Greene, 1999; Nichols et al., 2002; Yezerski and Greene, 2009; Matteri and Greene, 2010; Greene and Herring, 2013) indicates that the Confusion Range is more accurately characterized as an east-vergent, fold-thrust system with significant (~10 km) horizontal shortening during Late Jurassic to Eocene Cordilleran contractional deformation.

I present here a series of four balanced and restorable cross sections across the Confusion Range and adjacent Tule Valley (location map, Plate 1; sections, Plates 2–5) that characterize the structural architecture and style of deformation. A fifth strike-parallel cross section (Plate 6) ties the strike-perpendicular cross sections together while delineating the lateral and oblique thrust ramps that form a significant complicating factor in the structure of the fold-thrust system. Together, these five cross sections total almost 300 km in map length. Enlarged versions of the cross sections at a scale of 1:50,000, along with a discussion of the petroleum potential of the region, may be found in Greene and Herring (2013).

Similar structural style and fold-thrust structures are continuous southward throughout the length of the originally proposed synclinorium, forming a fold-thrust belt more than 130 km in length that is herein named the western Utah thrust belt. Comparison with the central Nevada thrust belt and similar zones of fold-thrust deformation in eastern Nevada and western Utah suggests that this region is not a little-deformed "hinterland" to the Sevier thrust belt, as has been previously envisioned, but is instead a zone of significant distributed Mesozoic contractional deformation.

In this paper, the term "thrust system" is used for a zone of closely related thrusts and associated folds that are geometrically and mechanically linked (McClay, 1992), and "thrust belt" is used more generally for a relatively narrow zone of fold-thrust deformation of regional extent. The continental-scale Cordilleran thrust belt is considered to consist of multiple smaller thrust belts of regional extent that may show differences in location, timing, structural style, and magnitude of shortening.

Regional Setting

In what is now western Utah, more than 13 km of Neoproterozoic to Triassic strata were deposited on the rifted western edge of cratonic North America (Fig. 3). Four kilometers or more of Neoproterozoic and Lower Cambrian predominantly clastic strata, exposed in the Snake and Deep Creek Ranges to the west of the Confusion Range, are overlain by 8–9 km of Middle Cambrian to Devonian strata, largely

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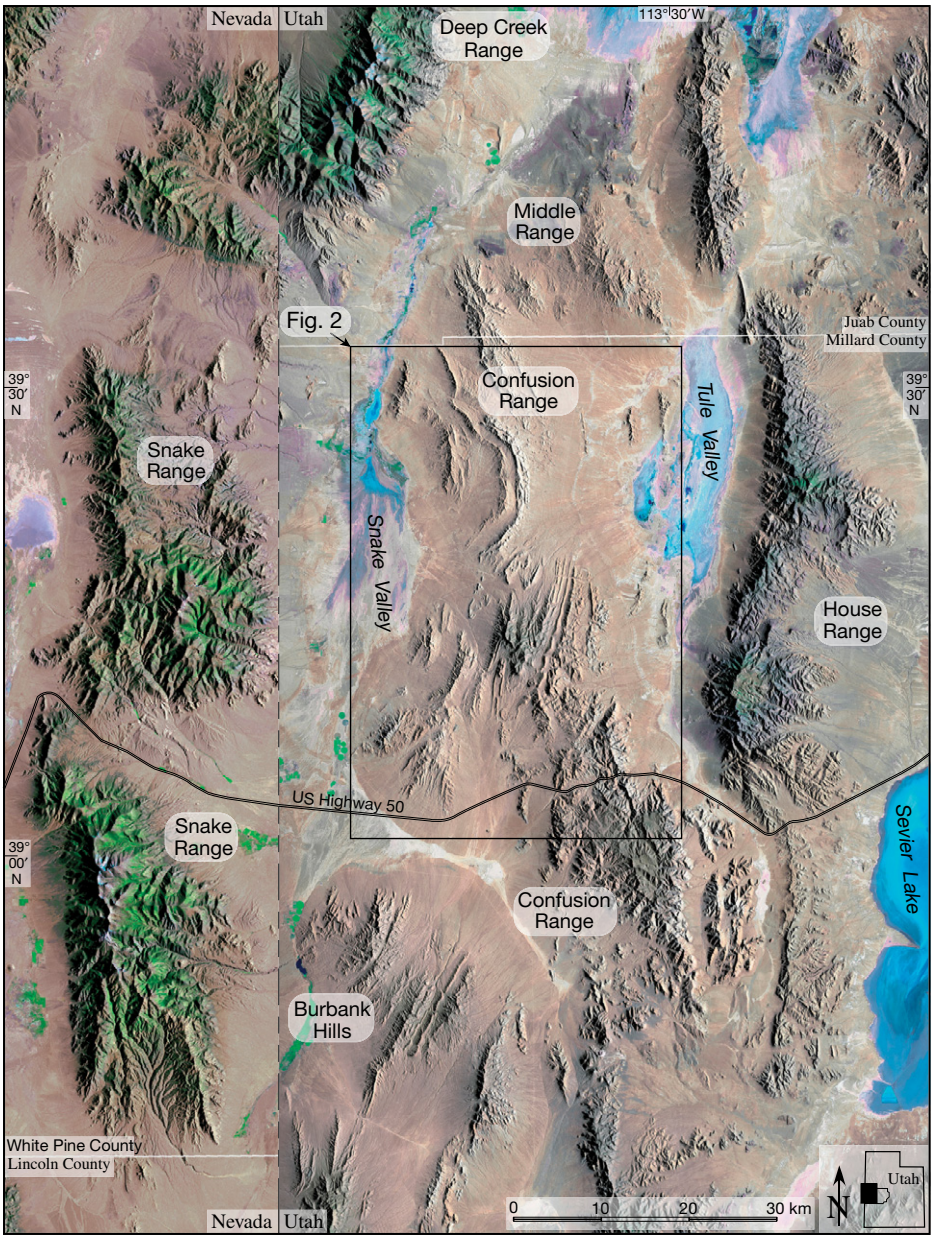

Figure 1. Map showing location and topography of the Confusion Range and surrounding region, modified from U.S. Geological Survey orthophoto state map series. Central box indicates the location of Figure 2.

carbonates deposited in a stable passive-margin setting (Link et al., 1993; Cook and Corboy, 2004; Hintze and Davis, 2003; Hintze and Kowallis, 2009) and now well exposed in the House Range and Confusion Range.

The carbonate-dominated passive margin was disrupted in early Mississippian time by clastic foredeep sediments associated with the Antler orogeny to the west, and by subsequent development of the Oquirrh Basin and disturbances related to the Pennsylvanian Ancestral Rockies and Permian–Triassic Sonoma orogenies (Trexler et al., 2004; Dickinson, 2006). By late Mesozoic time, an organized subduction system was established along the Cordilleran continental margin, and a major retroarc fold-thrust belt developed inboard of the magmatic arc. The segment of this fold-thrust belt in southern Nevada and Utah has been termed the Sevier belt (Armstrong, 1968; DeCelles and Coogan, 2006).

In Utah, fold-thrust deformation began in the Late Jurassic and continued into the Paleocene, with a general west-to-east progression (Royse, 1993; DeCelles, 2004; DeCelles and Coogan, 2006; Yonkee and Weil, 2011). The Sevier frontal thrust belt in central Utah consists of four main thrust systems, the Canyon Range, Pavant, Paxton, and Gunnison thrusts, with total shortening of at least 220 km (DeCelles and Coogan, 2006). The Canyon Range and Pavant thrust sheets, in particular, include a strong Precambrian to Lower Cambrian quartzite sequence that supported long-distance eastward transport. These thrust sheets apparently root at midcrustal levels beneath the Confusion Range (Allmendinger et al., 1983; DeCelles and Coogan, 2006) and are continuous eastward under the Sevier Desert basin as long hanging wall-on-footwall flats, initially ramping to the surface in the Canyon Range.

Late Cretaceous to middle Cenozoic paleogeography in the region likely consisted of a high-elevation, low-relief plateau referred to as the "Nevadaplano," with a steep topographic front and foreland basin to the east (Coney and Harms, 1984; DeCelles, 2004; Best et al., 2009; Henry et al., 2012). Paleogene conglomerates, lacustrine limestones, and interbedded volcanics were deposited in local basins and paleochannels, possibly related to early extensional collapse within the plateau (Vandervoort and Schmitt, 1990; Constenius, 1996; Greene and Herring, 1998; Hintze and Davis, 2003; Druschke et al., 2011; Lechler et al., 2013). Widespread pyroclastic volcanism, the "ignimbrite flareup" (Coney, 1978; Best et al., 2009, 2013), began in the late Eocene and continued through the early Miocene. Beginning in the early Miocene, predominantly high-angle extensional faulting formed the typical Basin and Range topography observed today (e.g., Dickinson, 2006). North-striking, fault-bounded valleys such as Snake Valley and Tule Valley, which formed adjacent to uplifted ranges, contain up to 3000 m of fluvial, alluvial, and lacustrine sediments, with interbedded volcanics.

CROSS-SECTION CONSTRUCTION

Four cross sections transverse to structural strike and one tie section parallel to structural strike were constructed for this study. Existing surface mapping, detailed new surface mapping over the lines of section, and the very limited subsurface data available were incorporated into the cross sections.

The Confusion Range is well covered by geologic mapping completed mostly in the 1960s and 1970s (Hose, 1963a, 1963b, 1965a, 1965b, 1974a, 1974b; Hose and Repenning, 1963, 1964; Hose and Ziony, 1963, 1964; Hintze, 1974a; Sack, 1994a; Hintze and Davis, 2002a). Exposure is generally excellent, bedding orientations are widely available, and the stratigraphy is well understood. Within the range, therefore,

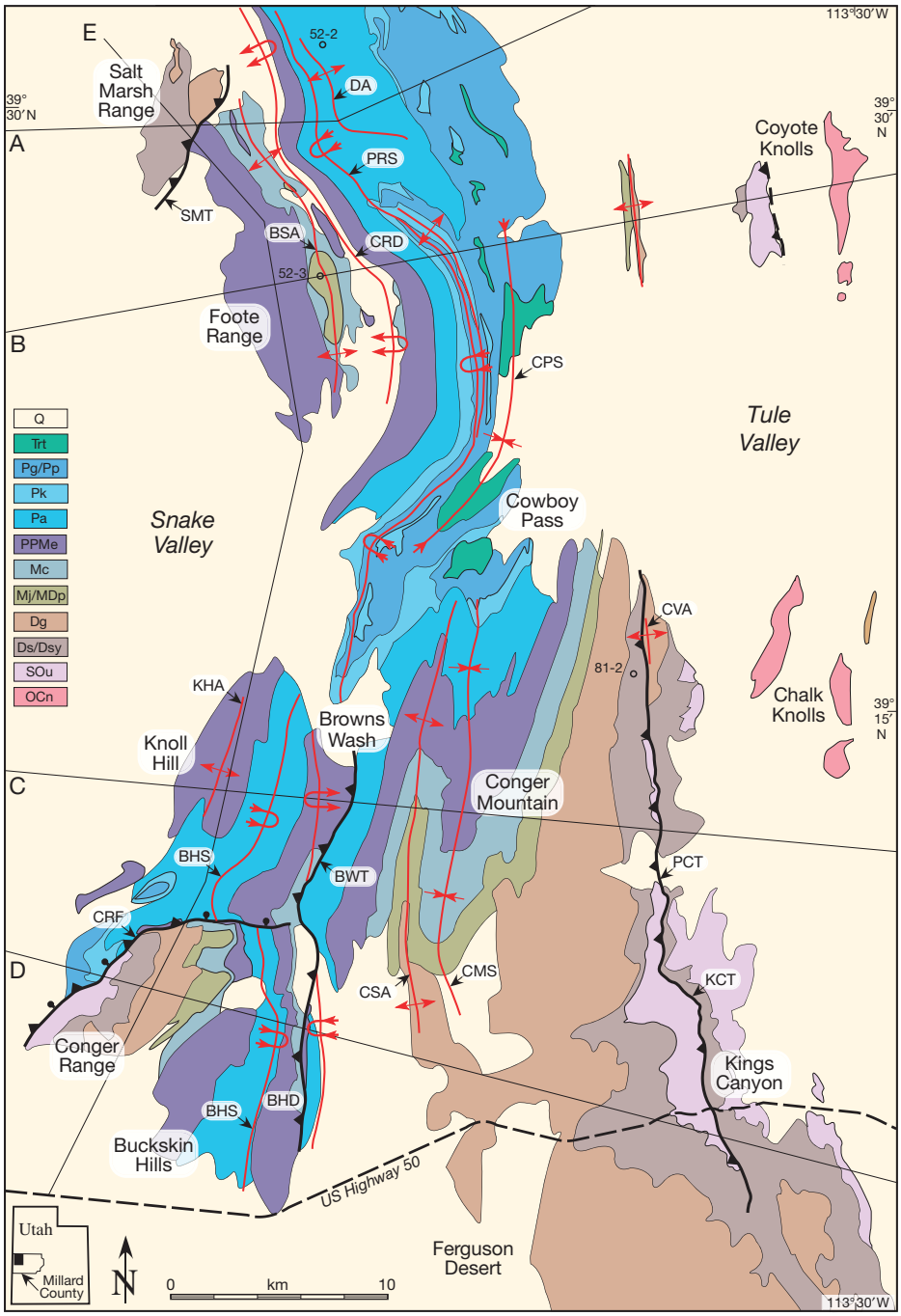

Figure 2. Generalized geologic map of the Confusion Range showing major geographic and structural features. Unit colors and abbreviations are as shown in Figure 3. Note that cross-section lines continue beyond the margins of the diagram (see Plate 1). Base map is modified from Hintze and Davis (2002a). BHD—Buckskin Hills detachment fold, BHS—Buckskin Hills syncline, BSA—Bishop Springs anticline, BWT—Browns Wash thrust, CMS—Conger Mountain syncline, CPS—Cowboy Pass syncline, CRD—Chevron Ridge detachment fold, CRF—Conger Range fault, CSA—Conger Springs anticline, CVA—Cattlemans Valley anticline, DA—Desolation anticline, KCT—Kings Canyon thrust, KHA—Knoll Hill anticline, PCT—Payson Canyon thrust, PRS—Plympton Ridge syncline, SMT—Salt Marsh thrust, 52–2—Desolation anticline drill hole, 52–3—Bishop Springs anticline drill hole, 81–2—State AB#1 drill hole.

cross sections are well constrained at the surface, although the regional scale of this work has required generalization and simplification of local detail. In particular, Tertiary normal faults with small displacement have generally been omitted from the cross sections.

There are few deep drill holes in the Confusion Range, and the probability of major structural discontinuities underlying Snake Valley to the west means that data from drill holes in Snake Valley cannot be directly used to interpret structures within the Confusion Range. Sparse wells drilled for water resource investigations (Utah Geological Survey, 2011) locally provide depth to base of valley fill but are not deep enough to provide much structural information. The only published seismic data covering the Confusion Range are the Consortium for Continental Reflection Profiling (COCORP) Nevada Line 5 and Utah Line 1, collected in the 1980s (Allmendinger et al., 1983, 1986, 1987; Hauser et al., 1987). Nevada Line 5 crosses northern Snake Valley and terminates near the Bishop Springs anticline in the northern Confusion Range. Utah Line 1 begins at the Nevada-Utah border and crosses Snake Valley, the Confusion Range at Cowboy Pass, Tule Valley, and the House Range. Acquisition of these seismic lines was optimized for deep reflections, and they are of limited usefulness in interpreting upper-crustal structure.

Given the general lack of borehole information and useful public seismic data, the subsurface interpretation presented in these cross sections is much less constrained by direct observation than the surface trace of each section. The location and geometry of specific subsurface structures are subject to considerable uncertainty, and the interpretation of deeper structural levels should be considered speculative.

Stratigraphy and Mechanical Stratigraphy

The Confusion Range consists of Cambrian–Ordovician through Triassic strata. Thick-bedded, competent carbonate rocks dominate the Lower Paleozoic section, and less competent shales, sandstones, and thin-bedded carbonates comprise the Upper Paleozoic and Mesozoic section. Regional stratigraphy is described in detail by Hintze and Davis (2003), Peterson (1994), Rodgers (1984), and Hose et al. (1976). Stratigraphic nomenclature and unit thicknesses used here (Fig. 3) follow those of Hintze and Davis (2003) for the northern Confusion Range and northern House Range, with the exception that, as documented by Hose (1974b), the Joana Limestone is absent in the northernmost Confusion Range, and adjacent units are thinner than elsewhere.

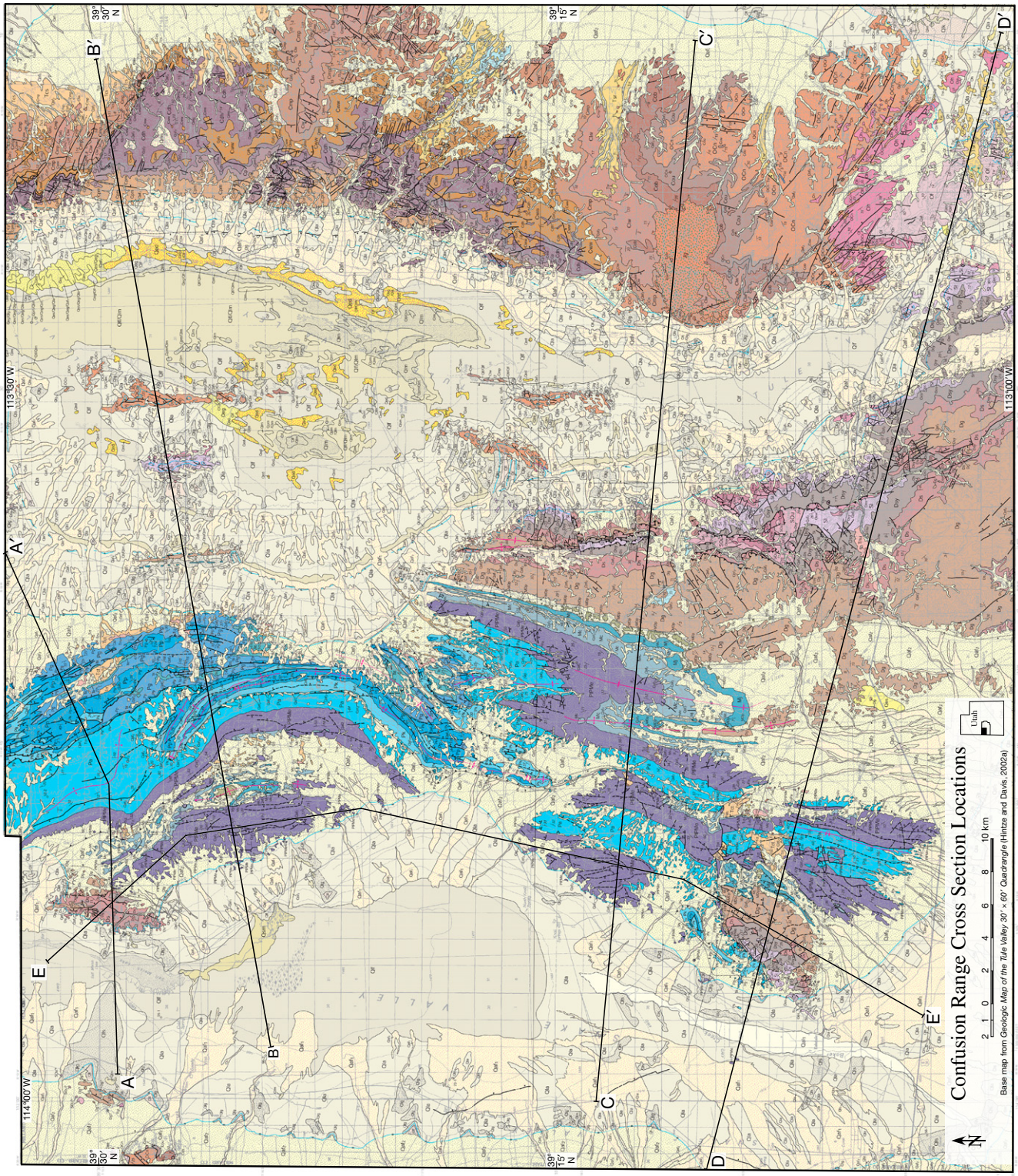

Plate 1. Confusion Range cross section locations. If you are viewing the PDF of this paper or reading it offline, please visit http://dx.doi.org/10.1130/GES00972.S1 or the full-text article on www.gsapubs.org to view the full-sized version of Plate 1.

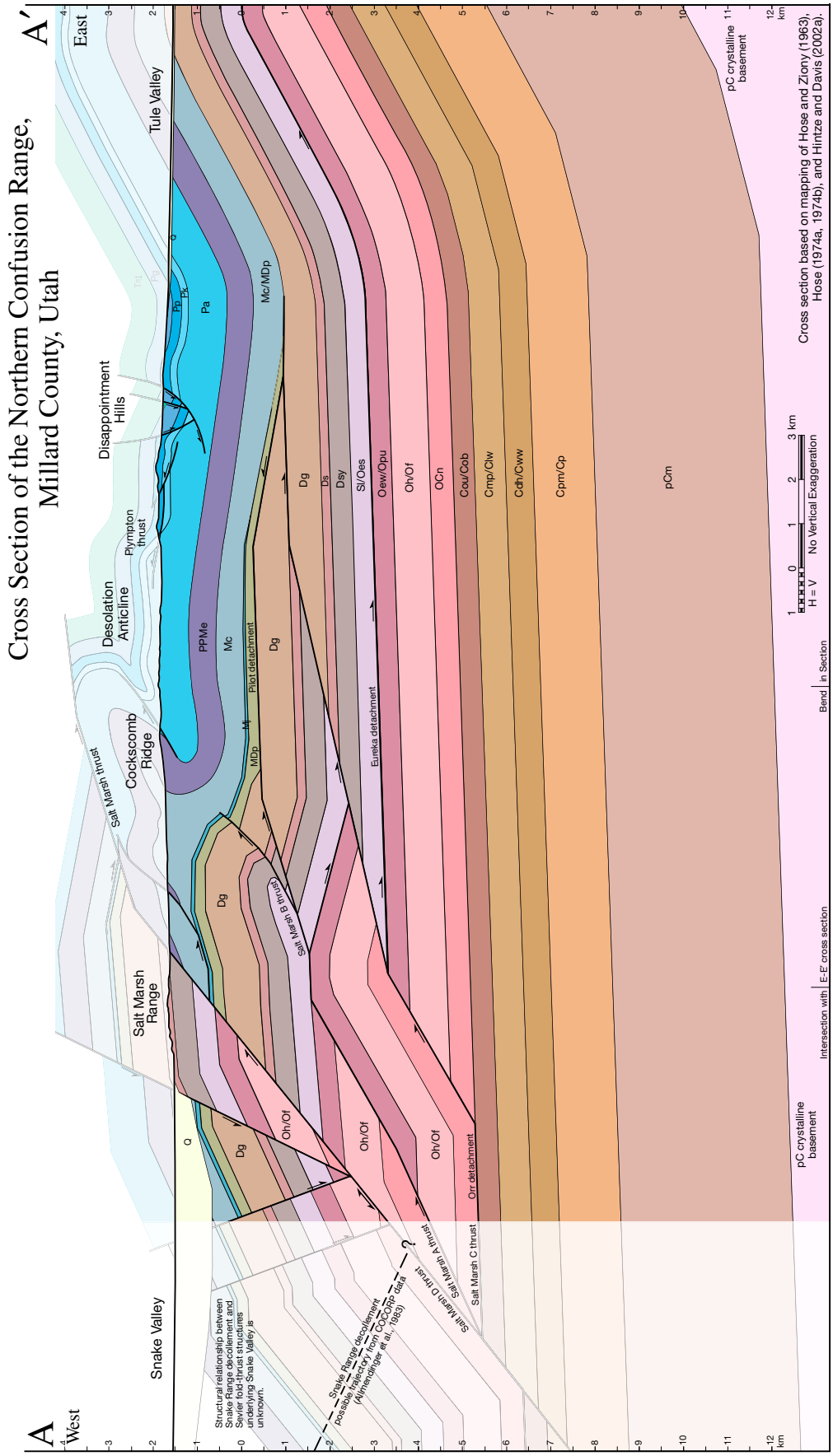

Plate 2. Cross section of the northern Confusion Range, A–A′. If you are viewing the PDF of this paper or reading it offline, please visit http://dx.doi.org/10.1130/GES00972.S2 or the full-text article on www.gsapubs.org to view the full-sized version of Plate 2.

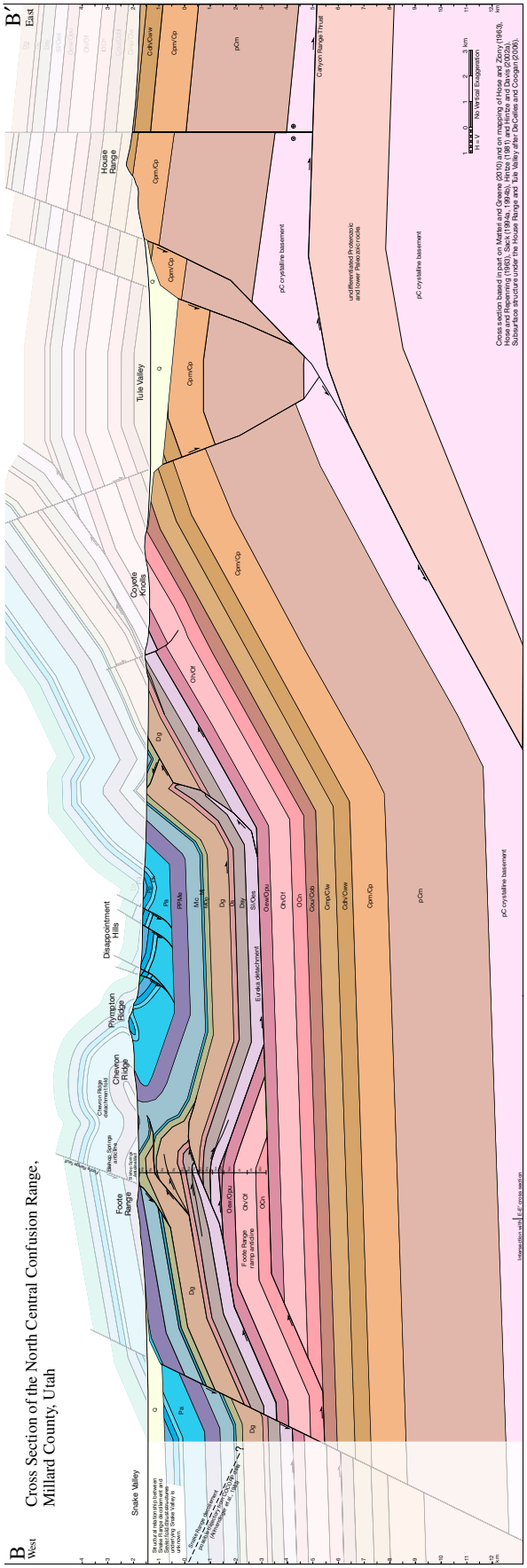

Plate 3. Cross section of the north central Confusion Range, B–B′. If you are viewing the PDF of this paper or reading it offline, please visit http://dx.doi.org/10.1130/GES00972.S3 or the full-text article on www.gsapubs.org to view the full-sized version of Plate 3.

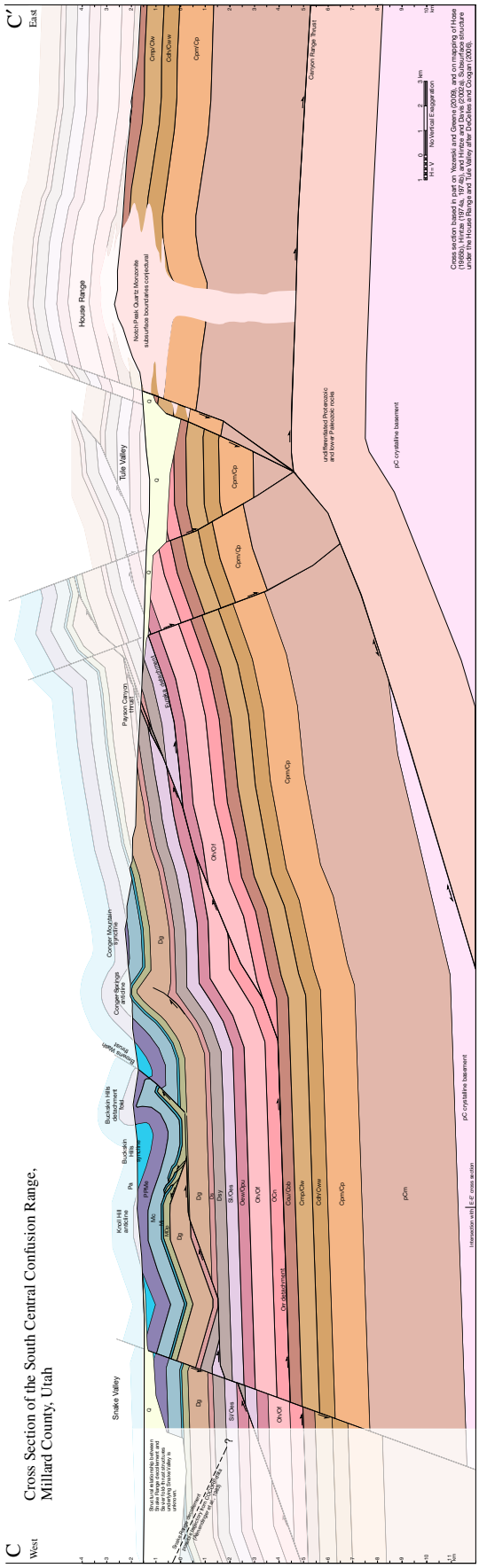

Plate 4. Cross section of the south central Confusion Range, C–C′. If you are viewing the PDF of this paper or reading it offline, please visit http://dx.doi.org/10.1130/GES00972.S4 or the full-text article on www.gsapubs.org to view the full-sized version of Plate 4.

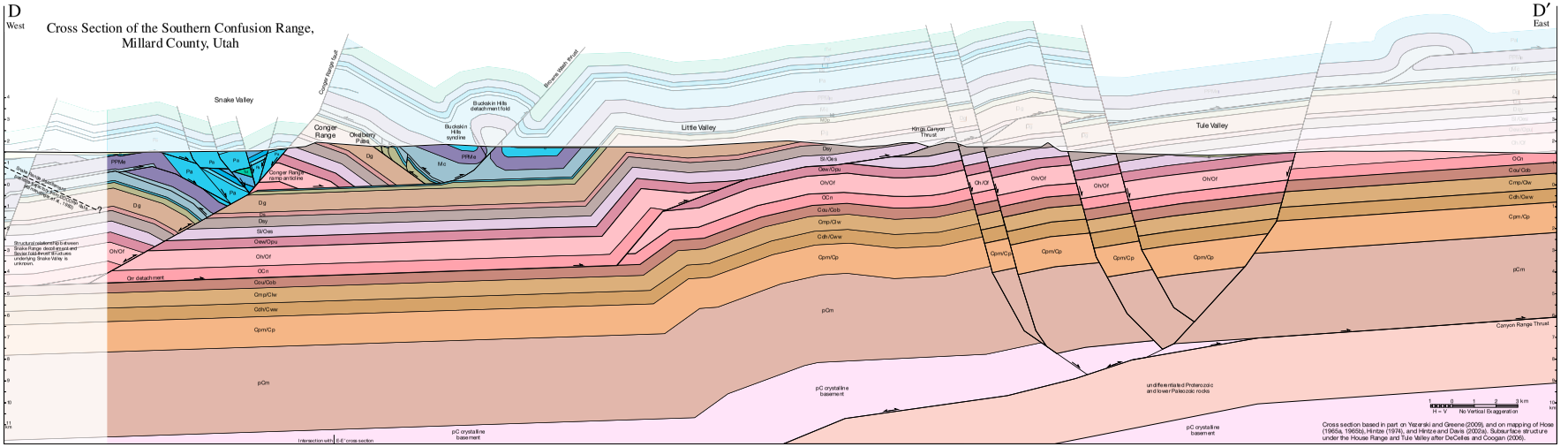

Plate 5. Cross section of the southern Confusion Range, D–D′. If you are viewing the PDF of this paper or reading it offline, please visit http://dx.doi.org/10.1130/GES00972.S5 or the full-text article on www.gsapubs.org to view the full-sized version of Plate 5.

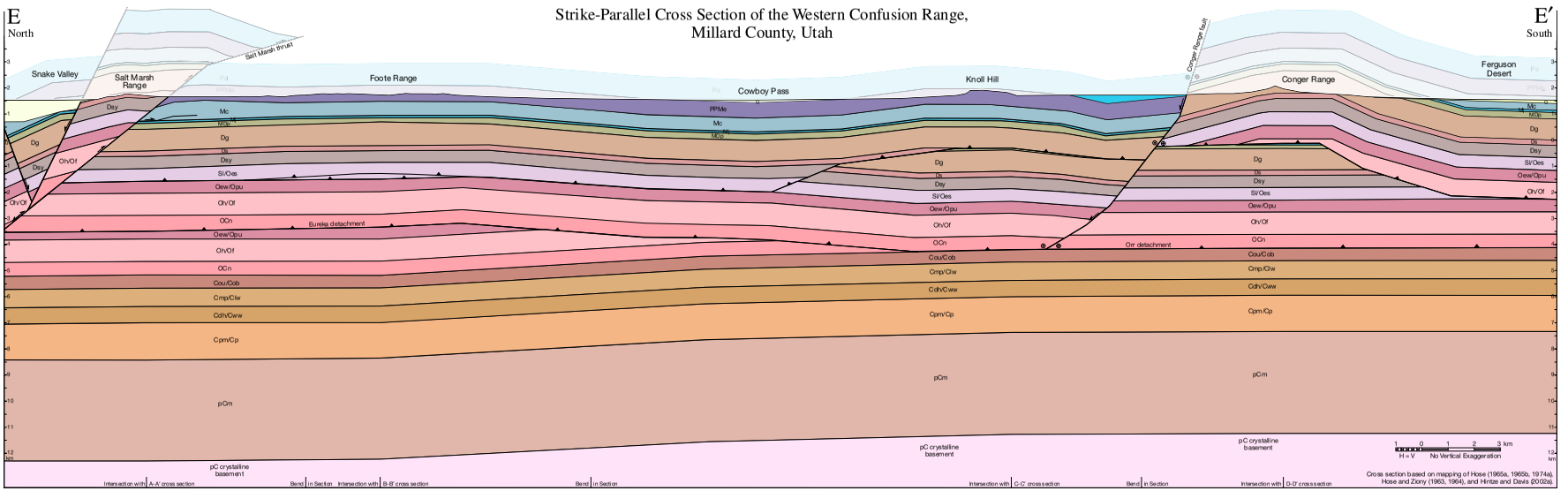

Plate 6. Strike-parallel cross section of the western Confusion Range, E–E′. If you are viewing the PDF of this paper or reading it offline, please visit http://dx.doi.org/10.1130/GES00972.S6 or the full-text article on www.gsapubs.org to view the full-sized version of Plate 6.

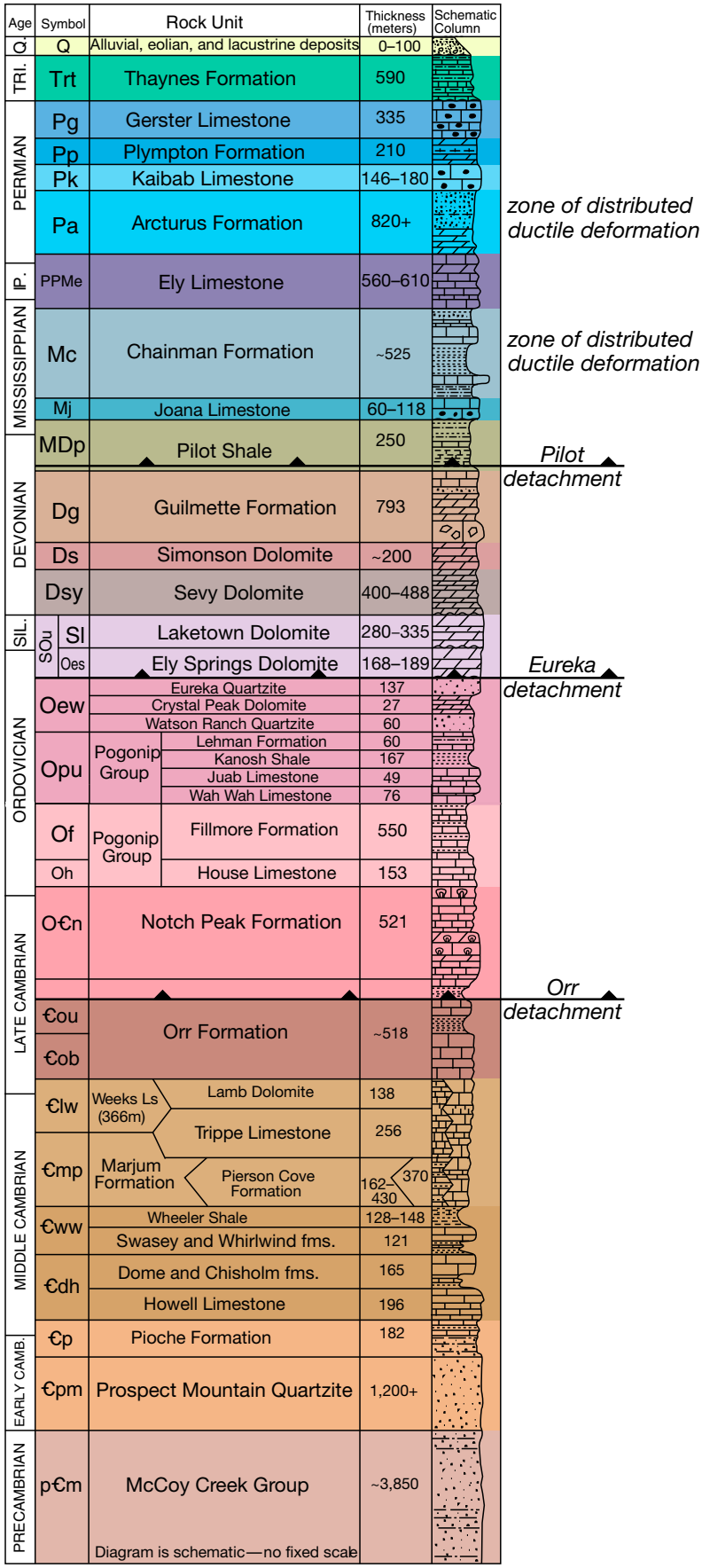

Figure 3. Composite stratigraphic column and unit thicknesses used in constructing the cross sections. Colors and symbols are as used on the cross sections. Major detachment levels are indicated by heavy lines with teeth, and informally named: the Orr detachment, in the Corset Spring Shale Member of the Orr Formation; the Eureka detachment, at the top of the Eureka Quartzite; and the Pilot detachment, at the top of the Guilmette Formation. Major zones of detachment due to internal ductile deformation are also present in the Chainman and Arcturus Formations. Figure is adapted from Hintze and Davis (2003) with additional data from Hose et al. (1976) and Rodgers (1984).

In general, the Lower Paleozoic carbonate section forms a strong "beam" that deforms primarily by ramp-flat thrust faulting. The Upper Paleozoic section, in contrast, deforms primarily by large-scale detachment folding, with local disharmonic folding and faulting.

Lower Paleozoic Mechanical Stratigraphy

Two major detachment horizons in the Lower Paleozoic section were used in constructing these cross sections. A detachment located in the Corset Spring Shale Member of the Cambrian Orr Formation, just below the base of the Notch Peak Formation (Fig. 3), is herein informally referred to as the Orr detachment. In constructing the cross sections, the 56-m-thick Sneakover Limestone Member of the uppermost Orr Formation was included with the overlying Notch Peak Formation, so that the illustrated unit boundary coincides with the detachment level.

The Orr detachment is not exposed in the Confusion Range, but it is interpreted based on the following considerations:

(1) The Corset Springs Shale forms a lithologically weak zone at the base of a >600-m-thick sequence of massive, cliff-forming carbonates (House Limestone and Notch Peak Formation).

(2) A detachment near this level is indicated by the geometry of exposed structures, especially in the Foote Range and Conger Range ramp anticlines, where Lower Paleozoic strata apparently continuous through the Notch Peak Formation are emplaced at an anomalously high structural level, indicating an underlying detachment (Fig. 2; Plates 3 and 5).

(3) Regionally, thrust sheets in the Timpahute, Quinn Canyon, Grant, and Pahranagat Ranges in the central Nevada thrust belt typically place Upper Cambrian rocks over Devonian or younger strata, indicating detachment in

the Upper Cambrian strata (Taylor et al., 1993, 2000). The Canyon Range thrust, on the west side of the Canyon Range in central Utah, is interpreted to place Proterozoic Pocatello Formation on Upper Cambrian strata (DeCelles and Coogan, 2006), indicating local detachment in the Upper Cambrian section.

(4) The Gulf/Tiger No. 1 Bishop Springs anticline drill hole (map reference 52–3 on Fig. 2 and *in* Hintze and Davis, 2003) and the Cities Service No. 1 State AB drill hole (centered on Cattlemans Valley anticline; map reference 81–2 on Fig. 2 and *in* Hintze and Davis, 2003) both penetrated an apparently continuous Lower Ordovician stratigraphic section including all units of the Pogonip Group and the underlying Notch Peak Formation (e.g., Hintze and Davis, 2003). This precludes thrust repetition on a detachment in the Kanosh Shale of the upper Pogonip Group (Fig. 3), the only other significant shale in the middle Paleozoic section that would be expected to be lithologically weak and form a zone of detachment.

A detachment at the top of the Ordovician Eureka Quartzite (top of Oew on the cross sections) is herein referred to informally as the Eureka detachment. The Eureka detachment is locally evident in outcrop, especially in the Kings Canyon thrust zone. Regionally, a detachment at this stratigraphic level is also exposed or interpreted in central Nevada (e.g., Roeder, 1989). Other detachment levels lower in the section that are significant regionally include the middle Cambrian Pioche Formation (Miller et al., 1983; McGrew, 1993) and the Neoproterozoic Pocatello Formation (equivalent to the lower part of the McCoy Creek Group; DeCelles and Coogan, 2006).

Upper Paleozoic Mechanical Stratigraphy

Thick (>300 m) ductile shales in the Camp Canyon Member of the Chainman Formation (Fig. 3), and in the Pilot Shale at the top of the Devonian Guilmette Formation, form zones of detachment that separate fold-thrust structures in the underlying Lower Paleozoic section from predominantly folding in the less competent Upper Paleozoic section. In the cross sections, these zones are generalized to a single detachment drawn in the Pilot Shale at the top of the strong carbonates of the Guilmette Formation, referred to informally as the Pilot detachment.

The Pennsylvanian Ely Limestone in the Confusion Range is a prominent ridge-forming marker unit that outlines major structures in the Upper Paleozoic section (Figs. 1 and 2). The well-bedded Ely Limestone forms a relatively strong layer between two weak, ductilely deforming units, the Mississippian Chainman and Permian Arcturus Formations (Fig. 3). Ely Limestone deforms internally primarily by flexural-slip folding and internal accommodation faulting. It characteristically forms large detachment folds (e.g., Dahlstrom, 1990; Mitra, 2003; Atkinson and Wallace, 2003) cored by mobile shales of the Chainman Formation (e.g., Plates 3 and 5). The Permian Kaibab Limestone is a relatively thin (~165 m), massive, carbonate unit that deforms in a style similar to the Ely Limestone, forming complex disharmonic detachment folds between the weaker Arcturus Formation and overlying Permian and Triassic units (Fig. 4).

Balance, Retrodeformability, and Assumptions

The cross sections of this study (Plates 2–6) were originally constructed at a scale of 1:50,000 (Greene and Herring, 2013), utilizing existing geologic mapping at 1:24,000, 1:48,000, and 1:100,000 scale and new field work. A regional original average dip of 2° to the west, off the continental platform in central Utah, is assumed.

The cross sections were constructed to have consistent bed lengths and areas, and to be retrodeformable. Complete balancing is not possible because they do not cover a large enough cross-strike length to contain regional pin lines with no deformation, and thus within the plane of section strata move both into and out of the sections. However, the shortening shown is compatible within and between sections, and, where possible, fold-thrust shortening in the Lower Paleozoic section is balanced with shortening via ductile thickening and detachment folding in the overlying Chainman and Ely Formations. Upper Paleozoic units above the Ely Limestone are not formally balanced due to insufficient exposure and the common occurrence of additional internal structural complexities where they are exposed (discussed further later herein).

Structures within the Confusion Range are predominantly contractional, and large-offset normal faulting appears to be mostly restricted to range-bounding faults adjacent to Snake Valley on the west and Tule Valley on the east. Normal faults mapped within the range generally have small displacements and do not significantly offset unit boundaries. In particular, the Ely and Kaibab Limestones as mapped by Hose (e.g., Hose, 1965a, 1965b; Hose and Repenning, 1964) have a chaotic, "shattered glass" pattern of pervasive small faults that accommodate distributed brittle deformation relative to the ductilely deforming units above and below them. These small faults are generally omitted from the cross sections.

Exposures of Oligocene lacustrine limestone with interbedded conglomerate and rhyolitic tuff (Anderson, 1983; Greene and Herring, 1998; Hintze and Davis, 2003) are present at scattered locations in the Confusion Range, for example, Toms Knoll (Hose, 1965b) and Little Mile and a Half Canyon (Hintze, 1974a). Layering in these units can be highly variable, often with steep dips and no consistent relationship to the orientation of underlying strata. In places (e.g., Little Mile and a Half Canyon, 5 km east of Conger Mountain), layering in these Tertiary limestones can be demonstrated to be concentric and nodular, related to precipitation on an irregular substrate rather than reflecting an original

Figure 4. Overturned, east-vergent, detachment fold in Kaibab Limestone exposed on the east side of Plympton Ridge. View is toward the southwest. Pa—Arcturus Formation, Pk—Kaibab Limestone, Pp—Plympton Formation. Field of view about 500 m.

paleohorizontal surface. The orientation of layering in rhyolitic tuffs deposited on irregular terrain may also commonly reflect compaction foliation rather than a paleohorizontal surface (e.g., Henry and Faulds, 2010). For these reasons, Paleozoic bedding orientations have not been corrected for the tilt of locally overlying Tertiary units, although further study may indicate that this is justified at some locations.

The focus of this study and the emphasis of the cross sections are on understanding contractional deformation in the Confusion Range. The House Range to the east was not a focus of this work, and no new field work was completed there. Three of these cross sections do, however, include the House Range in order to (1) illustrate the dramatic change in structural level between Upper Paleozoic strata in the eastern Confusion Range and Lower Cambrian strata in the adjacent House Range, and (2) provide a direct connection to the work of DeCelles and Coogan (2006), who presented a balanced cross section that extends eastward from the House Range to the Canyon Range and the Sevier frontal thrust belt.

The cross sections presented here begin in Snake Valley just west of the Confusion Range, and structures implied by the structural architecture in the range are continued on the cross sections for a few kilometers into the subsurface beneath Snake Valley. There is, however, a sharp contrast between little-extended Paleozoic strata in the Confusion Range and highly extended, predominantly Cambrian and Precambrian rocks in the northern Snake Range on the west side of Snake Valley (e.g., Gans et al., 1999a, 1999b), suggesting the presence of a major structural discontinuity in the subsurface beneath Snake Valley.

One proposal for this major discontinuity is that the northern Snake Range décollement, with up to 60 km of extensional displacement, continues from exposures on the east side of the Snake Range into the subsurface beneath Snake Valley and the Confusion Range with a dip of 15°–25° to the east (e.g., Allmendinger et al., 1983; Allmendinger, 1992; Bartley and Wernicke, 1984; Miller et al., 1999; Lewis et al., 1999). A reflector that could represent such a structure was imaged by the seismic line COCORP Utah Line 1 (Allmendinger et al., 1983). This proposal is controversial, however (e.g., Smith et al., 1991; Hintze and Davis, 2003), and in fact COCORP Nevada Line 5 in the northern Snake Valley did not image such a reflector (Hauser et al., 1987; Hintze and Davis, 2003). Borehole drilling results in Snake Valley west of the current study area do not appear to intersect any juxtapositions that would confirm the décollement (e.g., Herring, 1998a, 1998b), although boreholes further south in Snake Valley do penetrate an attenuated Lower Paleozoic section (Hintze and Davis, 2003).

Because of this uncertainty and lack of data, structures projected from the Confusion Range into the subsurface beneath Snake Valley are shown grayed out on the cross sections (Plates 2–5), and no attempt has been made in this work to correlate units or structures across Snake Valley. The constant-dip trajectory proposed by some workers for the Snake Range décollement is shown diagrammatically on the west edge of the sections to emphasize the potential conflict between the deeply rooted fold-thrust structures illustrated here and a major low-angle extensional fault at shallow depth beneath the Confusion Range.

DISCUSSION OF CROSS SECTIONS

Structural Style and Major Structures

The apparently synclinal aspect of the Confusion Range results from separate thrusts and related folds that uplift and expose Lower Paleozoic strata on the flanks of the range (Fig. 2; also see, for example, cross section D–D′, Plate 5). Contractional structures postdate the Early Triassic Thaynes Formation, which is involved in the folding, and predate late Eocene and Oligocene volcanic rocks, which are deposited unconformably on deformed Upper Paleozoic strata. Tertiary high-angle normal faults of probable Miocene age bound the range and also cut previously deformed Paleozoic strata.

The primary influence on the structural architecture of the Confusion Range is a series of frontal and lateral ramps that formed in Lower Paleozoic strata in the subsurface on the west side of the range. Frontal ramp anticlines and anticlinal duplexes resulted in uplift of Ordovician through Pennsylvanian strata on the present west edge of the Confusion Range, defined by the topographic expressions of the Salt Marsh Range, Foote Range, Knoll Hill, and Conger Range (Fig. 2; Plates 2–5).

A series of major anticlinal detachment folds, defined primarily by Ely Limestone, developed in the Upper Paleozoic section above and east of the frontal ramp anticlines. In the northern Confusion Range, the Chevron Ridge detachment fold forms a tight, east-vergent overturned anticline-syncline pair. Steeply west-dipping Ely Limestone in the overturned limb forms the prominent topographic features of Cockscomb Ridge and Chevron Ridge, and equivalent structures in the Kaibab Limestone form Plympton Ridge to the east (Fig. 4; Plates 2 and 3). A broad zone of gently dipping Upper Paleozoic and Triassic rocks is exposed east of the detachment folds. These relatively weak units are internally deformed, but no large throughgoing structures are apparent. West-dipping Lower Paleozoic units ramp to the surface under Tule Valley, and flat-lying Cambrian strata are exposed in the House Range.

In the southern Confusion Range, the Buckskin Hills detachment fold is upright and teardrop shaped, bordered by oppositely vergent synclines, and cut by the late Browns Wash thrust (Plates 4 and 5). A second thrust ramp formed east of the Buckskin Hills detachment fold, resulting in uplift and exposure of Lower Paleozoic rocks on the east side of the range. The Conger Springs anticline and Conger Mountain syncline (Fig. 5), which formed above

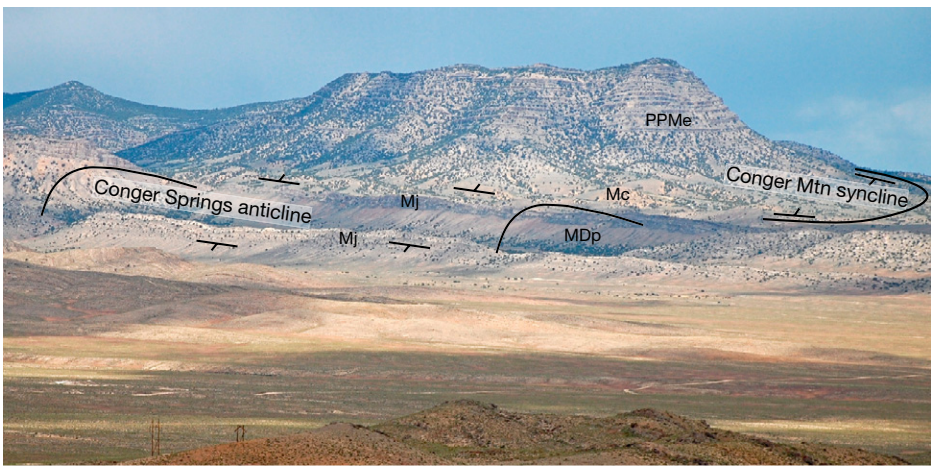

Figure 5. West side of Conger Mountain, showing the Conger Springs anticline outlined by Joanna Limestone (Mj) overlying Pilot Shale (MDp), and the Conger Mountain syncline with Ely Limestone (PPMe) overlying Chainman Formation (Mc) in the core of the fold. View is toward the northeast. Field of view about 5 km.

the thrust ramp, plunge gently northward, indicating a gently north-dipping lateral ramp that terminates at Cowboy Pass. The thrust underlying these structures is exposed on the east side of the Confusion Range as a continuous series of structures that includes the Kings Canyon thrust, the Payson Canyon thrust, and the Cattlemans Valley anticline.

On the east side of the Confusion Range and in the subsurface of Tule Valley, Lower Paleozoic strata ramp upward in a west-dipping monocline that brings Cambrian strata to the surface in the House Range. A series of westward-dipping reflectors underlying the House Range at a depth of 10–15 km are imaged on the COCORP Utah Line 1 seismic line and have been interpreted to indicate Mesozoic thrust ramps that imbricate crystalline basement (e.g., Allmendinger et al., 1983, 1986). This basement duplex was referred to as the Sevier culmination by DeCelles et al. (1995) and was incorporated into the cross sections of DeCelles and Coogan (2006). Displacement of hanging-wall rocks above the developing basement duplex probably resulted in the uplift and westward tilting now observed in Tule Valley and the House Range.

Description and Interpretation of Cross Sections

The four cross-strike cross sections A through D (Plates 2–4) are described and interpreted next, from north to south, followed by the strike-parallel cross section E (Plate 5). Locations of the cross sections are indicated on Figure 2 and Plate 1. Stages in the evolution of structures in the Confusion Range are illustrated for cross section A in the northern Confusion Range (Fig. 6) and cross section D (Fig. 7) in the southern Confusion Range. A more detailed discussion of individual structures in the cross sections may be found in Greene and Herring (2013).

Northern Confusion Range, A–A′

Cross section A–A′ (Plate 2) crosses the northern Confusion Range, extending from northern Snake Valley east across the Salt Marsh Range and Cockscomb Ridge to Tule Valley, and the base of the Middle Range.

The Salt Marsh Range forms a topographic outlier on the west edge of the northern Confusion Range that exposes gently west-dipping Devonian carbonate rocks faulted against Upper Paleozoic strata on the Salt Marsh thrust, here interpreted as a late out-of-sequence thrust that cuts a previously formed thrust duplex. Eastward, the prominent, linear Cockscomb Ridge is formed by overturned, west-dipping Ely Limestone in an overturned, east-vergent detachment fold.

The Desolation anticline was penetrated by a drill hole (52–3 on Fig. 2) that encountered a normal stratigraphy of Arcturus to Guilmette Formations (Hintze and Davis, 2003) and included a thick sheared interval that coincides with the Pilot detachment. The Disappointment Hills are cut by northwest-striking normal faults that form a graben in which Triassic Thaynes Formation and Tertiary volcanic rocks are locally preserved. Alluvium in Tule Valley obscures outcrop to the east, but exposures to the north and south indicate that west-dipping Lower Paleozoic strata underlie this northwestern corner of Tule Valley.

Structural evolution of A–A′. The primary subsurface structure in this section is a stacked duplex developed above a lower detachment in the Corset Spring Shale Member of the uppermost Orr Formation ("Orr detachment"). Four major thrust faults that form the Salt Marsh duplex are indicated in the cross section (Plate 2). Stages in the structural evolution of the duplex are illustrated in Figure 6 and are described next.

In stage 1 (Fig. 6A), the Salt Marsh A thrust developed, stepping upward from the Orr detachment level to the Eureka detachment level and forming a ramp anticline in the overlying Guilmette Formation. Initial displacement of the hanging wall is interpreted to propagate eastward out of the section at the level of the Eureka detachment. The Salt Marsh B thrust subsequently developed, breaking upward through the Lower Paleozoic section to an upper detachment in the Pilot Shale, and initiating detachment folding in the overlying Chainman Formation and Ely Limestone.

In stage 2 (Fig. 6B), the Salt Marsh C thrust developed in a break-forward pattern, ramping upward through the entire Lower Paleozoic section to the Pilot detachment level. A west-vergent back thrust in the Pilot Shale connects shortening via thrust duplication of the Guilmette Formation and Lower Paleozoic section under the Disappointment Hills with shortening via detachment folding in the Ely Limestone and Upper Paleozoic section to the west. Displacement up the Salt Marsh C thrust ramp uplifted and back-rotated hanging-wall structures developed during Salt Marsh A thrusting. Weak strata in the Upper Paleozoic section to the east (Arcturus Formation and overlying units) were uplifted and passively folded to form the Desolation anticline.

In stage 3 (Fig. 6C), the Salt Marsh D thrust formed as a late, out-of-sequence, break-back structure that uplifted Lower Paleozoic strata (Devonian Sevy and Simonson Dolomites) now exposed at the surface in the Salt Marsh Range. A Tertiary normal fault on the east edge of Snake Valley, inferred from gravity data but presently obscured by alluvium, is interpreted to have reactivated the lower part of the Salt Marsh thrust as a west-down normal fault.

Westward tilting of strata under Tule Valley may have occurred during either stage 2 or 3 and is here interpreted to have resulted from passive uplift of the Paleozoic section during formation of a thrust duplex in Precambrian crystalline basement underlying the House Range to the east, as suggested by Allmendinger et al. (1983, 1986), DeCelles et al. (1995), and DeCelles and Coogan (2006) based on interpretation of the COCORP Utah Line 1 seismic line. Westward tilting of the section under Tule Valley may have increased resistance to forward propagation of the thrust front, favoring localized out-of-sequence thrusting and duplex formation in the Salt Marsh Range.

Balance and shortening of A–A′. Cross section A–A′ shows a total of 12 km of horizontal shortening of Lower Paleozoic strata. Line length balancing indicates that shortening on two thrust duplexes in Cambrian–Ordovician strata (OCn to Oew) is balanced by folding and thrust imbrication in the Devonian strata, except for 4 km of displacement, which is interpreted to be transferred eastward on a bedding-parallel detachment at the top of the Eureka Quartzite ("Eureka detachment"). The Upper Paleozoic strata are decoupled from the strong Guilmette Formation and deform primarily by folding, with compensation by ductile flow of shales in the Chainman Formation and internal disharmonic folding in the Arcturus Formation. Line length and area balancing show that shortening of Upper Paleozoic strata is roughly equivalent to that of Devonian strata within the section.

North-Central Confusion Range, B–B′

Cross section B–B′ (Plate 3) extends from Snake Valley east-northeast across the Foote Range, Plympton Ridge, the Coyote Knolls, and Tule Valley to the east flank of the House Range. This cross section follows the same line as cross section A–A′ of Hintze and Davis (2002a).

The Foote Range is underlain by a broad, gently west-dipping block of Ely Limestone. The Bishop Springs anticline is a north-trending, doubly plunging fold that is one of a series of aligned north- to northwest-trending anticlines exposed in the valley between the Foote Range and Chevron Ridge. The No. 1 Bishop Springs anticline drill hole, located on the crest of the Bishop Springs anticline (81–2 on Fig. 2), encountered a highly faulted section consisting of repeated thrust slices of Guilmette and underlying carbonate rocks above an apparently intact Ordovician section (Hintze and Davis, 2003). The complexity in the interpretation of

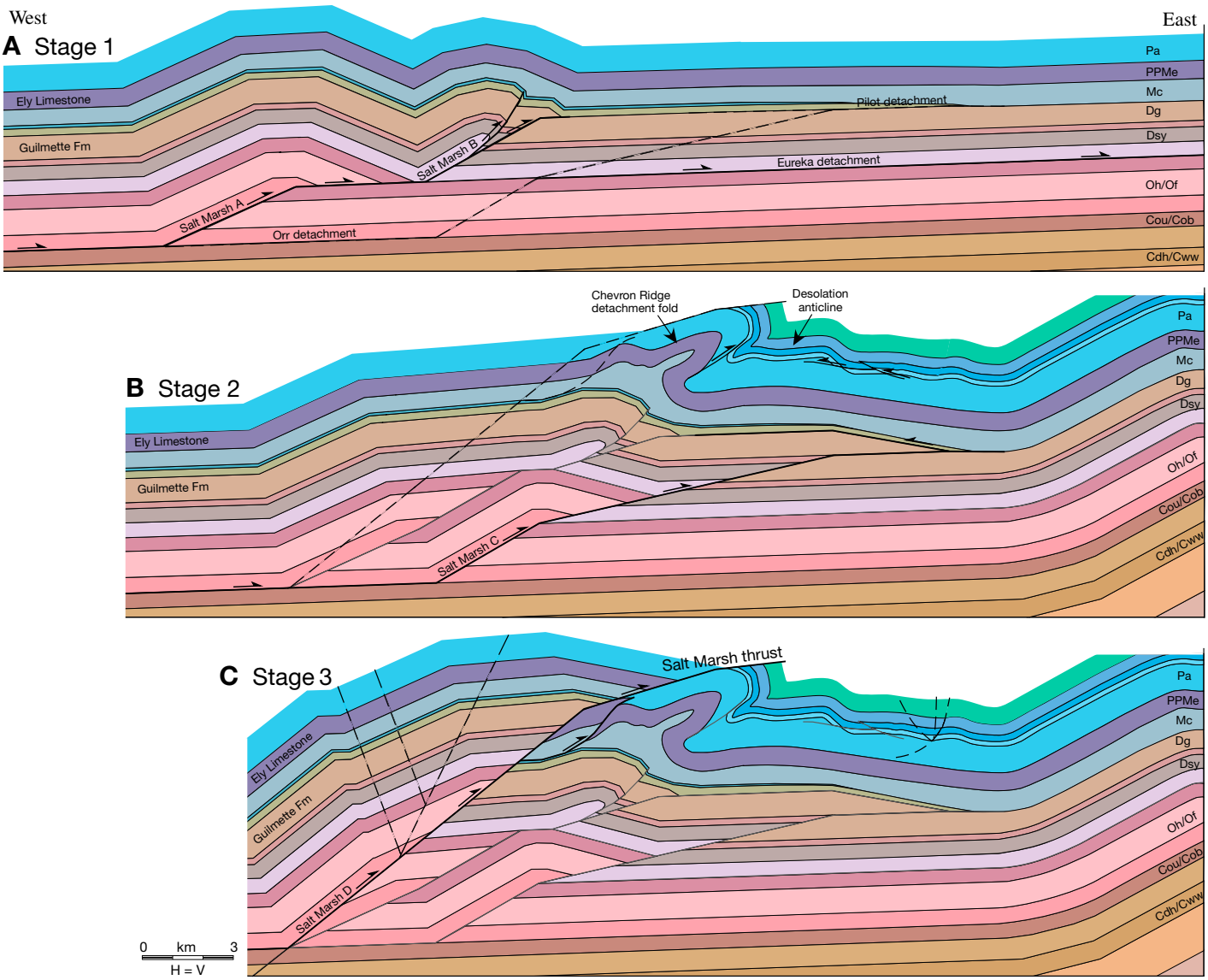

Figure 6. Stages in the evolution of structures in cross section A–A′ (Plate 2) of the northern Confusion Range. Primary active faults at each stage are shown as solid black lines, faults active in previous stage are shown as solid gray lines, and faults active in the next stage are shown as dashed lines. Four major thrust faults that form the Salt Marsh duplex are labeled Salt Marsh A, B, C, and D. Unit colors and abbreviations are as in Figure 3. See text for more detailed discussion. (A) Stage 1: Salt Marsh A thrust develops, forming a ramp anticline in overlying Paleozoic units. Initial displacement on Salt Marsh A propagates eastward out of the section at the level of the Eureka detachment. Subsequently, Salt Marsh B develops, initiating detachment folding in the overlying Chainman and Ely Formations. (B) Stage 2: Salt Marsh C thrust develops, ramping upward through the entire Lower Paleozoic section. A west-vergent back thrust connects shortening via thrust duplication of the Guilmette Formation and Lower Paleozoic section with shortening via detachment folding in the Ely Limestone and Upper Paleozoic section to the west. Displacement up the Salt Marsh C thrust ramp uplifts and back-rotates hanging-wall structures developed during Salt Marsh A thrusting. Weak strata in the Upper Paleozoic section to the east are uplifted and passively folded to form the Desolation anticline. (C) Stage 3: Salt Marsh D thrust forms as a late, out-of-sequence, break-back structure that uplifts Lower Paleozoic strata now exposed in the Salt Marsh Range. Subsequently (Plate 2), a Tertiary normal fault on the east edge of Snake Valley is interpreted to reactivate the lower part of the Salt Marsh D thrust as a west-down normal fault.

the thrust stacking here is required by the drilled sequence and exhibits the kind of subsidiary structures likely to be found widely in the subsurface of the Confusion Range but that have not been drawn into the cross sections elsewhere because direct evidence is lacking.

Chevron Ridge consists of overturned, steeply west-dipping Ely Limestone in the east limb of a tight anticlinal detachment fold that is a southward continuation of the detachment fold forming Cockscomb Ridge. Plympton Ridge is formed by tight fold repetitions of resistant Kaibab Limestone overlying ductile Arcturus Formation (Fig. 6). Complex detachment folds, as seen here, characteristically develop in the Kaibab Limestone between the ductilely deforming units that enclose it (e.g., Hose, 1974a, 1977).

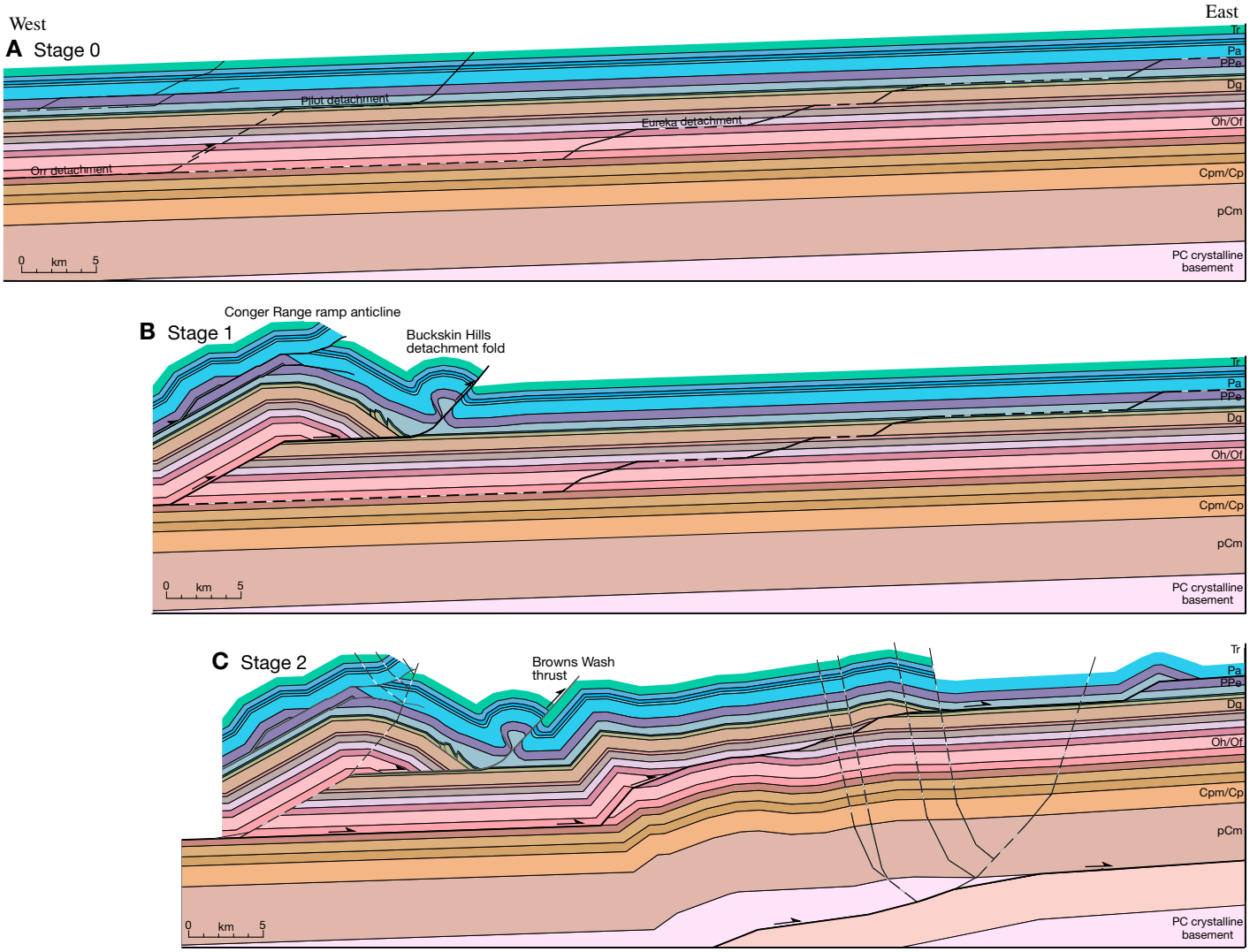

Figure 7. Stages in the evolution of structures in cross section D–D′ (Plate 5) of the southern Confusion Range. Primary active faults at each stage are shown as solid black lines, faults active in previous stage are shown as solid gray lines, and faults active in the next stage are shown as dashed lines. Unit colors and abbreviations are as in Figure 3. See text for more detailed discussion. (A) Stage 0: Stratigraphic section prior to deformation, showing inferred thrust trajectories and detachment levels. (B) Stage 1: Emplacement of Conger Range ramp anticline, with triangle zone and detachment fold forming ahead of hanging wall, and eventual breakthrough of Browns Wash thrust. (C) Stage 2: Break forward to form the Kings Canyon thrust, subsequently folded by basement duplexing in the deep subsurface beneath the House Range. Note that normal fault systems are generalized and do not fully account for complications associated with subsidence and out-of-plane motion on the east side of Tule Valley.

Subsurface structure and structural evolution of B–B′. The Foote Range ramp anticline is interpreted to repeat the Cambrian–Ordovician section (OCn to Oew) in the subsurface on the west side of the Confusion Range. Doubling of the section is required by the contrast in structural level between the Notch Peak Formation at the bottom of the Bishop Springs anticline drill hole and its projected stratigraphic position under the Disappointment Hills.

Silurian–Devonian carbonate strata above the Foote Range ramp anticline are highly faulted, with small thrusts and back thrusts accounting for stratigraphic repetitions indicated by electric and lithologic logs of the No. 1 Bishop Springs anticline drill hole. Displacement is transferred eastward on the Eureka detachment, which is inferred to intersect the ground surface at Coyote Knolls. A splay from this detachment forms a tight fault-propagation anticline in the Guilmette Formation, the crest of which is exposed as a narrow ridge on the west side of Tule Valley.

The COCORP seismic line Utah Line 1 that crossed Tule Valley 20 km to the south imaged a prominent west-dipping reflector at a depth of ~7 km that appears to merge with the House Range normal fault on the east side of Tule Valley. This reflector is inferred to be a westward-tilted segment of the Canyon Range thrust, reactivated in extension by the Tertiary House Range normal fault (e.g., Allmendinger et al., 1983; Bartley and Wernicke, 1984; DeCelles and Coogan, 2006). That interpretation is followed here, and the high-angle normal faults bounding Tule Valley are drawn intersecting and reactivating a west-dipping detachment tentatively correlated with the Canyon Range thrust of DeCelles and Coogan (2006).

Westward tilting of strata under Tule Valley probably occurred late in the contractional deformation history and is interpreted to have resulted from passive uplift of the Paleozoic section during formation of a thrust duplex in underlying Precambrian crystalline basement, as suggested by Allmendinger et al. (1983) and DeCelles and Coogan (2006) based on interpretation of the COCORP Utah Line 1 seismic line.

In the interpretation presented here, contractional deformation began with eastward displacement above the Eureka detachment (top of Oew), propagating into the section from the west. This drove initial folding and thrust faulting in the Devonian section, and initiated detachment folding in the overlying Ely Limestone.

In the next stage of deformation, displacement shifted to the lower Orr detachment (top of Cou), with eastward displacement stepping upward to the Eureka detachment. The Foote Range ramp anticline began to form at this time, driving uplift and tightening of the overlying Bishop Springs anticline in the Guilmette Formation and Chevron Ridge anticline in the Ely Limestone (Plate 3). Subsequent eastward transport of Ordovician units in the hanging wall of the ramp anticline was probably accommodated by eastward displacement on the Eureka detachment. The tight anticline in Guilmette Formation on the edge of Tule Valley may have formed during this phase, as a fault-propagation fold driven by a splay off the underlying detachment. This structure and surrounding strata underlying Tule Valley were rotated to steeper westward dips by uplift on inferred thrust duplexes in crystalline basement underlying the House Range.

Balance and shortening of B–B′. Cross section B–B′ (Plate 3) shows a total of 9 km of horizontal shortening of the Cambrian–Ordovician section in the Foote Range ramp anticline, relative to the Cambrian units below. There is 2 km of total shortening of the overlying Silurian–Devonian section in the Bishop Springs anticline, and 1 km in the anticline on the west side of Tule Valley. Thus, this interpretation implies that ~6 km of displacement is transferred eastward on the Eureka detachment, as suggested diagrammatically by a hypothetical ramp in the Guilmette Formation above the present erosion surface in Tule Valley. Total shortening indicated by the bed length of folded Ely Limestone matches that in the Guilmette Formation, as does area balancing of the ductile Chainman Formation.

South-Central Confusion Range, C–C′

Cross section C–C′ (Plate 4) extends from Snake Valley east across Knoll Hill, Conger Mountain, and Tule Valley to the east flank of the House Range.

Knoll Hill is a broad doubly plunging anticline of Ely Limestone formed by a ramp anticline in underlying Guilmette Formation. East of Knoll Hill, an anticlinal detachment fold in Ely Limestone is cored by mobile shales of the underlying Chainman Formation and bounded by oppositely vergent synclines in overlying relatively ductile Arcturus Formation. While unusual in shape compared to the symmetrical folds common in strata with more uniform bed-parallel strength, detachment folds are well known in areas where a relatively thin strong layer overlies or is enclosed in more mobile layers (e.g., Dahlstrom, 1990; Mitra, 2003; Atkinson and Wallace, 2003; Scharer et al., 2004). In this case, the relatively strong Ely Limestone is enclosed in highly mobile Chainman Formation shales below and the thick, but relatively weak, fine-grained clastic strata of the Arcturus Formation above. The Buckskin Hills detachment fold and related structures can be traced southward along the east side of the Conger Range, with an eastward, left-lateral offset across a tear fault north of Toms Knoll (Fig. 2; Plate 1).

Resistant Ely Limestone in the axis of the Conger Mountain syncline forms the southeast-facing cliffs and high plateau that underlie the summit of Conger Mountain (Fig. 5). In the eastern Confusion Range, a complex zone of imbricate thrust faults and structural attenuation (Hintze, 1974a) is part of a system of thrust faults and subsidiary folds that include the Payson Canyon and Kings Canyon thrusts to the south, and the Cattlemans Valley anticline to the north.

Structural evolution and shortening of C–C′. Total shortening in this section is estimated at 6 km, i.e., 3–6 km less than shortening to the north and south. The moderate amplitude of the Knoll Hill anticline suggests relatively small displacement on an underlying ramp anticline that repeats the Guilmette Formation. Eastward displacement of 2.5 km is interpreted to ramp upward from the Orr detachment to a flat in Sevy Dolomite, and then upward again to the Pilot detachment level at the top of the Guilmette Formation. An alternative interpretation is that this increment of displacement enters the cross section from the west at the Eureka detachment level. The Buckskin Hills detachment fold began to form at this time in front of the advancing hanging wall. Continued displacement resulted in the thrust tip cutting upward through the detachment fold, where it intersects the present ground surface as the Browns Wash thrust.

A second phase of shortening is interpreted to propagate eastward on the Orr detachment and ramp upward beneath Conger Mountain to be exposed on the east side of the Confusion Range as the Kings Canyon–Payson Canyon thrust system (Hintze and Davis, 2003). The Conger Springs anticline is here interpreted as a tight fold formed by local faulting and buckling at the top of the Guilmette Formation, associated with the thrust ramp under Conger Mountain.

Displacement of 3.5 km on the Orr detachment is distributed eastward into two faults, the Payson Canyon thrust with 1.5 km of displacement, and the Eureka detachment. The Payson Canyon thrust is a low-angle thrust with a hanging-wall ramp-on-footwall ramp relationship, including local imbrication and attenuation of units. A hypothetical thrust ramp above the present erosion surface in Tule Valley transfers 2 km of displacement on the Eureka detachment upward to the Upper Paleozoic section.

The structures illustrated form a simple break-forward thrust system, with primary displacement on the basal Orr detachment ramping upward first under Snake Valley to form the Knoll Hill anticline and Browns Wash thrust, and then propagating eastward to ramp up under Conger Mountain and form the Payson Canyon thrust, with further eastward propagation of displacement on the Eureka detachment, ramping upward into the Upper Paleozoic section.

Lower Paleozoic units above the Orr detachment are line length balanced. Upper Paleozoic units (e.g., Ely Limestone) average ~3% shorter in line length due to internal shortening not resolved at the scale of the cross section (Greene and Herring, 2013).

Southern Confusion Range, D–D′

Cross section D–D′ (Plate 5) extends from the Nevada-Utah state boundary east-southeast across Snake Valley, the Conger Range, the eastern escarpment of the Confusion Range, and the southern end of Tule Valley. The interpretation presented here may be compared with that of line C–C′ of Hintze and Davis (2002a), which approximately parallels this section line 1–3 km to the north.

Low pediment outcrops of Upper Paleozoic units up to 6 km west of the Conger Range frontal scarp are poorly exposed and structurally complex, with steep dips and numerous juxtapositions of noncontiguous units. The seemingly chaotic units are interpreted to be extensional fault blocks in the hanging wall of the Conger Range fault that were previously deformed by Mesozoic folding and thrust faulting. The Conger Range is similar to the Salt Marsh Range in that it is an isolated, structurally and topographically high block of older Silurian and Devonian rocks faulted against younger Upper Paleozoic units on the west edge of the Confusion Range.

The northwest-trending portion of the Conger Range fault as presently exposed is a normal

fault with ~7 km of west-down displacement. It is inferred to intersect and reactivate the ramp and lower flat segments of a previous thrust fault that emplaced the Lower Paleozoic Conger Range block as a hanging-wall ramp anticline above a detachment in Pilot Shale (Dubé and Greene, 1999). Thus, the Conger Range is interpreted as the truncated, east-dipping forelimb of a ramp anticline that formed in the Lower Paleozoic carbonate section, rising from a basal detachment in the Upper Cambrian Orr Formation to an upper detachment in the Pilot Shale.

In front of the advancing hanging wall, the Buckskin Hills detachment fold formed in the overlying Ely Limestone, cored by mobile shales of the Chainman Formation and with oppositely vergent synclines in Arcturus Formation on either side. The detachment fold was tightened and then cut by the Browns Wash thrust, closely juxtaposing the east- and west-vergent synclines.

Gently west-dipping Lower Paleozoic carbonate units on the east side of the Confusion Range are cut by the Kings Canyon thrust. A series of northeast-dipping normal faults and the steeply southwest-dipping House Range normal fault form the southern end of Tule Valley, here floored by bedrock at shallow depths.

Structural evolution of D–D′. Stages in the evolution of this cross section are illustrated in Figure 7. Inferred thrust trajectories prior to deformation are shown in Figure 7A and indicate a break-forward system with successive thrusts progressing eastward and up section.

In stage 1 (Fig. 7B), initial displacement propagating eastward into the section at the level of the Pilot and Chainman shales resulted in imbrication of the Ely Limestone and shortening of the Upper Paleozoic section. Subsequent eastward displacement on the underlying Orr detachment ramped upward through the entire Paleozoic carbonate section to the upper Pilot-Chainman detachment zone, producing a large ramp anticline cored by Lower Paleozoic carbonate units. Continued thrust imbrication and folding in the Ely Limestone preceded and accompanied shortening in the Lower Paleozoic section, connected by a west-vergent back thrust at the leading edge of the ramp anticline.

The Buckskin Hills detachment fold developed in the Ely Limestone in front of the advancing hanging-wall block. Continued advance of the hanging-wall block first tightened the detachment fold, and then resulted in propagation of the thrust tip upward, cutting and displacing the east limb of the fold.

Subsequently (stage 2, Fig. 7C), displacement on the basal Orr detachment propagated eastward and ramped upward to the upper Eureka detachment, presently exposed on the east side of the Confusion Range as the Kings Canyon thrust. Uplift resulting from thrust duplexes in the crystalline basement below tilted the entire Lower Paleozoic section, including the Kings Canyon thrust, to steeper westward dips.

Finally, steeply dipping Tertiary normal faults developed on the flanks of the range, forming the Tule Valley graben and the east edge of Snake Valley (Plate 5). The Conger Range normal fault reactivated the lower ramp segment of the Browns Wash thrust, cutting the previously formed ramp anticline and leaving the Conger Range as a high-standing block of Lower Paleozoic strata on the west edge of the Confusion Range.

Balance and shortening of D–D′. Total shortening of the Lower Paleozoic section during formation of the Conger Range ramp anticline was ~9.5 km. Equivalent shortening in the Upper Paleozoic section during this time was divided among the Browns Wash fault, the Buckskin Hills detachment fold, and imbrication of Ely Limestone and overlying units on the west limb of the Conger Range ramp anticline.

Subsequent displacement on the Kings Canyon thrust resulted in an additional 2.5 km of shortening in Ordovician and Silurian strata. Thus, total shortening across the Confusion Range along this cross section line is ~12 km.

This cross section is fully restorable, as illustrated in Figure 7, although some degree of rotation and internal deformation is assumed in normal fault blocks. Because units move both into and out of the section at various stratigraphic levels on the west edge, the section cannot be internally line balanced. Shortening in Lower Paleozoic units is compatible with that illustrated in Upper Paleozoic units, however, and area balancing of distributed ductile flow in the Chainman Formation indicates shortening comparable to the overlying folded Ely Limestone.

Strike-Parallel Cross Section of the Confusion Range, E–E′

Cross section E–E′ (Plate 6) illustrates the structure in a strike-parallel transect along the west side of the Confusion Range from northern Snake Valley to the Ferguson Desert, crossing the Salt Marsh Range, the Foote Range, Knoll Hill, and the Conger Range. This cross section ties together the four transverse cross sections (A–A′, B–B′, C–C′, and D–D′) while emphasizing the location of lateral ramps that form an important component of the regional structure. The section is drawn approximately perpendicular to transport direction, with displacement predominantly top-to-the-east, into the plane of the section. Thus, this section cannot be balanced.

The structures illustrated are predominantly bedding-parallel detachments with hanging-wall flat–on–footwall flat relationships that developed as eastward-transported thrust sheets climbed up a series of footwall ramps underlying the west edge of the Confusion Range. Lateral changes in the number of thrust slices or the location and height of the frontal ramp control the stratigraphic level exposed at the surface.

The section obliquely cuts the Salt Marsh thrust and underlying duplex, which are responsible for uplift and exposure of older Devonian rocks in the Salt Marsh Range, as illustrated in more detail on cross section A–A′ (Plate 2). Southeast of the Salt Marsh Range, the section follows the strike of the Foote Range, a gently west-dipping ridge of Ely Limestone. Knoll Hill also exposes Ely Limestone, in a ramp anticline resulting from repetition of Devonian Guilmette Formation with a hanging-wall ramp–on–footwall flat relationship.

In the Conger Range, Lower Paleozoic rocks are exposed in a ramp anticline above a westward-protruding footwall ramp, as illustrated in section D–D′ (Plate 5). Lateral ramps bound the Conger Range on the north and south. A major normal fault bounding the north and northwest sides of the Conger Range reactivates the preexisting lateral and frontal ramps (Dubé and Greene, 1999; Yezerski and Greene, 2009). The east-striking lateral ramp on the north side of the Conger Range forms a significant transverse structural break that continues eastward to offset Ely Limestone in the Buckskin Hills with an apparent left-lateral sense.

REGIONAL STRUCTURAL INTERPRETATION

Snake Range Décollement and the Confusion Range

The Confusion Range lies 15 km east of the northern Snake Range across Snake Valley, (Fig. 1), but whereas the Confusion Range exposes unmetamorphosed, little-extended Paleozoic strata, the northern Snake Range is a classic metamorphic core complex, with a low-angle normal fault, the northern Snake Range décollement, that juxtaposes a highly extended, brittlely deformed upper plate consisting of Paleozoic and Tertiary strata against a ductilely thinned lower plate consisting of predominantly Cambrian and Precambrian strata (Armstrong, 1972; Gans and Miller, 1983; Miller et al., 1983, 1999; Bartley and Wernicke, 1984; Lee, 1995; Sullivan and Snoke, 2007). Metamorphosed footwall rocks record burial depths of 25–30 km (e.g., Lewis et al., 1999; Cooper et al., 2010a).

The Confusion Range lies east of and apparently in the hanging wall of the east-dipping northern Snake Range décollement, which

is well exposed on the east side of the Snake Range (Gans et al., 1999a, 1999b; Cooper et al., 2010b). COCORP Utah Line 1 and cross sections derived from these data imply that a planar detachment surface with a constant dip of 15°–25° and up to 60 km of extensional displacement continues from exposures on the east side of the northern Snake Range into the subsurface beneath Snake Valley and the Confusion Range (e.g., Allmendinger et al., 1983; Allmendinger, 1992; Bartley and Wernicke, 1984; Miller et al., 1999; Lewis et al., 1999; Niemi et al., 2004). If the northern Snake Range décollement is indeed shallowly dipping and planar, then the Paleozoic sedimentary rocks of the Confusion Range are shallow and "rootless," riding in the hanging wall of the northern Snake Range décollement, and underlain at depths of as little as 5 km by midcrustal metamorphic and igneous rocks similar to footwall rocks exposed in the Snake Range. In this case, much of the Mesozoic fold-thrust structure illustrated in the cross sections presented here would not actually be present in the subsurface, having been "beheaded" and left in the footwall up to 60 km to the west.

Alternatively, the northern Snake Range décollement may not be continuously planar and shallow dipping, but instead may steepen with depth beneath Snake Valley, possibly offset on range-bounding normal faults that contribute to the present topography and depth of valley fill (e.g., Hintze and Davis, 2003) and/or reflecting a larger component of vertical displacement as suggested by rolling hinge and diapiric models of core complex formation (e.g., Lee, 1995; Cooper et al., 2010a; Konstantinou et al., 2012).

In either case, structures presently exposed in the Confusion Range were formed in a Mesozoic fold-thrust belt that probably involved the entire Upper Proterozoic to Paleozoic continental margin stratigraphic section and underlying crystalline basement. In the subsurface beneath the Confusion Range, this fold-thrust belt may be (1) presently intact in its present location; (2) cut off by the northern Snake Range décollement at relatively shallow depths (5–8 km) and completely displaced from a former root zone up to 60 km to the west; or (3) intact to some intermediate depth (~8–10 km), with the northern Snake Range décollement perhaps merging with the trace of former Mesozoic thrust detachment horizons.

Western Utah Thrust Belt

This study shows that the Confusion Range is an east-vergent fold-thrust system with 10 km or more of shortening, rather than a structural trough or synclinorium with minimal shortening as portrayed on many regional compilations (e.g., Hose, 1977; Anderson, 1983; Gans and Miller, 1983; Smith et al., 1991; Allmendinger, 1992; DeCelles, 2004; Rowley et al., 2009; Long, 2012). Fold-thrust structures and structural style are continuous from the Confusion Range southward into the Burbank Hills and Mountain Home Range (Hintze, 1986a, 1986b, 1997; Hintze and Best, 1987; Hintze and Davis, 2002b), indicating a fold-thrust belt with a strike length of more than 130 km (Fig. 8). Thus, the "Confusion Range synclinorium" of previous authors is a fold-thrust belt of regional extent, herein named the western Utah thrust belt.

South of the Mountain Home Range, Paleozoic rocks and structures are buried by Tertiary volcanic rocks of the Indian Peak caldera, but structural trends (e.g., Steven et al., 1990) and subcrop stratigraphic patterns (Long, 2012) suggest that the thrust belt intersects the Wah Wah thrust and related structures of the Sevier frontal thrust belt near the south end of the Indian Peak Range (Fig. 8).

North of the Confusion Range, the continuation of the thrust belt is uncertain, as north-northwest–trending structures are obscured by Cenozoic cover in northern Snake Valley and appear to terminate against Tertiary normal faults bounding Neoproterozoic strata on the west edge of the Deep Creek Range. However, Mesozoic contractional structures possibly related to this thrust belt have been reported in the Deep Creek Range (Rodgers, 1989; Nutt and Thorman, 1994), and the Gold Hill area (Nolan, 1935; Robinson, 1993) to the north, and in the Cedar Mountains (Moore and Sorensen, 1979; Clark et al., 2012) to the northeast. If 47 km of top-to-the-west displacement on the Sevier Desert detachment (DeCelles and Coogan, 2006) is restored (see further discussion on restoration of extension in a following section), Upper Paleozoic rocks and structures in the Confusion Range align with the similar Upper Paleozoic strata and fold-thrust structures in the Cedar Mountains to the north (Fig. 8). These structural correlations to the north and south suggest that the western Utah thrust belt is a coherent fold-thrust belt that diverges from the Sevier frontal thrust belt in southwestern Utah and can be traced for at least 250 km northward into west-central Utah.

The western Utah thrust belt is comparable in size and structural style to the central Nevada thrust belt, located 175 km to the west in east-central Nevada (Fryxell, 1988; Speed et al., 1988; Taylor et al., 1993, 2000; DeCelles, 2004; Long, 2012). The central Nevada thrust belt is a narrow, generally north-striking zone of thrust faults and related folds that involve rocks as young as Permian. Timing constraints are minimal, but deformation was probably active between Late Jurassic and Middle Cretaceous time (Taylor et al., 1993, 2000; DeCelles, 2004).

The central Nevada thrust belt is exposed for 250 km along strike in south-central Nevada, and correlation with structures as far north as the Adobe Range extends the strike length to greater than 400 km (Taylor et al., 2000). Maximum total shortening across the central Nevada thrust belt is 10–15 km (Taylor et al., 1993, 2000; DeCelles, 2004), similar to that documented here for the Confusion Range segment of the western Utah thrust belt.

A notable difference between the central Nevada and western Utah thrust belts, however, is that the western Utah thrust belt coincides with a regional structural low (Confusion Range structural trough of Hose, 1977), where rocks as young as Early Triassic are preserved, and erosional exhumation was apparently generally low, in the range of 1–3 km according to Long (2012). The central Nevada thrust belt, in contrast, appears to be a zone of high structural

Figure 8 (*on following page*). Generalized geologic map of eastern Nevada and western Utah showing regional structures associated with Mesozoic fold-thrust deformation. Box indicates the location of Figure 2. Fold-thrust structures in the Confusion Range (CR) continue southward into the Burbank Hills (BH) and Mountain Home Range (MHR) and are interpreted to merge with the Wah Wah thrust (WWt) and the Sevier frontal thrust belt at the south end of the Indian Peak Range (IPR). Northward, restoration of 47 km of extension on the Sevier Desert detachment brings fold-thrust structures in the Confusion Range into alignment with similar structures in the Cedar Mountains (CM). AR—Adobe Range, BH—Burbank Hills, BCt—Broad Canyon thrust, CM—Cedar Mountains, CR—Confusion Range, Ct—Cedar thrust, CYR—Canyon Range, CYRt—Canyon Range thrust, DCR—Deep Creek Range, ER—Egan Range, GH—Gold Hill, GPt—Gass Peak thrust, IPC—Indian Peak caldera, IPR—Indian Peak Range, MHR—Mountain Home Range, PM—Pequop Mountains, RMt—Roberts Mountains thrust, SCR—Schell Creek Range, SDB—Sevier Desert Basin, SR—Snake Range, SVt—Skull Valley thrust, TVt—Tintic Valley thrust, WPR—White Pine Range, WWt—Wah Wah thrust. Map is adapted from Hintze (1974c), Stewart and Carlson (1977), Hintze and Kowallis (2009), and Long (2012).

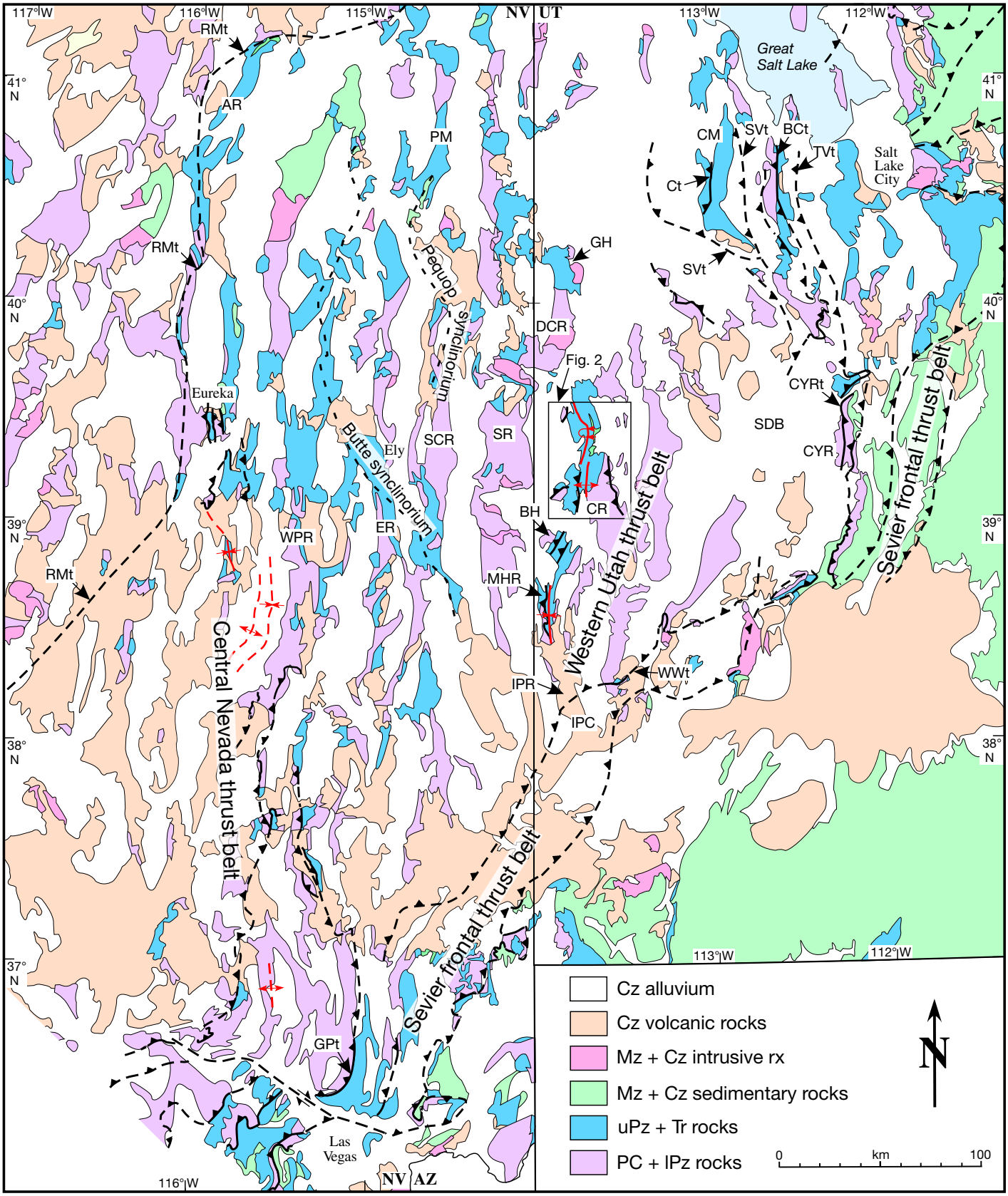
117°W
116°W
115°W
113°W
112°W
41° N
40° N
39° N
38° N
37° N
NV
UT
NV
AZ
Great Salt Lake
Salt Lake City
Eureka
Ely
Las Vegas
RMt
AR
PM
CM
SVt
BCt
TVt
Ct
GH
DCR
Fig. 2
CR
SDB
CYRt
CYR
SCR
SR
BH
MHR
WPR
ER
IPR
IPC
WWt
GPt
Pequop synclinorium
Butte synclinorium
Western Utah thrust belt
Sevier frontal thrust belt
Central Nevada thrust belt
Cz alluvium
Cz volcanic rocks
Mz + Cz intrusive rx
Mz + Cz sedimentary rocks
uPz + Tr rocks
PC + lPz rocks
N
0
km
100

Figure 8.

relief with erosional exhumation in the range of 4–6 km (Long, 2012). This fits with the observations of Taylor et al. (1993, 2000), who noted that thrust faults in the central Nevada thrust belt are characteristically steeply dipping with large stratigraphic throws.

Taylor et al. (2000) correlated the southern end of the central Nevada thrust belt with the Gass Peak thrust in the Sevier frontal thrust belt in southern Nevada and suggested that these are linked, with the central Nevada thrust belt as an internal branch of the Sevier thrust belt. The western Utah thrust belt fits well into this framework, as a similar north-south–striking zone of localized contractional deformation involving the Paleozoic miogeoclinal section, which merges southward with the northeast-striking Sevier frontal thrust belt.

Timing constraints are presently insufficient to distinguish with certainty whether these two thrust belts were active at the same time as shortening in the Sevier frontal thrust belt in Early Cretaceous to Eocene time (DeCelles and Coogan, 2006), or whether deformation was sequential from west to east, with the central Nevada and western Utah thrust belts transitioning from "foreland" to "hinterland" positions as the locus of contractional deformation swept eastward (Taylor et al., 2000).

Western Utah Thrust Belt and the Sevier Hinterland

Eastern Nevada and western Utah, west of the Sevier frontal thrust belt, are often referred to as the Sevier hinterland, envisioned as a little-deformed interior zone between the Sevier frontal thrust belt and the Sierra Nevada magmatic arc (Armstrong, 1968, 1972; Gans and Miller, 1983; Miller and Gans, 1989; DeCelles, 2004; Drushke et al., 2011; Long, 2012). This definition of the hinterland is based primarily on regional map compilations showing the stratigraphic level of Paleozoic rocks exposed under a regional Paleogene unconformity (Armstrong, 1972; Gans and Miller, 1983; Konstantinou et al., 2012; Long, 2012) and interpreted to indicate little structural relief and therefore little deformation across a broad region of eastern Nevada and western Utah, between the central Nevada thrust belt on the west and the Sevier frontal thrust belt on the east. However, these compilations highlight broad regional patterns at the expense of local detail involving individual structures with shortening in the range of 1–3 km. The methods used emphasize the youngest strata preserved, but they commonly do not resolve adjacent structural highs, thus possibly obscuring multiple localized fold-thrust systems with significant cumulative deformation.

For instance, the Confusion synclinorium of previous authors (e.g., Hose, 1977; Anderson, 1983; Hintze and Davis, 2003; Long, 2012), considered a zone of little deformation, is coincident with the zone of localized folding and thrusting in the Confusion Range that is documented in this study. The Pequop and Butte synclinoria of Long (2012) are also coincident with zones of large-scale folding of Upper Paleozoic strata (e.g., Brokaw, 1967; Brokaw and Barosh, 1968; Hose et al., 1976; Fraser et al., 1986; Coats, 1987; Gans et al., 2011). Radar Ridge, in the Egan Range northwest of Ely, is located on the northeast flank of the Butte synclinorium, or structural trough, of Hose et al. (1976) and Long (2012). As mapped by Brokaw and Barosh (1968), Radar Ridge forms the overturned limb of an anticlinal detachment fold in Ely Limestone cored by Chainman Formation shales, closely analogous to Chevron Ridge and the Chevron Ridge detachment fold in the northern Confusion Range. In both Radar Ridge and Chevron Ridge, shortening in excess of 4 km is required to restore bed length in the Ely Limestone to prefolding geometry. Similarly, in the Pequop synclinorium, steep to overturned west-vergent folds in Upper Paleozoic strata in the southern Pequop Mountains (Fraser et al., 1986) show that Triassic strata are preferentially preserved in a structural low that was the locus of significant Mesozoic contractional deformation.

Thus, far from being zones with the lowest overall deformation, the identified synclinoria in previous studies appear to be zones of concentrated Mesozoic shortening, and they are likely the expression of subsurface thrust systems in Lower Paleozoic strata, commonly represented at the present erosion level as zones of detachment folding in Upper Paleozoic strata. Also, while the Sevier hinterland in east-central Nevada and west-central Utah appears to lack regional-scale surface-breaking thrust faults comparable to the Canyon Range and Pavant thrusts in the Sevier frontal thrust belt, the "hinterland" was not an undeformed region during Jurassic to Eocene Cordilleran deformation, but was instead a region of significant contractional deformation distributed across at least three zones of folding and thrusting.

Restoration of Cenozoic Extension and Relation to the Sevier Frontal Thrust Belt

Mesozoic upper-crustal shortening occurred across a broad region, from at least east-central Nevada to central Utah, that was subsequently dismembered by Cenozoic extension (e.g., Bartley and Gleason, 1990; Stuart and Taylor, 1997). Restoration of this extension reduces the original width of the orogenic belt and indicates that the individual thrust systems were closer together, and more closely related, than is apparent in their present configuration.

The Confusion Range is presently located 120 km west of the Canyon Range (Fig. 8), where the Canyon Range thrust, the oldest and structurally highest thrust of the Sevier frontal thrust belt in central Utah, is exposed (DeCelles et al., 1995; Mitra and Sussman, 1997; DeCelles and Coogan, 2006). Between these two ranges lies the Sevier Desert basin, which is underlain by the shallow, west-dipping Sevier Desert detachment, generally thought to have accommodated ~47 km of Tertiary extension (e.g., Coogan and DeCelles, 1996; DeCelles and Coogan, 2006; but see also Anders et al., 2012). When displacement on the Sevier Desert detachment is restored, folds and associated thrusts in the Confusion Range are located ~75 km west of the Canyon Range thrust, the west edge of the exposed Sevier frontal thrust belt (Fig. 9).

The Confusion Range lies 15 km east of the Snake Range, in the hanging wall of the east-dipping Snake Range décollement, which exposes metamorphosed midcrustal rocks in its footwall and shows evidence of large-scale extensional detachment (e.g., Bartley and Wernicke, 1984; Sullivan and Snoke, 2007). The unmetamorphosed Paleozoic strata of the Confusion Range likely originally formed the cover rocks to the Snake Range.

The structural history and amount of extension represented by the Snake Range core complex and décollement are not well understood (Miller et al., 1983; Bartley and Wernicke, 1984; McGrew, 1993; Lee, 1995; Lewis et al., 1999; Miller et al., 1999; Sullivan and Snoke, 2007; Cooper et al., 2010b), but extension is likely substantial. Bartley and Wernicke (1984) and Wernicke (1992) suggested that total extension associated with the Snake Range and adjacent Schell Creek and Egan Ranges was ~75 km. Restoration of this displacement, placing Paleozoic strata of the Confusion Range adjacent to similar-age rocks in the Egan Range, locates the western Utah thrust belt in the Confusion Range only 50 km east of structures in the White Pine Range correlated with the central Nevada thrust belt (Fig. 9).

Given these restorations, it is clear that the Sevier thrust belt in the east-central Basin and Range originally consisted of a frontal zone, where major thrusts with 50–100 km of displacement breached the surface (e.g., Canyon Range and Pavant thrusts; DeCelles and Coogan, 2006), and a hinterland zone, characterized by more distributed fold-thrust systems, with three or more thrust belts (central Nevada, Butte "synclinorium," and western Utah), each accommodating on the order of 10 km of shortening

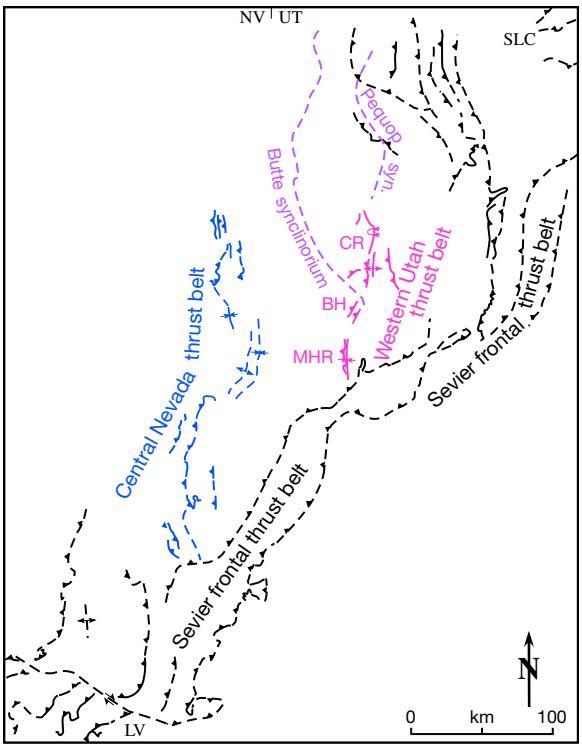

Figure 9. Simplistic restoration of 45 km of Tertiary extension on the Sevier Desert detachment and 75 km of extension across the Snake Range core complex and adjacent ranges yields a coherent Mesozoic fold-thrust belt consisting of a frontal zone, where major thrusts with 50–100 km of displacement breached the surface (Sevier frontal thrust belt), and a hinterland zone, characterized by more distributed fold-thrust belts, with three or more thrust belts (central Nevada, Butte "synclinorium," and western Utah) each accommodating on the order of 10 km of shortening. BH—Burbank Hills, CR—Confusion Range, MHR—Mountain Home Range. Locations of Las Vegas (LV), Salt Lake City (SLC), and the Nevada (NV)–Utah (UT) border are shown in present geographic coordinates for reference. Structural traces were adapted in part from Stewart and Carlson (1977), Hintze and Kowallis (2009), and Long (2012).

(Fig. 9). Large thrust displacements and surface-breaching faults in the frontal zone created high topographic and structural relief, as indicated by structural culminations, high exhumation, and foreland basins with coarse synorogenic clastic fill (DeCelles et al., 1995; Currie, 2002; Long, 2012). In the hinterland west of the frontal zone, folding and predominantly subsurface thrust faulting broadly distributed in regional thrust belts thickened the crust and maintained relatively high elevation (3–4 km) but low topographic relief (DeCelles, 2004; Best et al., 2009; Henry et al., 2012).

This Mesozoic to early Cenozoic Sevier hinterland plateau, often referred to as the Nevadaplano, has been compared to the modern Altiplano-Puna Plateau in the central Andes Mountains, in that both are high-elevation plateaus with unusually thick crust formed in a contractional retroarc tectonic setting (e.g., Coney and Harms, 1984; DeCelles, 2004; Long, 2012). However, as emphasized by Long (2012), significantly more total uplift and structural relief are evident in the central Andean plateau as compared to the Sevier hinterland plateau. In the Altiplano, complex synorogenic deformation has resulted in greater than 12 km of structural relief (McQuarrie, 2002; Long, 2012), whereas contractional deformation in the interior of the Sevier plateau, while probably widespread, appears to have maintained more uniform topography and structural relief of less than 5 km.

In summary, the Cordilleran thrust belt in east-central Nevada and west-central Utah was originally a more coherent and closely spaced series of regional fold-thrust belts, with less distinction between a narrow frontal thrust zone and a little-deformed hinterland. It was perhaps more similar to the present Sevier thrust belt north of the Sevier Desert Basin, where the Skull Valley, Cedar, and Broad Canyon thrust systems are exposed in a broad 75-km-wide zone west of the Tintic Valley–Canyon Range thrust system, which forms the west edge of the Sevier frontal thrust belt (Morris, 1983; Tooker, 1983; Long, 2012).

CONCLUSIONS

The Confusion Range in west-central Utah has previously been considered to be a broad structural trough or synclinorium with little overall shortening. However, new balanced cross sections across the range and adjacent Tule Valley indicate that the Confusion Range is more accurately characterized as an east-vergent, fold-thrust system with significant (~10 km) horizontal shortening during Late Jurassic to Eocene Cordilleran contractional deformation.

Subsurface structure is dominated by a series of frontal and lateral ramps in Lower Paleozoic strata on the west side of the range. Ramp anticlines and anticlinal duplexes characteristic of Lower Paleozoic strata are balanced by faulted and rotated detachment folds in Upper Paleozoic strata, with a major detachment zone in shales of the Chainman and Pilot Formations. The apparently synclinal aspect of the Confusion Range results from two different sets of thrust structures that uplift and expose Lower Paleozoic strata on the flanks of the range. The east-dipping Snake Range décollement, with top-to-the-east displacement possibly exceeding 60 km, projects under the Confusion Range at a depth of 5–10 km or more, and may truncate deeper-level structures of the fold-thrust belt.

Similar styles and timing of contractional deformation to the south in the Burbank Hills and Mountain Home Range indicate that the Confusion Range forms part of a Mesozoic fold-thrust belt with a strike length of greater than 130 km, here named the western Utah thrust belt. More speculative correlations with structures to the north in the Cedar Mountains suggest that the western Utah thrust belt may have originally formed a coherent thrust belt more than 250 km in length.

The western Utah thrust belt merges with the Wah Wah thrust and related structures of the Sevier frontal thrust belt near the south end of the Indian Peak Range. This newly recognized western Utah thrust belt is similar in size and structural style to the central Nevada thrust belt. Together, these thrust belts and related structures in eastern Nevada indicate significant, broadly distributed Mesozoic shortening. The Sevier hinterland is thus not an undeformed interior zone as originally envisioned, but instead preserves an important component of Mesozoic fold-thrust deformation in the Cordilleran orogen.

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