EVIDENCE FOR LATE CRETACEOUS-EARLY TERTIARY(?) EXTENSION IN THE PEQUOP MOUNTAINS, NEVADA: IMPLICATIONS FOR THE NATURE OF THE EARLY TERTIARY UNCONFORMITY

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ABSTRACT

The northern Pequop Mountains, in the Sevier hinterland in northeast Nevada, contain evidence for a substantial amount of structural relief beneath a regional early Tertiary unconformity due to a period of large-magnitude Late Cretaceous or early Tertiary normal faulting. Mesozoic to Cenozoic tectonic reconstructions of the Sevier hinterland often rely on inferences of Mesozoic to early Tertiary paleogeography, which are derived from geologic relationships beneath an early Tertiary unconformity that separates mid-Tertiary volcanic rocks from unmetamorphosed upper Paleozoic and Mesozoic strata. Because the volcanic rocks tend to depositionally overlie upper Paleozoic or Mesozoic rocks with little angular discordance, it is commonly assumed that little structural or erosional relief occurs across the unconformity. Moreover, it is commonly assumed that large-magnitude extension involving surface-breaking faults postdates the unconformity.

New geologic mapping in the northern Pequop Mountains reveals the presence of a pre-unconformity Cretaceous or early Tertiary low-angle normal fault (Pequop fault) that juxtaposes two different Paleozoic sections that were previously duplicated by thrust faulting. Upper Paleozoic strata in the footwall and hanging wall of the Pequop fault are depositionally overlapped by a mid-Tertiary (41-39 Ma) volcanic sequence with little angular discordance. Based on reconstruction, the Pequop fault exhumed upper Paleozoic rocks from a mid-crustal structural depth of ~ 11 km. Both the mid-crustal footwall rocks and upper-crustal upper Paleozoic rocks in the hanging wall of the Pequop fault lie directly beneath the unconformity. These data emphasize (1) that although the mid-Tertiary volcanic sequence commonly lies depositionally on upper Paleozoic rocks, significant upper crustal structural relief existed prior to the development of the early Tertiary unconformity in this region, (2) that there existed a pre-unconformity extensional event that was comparable in magnitude to post-unconformity extension, and (3) a need to reevaluate Mesozoic and early Tertiary tectonic models for the Sevier hinterland that require no major surface-breaking normal faults.

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INTRODUCTION

One of the least structurally understood parts of the Sevier orogen (Fig. 1) is its hinterland in eastern Nevada. This part of the hinterland contains an ~ 12-km-thick miogeoclinal sequence of Precambrian to Mesozoic strata that is deformed by Mesozoic contractional structures that are overprinted by Cenozoic normal faults. Complex overprinting of contractional and extensional structures has confounded the structural history, and hence, attempts to reconstruct and understand Tertiary to Mesozoic structures often require relying on many assumptions. In particular, assumptions are commonly made about the pre-Tertiary geology based largely on structural and stratigraphic relations beneath sparse exposures of a regional early Tertiary unconformity. This paper focuses on the nature of this unconformity in the northern Pequop Mountains (Fig. 1) and reveals that some important geologic assumptions derived from the nature of the unconformity, that are used in tectonic reconstructions, need to be reevaluated.

The hinterland of the Sevier thrust belt in eastern Nevada experienced at least two phases of contractional deformation and metamorphism during the Late Jurassic and Cretaceous (Miller and others, 1988; Snoke and Miller, 1988; Miller and Gans, 1989; Thorman and others, 1991; Camilleri and Chamberlain,

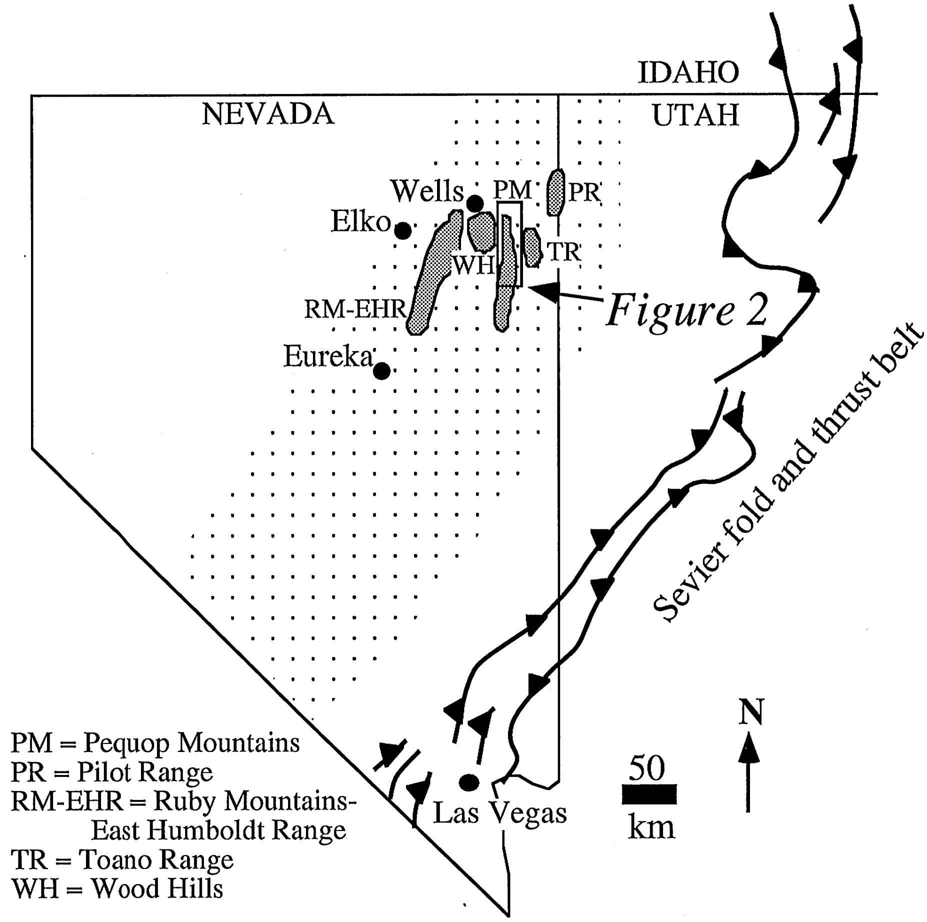


Figure 1. Map showing position of the Sevier fold and thrust belt and location of the Pequop Mountains. Stippled region represents that portion of the Sevier hinterland which is referred to in this paper.

in press). Widespread, mid-Tertiary (mid-Eocene-Oligocene) volcanism followed Mesozoic deformation and signaled the inception of large-magnitude Cenozoic extension (Armstrong, 1968; Gans and Miller, 1983; Gans and others, 1989). Young (1960), Moores and others (1968), and Armstrong (1968) pointed out that the mid-Tertiary volcanic rocks commonly overly upper Paleozoic or Mesozoic strata with little angular discordance. The unconformity separating the mid-Tertiary volcanic rocks and upper Paleozoic-Mesozoic rocks is commonly referred to as the "early Tertiary unconformity" (e.g., Gans and Miller, 1983). Armstrong (1968) used relationships beneath the early Tertiary unconformity to infer that hinterland Mesozoic-early Tertiary paleogeology dominantly consisted of gently folded upper Paleozoic and Mesozoic rocks. Armstrong (1968) also suggested that large-magnitude extension involving surface-breaking faults postdated the unconformity. Subsequent workers have used Armstrong's premises as constraints in developing Mesozoic and Cenozoic tectonic models and paleogeographic reconstructions (e.g., Gans and Miller, 1983; Miller and Gans, 1983; Miller and others, 1988; Bartley and Wernicke, 1984; Snoke and Miller, 1988; Thorman and others, 1991; Hodges and Walker, 1992; Miller and Hoisch, 1992; Thorman and others, 1992; Thorman and others, 1993). These models employ the assumption that there was little erosional or upper crustal structural relief during the late Mesozoic or early Tertiary, i.e., prior to the development of the unconformity, the uppermost part of crust consisted regionally of a gently folded Mesozoic-Paleozoic section with no large-magnitude, surface-breaking thrusts or normal faults.

This paper examines an exposure of the early Tertiary unconformity and structures in Paleozoic strata that underlie the unconformity in the northern Pequop Mountains (Fig. 1). The unconformity and its relation to structures in underlying Paleozoic strata provide evidence for a large amount of structural relief beneath the early Tertiary unconformity because of a period of Late Cretaceous or early Tertiary normal faulting.

GEOLOGIC RELATIONS IN THE NORTHERN PEQUOP MOUNTAINS

The northern Pequop Mountains provide an oblique, tilted cross section of the upper crust just after development of the early Tertiary unconformity. Rocks in the range comprise complexly faulted, metamorphosed and unmetamorphosed Proterozoic to Mesozoic strata that lie beneath the early Tertiary unconformity (Thorman, 1970; Camilleri, 1994) and an overlying sequence of Eocene (41-39 Ma) volcanic rocks (Brooks and others, 1995) (Fig. 2A, B). Following deposition of the volcanic rocks, rocks were uplifted and tilted to the east along a west-dipping, range-bounding normal fault.

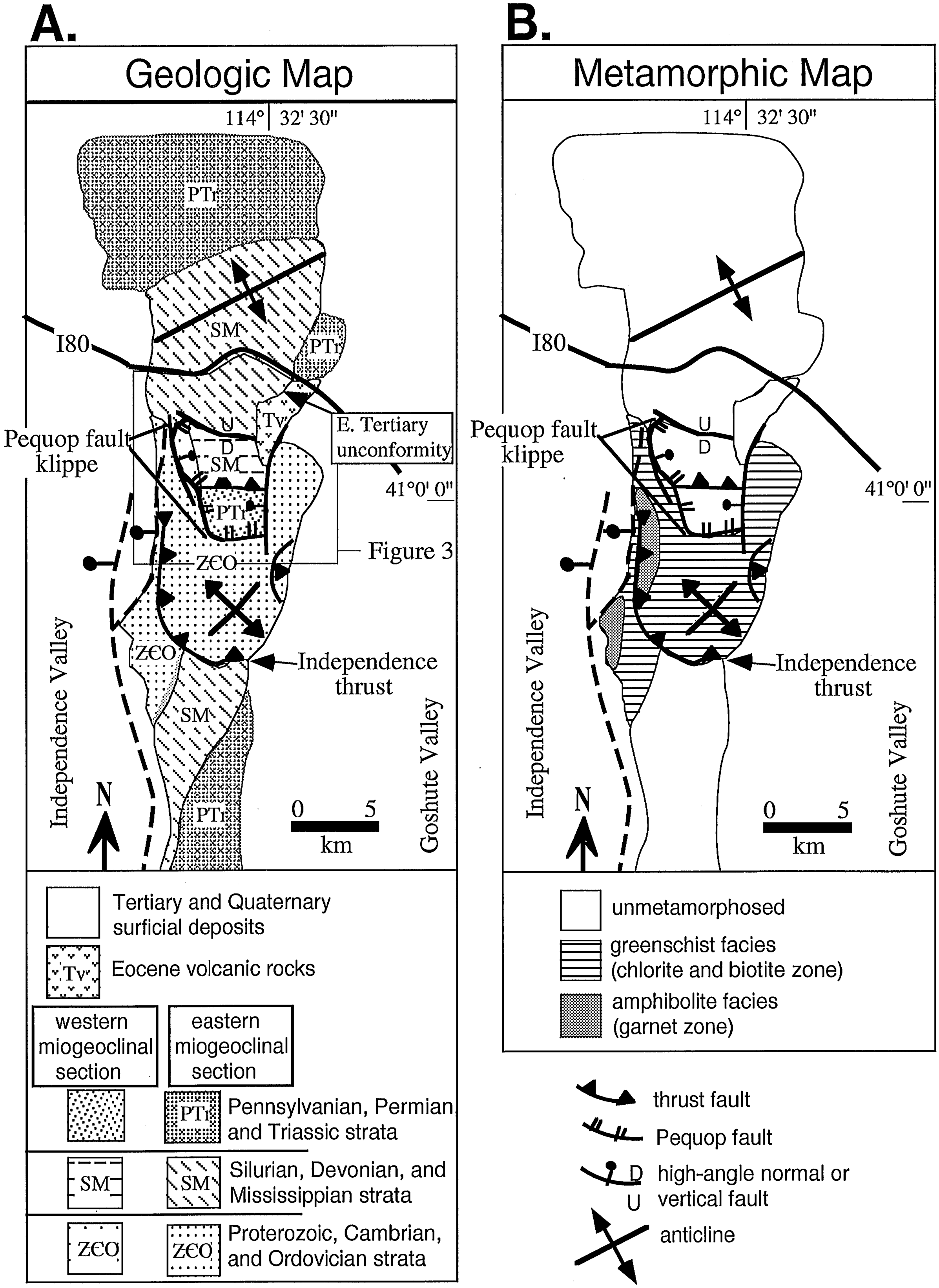
The most important structure beneath the unconformity is the Pequop fault. The Pequop fault is a gently east-dipping, brittle low-angle fault that forms the base of a klippe (Figs. 3 and 4). Locally, the Pequop fault is cut by two minor NNW- and NNE-trending high-angle faults (Fig. 3). Strata in the hanging wall and footwall of the Pequop fault, as well as a minor high-angle fault that cuts the Pequop fault, are depositionally overlapped by the 41-39 Ma volcanic rocks (Fig. 3) indicating that the Pequop fault is pre-mid Eocene. The Pequop fault separates two structurally, stratigraphically, and metamorphically different Paleozoic sections (Fig. 2B). Assessment of the structural and stratigraphic differences and cross-cutting relationships suggest that the Pequop fault provides evidence for a large amount of structural relief beneath the unconformity.

Structural and metamorphic architecture of the hanging wall and footwall of the Pequop fault

The Pequop fault juxtaposes two different Paleozoic sections that are cut by minor thrust faults (Figs. 2A and 3). Cross-cutting relationships and chronologic data indicate that the minor thrusts predate the Pequop fault and that the age of the Pequop fault is bracketed between 84 and 41 Ma (Camilleri and Chamberlain, in press). The hanging wall of the Pequop fault comprises unmetamorphosed Ordovician to Permian strata that are cut by an unnamed, east-trending, top-to-the-southeast thrust (Figs. 3 and 4). The thrust emplaces Ordovician to Mississippian strata over Permian strata. The unnamed thrust is cut by the Pequop fault indicating that the thrust predates formation of the Pequop fault (Fig. 4). The footwall of the Pequop fault contains a metamorphosed to unmetamorphosed Proterozoic to Permian section that is cut by the top-to-the-southeast Independence thrust (Figs. 2A, 2B and 4). Ordovician and older strata in the hanging wall and footwall of the Independence thrust are metamorphosed (cf. Fig. 2A, 2B, and 2C) and contain an 84 Ma prograde metamorphic fabric (S_1) that is parallel, or at a low-angle, to bedding (Camilleri and Chamberlain, in press). The Independence thrust cuts S_1 and locally emplaces metamorphosed rocks over unmetamorphosed strata (Fig. 2B). Strata and S_1 in the hanging wall of the Independence thrust are deformed by several back-folds and a back thrust (Fig. 4). The Pequop fault cuts the back folds indicating that the Pequop fault postdates the Independence thrust as well as the 84 Ma metamorphic fabric (Camilleri, 1994; Camilleri and Chamberlain, in press). Combining this age constraint with the observation that the Pequop fault must predate the volcanic rocks results in an age bracket of 84 - 41 Ma for the Pequop fault.

Cross-cutting relationships suggest that the Pequop fault is a top-to-the-west or -northwest low-angle normal fault. The Pequop fault is interpreted as a normal fault because it omits crustal section and metamorphic grade. For example, the unmetamorphosed Permian section in the hanging wall of the Pequop fault lies structurally above Silurian, Devonian, and metamorphosed Ordovician rocks (Figs. 2C and 3). Sense-of-slip of the Pequop fault is inferred to be top-to-the-west or -northwest because it cuts down-structure and down-section in this direction (Figs. 3 and 4; Camilleri and Chamberlain, in press).

The repetition of Paleozoic section across the Pequop fault requires that the Pequop fault excised two miogeoclinal sections that were duplicated by thrust faulting prior to the formation of the Pequop fault. This inference is supported by the fact that the miogeoclinal sections in the hanging wall and footwall of the Pequop fault are distinctly different. For example, Ordovician and older strata in the footwall of the Pequop fault are regionally metamorphosed, whereas, in the hanging wall they are unmetamorphosed. More fundamentally, however, the two Paleozoic sections differ stratigraphically. The most salient stratigraphic difference is the presence of different facies of the Silurian Roberts Mountain Formation. An eastern dolomitic facies of the formation (Thorman, 1970; Sheehan, 1979) is present in the footwall of the Pequop fault and a western platy limestone facies (Thorman, 1970; Berry and Boucot, 1970) occurs in the hanging wall (Camilleri, 1994; Fig. 2C). Thus, despite the minor thrust faults, the Pequop fault separates two fundamentally different Paleozoic sections: a western miogeoclinal section lies structurally above an unmetamorphosed to metamorphosed eastern miogeoclinal section (Fig. 2C). The implication here is


A.
Geologic Map
114° 32' 30"
PTr
SM
PTr
I80
Pequop fault klippe
U
D
SM
Tv
E. Tertiary unconformity
41°0' 0"
PTr
Figure 3
ZЄO
ZЄO
Independence thrust
SM
Independence Valley
Goshute Valley
N
0 5
km
PTr
Tertiary and Quaternary surficial deposits
Tv
Eocene volcanic rocks
western miogeoclinal section
eastern miogeoclinal section
PTr
Pennsylvanian, Permian and Triassic strata
SM
SM
Silurian, Devonian, and Mississippian strata
ZЄO
ZЄO
Proterozoic, Cambrian, and Ordovician strata
B.
Metamorphic Map
114° 32' 30"
I80
Pequop fault klippe
U
D
41°0' 0"
Independence thrust
Independence Valley
Goshute Valley
N
0 5
km
unmetamorphosed
greenschist facies (chlorite and biotite zone)
amphibolite facies (garnet zone)
thrust fault
Pequop fault
D
U
high-angle normal or vertical fault
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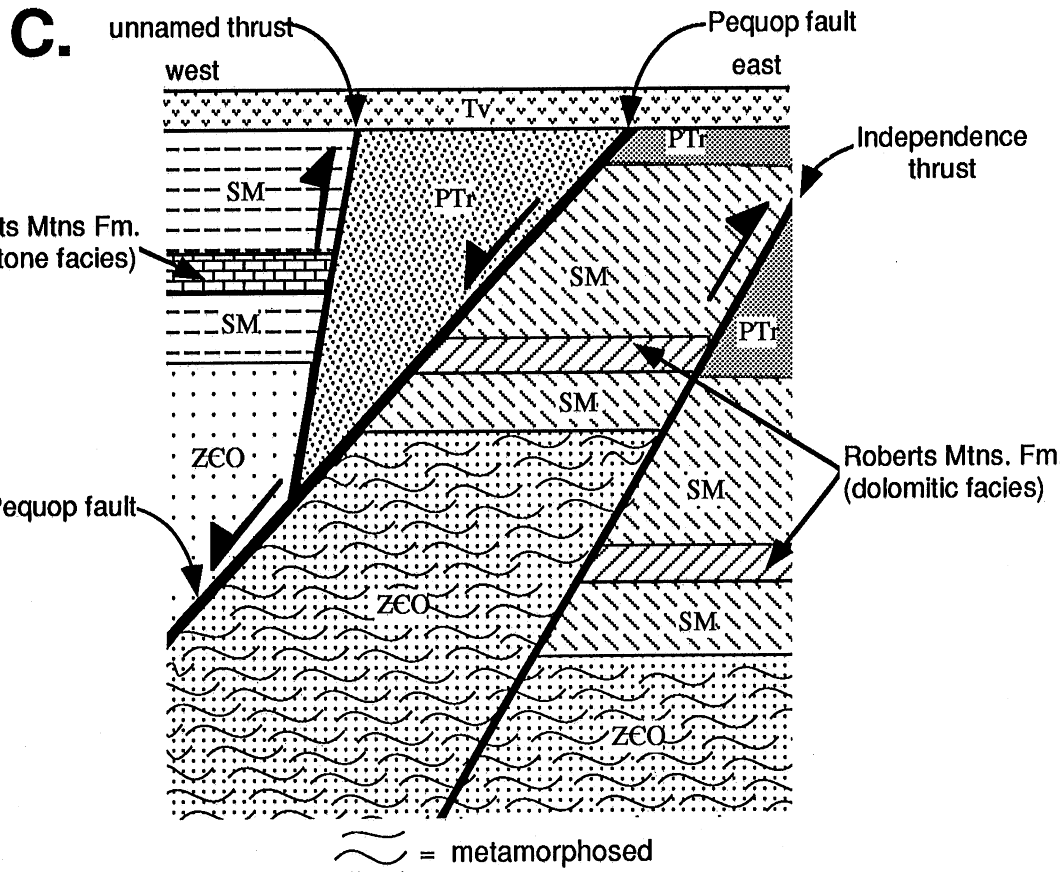

Figure 2. A. Geologic map of the northern Pequop Mountains. B. Metamorphic map of the northern Pequop Mountains. C. Schematic cross-section illustrating structural and stratigraphic relationships in the northern Pequop Mountains. Figure 1 shows map location. Data from Camilleri (1994).

that the two miogeoclinal sections must have been duplicated along a top-to-the-east or top-to-the-southeast thrust and then extended back to west to northwest along the Pequop fault. The thrust fault responsible for duplication of section is not exposed in the range and must have been excised by the Pequop fault.

Estimate of the magnitude of structural relief beneath the unconformity

The amount of structural relief beneath the early Tertiary unconformity can be estimated by assessing the magnitude of throw and slip along the Pequop fault using a structural reconstruction by Camilleri and Chamberlain (in press; Fig. 5). Camilleri and Chamberlain's (in press) reconstruction covers and incorporates data from adjacent regions, in particular the Wood Hills region (Fig. 1) to the west of the Pequop Mountains, but incorporates the following fundamental observations and inferences derived from the Pequop Mountains.

1. The Paleozoic sections in the hanging wall and footwall of the Pequop fault were duplicated by an east-directed thrust fault prior to the formation of the Pequop fault.

2. The Pequop fault postdates minor thrusts in its hanging wall and footwall.

3. Camilleri and Chamberlain (in press) correlated the unnamed thrust in the hangingwall of the Pequop fault with the Independence thrust in its footwall citing that the unnamed thrust provides a hanging wall cutoff for the Pequop fault, and that although the footwall cutoff is not exposed, the Independence thrust is the only visible candidate for correlation.

Combination of regional stratigraphic and structural data resulted in a pre-Pequop fault reconstruction for the Pequop Mountains that shows the unmetamorphosed western miogeoclinal section thrust over the unmetamorphosed to metamorphosed eastern miogeoclinal section along a top-to-the-southeast thrust, the Windermere thrust, which is cut by the Independence thrust (Fig. 5A). Figure 5B and C show the structural configuration of the Pequop Mountains

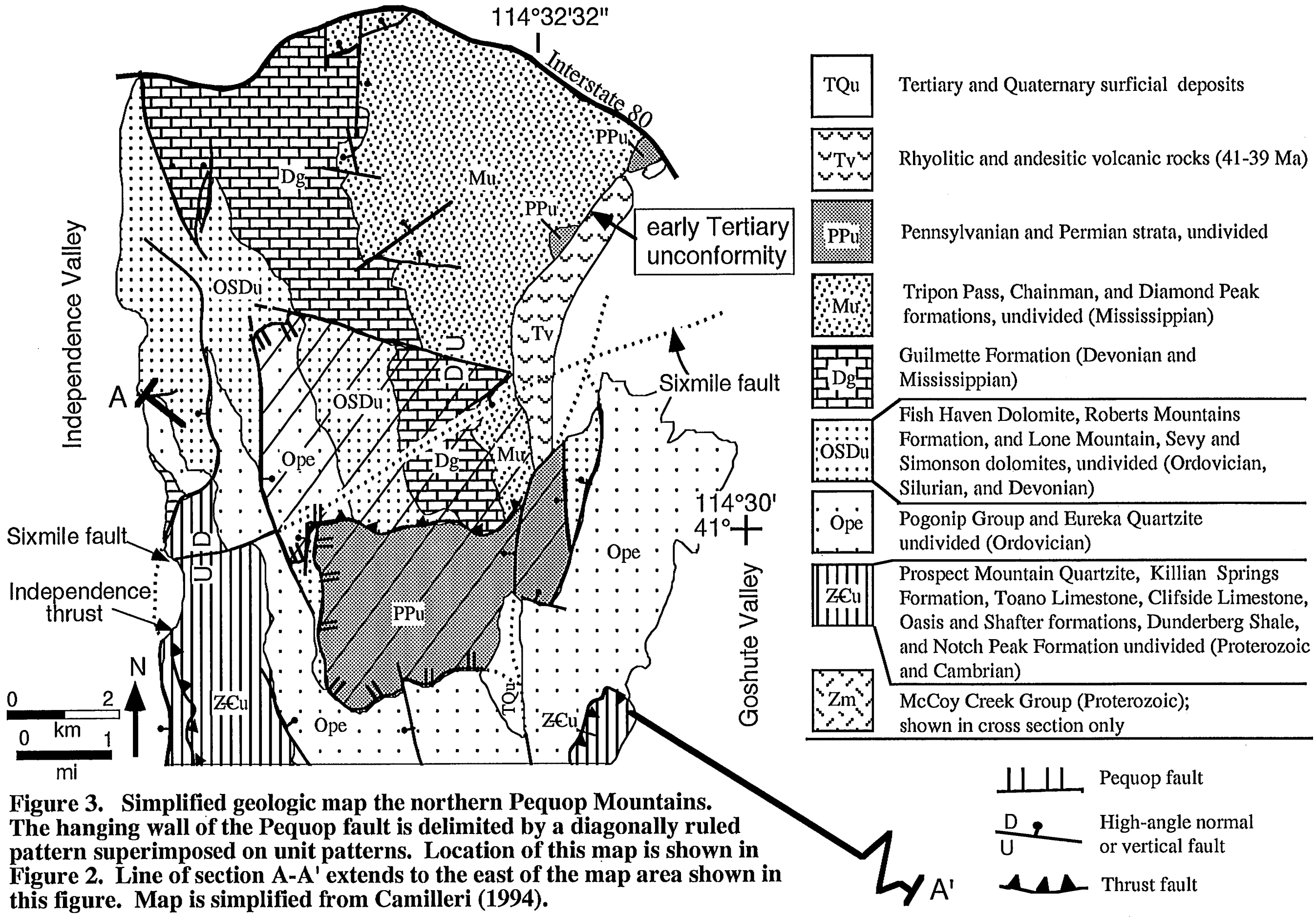

Figure 3. Simplified geologic map the northern Pequop Mountains. The hanging wall of the Pequop fault is delimited by a diagonally ruled pattern superimposed on unit patterns. Location of this map is shown in Figure 2. Line of section A-A' extends to the east of the map area shown in this figure. Map is simplified from Camilleri (1994).

after cessation of slip along the Pequop fault. The Pequop fault is interpreted as a major surface-breaking normal fault because it is a brittle fault (Fig. 5B). Slip along the Pequop fault resulted in transection of the upper part of the Independence thrust and lateral juxtaposition of the western and eastern miogeoclinal sections (Fig. 5B). The Pequop fault exhumed rocks in the eastern miogeoclinal section that were at a structural depth of ~ 11 km. The amount of slip on the Pequop fault shown on Figure 5B is approximately 23 km and the amount of extension is ~ 21 km. The estimate of extension is derived by measuring the horizontal distance between the hanging wall and footwall cut offs of the Independence thrust. Figure 5C shows relations at ~ 39 Ma, after deposition of the volcanic rocks. As much as 6 km of footwall rocks, as well as any synextensional basin fill in the hanging wall, were eroded prior to development of the unconformity. Development of a subsequent east-dip of the unconformity and overlying volcanic rocks (cf. Figs. 4B and 5) is probably a product of Miocene and(or) younger down-to-the-west post-volcanic normal faults related to uplift of the Pequop Mountains.

In summary, the Pequop fault is interpreted to be a large-magnitude pre-unconformity normal fault that exhumed rocks once at ~11 km depth. The Pequop fault is important because it juxtaposes rocks of similar age but from markedly different levels of the Mesozoic crust, hence, providing evidence for a large amount of structural relief beneath the unconformity.

DISCUSSION

The evidence presented for a pre-unconformity extensional event involving a surface-breaking normal fault is not unique to northern Nevada. In southeastern Nevada, Bartley and others (1988) and Taylor and Bartley (1992) present evidence for normal faults that predate the unconformity and whose relationships permit an early Tertiary or Mesozoic age. Additional evidence for extension predating the unconformity are Late Cretaceous to Eocene strata in east-central Nevada that are interpreted to have been deposited in extensional basins (Vandervoort and Schmitt, 1990). The foregoing data and data presented in this paper illustrate the importance of pre-unconformity upper crustal extension in the Sevier hinterland as well as the possibility of large amounts of structural relief below the unconformity, despite the age of the rocks beneath the

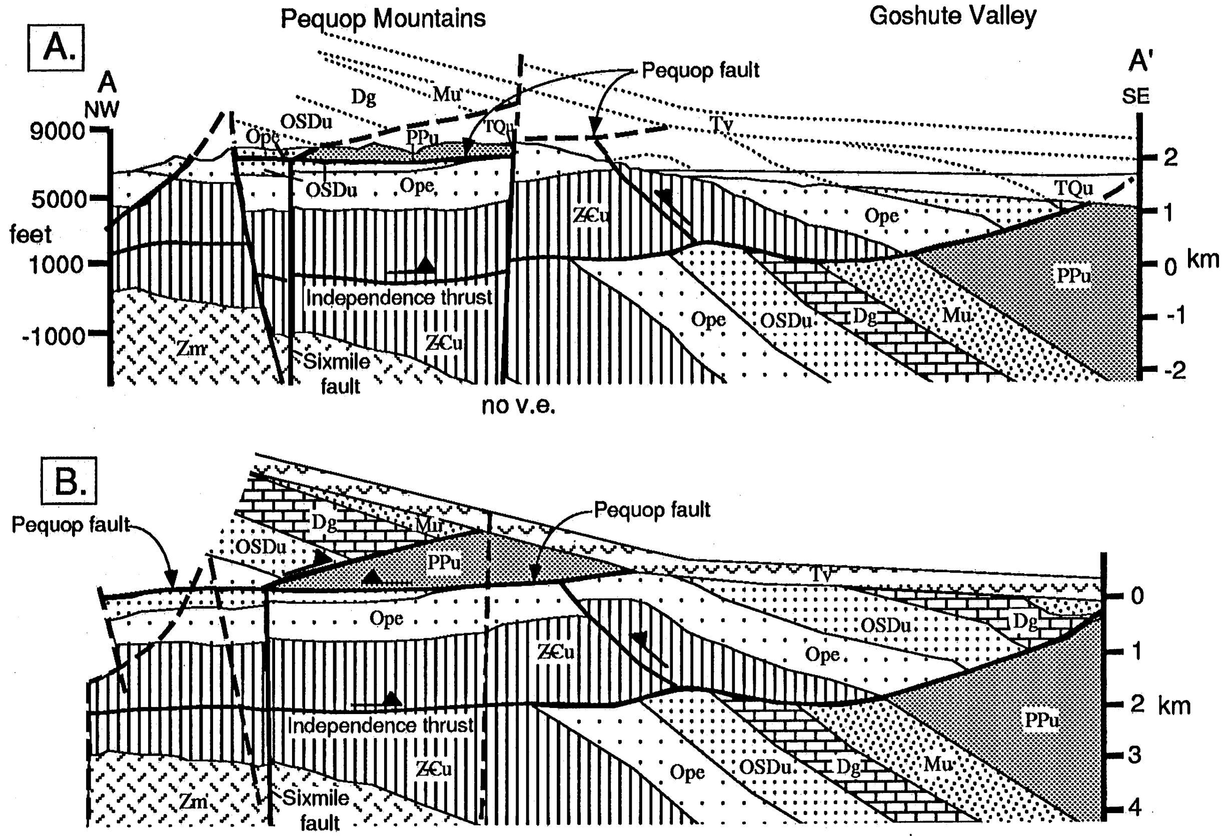

Figure 4. A. Cross section A-A' with eroded units and structures projected above the line of section. B. Cross section A-A' with retrodeformed post-volcanic normal faults and eroded units and structures restored. Line of section is shown in Figure 3.

unconformity. For example, data from the Pequop Mountains raise the possibility that the early Tertiary unconformity may, in other parts of the hinterland, overlie upper Paleozoic or Mesozoic rocks once duplicated by thrust faulting and subsequently extended prior to the development of the unconformity (e.g., as in Fig. 5).

CONCLUSIONS

The Pequop Mountains provide a tilted cross section of the upper crust just prior to development of the early Tertiary unconformity. This cross section illustrates a structurally complex upper crust that contained an array of Mesozoic thrust faults and folds as well as a large-magnitude normal fault, the Pequop fault.

The Pequop fault is an important fault because it serves to illustrate that, although the mid-Tertiary volcanic sequence commonly lies depositionally on upper Paleozoic or Mesozoic rocks, a large amount of structural relief (~11 km) and a moderate amount of erosional relief probably existed prior to the development of the early Tertiary unconformity in this region. Data presented in this paper imply that there exists a pre-unconformity extensional event comparable in magnitude to post-unconformity extension; and that when making Mesozoic or early Tertiary tectonic reconstructions in the Sevier hinterland in the northeastern Great Basin, the assumption that no major normal faults existed in upper crust or breached the surface should be exercised with caution.

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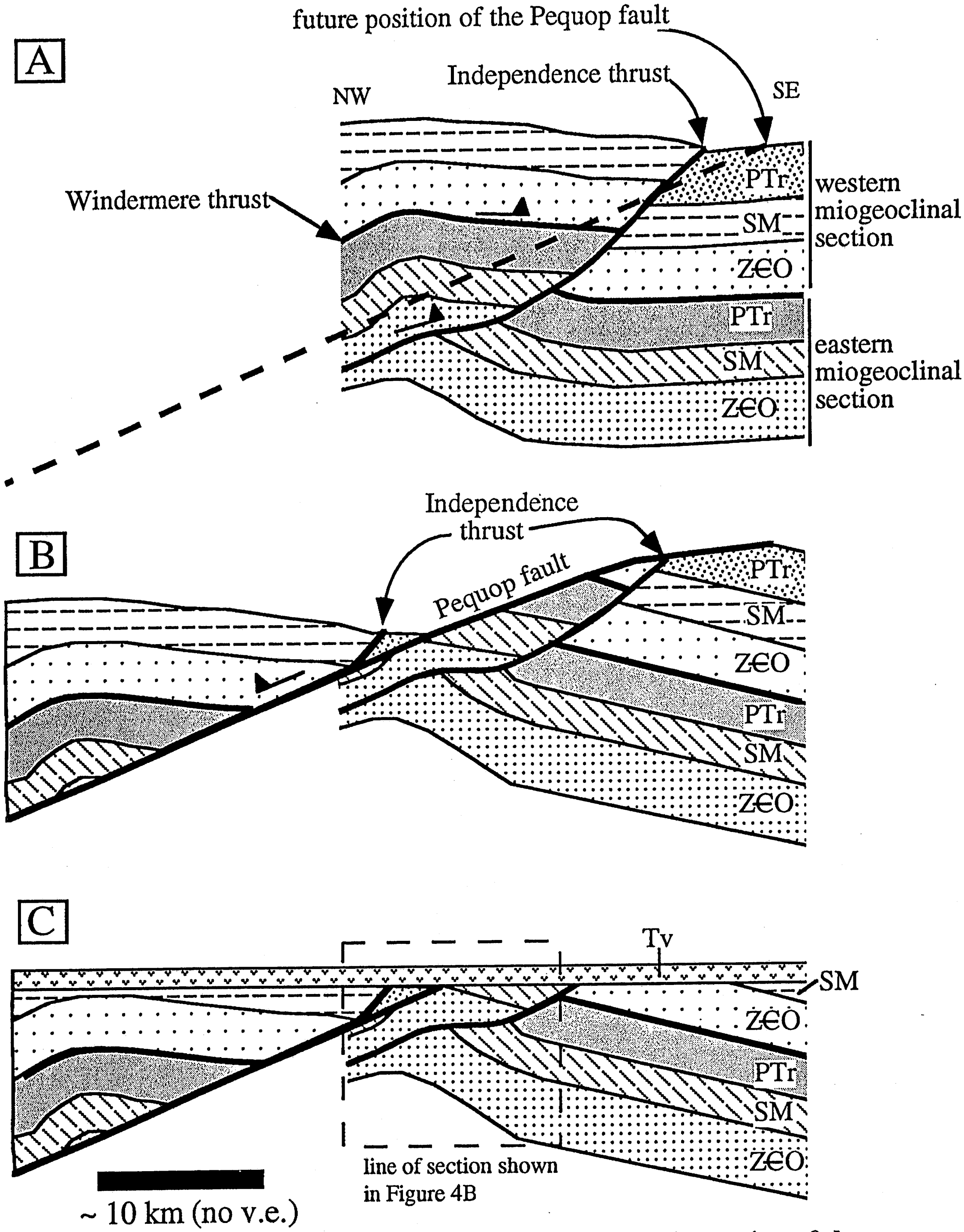

Figure 5. Generalized cross-sections illustrating retrodeformation of the Pequop fault. See text for explanation. Units shown in this figure are the same as in Figure 2. For simplicity the Sixmile fault (Figs. 3 and 4) is not shown. ZCO = Cambrian and Ordovician strata; SM = Silurian, Devonian, and Mississippian strata; PTr = Pennsylvanian, Permian and Triassic strata; Tv = Eocene volcanic rocks.

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