Sierra Nevada–Basin and Range transition near Reno, Nevada: Two-stage development at 12 and 3 Ma

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ABSTRACT

Relative and absolute elevations of the Sierra Nevada and adjacent Basin and Range province, timing of their differentiation, and location, amount, and timing of strike-slip movement between them are controversial. The provincial boundary near Reno developed in two stages. (1) At ca. 12 Ma, the ≥700 km^2 Verdi-Boca sedimentary basin formed across what was to become the boundary, probably as a result of a small-magnitude but regional extensional episode that affected much of the western Basin and Range. (2) At 3 Ma, the basin was complexly faulted and folded during a larger magnitude extensional episode that established the modern Sierran structural and topographic boundary in this area. The boundary is really a transition zone with a western edge along the Donner Pass, California, fault zone, which is farther west than previously placed. Both episodes appear to have resulted from east-west extension only, which suggests that northwest motion of the Sierra Nevada relative to the Basin and Range shown by geodetic data began after 3 Ma or was taken up farther east.

Keywords: Sierra Nevada, Basin and Range, extension, $^{40}Ar/^{39}Ar$, tephrochronology, sedimentary basins.

INTRODUCTION

The Sierra Nevada–Basin and Range transition has long been of interest and has recently taken on additional importance. New geodetic data demonstrate that ~20% of relative Pacific–North American plate motion is taken up in a zone east of the Sierra Nevada, in the Great Basin or Walker Lane (Fig. 1; Dixon et al., 2000; Bennett et al., 1999; Thatcher et al., 1999). Additionally, the timing of Sierra Nevada uplift and whether the Great Basin was relatively high or low before middle to late Cenozoic extension have long been controversial. The prevalent view had been that most uplift of the Sierra Nevada occurred after 10 Ma (Lindgren, 1911; Axelrod, 1962; Huber, 1981; Unruh, 1991). More recently, it has been suggested that (1) the Sierra Nevada was a topographic high much earlier, possibly at 4–5 km elevation in the early Cenozoic, and subsided in the late Cenozoic, (2) the Sierra Nevada was the western flank of a broad plateau now occupied by the Great Basin, and (3) that plateau was substantially higher, possibly 3 km in elevation, before ca. 15 Ma and subsided during late Cenozoic extension (Wernicke et al., 1996; Wolfe et al., 1997).

In this paper, we show that a large sedimentary basin was continuous across what is now the Sierra Nevada–Basin and Range transition between 12 and 3 Ma. The basin probably formed as a result of small-magnitude extension related to initial formation of the transition. The basin was complexly deformed at 3 Ma when the current, well-defined transition fault zones developed.

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VERDI-BOCA BASIN

Character, Timing, and Origin

The 12–3 Ma Verdi-Boca basin is preserved in two parts, west and south of Reno, Nevada, and around Boca Reservoir, California, separated by the west-tilted Verdi Range (Fig. 2). The sedimentary sequence is similar in both parts (Trexler et al., 2000), and removal of uplift of the postdepositional Verdi Range leaves no topographic barrier between the two areas, which once formed a connected basin. The distribution of preserved deposits and reasonable extrapolation suggest that the basin covered at least 700 km^2. Its full dimensions are unknown, because the 3 Ma deformation complexly disrupted western Nevada and the eastern Sierra Nevada. However, Neogene sedimentary rocks are widely preserved in western Nevada (Fig. 1; Gilbert and Reynolds, 1973; Stewart and Diamond, 1990; Stewart, 1992; Dilles and Gans, 1995; Perkins et al., 1998; Trexler et al., 2000).

Both the Verdi and Boca parts of the basin were filled with a generally fining-upward sequence from conglomerate composed of clasts of underlying andesite through sandstone and into lacustrine diatomite (Bell and Garside, 1987; Trexler et al., 2000). Basaltic andesite lavas are common in the lower parts of the basin (Fig. 2). Ash beds are preserved within diatomite in the upper parts.

$^{40}Ar/^{39}Ar$ and tephrochronologic ages on underlying lavas, interbedded lavas and tephra, and an overlying basaltic andesite demonstrate that deposition began at ca. 12 Ma and continued to ca. 3 Ma (Tables 1 and 2[1]). The oldest sedimentary deposits rest conformably upon andesite dated at 12.10 ± 0.20 Ma (plagioclase, Fig. 2), and lava capping the Verdi Range gives ages of 11.91 ± 0.06 Ma (hornblende) and 11.91 ± 0.15 Ma (plagioclase). Andesite breccia, dated at 11.72 ± 0.11 Ma (hornblende) and 11.39 ± 0.11 Ma (plagioclase), is interbedded with conglomerate southwest of Reno. Basaltic andesite lavas in the lower part of the basin fill range from 10.1 to 10.4 Ma (Fig. 2).

Dating of ash beds within diatomite indicates that deposition continued until 3.1 Ma. At Boca, the stratigraphically highest of several andesitic ash beds gives a plagioclase $^{40}Ar/^{39}Ar$ age of 3.24 ± 0.10 Ma; lower ash beds give ages of 3.7 ± 0.1 and 3.9 ± 2.4 Ma (Table 1; see footnote 1). Also, the 3.4 ± 0.1 Ma Putah ash bed (Sarna-Wojcicki, 1976) is identified near the 3.24 Ma ash bed, and an unnamed 3.26 Ma ash bed is identified at ~20 m above the Putah bed (Table 2). In the Verdi basin, correlation of tephra brackets the age of diatomite at 4.45 Ma near the base (Kilgore ash bed; Morgan et al., 1998) and 3.06 Ma near the top (upper Horse Hill ash bed).

An extensional origin of the Verdi-Boca basin at 12 Ma is likely. A north-northwest–striking, down-to-the-east fault zone near Donner Pass, which is ~17 km west of exposed basinal rocks (Fig. 1), may have formed the basin's western boundary. Basinal rocks are covered by younger rocks west of Boca Reservoir (Birkeland, 1963; Latham, 1985), so their western continuation is unknown. Total displacement across the Donner Pass zone is ≥800 m and may have occurred in several episodes in the late Cenozoic (Hudson, 1951). Andesitic lavas dated at 13 Ma show the greatest displacement, and lavas correlated with an 8 Ma flow are displaced less (Hudson, 1951; Saucedo and Wagner, 1992). Thus, the Donner Pass zone underwent an episode of faulting between 13 and 8 Ma.

[1]GSA Data Repository item 2001085, $^{40}Ar/^{39}Ar$ and tephrochronologic data for the Verdi-Boca basin, Nevada and California, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/ft2001.htm.

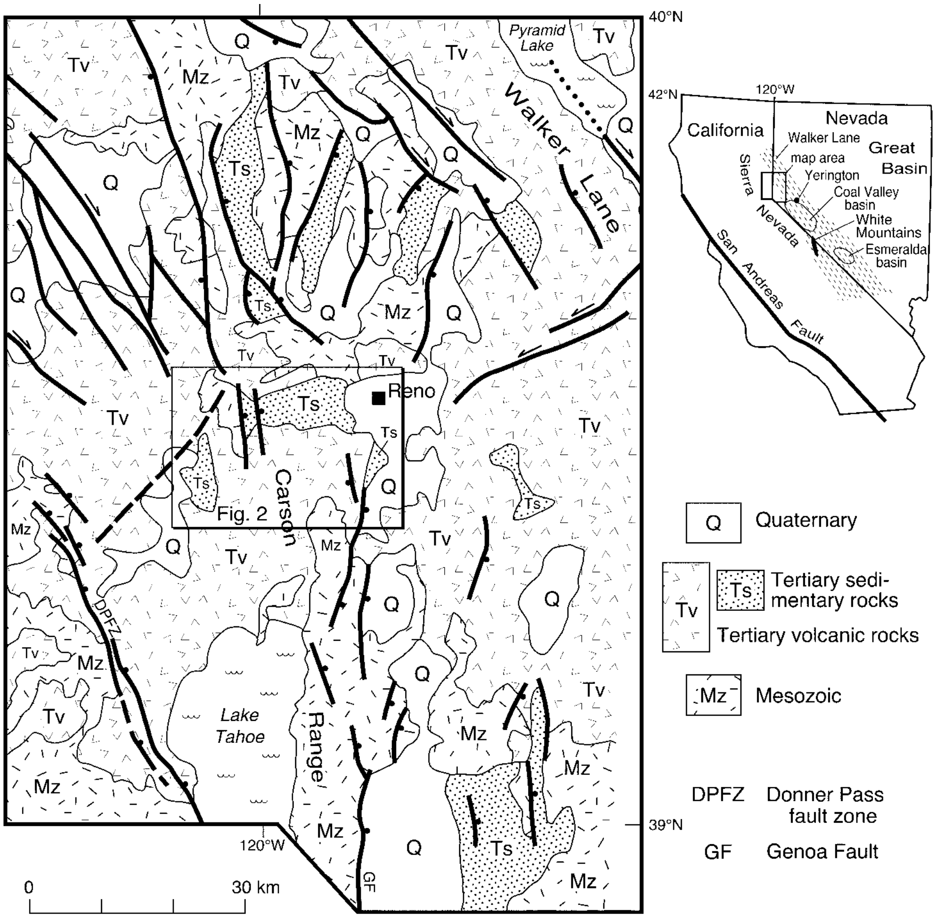

Figure 1. Generalized geologic map of Sierra Nevada–Basin and Range transition near Reno, Nevada (from Stewart and Carlson, 1978; Saucedo and Wagner, 1992). Solid lines are faults with ball on downthrown side. Arrows show relative motion. Dashed lines are approximately located faults.

The base of the Verdi-Boca basin had minor relief. Most relief probably reflects volcanic highs on the early andesitic volcanism. However, deposition of 10 Ma basaltic andesite on Mesozoic rocks in the Verdi Range indicates that the range was a minor topographic high then. This high may have resulted from early (ca. 12 Ma?) uplift along Verdi Range faults, which then underwent much greater displacement at 3 Ma. Nevertheless, the conformable relationship between andesite and basal sedimentary rocks demonstrates that no measurable tilting occurred at the time. Therefore, total extension at 12 Ma was small.

3 Ma Deformation

The Verdi-Boca basin was intensely deformed at 3 Ma. The simplest structure is illustrated by the W-tilted Verdi Range (Fig. 2). Two east-dipping normal faults bound the east side of the range and drop Verdi-Boca strata down against Mesozoic rocks. Cumulative vertical offset is at least 2 km. The range is tilted westward ~20°, as shown by dips on a 10 Ma basaltic andesite and conglomerate on top of the range. The Verdi-Boca sequence east of the two faults also dips westward. Piercing points are not available, but fault and tilt geometry suggests approximately east-oriented extension with little if any lateral displacement.

Basal conglomerate near Boca Reservoir along the west side of the Verdi Range dips 20° westward. Dips decrease westward and up section into diatomite, which dips mostly ~10°, and 3°–4° at the westernmost exposures. We attribute this change in dip to progressive westward decrease in footwall uplift of the Verdi Range rather than to fanning of dips up section. Footwall uplift of normal faults is common (Jackson and McKenzie, 1983), and fanning dips were not found anywhere else.

Structure east of the Verdi Range is complex. The Carson Range and Peavine Peak rose relative to the preserved, Verdi part of the basin. Sedimentary rocks dip northward off the Carson Range and southward off Peavine Peak, forming a broad, topographically low syncline between the two ranges (Fig. 2). At the same time, sedimentary strata in the western part of the basin dip west, toward the Verdi Range, but roll over to an east dip ~6 km east of the eastern Verdi Range fault. The resulting structure is an east-trending, doubly plunging syncline. Mesozoic granite bounded by high-angle faults is exposed in the middle of the syncline.

The origin of this geometry is complex. The Carson Range south of Reno is a west-tilted block bounded on the east by the active Genoa fault and similar, east-dipping normal faults (Fig. 1; Ramelli et al., 1999). The Genoa fault is commonly considered the eastern margin of the Sierra Nevada at this latitude (Thatcher et al., 1999), although Cenozoic faulting demonstrably occurs farther west, in the Verdi Range, near Donner Pass, and around Lake Tahoe along the southern continuation of the Donner Pass zone (Hudson, 1951; Birkeland, 1963; Schweickert et al., 2000; our work). Displacement on the Genoa fault decreases northward toward Reno, where Quaternary faults splay northeastward away from the Carson Range. Dips along the east side of the range change from westward to eastward, and the northern part of the range is a north-trending anticline (Thompson and White, 1964). The northern 10 km of the eastern range front is a conformable, east-dipping, depositional contact between Verdi-Boca strata and Miocene andesites, similar to the 12 Ma lava on the north flank.

Verdi-Boca strata are not preserved on top of the Carson Range or Peavine Peak, but undated (10 Ma?) basaltic andesite lavas overlie Miocene andesite on top of the Carson Range. Preservation of the sedimentary rocks along the east flank of the range as much as 10 km south of its northern end suggests that sediments initially covered what is now the Carson Range.

Timing of Deformation

Dismemberment of the Verdi-Boca basin occurred between 3.1 Ma, the age of the youngest dated ash beds, and 2.61 ± 0.03 Ma, the age of an ~4° west-dipping basaltic andesite lava that overlies 15°–20° west-dipping sedimentary rocks near Boca Reservoir (Fig. 2). The dip of the lava could indicate additional tilting of the Verdi Range after 2.6 Ma (Birkeland, 1963), or it could be the primary dip of a lava that flowed westward down the range. In either case, the Verdi Range was tilted 15°–20° westward, and most of the sedimentary section removed, in ~0.5 m.y. Rapid erosion of the soft, easily eroded sediments seems reasonable. Preserved rocks beneath the lava are mostly resistant conglomerate.

Uplift of the Carson Range almost certainly occurred at 3 Ma also, because the youngest sedimentary rocks in that part of the basin are also dated at 3.1 Ma. However, an overlying,

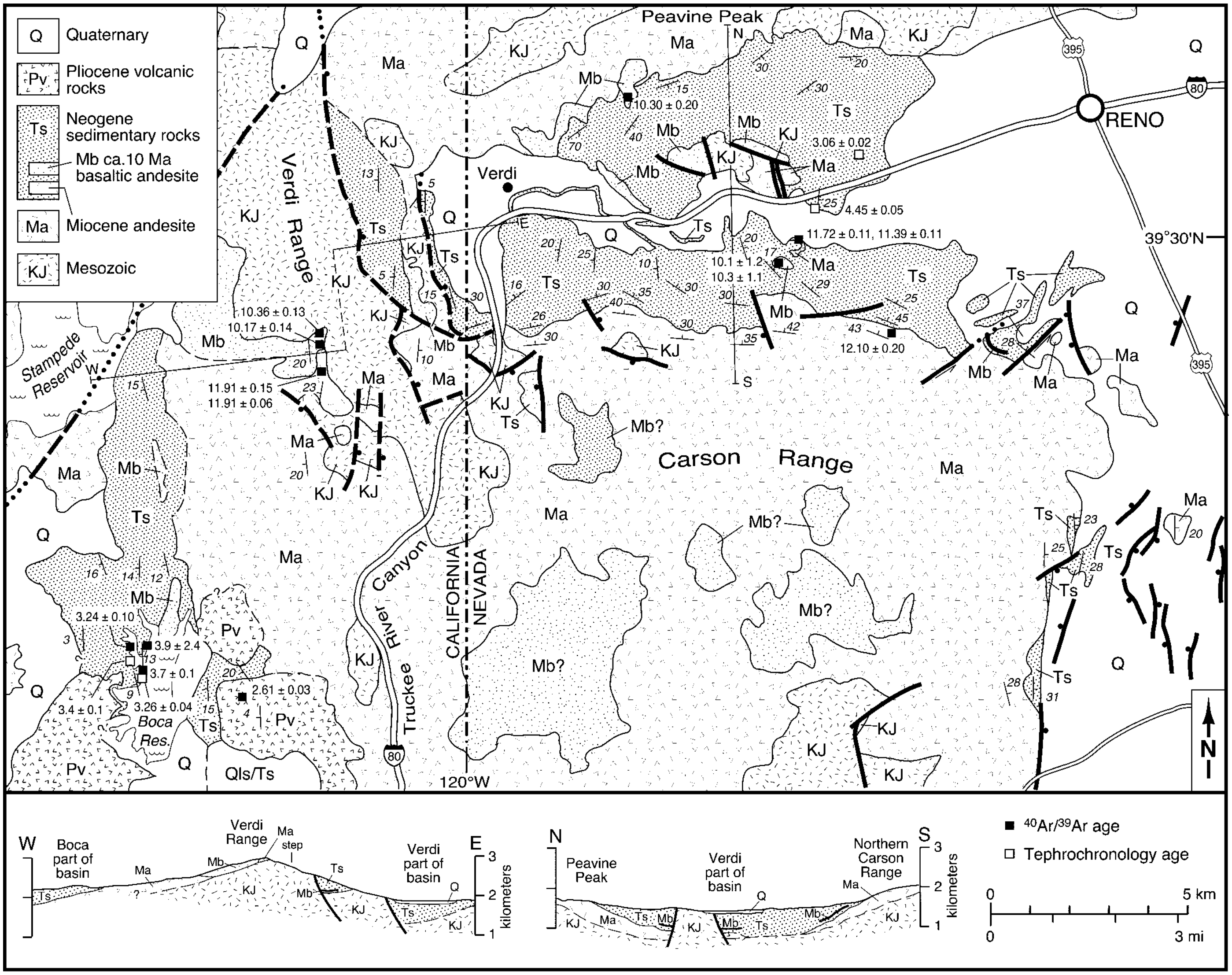

Figure 2. Geologic map and cross sections of Verdi-Boca basin (map modified from Birkeland, 1963; Thompson and White, 1964; Stewart and Carlson, 1978; Latham, 1985; Bell and Garside, 1987; Saucedo and Wagner, 1992).

young lava is not present to provide a younger age limit. U-Th/He data also show uplift of the Carson Range at 3 Ma (Surpless et al., 2000).

The Donner Pass fault zone was probably reactivated at 3 Ma. The 13 Ma andesite is displaced ~800 m, whereas the 8 Ma basalt is displaced ~200–300 m (Hudson, 1951; Saucedo and Wagner, 1992). Quaternary displacement is known on faults along the southern continuation of the Donner Pass zone west of Lake Tahoe (Schweickert et al., 2000).

DISCUSSION

Major deformation and development of the Sierra Nevada–Basin and Range boundary in the Verdi-Boca area occurred at 3 Ma, but initial extension probably occurred at ca. 12 Ma. Several other studies indicate that a regional episode of extension at ca. 12 Ma was instrumental in early development of the boundary. Moderate extension beginning 12–13 Ma formed the large Coal Valley and Esmeralda basins in western Nevada along or near the boundary (Fig. 1; Gilbert and Reynolds, 1973; Stewart and Diamond, 1990; Stewart, 1992; Dilles and Gans, 1995; Perkins et al., 1998; Surpless et al., 2000). Both basins were dismembered by late Cenozoic faulting, but the Esmeralda basin formerly covered 2000 km^2 (Stewart and Diamond, 1990). The Verdi-Boca basin may have covered a similar area, if Neogene sedimentary rocks north of Reno (Fig. 1) were formerly part of the same basin. Extensional faulting uplifted and tilted the White Mountains 25° eastward beginning at 12 Ma (Stockli et al., 2000), approximately between these two basins. Thus, this episode of extension is recognized along nearly 300 km of the Sierra Nevada–Basin and Range boundary.

Faulting in the Donner Pass zone at 12 Ma places the Sierra Nevada–Basin and Range boundary much farther west than generally recognized, either at that early date or at present. Extension apparently stepped well into the Sierra at that time and has not stepped farther west since. Nevertheless, extension at 3 Ma was much greater than at 12 Ma in the Verdi-Boca area. Therefore, early 12 Ma extension does not contradict the general pattern of late Cenozoic westward expansion of the Basin and Range into the Sierra (Dilles and Gans, 1995; Surpless et al., 2000).

Moderate extension and formation of the Coal Valley basin followed rapid, large-magnitude extension between 14 and 12.5 Ma near Yerington, Nevada (Dilles and Gans, 1995; Fig. 1). Large-magnitude extension also immediately preceded formation of some slightly older basins farther east in Nevada (Stewart, 1992). In contrast, the Verdi-Boca area definitely has not undergone large-magnitude extension at any time, and we have no evidence of extension before 12 Ma.

The 3 Ma event involved much greater deformation and relative subsidence of the Basin and Range compared to the Sierra Nevada than did the 12 Ma event and generated essentially all of the present-day structure and topography. Our data do not define absolute elevations or whether the Sierra Nevada rose or the Basin and Range subsided in an absolute sense. Our data are consistent with apatite fission-track and U-Th/He results that show uplift of the Carson Range at 3 Ma (Surpless et al., 2000). More recent activity, including common Quaternary faulting (Bell, 1984; Ramelli et al., 1999), has not modified the area significantly. As noted by Stewart and Diamond (1990) and Dilles and Gans (1995), the present structure and topography are distinctly unlike that during late Miocene basin deposition. The Sierra Nevada–Basin and Range boundary near Reno should be considered a left-stepping transition zone, the boundary stepping westward from the Genoa fault to the Donner Pass fault zone.

Both 12 and 3 Ma episodes of deformation appear to reflect approximately east-west extension only. However, it is well established that the Sierra Nevada is moving northwest relative to the Basin and Range (Fig. 1; Bennett et al., 1999; Thatcher et al., 1999), and focal mechanisms are consistent with current dextral slip along northwest-striking faults in and north of the Donner Pass zone (Dixon et al., 2000). These data suggest either that strain had been partitioned until recently between areas of extension and strike-slip, with all dextral motion farther east in the Walker Lane, or that strike-slip motion began recently along the boundary. The latter possibility seems consistent with current right-lateral motion in the Donner Pass zone but inconsistent with the interpreted onset of strike-slip faulting at 23 Ma near Yerington in the Walker Lane only 100 km to the southeast (Fig. 1; Dilles and Gans, 1995).

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