INTRODUCTION

The Mojave-Sonora megashear was proposed by Silver and Anderson (1974), Anderson and Silver (1979, 1984), and Anderson and Schmidt (1983) as a Middle or Late Jurassic left-lateral fault that displaced Paleoproterozoic and Mesoproterozoic crystalline basement rocks from southeastern California to Sonora. As a part of their original proposal, Silver and Anderson (1974) noted “intriguing similarities” between Cambrian strata in the Inyo Mountains in eastern California on the northeast side of the fault and in the Caborca area in northern Sonora on the southeast side of the fault. They used this similarity to suggest an offset of 700–800 km along the proposed megashear. Since the original work of Silver and Anderson, much has been learned about the Neoproterozoic and Paleozoic stratigraphy in the western United States and Sonora that bears on the “intriguing similarities” of the rocks possibly offset by the proposed fault. This paper summarizes this new information and interprets the data as supporting the original idea of the Mojave-Sonora megashear.

Two different models of the Neoproterozoic to Triassic continental margin of the western United States and northern Mexico have been proposed (Stewart et al., 1984) (Fig. 1). In one, Neoproterozoic to Triassic rocks wrap around the Laurentian (ancestral North American) continental margin with only minor, if any, lateral structural displacement. In the other, the Laurentian margin is truncated by major left-lateral offset along the proposed Mojave-Sonora megashear (Stewart et al., 1984). Debate between proponents of these two ideas has been lively, and no consensus has been reached concerning which of the two models is correct. Discussions emphasizing one or the other of the two ideas include Silver and Anderson (1974, 1983), Anderson and Silver (1979, 1984), Dickinson (1981), Anderson and Schmidt (1983), Stewart et al. (1984), Cohen et al. (1986), Ketner (1986), Jacques-Ayala et al. (1991), Anderson et al. (1991, 1995), Stevens et al. (1992), Sedlock et al. (1993), DeJong and Jacques-Ayala (1993), Bartolini (1993), Stanley and González-León (1995), Poole et al. (1995a, 1995b, 1991, 2000a), Marzolf and Anderson (1996, 2000), Anderson (1997), Marzolf (1997), Caudillo-Sosa et al. (1996), González-León (1997a, 1997b), Campbell and Anderson (1998), Molina-Garza and Geissman (1998, 1999), Iriondo et al. (1998), Iriondo (2001a, 2001b), Stewart et al. (1990, 1997, 1999), Dembosky et al. (1999), Poole and Amaya-Martínez (2000), and Dickinson and Lawton (2001).

Figure 1. Wraparound and Mojave-Sonora megashear models of Neoproterozoic and Paleozoic rocks in the western United States and northwest Mexico.

Stewart, GSA SP 393, 2005

Miogeocline extends into CA on NNE–SSW trend but then vanishes—but very similar rocks show up in Caborca, Mexico. Which geometry is right?
J.H. Stewart

commonly considered to have been deposited in deep water west of the miogeoclinal belt and to have fringed the western margin of ancestral North America. Transport along thrust faults emplaced these strata over miogeoclinal strata of ancestral North America. The history of emplacement is complex. In Nevada, the first emplacement took place during the Late Devonian to Early Mississippian Antler orogeny, when Ordovician to Devonian strata were transported along the Roberts Mountains thrust over miogeoclinal strata. Renewed offshelf deep-water deposition took place in Nevada in the Pennsylvanian and Permian, and these rocks were in turn emplaced over miogeoclinal strata during the Late Permian to Early Triassic Sonoma orogeny. The history of emplacement in Mexico is different. Here Ordovician to Permian deep-water siliceous strata are in a continuous sedimentary succession that was emplaced over, or transpressionally against, miogeoclinal strata in the Permian or Early Triassic. As described previously, no evidence of the Antler orogeny has been described in Mexico, and the relation of a continuous succession of siliceous strata unbroken by a thrust comparable to the Roberts Mountains thrust is indicative of the difference in tectonic history between Nevada and Mexico.

Ordovician to Devonian deep-water siliceous rocks of the Roberts Mountains allochthon and comparable age strata in the Sonora allochthons (Fig. 13) consist of relatively deep-water marine strata originally deposited along the Laurentian continental margin outboard of the Cordilleran miogeocline (Madrid et al., 1992b). The rocks consist of complexly deformed radiolarian chert, graptolitic shale, quartzite, feldspathic sandstone, siltstone, minor mafic lava flows, bedded tuff, limestone, and bedded barite (Poole et al. 1991, 1995b; Madrid et al., 1992b; Madrid et al., 1992b).
Right plot suggests that miogeocline trend in Caborca also cut off.
Figure 7. Distribution and thickness of Ordovician miogeoclinal strata in the San Bernardino Mountains provide control on the trend of unconformably on Cambrian strata. Outcrops of Paleozoic strata exposure the presumed depositional relations of Devonian strata from structural and sedimentary data (Poole and Sandberg, 1977, 1991), Poole et al. (1992), and Stewart and Poole (2002). In the western United States and northwestern Mexico. Based on Ross (1977), Ross et al. (1991, 1992), Poole and Sandberg (1992a), Poole et al. (1992), and Poole et al. (1997, 1998, 2000a, 2000b), Stewart et al. (1997, 1999; Poole et al., 2000b; Stewart et al., 1997, 1999; Poole et al., 2000b; Stewart and Poole, 2002). In the western United States, no outcrops of Ordovician strata are known, and the Antler trough strata, and no shale-basin strata are significantly different from that in the western United States. In Sonora, Mississippian miogeoclinal strata are mostly limestone (Stewart et al., 1997, 1999; Poole et al., 2000b; Stewart and Poole (2002)).

Antler orogeny led to a marked change in the sedimentary and structural setting of the western United States (Poole, 1974; Carr et al., 1992, 1997). However, Poole (1974) and Carr et al. (1992, 1997) have argued against this interpretation and doubt that Antler orogenic highland. In the Pilot Knob Valley area, Carr et al. (1992) interpret metaconglomerate and metaargillite as Antler orogenic highland. In the Pilot Knob Valley area, Carr (1997). However, Poole (1974) and Carr et al. (1992, 1997) have argued against this interpretation and doubt that Antler orogenic highland. This and was emplaced eastward above Devonian and older Paleozoic strata in Sonora. A fairly complete section of Devonian and Mississippian shelf at Rancho Placeritos in Sonora (Fig. 9) (Poole et al. 1992).

Localities: CC, Cerro Cobachi; RB, Rancho Bízani; RP, Rancho Placeritos; SB, San Bernardino Mountains; SA, Sierra Aguas Verdes; SB, San Bernardino Mountains.

Figure 8. Distribution of Silurian and Devonian strata in the western United States and northwestern Mexico. Based on Ross (1977), Ross et al. (1991, 1992), Poole and Sandberg (1992a), Poole et al. (1992a), and Stewart and Poole (2002).
The Pennsylvanian–Early Permian Bird Spring Carbonate Shelf (1962) have not gained general acceptance. Shelf carbonate strata equivalent to parts of the Bird Spring Formation are represented by the Callville Limestone (Longwell, 1928) and Pakoon Limestone (McNair, 1951) in southeasternmost Nevada, northwestern Arizona, and southwestern Utah, and by the Tippipah Limestone (Johnson and Hibbard, 1957) in southwestern Nevada.

In southeastern California, early geologic mapping and stratigraphic studies (e.g., Hazzard, 1937, 1954; Hewett, 1956) showed that the Bird Spring Formation occurs in several widely separated ranges in the Mojave Desert region. The formation is now recognized as far south as the San Bernardino Mountains (Brown, 1991) and as far north as the Death Valley area (Panamint Range and Cottonwood Mountains) (Stone and Stevens, 1984) (Fig. 1).

The seven outcrop areas represented in this study provide a regional transect across the Bird Spring Shelf in California. From southeast to northwest, these areas are (1) the Ship Mountains, (2) the Providence Mountains, (3) Old Dad Mountain, (4) Cowhole Mountain, (5) Striped Butte and (6) nearby Warm Spring Canyon in the southern Panamint Range, and (7) Panamint Butte in the southern Cottonwood Mountains (Fig. 1). Outcrop areas not considered for this study include Marble Canyon in the central Cottonwood Mountains (Stone, 1984) and the Nopah Range (Hazzard, 1937; Burchfiel et al., 1982), where fusulinids are rare and the Bird Spring Formation does not extend into the Permian; the Clark Mountain Range (Clary, 1967) and the San Bernardino Mountains (Brown, 1991), where only Pennsylvanian fusulinids

Figure 3. Map showing paleogeographic setting of the Bird Spring Shelf on the late Paleozoic continental margin of southwestern United States. In California, paleogeographic features are offset by the Mesozoic Intrabatholithic Breaks 2 and 3 (IBB2, IBB3) and by the Cenozoic San Andreas, Garlock, and Death Valley–Furnace Creek (DVFCF) Faults. Modified from Stevens (1982), Miller et al. (1992), and Stevens et al. (1992).
Today things are hacked up, but in the pieces between can divine the SSW trend possibly turning to SE in Mojave. Note the Permian–Tr plutons—will come back to those.
Keeler basin (late Penn) inferred to be extensional from truncation event, then shortening in early Permian starved Keeler/Lone Pine basin. Darwin basin interpreted as a foredeep to Conglomerate Mesa uplift. Get very tight age controls indicating LCT moved 3 mm/yr over 10 m.y. Associates extension with left–lateral fault, LCT with Penn. deformation (Pinon orogeny?) in Nevada.
Sierra Nevada-Death Valley thrust system

Neo-proterozoic to middle Paleozoic facies trends and continental margin (Stevens and Greene, 1999)

East Sierran thrust system (Stevens and Greene, 1999)

Late Paleozoic: (a) Atokan. (b) Bursumian. (c) Late Sakmarian. (d) Middle Artinskian.

Localities shown: CH—Cowhole Mountain; CM—Conglomerate Mesa; DC—Darwin Canyon; MC—Marble Canyon; OD—Old Death Valley; SRH—Santa Rosa Hills; UM—Ubehebe Mine; WSC—Warm Spring Canyon.

Figure 12: Paleogeographic maps illustrating evolution of the Bird Spring Shelf and adjacent basins during Pennsylvanian time. (Stevens and Stone, 2005)

Acknowledgments

We are grateful to George Dunne and Norm SilberLING for their careful reviews of the manuscript. Robert Barth, A.P., Tosdal, R.M., Wooden, J.L., Howard, K.A., 1997. Triassic plutonism in southern California: southward younging of arc initiation along a truncated continental margin. Tectonics 16, 290 – 304.

References


Stevens and Stone, Earth Sci Rev., 2005
Deformation belt in B is Penn deformation in Nevada. There is also deformation like that in A that was left off.
But are younger units truncated and offset?? Can we look at latest Paleozoic to unravel?
Is Caborca offset late Paleozoic?
El Paso Mtns also have a pretty thick sequence of Ordovician–Cambrian deep water clastic seds and quite a bit of Devonian (including, apparently, a Devonian ash fall tuff—El Paso Mtn Geol Map)
Recall the elements of the Permian here. If we restore for Cz and likely K faults, we get picture on right. Note in particular the distribution of Permian-Triassic plutons and how they cross the Devonian facies belts in NW.
Recovering the SW end of the miogeocline...
The time span of subduction initiation to magmatism in the Gurnis et al. (2004) model is less than 10 m.y. (Fig. 13). For the Permian section proximal magmatism (andesite intrusions and fl.

Deep-marine strata occur throughout member B, where renewed carbonate at the base of member C are consistent with further transgression/subsidence in opposition to global eustatic trends (Fig. 8). Between ca. 275 Ma and ca. 270 Ma, as determined by sedimentary isopachs (Zahler, 2012), shoreline regression on the western edge of the Colorado Plateau between 285 Ma and 277 Ma resulting in a large density contrast between outer continental and negative lithospheric density (Gurnis et al., 2004) (Fig. 1), which may include shoreline migration on the western El Paso Mountains to show a proximal sequence consistent with subduction initiation occurring at the same time as uplift in the El Paso Mountains is found. As subduction resistance lessened (Fig. 13), vertical changes at subduction inception, followed by more substantial subsidence as subduction resistance lessened (Fig. 13), on the overriding plate, the rock record would show subtle vertical changes at subduction inception, followed by more substantial subsidence as subduction resistance lessened (Fig. 13). Taking into account vertical changes at subduction inception, followed by more substantial subsidence as subduction resistance lessened (Fig. 13), on the overriding plate, the rock record would show subtle vertical changes at subduction inception, followed by more substantial subsidence as subduction resistance lessened (Fig. 13).
Note summary of ages of Permian into early Triassic on left. Oldest continental rocks receiving detritus from this arc is Chinle. Interestingly, these might not be quite as old as start of arc...
Subset of Permian–Triassic zircons. Suggests presence of arc even back to 280 Ma.
The North Park sample is unique in its comparatively high percentage (13%) of Permian grains. Six of these grains lie in a discrete cluster from 288 to 282 Ma, and their source is uncertain. Zircons of this age are inferred by Dickin et al. (2008) to derive from the East Mexico arc; however, we question this interpretation for reasons provided above. On the western margin of Laurentia, transcurrent faulting was likely active at ca. 280 Ma, and subduction was established by ca. 270 Ma. Thus these grains are not considered likely to be derived from the Cordilleran margin. The majority of grain ages are in a comparatively narrow range, from ca. 270 to 247 Ma (n = 13); ages and Th/U are compatible with derivation from the Mojave Desert plutons and the Sonora portion of the arc (Fig. 6).

The youngest grains from the Holbrook, Hunt, and Joseph City samples are very similar in their age and chemistry; Hunt and Joseph City samples additionally have an older group of grains in the ca. 240–260 range Ma that were likely derived from the San Bernardino suite and/or older plutons in the northern Mojave Desert (Miller et al., 1995); Th/U ratios support correlation with both suites of plutons (Fig. 6). Grains as young as 218 Ma may have been subject to lead loss; on probability density plots the maxima are between 226 and 223 Ma (Fig. 4), and these older ages may be more suitable estimates.

Lag in timing reflects, authors argue, presence of marine arc until c 230 Ma.
Permian subduction initiation in the El Paso Mountains, California

RESEARCH

in a recrystallized mud matrix. Iron-stained grayish-orange, laminated to thin-bedded argillite to sandy siltstone beds form a continuously exposed section near the top of the member. In thin section, one sample contains very angular to well-rounded, fine- to very fine-grained chert lithic fragments (~20%), quartz grains (~7%), angular to subangular opaque grains (~7%), and trace sponge spicules, set in a cherty-silty clay matrix (~60%) with patchy calcite cement. The opaque minerals define lamination.

Member B (Phb) is more calcareous than member A (Pha) and consists of thinly to thickly bedded, medium- to dark-gray argillite and medium-gray to yellowish-brown calcareous argillite interbedded with dark-yellowish-orange calc-siltstone. Covered intervals between outcrops are more extensive than in member A (Pha). In thin section, all samples from member B (Phb) consist of clay or silt with local sponge spicules, and opaque, (organic?) material.

Facies changes in El Paso Mtns not global—what is this telling us about SW margin c. 280 Ma? (WOrth noting that this same deepening was inferred by Snow long ago as a fore deep in front of the Last Chance thrust system).
Interpreted as early phase of subduction initiation. We’ll come back to the arc much later, but this would seem to help clinch truncation by Permian.
Standing back, how does all this fit in?