Speculative tectonic model for the early Mesozoic arc of the southwest Cordilleran United States

Cathy J. Busby-Spera
Department of Geological Sciences, University of California, Santa Barbara, California 93106

ABSTRACT

The early Mesozoic continental arc of Arizona, California, and western Nevada is here interpreted to have occupied a continuous graben depression, more than 1000 km long, similar to the modern extensional arc of Central America. High calculated rates of subsidence, the presence of syndepositional normal faults and fault-talus breccias, the abundance of calderas and high-level intrusions, and interstratification of calc-alkalic and alkalic volcanic rocks provide support for this model. The arc graben depression acted as a long-lived (more than 40 m.y.) trap for craton-derived quartz sands, which were funneled along the length and across the width of the depression.

INTRODUCTION

The term "Andean-type arc" has been applied to the Mesozoic volcanic-plutonic arc of California and Arizona because this arc formed on continental crust (Hamilton, 1969; Burchfiel and Davis, 1972). This analogy has led to the notion that this arc formed a high-standing region of uplift. Although there is evidence for uplift and erosion of the arc in late Mesozoic time (Dickinson and Rich, 1972; Fiske and Tobisch, 1978), a growing body of evidence indicates that subsidence was important along much of the arc in early Mesozoic time.

I speculate that the Late Triassic–Early Jurassic arc of Arizona, California, and western Nevada bore many similarities to the present-day arc of Central America (Fig. 1). Nearly all the arc volcanoes in Central America are within deep, fault-bounded depressions that owe their origin to extension and transtension along the trailing edge of the Caribbean plate (Burkart and Self, 1985). "Graben syncline" structures control the site of stratovolcanoes and large calderas in the Kamchatka arc as well (Erlich, 1979). Whereas these modern analogues provide a "snapshot" of surficial features in extensional arcs, the early Mesozoic arc of the southwest Cordillera provides a three-dimensional view of an extensional or transtensional arc as it evolved over 40 m.y.

EVIDENCE FOR AN ARC GRABEN DEPRESSION

The origin of intra-arc basins, with extremely complex and episodic patterns of subsidence, sedimentation, and volcanism, is in general poorly understood. Structural depressions or troughs coincident with a volcanic-plutonic arc have been attributed to a variety of mechanisms. These include extension across the arc, transtension along intra-arc strike-slip fault zones, gravitational spreading above domes created by voluminous plutonism, faulting of the upper plate in response to segmentation of the subducting slab, and broad downwarps created by loss of eruptive products to atmospheric transport (Burkart and Self, 1985; Carr, 1976; Cole, 1984; Dalmayrac and Molnar, 1981; Erlich, 1979; Fitch, 1972; Hildebrand and Bowring, 1984; McBirney and Williams, 1965; Tobisch et al., 1986; Smith et al., 1987). Several lines of evidence, when considered together, suggest that the early Mesozoic arc of the southwestern United States occupied an extensional or transtensional graben depression (see Fig. 2), including (1) extreme thickening of Upper Triassic to Middle Jurassic continental and shallow-marine successions along the arc, relative to the adjacent craton, requiring high subsidence rates for their accumulation and preservation; (2) dispersal of quartz arenites across the width and along the length of the arc, suggesting that it acted as a funnel and a trap for craton-derived detritus; (3) abundance of high-level intrusions and thick ignimbrite sequences, and relative dearth of

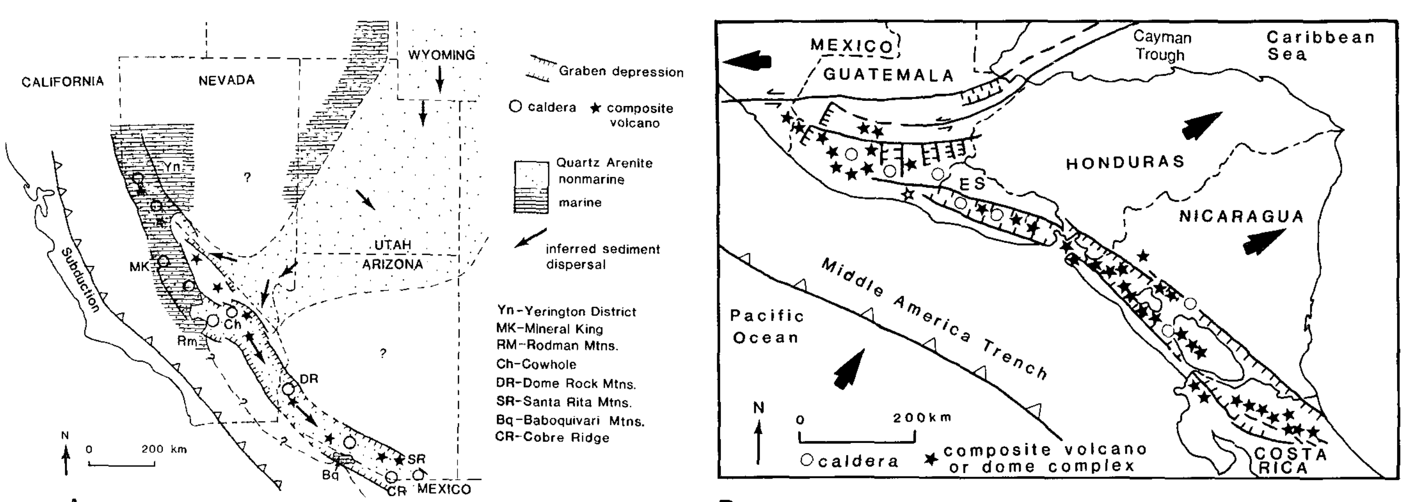

Figure 1. Modern arc graben depression of Central America (from Burkart and Self, 1985; Dengo et al., 1970) and speculative model for southwest United States Cordillera in Late Triassic to early Middle Jurassic time. If an arc graben depression of dimensions of that in Central America is drawn on a map of southwestern United States, it encompasses nearly all thick intra-arc successions of early Mesozoic age; it is not clear, however, if proposed depression was as continuous as modern analogue at any one time, and its position could have shifted somewhat with time. Sections discussed in text (Figs. 3, 4, and 5) are plotted in Figure 1A. Inferred sediment dispersal in Wyoming, Utah, Arizona, and Nevada taken from Kocurek and Dott (1983); inferred sediment dispersal within arc is speculative. Large arrows in Figure 1B indicate plate-motion vectors. Calderas and volcanoes in Figure 1A are schematic.

mesozonal intrusions despite present-day exposures at a variety of crustal levels, suggesting that most magmas rose easily to upper crustal levels and erupted into volcano-tectonic depressions similar to those in modern extensional/transtensional environments (e.g., Sumatra, New Zealand); (4) presence of alkalic volcanic rocks locally interstratified with calc-alkalic volcanic rocks, similar to modern rifted arcs like the Colima graben, Mexico (Allan et al., 1988); (5) stratigraphic and structural evidence for syndepositional normal faults, including localized, thick sequences of polylithologic breccia that suggest faulting contemporaneous with sedimentation; and (6) occurrences of limestone and calc-silicate rocks interstratified with continental arc deposits, suggesting depressions occupied by marine embayments and/or large lakes.

Previous workers have suggested that subsidence rates in the early Mesozoic continental arc were high; furthermore, the distribution of craton-derived quartz sands across the width and along the length of the arc argues against its origin as a continuous high-standing feature (Miller, 1978; Busby-Spera, 1984a; Karish et al., 1987). Earlier workers correlated all intra-arc quartz arenites with the upper Pleinsbachian to Toarcian Navajo Sandstone (Stanley et al., 1971; Bilodeau and Keith, 1986; Marzolf, 1982). New age data, however, show that these intra-arc quartz arenites vary in age by at least 40 m.y. (Wright et al., 1981; Riggs et al., 1986; Busby-Spera et al., 1987; Asmerom et al., 1988).

An arc graben depression could have acted as a long-lived trap for craton-derived quartz sands. These sands may have been funneled along the length of the depression, even if they only impinged upon a short segment of it (Fig. 1). Thus, the entire length of the arc graben depression could have been continuously fed quartz sands from once-extensive dune fields not preserved on the craton, as well as by less extensive coastal dunes that characterized periods of marine transgression on the craton (e.g., dune deposits at the southern margin of the Bajocian-Bathonian Carmel seaway). Additional sources of quartz sand could include recently deposited layers eroded from fault scarps (see recycling of quartz sand, Fig. 2).

A brief review, by geographic region, of published and new data that support my speculative model is given below.

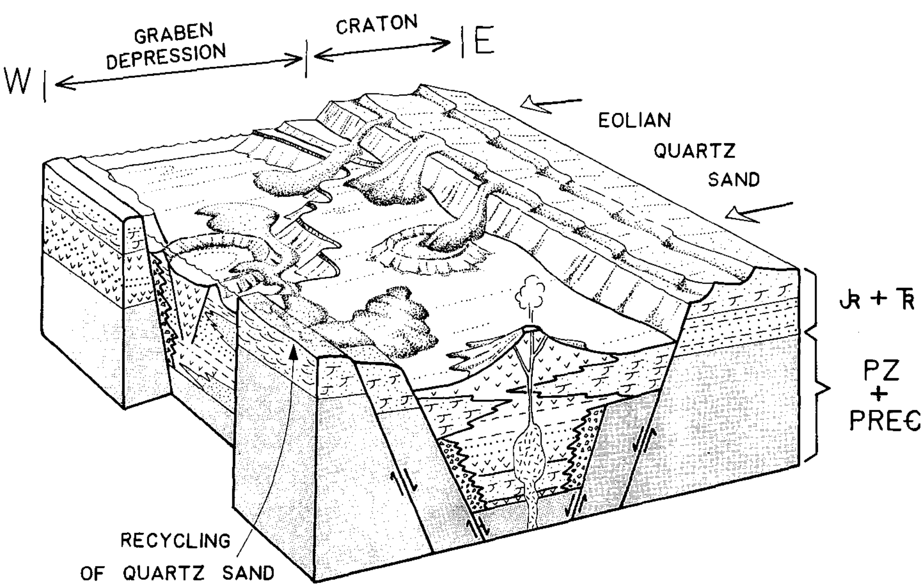

Figure 2. Speculative tectonic model for Late Triassic through Middle Jurassic arc of Arizona, California, and west-central Nevada.

Southern Arizona

Jurassic supracrustal rocks crop out extensively in this region (Reynolds, 1988). Quartz arenites interstratified with volcanic rocks in six ranges have all been correlated with the Lower Jurassic Navajo Sandstone by Bilodeau and Keith (1986). This interpretation is supported in the Baboquivari Mountains and Sil Nakya Hills by an upper intercept U-Pb zircon age of 190 Ma on metavolcanic rocks interstratified with quartz arenites (Wright et al., 1981). U-Pb zircon ages from the Santa Rita Mountains, however, suggest that some of these quartz arenites are older (205–210 Ma), perhaps Wingate-equivalent in age (Riggs et al., 1986; Asmerom et al., 1988).

Several features of the Fresnal Canyon sequence in the Baboquivari Mountains (Fig. 3A) suggest that it accumulated in an extensional arc setting (Haxel et al., 1985; Tosdal et al., 1988). U-Pb zircon dates from the bottom and top of

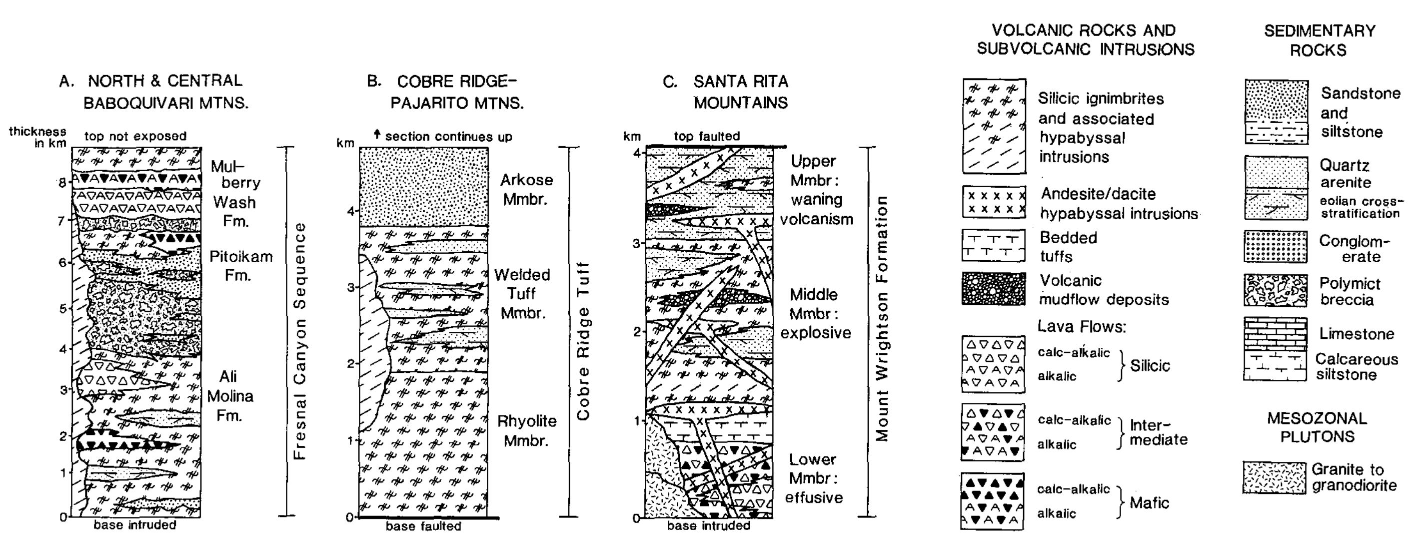

Figure 3. Lithostratigraphic sections through Jurassic rocks of south-central Arizona. A: Baboquivari Mountains (Haxel et al., 1980; Tosdal et al., 1988). B: Cobre Ridge–Pajarito Mountains (Knight, 1970; Riggs, 1985; and unpub. data). C: Santa Rita Mountains (Drewes, 1971; Riggs and Busby-Spera, 1987; and unpub. data).

the section, and from a hypabyssal intrusion that cuts most of the section, indicate that this 8-km-thick section of continental volcanic and sedimentary rocks accumulated in less than 10 m.y. (Wright et al., 1981). High rates of subsidence are required to preserve such a thick continental succession. Minor alkalic mafic to silicic volcanic rocks interstratified with calc-alkalic ignimbrites provide evidence for extensional processes within the arc (Haxel et al., 1985). The 2.0-km-thick Pitoikam Formation contains a thick succession of angular to subangular polymict breccia that I interpret as fault talus breccia reworked by debris flows. Geochemical data on marbles and Mn-bearing metasedimentary rocks in the southern Baboquivari Mountains (not shown in Fig. 3A) suggest that a marine environment may have existed for part of the Early Jurassic Period (Goodwin, 1985). This is shown as a marine embayment in Figure 1A, similar to modern-day embayments in Central America.

The Cobre Ridge tuff (Fig. 3B) is a 4.5-km-thick section of silicic ignimbrites and associated shallow-level intrusions, with locally interstratified quartz arenites, that occurs in the Pajarito Mountains and along Cobre Ridge in Arizona and Mexico. Work in progress and published data suggest that this may represent an Early or Middle Jurassic caldera complex (Riggs, 1987; Riggs and Busby-Spera, 1987).

Geochronological work on the Mount Wrightson Formation of the Santa Rita Mountains (Riggs et al., 1986; Asmerom et al., 1988) suggest that this 4-km-thick continental succession accumulated in a relatively short time; thus, high subsidence rates are required for its preservation. The Mount Wrightson Formation records the evolution of a multivent stratovolcano complex from an early effusive stage to a late explosive stage followed by waning volcanism (Fig. 3C). Rapid intra-arc subsidence resulted in burial of active vents by ignimbrites and reworked tuffs derived from other vents in the complex (Riggs and Busby-Spera, unpub. data). The Sawmill Canyon discontinuity, a northwest-trending regional lineament that bounds the Mount Wrightson Formation to the northeast, has been postulated to show hundreds of metres of normal slip (down to the southwest) between Permian and Middle Jurassic time (Titley, 1976). I speculate that this discontinuity, which marks the northern limit of thick Jurassic volcanic successions, formed the northeastern structural boundary of the arc graben depression in southern Arizona.

Southeast California–Southwest Arizona

Lower Mesozoic strata of this region can be divided into an older package correlative with Triassic strata of the Colorado Plateau, and a younger package consisting of eolian quartz arenites overlain and intruded by silicic volcanic rocks (Fig. 4A). The silicic volcanic rocks, referred to as the Dome Rock sequence (Tosdal et al., 1988), have yielded a discordant Early or Middle Jurassic U-Pb zircon age at one locality in southeast Arizona (L. T. Silver, personal commun., *in* Crowl, 1979). The Dome Rock sequence is widely exposed in more than a dozen ranges and locally consists of ignimbrite sections up to 1 km thick that probably represent intracaldera accumulations (Tosdal et al., 1988).

Mojave Desert

Numerous workers have referred to quartz arenites, interstratified with volcaniclastic rocks in known or suspected early Mesozoic sections across the Mojave Desert, as "Aztec Sandstone," and have tentatively correlated this unit with the Lower Jurassic Navajo Sandstone (Hewett, 1931, 1956; Grose, 1959; Dunne, 1977; Miller and Carr, 1978; Marzolf, 1980). This interpretation has recently been called into question by new U-Pb zircon age data from the Cowhole Mountains (Fig. 5A) which show that a lava flow within the Aztec Sandstone is 172 Ma and the overlying Delfonte Volcanics are 167 Ma (Busby-Spera et al., 1987). The "Aztec Sandstone" in the Cowhole Mountains may thus be age-equivalent to the Carmel Formation or possibly the Entrada Sandstone (using the DNAG geologic time scale; Palmer, 1983), and it is 20–30 m.y. younger than the quartz arenites in southern Arizona discussed above.

Several features taken together are suggestive of early Mesozoic intra-arc extension in the Mojave Desert region. Craton-derived quartz sand was distributed across the width of the arc, individual horizons reaching thicknesses of up to 700 m in the western Mojave (Fig. 4B) and 300 m in the eastern Mojave (unpub. data), suggesting that the arc occupied a low-lying region. Widespread, very thick ignimbrite sequences may represent intracaldera accumulations (see Sidewinder Volcanic Series, Fig. 4B). Mildly alkalic volcanic rocks are locally interstratified with calc-alkalic volcanic rocks (Fig. 5B; also see Karish et al., 1987). Marbles and metacalcareous siltstones in the western Mojave (Fig. 4B; also in the Bean Canyon pendant, unpub. data) and in the eastern Mojave (Cowhole Mountains, unpub. data) may indicate flooding of an arc graben depression by marine embayments or lakes. Evidence for syndepositional faults is sparse, but polymict breccia at the base of the Aztec Sandstone (Fig. 5A) may represent talus shed from such faults.

Sierra Nevada and West-Central Nevada

Upper Triassic through Lower Jurassic sequences in the Mineral King and Ritter Range pendants of the High Sierra represent the northern extension of the arc graben depression into the marine realm (Fig. 1). Triassic through Lower Jurassic volcanic and sedimentary rocks of the Yerington region may owe their marine character to broad subsidence in the Sonomia successor basin (northwest Nevada marine province of Speed, 1978) rather than to intra-arc

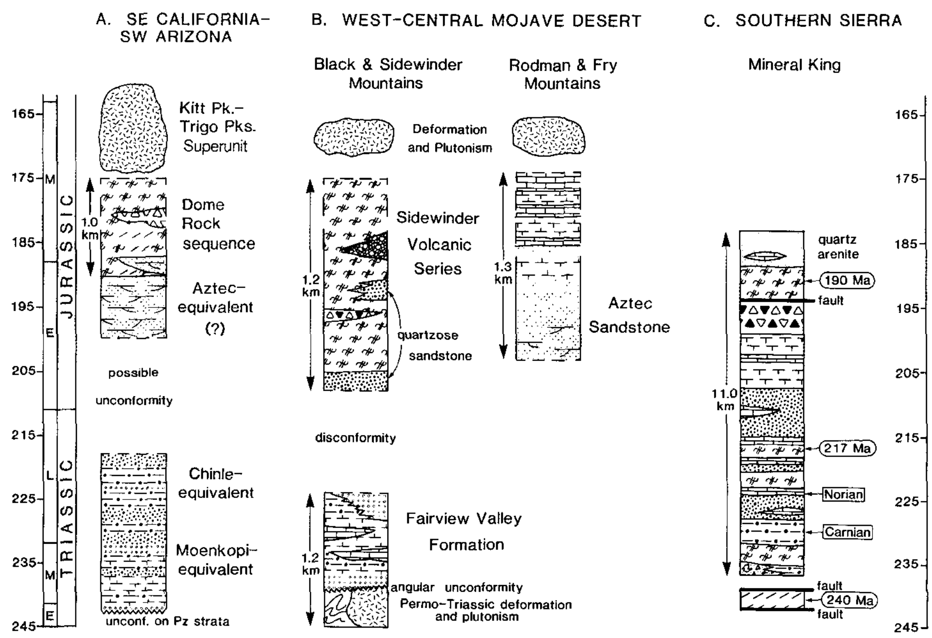

Figure 4. Selected early Mesozoic intra-arc lithostratigraphic sections of California plotted against DNAG geologic time scale (Palmer, 1983; lithologic symbols as in Fig. 3). A: Composite, generalized section along California-Arizona border (after Tosdal et al., 1988). B: Selected ranges in west-central Mojave (after Miller, 1978; Miller and Carr, 1978; Karish et al., 1987). C: Mineral King roof pendant of southern High Sierra (Busby-Spera, 1984a, 1984b; Busby-Spera and Saleeby, 1987). Rectangles show fossil ages; ovals show U-Pb zircon ages.

subsidence, although a combination of the two subsidence mechanisms is possible. By Middle Jurassic time, however, the marine province was lifted above sea level and the Yerington region was undergoing intra-arc extension and subsidence (Dilles and Wright, 1988).

Several features of the Mineral King section of the southern Sierra Nevada suggest that it was deposited in an arc graben depression: (1) high rates of subsidence of at least 200 m/m.y. are required to accumulate at least 6 km of shallow-marine sediment in less than 25 m.y. (calculated from upper half of section, Fig. 4C); (2) syndepositional normal faults and associated fault talus breccias are present near the base of the Mineral King section; (3) four large-volume, caldera-forming eruptions are recorded in the section (Busby-Spera, 1984b); and (4) locally derived volcanic lithic sandstones occur throughout the section, but quartz arenites that conformably overlie an ignimbrite dated at 190 Ma (Busby-Spera and Saleeby, 1987) may indicate that Navajo-equivalent sands gained access to the marine segment of the arc graben depression.

North of Mineral King, in the region of the Saddlebag Lake and Ritter Range pendants, a 10-km-thick section of silicic pyroclastic rocks accumulated in a shallow-marine environment in Late Triassic to Early Jurassic time. This indicates high intra-arc subsidence rates (Fiske and Tobisch, 1978) similar to those estimated for the Mineral King section (Busby-Spera, 1984a).

High rates of subsidence are required to accumulate and preserve the 4-km-thick section of continental strata that accumulated in less than 4 m.y. in the Yerington region (Dilles and Wright, 1988). This subsidence occurred within a graben bounded by syndepositional normal faults that downdropped the 169 Ma Yerington batholith and were cut by 165 Ma dikes. The volcanic rocks show a transitional calc-alkalic to mildly alkalic chemistry (Dilles and Wright, 1988) suggestive of intra-arc extension.

CONCLUSIONS

I suggest that continuous or semicontinuous belts of thick continental-arc sequences originate largely in extensional settings similar to the modern-day Central American arc graben depression. The early Mesozoic arc of the southwest United States provides an opportunity to document patterns of faulting, subsidence, and magmatism in three dimensions through approximately 40 m.y. of intra-arc extension. These results can then be applied to interpretation of more disrupted or metamorphosed continental arc successions of all ages.

The inference that craton-derived quartz sands gained access to the continental arc not once but many times over a period of at least 40 m.y. has important implications for terrane analysis. Rather than acting as a barrier, the rapidly subsiding arc received quartz sands across its width, and even beyond to the forearc region (Saleeby et al., 1989). Most of the forearc region, and possibly part of the arc, may have been subsequently removed by tectonic processes, probably including strike-slip faulting, but the approximate site of origin of these terranes may be inferred if quartz arenites are recognized within them.

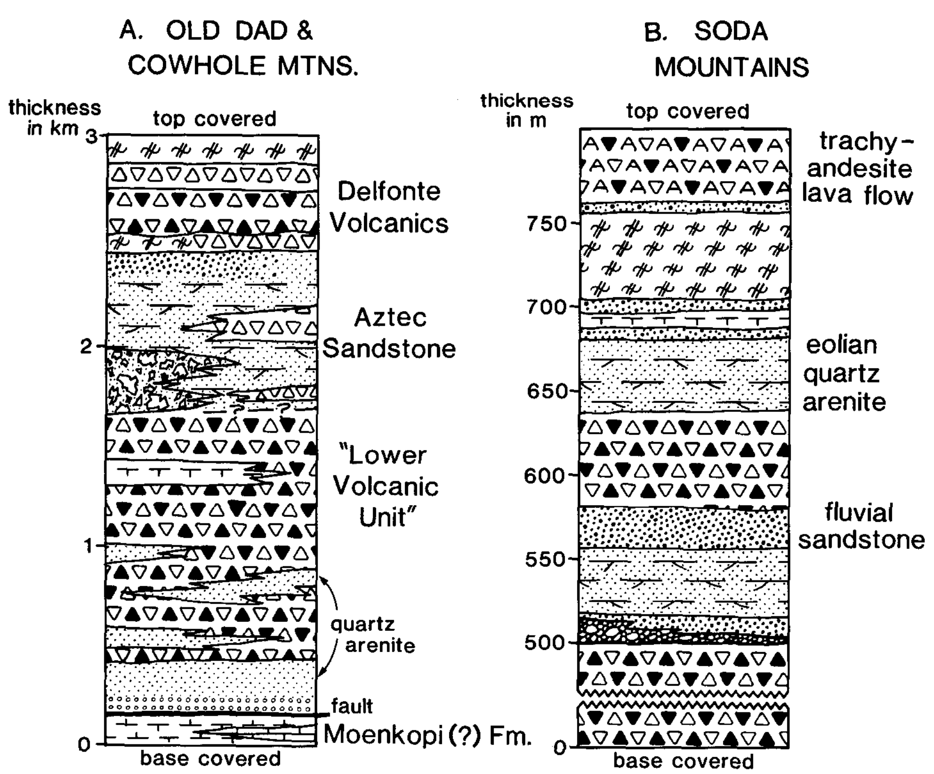

Figure 5. Aztec Sandstone and intercalated strata in eastern Mojave Desert near Baker, California (lithologic symbols as in Fig. 3). A: Composite section from Old Dad and Cowhole mountains (Dunne, 1977; Marzolf, 1983; and unpub. data). B: Highway Spur measured section, Soda Mountains (unpub. data).

REFERENCES CITED

Allan, J.F., Nelson, S.A., Luhr, J.F., Carmichael, I.S.E., and Wopat, M., 1988, Pliocene-Recent rifting in southwest Mexico and associated alkaline volcanism, *in* Dauphin, J.P., ed., The Gulf and Peninsular province of the Californias: American Association of Petroleum Geologists Memoir (in press).

Asmerom, Y., Zartman, R.E., Damon, P.E., and Shafiqullah, M., 1988, U-Th-Pb zircon ages from Santa Rita Mountains, southeast Arizona: Implications for timing of early Mesozoic magmatism: Geological Society of America Abstracts with Programs, v. 20, p. 140.

Bilodeau, W.L., and Keith, S.B., 1986, Lower Jurassic Navajo-Aztec–equivalent sandstones in southern Arizona and their paleogeographic significance: American Association of Petroleum Geologists Bulletin, v. 70, p. 690–701.

Burchfiel, B.C., and Davis, G.A., 1972, Structural framework and evolution of the southern part of the Cordilleran orogen, western United States: American Journal of Science, v. 272, p. 97–118.

Burkart, B., and Self, S., 1985, Extension and rotation of crustal blocks in northern Central America and effect on the volcanic arc: Geology, v. 13, p. 22–26.

Busby-Spera, C.J., 1984a, The lower Mesozoic continental margin and marine intra-arc sedimentation at Mineral King, California, *in* Bachman, S., and Crouch, J., eds., Tectonics and sedimentation along the California margin: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 135–156.

—— 1984b, Large-volume rhyolite ash-flow eruptions and submarine caldera collapse in the lower Mesozoic Sierra Nevada, California: Journal of Geophysical Research, v. 89, p. 8417–8427.

Busby-Spera, C.J., and Saleeby, J.B., 1987, Geologic guide to the Mineral King area, Sequoia National Park, California: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, 44 p.

Busby-Spera, C.J., Mattinson, J.M., and Riggs, N.R., 1987, Lower Mesozoic extensional continental arc, Arizona and California: A depocenter for craton-derived quartz arenites: Geological Society of America Abstracts with Programs, v. 19, p. 607.

Carr, M.J., 1976, Underthrusting and Quaternary faulting in northern Central America: Geological Society of America Bulletin, v. 87, p. 825–829.

Cole, J.W., 1984, Taupo-Rotorua depression: An ensialic marginal basin of the North Island, New Zealand, *in* Kokelaar, B., and Howells, M., eds., Marginal basin geology: Geological Society of London Special Publication 16, p. 109–120.

Crowl, W.J., 1979, Geology of the central Dome Rock Mountains [M.S. thesis]: Tucson, University of Arizona, 76 p.

Dalmayrac, B., and Molnar, P., 1981, Parallel thrust and normal faulting in Peru and constraints on the state of stress: Earth and Planetary Science Letters, v. 55, p. 473–481.

Dengo, G., Bohnenberger, O., and Bonis, S., 1970, Tectonics and volcanism along the Pacific mar-

gin zone of Central America: Geologische Rundschau, v. 59, p. 1215–1232.
Dickinson, W., and Rich, E., 1972, Petrologic intervals and petrofacies in the Great Valley sequence, Sacramento Valley, California: Geological Society of America Bulletin, v. 83, p. 3007–3024.
Dilles, J.H., and Wright, J.E., 1988, The chronology of early Mesozoic arc magmatism in the Yerington district of western Nevada and its regional implications: Geological Society of America Bulletin v. 100, p. 644–652.
Drewes, H., 1971, Mesozoic stratigraphy of the Santa Rita Mountains southeast of Tucson, Arizona: U.S. Geological Survey Professional Paper 658-C, 81 p.
Dunne, G.C., 1977, Geology and structural evolution of Old Dad Mountain, Mojave Desert, California: Geological Society of America Bulletin, v. 88, p. 737–748.
Erlich, E.N., 1979, Recent structure of Kamchatka and position of Quaternary volcanoes: Bulletin Volcanologique, v. 42, p. 13–42.
Fiske, R., and Tobisch, O., 1978, Paleogeographic significance of volcanic rocks of the Ritter Range pendant, central Sierra Nevada, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 209–222.
Fitch, T.J., 1972, Plate convergence, transcurrent faults, and internal deformation adjacent to Southeast Asia and the western Pacific: Journal of Geophysical Research, v. 77, p. 4432–4460.
Goodwin, L.B., 1985, The geologic history of the southern Baboquivari Mountains, south-central Arizona: Geological Society of America Abstracts with Programs, v. 17, p. 594–595.
Grose, L.T., 1959, Structure and petrology of the northeast part of the Soda Mountains, San Bernardino County, California: Geological Society of America Bulletin, v. 70, p. 1509–1548.
Hamilton, W., 1969, Mesozoic California and the underflow of Pacific mantle: Geological Society of America Bulletin, v. 80, p. 2409–2430.
Haxel, G., Wright, J.E., May, D.J., and Tosdal, R.M., 1980, Reconnaissance geology of the Mesozoic and lower Cenozoic rocks of the southern Papago Indian Reservation, Arizona: A preliminary report: Arizona Geological Society Digest, v. 12, p. 17–29.
Haxel, G., Briskey, J., May, D., Tosdal, R., and Wright, J., 1985, Reconnaissance petrochemistry of Jurassic igneous rocks, Baboquivari and Comobabi mountains area, southern Arizona: Geological Society of America Abstracts with Programs, v. 17, p. 361.
Hewett, D.F., 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U.S. Geological Survey Professional Paper 162.
——1956, Geology and mineral resources of the Ivanpah quadrangle, California and Nevada: U.S. Geological Survey Professional Paper 275, 172 p.
Hildebrand, R., and Bowring, S., 1984, Continental intra-arc depressions: A non-extensional model for their origin, with a Proterozoic example from Wopmay orogen: Geology, v. 12, p. 73–77.
Karish, C.R., Miller, E.L., and Sutter, J.F., 1987, Mesozoic tectonic and magmatic history of the central Mojave Desert, *in* Dickinson, W., and Klute, M., eds., Mesozoic rocks of southern Arizona and adjacent regions: Arizona Geological Society Digest, v. 18, p. 15–32.
Knight, L.H., Jr., 1970, Structure and mineralization of the Oro Blanco mining district, Santa Cruz County, Arizona [Ph.D. thesis]: Tucson, University of Arizona, 251 p.
Kocurek, G., and Dott, R., 1983, Jurassic paleogeography and paleoclimate of the central and southern Rocky Mountains region, *in* Reynolds, M.W., and Dolly, E.D., eds., Mesozoic paleogeography of west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 2, p. 101–116.
Marzolf, J.E., 1980, The Aztec Sandstone and stratigraphically related rocks in the Mojave Desert, *in* Fife, D.L., and Brown, G.R., eds., Geology and mineral wealth of the California desert: Santa Ana, California, South Coast Geological Society, p. 215–220.
——1982, Paleogeographic implications of the Early Jurassic(?) Navajo and Aztec Sandstones, *in* Frost, E., and Martin, D., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona and Nevada (Anderson-Hamilton volume): San Diego, California, Cordilleran Publishers, p. 493–501.
——1983, Early Mesozoic eolian transition from cratonal margin to orogenic-volcanic arc: Utah Geological and Mineral Survey Special Studies, no. 60, p. 39–46.
McBirney, A.R., and Williams, G., 1965, Volcanic history of Nicaragua: University of California Publications in Geological Science, v. 55, 63 p.
Miller, E., 1978, The Fairview Valley Formation; a Mesozoic intraorogenic deposit in the southwestern Mojave Desert, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 277–282.
Miller, E., and Carr, M., 1978, Recognition of possible Aztec-equivalent sandstones and associated Mesozoic metasedimentary deposits within the Mesozoic magmatic arc in the southwestern Mojave Desert, California, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 283–289.
Palmer, A.R., compiler, 1983, The Decade of North American Geology 1983 geologic time scale: Geology,v. 11, p. 503–504.
Reynolds, S.J., 1988, Geologic map of Arizona: Arizona Bureau of Geology and Mineral Technology, scale 1:1,000,000.
Riggs, N.R., 1985, Stratigraphy, structure, and mineralization of the Pajarito Mountains, Santa Cruz County, Arizona [M.S. thesis]: Tucson, University of Arizona, 102 p.
——1987, Stratigraphy, structure, and geochemistry of Mesozoic rocks in the Pajarito Mountains, Santa Cruz County, Arizona, *in* Dickinson, W., and Klute, M., eds., Mesozoic rocks of southern Arizona and adjacent regions: Arizona Geological Society Digest, v. 18, p. 165–176.
Riggs, N.R., and Busby-Spera, C.J., 1987, Tectonic setting of Lower Jurassic rocks in southern Arizona: Geological Society of America Abstracts with Programs, v. 19, p. 820.
Riggs, N., Mattinson, J.M., and Busby-Spera, C.J., 1986, U-Pb ages of the Mount Wrightson Formation, southern Arizona, and possible correlation with the Navajo Sandstone [abs.]: EOS (American Geophysical Union Transactions), v. 64, p. 1249.
Saleeby, J.B., Busby-Spera, C.J., Wright, J.E., Oldow, J.S., Walker, N.W., Dunne, G.C., Cowan, D.S., and Allmendinger, R.W., 1989, Early Mesozoic tectonic evolution of the western U.S. Cordillera, *in* Burchfiel, B.C., et al., eds., The Cordilleran orogen: Conterminous U.S.: Boulder, Colorado, Geological Society of America, The Geology of North America, v. G-3 (in press).
Smith, G.A., Snee, L.W., and Taylor, E.M., 1987, Stratigraphic, sedimentological, and petrologic record of late Miocene subsidence of the central Oregon High Cascades: Geology, v. 15, p. 389–392.
Speed, R.C., 1978, Paleogeographic and plate tectonic evolution of the early Mesozoic marine province of the western Great Basin, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 253–270.
Stanley, K., Jordan, W., and Dott, R., 1971, New hypothesis of Early Jurassic paleogeography and sediment dispersal for western United States: American Association of Petroleum Geologists Bulletin, v. 55, p. 10–19.
Titley, S.R., 1976, Evidence for a Mesozoic linear tectonic pattern in southeastern Arizona: Arizona Geological Society Digest, v. 10, p. 71–101.
Tobisch, O.T., Saleeby, J.B., and Fiske, R.S., 1986, Structural history of continental volcanic rocks, eastern Sierra Nevada, California: A case for extensional tectonics: Tectonics, v. 5, p. 65–94.
Tosdal, R.M., Haxel, G.B., and Wright, J.E., 1988, Jurassic geology of the Sonoran Desert region, southern Arizona, southeastern California, and northernmost Sonora: Construction of a continental-margin magmatic arc, *in* Jenny, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest (in press).
Wright, J.E., Haxel, G., and May, D.J., 1981, Early Jurassic uranium-lead isotopic ages for Mesozoic supracrustal sequences, Papago Indian Reservation, southern Arizona: Geological Society of America Abstracts with Programs, v. 13, p. 115.

ACKNOWLEDGMENTS

Supported by National Science Foundation Grant EAR-8519124. I thank W. Dickinson, G. Davis, E. Miller, N. Riggs, G. Smith, and R. Tosdal for reviews of the manuscript, and G. Haxel, J. Mattinson, and J. Wright for helpful discussions. U-Pb zircon analyses were performed by James Mattinson.

Manuscript received January 29, 1988
Revised manuscript received August 8, 1988
Manuscript accepted August 18, 1988

Reviewer's comment

One of the most thoughtful and potentially useful fresh ideas on Cordilleran geology to emerge in the last decade.

William R. Dickinson