

California terranes

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...subjected to the principle of least astonishment, geologic science has always tended to adopt the most static interpretation allowed by the data, and evidence indicating displacements larger than conceivable...has consistently met strong resistance.

Seeber, 1983, p. 1528

A vital lesson of plate tectonics is that there is no validity to any assumption that the simplest and therefore most acceptable interpretation demands a proximal rather than a distant origin.

Coombs, 1997, p. 763

INTRODUCTION

Two of this volume's coeditors persuaded the third into commenting on his own paper. There are three clear alternatives as a "classic paper" on California terranes. In the first of these, Hamilton (1969) first mentioned the North American Cordillera as a collage of exotic terranes and argued that the continental margin of North America was built out from the shelf edge by material carried to it on a converging oceanic plate. He argued for a process of "ocean-floor sweeping" caused by "underflow" (later called subduction; White et al., 1970) of Pacific mantle beneath the North American margin. Although it was a revolutionary paper, Hamilton (1969) emphasized exclusively east-dipping subduction beneath North America. The single-subduction tectonic model rapidly became a "ruling theory" (Chamberlin, 1890), a position it has held for the past 30 years. In the second alternative paper, Irwin (1972, p. C103) first defined a tectonic terrane as "an association of geologic features...which lend a distinguishing character to a particular tract of rocks and which differ from those of an adjacent terrane."

We, however, base our discussion on the third paper by one of us (Moores, 1970). This paper had its origins at the second Penrose conference, convened by W. R. Dickinson and described briefly earlier in this volume (in the biography of Dickinson). One of us (E. M. M.) attended this conference. In 1969, I (E. M. M.) had

been working in ophiolites for some six years, first on the Vourinos complex in northern Greece and subsequently on the Troodos complex in Cyprus (Moores and Vine, 1971). At the Penrose conference I reported on the evidence for sea-floor spreading in the Troodos complex, although I had not yet made the connection to all ophiolites. One of the informal breakout sections at the Penrose conference was devoted to discussion of the problem of ophiolite emplacement. One model discussed during this session was emplacement of ophiolites on continents by collision of a continental margin with a subduction zone dipping away from the continent. I had recently read an abstract from the annual meeting of the GSA by Ralph J. Roberts (Roberts, 1969), in which he described the Phanerozoic tectonic history of the U.S. Cordillera as an alternation of eugeosyncline and miogeosyncline depositional conditions along the margin with orogeny involving thrust from the continental margin toward the interior of the continent. As described earlier in this volume, in the final session of the conference, convenor Dickinson summarized his emerging ideas relating ancient geosynclines to modern tectonic environments, a talk I earlier described as "one of the most exciting moments of my scientific life." Sitting there greatly inspired after Dickinson's remarks, I was meditating on the previous evening's discussions of ophiolite emplacement and Roberts' account of Cordilleran history, when in a blinding flash of insight, it came to

me that Roberts' scenario could be explained as an alternation of Japan Sea and Andean continental marginal depositional systems with collisions of oceanward-dipping subduction zones. The ophiolites and island-arc terranes preserved in the Cordillera represented the remains of the colliding blocks.

To say that I was excited is a gross understatement—for weeks, I could hardly contain myself. Suddenly the entire Phanerozoic tectonic history of the U.S. Cordillera seemed crystal-clear. And the importance of ophiolites as tectonic indicators seemed equally clear. *Ophiolites were the key tectonic indicator. Their emplacements represented first-order tectonic events. Because these collisions were the cause of fold-thrust belts directed toward the interior of a continent, the latter, which were and still are much better studied than ophiolites, were derivative features, and thus secondary.* In my mind, this interpretation placed in plate tectonic context the arguments made earlier by Hess (1939, 1955) that “Alpine-type peridotite intrusions” (ophiolites) represented *the* major orogeny-initiating tectonic events. The first words of the title of my (Moores, 1970) paper, “Ultramafics and orogeny” were deliberately paraphrased after that of Hess's (1955) paper: “Serpentines, orogeny, and epeirogeny.”

Because Penrose conferences had a no-publication requirement (rescinded in 1997 by act of the GSA Council), a moderate length of time had to pass until ideas generated at these conferences could be submitted for publication. The resulting publication (Moores, 1970) was the first to apply the collisional model of ophiolite and/or island-arc emplacement to an explanation of the multiple orogenic episodes found in California and surrounding regions in the Phanerozoic (Moores, 1970, Fig. 4; see also Moores and Twiss, 1995, Fig. 12.10; Ingersoll, 1997, Fig. 3). (In his evaluation of the paper, one of the *Nature* reviewers, F. J. Vine, commented that it was the first paper to invoke the existence of plate tectonics in pre-Mesozoic time.)

This was the first paper expressly to suggest the existence of a role in Cordilleran tectonics for one or more subduction zones dipping away from the continent. In this model, the “two-sided” Cordilleran orogen (see Şengör, this volume) developed by collision of these seaward-dipping subduction zones with the North American continental margin on the downgoing plate and a subsequent polarity flip. The ophiolites or island arcs were not explicitly called “terrane” as such, but it was clear that they originated elsewhere than their present position. Although the analysis was essentially two-dimensional, possible diachroneity of collision (orogeny) along the continental margin was explicitly discussed, and margin-parallel transform faulting was mentioned as an important alternative possibility.

DEVELOPMENT OF IDEAS

The “conceptual revolution” visualized by Moores (1970) was slow to gather steam. Early subsequent developments included a synthesis of the relationship between plate tectonics and orogenic belts (Dewey and Bird, 1970), an authoritative and influential synthesis of Phanerozoic history from regional information (Burchfiel

and Davis, 1972, 1975) and a synthesis of the “non-collisional” tectonic development of western North America (Coney, 1972). Coleman's (1971) model of the emplacement of ophiolites by “obduction” was quickly and generally accepted. Most workers assumed that obduction was antithetic to subduction beneath a continental margin, in concert with the single subduction zone “ruling theory.” By contrast, under the collisional model of ophiolite emplacement, obduction amounts effectively to aborted subduction of a continental margin (e.g., Moores, 1982, 1998).

Terrane tectonic analyses burgeoned after Irwin's (1972) paper (e.g., Coney et al., 1980; Schermer et al., 1984, and references therein). Maps that formerly displayed rock units and fault slices were reissued as terrane maps. A Circumpacific terrane map (Howell et al., 1985) contains a total of 333 separately defined units (~ 30 in California and contiguous states).

The terrane concept has added immeasurably to our understanding of orogenic belts and their evolution (e.g., Howell, 1989), and it has made it clear that a multidisciplinary approach is necessary in order to understand orogenic belts. Terrane analysis has focused attention on the existence of far-traveled crustal pieces that have ended up in various locations, as well as on the existence in orogenic belts of large-scale transcurrent, or strike-slip, displacements. The approach has catalyzed much research in all orogenic regions, particularly in the Circumpacific region. Paleomagnetic investigations of individual terranes (e.g., Alvarez et al., 1980; Debiche et al., 1987; Butler et al., 1997; Irving et al., 1996; and many others) have enriched our understanding of the trajectory of individual terranes. New tectonic terms, such as “superterrane,” “docking,” and “stitching” (e.g., Monger et al., 1982), have appeared. Silver and Smith (1983) drew a clear analogy between Mesozoic western North America and the present-day western Pacific. Careful structural analysis along the soles of ophiolites has elucidated the kinematic history of these complexes (e.g., Cannat and Boudier, 1985; Harper et al., 1990).

Problems exist, however, with the terrane concept as it has been applied in western North America. Five of these are as follows.

1. A few terranologists have somewhat piously proclaimed that the approach is objective (e.g., Jones, 1990), a misconception roundly and rightly criticized by Şengör and Dewey (1990), but one often held about geologic mapping (Moores, 1985).

2. Terrane analysis as commonly practiced is essentially a map-view analysis of an orogen; the shape of terranes in three dimensions has seldom been considered. This fact has led to sweeping, somewhat grandiose pronouncements about the significance of terranes in the growth of continents, assuming that each terrane is a block of crustal thickness. Careful geophysical surveys (Clowes et al., 1993) and geologic work (Hansen and Dusel-Bacon, 1998) have shown in southern Canada and Alaska, respectively, that terranes there are not complete crustal blocks but thin sheets, and that the volumetric addition to the continental crust in many cases is minor. In other words, these terranes are thrust sheets or nappes, rather than continental blocks, and are thus amenable to comparison with the nappes in the Alpine-Himalayan terrane that have been known for more than a century

(Şengör and Dewey, 1990, and references therein; Hansen and Dusel-Bacon, 1998; Moores and Day, 1984).

3. Many tectonic models for the western United States have considered only east-dipping subduction zones, and the role of terranes in structural development of an orogen has seldom been considered explicitly. There have, however, been important exceptions. Tempelman-Kluit (1979) presented a very clear description of an ophiolite-related arc-continent collision interpretation for the northern Omineca belt in Canada and Alaska that closely resembles the models of Moores (1970). Arc-continent collision models have been invoked for the mid-Mesozoic Nevadan and related orogenies (e.g., Schweickert and Cowan, 1975; Ingersoll and Schweickert, 1986; Dilek et al., 1988), and to explain Paleozoic tectonics of the Sierra Nevada and surrounding region (Schweickert and Snyder, 1981). Ehlig (1981) associated a Paleocene, west-dipping subduction with the development of the Pelona-Orocopia schists. Cannat and Boudier (1985) suggested north- and west-dipping subduction for ophiolitic zones of Paleozoic and Mesozoic age, respectively, in the Klamath Mountains. Henderson et al. (1984) modeled the Laramide orogeny as a collision of a large oceanic plateau on the Farallon plate with North America. Dilek and Moores (1992) suggested a model of oceanic arcs separated by a sinistral transform fault for terranes in the Klamaths and Sierra Nevada prior to their collision with North America. Cloos (1993) analyzed the relationship between the size of accreted blocks and structure, although his analysis considered only a single subduction zone, as did Henderson et al. (1984). Wakabayashi (1992, Fig. 3) considered the impact of accretion of much smaller-scale Jurassic and Cretaceous Franciscan Complex terranes on the structural evolution of the Franciscan Complex and coeval tectonic events in the North American Cordillera (including a possible collision in western Nevada). Maxson and Tikhoff (1996) suggested a “hit-and-run” collisional model for the Laramide orogeny caused by arrival and subsequent northward shift of the Wrangell-Insular superterrane.

4. With a few exceptions (e.g., Tarduno et al., 1985; Debiche et al., 1987; Wakabayashi, 1992), terrane analyses in western North America have mostly considered only margin-parallel movement of terranes for latitudinal transport (see summary of accounts in Cowan et al., 1997). This restricted view of latitudinal transport of terranes may have resulted from a model of strain partitioning of oblique subduction, wherein all of the tangential component of the relative plate motion is partitioned into strike-slip faulting on the continent (e.g., Jayko and Blake, 1993). McCaffrey (1996) showed that the fraction of the tangential component of oblique subduction partitioned into strike-slip faulting ranges from 0% to 100%, depending on the subduction zone, so the 100% partitioning model applied in the Cordillera represents the *maximum* possible amount of strike-slip faulting. Paleomagnetic data constrain latitude, but not longitude; few data from terranes fix their longitudinal positions during transport relative to the western margin of North America.

5. Most terrane analyses have considered only dextral translation of terranes relative to North America. Exceptions, however, include Avé Lallemant (1995), Oldow et al. (1993), Wakabayashi

(1992), and Moores (1998). Plate-motion models indicate both sinistral oblique and dextral oblique plate convergence between the North American and Farallon plates during the late Mesozoic (Engelbreton et al., 1985), although these plates may not have been in contact with each other until the Late Cretaceous (Moores, 1998). Hansen (1996) has invoked what she terms “yo-yo tectonics” for motions of Wrangellia and Stikinia, involving Permian–Early Jurassic paleolatitudes concordant with North America, and Late Jurassic–Cretaceous southward and mid-Cretaceous and younger northward motions, respectively, relative to North America. Motions of entirely oceanic plates in Early Jurassic and earlier time are constrained only by paleomagnetic evidence from ophiolites around the Pacific Rim, because of the lack of preserved ocean floor of that age.

TERRANES AND CALIFORNIA TECTONIC DEVELOPMENT: CURRENT STATUS

We summarize here tectonic events related to terranes in California, proceeding forward in time. The reader should bear in mind that at present no consensus exists, even among ourselves, as to the nature of some of the most fundamental geologic contacts in California, or the number and polarity of subduction zones represented in the Sierra Nevada and surrounding regions (Fig. 1) (cf. Moores, 1970, 1998; Ingersoll, 1997; Moores and Twiss, 1995, Fig. 12.10; Ingersoll and Schweickert, 1986; Schweickert and Snyder, 1981; Burchfiel and Davis, 1972, 1975; Saleeby, 1982; Sharp, 1988). When appropriate, we use the more traditional nomenclature (e.g., nappe, block, thrust fault, allochthon, ophiolite) in order to enhance the precision of the discussion.

The principal terrane-related tectonic events for California and surroundings include the following.

1. Rifting of the western North American margin occurred during the latest Proterozoic–earliest Cambrian, possibly from Antarctica–Australia (e.g., Schweickert and Snyder, 1981; Moores, 1991). The Neoproterozoic–Paleozoic Trinity ophiolite (also called the Trinity terrane) in the Klamath Mountains may, but need not be a remnant of the oceanic crust formed during this rifting event. This complex includes two or three separate blocks with different histories sutured together, presumably in an ocean in Neoproterozoic–Ordovician time (N. Lindsley-Griffin, 1998, written commun.). Ophiolite formation was followed by Silurian–Devonian arc development (Wallin et al., 1995), and Devonian thrusting of the ophiolite complex over the “Central Metamorphic Belt.” The present east-over-west direction of thrusting becomes north-northeast over south-southwest in present coordinates if 100° clockwise rotation during Late Jurassic time of the eastern Klamaths is applicable (e.g., Cannat and Boudier, 1985; Fagin and Gose, 1983).

2. The Roberts Mountain allochthon of deep-water sedimentary and volcanic rocks was thrust over miogeoclinal rocks from central Nevada to the east-central Sierra Nevada roof pendants (Burchfiel et al., 1992; Saucier, 1997). Foredeep strata, the Diamond Peak–Chainman Formations, deposited in the miogeocline, attest to significant topography to the west (present coordinates)

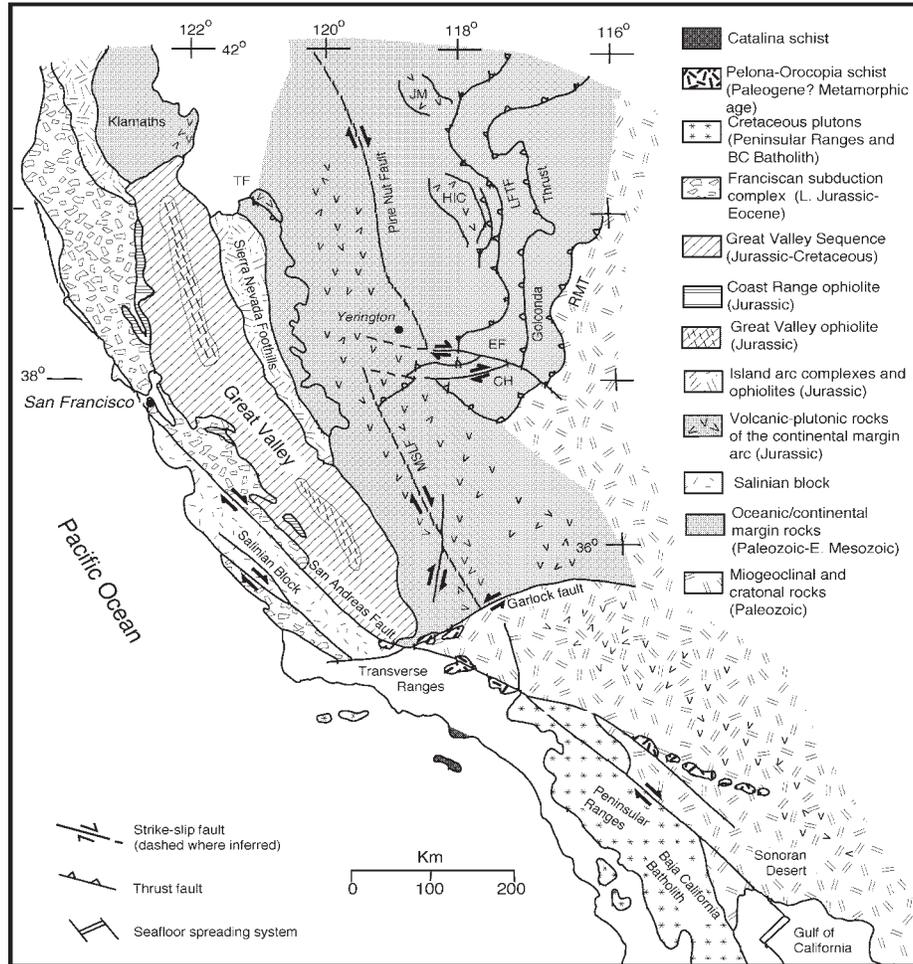


Figure 1. Simplified tectonic map of part of the western U.S. Cordillera (modified from Dilek and Moores, 1993). Key to lettering: CH—Coaldale fault, EF—Excelsior fault, HIC—Humboldt igneous complex, JM—Jackson Mountains, LFTF—Luning-Fencemaker thrust fault, MSLF—Mojave–Snow Lake fault, RMT—Roberts Mountains thrust, TF—Taylorsville fault.

after thrusting. No Paleozoic ophiolitic sequence has been found in Nevada, although possibly correlative deposits are present in the eastern belt of the Sierra Nevada, as described in the following (Varga and Moores, 1981; Schweickert and Snyder, 1981).

3. The “Northern Sierra terrane” or Sierra Nevada Eastern Belt developed. Thrusts and melange in the lower Paleozoic Shoo Fly Complex include volcanic and metasedimentary complexes, and serpentinite (Saleeby et al., 1989; Hansen et al., 1993). Overlying are three island-arc complexes, of Devonian-Mississippian, Permian-Triassic, and Jurassic age (Day et al., 1985). Unconformities are present within the Shoo Fly Complex, between Jurassic and older rocks, and possibly at the base of the Triassic sequences. The Shoo Fly melange and serpentinite could be related to the Roberts Mountain allochthon, *but there is no a priori requirement that the Sierra rocks were adjacent to North America prior to Middle Jurassic time*. Harwood and Murchey (1990) argued for proximity of the Sierra Nevada and the Havallah sequence of the Golconda allochthon of western Nevada (event 6 here) based on stratigraphic

and paleontologic similarity. The stratigraphic evidence is not compelling; widely scattered arcs of the western Pacific show similar stratigraphies (e.g., Kennett et al., 1977; Moores and Twiss, 1995, p. 195). Arguments of proximity based solely on paleontologic similarity are simply incorrect, as any observation of present global biostratigraphic patterns demonstrates (e.g., Valentine and Moores, 1974). For example, the Indo-Pacific faunal province extends 15,000 km from east Africa to the Tuamotus. This often-made correlation between faunal similarity and proximity is another “ruling theory” in the sense of Chamberlin (1890).

4. Arc development in the eastern Klamath occurred during the mid-late Paleozoic. These arc sequences have often been correlated with those of the northern Sierra Nevada, but chemical differences argue for a distinct origin (Roure and Lapiere, 1989).

5. The formation of the Feather River–Devil’s Gate ophiolite complex, northern Sierra Nevada, occurred during the mid-late Paleozoic (Edelman et al., 1989a; Day et al., 1985; Saleeby et al., 1989). This enigmatic body may represent the remnant of ocean

lithosphere preserved by out-of-sequence thrusting during collision of two opposing-polarity colliding arcs in Jurassic time (Moore, 1998), or it may represent a remnant of a long history of mostly east-dipping subduction and suturing.

6. The Golconda allochthon of late Paleozoic deep-water sedimentary and volcanic rocks was emplaced. Rocks of this allochthon previously were deposited oceanward of the Roberts Mountain allochthon and were thrust over it in a Permian-Triassic Sonoma orogeny representing an island arc-continent collision, followed possibly by arc reversal (Speed, 1978; Schweickert and Snyder, 1981; Ingersoll, 1997). No foredeep deposit has been identified corresponding to that of the Antler event, however. Possibly correlative structures of comparable age are present in the White-Inyo Mountains, and in the eastern Sierra Nevada roof pendants (e.g., Lahren and Schweickert, 1989).

7. Formation of the late Paleozoic-early Mesozoic chaotic deposits (either melanges or olistostromes) containing Carboniferous-Permian limestone blocks of Tethyan affinity, early Mesozoic chert-argillite sequences, and Late Triassic basalt (Irwin, 1981; Edelman et al., 1989a). These deposits crop out in the Western Paleozoic-Triassic belt of the Klamaths and the central belt of the Sierra Nevada.

8. An early Mesozoic continental arc formed in west-central Nevada, followed to the west by a basinal sequence and an allochthonous ophiolite-arc assemblage, the Humboldt complex (Dilek and Moore, 1995).

9. Early Jurassic volcanic arcs are present in the eastern Klamath Mountains and Sierra Nevada. These may have been, but are not required to be, continuous with each other. They may or may not have been contiguous with Nevada.

10. The basement rocks of the western Klamath Mountains volcanic arcs formed; the rocks appear to be a multiple series of oceanic-affinity terranes (Hacker et al., 1993). They may have, but need not have, formed near the North American continental margin.

11. Formation of "old ophiolitic" basement of the Smartville, Slate Creek, and other western-central belt ophiolites of the Sierra Nevada occurred, probably in an oceanic environment at about 200 Ma (Dilek et al., 1990; Edelman et al., 1989b).

12. The mid-Mesozoic (ca. 170 Ma) arrival of early Mesozoic and older arc-ophiolite assemblages in northern Sierra (old Smartville, Slate Creek), and possibly the western Klamath Mountains (e.g., Chetco, Preston Peak), was part of an east-facing Stikine-Intermountain superterrane (e.g., Moore, 1998).

13. During the late Mesozoic (ca. 160 Ma) there was development of the west-facing arc and backarc basin in the Klamath Mountains (Josephine ophiolite) and spreading in the northwest Sierra Nevada within the collided block and adjacent oceanic region (Smartville dikes, Coast Range, Great Valley [?] ophiolites; Dilek and Moore, 1992).

14. The late Mesozoic (150–160 Ma) emplacement of the Great Valley and possibly the Coast Range ophiolites (Godfrey and Klemperer, 1998), and possibly the Josephine ophiolite (Harper et al., 1996), occurred over the western edge of the continent along a west-dipping subduction zone. There was defor-

mation of the northern Sierra Nevada, emplacement of the Humboldt complex in western Nevada (e.g., Wakabayashi, 1992, Fig. 6), possible arc-arc collision followed by westward thrusting in the Klamath Mountains (Harper et al., 1996), and arrival of western volcanic terrane in the Peninsular Ranges of Baja California and southern California (Dilek and Moore, 1993). The inception of Franciscan Complex subduction and possibly Coast Range ophiolite emplacement was about 165–160 Ma. The general pattern possibly was reminiscent of the present-day Philippines (e.g., Moore, 1998; Silver and Smith, 1983).

15. Sinistral faulting in the Sierra Nevada and adjacent Nevada and major 800 km displacement along Mojave-Sonora megashear occurred during the late Mesozoic (150–140? Ma).

16. During the late Mesozoic (150–80 Ma), development of Franciscan subduction complex, including nappe formation, arrival of exotic terranes of various dimensions, and metamorphism of blueschists (e.g., Wakabayashi, 1992, and many others) occurred. Initiation of subduction associated with development of the Catalina schist occurred about 110 Ma (cf. Mattinson, 1986; Grove and Bebout, 1995). There was dextral displacement on the Mojave-Snow Lake and related faults (Lahren and Schweickert, 1989; Maxson and Tikoff, 1996).

17. The Wrangell-Insular superterrane arrived in "Baja BC" at the latitude of California (Irving et al., 1996) in the late Cretaceous (ca. 80–70 Ma). If this superterrane collided with the Franciscan subduction zone (Maxson and Tikoff, 1996), subsequent translation northward may have taken place either inboard (east) of the Franciscan Coastal Belt (which arrived later) along the present Coastal Belt-Central Belt boundary, or entirely west of the Franciscan subduction zone.

18. The latest Cretaceous-Tertiary (70–25 Ma) emplacement of the Franciscan Coastal Belt was near its present location. Initiation of subduction associated with the development of the Pelona-Orocopia schists occurred at about 65 Ma; the polarity of subduction is controversial (Ehlig, 1981; Jacobsen, 1990). Juxtaposition of the Salinian block with the Franciscan occurred between 80 and 50 Ma along a contact distance of 150 km or more (Wakabayashi and Moore, 1988; Wakabayashi and Hengesh, 1995).

19. Collision of a spreading ridge-transform system with the Franciscan subduction zone occurred at 25 Ma, and was followed by progressive development (to present) of the San Andreas fault system (e.g., Atwater, 1970, and many others).

DISCUSSION

Although we reiterate that there is no consensus on the tectonic development of California, we can draw the following conclusions.

1. West of the Cordilleran miogeocline, the multiplicity of terranes implies a complex mosaic of intraoceanic and continent-oceanic interactions reminiscent of the modern western Pacific (Silver and Smith, 1983; Moore, 1998). The Paleozoic and early Mesozoic tectonic histories of the Sierra Nevada and Klamath Mountains involve multiple tectonic interactions of distal continent-derived debris, oceanic island arcs, ophiolites, and associated

features. Despite the Antler and Sonoma orogenic events, there is no a priori evidence that *requires* that the terranes of the Klamath Mountains and Sierra Nevada developed close to the North American continent or were next to it prior to Middle Jurassic time.

2. Much of the Mesozoic and associated Paleozoic terranes may represent part of a major oceanic-island arc complex, similar to the Philippines, comprising the Stikine-Intermountain-Guerrero terranes; the complex collided with the continental margin about 170 Ma and was involved in subsequent simultaneous dextral and sinistral strike-slip faulting. This complex strike-slip faulting situation recalls that of the Himalayan-Tibetan tectonic region, to which a rigid-plastic slip-line tectonic model has been applied (Moores, 1998; Tapponnier and Molnar, 1976). This scenario implies that the Sierra Nevada and Klamath Mountains were decoupled from Nevada during much of the Mesozoic, and that the early to mid-Mesozoic Nevada thus did not necessarily constitute a backarc environment to the continental margin arc (Dilek and Moores, 1993), a view expressed by Hamilton (1969) and entrenched deeply in the “ruling theory” Cordilleran-type models.

3. The recently documented presence of a 600-km-long ocean crust-mantle slab beneath the Great Valley (Godfrey et al., 1997; Godfrey and Klemperer, 1998) is a major new result that should be taken into account in all future tectonic scenarios for California.

4. In the three decades since Moores (1970), there have been many important advances in the methodology of analyzing orogenic belts. Nevertheless, the significance of ophiolites in large-scale crustal tectonics and terrane amalgamation has not yet been universally grasped. *To reiterate, ophiolites emplaced by collision represent major first-order tectonic structures; associated decollement fold-thrust belts are secondary.* The major paradigm shift, dreamed of by Moores (1970) following Hess (1939, 1955), that ophiolite emplacements are the tectonic events of prime importance, has yet to happen. Why? Possibly because most regional structural geologists and/or tectonicists are trained mainly in the traditionally dominant fields of structure and stratigraphy. Ophiolite workers have tended to be petrologists and geochemists, less concerned with details of regional tectonics. The true tectonic significance of ophiolites represents an interdisciplinary issue, and thus falls into the “interdisciplinary oceans of ignorance” lamented by Ziman (1996), and fostered by traditional discipline-based educational curricula. Further progress in tectonics of orogenic belts will be made primarily by exploration of this other type of “ocean.”

Note on computer animation of the southwest Pacific–Southeast Asia region. The actual complex patterns of terrane interaction in continental orogenic belts such as the North American Cordillera may never be known because of the inherent gaps in the record, particularly the oceanic history of various pieces. The modern region most reminiscent of the Paleozoic-Mesozoic Cordillera is the southwest Pacific (Silver and Smith, 1983; Hamilton, 1979; Moores, 1998). There the tectonic interactions that will eventually lead to continental orogenic terranes are still ongoing. To accompany his tectonic reconstruction of this region (Hall, 1996), Robert Hall has developed a computer animation of the complex, even

counterintuitive motions of the southwest Pacific–Southeast Asian region. This animation is reproduced on the compact disk included with this volume. It should serve as a conceptual model of the motions that acted to produce the North American Cordillera.

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