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INSIDE

Tectonic Wedging Beneath Fore-arc Basins: Ancient and Modern Examples from California and the Lesser Antilles

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View north up the Great Valley Group homocline on the west side of Capay Valley, California. These Upper Cretaceous subsea-fan rocks may have been rotated to their present moderate to steep east dips along west-vergent thrusts that rise from the east-vergent master detachment that underlies the Coast Ranges and western Sacramento Valley. Photo by Stephen Phipps. Flight courtesy of Norman Pease.

ABSTRACT

Eastward-tapering tectonic wedges, interpreted to underlie the western Great Valley of California, may be analogous to underthrust wedges beneath the Tobago trough in the Lesser Antilles arc-trench system. In both regions, the proposed wedges consist of accretionary prism rocks thrust arcward beneath a fore-arc basin. The wedges are bounded above by a roof thrust or passive backthrust, and they appear to have propagated by forward imbrication and duplexing beneath the fore-arc basin. Displacement on the bounding thrust systems is zero at the wedge tips. Seismic refraction, gravity, and magnetic studies suggest that the fore-arc basement in both regions dips gently seaward and does not form a buttress to prevent arcward underthrusting. Propagation of the wedges during plate convergence and subduction is reflected in patterns of syntectonic sedimentation in the Great Valley and Tobago trough fore-arc basins.

The Lesser Antilles analogue implies that a mantle-rooted subduction-zone suture associated with late Mesozoic and Tertiary plate convergence beneath western California is not exposed in the eastern Coast Ranges. Instead, the dominant crustal-scale structure may be a subhorizontal detachment surface beneath the accretionary prism and tectonic wedge. Late Cenozoic thrust and strike-slip faults of the Coast Ranges may all root in this detachment. Seismically active blind thrusts in the western Great Valley may be reactivated structures associated with earlier tectonic wedging. The Lesser Antilles analogue may thus provide insights into the kinematics of active crustal shortening in the Coast Ranges and western Great Valley.

INTRODUCTION

Over the past two decades, the Mesozoic-Paleogene rocks of the California Coast Ranges, principally the Great Valley and Franciscan complexes, have become the classic on-land model for sedimentary and tectonic processes at convergent margins. Recent structural and geophysical work in the California Coast Ranges suggest, however, that a revision of this classic model is in order. Structural, geophysical, and ocean-drilling studies of the Lesser Antilles fore arc suggest that this region may constitute an actualistic model for a reinterpretation of the California Coast Ranges. This new model potentially offers insights into processes within convergent margins, the mechanisms of crustal growth, and the kinematics of transpressional plate motion.

Recent geophysical studies suggest that eastward-tapering tectonic wedges underlie the western margin of California's Great Valley (Wentworth et al., 1984; Wentworth and Zoback, 1989; see Fig. 1A). The wedges are bounded below by a west-dipping detachment system, and above by an east-dipping roof thrust or a series of east-dipping backthrusts. Displacement on the thrusts bounding the wedges is zero at the wedge tips at their eastern end. The kinematics of wedge emplacement may be similar to the growth and propagation of passive roof duplexes or "triangle zones" in the eastern Canadian Cordillera (Unruh and Moores, 1992; Jones, 1982; Price, 1986).

The origin of these wedges is enigmatic. The wedges underlie the western margin of a Mesozoic to Tertiary fore-arc basin. Stratigraphic and structural relations suggest that the wedges were emplaced by early Tertiary time (Wentworth et al., 1984), and thus are temporally related to plate convergence and subduction beneath western California. Recent studies of the Lesser Antilles arc-trench system suggest the existence of similar underthrust wedges beneath the Tobago trough fore-arc basin (Torrini and Speed, 1989; see Fig. 1B). The underthrust wedges of the Lesser Antilles system are probably related to the growth of a two-sided outer-arc ridge between the trench and fore-arc basin, and represent arcward underthrusting of the accretionary prism.

In this paper we compare the late Mesozoic to Tertiary trench-arc system in western California to the modern Lesser Antilles trench-arc system. The general structural similarity between the two regions and the importance of arcward-vergent thrusting in accretionary complexes were pointed out by Silver and Reed (1988). The eastward-tapering tectonic wedges beneath the western Great Valley of California are viewed as analogous to underthrust wedges beneath the Tobago trough.

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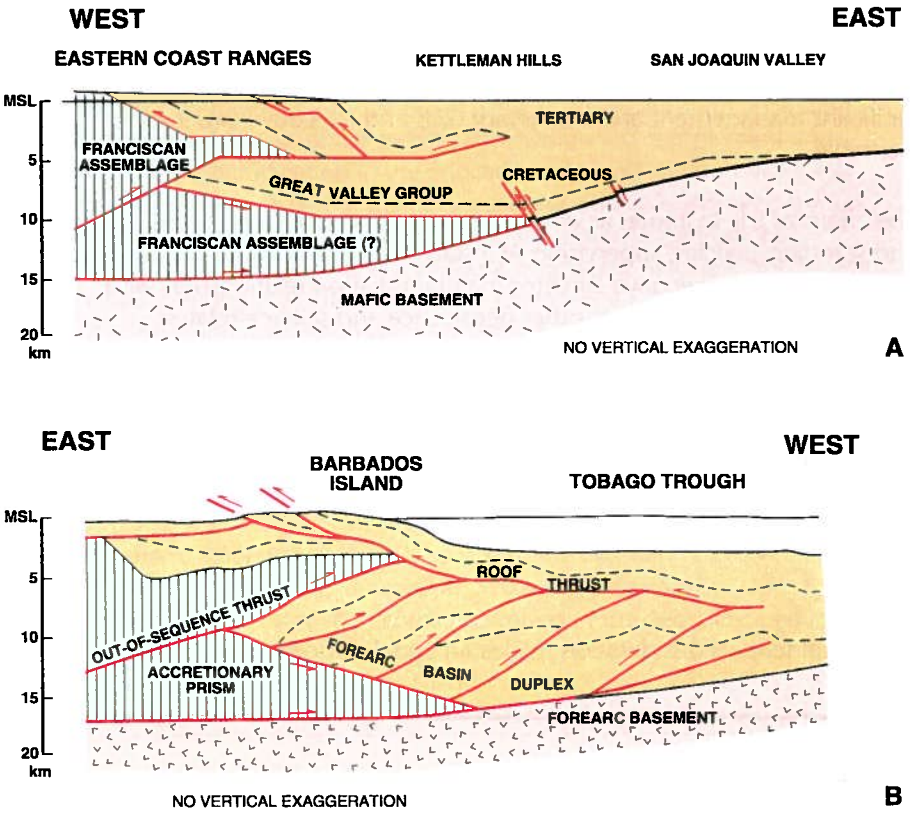

Figure 1. A: Tectonic wedges beneath the western San Joaquin Valley, California, inferred from analysis of seismic reflection and refraction data (modified from Fig. 2 in Wentworth et al., 1984). The wedges are interpreted to consist primarily of accretionary prism rocks of the Franciscan assemblage simultaneously thrust eastward over subhorizontal to gently west-dipping fore-arc basement, and beneath strata of the Mesozoic Great Valley group. East-vergent out-of-sequence thrusts have imbricated the Franciscan wedge. West-vergent backthrusts exposed in the eastern Coast Ranges are rooted in the out-of-sequence thrust. **B:** Model for tectonic wedging beneath the Tobago trough in the Lesser Antilles arc-trench system, based on interpretation of seismic reflection and refraction data (modified from Fig. 16 in Torrini and Speed, 1989). Note the similarities between the Lesser Antilles and western San Joaquin Valley wedges.

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This modern analogue perhaps has implications for the deep crustal structure of western California and for the kinematics of late Cenozoic transpressional deformation between the Pacific and North American plates.

TECTONIC WEDGING AND CRUSTAL STRUCTURE IN WESTERN CALIFORNIA

Through late Mesozoic and most of Tertiary time, the Pacific–North American plate boundary in western California was a convergent margin (Dickinson and Seely, 1979). With formation of the Mendocino triple junction during latest Oligocene time and its subsequent northward migration, plate convergence and subduction were replaced by transform faulting (Atwater, 1989). More recently, a change in relative plate motion at 3.4–3.9 Ma increased transpressional deformation along the plate boundary (Harbert, 1991). Late Cenozoic uplift of the Coast Ranges and the development of seismically active fold-and-thrust belts parallel to the San Andreas fault in western California may be an accommodation of transpressional plate motion (Namson and Davis, 1988; Harbert and Cox, 1989; Harbert, 1991).

Traditional Plate-Tectonic Models

Until recently, the crustal structure of the western California Coast Ranges was thought to be well understood in the context of this plate-tectonic scenario (Fig. 2). From west to east, the Coast Ranges have been divided into three lithotectonic belts (Bailey et al., 1970; Dickinson and Seely, 1979): (1) a Late Jurassic to Neogene accretionary complex, now represented by the Franciscan assemblage; (2) a fragmentary Late Jurassic ophiolite, in thrust contact with and structurally overlying the Franciscan assemblage; and (3) fore-arc basin strata of Late Jurassic to Tertiary age (Ingersoll, 1978). Mesozoic fore-arc strata are referred to collectively as the Great Valley group.

In early plate-tectonic models of California, these lithotectonic belts were interpreted as elements of the Mesozoic to Tertiary arc-trench system (Ingersoll, 1978; Dickinson and Seely, 1979). According to these models, the ophiolite is the uplifted, east-tilted basement of the fore-arc basin. The thrust contact between the ophiolite and structurally underlying Franciscan assemblage is interpreted as a preserved, mantle-rooted subduction-zone suture. These models view the ophiolite as extending eastward beneath the fore-arc strata, possibly as a trapped fragment of oceanic crust, and suggest that it may act as a backstop to prevent arcward thrusting of the accretionary complex. The accretionary complex is interpreted to have grown from east to west by addition of thrust imbricates to the toe of the prism. Upward growth of the prism led to the development of an outer-arc ridge between the fore-arc basin and trench-slope break, which in turn ponded the fore-arc basin sediments. Aside from uplift, shortening, and some strike-slip modification, these models portray the suture and other tectonic elements of the former arc-trench system as generally intact (Fig. 2).

Reinterpretation: Tectonic Wedging and Imbricate Thrusting

Recent geological and geophysical studies have suggested a reevaluation of these models. Seismic refraction and reflection studies, as well as gravity and magnetic modeling, in the western Great Valley suggest that the crystalline Sierra Nevada basement extends beneath the Great Valley and westward beneath the Coast Ranges without major deflection (Wentworth et al., 1984; Griscom and Jachens, 1990). Resting on this seaward-dipping arc basement are eastward-tapering tectonic wedges (Wentworth et al., 1984; Fig. 1A). Structural relations suggest that the wedges were simultaneously thrust eastward over the crystalline basement and beneath the sedimentary deposits of the fore-arc basin. Seismic refraction studies indicate that the acoustic velocities of the rocks within the wedges are greater than the velocities of the overlying Great Valley group fore-arc strata. Wentworth et al. (1984) interpreted the higher velocities as evidence that the wedges consist primarily of Franciscan assemblage (Fig. 1A). If so, emplacement of the wedges represents eastward underthrusting of the accretionary complex beneath the fore-arc basin.

The wedges may have been emplaced by movement on west-dipping blind thrusts. Thrusts at high levels in the wedges terminate against east-dipping backthrusts or passive roof thrusts. Relatively younger thrusts root west of the wedge tips, ramp up to the east, and locally terminate against the backthrusts (Fig. 1A). These younger thrusts are "out-of-sequence" with respect to the faults that emplaced the wedges; that is, the younger thrusts are not successively developed at the wedge tip, as is the normal case. Examples of these structures have been described in the western San Joaquin Valley (Wentworth et al., 1984; see Fig. 1A) and in the southwestern Sacramento Valley (Unruh and Moores, 1992).

Timing of Wedging and Underthrusting

The history of wedge emplacement and propagation in western California is not yet fully documented. On the basis of stratigraphic and structural relations in the Coast Ranges, Wentworth et al. (1984) proposed that the tectonic wedges were emplaced beneath the western Great Valley by early Tertiary time.

Evidence for early Tertiary wedging, in the form of uplift and eastward tilting along the western fore-arc basin margin, can be inferred from angular unconformities between Upper Cretaceous fore-arc strata and early Tertiary submarine valley fill deposits. Analysis of subsurface data reveals that several cycles of submarine valley formation and filling occurred in the northern Great Valley during Tertiary time (Redwine, 1984; Almgren, 1984). Each cycle was preceded by a period of uplift and erosion along the western margin of the basin (Almgren, 1984).

The pattern of uplift, erosion, and subsequent filling of the submarine valleys is illustrated by the evolution of the Paleocene to early Eocene Princeton valley (Fig. 3). Correlated drill-hole data reveal that the thalweg of the Princeton valley (the deepest part of the channel) had a low gradient in its upper 112 km (12.3 m/km; 1.3°). As it crossed the western margin of the northern Great Valley basin, however, it abruptly cut 2133 m down through the Upper Cretaceous rocks over a lateral distance of 48 km or less (43.6 m/km; 4°). We attribute this increase in gradient to tectonic uplift above an eastward-tapering, underthrust wedge. Since the position of the Paleocene continental slope is unknown, it is not clear whether the Princeton valley formed simultaneously with the elevation of the Upper Cretaceous rocks that formed the continental slope, or whether the valley truncated previously elevated strata at its normal 1.3° gradient. Similar stratigraphic relations between the Paleocene Martinez submarine valley fill and underlying Upper Cretaceous in the west-central Great Valley (Almgren, 1984) suggest that uplift along the basin margin may have occurred in early Paleocene and perhaps latest Cretaceous time, and thus support the latter hypothesis.

The Princeton valley fill deposits in the northwestern Great Valley are separated from overlying Pliocene-Pleistocene strata by an angular unconformity. The unconformity progressively cuts down section through the Princeton valley fill deposits (e.g., Capay Formation) from east to west (Brooks et al., 1962, Pl. 25), suggesting post–early Eocene uplift and eastward tilting along the western basin margin. The Pliocene-Pleistocene strata above the angular unconformity are also tilted east, but to a lesser extent than the underlying strata (Unruh and Moores, 1992). These relations imply progressive uplift and eastward tilting in the northwestern Great Valley during the Tertiary. Numerous angular unconformities indicating progressive uplift and eastward tilting also separate Tertiary strata in the southwestern Great Valley (V. R. Ramirez, unpub. data). We attribute the uplift and tilting to progressive tectonic wedging.

Structural relations in the Coast Ranges indicate early Tertiary deformation due to marked contraction and

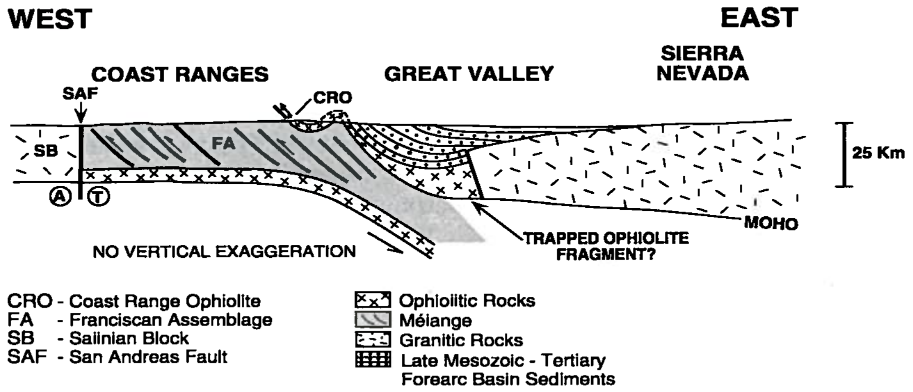

Figure 2. Early model for the crustal structure of western California (modified from Fig. 11 in Dickinson and Seely, 1979). The basement of the Great Valley fore-arc basin was thought to be uplifted, tilted eastward, and exposed in the eastern Coast Ranges as the Coast Range ophiolite. The thrust contact between the ophiolite and structurally underlying Franciscan assemblage was interpreted as a mantle-rooted subduction zone suture. The ophiolite was inferred to extend eastward beneath the Great Valley group fore-arc sediments and possibly serve as a buttress for the Franciscan accretionary wedge. These structural elements of the arc-trench system were thought to be intact but modified by regional shortening and strike-slip faulting.

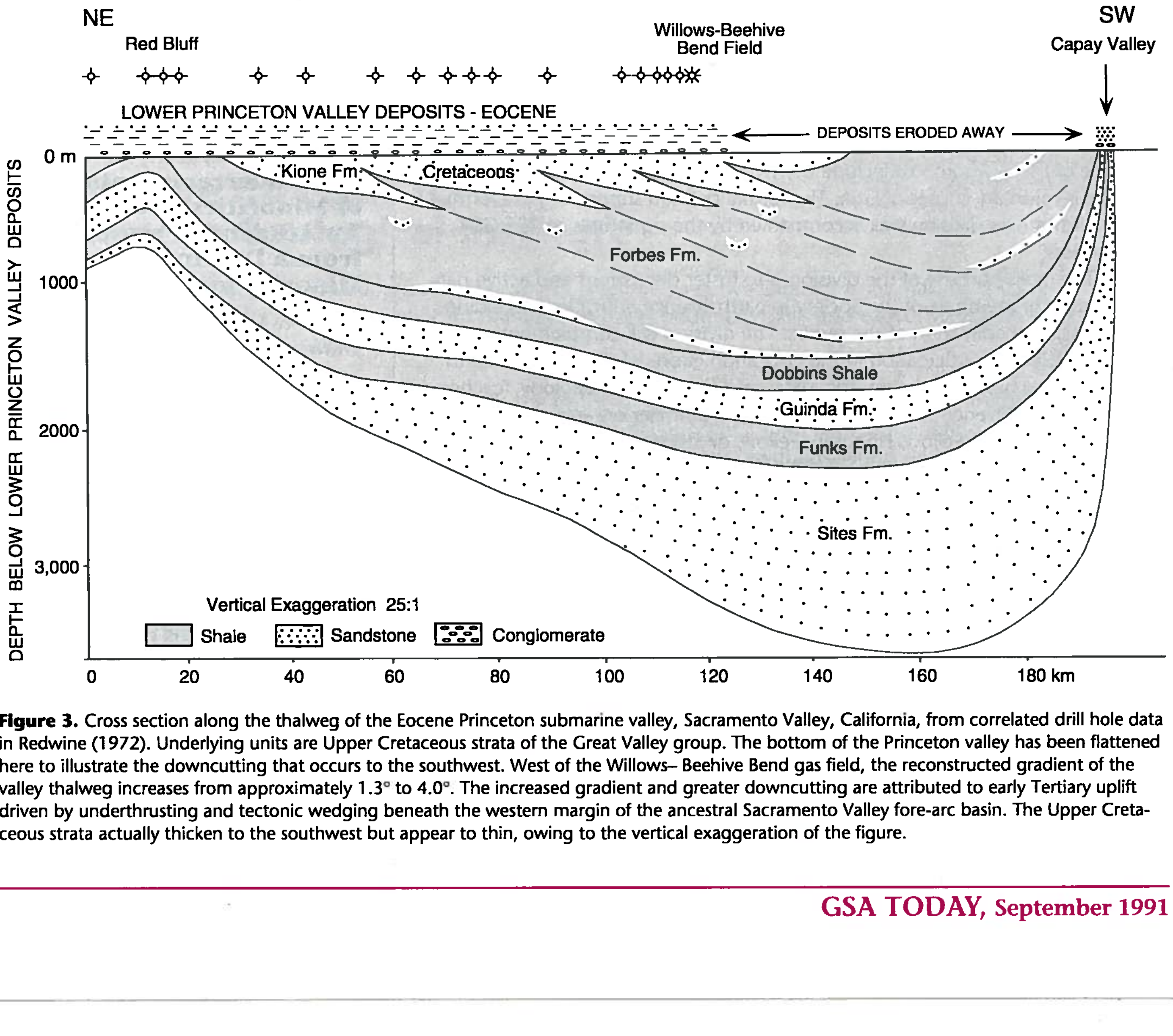

Figure 3. Cross section along the thalweg of the Eocene Princeton submarine valley, Sacramento Valley, California, from correlated drill hole data in Redwine (1972). Underlying units are Upper Cretaceous strata of the Great Valley group. The bottom of the Princeton valley has been flattened here to illustrate the downcutting that occurs to the southwest. West of the Willows– Beehive Bend gas field, the reconstructed gradient of the valley thalweg increases from approximately 1.3° to 4.0°. The increased gradient and greater downcutting are attributed to early Tertiary uplift driven by underthrusting and tectonic wedging beneath the western margin of the ancestral Sacramento Valley fore-arc basin. The Upper Cretaceous strata actually thicken to the southwest but appear to thin, owing to the vertical exaggeration of the figure.

perhaps tectonic wedging. In much of the northern Coast Ranges, surface structures are dominated by west-vergent imbricate thrusts (Suppe, 1978; Phipps, 1984; Ramirez, 1990). These thrusts shuffle Great Valley group strata, the Coast Range ophiolite, and Franciscan assemblage into a complex structural stack. The thrusts are associated with ramp anticlines with up to 12 km of structural relief. Fission-track dates from Franciscan rocks in the cores of the anticlines yield early Tertiary dates (Rahman, 1989; Dumitru, 1989; Miller, 1991; S. P. Phipps et al., unpublished), indicating that the rocks were uplifted through approximately 120 °C at that time (12 km depth at prevailing geothermal gradients). Tectonic wedging during latest Cretaceous to early Tertiary time provides a potential mechanism for the uplift suggested by the fission-track data. The west-vergent thrusts in the northern Coast Ranges may be backthrusts related to east-vergent wedging (Ramirez, 1990; Phipps et al., 1991), similar to backthrusts in the east-central Coast Ranges (Fig. 1A).

To summarize, we interpret stratigraphic, structural, and fission-track data as evidence that tectonic wedges were emplaced beneath the western Great Valley by early Tertiary time, and that the wedges were probably active episodically through Cenozoic time. Early to mid-Tertiary wedging was coeval with plate convergence and subduction beneath western California. Patterns of syntectonic sedimentation along the western Great Valley in early Tertiary time, described above, indicate that the tectonic wedges were propagating beneath a fore-arc basin, which was actively trapping sediment. The wedges, or thrusts related to wedging, may have been reactivated in late Cenozoic time in response to transpressional Pacific–North American plate motion (Wentworth et al., 1984; Unruh and Moores, 1992).

UNDERTHRUSTING BENEATH THE TOBAGO TROUGH, LESSER ANTILLES ARC-TRENCH SYSTEM

The southern Lesser Antilles fore-arc is distinguished by a 50–70-km-wide zone of active deformation between the structural high of the Barbados accretionary prism and the undeformed western part of the Tobago trough fore-arc basin (Fig. 1B). This zone, called the inner fore-arc deformation belt by Torrini and Speed (1989), is characterized by seaward-dipping blind thrusts propagating beneath the eastern margin of the fore-arc basin. The thrusts are interpreted to root in a deep detachment along the basement–accretionary prism contact, and rise to join a conjugate backthrust or passive roof thrust. Displacement on the thrust system is effectively zero at the intersection of the basal detachment and the backthrust, forming an arcward-tapering underthrust wedge (Fig. 1B). Seismic refraction and gravity studies suggest that the surface of the fore-arc basement dips gently seaward beneath the fore-arc basin and outer-arc ridge (Westbrook, 1975), and apparently does not form a buttress to prevent arcward underthrusting of the wedge.

Seismic reflection profiles reveal that the thrust wedge is characterized by a general lack of coherent seismic signals, except for discontinuous and isolated sets of dipping reflections. In contrast, the overlying fore-arc basin cover strata appear on reflection profiles as closely spaced, layered, and laterally continuous reflections. From these data, Torrini and Speed (1989) inferred that the underthrust wedge consists primarily of deformed layered rocks of the accretionary prism.

Underthrusting beneath the seaward margin of the Tobago trough has been accompanied by deformation of the cover strata above the tectonic wedge. Fore-arc strata riding up the roof thrust of the wedge are tilted westward toward the basin axis, reflecting the upper slope of the wedge taper. The tilting has been accompanied by seaward backthrusting within the fore-arc cover strata (Fig. 1B).

Torrini and Speed (1989) proposed that initial emplacement of the underthrust wedge was followed by an episode of shortening across the inner fore-arc deformation belt. The late deformation was accommodated primarily by thrusting and duplexing within the wedge. Relatively younger "out-of-sequence" thrusts cut older faults related to initial emplacement of the wedges (Fig. 1B). The late deformation is also reflected in patterns of syntectonic sedimentation along the eastern margin of the Tobago trough. Duplexing, out-of-sequence thrusting, and thrust-tip propagation have resulted in the local folding of the fore-arc cover strata. Sedimentation during growth of the fault-related folds has produced numerous onlap relations and angular unconformities along the eastern margin of the Tobago trough (Torrini and Speed, 1989).

COMPARISON OF THE LESSER ANTILLES AND WESTERN CALIFORNIA ARC-TRENCH SYSTEMS

The eastward-tapering tectonic wedges inferred to underlie the western Great Valley may be analogous to underthrust wedges beneath the Tobago trough. In both regions, the wedges have apparently propagated above a gently seaward-dipping basement surface and do not appear to be buttressed against trapped fragments of oceanic crust beneath the fore-arc basin. Tectonic wedging in both regions involves thrusting of accretionary complex rocks beneath a fore-arc basin. The style of underthrusting, including development of relatively younger "out-of-sequence" thrusts, is similar in both basins.

The cause of arcward wedging remains an unsolved problem. In the Lesser Antilles, Torrini and Speed (1989) suggested three possible causes: (1) formation of a new subduction zone and reconfiguration of the arc-trench system; (2) a change in the rate and relative obliquity of subduction; and (3) a change in accretion mechanism. Of these three mechanisms, changes in the rate and obliquity of subduction beneath western California during late Mesozoic and Tertiary time have been well documented (Engebretson et al., 1985; Harbert, 1991). Wedging in California may also have resulted from collision of exotic terranes, the existence of which was proposed by McLaughlin and Ohlin (1984).

Alternatively, the initiation of tectonic wedging may depend primarily on the geometry of the fore-arc basement surface and on rheology contrasts between the wedge and basement rocks. Experimental (Byrne et al., 1988) and numerical (Willet, 1990) modeling studies suggest that in the absence of a mechanical buttress beneath the fore-arc basin, the accretionary prism sediments will form a two-sided wedge that must maintain a critical taper in both directions. The models show that the outer-arc ridge in an arc-trench system may represent the crest of a two-sided wedge. As the ridge grows and begins to trap sediment in a fore-arc basin, accumulation of sediment on the arcward slope of the ridge will eventually reduce the taper of the wedge to the point where gravitational body forces are no longer sufficient to drive propagation of the wedge. Willet (1990) suggested that the accretionary prism, outer-arc ridge and fore-arc basin may form a single mechanical system that responds dynamically to changes in prism growth, accretion mechanism, isostatic compensation, and sediment supply. Recognition of tectonic wedging beneath a fore-arc basin in Taiwan (Lundberg, 1990), and in several other fore arcs discussed by Silver and Reed (1988), suggests that the process may be more common than previously recognized.

DISCUSSION

Tectonic wedging beneath the Tobago trough is an attractive kinematic analogue for the western Great Valley because it accounts for the interpreted tectonic wedges and provides a mechanism for progressive uplift, thrusting, and folding along the basin margin. At present, however, several elements of the model must be rigorously tested. The inference that the wedges in western California consist of Franciscan assemblage rocks comes primarily from interpretation of seismic reflection and refraction data (Wentworth et al., 1984). Meltzer (1988) reexamined some of these data from the Coalinga area and noted that relatively high velocity rocks at approximately 12 km depth, previously interpreted as Franciscan assemblage (Wentworth et al., 1984), produced coherent layered reflections. She interpreted these rocks as Great Valley strata and suggested tectonic thickening of the Cretaceous fore-arc basin strata as an alternative to underthrusting of accretionary prism rocks. An alternative interpretation of seismic reflection data across the Coalinga anticline showing no tectonic wedges was also proposed by Fielding et al. (1984). Additional deep seismic reflection and refraction studies, specifically designed to test the wedge hypothesis, must be conducted in the eastern Coast Ranges and western Great Valley.

The Lesser Antilles analogue potentially offers several insights into the crustal structure of western California. If the two regions are structurally analogous, the Mesozoic and Tertiary mantle-rooted subduction zone suture probably underlies the Franciscan assemblage and thus is nowhere exposed in the eastern Coast Ranges. The Lesser Antilles analogue also suggests that rather than a mantle-rooted subduction-zone suture, the dominant crustal-scale structure of the Coast Ranges may be a horizontal detachment surface that originally separated the accretionary prism from the subducting oceanic crust during plate convergence (Fig. 4). The presence of a major horizontal detachment or detachments beneath western California has been inferred from analysis of seismic reflection and refraction data (Meltzer, 1988), and from construction of regional balanced cross sections (Namson and Davis, 1988).

A subhorizontal detachment may significantly influence the kinematics of late Cenozoic transpression. Coeval translational and contractional structures in transpressional regimes probably share the same detachment system (Oldow et al., 1990). The late Cenozoic strike-slip and thrust faults that accommodate distributed Pacific–North American transpressional deformation in the northern Coast Ranges (Fox, 1983) may all be rooted in a mid-crustal detachment system inherited from Mesozoic and Tertiary tectonic wedging. Such a detachment is implicit in models for northern California lithospheric structure which suggest that the relative motion between the Pacific and North American plates in the mantle does not occur directly beneath the San Andreas fault (Furlong et al., 1989).

Preexisting thrust faults associated with emplacement of the tectonic wedges have apparently been reactivated to accommodate late Cenozoic shortening. These thrusts are responsible for Quaternary uplift and folding in the western Great Valley (Namson and Davis, 1988; Wentworth and Zoback, 1989; Unruh and Moores, 1992) and may also be responsible for the uplift of the northern Coast Ranges (Phipps et al., 1991). Furthermore, these thrusts are seismically active, as demonstrated by the 1892 Winters-Vacaville earthquake, the 1983 Coalinga earthquake, and recent microseismic activity in the western Great Valley (Stein and Ekström, 1989; Eaton, 1990; Unruh and Moores, 1992). The Lesser Antilles analogue may provide a framework for understanding the kinematics of reactivated faults within the tectonic wedges and assessing potential seismic hazards from blind thrusts.

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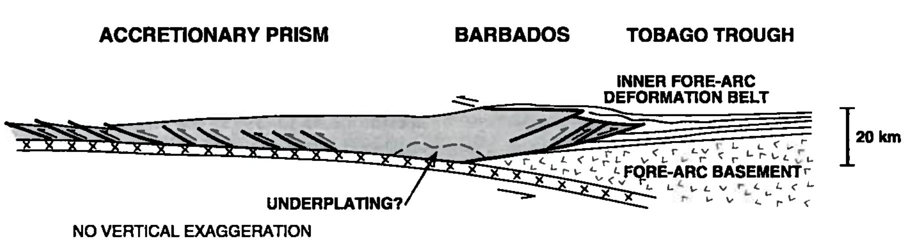

Figure 4. Generalized model for the Lesser Antilles arc-trench system (modified from Fig. 1 in Torrini and Speed, 1989). The accretionary complex is a two-sided wedge largely detached from the underlying fore-arc basement and down-going oceanic crust. The fore-arc basement dips gently seaward (east) and apparently does not form a buttress to prevent arcward wedging of the accretionary prism. The subduction zone suture approximately underlies the eastern Barbados ridge complex.

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support in the Graduate Intern Program. However, as the result of funding constraints, very few new scientists were hired to replace those lost by attrition. During this period the number of minority applicants for the Graduate Intern Program dropped sharply from the level of previous years.

Three years ago, realizing that near-term prospects for the permanent hiring of minority scientists were very limited, the Division focused efforts on expanding the educational pipeline for science, particularly for the kindergarten to grade 12 levels, with special emphasis on minority students. The Division expanded its activities with scientific societies and teacher associations in support of education and minority participation, including committees of the Geological Society of America, American Geological Institute, and American Geophysical Union. Partnerships were also formed with minority universities to support earth-science education, particularly the preparation and continued training of K–12 teachers. Summer intern positions have been provided for minority science and science-education majors, and funding for Graduate Intern positions has recently been increased. The Division plans to continue to serve as a training ground for minority scientists and science educators.

Now, as funding prospects appear to allow for at least modest replacement of scientific positions lost by attrition, the Division is preparing to form a Minority Advisory Committee to advise the Chief Geologist on ways to enhance the professional development of minority employees and guide efforts to recruit and retain outstanding minority earth scientists for our organization. The Division has combined all education, minority outreach, and personnel activities together under a Human Resources Officer in order to integrate and increase the impact of these activities.

In order to remain the premier Federal source of geologic knowledge, the Geologic Division must recruit and retain the best, brightest, and most dedicated earth scientists this country has to offer. Demographic trends indicate that in the near future the majority of the new scientists will be minorities and women. Our challenge is to help find, educate, and recruit them.

PERSPECTIVE 5:
Building Children into Scientists

Robert M. Romero, Colorado Minority Engineering Association, Denver

The underrepresentation of ethnic minorities in engineering and science is well documented; the problem is even more acute in the geosciences. A lack of career awareness and poor preparation are the main reasons why there are so few Blacks, Hispanics, and Native Americans in geoscience careers.

The Colorado Minority Engineering Association (CMEA) adapted and modified the California Mathematics, Engineering, and Science Achievement (MESA) Program for use in Colorado in 1980. The CMEA/MESA program has grown from 30 students to more than 2220 students, statewide, to address problems of underrepresentation by ethnic minorities in science and engi-

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