Accretionary Mesozoic–Cenozoic expansion of the Cordilleran continental margin in California and adjacent Oregon

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ABSTRACT

The Mesozoic–Cenozoic Cordilleran orogen of California includes multiple accretionary belts incorporated sequentially into the continental margin since Middle Triassic time. Accreted tectonic elements include subduction complexes assembled along the Cordilleran margin, intraoceanic island arcs attached to the continental margin by Jurassic arc-continent collision, and subduction complexes associated with the flanks of the exotic island arcs. Systematic analysis of areal relations and geochronological data displayed on subregional geologic maps and summary chronostratigraphic diagrams allows the punctuated but quasi-continuous pattern of tectonic accretion to be discerned. Stitching plutons and sedimentary overlap successions constrain the times that successive accretionary belts were juxtaposed and amalgamated into the edge of the continental block. In the Klamath Mountains and Sierra Nevada, a continental-margin magmatic arc of Triassic–Jurassic age includes volcanic and plutonic components built upon and intruded into deformed Paleozoic assemblages that were accreted to the Laurentian margin before Middle Triassic time. The native arc assemblage is separated from intraoceanic Triassic–Jurassic arc assemblages exposed farther west by a compound suture belt of mélangé and broken formation derived from the remnant ocean basin that separated the east-facing intraoceanic arc system from the Cordilleran margin. Polarity reversal after Middle to Late Jurassic arc-continent collision was followed by accretion of a disrupted ophiolitic belt forming mafic basement in the subsurface of the Great Valley forearc basin. Subsequent forearc sedimentation accompanied the assembly of multiple belts of mélangé and broken formation that form the Mesozoic–Cenozoic Franciscan subduction complex of the California Coast Ranges.

Franciscan subduction was largely coeval with intrusion of the dominantly Cretaceous Sierra Nevada batholith into the roots of the Cordilleran magmatic arc, but Franciscan accretion was just a late phase of continuing tectonic expansion that spanned more than 200 m.y. along the California continental margin.

Keywords: accretion, California, Klamath Mountains, Sierra Nevada, tectonics.

INTRODUCTION

Ever since the seminal papers of Hamilton (1969) on “underflow” (subduction) of Pacific mantle beneath California, and of Moores (1970) on the accretion of intraoceanic arc structures to the continental margin, geoscientists have been trying to comprehend the scope and geometry of tectonic accretion at ancient subduction zones in California (e.g., Ernst, 1983, 1984). This paper is an appraisal of the Mesozoic–Cenozoic accretionary expansion of the California continental margin based on a fresh synthesis of incremental geologic mapping and geochronological studies by many geoscientists during the past several decades. Traverses along key transects across all the accretionary belts during the interval 1998–2004 gave me personal impressions of each as a context for understanding descriptions by others in the literature. This overview does not extend southward into the California Transverse Ranges, where onshore transrotation and offshore rifting have transposed and disrupted key tectonic elements, but does extend northward to include the Oregon extension of the Klamath Mountains.

My aim is to outline the pattern of punctuated but quasi-continuous accretion of diverse oceanic elements to the California continental margin from mid-Triassic to mid-Tertiary time. Subsequently, tectonic accretion ended as subduction of the Farallon and derivative oceanic plates was gradually supplanted by lateral motion of the Pacific plate along the evolving San Andreas transform. My method is to present summary geologic maps showing the accretionary belts in plan view and accompanying chronostratigraphic diagrams that display transverse age relationships of rocks both within the accretionary belts and superimposed upon them. The coordinated maps and diagrams spanning the full width of California Mesozoic–Cenozoic accretionary tracts were compiled from multiple sources cited in figure captions, and have no counterparts of equivalent scope in the literature. The ages of the rock assemblages within the accretionary belts, and of the stitching plutons and sedimentary cover sequences that tie the belts together, set constraints on the times of amalgamation of the successive belts into the edge of the continent. Systematic interpretations of the maps and diagrams also call attention to shortcomings in the currently available database, and thereby indicate the kinds of information needed to resolve uncertainties in the tectonic history of the region.

The northwest-trending Mesozoic–Cenozoic lithotectonic belts of California are separated from the interior of the Laurentian craton by the deformed Cordilleran miogeocline overthrust by Paleozoic terranes accreted before Middle Triassic time and discussed in detail elsewhere (Dickinson, 2000, 2006). Westward toward the coast, multiple subparallel tectonic assemblages of diverse origin were thereafter added to the flank of Laurentia during Mesozoic–Cenozoic subduction (Fig. 1): (1) a native Mesozoic arc succession built on pre-Mesozoic rocks of the evolving continental margin; (2) a suture zone of tectonic mélangé and broken formation immediately seaward; (3) accreted Mesozoic arc structures seaward from the mélangé belts; and (4) both Mesozoic and Cenozoic components of the Franciscan subduction complex farther west near the coast.

Following introductory passages addressing key topical issues, my areal treatment begins with a discussion of the Klamath Mountains.
Figure 1. Position of California continental margin (west of Great Valley forearc basin) in tectonic framework of southwest Laurentia (adapted after Reed et al., 2005). Regional tectonic relations after Dickinson (2000, 2004, 2006), Dickinson et al. (2005), and this paper, with Jurassic–Cretaceous Bisbee rift basin after Dickinson and Lawton (2001b) and Triassic–Jurassic backarc basin in Nevada adapted after Wyld (2002). Barbed lines are principal thrusts (solid barbs where active). Heavy lines are strike-slip faults (Gaf—Garlock; Naf—Nacimiento; Rif—Rinconada; SAF—San Andreas; SHF—San Gregorio–Hosgri; SIF—San Isidro) with associated Mendocino triple junction (MTJ) and Salinian block (SB). Symbols: A (T-Fran)—Tertiary–uppermost Cretaceous Franciscan subduction complex and Paleogene Siletz-Umpqua assemblage; B (K-Fran)—Cretaceous–latest Jurassic Franciscan subduction complex; C (is arcs)—accreted intraoceanic Triassic–Jurassic island arcs; D (sut belt)—mid-Mesozoic suture belt (pre-Franciscan mélanges); E (acc Pz)—accreted Paleozoic crustal elements (oceanic allochthons and island arcs); F (nat arc)—native Triassic–Jurassic continental-margin arc assemblage (not shown to southeast where crosses miogeocline and southwestern prong of craton); G (batho)—major batholiths of largely Cretaceous age (IDb—Idaho; PRb—Peninsular Ranges; SNb—Sierra Nevada).
Accretionary expansion of California

BACKGROUND

To avoid repetitious discussions of the same issues, selected aspects of regional tectonics that influence interpretations of multiple tectonic belts in California are discussed here before specific treatment of the various accretionary assemblages.

Continental Truncation

Mesozoic accretion along the Cordilleran continental margin of California was preceded by oblique truncation of the continental block by late Paleozoic–earliest Mesozoic strike slip (Hamilton, 1978; Davis et al., 1978). Sinistral strike slip displaced crustal blocks by ~950 km along the California-Coahuila transform (Fig. 2) during the interval from mid-Carboniferous to Middle Triassic time (Stevens et al., 1992, 2005; Dickinson, 2000). The transform connected orogenic trends on the northwest, including the Golconda thrust of Nevada, to the subduction zone associated with a Permian–Triassic (284–232 Ma) magmatic arc in eastern Mexico to the southeast (Dickinson and Lawton, 2001a). Major strike slip postdated terminal juxtaposition of Gondwana against Laurentia along the diachronous Ouachita-Marathon suture belt that closed in earliest Permian time in west Texas (Ross, 1986).

The line of truncation was oriented northwest-southeast at a high angle to the northeast-southwest trend of Paleozoic tectonic elements crossing Nevada (Dickinson, 2000), and is delineated in California by the eastern limit of subsequently accreted Mesozoic tectonic elements. The truncated continental margin that formed near the Paleozoic–Mesozoic time boundary became the locus for subsequent circum-Pacific subduction of seafloor beneath California (Hamilton, 1969). The diverse post–Middle Triassic accretionary belts underlying about half the width of California accumulated sequentially against the truncated continental margin.

Paleozoic limestone blocks are embedded in some Mesozoic mélanges west of the line of truncation, but the structurally isolated limestone blocks are afloat in matrices of deformed Triassic–Jurassic argillite and chert, and the age of formation of a tectonic mélangé is given by the age of its youngest, not its oldest, lithic component (Hsiü, 1968). Tethyan faunas in some of the limestone blocks were pantropic forms that migrated into island chains of the proto-Pacific Ocean west of Mesozoic North America (Miller and Wright, 1987; Newton, 1988). Tectonic transport estimated from paleofaunal interpretations as thousands of kilometers of longitude was required to bring the Tethyan limestones to the Cordilleran continental margin (Stevens et al., 1990, 1991; Belasky and Stevens, 2006).

Lateral Translation

Interpretations of the California segment of the Cordilleran orogen developed for the Geological Society of America Decade of North American Geology program infer that many of the accretionary assemblages treated in this paper were displaced hundreds of kilometers during Mesozoic time by lateral translation parallel to the continental margin before reaching their present positions relative to the interior craton (Oldow et al., 1989; Saleeby and Busby-Spera, 1992; Saleeby, 1992). Most postulated lateral motions do not directly affect interpretations of this paper bearing on the times of amalgamation of different accretionary belts into the continental margin because the nature and magnitude of tectonic movements that preceded accretion are not addressed by evidence for the times of final amalgamation. It is noteworthy, however, that paleomagnetic data from Mesozoic rock assemblages of the Klamath Mountains and Sierra Nevada support no inferred latitudinal motions that exceed the inherent paleomagnetic uncertainties in paleolatitude (Mankinen and Irwin, 1990). In any case, the times of amalgamation of accreted tectonic elements into the California margin as indicated by ages of stitching plutons and sedimentary overlaps provide constraints on

Figure 2. Regional tectonic relations of Permian–Triassic truncation of the California continental margin along the California-Coahuila transform adapted after Dickinson (2000) and Dickinson and Lawton (2001a). Abbreviations: CA—California; MEX—Mexico; NV—Nevada.
the times that any lateral translation may have occurred.

Snow Lake Fault

Offset across the Early Cretaceous Snow Lake fault is significant, however, for my analysis because the fault displaced pre-Cretaceous rock assemblages previously accreted to central California. The fault trace was along the axis of the Sierra Nevada batholith before intrusion of Late Cretaceous plutons that form the bulk of the batholith, and is now a cryptic structure overprinted by intrusion of the batholith. The present areal pattern of preexisting tectonic elements cannot be understood, however, without attention to Snow Lake fault offset.

The existence of the Snow Lake fault was detected by recognition of the Cambrian Zabriskie Quartzite within the Snow Lake roof pendant of the central Sierra Nevada, where its exposures are separated from stratal counterparts in the southeastern or Death Valley facies of the Cordilleran miogeocline by a wide expanse across which only the northwestern or Inyo facies is exposed. The structure was originally termed the Mojave–Snow Lake fault from the interpretation that it displaced Zabriskie Quartzite from its western extension into the Mojave block south of the Sierra Nevada, and a displacement of 400–500 km was initially suggested (Lahren and Schweickert, 1989; Schweickert and Lahren, 1990, 1993a). Reconsideration of regional stratigraphic and structural relations indicates, however, that Zabriskie Quartzite was more probably offset into the Snow Lake roof pendant from exposures of the Death Valley facies in the Inyo Mountains east of the Sierra Nevada, and that its presence in the Snow Lake pendant requires fault transport of only 210 ± 15 km (Dickinson, 2006). Moreover, that total displacement can be viewed as the net offset across a family of dextral faults, one of greater offset (e.g., Wyld and Wright, 2001) are viewed as questionable, and not incorporated into the interpretations of this paper.

Mélange Origin

Key interpretations of this paper rest upon the premise that mélange and broken formation are formed by pervasive structural disruption of oceanic facies and trench fill by intracratonic shear of progressively dewatering strata within subduction zones. Mélanges are standard components of the accretionary wedges developed along the flanks of magmatic arcs (Hamilton, 1988). By analogy with lubrication theory, their origin has been ascribed to flow within a deforming subduction channel of finite thickness developed between overriding and subducted plates (Shreve and Cloos, 1986; Cloos and Shreve, 1988a, 1988b). The distinction between mélange and broken formation lies in the greater lithologic heterogeneity of the former. Intrinsically disrupted domains derived entirely from seafloor or turbidite sedimentary successions, without admixture of igneous or blueschist blocks, are termed broken formation (Hsu, 1968), but could equally well be described as chert-argillite or graywacke-argillite mélange (Cowan, 1974). Both mélange and broken formation display the same characteristic phacoidal or lentiform fabric of internal dislocation from outcrop scale to map scale (Dickinson, 1977). The characteristic fabric is well illustrated by outcrop photographs from multiple worldwide settings (Moore and Wheeler, 1978; Moore and Karig, 1980; Cowan, 1982; Nelson, 1982; Bell, 1987; Barnes and Korsch, 1991; Ujiie et al., 2000; Onishi et al., 2001; Fukai and Kano, 2007).

Elongate tracts of mélange or broken formation, or both in combination, can be termed mélange belts as convenient shorthand, and are inferred here to mark the sites of former ocean basins of indeterminate width that did not close until after their youngest lithologic components were formed. Tectonic elements that are seaward of mélange belts but include rocks of the same age are inferred here to have formed within oceanic realms west of the continental block. They were not accreted to the continental margin until formation of the intervening mélange belts was completed by subduction that closed intervening tracts of oceanic crust underlying remnant ocean basins. Mélange belts between more intact crustal blocks are taken to be suture zones marking the sites of former ocean basins, and commonly include tectonic slivers or thrust panels of deformed serpentinite representing scraps of oceanic lithosphere incorporated structurally into growing subduction complexes.

Some descriptions of Klamath and Sierran mélange belts dating to 30–35 yr ago infer an olistostromal character (Cox and Pratt, 1973; Schweickert et al., 1977; Saleeb et al., 1978), implying sedimentary origin, but subsequent descriptions in later years reinterpret the same exposures as mélange and broken formation of tectonic origin (Wright, 1982; Goodge and Renne, 1993; Schweickert et al., 1999). A parallel evolution in thinking occurred globally over the past few decades as a growing appreciation of processes within subduction zones led to the understanding that many disrupted stratal assemblages regarded as olistostromal before the advent of plate tectonics were actually formed as tectonic mélange.

The local generation of massive olistostromes from failure by mass movement of dislocated strata exposed on trench slopes at subduction zones where mélange forms is nevertheless widely appreciated (Pini, 1999). Outcrop distinction between mélange formed from previously undisturbed bedded sequences and from dislocated strata of redeposited olistostromes is therefore challenging (Raymond, 1984; Underwood, 1984; Cowan, 1985; Lash, 1987). For either mélanges or olistostromes, however, the age of the youngest block or matrix component constrains the oldest possible age of formation of the disrupted rock mass (Hsu, 1968).

Crustal Collision

Usage of the term “collision” is currently inconsistent in the tectonic literature. The text of this paper follows the recommendation of Cloos (1993) to reserve the term crustal collision for juxtaposition of tectonic elements that are buoyant enough to jam subduction zones, and thereby to change either the positions of subduction zones or the patterns of plate motion (or both).

In the context of California tectonics, the crustal structures of intraoceanic island-arc complexes attached to the Cordilleran continental margin at intervals over time are the only features bulky enough to merit the term “collision” to describe their accretion. Ongoing subduction of oceanic plates, to form incrementally accreted mélange belts and to underthrust ophiolitic slabs, is not described herein as “collision” even though convergent plate motions are involved.

KLAMATH MOUNTAINS

The principal accretionary belts of the Klamath Mountains and adjacent Northern Coast Ranges (Figs. 3 and 4) were first delineated as discrete lithic belts by Irwin (1960) before we had the concepts of plate tectonics to help interpret them. Now commonly termed terranes (Snake and Barnes,
Figure 3 (continued on next page). Pattern of Mesozoic–Cenozoic accretionary tectonic belts flanking eastern Klamath Paleozoic terranes (overlapping segments: A—northern, mostly in Oregon; B—southern, mostly in California). Barbed subregional thrusts (CMW—Condrey Mountain window) between successive accretionary belts (see Fig. 4 for symbols and ages) modified locally by younger faults (not shown to preserve indications of initial structural stacking). Exposures of native eastern Klamath Triassic–Jurassic arc assemblage of Figure 4 overlie Paleozoic rocks just beyond eastern margin of B. Ages of stitching (post-accretion) plutons (shaded) after Irwin and Wooden (1999) and Allen and Barnes (2006). Pre-Oligocene sedimentary cover stippled (and yellow) after Figure 4, but post-Oligocene volcanic and sedimentary cover is blank. Letter designations of tectonic belts (refer to Fig. 4): CHf—Cape Sebastian–Hunters Cove Formations; CM—metavolcanic rind of CMW; CoB—Coastal Belt Franciscan (see Figs. 5 and 6); CS—Colebrook (~Pickett Peak) Schist; DF—Dothan–Franciscan subduction complex; EH—Eastern Hayfork belt; GVG—Great Valley Group; HC—Happy Camp window; Hf—Hornbrook Formation; MG—Myrtle Group; NF—North Fork (~Sawyers Bar) belt; RC—Rattlesnake Creek belt; SF—Stuart Fork (~Fort Jones) belt; SU—Siletz-Umpqua belt; WH—Western Hayfork belt; WJ—Western Jurassic belt; Yf—Yager Formation. Small klippen, fensters, granitic bodies, and patches of Cenozoic cover are omitted for reasons of scale. Adapted after Peck (1961), Dott (1971), Coleman (1972), Baldwin (1974), Irwin et al. (1974), Klein (1977), McLaughlin et al. (1982, 1994), Underwood (1983), Ryberg (1984), Blake et al. (1985a), Cashman et al. (1986), Donato (1987), Wagner and Saucedo (1987), Saleeby and Harper (1993), Irwin (1994), Wright and Wyld (1994), Goodge (1995), McCrory (1995), Ernst (1998), Irwin and Mankinen (1998), Blake et al. (1999), Wells et al. (2000), Dickinson (2000), Snoke and Barnes (2006), and Allen and Barnes (2006). Selected towns (for orientation): A—Agness; B—Brookings; CB—Coos Bay; CC—Crescent City; E—Etna; Eu—Eureka; GP—Grants Pass; HC—Happy Camp; M—Medford; R—Redding; Ro—Roseburg; SB—Sawyers Bar; W—Weaverville; WC—Willow Creek; Y—Yreka.
Figure 3 (continued).
provide minimum ages (170–140 Ma) for the time frames during which disparate accretionary belts of the Klamath Mountains were stitched together along the continental margin (Fig. 4). Older increments (240–170 Ma) of the continental-margin arc assemblage are represented by Triassic–Jurassic volcanic rocks overlying previously accreted Paleozoic terranes of the eastern Klamath Mountains (Fig. 4). Granitic plutons that intrude the Paleozoic basement represent younger increments (<140 Ma) of the arc assemblage (Fig. 3B).

The successive accretionary belts of variably deformed seafloor and intraoceanic seamount or arc assemblages in the western Klamath Mountains and adjacent coastal ranges form a record of punctuated but continuing subduction along the continental margin from Late Triassic to early Paleogene time. Each has a lithology and internal structure differentiable from the adjoining belts, and is separable from other belts as a mappable entity. The tectonic entities are denoted here simply as belts, rather than as terranes, because the latter usage tends to imply wholly disparate origins, and thereby to prejudice whether there are genetic connections between selected pairs or groups of the tectonic belts. Moreover, mélange belts assembled incrementally by subduction along the continental margin or the flanks of intraoceanic island arcs were formed in those positions, and did not exist as coherent tectonic entities before assembly. To term a subduction complex a terrane risks the implication of pre-assembly existence that would be misleading.

The belts are discussed here from east to west, in the order they were accreted to the continental margin.

**Stuart Fork–Fort Jones Belt**

Upper Triassic blueschists of the Stuart Fork or Fort Jones belt (Figs. 3B and 4) mark the onset of post-truncation Mesozoic accretion west of the eastern Klamath Paleozoic assemblages (Goodge, 1989a). The blueschist assemblage includes phyllitic metachert, metasedimentary semischist, and mafic metavolcanic rocks of an oceanic assemblage including igneous seafloor and its pelagic to hemipelagic sediment cover (Goodge, 1989b, 1990). The occurrence of the oldest and most intensely developed blueschist metamorphism along the inland flank of the Mesozoic accretionary belts of the western Klamath Mountains is in harmony with the general observation that global blueschists are highest in grade along arcward flanks of accretionary prisms built at ancient subduction zones (Ernst, 1975). This relationship may reflect the higher temperature of rock masses structurally overlying the underthrust subduction channel at the inception of subduction in comparison to later, when underplating of cooler subducted materials insulates the active subduction channel from a structural lid of pre-accretion lithosphere.

**North Fork–Eastern Hayfork Belts**

Internally dislocated belts of mélange and broken formation were successively underthrust from the west beneath the blueschist-bearing Stuart Fork–Fort Jones assemblage to form the North Fork and Eastern Hayfork belts sandwiched between the previously expanded continental margin and accreted intraoceanic arc assemblages farther west (Figs. 3 and 4). Both the North Fork and Eastern Hayfork belts are composed predominantly of disrupted seafloor chert-argillite successions and metamorphic assemblages derived from seafloor and oceanic seamounts, with minimal elastic input of sandy terrigenous sediment (Wright, 1982). Protoliths are inferred here to have formed the ophiolitic floor and sediment fill of a remnant ocean basin that was between the Triassic–Jurassic Cordilleran margin and an intraoceanic arc complex that evolved from an initial position some indeterminate distance offshore. The contact between the North Fork and Eastern Hayfork belts may mark the cryptic join between a North Fork subduction complex to the east that was associated with a paleotrench along the active Cordilleran continental margin and an Eastern Hayfork subduction complex to the west related to a paleotrench that was along the flank of the accreted arc complex. Occurrences of late Paleozoic as well as early Mesozoic fossils within both belts (Irwin, 1972, 1981; Wright, 1982; Blome and Irwin, 1983; Mortimer, 1984; Hacker and Ernst, 1993; Hacker et al., 1993, 1995; Miller and Ernst, 1998) imply derivation of mélange from subduction of long-lived seafloor that underlay the remnant ocean basin. Discrete pods of limestone encased in mélange probably represent either structurally detached cappings of oceanic seamounts or olistoliths that slid down the flanks of seamounts (Wright, 1982; Miller and Wright, 1987; Miller and Saleeby, 1991).

Metasedimentary strata of the North Fork belt are broken formation derived from seafloor chert-argillite successions that are locally preserved intact as structural enclaves encased in more severely deformed domains. Subordinate seafloor limestone is present as thin beds intercalated within successions of chert and argillite. Metavolcanic strata form large slab-like tectonic rafts laced internally by narrow bands of crushed rock or broken formation, but depositional contacts between chert and metavolcanic rock are locally preserved as a record of sedimentation on either
the seafloor or the flanks of seamounts. Multiple tectonic sheets of sheared serpentinite derived from oceanic lithosphere slice through the North Fork belt at widely spaced intervals. The belt as a whole can be viewed as a disrupted ophiolite (Ando et al., 1983), but without any implication that all its components formed at the same locale in simple vertical succession. The general paucity of volcanioclastic strata suggests that most metavolcanic components of the North Fork belt were seafloor accumulations or seamount edifices, rather than arc structures. One bulky and relatively intact metavolcanic component of the North Fork belt termed the Sawyers Bar terrane has been interpreted, however, as an immature intraoceanic island arc of uncertain polarity (Ernst, 1990, 1991, 1999; Ernst et al., 1991; Hacker and Ernst, 1993; Hacker et al., 1993).

The Eastern Hayfork belt is a subduction complex or accretionary prism (Wright, 1982; Hacker and Ernst, 1993) that includes large tracts of argillite-rich metasedimentary broken formation, overprinted by metamorphism, with phacoidal slivers of chert encased in a pelitic matrix at multiple scales. Also present is heterogeneous mélangé including lenositoid blocks of greenstone and slivers of serpentinites, together with intact enclaves of ribbon chert and limestone. Minor quartzose turbidites in the lithologic assemblage show that distal pulses of continuously derived sediment were spread across the floor of a remnant ocean basin before its closure by subduction.

Western Hayfork–Rattlesnake Creek Belts

West of the mélangé belts in the central Klamath Mountains, an internally deformed island-arc complex of intraoceanic origin was accreted as the Triassic to Lower Jurassic Rattlesnake Creek belt over lain depositionally by the less deformed Lower to Middle Jurassic Western Hayfork belt. The two arc assemblages have locally been telescoped by post-accretion thrusting (Fig. 3B), but the contact between them is commonly obscured by metamorphism. The Rattlesnake Creek arc assemblage was erupted upon an ophiolitic oceanic substratum of deformed peridotite and gabbro with no vestige of continental basement in its roots (Donato, 1987; Coleman et al., 1988; Hacker and Ernst, 1993). Multiple Triassic–Jurassic U-Pb ages (212–193 Ma) of constituent plutons (Wright and Fahan, 1988; Hacker and Ernst, 1993; Wright and Wylde, 1994) indicate emplacement during an interval of time when seafloor successions were still being deposited within a remnant ocean basin to the east, and a separate arc assemblage was being erupted across the continental margin (Fig. 4). Widespread stratal disruption in the deepest structural horizons of the Rattlesnake Creek arc assemblage (Wright and Wylde, 1994; Miller and Ernst, 1998) implies that the arc structure was built in part on previously assembled mélangé.

The polarity of the accreted arc complex is not known with certainty, but it was probably east facing, with subduction downward to the west beneath an island arc as it approached the continental margin. No coeval subduction complex is known to the west of the deformed arc structure, whereas coeval mélanges of the Eastern Hayfork belt are to the east (Fig. 4). The postulated polarity of the Rattlesnake Creek arc implies that mélanges and broken formations of the central Klamath Mountains are the record of a suture zone between the west-facing continental-margin arc and an offshore island arc of opposed polarity. Plutons injected into the roots of the Rattlesnake Creek arc assemblage overlap in age with components of the native magmatic arc overlying Paleozoic rocks in the eastern Klamath Mountains (Fig. 4). Oceanic protoliths of the mélangé terranes in the central Klamath Mountains are coeval with both arc assemblages (Fig. 4). The width of the ocean basin that was between the Cordilleran margin and the offshore intraoceanic arc is indeterminate, but the bulk and complexity of intervening mélangé belts (Fig. 3) imply a broad remnant ocean before arc–arc collision.

Following accretion of the intensely deformed Rattlesnake Creek arc structure of intraoceanic character, reversal of arc polarity may have occurred before eruption of the less deformed volcanic rocks of the Western Hayfork belt, which is younger than any mélangé protoliths to the east (Fig. 4). Abundant volcaniclastic strata in the Western Hayfork belt and its petrology clearly reflect formation within a magmatic arc (Wright, 1982; Hacker and Ernst, 1993), which may have been related to subduction downward to the east (Wright and Fahan, 1988; Wright and Wylde, 1994). If so, Western Hayfork volcanism can be taken to mark initiation of a west-facing magmatic arc built on the newly expanded continental margin (Donato, 1987). Older components of the Western Hayfork arc overlap in age, however, with waning phases of volcanism along the native continental-margin arc of the eastern Klamath Mountains 100 km to the east (Fig. 4).

This space-time relationship suggests the possibility that the Western Hayfork arc represented a waning phase of intraoceanic arc evolution before collision of an east-facing intraoceanic arc complex (Rattlesnake Creek–Western Hayfork) with the subduction zone along the continental margin. Locally severe dislocation of Western Hayfork volcanic rocks to the condition of broken formation can then be understood as a structural overprint imposed during accretion of an intraoceanic arc assemblage to the edge of the growing continent. Limestone cobbles in the Western Hayfork belt contain McCloud fauna (Hacker and Ernst, 1993), native to tropical island settings, which from paleoфаunal analysis were initially at least 1000 km and possibly >5000 km from the continental margin of Laurentia (Stevens et al., 1990).

Stitching Plutons

Plutons of Middle Jurassic age (170–160 Ma) stitch all the accreted Klamath terranes together as far west as the Western Hayfork and Rattlesnake Creek belts (Fig. 4). There is a hint from detailed age relationships that the Western Hayfork–Rattlesnake Creek arc structure may have been stitched to the paired Eastern Hayfork subduction complex along its eastern flank somewhat earlier than the combined exotic arc assemblage was stitched across the collisional mélangé belts of the central Klamath Mountains to the blueschist-bearing Sturt Fork–Fort Jones belt flanking the ancestral Cordilleran margin to the east. The wide distribution of Middle Jurassic plutons (Fig. 3) indicates that the Cordilleran magmatic arc had migrated seaward across all the accreted pre–Late Jurassic Klamath belts by the time of pluton intrusion (Wright and Fahan, 1988). This relationship indicates that the remnant ocean basin between the Cordilleran margin and the exotic offshore island arc of Triassic–Jurassic age now exposed as the Rattlesnake Creek–Western Hayfork arc complex in the western Klamath Mountains had closed by Middle Jurassic time. Both the mélangé belts of the central Klamath Mountains and the exotic arc structure to the west were by then incorporated into the expanding continental margin.

Western Jurassic Belt

The pre–Late Jurassic Western Hayfork and Rattlesnake Creek arc assemblages are locally overlain depositionally and elsewhere widely underthrust by the Western Jurassic belt (Fig. 3) of Late Jurassic age (Fig. 4). The Western Jurassic belt was formed by post-accretion arc magmatism and incipient backarc spreading that produced west-facing frontal and remnant arcs separated by an interarc basin floored by ophiolitic crust along the expanded Cordilleran continental margin (Harper, 1984; Harper and Wright, 1984; Wright and Fahan, 1988; Saleebey and Harper, 1993; Hacker et al., 1995; Wylde and Wright, 1988; Yule et al., 2006; MacDonald et al., 2006). Plutonic arc roots, frontal and remnant arc edifices, the ophiolitic interarc basin floor, and the interarc basin fill are commonly

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denoted as separate though generically related subterranea (Alexander and Harper, 1992; Hacker and Ernst, 1993; Hacker et al., 1995).

Combined isotopic and biostratigraphic ages indicate a time span of only 10–15 m.y. for evolution of the entire arc-interarc assemblage (Fig. 4); both the arc edifices and the ophiolitic floor of the interarc basin formed during the interval 165–155 Ma and sediment cover of the interarc basin was deposited during the interval 160–150 Ma (Saleeby et al., 1982; Harper and Wright, 1984; Wyld and Wright, 1988; Harper et al., 1990, 1994; Alexander and Harper, 1992; Saleeby and Harper, 1993; Hacker and Ernst, 1993; Hacker et al., 1995). The compound assemblage was structurally telescoped by Late Jurassic thrusting along the continental margin (Wright and Fahan, 1988; Harper et al., 1990), and was stitched into place by post-thrust plutons during the interval 155–145 Ma near the close of Late Jurassic time (Fig. 4).

Underthrusting of the Western Jurassic belt beneath the accretionary assemblages of the central Klamath Mountains by tectonic telescoping during structural evolution of the continental margin is revealed by exposures within the Condrey Mountain and Happy Camp tectonic windows, or fensters (Figs. 3 and 4). A tectonic rind of metavolcanic rock that discontinuously bounds the windows is viewed here as a tectonic sliver derived from the structurally overlying Rattlesnake Creek–Western Hayfork arc complex, and has yielded pre-Late Jurassic isotopic ages (Helper, 1986; Coleman et al., 1988; Saleeby and Harper, 1993). The absence of any Middle Jurassic intrusions in the tectonic windows indicates that the Middle Jurassic plutons cutting structurally overlying accretionary assemblages are now rootless, truncated downward by the Late Jurassic thrust system that bounds the windows (Wright and Fahan, 1988; Coleman et al., 1988). The position of the Condrey Mountain window indicates that the arc-interarc assemblage of the Western Jurassic belt was underthrust for at least 75 km and probably ~100 km beneath the continental margin.

Franciscan Subduction Complex

Continued subduction through Cretaceous and into Cenozoic time of the Klamath Mountains progressively assembled the various accretionary belts of the Dothan-Franciscan subduction complex (Fig. 3) and the related Siletz-Umpqua assemblage to the north (Fig. 3A). Strongly foliated schists (Colebrook, Redwood Creek, South Fork Mountain) of the Pickett Peak schist belt (Fig. 4) occur along the eastern fringe of the Dothan-Franciscan belt, or as klippen representing the highest structural levels of the subduction complex. Their distribution perhaps reflects higher crustal temperatures that fostered more penetrative deformation beneath the initial lid of the Franciscan subduction channel when it was positioned directly below amalgamated arc complexes forming the western edge of the Klamath accretionary assemblages. As the subduction complex evolved, older components of the Dothan-Franciscan accretionary prism would have served to insulate younger components of the accretionary prism as they were drawn into the active subduction channel. Cretaceous–Paleogene components of the growing accretionary prism were capped over time by the overlap successions of various forearc and trench-slope basins (Fig. 4), except where the King Range terrane is present as a Miocene increment to the Franciscan subduction complex along one short segment of the present coast (Figs. 3B and 4). Paleogene structural relationships northwest of the Dothan-Franciscan belt in Oregon were clarified by Ryberg (1984), who showed that Paleocene to lower Eocene Siletz seamount volcanics and Umpqua turbidites were imbricated together by accretionary tectonism along the continental margin. These deformed strata are overlain by lower to middle Eocene strata of the forearc basin that developed along the length of the Oregon Coast Range parallel to the present coastline (Heller and Ryberg, 1983).

**SIERRA NEVADA AND COAST RANGES**

Tectonic relationships across the Northern Coast Ranges and northern Sierra Nevada (Figs. 5 and 6) are similar to those across the Klamath Mountains to the north, i.e., successive accretionary belts becoming younger to the west (Saleeby et al., 1989a). Exposures of the Franciscan subduction complex are much wider, however, leading to subdivision of the Franciscan belt into multiple subunits. Moreover, the tectonic stacking of accretionary assemblages in the Sierra Nevada foothills is more complex, and a belt of mafic basement not present in the Klamath Mountains intervenes between Sierran and Franciscan belts in the subsurface of the Great Valley. Across the Southern Coast Ranges and southern Sierra Nevada (Fig. 7), patterns of tectonic accretion can only be discerned by analogy with relations farther north. Massive Late Cretaceous granitic intrusions of the Sierra Nevada batholith have partly obliterated eastern accretionary belts, Cenozoic deformation associated with development of the Neogene San Andreas transform system has folded western accretionary belts and their bounding thrusts on a large scale, and the San Andreas fault has truncated the accretionary terranes on the west and translated the Salinian block of Sierran affinity into an anomalous position west of exposures of the Franciscan subduction complex (Fig. 7).

Accretionary tectonic relationships south of the Klamath Mountains are discussed here from east to west along the length of California, with treatment of the Sierra Nevada first, then the mafic basement of the Great Valley to the west, and finally the Franciscan subduction complex of the Coast Ranges. The Nacimiento fault along the western side of the Salinian block, and displaced components of the Franciscan subduction complex west of the fault, have been discussed elsewhere (Dickinson, 1983; Dickinson et al., 2005), and are not treated here.

**Sierra Nevada**

At the northern end of the Sierra Nevada block where the western edge of the main batholith trends eastward off the range crest, the native Cordilleran arc assemblage of Jurassic age (Fig. 6) overlies an accreted Devo- nian–Permian arc assemblage that rests depositionally on imbricated thrust panels of the lower Paleozoic Shoo Fly subduction complex (Fig. 5), also accreted to Laurentia before Middle Triassic time (Dickinson, 2000). Southward, the native Jurassic arc assemblage onlaps the Shoo Fly complex (Fig. 5), and both assemblages continue southward into the southern Sierra Nevada, where increasingly voluminous baltholithic intrusions progressively obscure the relationship between them (Fig. 7). The native Jurassic arc succession further onlaps southward over deformed Paleozoic strata of the Cordilleran miogeocline both to the east and to the west of the cryptic Early Cretaceous Snow Lake fault (Fig. 7). The Snow Lake fault is inferred to have dextrally offset a facies transition within the miogeoclone by ~215 km from Lone Pine to Snow Lake before intrusion of the Late Cretaceous Sierra Nevada batholith (Dickinson, 2006). The Shoo Fly Complex is inferred to be truncated southward along sinistral fault strands of the California-Coahuila transform (Fig. 2) that are also cryptic due to batholithic intrusion (Fig. 7). Offset counterparts of the Shoo Fly Complex are present on the Kern Plateau at the southern end of the Sierra Nevada block (Dunne and Suczek, 1991), where they are overlain by clastic strata of Paleozoic age not delineated separately here (Fig. 7).

West of exposures of the Shoo Fly complex, bound in the northern Sierra Nevada by the Paleozoic Feather River peridotite belt (Figs. 5 and 6), the Calaveras mélange belt is the oldest principal component of the post–Middle Triassic accretionary assemblages west of the locus of continental truncation along the Permain–Triassic California-Coahuila transform (Fig. 2).
Figure 5. Accretionary tectonic belts (see Fig. 6 for symbols and ages) of northern Sierra Nevada and Northern Coast Ranges (K—southern tip of Klamath Mountains bedrock from Fig. 3B). Ages of stitching (post-accretion) plutons (shaded) after Irwin (2003) and others (see below). Post-subduction faults overprinting contacts between intra-Franciscan belts not shown separately (to preserve indications of initial structural stacking). Small granitic bodies, narrow enclaves of disparate rock within Franciscan accretionary belts, Tertiary volcanic cover on Sierra Nevada interfluvuses, and local alluviated valleys are omitted for reasons of scale (broad expanses of Quaternary alluvium and Tertiary volcanic cover are blank). Tilted normal faults (northwestern Great Valley): CF—Cold Fork; EC—Elder Creek; PF—Paskenta. Ultramafic belts (black): FRP—Feather River peridotite belt; TCs—Tehama-Colusa serpentinite mélange. Cenozoic volcanic fields (x): CL—Clear Lake; SBv—Sutter Buttes. Pz-Mz denotes Butt Valley and Soda Ravine blocks with Paleozoic–Mesozoic stratigraphy similar to northern Sierra Nevada and eastern Klamath Mountains, respectively (Jayko, 1990). Letter designation of tectonic belts (refer to Fig. 6): CaB—Calaveras mélange belt; CeB—Central Belt Franciscan; CoB—Coastal Belt Franciscan; FC—Fiddle Creek (—Tuolumne River) belt; GVG—Great Valley Group; PP—Pickett Peak Schist belt; RA—Red Ant blueschist; SB—Smartville block; SC—Slate Creek (—Lake Combie) arc; SF—Shoo Fly Complex; SM—Snow Mountain seamount; TS—Tehama-Colusa serpentinite mélange; VS—Valentine Springs belt; YB—Yolla Bolly belt; Yf—Yager Formation. Adapted after Maxwell (1974), Cady (1975), Saleeby and Sharp (1980), Ingersoll and Dickinson (1981), Schweickert et al. (1980, 1984a, 1988, 1999), Wagner and Bortugno (1982), McLaughlin et al. (1982, 1994), MacPherson (1983), Blake et al. (1984, 1985b, 1988, 2002), McLaughlin and Ohlin (1984), Jayko and Blake (1987), Edelman et al. (1989a), Ernst (1990b), Harwood (1992), Day (1992a, 1992b), Saucedo and Wagner (1992), Constenius et al. (2000), Dickinson (2000), Blake et al. (2002), Day and Bickford (2004), and Hopson and Pessagno (2004). Selected pluton ages after Hanson et al. (1996, 2000), Fagan et al. (2001), Day and Bickford (2004), and Hopson and Pessagno (2004). Selected towns (for orientation): B—Blairsden; Ci—Chico; Co—Covelo; FB—Fort Bragg; G—Garberville; GV—Grass Valley; M—Marysville; Sa—Sacramento; So—Stonyford; SR—Santa Rosa; N—Napa; RB—Red Bluff; U—Ukiah.
Figure 7. Accretionary tectonic belts (offset locally by strike-slip faults) of southern Sierra Nevada and Southern Coast Ranges (QS—Neogene Quien Sabe volcanic field). Selected roof pendants within Sierra Nevada batholith enlarged for clarity (and some clusters of small roof pendants conjoined). Outcrop patterns of granitic-metamorphic basement rock and sedimentary-volcanic cover not depicted in Basin and Range province east of Sierra Nevada frontal escarpment, or within Salinian block of California Coast Ranges. Quaternary alluvium is blank. Small granitic bodies, narrow enclaves of disparate rock within Franciscan accretionary belts, Tertiary volcanic cover on Sierra Nevada interfluves, and local alluviated valleys omitted for reasons of scale. Southeasternmost exposures of Paleozoic allochthons (Fig. 6) include depositionally overlying Paleozoic strata. Letter designation of tectonic belts (refer to Fig. 6): BH—Burnt Hills terrane; CaB—Calaveras mélangé belt; CeB—Central Belt Franciscan; CoB—Coastal Belt Franciscan; CM—Cordilleran miogeocline; FA—Foothills arc; KK—Kings-Kaweah belt; P—Permanente terrane; SF—Shoo Fly belt; TR—Tuolumne River (–Fiddle Creek) belt. Asterisk (DP) denotes Del Puerto ophiolite. Adapted after Cady (1975), Nelson (1976), Saleeby and Sharp (1980), Jayko and Blake (1984), Schweickert and Lahren (1987, 1991, 1993b), Schweickert et al. (1988, 1999), Lahren and Schweickert (1989), Dunne and Suczek (1991), Ernst (1993a, 1993b), Saleeby and Busby (1993), Greene et al. (1997), Stevens and Greene (1999, 2000), Blake et al. (2002), Graymer et al. (2002), and Dickinson et al. (2005). Selected towns (for orientation): B—Bishop; F—Fresno; LP—Lone Pine; Me—Merced; Mo—Modesto; M—Monterey; PR—Paso Robles; S—Stockton; SJ—San Jose; T—Tulare.
The Calaveras mélangé belt, continuous for the length of the Sierra Nevada (Figs. 5 and 7), has a pervasively disrupted internal structure of phacoidal or lentiform chert bodies encased in argillite representing mélange matrix of initially scaly clay now overprinted by post-mélangé foliation. The belt also includes fault-bound enclaves of greenstone representing dislocated seafloor or seamount volcanic rock as well as intact fault duplexes or tectonic rafts composed of chert-argillite successions representing domains of undisrupted seafloor sedimentary strata. The enclaves of intact stratatal successions individually top to the east, but the belt as a whole youngs to the west (Bateman et al., 1985), suggesting an imbricate internal structure produced by incremental accretion at a subduction zone along the continental margin. Chert phacoids are commonly flattened to extreme aspect ratios, and the belt can aptly be described as metamélange. Paleozoic limestone blocks that were probably derived from seamount caps are also present within the Calaveras mélangé belt (Schweickert et al., 1977; Day et al., 1985, 1988; Dilek, 1989a; Edelman, 1990; Edelman and Sharp, 1989; Edelman et al., 1989b; Hacker, 1993), as they are in central mélange belts of the Klamath Mountains.

Southward from the southern tip of the Feather River peridotite belt, the contact between the Shoo Fly Complex and the Calaveras mélangé belt is marked by the contrast between coherent though internally imbricated metasedimentary strata of the Shoo Fly complex and intricately dislocated though metamorphosed mélange of the Calaveras belt. In one restricted area of the northern Sierra Nevada, an enclave of Red Ant blueschist (Fig. 5) is structurally interleaved with the Feather River peridotite belt (Schweickert et al., 1980; Saleebey, 1989a; Dilek et al., 1990) as a record of metamorphism within the early Mesozoic subduction zone, but post-accretion metamorphism in greenschist and amphibolite facies has elsewhere overprinted all the Sierran accretionary assemblages. Metasedimentary Red Ant blueschist blocks are enclosed as phacoidal bodies within heterogeneous metamélange that also includes dispersed lentiform blocks of metavolcanic greenstone.

West of the Calaveras mélangé belt (Fig. 5) is a complex assemblage of accreted island arcs (Slate Creek–Lake Combie belt, Smartville block–Foothills arc) and associated subduction complexes (Fiddle Creek–Tuolumne River belt) that have been progressively attenuated southward by post-accretion deformation (Fig. 7). Large segments of the Smartville block and its southern extensions along the Foothills arc are massive metavolcanic rock with minimal foliation and no indication of structural dislocation by mélange fabric. Many other components of the Foothills arc belt, including associated metasedimentary strata, and much of the Slate Creek–Lake Combie arc belt, are strongly foliated, though undisrupted by mélange fabric. The Fiddle Creek–Tuolumne River belt is composed of mélange and broken formation in which blocks and lenses of argillite, ribbon chert, and metavolcanic rock are dominant but ultramafic lenses are also present (Hacker, 1993).

The Smartville block (Figs. 5 and 6) is a complex of both intrusive and extrusive igneous rocks representing a dissected magmatic arc that overlies an ophiolitic substratum, in part Paleozoic age, that was strongly imprinted by intraarc rifting (Saleebey, 1982; Beard and Day, 1987; Beiersdorfer et al., 1991; Beiersdorfer and Day, 1992). Deeper structural levels include metagabbro cut by sheeted and unsheeted diabase dike swarms, and higher structural levels include lavas and pillow lavas grading upward to volcaniclastic successions, with gabbroic to tonalitic plutons an integral part of the intracratonic volcanicplutonic complex. The Smartville block structurally overlies deformed arc assemblages of the Slate Creek–Lake Combie belt, which in turn structurally overlies mélange of the Fiddle Creek–Tuolumne River belt (Day et al., 1985, 1988; Edelman and Sharp, 1989; Edelman et al., 1989a; Edelman, 1991; Dilek et al., 1990; Fagan et al., 2001; Day and Bickford, 2004). These structural relationships imply eastward thrusting within the accretionary assemblages west of the Calaveras mélangé belt (Ricci et al., 1985). The Smartville and Slate Creek–Lake Combie arc assemblages are in part coeval in age (Fig. 6), and the contact between them represents structural telescoping within a compound arc complex of intracratonic origin (Sharp, 1988; Dilek, 1989a, 1989b; Dilek et al., 1990). The Slate Creek–Lake Combie arc assemblage was constructed on an ophiolitic substratum, with no evidence of continental basement in the arc roots (Edelman, 1990; Edelman et al., 1989a, 1989b; Hacker, 1993; Fagan et al., 2001; Day and Bickford, 2004).

The Foothills arc belt (Figs. 6 and 7) farther south is a polygenetic intracratonic assemblage built upon a severely disrupted ophiolitic substratum (Schweickert and Bogen, 1983; Edelman and Sharp, 1989), and is composed of structurally interleaved volcanic and volcaniclastic strata that probably include counterparts of the Slate Creek–Lake Combie belt as well as the Smartville block to the north (Sharp, 1988; Herzig and Sharp, 1992). The least deformed components of the Foothills arc assemblage include thick intact successions (1000–5000 m) of largely volcanogenic strata (Bogen, 1984, 1985; Schweickert et al., 1988). Recent petrogenetic studies indicate that thick calc-alkaline basalts of arc affinity overlie thinner tholeiitic basalts of seafloor affinity (Snow, 2007) to form the type of stratigraphic succession expected for an intracratonic arc.

### Stitching Plutons

As in the Klamath Mountains, migration of the Cordilleran magmatic arc into the domain of Sierran accretionary belts provides evidence in the form of stitching plutons for minimum ages of accretion. The Calaveras mélange belt was firmly stitched to the Cordilleran continental margin by post-accretion plutons of Middle Jurassic age (170–160 Ma), and the more western accretionary belts exposed in the Sierra Nevada foothills were conjoined by only slightly younger Middle to Late Jurassic (160–150 Ma) stitching plutons (Fig. 6). The oldest plutons that stitch the western accretionary belts to the Calaveras mélange belt are, however, of younger Late Jurassic age (ca. 140 Ma), and this dichotomy in the ages of stitching plutons (Fig. 6) leads to an ambiguity of interpretation for times of accretion. If all the more western plutons are viewed as records of the native Cordilleran arc, then the pluton ages imply accretion of all the Sierran accretionary belts by Middle Jurassic time (Edelman and Sharp, 1989; Girty et al., 1995). On the other hand, if the older of the more western plutons are viewed as the record of igneous activity within an offshore intracratonic arc complex, then accretion of the exotic arc terranes was delayed until Late Jurassic time. In either case, however, arc crust of intraoceanic origin was incorporated into the Sierra Nevada foothills by arc-continent collision (Moore and Day, 1984; Godfrey and Dilek, 2000; Ingersoll, 2000).

The Calaveras mélange belt is here interpreted as the record of subduction along a paleotrench flanking the continental margin, whereas the more western mélanges (Fiddle Creek–Tuolumne River belt) are interpreted as the record of a subduction zone along the flank of an offshore intracratonic island arc as it approached the continental margin (Moore and Day, 1984). The intermélange contact (Dilek et al., 1990) along the western flank of the Calaveras mélange belt (Fig. 5) is accordingly interpreted as a suture between mélangé assembled at the continental margin and mélangé transported to the continental margin together with an exotic island arc. Where accreted arc assemblages are in direct contact with the Calaveras mélangé belt southward along the Sierra Nevada foothills (Fig. 7), the placement of the suture between the evolving continental margin and exotic arc terranes is not in doubt, but the ambiguity for time of accretion remains. If arc collision and accretion were
Middle Jurassic in age in the Sierra Nevada as well as in the Klamath Mountains (Sharp, 1988; Girty et al., 1995). Upper Jurassic lithic assemblages of the Smartville block (Figs. 5 and 6) and their continuations southward along the foothills arc belt can be viewed as direct analogues of the Western Jurassic belt of the Klamath Mountains (Dilek and Moores, 1988).

For the alternate scenario of Late Jurassic arc-arc collision between an east-facing intraoceanic arc complex and the west-facing continental-margin arc-trench system, upper Oxfordian–lower Kimmeridgian (155 ± 2.5 Ma) metasedimentary strata are interpreted as the clastic fill of a suture basin that developed along the collision zone (Schweickert and Bogen, 1983). The strata contain quartzolithic detritus derived mainly from subduction complexes caught along the suture belt. Older Callovian–Oxfordian (160–155 Ma) strata of both similar and volcaniclastic petrology are interpreted as the sediment fill of the remnant ocean basin and trench present along the evolving suture zone before arc-arc collision was complete (Ingersoll and Schweickert, 1986; Dickinson et al., 1996b).

Great Valley

Bedrock under the Great Valley between the Sierra Nevada and the Coast Ranges is masked for a lateral span of 30–90 km over a length of ~650 km by Quaternary alluvium overlying thick successions of Cretaceous and Tertiary forearc strata (Figs. 5 and 7). Forearc sedimentation expanded laterally through Cretaceous and Paleogene time as successive increments of the Franciscan subduction complex were accreted by underthrusting on the west (Fig. 5), and forearc strata progressively onlapped the western flank of the accreted arc assemblages forming the exposed fringe of the Sierra Nevada block to the east (Ingersoll, 1982). An elongate band of mafic basement rock in the subsurface beneath the center of the Great Valley is delineated by a prominent magnetic and gravity anomaly (Cady, 1975). Geophysical modeling of the mafic basement responsible for the anomalies has suggested a unitary slab of obducted but otherwise essentially undeformed ophiolite emplaced as backarc oceanic crust during arc accretion in the Sierra Nevada foothills (Godfrey et al., 1997; Godfrey and Klemperer, 1998; Godfrey and Dilek, 2000). When the subcrop of mafic basement delineated by Cady (1975, his oversize Fig. 2) is traced southward, however, the mafic rocks emerge at the surface along the fringe of the Great Valley east of Fresno and northeast of Tulare as the deformed Kings-Kaweah ophiolite belt of the Sierra Nevada foothills (Fig. 7).

The Kings-Kaweah ophiolite belt is a tectonic megabreccia (Saleeby, 1977) of heterogeneous lithology intruded by Lower Cretaceous plutons (Saleeby, 1992). The entire ophiolite belt has been metamorphosed since its emplacement by proximity to the Sierra Nevada batholith (Saleeby, 1977). A reconstruction of the structural fabric of the southern (Kaweah) part of the belt before intrusion reveals an array of lozenge-shaped tectonic blocks as much as 1000–1500 m long and 250 m wide, but ranging downward in dimensions to outcrop scale, encased in an anastomosing matrix of sheared serpentinite forming outcrop bands as much as 1 km wide (Saleeby, 1977). The northern (Kings) part of the belt is composed of multiple intact slabs of ophiolite that are structurally interleaved with only thin seams of sheared serpentinite separating them (Saleeby, 1977). As reconstructed, the structural thickness of the belt is 10–15 km. Blocks and slabs within the belt include lithologic representatives of all levels of oceanic crust and uppermost mantle: chert, pillow basalt, ophicalcite and detrital serpentinite, diabase dikes, gabbro and pyroxenite, and peridotites, including websterite, harzburgite, and dunite. The variety of the blocks closely matches lithologies described from bottom-hole samples of cores that penetrate mafic basement rock in the subsurface of the Great Valley, i.e., greenstone, diabase, greenschist, gabbro, and serpentinite (Cady, 1975; Constenius et al., 2000). Plagiogranite and metadiorite of the Kings-Kaweah belt include Permian as well as Triassic–Jurassic ophiolitic rocks (Saleeby and Sharp, 1980).

Pervasive deformation of the Kings-Kaweah ophiolite belt has been attributed to dislocation during strike slip along the transform fault responsible for latest Paleozoic to earliest Mesozoic truncation of the continental block (Saleeby, 1977, 1992; Saleeby et al., 1978). This interpretation is not favored here because the Kings-Kaweah belt is west of the Calaveras mélangé belt (Fig. 7), which was not accreted to the continental margin until Middle Jurassic time (Fig. 6), long after continental truncation by transform slip. The internal structure of the Kings-Kaweah belt, marked by structural stacking of Kings ophiolite slabs and by dispersal of elongate lenticular blocks of ophiolitic lithology in Kaweah serpentinite mélangé, can be viewed instead as structural features imparted by subduction of oceanic crust and lithosphere.

Spatial correlation of subsurface mafic basement under the Great Valley with the exposed Kings-Kaweah ophiolite belt implies that the elongate band of buried mafic rocks is not an intact slab of ophiolite, but instead a deformed belt of disrupted oceanic crust and lithosphere. Accretion to the California continental margin can be inferred during subduction that succeeded accretion of exotic island-arc structures of the Sierra Nevada foothills in Middle to Late Jurassic time. From that perspective, suturing of the island arcs into the Cordilleran margin along a collision zone within the Sierra Nevada foothills was followed by polarity reversal that led to accretion of the Kings-Kaweah belt and the mafic Great Valley basement to their western flank. If this interpretation is correct, modeling of the mafic Great Valley basement as an intact ophiolite (Godfrey et al., 1997; Godfrey and Klemperer, 1998) can be viewed as the simplest possible model that satisfies available geophysical constraints, but not a valid model of the subsurface. The modeled thickness of the subsurface ophiolitic basement and the structural thickness of the disrupted Kings-Kaweah ophiolite belt are strikingly similar (10–15 km), but full reconciliation of the subsurface geophysical data with the interpretation of the Great Valley mafic basement preferred here is beyond the scope of this paper.

The age range (225–160 Ma) of Mesozoic lithic components of the Kings-Kaweah belt and the age (130–125 Ma) of stitching plutons that tie the Kings-Kaweah belt to foothills arc assemblages imply accretion in Late Jurassic–Early Cretaceous time (Fig. 6). The earlier part of that time interval (160–130 Ma) is preferred here because accretion of the Kings-Kaweah belt logically preceded accretion of Franciscan assemblages in the Coast Ranges to the west, and blueschists of the Franciscan subduction complex have yielded metamorphic Late Jurassic ages as old as ca. 160 Ma (Fig. 7). In a regional sense, accretion of the Kings-Kaweah belt and the mafic basement of the Great Valley to the continental margin can be viewed as the result of a short-lived phase of pre-Franciscan subduction that followed postcollision polarity reversal in the Sierra Nevada foothills.

Coast Range Ophiolite

West of the northern Great Valley (Fig. 5), a steeply dipping belt of ultramafic and associated mafic rocks exposed west of the Great Valley forearc basin have been termed the Coast Range ophiolite (Fig. 6). Upper horizons of the ophiolitic succession include volcano-pelagitic strata containing a radiolarian fauna inferred to reflect deposition at more southern paleolatitudes than radiolarian faunas of the adjacent Cordilleran margin (Hopson et al., 1996). An inferred extension of the ophiolite into the subsurface of the forearc basin to the east has been thought to form obducted basement beneath the Great Valley. The ophiolitic assemblage as a whole has long been regarded as a dismembered slab of oceanic crust.
and lithosphere overlain depositionally by basal horizons of the Great Valley succession (Bailey et al., 1970; Dickinson and Seely, 1979; Ingersoll, 1982, 2000). Recent evaluation of the ultramafic components of the ophiolitic assemblage has shown, however, that the bulk of the ultramafic belt is serpentinite mélangé (Tehama-Colusa serpentinite mélangé of Hopson and Pessagno, 2004), viewed here as an eastern component of the Franciscan subduction complex analogous to the hydrated mantle described from modern arc-trench systems as forearc serpentinite (Bostock et al., 2002; Blakely et al., 2005). The protolith for the serpentinite was oceanic upper mantle, with blocks of oceanic crust including basaltic pillow lava, radiolarian ribbon chert, slaty argillite, and rare diabase and gabbro enclosed within the foliated serpentinite matrix (Hopson and Pessagno, 2004).

Recognition that the voluminous ultramafic belt previously regarded as an integral lower part of the Coast Range ophiolite is instead the structurally distinct Tehama-Colusa serpentinite mélangé (Fig. 6) challenges past interpretations of the Coast Range ophiolite. With regard to the Great Valley subsurface, there is no longer any justification for the inferred extension of the ultramafic mass now known to be composed of serpentinite mélangé eastward beneath the Great Valley as an obducted slab of undeformed ophiolite. My interpretation of mafic basement beneath the Great Valley as an analogue along strike of the Kings-Kaweah ophiolite belt formed within an evolving subduction zone obviates the need to postulate an obducted slab of ophiolite beneath the Great Valley, but other aspects of the Coast Range ophiolite as currently conceived are called into question as well.

Alternative suggested origins of the exposed Coast Range ophiolite have assumed that related ophiolite spans the width of the Great Valley basement from the Coast Ranges to the Sierra Nevada (Dickinson et al., 1996a): (1) backarc oceanic lithosphere formed behind an east-facing island-arc complex now accreted to the continental margin in the Sierra Nevada foothills (Dickinson et al., 1996b); (2) mid-ocean lithosphere accreted to the continental margin west of the Sierra Nevada foothills after plate transport from afar (Hopson et al., 1996); or (3) oceanic lithosphere formed in place by forearc spreading induced by slab rollback along the western flank of the continental-margin Sierra Nevada arc (Saleby, 1996).

The controversy becomes moot if (1) mafic basement beneath the Great Valley (Great Valley ophiolite of Godfrey and Dilek, 2000) is a deformed belt of stacked ophiolite thrust sheets and ophiolite-bearing mélangé akin to the Kings-Kaweah ophiolite belt, and (2) exposures of ophiolitic rocks depositionally underlying Great Valley forearc strata along the eastern flank of the Coast Ranges to the west (Coast Range ophiolite of Godfrey and Dilek, 2000) are the outcrop expression of an analogous but younger accretionary belt structurally overlapping forearc serpentinitic mélangé and the Franciscan subduction complex. Several lines of argument favor the interpretation that the ophiolitic assemblages described herefore as parts of the Coast Range ophiolite represent a collage of disparate ophiolitic slabs rather than a coherent and laterally contiguous ophiolitic succession.

(1) With the Tehama-Colusa serpentinite mélangé removed from the Coast Range ophiolite, exposures of the latter are restricted to ~20 geographically isolated remnants of limited individual extent exposed beneath forearc strata along the west side of the Great Valley and within the Coast Ranges to the west (Hopson et al., 1981; McLaughlin et al., 1988; Hopson and Pessagno, 2004). Original lateral continuity of the ophiolite remnants is commonly inferred, but cannot be demonstrated on outcrop. Infalling into the structurally underlying Franciscan subduction complex, displacement by detachment faults (Jayko et al., 1987; Harms et al., 1992), and lateral translation by strike slip (McLaughlin et al., 1988) have all contributed to the structural isolation of the various remnants of the Coast Range ophiolite, but do not preclude earlier deformation of the ophiolitic assemblage prior to the deposition of overlying sedimentary cover forming the Great Valley Group.

(2) Sedimentary strata, including ophiolitic breccias that depositionally overlie the dispersed fragments of Coast Range ophiolite, rest alternately on basaltic pillow lava, sheeted dike complexes, gabbro, serpentinite, metadacite, and andesitic breccia (Hopson et al., 1981; Lagabrielle et al., 1986; McLaughlin et al., 1988; MacPherson and Phipps, 1988; Robertson, 1989, 1990). These diverse contact relationships indicate that the ophiolitic assemblage of the Coast Range ophiolite was deformed enough before deposition of overlying sedimentary strata to expose locally different horizons of the ophiolite pseudostratigraphy from place to place, and are compatible with origin of the Coast Range ophiolite as a tectonic collage of ophiolitic character. Chronostratigraphic equivalence of the volcanopelagic strata forming the uppermost tiers of the local ophiolite successions imply derivation of all exposures from the same oceanic realm, but do not indicate how far apart the various exposed ophiolite remnants originally were within that realm.

(3) Petrologic studies of various segments of the Coast Range ophiolite have suggested diverse origins across a spectrum of ophiolitic settings, including open-ocean seafloor, oceanic seamounts, intra-arc rifts, and backarc basins (Shervais and Kimbrough, 1985; Shervais, 1990; Giaramita et al., 1998; Huot and Maury, 2002; Shervais et al., 2004, 2005). Descriptions thereof imply a composite origin for the Coast Range ophiolite. Reconciliation of its varied petologic character with the concept of a coherent, laterally contiguous slab of ophiolite is challenging, but unnecessary if the Coast Range ophiolite constitutes a diachronous collage of disparate tectonic elements.

(4) Several locally exposed ophiolitic slabs that are structurally beneath the forearc sedimentary succession, and have been viewed as segments of the Coast Range ophiolite, actually display equivocal relations with the Great Valley Group. Perhaps the best known and most widely discussed is the Del Puerto ophiolite (Evarts, 1977; Evarts et al., 1999; Coleman, 2000), exposed along the eastern flank of the Diablo Range west of the Great Valley (Fig. 7). Variably metamorphosed exposures of ultramafic, plutonic, and volcanic rock distributed along Del Puerto Creek have been interpreted as dismembered fragments of a coherent ophiolite succession depositionally underlying the Great Valley forearc succession, and largely undeformed prior to forearc sedimentation. As mapped in detail, however, ultramafic rocks of the ophiolitic assemblage are faulted against forearc strata, which depositionally overlie the volcanic rocks. The volcanic rocks are cut by small mafic intrusions and gabbro layers are present within the nearby ultramafic body, but the volcanic and plutonic masses are structurally disconnected on outcrop, and their reconstruction into a single ophiolite profile is inferential, even though widely accepted (Evarts, 1977; Evarts et al., 1999; Coleman, 2000). The actual outcrop relations are compatible with the alternate view that different components of the local ophiolitic suite were structurally telescoped along the tectonic contact between the Great Valley Group and the Franciscan Complex, and do not define a unitary ophiolite succession.

(5) Some ophiolite exposures identified in the past as remnants of the Coast Range ophiolite are surrounded by exposures of the Franciscan subduction complex, and need not necessarily be termed Coast Range ophiolite (Ingersoll and Schweickert, 1986). In sum, the perspective that the mafic basement beneath the Great Valley is a complexly deformed accretionary belt of ophiolitic rocks suggests that the Great Valley Group of the forearc basin was not deposited on a laterally coherent ophiolite, but instead overlapped an intricately deformed ophiolitic substrate as it onlapped westward over the growing Franciscan.
subduction complex (Ingersoll and Dickinson, 1981). Existence of a discrete Coast Range (or Great Valley) ophiolite is an unnecessary and unlikely postulate that forces tectonic interpretations to contrasting and mutually contradictory avenues of thought that can be avoided with the view that the isolated remnants of the Coast Range ophiolite were accreted separately to the continental margin.

Coast Ranges

The bulk of the Coast Ranges west of the Great Valley is formed by the vast Franciscan subduction complex coeval with the Sierra Nevada batholith, which forms the roots of the paired and coeval magmatic arc (Fig. 6). The Franciscan accretionary prism has been subdivided into multiple components of varied lithology and internal structure grouped here on maps and diagrams into just a few main belts. Each belt was thrust successively beneath the belt to the east, as seen clearly in the Northern Coast Belt was thrust successively beneath the belt to the east, as seen clearly in the Northern Coast Ranges (Fig. 5). The present outcrop distributions of some Franciscan assemblages have been influenced by synaccretion tectonic denu- ciation along low-angle normal faults (Jayko et al., 1987; Harms et al., 1992), probably in response to thickening of the accretionary prism by subcretion or underplating (Platt, 1986). The tectonic denudation locally attenuated structural cover over deeper horizons of the subduction complex, but did not alter the fundamental structural stacking achieved by underthrusting during subduction. Post-accretion deformation associated with Neogene evolution of the San Andreas transform system folded many fault contacts between tectonic belts, and their outcrop patterns become progressively more complex southward (Fig. 7). Protoliths and times of inferred accretion generally become younger westward within the Franciscan complex, although in complex and partly overlapping fashion (Fig. 6).

Detailed discussion of internal relations within the Franciscan Complex is beyond the scope of this paper, but the Central Belt and the Coastal Belt have the overall character of mélange and broken formation, respectively. Undisrupted phacoidal blocks encased in a mélange matrix of scaly clay in the Central Belt range widely in dimensions, from the size of a fist to the size of a mountain. Graywacke derived from trench turbidites is the dominant block lithology (Bail- ley et al., 1964), but metavolcanic greenstone of both seafloor and seamount origin (MacPherson et al., 1990; Shervais, 1990) is also a ubiquitous component, as is associated ribbon chert derived from seafloor stratal successions. The Coastal Belt is largely broken formation formed by disrupted graywacke-argillite successions, but bands of mélange including greenstone blocks lace through the outcrop belt, and its strata probably represent both trench-floor and trench-slope deposits (Bachman, 1982; Bachman et al., 1984). Large domains of Lower Cretaceous metavolcanic rock representing oceanic sea- mount edifices were locally incorporated into the Franciscan accretionary prism to form the Snow Mountain block (Figs. 5 and 6) and much of the Permanente terrane (Figs. 6 and 7).

The most eastern components of the Franciscan subduction complex are schistose or semischistose domains (Pickett Peak–Valentine Springs and Yolla Bolly belts of Figs. 5–7) that appear to be intact though metamorphosed successions lacking the mélange fabric imparted to the Central Belt by stratal dislocation. Intricate interleaving of metachert bands with domains dominated by metagraywacke and the occurrence of lensoid metavolcanic bodies commonly associated with the metachert occurrences suggest an imbricate internal structure overprinted by the metamorphism that developed the schistosity (Ernst, 1993b). The original nature of lithologic contacts within the schistose rocks cannot be discerned through the metamorphic overprint, but intricate intermingling of graywacke, chert, and basalt protoliths can best be understood as the result of thrust imbrication of multiple panels of oceanic seafloor (chert-basalt) overlain by trench-fill turbidites (graywacke). It is likely that stratral successions of this kind were formed repetitively as successive increments of seafloor were rafted into the Franciscan paleotrench.

To my eye, transitional outcrops between Central Belt mélanges and more eastern schis- tose rocks in the Northern Coast Ranges suggest that the schistose fabrics were superimposed in part on broken formation. If so, the planar lithologic interfaces that were ancestral to schistosity, and commonly interpreted as bedding surfaces, may in some cases have been part of the shear fabric of mélange. This interpretation suggests that some of the schistose eastern Franciscan rocks may have passed through a premetamorphic phase of mélange formation as well as structural imbrication before acquiring their schistose fabrics. If that viewpoint is invalid, it remains unclear why the easternmost Franciscan assemblages were underthrust as intact stratal successions before the accretion of the mélange assemblages exposed so prominently farther west.

NEVADAN OROGENY

The concept of a Nevadan orogeny looms large as a historical legacy in our thoughts about California tectonics. Originally conceived as a climactic or paroxysmal event that terminated Cordilleran eugeosynclinal evolution and included intrusion of the Sierra Nevada batholith, the idea of Nevadan orogeny was extended to global scale in the guise of a universal end-Jurassic event. This original view of the Nevadan orogeny became untenable once it was learned that the bulk of the Sierra Nevada batholith is Cretaceous in age.

When plate tectonic concepts were first applied in detail to the Sierra Nevada foothills by Schweickert and Cowan (1975), it was suggested that deformation and metamorphism traditionally ascribed to the Nevadan orogeny was associated with Late Jurassic collision and accretion of an exotic intraoceanic island arc in the Sierran foothills. This viewpoint requires diachronity for the Nevadan orogeny because arc collision and accretion was Middle Jurassic in age along tectonic strike in the western Klamath Mountains.

Two disparate perspectives have accordingly been adopted for the timing of the Nevadan orogeny in the Klamath Mountains. On the one hand, Hacker and Ernst (1993) argued for a continuum of structural deformation, metamorphism, and plutonism that spanned the interval 170–150 Ma (Middle to Late Jurassic) with no distinct Nevadan orogeny discernible from the geologic record. Others prefer to regard the structural amalgamation of the Western Jurassic belt with older accretionary belts of the Klamath Mountains as a deformational event that deserves the appellation of Nevadan orogeny (Saleebey et al., 1982; Wright and Fahan, 1988; Harper and Wright, 1984; Harper et al., 1990). Using the best available information for the timing of the structural telescoping that carried the Western Jurassic belt beneath the expanding continental margin, this approach dates the initiation of Nevadan thrusting as 155–150 Ma (Kimmeridgian), as marked by metamorphic ages for sole and roof thrusts, and the termina- tion of Nevadan thrusting as 150–145 Ma (Tithonian), as marked by the emplacement of crosscutting plutons (Harper et al., 1994).

Depending upon how the complex age relationships within the Sierra Nevada foothills are interpreted, this time span (155–145 Ma) for the Nevadan orogeny may be appropriate as well for Late Jurassic arc collision and accretion in the Sierra Nevada (Fig. 6). From an analysis of stratal ages and deformational features, Schweickert et al. (1984b) suggested an age of 155 ± 3 Ma for collisional Nevadan orogeny in the Sierra Nevada foothills. Others have subsequently argued, however, that penetrative deformation continued for tens of millions of years thereafter (Saleebey et al., 1989b; Tobisch et al., 1989).

Continued usage of the term Nevadan orogeny, originally conceived as marking the
endogenous terminal phase of a supposed geotectonic cycle, seems equivocal in an era when orogenic events are described in terms of the improved plate model. Those who continue to use the term have the obligation to specify the structural features and events to which the name Nevadan is attached, for multiple interpretations are logically possible.

**KLAMATH-SIERRAN CORRELATION**

The manner in which analogous tectonic belts of the Klamath Mountains and northern Sierra Nevada connect beneath Cretaceous and Cenozoic cover underlying and surrounding the northern end of the Great Valley has long been difficult to assess (Davis, 1969; Irwin, 2003). The respective tectonic belts strike subparallel to one another but are not in alignment (Fig. 1). Recognition that related Cretaceous faults (Fig. 8) along the western side of the northern Great Valley are tilted normal growth faults (Constenius et al., 2000), active during evolution of the Great Valley forearc basin, provides insight into this longstanding question.

**Forearc Faulting**

From their present steep dips, the faults were initially inferred to form a zone of sinistral strike slip (Jones and Irwin, 1971). Appreciation that the faults dipped gently before eastward tilting of the Great Valley Group led to the suggestion that they were syntectonic thrust faults (Dickinson and Seely, 1979). Reflection profiles beneath the Great Valley that connect to exposures on outcrop have now shown that the family of faults instead formed as a system of low-angle normal growth faults active during deposition of the Great Valley Group (Constenius et al., 2000). Strong contrasts in stratal thicknesses of Lower Cretaceous strata are evident across the individual fault traces, and apparent displacements across the faults decrease upward in the stratigraphic succession (Fig. 8).

The syndepositional faults carried the trenchward flank of the forearc basin progressively downward to the northwest as forearc sedimentation continued, and successive intervals of the Great Valley forearc succession change thickness in the appropriate sense across strands of the fault system bounding separate half-grabens. The half-graben fills have been tilted to steep eastward dips by Cenozoic uplift of the Northern Coast Ranges, but their initial configurations are recovered by retrodeformation of the Mesozoic succession of the Great Valley forearc basin (Constenius et al., 2000). The northernmost half-graben is floored by the pre-Cretaceous bedrock assemblage of the Klamath Mountains (Fig. 8), showing that the Klamath block participated in the growth faulting.

The trend of the headwall scarp for the forearc system of normal growth faults is northward in the subsurface (Constenius et al., 2000). This trend, parallel to the strike of the normal faults before they were tilted along with forearc basin fill, would carry the scarp into the covered zone between the Klamath and Sierra Nevada blocks (Fig. 9). In effect, foundering of the flank of the Great Valley forearc basin toward the Franciscan paleotrench calved the Klamath block off the trenchward flank of the arc massif and displaced it downward to the west, backtilting at least the eastern edge of the Klamath block during its displacement.

This kinematic scheme can account for deflection of pre-Cretaceous tectonic belts of the northern Sierra Nevada westward into the Klamath Mountains. The accreted arc assemblages on the west, the central mélangé belts, and the Paleozoic assemblages overlain by native Mesozoic arc successions on the east are all out of alignment by comparable amounts across the forearc normal fault system (Fig. 9). The original interpretation of strike slip along the growth faults as an explanation for offset of the Klamath block with respect to the Sierra Nevada fails because the tilted faults at their present steep dips strike toward the north-central Sierra Nevada rather than the northern end of the Sierra Nevada. The offset of an Early Cretaceous paleoshoreline that figured in the original interpretation of sinistral

![Figure 8. Outcrop configuration of syndepositional normal fault system displacing strata of the Great Valley Group near the juncture of the Northern Coast Range and the Klamath block (left). View downdip in Great Valley Group adapted after Constenius et al. (2000) to restore bedding to subhorizontal and display faults in original orientation.](https://pubs.geoscienceworld.org/gsa/geosphere/article-pdf/4/2/329/3336520/i1553-040X-4-2-329.pdf)
strike slip across the faults (Jones and Irwin, 1971) is equally well accommodated through displacement of the paleoshoreline by normal growth faulting.

The relative positions of northern extensions of the Great Valley forearc basin are compatible with syndepositional displacement of the Klamath block. Lower Cretaceous increments of forearc sediment overlie accreted arc and mélangé belts along the western flank of the accreted Klamath assemblages in California (Figs. 3B and 9), and extend into Oregon as the Myrtle Group exposed along and near the northwestern flank of the accreted Klamath assemblages (Fig. 3A). By contrast, Upper Cretaceous increments of forearc sediment forming the Hornbrook Formation (Figs. 3A, 3B, and 9) were deposited along the eastern flank of the Klamath Mountains after displacement and tilting of the Klamath block. These relations imply that (1) Early Cretaceous forearc sedimentation continued along the western flank of the Klamath block before and during its displacement, and exposures of Lower Cretaceous strata now appear to swing westward out of alignment with the Great Valley forearc basin to the south; whereas (2) Late Cretaceous forearc sedimentation was shunted east of the displaced Klamath block where exposures of Upper Cretaceous strata align with the Great Valley forearc basin to the south (Fig. 9).

The distribution of arc plutons also reflects displacement of the Klamath block toward the

Figure 9. Displacement of Klamath Mountains block (on northwest) from Sierra Nevada block (on southeast) by down-to-the-paleotrench forearc normal growth faults (Fig. 8) of Early Cretaceous age (areal geology adapted after Figs. 3 and 5). SBv—Sutter Buttes volcano (Pliocene—Pleistocene). Selected towns (for orientation): B—Blairsden; CC—Crescent City; Ci—Chico; Co—Covelo; Eu—Eureka; FB—Fort Bragg; G—Garberville; GV—Grass Valley; HC—Happy Camp; RB—Red Bluff; Re—Redding; U—Ukiah; W—Weaverville; WC—Willow Creek; Y—Yreka.
Franciscan paleotrench during Cretaceous time. Lower Cretaceous plutons (145–135 Ma) of the arc roots are intrusive into the eastern Klamath Mountains (Fig. 3B) as well as the foothills of the northern Sierra Nevada (Fig. 5). Upper Cretaceous plutons (younger than 125 Ma) of the main Sierra Nevada batholith occur, however, only along the Sierran crest well to the east of the Klamath block, which had been displaced into the forearc region by mid-Cretaceous time. Continuations of Late Cretaceous plutonism northward from the Sierra Nevada are reflected by granite exposures isolated by intervening Tertiary volcanic cover in northwestern Nevada and southwestern Idaho, but Upper Cretaceous plutons are unknown in the Klamath Mountains farther west (Fig. 3).

Tectonic Correlations

Comparison of Figures 3–7 and Figure 9 indicates the following correlations of tectonic belts (east to west) from the southern Klamath Mountains to the northern Sierra Nevada across the normal fault system transecting the northern end of the Great Valley: (1) Paleozoic accretionary assemblages added to the Laurentian margin before Middle Triassic time (Dickinson, 2000); (2) Mesozoic blueschist remnants (Hacker and Goode, 1990) forming the Stuart Fork–Fort Jones (Klamath Mountains) and Red Ant (Sierra Nevada) belts and recording initial stages of post–Middle Triassic accretionary tectonism; (3) central mélange belts that include mélanges assembled along the Cordilleran continental margin to form North Fork (Klamath Mountains) and Calaveras (Sierra Nevada) belts, and mélanges assembled along the flank of a colliding intraoceanic island-arc complex to form Eastern Hayfork (Klamath Mountains) and Fiddle Creek–Tuolume River (Sierra Nevada) belts; (4) an intraoceanic arc complex that was accreted diachronously from Middle Jurassic time in the Klamath Mountains (Rattlesnake Creek and Western Hayfork belts) to Middle or Late Jurassic time in the Sierra Nevada (Slate Creek–Lake Combie belt and Smithville block).

One puzzling aspect of Sierran-Klamath tectonics has been the overlap in ages of arc formation between the Northern Klamath Mountains (Josephine and Red Ant) and the western Klamath Mountains (Middle Jurassic) and Sierra Nevada foothills (Late Jurassic) with diachronous impingement of the Luzon arc on modern Taiwan to induce analogous polarity reversal at the south end of the Ryukyu arc in northern Taiwan (Ingersoll, 2000; Teng et al., 2000).

SUMMARY AND CONCLUSIONS

Systematic analysis of subregional tectonic maps and chronostratigraphic diagrams newly prepared for this paper indicate that tectonic accretion was quasi-continuous along the California margin of Laurentia from Late Triassic time, immediately following truncation of the continental margin by the California-Coahuila transform, until mid-Tertiary time, when evolution of the San Andreas transform along the coastal edge of the continental block sequentially terminated subduction of oceanic plates. The classic Franciscan subduction complex was paired with the Great Valley forearc basin and the Sierra Nevada batholith injected into the roots of the Cordilleran magmatic arc. Accreted pre-Franciscan tectonic elements include subduction complexes of mélangé and broken formation assembled incrementally at paleotrenches along the continental margin, and intraoceanic arc assemblages accreted in bulk by arc-continental collision after subduction of intervening oceanic lithosphere. The collisional events were largely face-to-face arc-arc collisions during which subduction complexes associated with colliding island arcs were melded with subduction complexes assembled in place along the continental margin. Pre-Franciscan subduction complexes have been overprinted by metamorphism within the evolving continental-margin arc massif, and appraisal of their initial character depends upon the recognition of premetamorphic disoclinal structural trends. Knowledge of the geometry of forearc normal faulting clarifies Klamath-Sierran tectonic correlations.

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