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Subduction and the rock record: Concepts developed in the Franciscan Complex, California

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INTRODUCTION

Ernst's (1970) paper was chosen as the classic paper for the Franciscan Complex because it related high-pressure, low-temperature (high *P-T*) metamorphism to subduction. Perhaps most significantly, the paper explained the association of low geothermal gradients and the metamorphism. The paper also pointed out the difficult tectonic problem of the exhumation of the high *P-T* rocks, a problem still vigorously debated today, and proposed a tectonic model explaining the exhumation of the deeply buried rocks. In addition, the paper explained the tectonic contact of the Great Valley forearc over the Franciscan subduction complex in the context of plate tectonics theory (Hamilton, 1969, gave a similar explanation; see following). Ernst's paper was one of the key advances in the plate tectonics revolution. Variations of Figure 3 of Ernst (1970) have become the textbook model of subduction-zone metamorphism. Geologists now regard high *P-T* (including blueschist facies) metamorphism as the strongest evidence of an exhumed subduction complex. Evaluation of thermal gradients associated with subduction and their connection to metamorphic assemblages, introduced by Ernst (1970), has become an important concept in understanding the evolution of orogenic belts (e.g., Ernst, 1975, 1988). An example of this type of analysis is the premise that Franciscan subduction was continuous, from its inception in the late Mesozoic to conversion to a transform plate boundary in the late Cenozoic, because Franciscan high *P-T* rocks lack thermal overprints (such as late greenschist facies assemblages) which should have resulted from any cessation of subduction (Cloos and Dumitru, 1987; Ernst, 1988).

Ernst's (1970) paper was one of several key papers that related the Franciscan Complex to subduction processes and established the Franciscan as the type subduction complex. Hamilton (1969) equated the Franciscan to a subduction complex, related subduction to arc volcanism in the Sierra Nevada, and pointed out the far-traveled nature of some Franciscan Complex rocks. Hsü (1968, 1971) formalized the concept and principles of melange (Bailey et al., 1964, had recognized the shear-zone character of what were later called melanges). Dickinson (1970) placed the Franciscan in the context of an arc-trench system, with the Franciscan, Great Valley Group, and Sierra Nevada as the subduction complex, forearc basin, magmatic arc (and main terrigenous sediment source), respectively. Bailey et al. (1964) set the stage for these papers by compiling and evaluating an enormous amount of data and presenting ideas that forecast the plate tectonic interpretation of the Franciscan; this is still a useful reference on the Franciscan.

Many major conclusions of these landmark papers have not been significantly challenged since their publication. Subsequent research has continued to provide insight into fundamental processes in subduction zones. Some developments in Franciscan geology since 1970, as well as major controversies, are discussed in the following. The general geology of the Franciscan Complex is shown in Figure 1.

DEVELOPMENTS IN FRANCISCAN GEOLOGY SINCE 1970

Reexamination of the tectonic boundary between the Franciscan Complex and the Coast Range ophiolite and/or Great Valley Group

Various studies led to the formulation of a general model for the arc-trench system, in which a forearc basin (the Great Valley Group) and its basement (the Coast Range ophiolite) rode passively and undeformed on the upper plate of the arc-trench system, while the Franciscan Complex was complexly deformed structurally beneath as the subduction complex (e.g., Dickinson and Seely, 1979). Recognition of east-vergent

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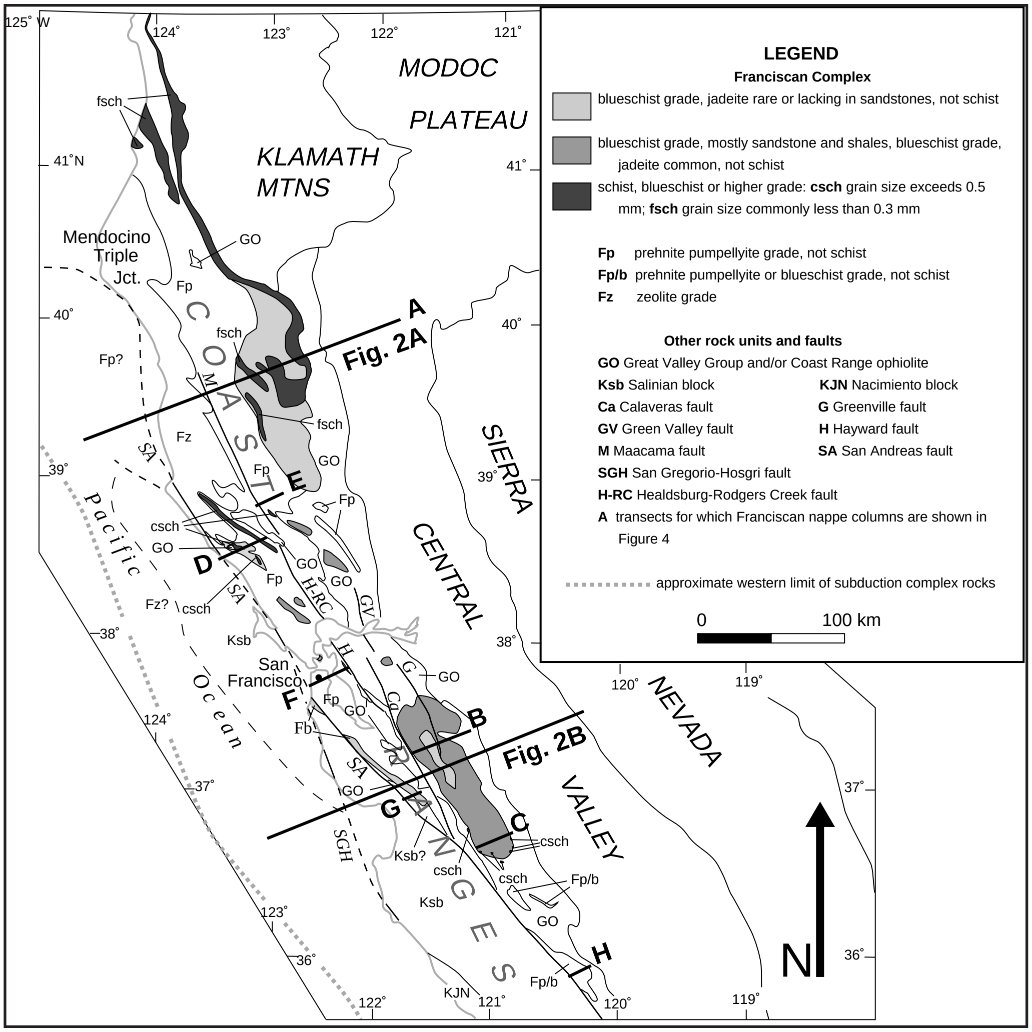


Figure 1. Distribution of Franciscan and other basement rocks of central and northern California, showing Franciscan Complex rocks of different metamorphic grades. Map derived from Jennings (1977) with modifications from Wakabayashi unpublished field data.

structures, comprising part of a tectonic wedge system that faulted the Great Valley Group and Coast Range ophiolite, and locally placed Franciscan Complex rocks *over* Great Valley Group rocks, greatly complicated this model (Wentworth et al., 1984) (Fig. 2).

The tectonic contact of the comparatively unmetamorphosed Great Valley Group and Coast Range ophiolite with the structurally underlying Franciscan Complex was initially called the Coast Range thrust (Bailey et al., 1970). This nomenclature reflected the recognition of the tectonic contact as a subduction boundary (Hamilton, 1969; Ernst, 1970). However, Suppe (1973) noted that the contrast of metamorphic assemblages (low-*P* rocks on high-*P* rocks) across this contact was consistent with normal rather than reverse slip. Neogene normal fault movement between the Great Valley Group and Franciscan was proposed by Ernst (1970). Platt (1986) indicated that the metamorphic contrast across the tectonic contact implied normal slip, and noted similar relationships in other high *P-T* belts. Wakabayashi and Unruh (1995) proposed that normal slip took place during one period of time along the ophiolite–Franciscan Complex contact and that tectonic wedging (and periodic thrust faulting along the contact) were operative during other periods (Fig. 2). Godfrey et al. (1997) presented evidence for a buried ophiolitic suture beneath the Great Valley Group that may be a consequence of an east-vergent collision event similar to that originally proposed by Moores (1970; see Moores and others, this volume) (Fig. 2A).

Metamorphism

Franciscan metamorphic rocks occur as tectonic blocks in melange and as intact units or thrust sheets (e.g., Bailey et al., 1964). Intact (termed coherent) Franciscan units range from blueschist-greenschist transition assemblages to zeolite facies (e.g., Blake et al., 1988) (Figs. 1 and 2), and grain sizes of meta-

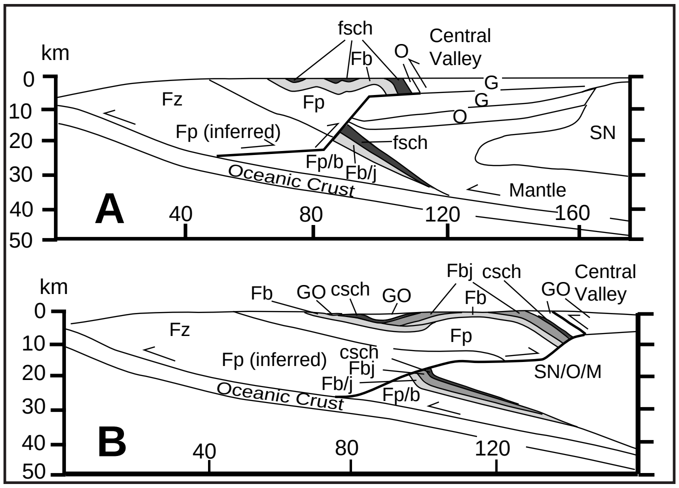


Figure 2. Schematic cross sections along lines shown in Figure 1. San Andreas fault system dextral slip is restored according to Wakabayashi and Hengesh (1995), and subsurface relations are restored to hypothetical geometry immediately prior to conversion to transform margin. Cross-section A is modified from Wakabayashi and Unruh (1995) and Godfrey et al. (1997). Abbreviations as in Figure 1, except: G—Great Valley Group; O—Coast Range ophiolite; SN/O/M—undifferentiated Sierran basement, ophiolitic rocks, and mantle beneath ophiolitic rocks; Fb/j, Fp/b designations reflect higher grade of metamorphism for deeper parts of equivalent unit.

morphic minerals are generally tenths of a millimeter or smaller. Tectonic blocks in melanges range from amphibolite to zeolite grade. Eclogite and amphibolite facies metamorphism is generally restricted to tectonic blocks (Bailey et al., 1964; Coleman and Lanphere, 1971). Amphibolite and eclogite blocks, with metamorphic grain sizes to 1 cm, along with blocks of similar coarse-grained blueschist, have been termed high-grade blocks (Coleman and Lanphere, 1971).

Although there have been many studies of Franciscan metamorphism since 1970, estimates for pressure (*P*) and temperature (*T*) of metamorphism for most coherent Franciscan rocks have not changed significantly. For blueschist and blueschist-greenschist transition facies rocks, these estimates range from 100 to 380 °C and 4 to 9 kbar (Maruyama and Liou, 1988; Blake et al., 1988; Ernst, 1993). The most significant update for *P-T* estimates of coherent rocks has been the characterization of blueschist-greenschist transition assemblages (Brown and Ghent, 1983; Maruyama and Liou, 1988). Direct estimates of *T* in coherent rocks are relatively scarce and have been based on oxygen isotope studies (Taylor and Coleman, 1968), data from thermal maturity of hydrocarbons, illite crystallinity, fluid-inclusion studies (e.g., Bostick, 1974; Cloos, 1983; Blake et al., 1988; Underwood, 1989; Dalla Torre et al., 1996), and chlorite geothermometry (Bröcker and Day, 1995).

Polymetamorphism was noted in high-grade blocks (Bailey et al., 1964; Dudley, 1972), and quantitative *P* and *T* estimates have been made for different stages of metamorphism (e.g., Brown and Bradshaw, 1979; Moore, 1984; Moore and Blake, 1989; Wakabayashi, 1990; Krogh et al., 1994). Petrologic studies show that the *P-T* conditions of these blocks evolved progressively from high to low geothermal gradients, probably in less than 5 m.y. (Wakabayashi, 1990) (Fig. 3). This type of thermal evolution has been suggested to be the result of metamorphism at the inception of Franciscan subduction (Wakabayashi, 1990) (Fig. 3). Alternatively, high-grade blocks may have been metamorphosed prior to Franciscan subduction (e.g., Coleman and Lanphere, 1971; Moore, 1984).

Coherent rocks are part of an inverted metamorphic gradient from zeolite to blueschist-greenschist grade (e.g., Blake et al., 1988; inverted metamorphic gradient first recognized by Blake, 1967). Thrust faults apparently separate the rocks of different metamorphic grade, but the metamorphic gradient may record changing thermal conditions within the subduction zone, and the structurally higher parts of the metamorphic gradient reflect the thermal influence and proximity of the hanging wall of the subduction zone (e.g., Ernst, 1971; Platt, 1975; Suppe and Foland, 1978; Cloos, 1985; Peacock, 1988) (Fig. 3). The *P-T* paths of representative high-grade blocks and coherent metamorphic rocks are shown in Figure 3.

Melanges

Following studies of Hsü (1968, 1971), research has further clarified details of melanges. Cloos (1982, 1985, and other papers) modeled a return-flow material path in melanges and used this flow pattern to explain the mixture of different blocks, the progressive accretion of melange terranes, and the large-scale thermal patterns noted in the Franciscan Complex. Cowan (1985) examined strain patterns in melanges and concluded that Franciscan melanges formed in several different tectonic settings in the subduction complex. Page (1978) and Aalto (1981) proposed that melanges resulted from a combination of tectonic shearing and earlier olistostromal development. There is evidence for Franciscan or ophiolitic material that had been exhumed and resedimented, supporting an olistostromal component for some melanges (Cowan and Page, 1975; Moore and Liou, 1980; Moore, 1984; Macpherson et al., 1990). Distinctive populations of blocks and structural relationships relative to other units have proved useful for distinguishing melanges as mappable units (e.g., Hsü and Ohrbom, 1969; Maxwell, 1974).

Major structure: Cross-sectional and along-strike variation

Following the recognition of melanges, units were mapped as chaotic melanges or coherent stratal packages (e.g., Raymond, 1970; Suppe, 1973; Cowan, 1974; Maxwell, 1974). Mapping of fault-bounded units developed into the formalized terrane concept (e.g., Blake et al., 1982; developed elsewhere in California by Irwin, 1972). The terrane concept added new levels of detail to Franciscan mapping and interpretation but did not separate discrete melanges; all melanges were considered to be one terrane.

Imbricate low-angle faults involving coherent units and intervening melanges were recognized in the eastern part of the

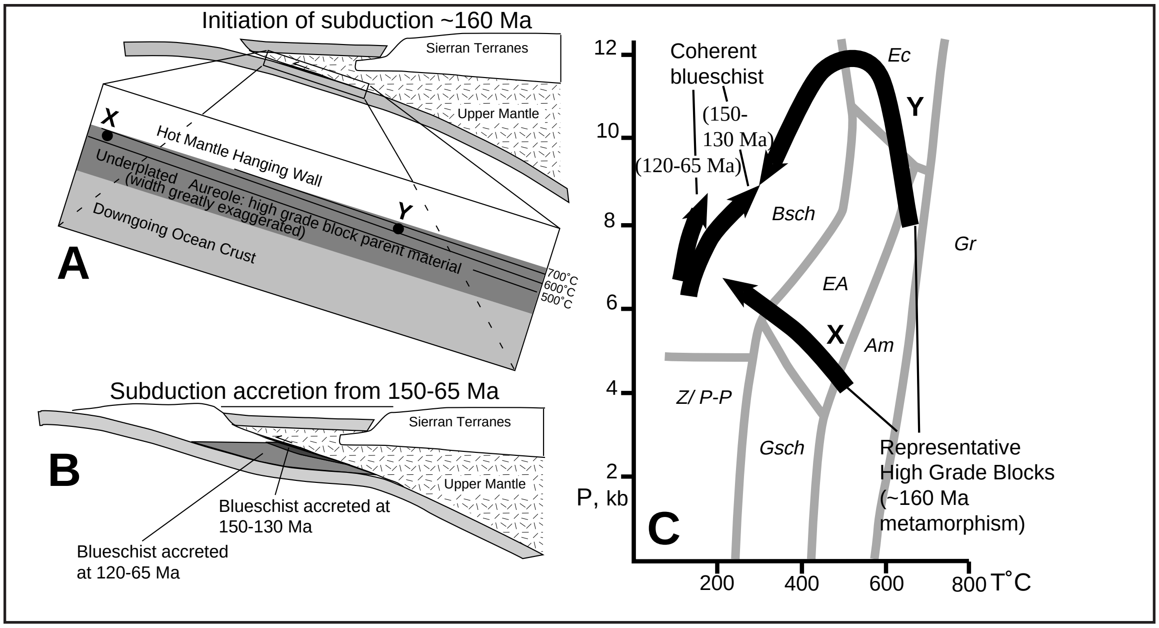


Figure 3. Pressure-temperature (*P*, *T*) paths of Franciscan metamorphism and schematic cartoons showing the tectonic setting of metamorphism. Letters X and Y in A correspond to locations of the similarly labeled *P-T* paths for high-grade blocks shown in C. *P-T* paths X and Y are from Wakabayashi (1990);150–130 Ma *P-T* path is from Maruyama and Liou (1988), and 120–65 Ma *P-T* path is from Maruyama et al., (1985). Tectonic setting diagram is modified from Wakabayashi (1992). Metamorphic facies abbreviations: Am, amphibolite; Bsch, blueschist; Ec, eclogite; EA, epidote amphibolite; Gr, granulite; Gsch, greenschist; Z/P-P, zeolite and prehnite-pumpellyite; Am, amphibolite.

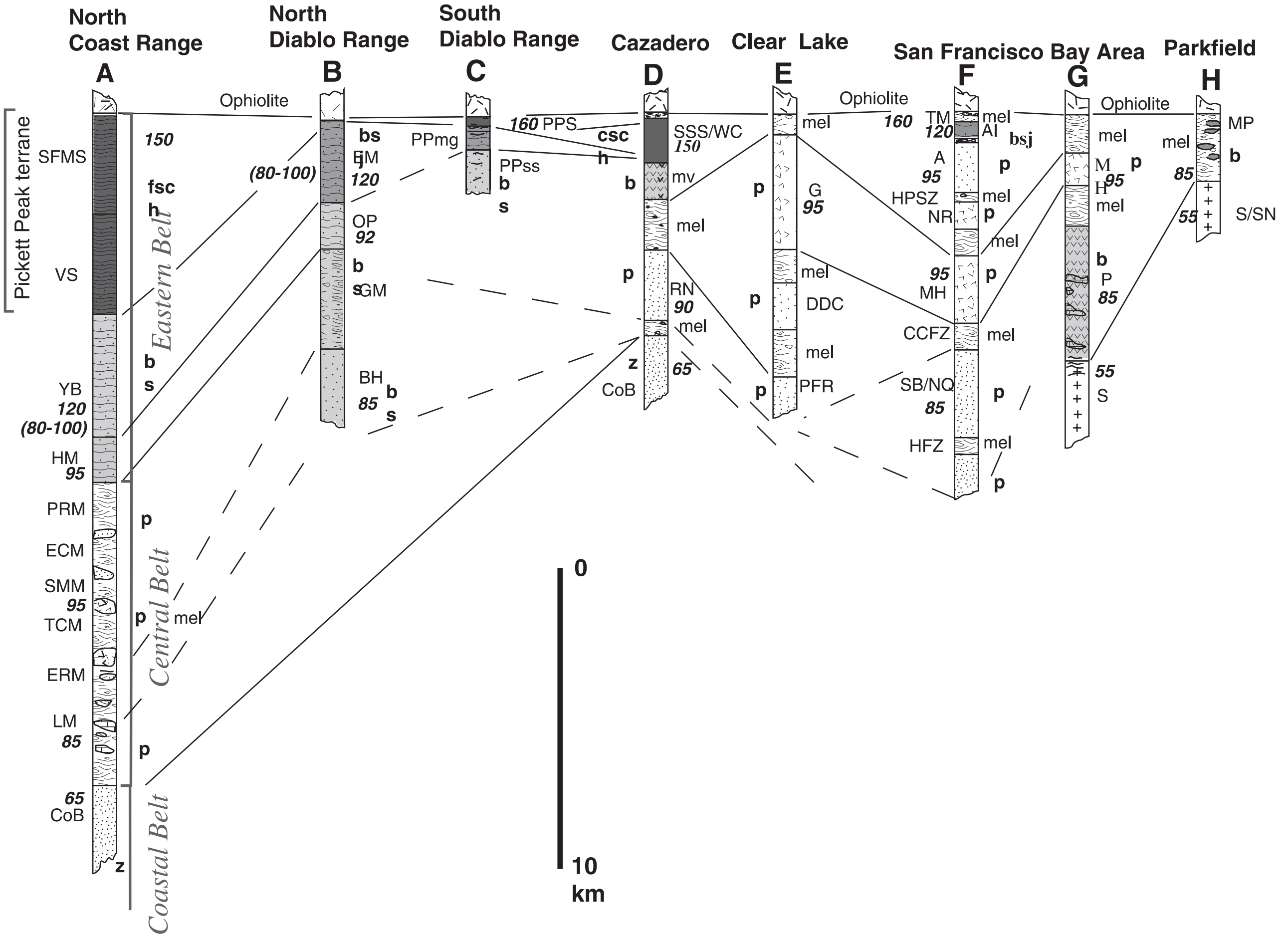
Franciscan in the northern Coast Ranges (Blake, 1967; Suppe, 1973; Worrall, 1981) and the Diablo Range (Cowan, 1974; Page, 1981). Suppe (1978) interpreted low-angle structures across the entire northern Coast Ranges; ultramafic rocks were interpreted as Coast Range ophiolite or klippen thereof. Blake et al. (1984) characterized the coherent units and melanges of the San Francisco Bay region as a set of gently folded thrust nappes, with discrete melange zones separating the coherent sheets. Wahrhaftig (1984) documented internal imbrication within a coherent nappe. Wakabayashi (1992) extended the nappe characterization to the entire Franciscan Complex (Fig. 4), related nappe emplacement to orogenic processes within the Franciscan and the Cordillera, and developed criteria for distinguishing Franciscan from post-Franciscan structures, on the basis of the progressive down-structure decrease in the times at which nappes were incorporated. Ultramafic rocks recently have been interpreted as both remnants of Coast Range ophiolite (structurally above the Franciscan Complex), and units structurally interleaved within the Franciscan (Blake et al., 1984; Wakabayashi, 1992; Coleman, 1996).

The Franciscan Complex exhibits considerable along-strike variation, even if dextral faulting associated with the San Andreas transform system is restored (Wakabayashi, 1992) (Figs. 1 and 2). This variation may be expected in subduction complexes, because offscraped elements, such as packets of trench and pelagic sediment and seamounts, would not be expected to extend the full length of the trench. Along-strike variation makes the "Coastal Belt, Central Belt, Eastern Belt" subdivision of the Franciscan Complex, in common usage since its introduction by Berkland et al. (1972), difficult to apply south of the northern Coast Ranges.

Geochronology

Analysis of tectonics relies heavily on geochronologic data. Many of the key geochronologic studies in the Franciscan Complex have been conducted since 1970. Geochronologic data from the Franciscan are summarized in Figure 5.

Initial data from sparse macrofossils in clastic sedimentary rocks (e.g., Bailey et al., 1964) have been supplemented by microfossil data from cherts and limestones (Sliter, 1984; Murchey and Jones, 1984). Detailed biostratigraphy from cherts demonstrated that what were once thought to be chert interbeds with basalt or graywacke were instead a consequence of structural imbrication (Murchey, 1984; Isozaki and Blake, 1994). Although clastic rocks of the Franciscan Complex are coeval with the forearc basin strata of the Great Valley Group (ca. 150 Ma and younger; Bailey et al., 1964; Blake et al., 1988), some oceanic rocks are older, such as cherts in the Marin Headlands and Yolla Bolly terranes (175–195 Ma; Murchey, 1984; Isozaki and Blake, 1994). This reflects the far-traveled nature of oceanic and/or pelagic rocks incorporated into the Franciscan Complex (e.g., Hamilton, 1969).



Abbreviations: Column A: SFMS—South Fork Mountain schist, VS—Valentine Springs formation, YB—Yolla Bolly terrane, HM—Hull Mtn. metagreywacke; PRM—Poison Rocks melange, ECM—Elk Creek melange, SMM—Sanhedrin Mtn. melange; TCM—Tin Cabin melange, ERM—Eel River melange, LM—Laytonville melange, CoB—Coastal Belt; **Column B:** EM—Eylar Mountain terrane, OP—Ortigalita Peak metagreywacke; GM—Garzas melange; BH—Burnt Hills terrane; **Column C:** PPS—Panoche Pass blueschist, PPmg—Panoche Pass jadeite-bearing metagreywacke, PPss—Panoche Pass jadeite-free metagreywacke; **Column D:** SSS/WC—Skaggs Springs schist and coherent schists of Ward Creek, mv—metavolcanics, incipient blueschist, RN—Rio Nido terrane, CoB—Coastal Belt; **Column E:** G—Geysers terrane, DDC—Devil's Den Canyon terrane, PFR—Pine Flat Road terrane; **Column F:** TM—Tiburon melange, AI—Angel Island nappe, A—Alcatraz terrane, HPSZ—Hunters Point shear zone, NR—Nicasio Reservoir terrane, MH—Marin Headlands terrane, CCFZ—City College fault zone, SB/NQ—San Bruno Mtn./Novato Quarry terranes, HFZ—Hillside fault zone; **Column G:** MH—Marin Headlands terrane, P—Permanente terrane, S—Salinia; **Column H:** S/SN—Salinia/Sierra Nevada, MP—Melange with blocks of Permanente terrane. **For all columns: b**—incipient blueschist metamorphism of mostly volcanic rocks, **z—**zeolite facies; **p—**prehnite pumpellyite facies, **bs—**blueschist metamorphism-jadeite absent or rare, **bsj**—same as **bs** except jadeite common, **fsch—**fine grained schists (completely recrystallized), **csch—**coarse grained schists (completely recrystallized), mel: major melange zone. ***120*** — estimated age of accretion, ***(80-100)***—age of exhumation (from Tagami and Dumitru, 1996).

Figure 4. Correlation of Franciscan Complex units as thrust nappes to relative structural position and estimated accretion ages. Blueschist facies units are shaded. Column locations are keyed to Figure 1. All contacts are tectonic; the incorporation age (not depositional age) decreases downward. Scale is approximate. Figure is modified from depository supplement of Wakabayashi (1992); additional data are from P. Renne, T. Dumitru and J. Wakabayashi.

Numerous isotopic dating studies conducted in the Franciscan Complex since 1970 (Coleman and Lanphere, 1971; Suppe and Armstrong, 1972; Lanphere et al., 1978; Mattinson and Echeverria, 1980; McDowell et al., 1984; Mattinson, 1986; Ross and Sharp, 1988) have greatly expanded the preexisting database (e.g., Lee et al., 1964; Peterman et al., 1967). Only metamorphic rocks of blueschist grade or higher, and rare intrusive rocks, have yielded dates. Because of the different methods employed, with different precision and accuracy, and because of the different closure temperatures of isotopic systems, many dates cannot be directly compared (Wakabayashi, 1992). Ages span a continuous range, but the precision of the dating techniques is not sufficient to indicate that they record a continuous or episodic metamorphism. The oldest metamorphic ages, 159–163 Ma (Ross and Sharp, 1986, 1988), have been interpreted to date approximately the inception of subduction (Wakabayashi, 1990). The youngest metamorphic ages obtained are 80–90 Ma (Suppe and Armstrong, 1972; Mattinson and Echeverria, 1980).

Fission-track data indicate that the structurally higher parts of the Franciscan Complex cooled from ~300 to ~100 °C, coinciding with the major exhumation of these high *P-T* rocks from depths of ~30 to ~10 km, from 100 to 70 Ma (Tagami and Dumitru, 1996). Many Franciscan rocks cooled below 90 °C, at 20 to 40 Ma (Dumitru, 1989) .

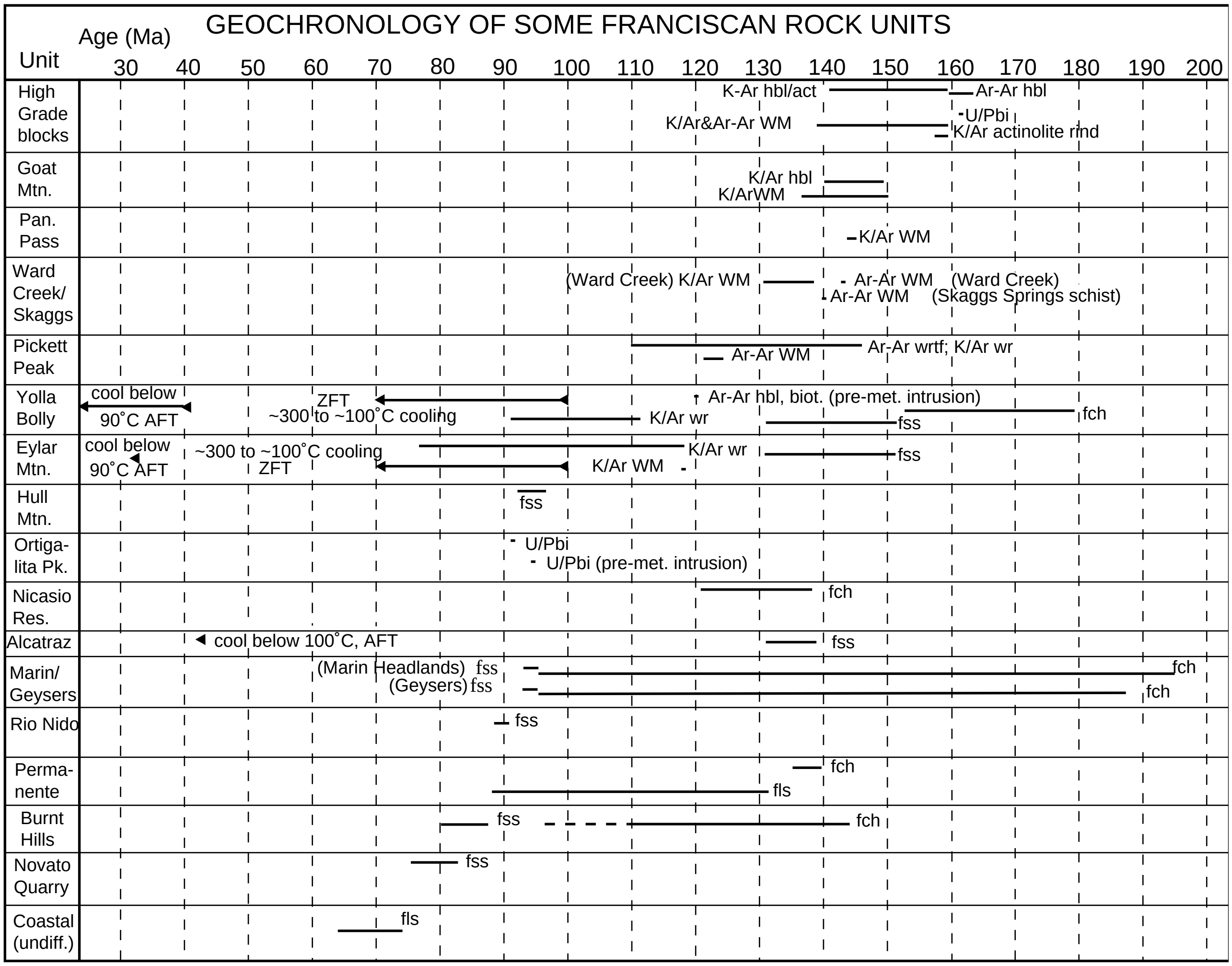


Figure 5. Geochronology of some Franciscan units. Blueschist and higher grade units are in bold. Abbreviations: AFT—apatite fission track; Ar-Ar—^{40}Ar/^{39}Ar step heating, except wrtf—whole-rock total fusion; fch—fossils from chert; fls—fossils from limestone; fss—fossils from clastic rocks; K/Ar—potassium-argon; U/Pbi—U/Pb isochron method, ZFT—zircon fission track. Mineral abbreviations: act—actinolite, biot—biotite, hbl—hornblende, WM—white mica; wr—whole rock. Sources: Lee et al. (1964), Coleman and Lanphere (1971), Suppe and Armstrong (1972), Lanphere et al. (1978), Suppe and Foland (1978); Mattinson and Echeverria (1980); McDowell et al. (1984); Mattinson (1986); Ross and Sharp (1988); Dumitru (1989); Wakabayashi and Deino (1989); Tagami and Dumitru (1996); Weinrich (1997). Older K/Ar dates recalculated using decay constants of Steiger and Jäger (1977).

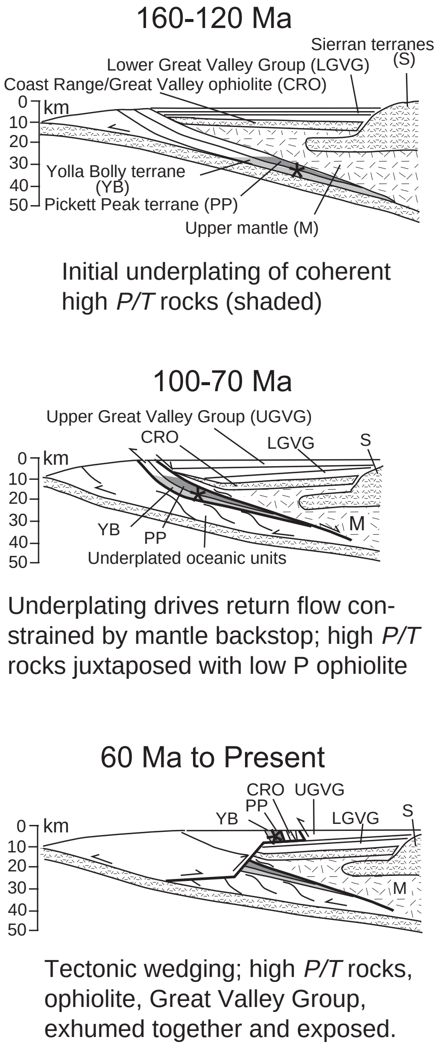


Figure 6. Cartoons illustrating exhumation of high pressure-temperature (*P-T*) rocks in the Franciscan. Asterisk marks position of high *P-T* rocks exposed today. Modified from Wakabayashi and Unruh (1995).

CONTROVERSIES AND UNSOLVED PROBLEMS

Some issues fundamental to the history of the Franciscan Complex, and to convergent plate margin tectonics in general, have not been resolved. Still others have not been addressed in a major way. Two major issues are discussed in the following.

To strike slip or not to strike slip

Plate tectonics theory predicts that pelagic sediments and oceanic volcanic rocks are transported long distances on the oceanic plate as it moves toward the subduction zone. In the Franciscan Complex, paleomagnetic studies of basalts and limestones have indicated southerly latitudes of deposition (e.g., Alvarez et al., 1980; Tarduno et al., 1985), and plate convergence was oblique during much of Franciscan history (Engebretson et al., 1985). However, the presence or absence of large-scale (thousands of kilometers of displacement) strike-slip faults passing through the Franciscan Complex is a subject of debate. Data from conglomerates have been alternatively interpreted to indicate negligible or large synsubduction strike-slip displacement between coeval rocks of the Franciscan and Great Valley Group (e.g., Seiders and Blome, 1988; Jayko and Blake, 1993; respectively). Some researchers have interpreted up to thousands of kilometers of strike-slip faulting within the Franciscan Complex (e.g., McLaughlin et al., 1988; Jayko and Blake, 1993), only a few hundred kilometers of which are attributed to the San Andreas transform fault system, which postdated the Franciscan Complex (e.g., Graham et al., 1989). I (Wakabayashi, 1992) suggested that Franciscan nappe structures were incompatible with major synsubduction strike-slip faulting in any part of the Franciscan Complex accreted prior to 80 Ma, and that most synsubduction strike-slip faulting was partitioned in the vicinity of the Sierra Nevada arc, similar to the position of such faulting in modern obliquely convergent plate margins (e.g., Fitch, 1972; Beck, 1983). The assumption of 100% partitioning of the strike-slip component of oblique subduction into strike-slip faulting has been adopted in some analyses of strike-slip faulting within the Franciscan Complex (e.g., McLaughlin et al., 1988; Jayko and Blake, 1993), but partitioning of the tangential component of active oblique subduction into strike-slip faulting varies from 0% to 100%, depending on the subduction zone (McCaffrey, 1992). Wakabayashi and Hengesh (1995) suggested that the total offset of Franciscan nappes across faults in the central Coast Ranges was identical to the late Cenozoic (transform) fault offsets in that region, indicating negligible synsubduction strike-slip faulting of the Franciscan Complex east of the Salinian block. Synsubduction offset of ~200 km is permissible on the Salinian-Franciscan contact (the proto San Andreas of Page, 1981); additional synsubduction dextral faulting may be permissible west of the Salinian block (e.g., Sedlock and Hamilton, 1991). Better estimates of synsubduction strike-slip faulting within the Franciscan Complex will illuminate processes of obliquely convergent plate margins and may test various models of large-scale latitudinal terrane translation in the Cordillera, such as the Baja British Columbia controversy (e.g., Cowan et al., 1997).

What went down came up: Exhumation of blueschists and other high **P-T** *rocks*

As the type subduction complex, the Franciscan Complex has become a testing ground for models of the exhumation of high *P-T* rocks. Many mechanisms can account for the exhumation of high-grade blocks in melanges, including melange return flow and shale diapirism (e.g., Cloos, 1982), or serpentinite diapirism (Carlson, 1981). Coherent high *P-T* metamorphic rocks present a more difficult problem because they are not thought to be as mobile as blocks in melanges; this problem is reviewed here. The critical part of the exhumation (hereafter called the critical path) is the rise of the high *P-T* rocks from depth (25 km or more) to the same crustal level as the ophiolite and Great Valley Group rocks that are now in contact with them, a difference in burial depth of 15 km or more; exhumation of the shallowly buried ophiolite and Great Valley Group is considered trivial.

Ernst (1970) proposed that high *P-T* rocks were less dense than the mantle they were subducted into and had to rise buoyantly back to the Earth's surface. Platt (1986) dismissed this model, noting that the high *P-T* rocks are more dense than the rocks that are currently found in contact with them. However, while traversing the critical path, the high *P-T* rocks may have been beneath mantle and therefore positively buoyant (Fig. 6). Platt (1986), noting that nearly unmetamorphosed ophiolite tectonically overlies deeply buried Franciscan Complex rocks, concluded that the high *P-T* rocks were exhumed by normal faulting associated with synsubduction extension. Ring and Brandon (1994) advocated exhumation by thrust faulting on the basis of brittle structures along the Franciscan-ophiolite contact. Wakabayashi and Unruh (1995) suggested that late Cenozoic (and active) thrust faulting on the ophiolite–Franciscan Complex contact obliterated earlier kinematic indicators, and that the critical path took place from 100 to 70 Ma, consistent with not only fission-track data of Tagami and Dumitru (1996), but also age constraints on normal slip on the ophiolite–Franciscan Complex contact.

The presence of high *P-T* rocks structurally above lower *P* metamorphic rocks (Figs. 2, 4, and 6) may not be well explained by the Platt (1986) model and is a common feature of many of the world's high *P-T* belts (Maruyama et al., 1996). These structures suggest that the high *P-T* rocks rose relative to their hanging wall *and* footwall, an extrusion-like process (Maruyama et al., 1996) (Fig. 6). If the faults bounding the high *P-T* rocks were coeval, the material flow pattern in the subduction complex was similar to that of corner flow (e.g., Cowan and Silling, 1978; Cloos, 1982; Pavlis and Bruhn, 1983), and exhumation may have been driven by large-scale underplating of oceanic terranes from 100 to 70 Ma (Ernst, 1971; Wakabayashi and Unruh, 1995) (Fig. 6). However, the timing of movement on the faults bounding the high *P-T* rocks has not been constrained with sufficient precision to determine whether movement on them was indeed coeval. Return flow in the accretionary prisms may be influenced by the shape of the backstop of the subduction complex, greater strength of the backstop (presumably mantle, see Fig. 6) compared to accreted materials, and lower density of the high *P-T* rocks relative to the mantle (e.g., Mancktelow, 1995).

Further detailed structural, geophysical, and geochronologic studies in the Franciscan Complex can help refine and test exhumation models for high *P-T* rocks.

CONCLUDING STATEMENT

In connecting high *P-T* metamorphism with subduction, Ernst (1970) made a key breakthrough in plate tectonics and helped make the Franciscan Complex one of the most famous rock units in the world. Nearly 30 years later, the Franciscan still poses fundamental problems, the resolution of which promise to advance our understanding of subduction complex processes significantly. It will be interesting to see what the next 30 years of research in the Franciscan Complex will yield.

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