Fragment of the Coast Range ophiolite and the Great Valley sequence in the San Juan Islands, Washington

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ABSTRACT

The Decatur terrane is a small, allochthonous fragment of Upper Jurassic oceanic crust with an overlying blanket of Upper Jurassic–Lower Cretaceous sedimentary rocks in the San Juan Islands. The stratigraphy and petrotectonic elements are dissimilar to those of coeval sequences in the Pacific Northwest (Oregon, Washington, and southern British Columbia), but are virtually identical to those of the Coast Range ophiolite and overlying Great Valley sequence *south* of San Francisco, California. This stratigraphic correlation, together with regional considerations, suggests that the Decatur terrane was detached and transported during Cretaceous time. The resultant displacement is in excess of 1000 km.

INTRODUCTION

The movement of terranes along the western margin of North America has recently been regarded as an important aspect of Cordilleran development (Coney et al., 1980; Beck, 1986). Paleomagnetic signatures and exotic faunal assemblages are typically used to determine whether a particular terrane has undergone substantial lateral transport. In this paper I propose a lithostratigraphic correlation of a small terrane in northwest Washington State to rocks that are currently in Calfornia (Figs. 1 and 2). This correlation suggests that some Upper Jurassic–Lower Cretaceous rocks have undergone substantial northward translation, part of which may have occurred during Early Cretaceous time and part (or all) of which must have occurred in Late Cretaceous time.

The San Juan Islands comprise a diverse assemblage of Paleozoic and Mesozoic terranes that were amalgamated in a middle Cretaceous (ca. 90–100 Ma) regional collisional event in which Wrangellia impinged against the North American margin (Brandon et al., 1988). During collision, various disparate crustal elements, or "miniterranes," were imbricated in the San Juan Island–North Cascade thrust system (Brandon et al., 1988); many elements within this system have no homeland in the surrounding region. Recent paleomagnetic analyses (Irving et al., 1985) indicate that Cretaceous plutons intruding the North Cascades part of the thrust system have been displaced over 2000 km northward since middle Cretaceous time. Many workers (Brandon et al., 1988; Garver, 1988) infer that the San Juan thrust system was continuous with the North Cascades thrusts.

Recently, workers have recognized that numerous coeval Jurassic-Cretaceous clastic units in the Pacific Northwest have dissimilar paleotectonic histories but were juxtaposed in the middle Cretaceous San Juan–North Cascades thrust system immediately after their deposition (Brandon et al., 1988; Garver, 1988). Cowan and Brandon (1981) first noted the general similarity of several Jurassic-Cretaceous clastic sequences in southern British Columbia and Washington State to those in California. This paper compares the stratigraphy of the Decatur terrane to the stratigraphy of coeval sequences in California and in the Pacific Northwest and examines the implications of such a correlation.

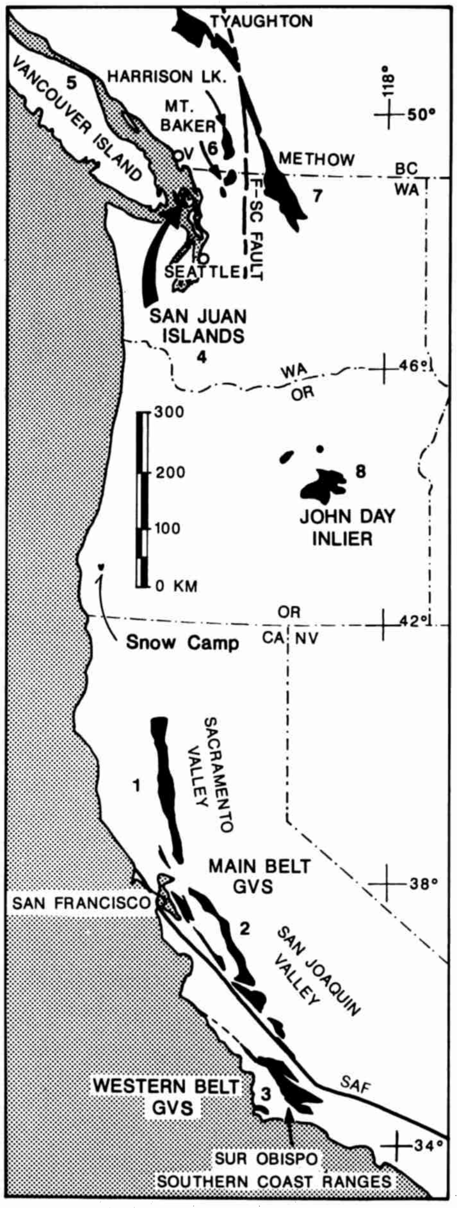

Figure 1. Locality map of Coast Range ophiolite (CRO) and Great Valley sequence (GVS) localities discussed in this paper. Main belt refers to virtually continuous outcrop belt that parallels west side of Sacramento and San Joaquin valleys and occurs entirely east of San Andreas fault (SAF). Western belt CRO/GVS refers to those exposures that occur adjacent to Sur-Nacimiento fault in southern Coast Ranges. Decatur terrane in San Juan Islands of northwest Washington State is probably fragment of CRO/GVS that has been displaced northward. Numbers 1–8 refer to generalized stratigraphic sections shown in Figure 2.

FIDALGO COMPLEX AND THE COAST RANGE OPHIOLITE

Fidalgo Complex

The Fidalgo Complex comprises a Middle to Upper Jurassic ophiolitic sequence, an Upper Jurassic arc-related volcanic-plutonic suite, and coeval volcaniclastic and pelagic sedimentary rocks (Gusey, 1978; Brown et al., 1979; Brandon et al., 1988; Garver, 1988). The dismembered sequence includes serpentinized harzburgite, clinopyroxenite, layered gabbro, pillow basalts, and interbedded chert. K/Ar ages on the layered gabbro provide *minimum* ages of 162 and 152 Ma (Brandon et al., 1988). The chert contains radiolarians ranging in age from Callovian to Oxfordian (Garver, 1988).

The younger igneous suite contains tonalite, minor diorite, and quartz diorite that crosscut the older ophiolitic suite (Brown et al., 1979; Brandon et al., 1988). Associated with these volcanic and plutonic rocks are unknown thicknesses of volcaniclastic sandstone, tuffaceous argillite, and chert. Radiolarians within the chert are late Kimmeridgian to early Tithonian (Brandon et al., 1988; Garver, 1988). Nearly concordant U/Pb ages on zircon from the igneous rocks are 170 to 160 Ma (Brandon et al., 1988). Geochemical data and lithologic associations suggest an island-arc origin for these rocks, and they are interpreted to represent a magmatic event separate from the older ophiolitic suite (Brown et al., 1979; Brandon et al., 1988).

Coast Range Ophiolite

The Coast Range ophiolite (CRO) is stratigraphically below the Main belt of the Great Valley sequence (GVS) (Fig. 1; west side of the Sacramento and San Joaquin valleys). Coeval and similar ophiolitic fragments are stratigraphically below GVS-like rocks in the southern Coast Ranges of California west of the San Andreas fault; these rocks are herein referred to as

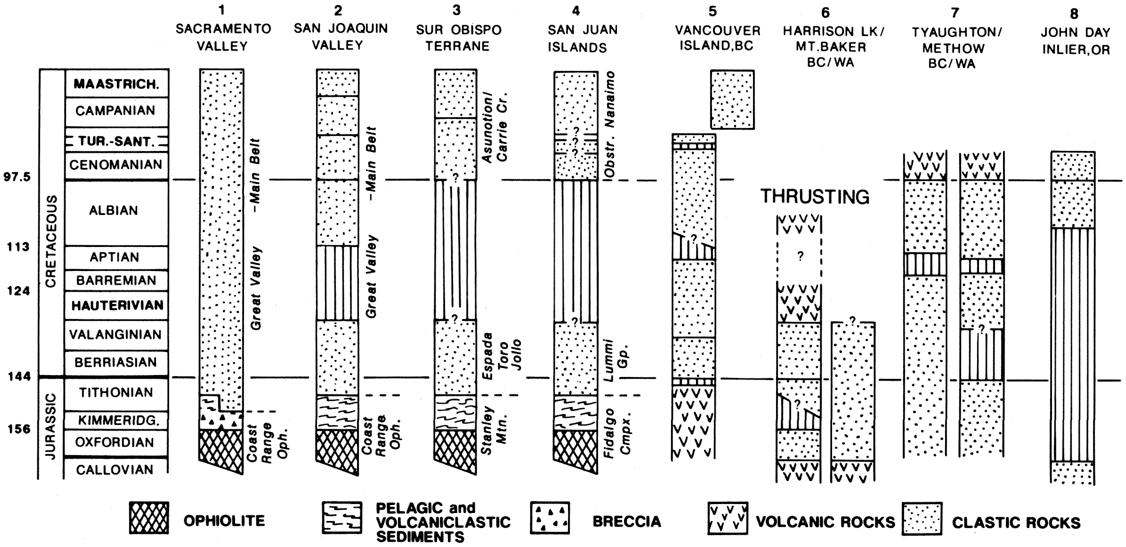

Figure 2. Generalized stratigraphic elements of Coast Range ophiolite and overlying sediments of Great Valley sequence (1–3), Decatur terrane in San Juan Islands (4), and other sequences in Pacific Northwest (5–8). Ruled areas represent unconformity or probable unconformity. Numbered localities shown in Figure 1. Thrusting is thought to have imbricated elements between Vancouver Island and the Tyaughton/Methow in middle Cretaceous and has affected stratigraphy accordingly. Stratigraphic information for columns: 1—Popenoe et al. (1960) and Ingersoll (1983); 2—Popenoe et al. (1960) and Ingersoll (1983); 3—Popenoe et al. (1960), Page (1972, 1981), Howell et al. (1977), Mackinnon (1978), and Vedder et al. (1983); 4—Garver (1988); 5—Pacht (1984); 6—Misch (1966) and Arthur (1986); 7—Jeletzky and Tipper (1968), Coates (1974), Barksdale (1975), and Glover et al. (1988); 8—Dickinson and Thayer (1978).

the Western belt CRO/GVS (Fig. 1). Most of the exposed sequences of Coast Range ophiolite are dismembered, but a general stratigraphy includes (1) harzburgite tectonite; (2) dunite, clinopyroxenite, and gabbro cumulates, and high-level gabbro, diorite, and plagiogranite; (3) sheeted dike complex; (4) pillow lavas and breccias; and (5) cherts, tuffaceous cherts, and volcaniclastic strata (Hopson et al., 1981). Radiolarians from interbedded sediments within the pillow basalts are pre-Oxfordian to Oxfordian in age. These fossil ages are in agreement with U/Pb radiometric ages on the igneous rocks which range between 153 and 165 Ma (Hopson et al., 1981).

The origin of and relations among the various Coast Range ophiolite fragments are controversial. The Coast Range ophiolite has been interpreted to have formed in a mid-ocean ridge setting (Page, 1972; Hopson et al., 1981) or in an arc-proximal setting (Evarts, 1977; Blake and Jones, 1981; Shervais and Kimbrough, 1985; Lagabrielle et al., 1986; Shervais, 1988). The presence of interbedded andesitic and dacitic volcaniclastic strata, which overlie the Coast Range ophiolite at Llanada and Del Puerto (Main belt), supports this interpretation.

South of San Francisco, pelagic and volcaniclastic strata at the stratigraphically highest level of the Coast Range ophiolite are Oxfordian to lower Tithonian. Several exposures in the northern part of the Main belt are not as young, on the basis of the age of the overlying GVS (Fig. 2; Hopson et al., 1981).

The Fidalgo Complex and parts of the Coast Range ophiolite *south* of San Francisco are virtually identical in terms of lithologies, petrotectonic assemblages, and age of stratigraphic units; north of San Francisco there are significant differences. Important similarities include (1) ultramafic and basaltic elements that are Oxfordian and older, (2) intrusive arc-related volcanic rocks, and (3) Oxfordian to Tithonian pelagic rocks and volcaniclastic strata. In Washington, southwest Oregon, and California, the overlying basal terrigenous strata are dated by the late Tithonian bivalve *Buchia piochii*.

LUMMI GROUP, GREAT VALLEY SEQUENCE, AND UPPER CRETACEOUS ROCKS

Lummi Group

The Fidalgo Complex of Washington is overlain by the Lummi Group, a sequence of terrigenous strata probably over 1000 m thick, comprising sandstone, mudstone, and conglomerate, all of which were deposited on submarine fans (Carroll, 1980; Garver, 1988). The strata are predominantly chert-rich volcaniclastic sandstones that have a distally derived, volcanic-rich component and a more proximally derived ophiolitic source (Garver, 1988). In addition, coarse conglomerates with ophiolitic debris suggest sedimentation during disruption of the underlying Fidalgo Complex. Basal beds contain the late Tithonian bivalve *Buchia piochii*. A tectonized mudstone, which may belong to the Lummi Group, lies within a complex fault zone and contains the Valanginian bivalve *Buchia pacifica* (Brandon et al., 1988).

Basal Great Valley Sequence

South of the San Francisco Bay area, the basal terrigenous rocks of the GVS, which overlie the Coast Range ophiolite in the Main belt and the Western belt, contain the late Tithonian bivalve *Buchia piochii*. The basal rocks from several localities in the northern part of the Main belt are slightly older (Fig. 2; Hopson et al., 1981, and references therein). Basal GVS strata were deposited in submarine fans that appear to have sources in the Klamath Mountains and the Sierra Nevada (Ingersoll, 1983; Suchecki, 1984).

The petrography of these sedimentary rocks reflects contemporaneous volcanism that was superimposed on accreted terranes east and north of the Great Valley forearc basin (Ingersoll, 1983). The composition of the lower GVS (Stony Creek petrofacies–Main belt) compares closely with the basal strata in the Western belt, which have been described by MacKinnon (1978).

The Lower Cretaceous stratigraphy of the GVS differs from north to south. The northern part of the Main belt has a rather complete section, uninterrupted by major unconformities. Both the southern part of the Main belt and the Western belt GVS have a fragmentary Lower Cretaceous stratigraphic record (Fig. 2) that is marked by a prominent post-Valanginian unconformity, which is locally angular (Popenoe et al., 1960; Howell et al., 1977; Vedder et al., 1983).

In sum, the age and depositional setting of the Lummi Group and the lower parts of the GVS are similar. The volcanic-lithic rich Lummi Group strata are compositionally similar to both the Main and Western belts, although the polycrystalline quartz content is higher in the Lummi Group and the proportion of volcanic lithics is lower. However, the Stony Creek petrofacies is the most variable of any petrofacies recognized in the GVS (Ingersoll, 1983). A probable Lower Cretaceous unconformity both in the Lummi Group and in the GVS south of San Francisco is particularly important when considering regional correlation. Stratigraphic parallels between the GVS and the Lummi Group end in the Lower Cretaceous.

DECATUR TERRANE VS. COEVAL PACIFIC NORTHWEST SEQUENCES

On the basis of the lithostratigraphy of individual units, there are no coeval sequences similar to the Decatur terrane from central Oregon to southern British Columbia (Fig. 2). Stratigraphically complete sequences that are coeval with the Decatur terrane are present in long linear belts in the Methow-Tyaughton basin of Washington and British Columbia (Fig. 1). These belts are a product of forearc-basin sedimentation along the margin of North America followed by collisional basin sedimentation in the middle Cretaceous (Cole, 1973). The petrography, depositional setting, and basement of these units are fundamentally different from those of the Lummi Group (Fig. 2). Another coeval sequence in the Pacific Northwest distinct from the Decatur terrane is the Nooksack Group in the Mount Baker window of the North Cascades thrust system, and there are probable correlatives at Harrison Lake, British Columbia (Fig. 2; Misch, 1966; Arthur, 1986; Garver, 1988). The Nooksack Group and equivalents lack chert detritus and sit on Middle Jurassic volcanic and clastic rocks. Sequences with pelagic sediments resting upon an ophiolite are not part of any of the coherent stratigraphic sequences in the Pacific Northwest. Differences in the composition of clastic sediments and depositional environments (Garver, 1988) preclude the possibility that the Lummi Group is simply a distal equivalent of other coeval sequences in Washington or British Columbia. In southwest Oregon, the Snow Camp terrane (Fig. 1) is similar to the Decatur terrane and the GVS/CRO, but it is inferred to be allochthonous as well (Blake et al., 1985).

IMPLICATIONS

We may interpret the presence of a terrane in the Pacific Northwest with a stratigraphy virtually identical to a linear belt of rocks in California in one of the following ways: (1) the linear belt of CRO/GVS extended as far north as northwest Washington State; (2) the Decatur terrane represents a displaced fragment from the southern part of this linear belt; or (3) the Decatur terrane formed in a *similar tectonic setting* to that of the GVS/CRO, but not necessarily in the same belt that was continuous with the GVS/CRO (Fig. 3, options 1–3).

If one accepts the first possibility, one must ignore differences in tectonic settings recorded in the Methow-Tyaughton basin, which has quite a different history, as outlined above. In addition, acceptance of the first possibility requires the wholesale abandonment of many paleomagnetic studies in the Cordillera. I consider this first alternative to be highly unlikely.

In order to evaluate the second and third options, a review of the geologic setting of the San Juan Islands is required. The San Juan–North Cascade thrust system contains Jurassic-Cretaceous elements that must have been fragmented and assembled prior to thrusting, because these Jurassic-Cretaceous units represent a wide range of coeval petrotectonic assemblages. In the San Juan Islands the thrust system includes rocks as young as Albian, and a provenance link suggests that deformation was complete by the Santonian. Syncollisional basin infilling is recorded in the Albian-Cenomanian parts of the Methow-Tyaughton stratigraphy (Cole, 1973; Glover et al., 1988). The thrust system, which includes the Decatur terrane, is intruded (in the North Cascades, not in the San Juan Islands as mentioned above) by coincident middle Cretaceous plutons (ca. 90 to 100 Ma) with low-latitude paleomagnetic signatures (Irving et al., 1985); this implies that thrusting occurred at these low latitudes. The thrust system is only part of a larger block, known as Baja British Columbia (Baja B.C.), which was apparently transported northward about 2400 km during the Late Cretaceous on the Kula plate to about its present position (Umhoefer, 1987). What relation did the Decatur terrane and other terranes in the Pacific Northwest have to Baja B.C., and to California during their formation, and when did these terranes become appended to Baja B.C.?

Other workers have suggested parallels between units in the Pacific Northwest and those of California. Specifically, Brown and Blake (1987) correlated the Shuksan metamorphic suite (North Cascades and southern British Columbia) to blueschist terranes in southern Oregon and northern California. These workers favor a model in which the Shuksan was formed with units in California in the Early Cretaceous and was later transported during the Late Cretaceous to the Pacific Northwest. However, these California-derived elements were involved in the middle Cretaceous thrust system and therefore must have partially moved prior to thrusting. The stratigraphy of the Decatur terrane is uninterrupted until the Hauterivian-Aptian, when there is no record of deposition; after this time the Decatur terrane was involved in the thrust system. During Hauterivian-Aptian time, the Decatur terrane and possibly the Shuksan metamorphic suite may have been laterally displaced and subsequently incorporated into the San Juan–North Cascade (SJ-NC) thrust system; the amount of displacement during this time is unknown. After thrusting, Late Cretaceous dextral strike-slip faulting moved the *entire system* northward.

In light of the foregoing discussion, options 2 and 3 (Fig. 3) may be examined. The SJ–NC thrust system is at the southern end of Baja B.C. (Umhoefer, 1987), which restores to a position south of California in the middle Cretaceous (Fig. 3). This possible reconstruction implies that the Early Cretaceous strike-slip movement of the Decatur terrane may have been *sinistral* if the Decatur terrane was formed at the southern end of the present CRO/GVS outcrop belt in California (option 2, Fig. 3). Alternatively, a similar tectonic setting of the GVS/CRO and Franciscan (i.e., forearc and accretionary prism) might have existed at very low paleolatitudes. *Dextral* translation might have attached these fragments to the southern end of Baja B.C., and they subsequently moved northward in the Late Cretaceous (Umhoefer, 1987). This alternative hypothesis (option 3, Fig. 4) is consistent with paleomagnetic data from the Decatur terrane (Bogue et al., 1985) and from basement elements of the Western belt GVS/CRO (McWilliams and Howell, 1982; Hopson et al., 1986), both of which show very low paleolatitudes in Upper Jurassic rocks. Some localities in the southern Main belt (Llanada) also show very low paleolatitudes (Hopson et al., 1986), bring-

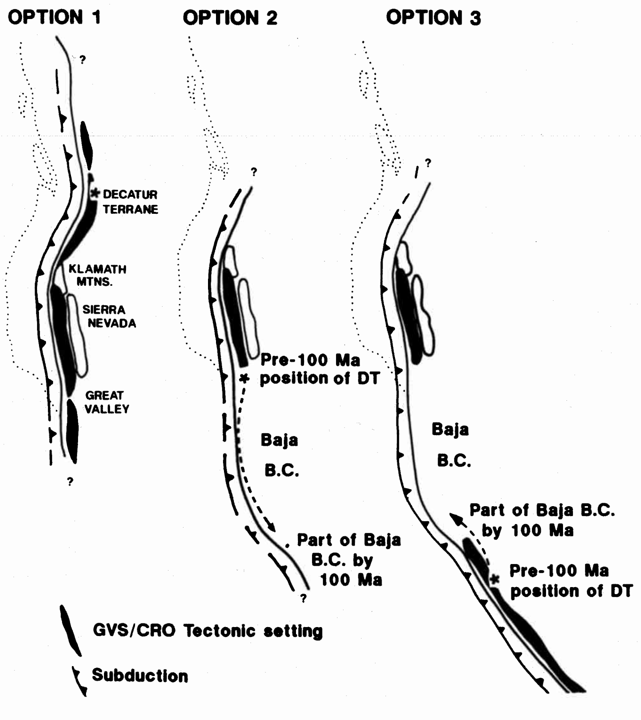

Figure 3. Options for origin of Upper Jurassic–Lower Cretaceous Great Valley sequence/Coast Range ophiolite-like terranes (Decatur terrane and Western belt GVS/CRO). 1: In place, no movement, GVS/CRO extends to Washington. 2: Detached from southern part of Main belt. 3: Similar tectonic setting to true GVS/CRO existed south of Baja B.C. Options 2 and 3 both require that Decatur terrane is attached to southern end of Baja B.C. by about 100 Ma. Adapted from Umhoefer (1987).

ing into question the autochthonous nature of the GVS and the significance of this sedimentary overlap that ties the CRO to the Klamath Mountains and the Sierra Nevada. An extreme view (not shown) might place *all* CRO fragments (Main belt, Western belt, and Decatur terrane) in a tectonic setting adjacent to the continental margin at very low latitudes; these fragments were subsequently dispersed along the North American margin at various times and for different distances. For example, the Western belt, west of the San Andreas fault, is still moving. However, until unequivocal paleomagnetic data are obtained from these GVS/CRO lookalikes, both options 2 and 3 (Fig. 3) remain viable alternatives for possible reconstructions of the Upper Jurassic–Lower Cretaceous margin of North America. The complexity of terrane movement inherent in both options 2 and 3 (Fig. 3) should serve as a warning to those who make simple paleogeographic reconstructions based solely on the present distribution of terranes in the Cordillera.

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