Eocene extension in Idaho generated massive sediment floods into the Franciscan trench and into the Tyee, Great Valley, and Green River basins

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ABSTRACT

The Franciscan Complex accretionary prism was assembled during an ~165-m.y.-long period of subduction of Pacific Ocean plates beneath the western margin of the North American plate. In such fossil subduction complexes, it is generally difficult to reconstruct details of the accretion of continent-derived sediments and to evaluate the factors that controlled accretion. New detrital zircon U-Pb ages indicate that much of the major Coastal belt subunit of the Franciscan Complex represents a massive, relatively brief, surge of near-trench deposition and accretion during Eocene time (ca. 53–49 Ma). Sediments were sourced mainly from the distant Idaho Batholith region rather than the nearby Sierra Nevada. Idaho detritus also fed the Great Valley forearc basin of California (ca. 53–37 Ma), the Tyee forearc basin of coastal Oregon (49 to ca. 36 Ma), and the greater Green River lake basin of Wyoming (50–47 Ma). Plutonism in the Idaho Batholith spanned 98–53 Ma in a contractional setting; it was abruptly superseded by major extension in the Bitterroot, Anaconda, Clearwater, and Priest River metamorphic core complexes (53–40 Ma) and by major volcanism in the Challis volcanic field (51–43 Ma). This extensional tectonism apparently deformed and uplifted a broad region, shedding voluminous sediments toward depocenters to the west and southeast. In the Franciscan Coastal belt, the major increase in sediment input apparently triggered a pulse of massive accretion, a pulse ultimately controlled by continental tectonism far within the interior of the North American plate, rather than by some tectonic event along the plate boundary itself.

INTRODUCTION

Underflow at the Franciscan subduction zone began ca. 165 Ma and continues today off northernmost California (United States). Over its prolonged history, this major subduction zone has consumed ~12,000 km of Pacific Ocean lithospheric plates and built the Sierra Nevada magmatic arc. Simultaneously, trench sediments and other materials have accreted to the margin of the North American plate, assembling the Franciscan accretionary prism (e.g., Ernst et al., 2009; Dumitru et al., 2010).

In fossil accretionary prisms, it is generally difficult to reconstruct source-to-sink links between specific sediment source areas and resulting bodies of accreted sediment. This paper describes a relatively brief, massive surge of Franciscan deposition and accretion in Eocene time. Sediments apparently were shed mainly from extension-related highlands in Idaho and Montana (Underwood and Bachman, 1986; Foster et al., 2007) that also fed large volumes of sediment to the Great Valley forearc basin in California, the Tyee forearc basin in coastal Oregon, and the greater Green River lake basin in Wyoming (Fig. 1; Heller et al., 1985, 1987; Chetel et al., 2011). The surge of deposition and accretion in the Franciscan is thus apparently an instructive example of a pulse of massive subduction accretion ultimately caused by continental tectonic activity far within the interior of an overriding plate, via a sediment supply link.

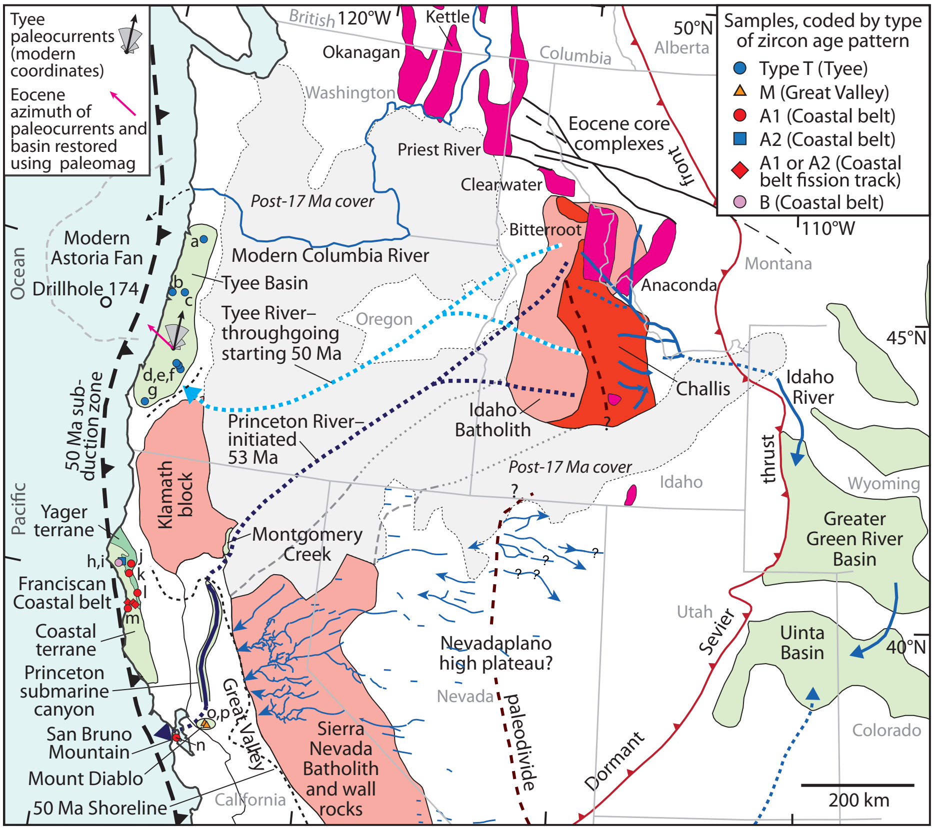

Figure 1. Map of western United States showing ca. 53–45 Ma sediment transport pathways, including major sediment source areas near core complexes, depocenters, paleovalleys, paleorivers, and submarine canyons. Cenozoic extension, translations, and rotations are not restored; Coastal belt probably translated north after accretion. Based mainly on Dickinson et al. (1979, 1988), Heller et al. (1985, 1987), Underwood and Bachman (1986), Foster et al. (2007), Chetel et al. (2011), Henry et al. (2012), Cassel et al. (2012), and our data.

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SETTINGS OF THREE EOCENE DEPOCENTERS

We present new detrital zircon U-Pb ages from Eocene sandstones that bear on the depositional ages and source areas of the Tyee, Franciscan Coastal belt, and Great Valley depocenters (Figs. 1 and 2). Table DR1 in the GSA Data Repository[1] compiles depositional age data and detrital muscovite contents for these areas.

In Oregon and Washington, accretion of Paleocene–Eocene oceanic basalts of the Siletz terrane to North America at 51 Ma caused the subduction zone to step westward, outboard of the accreted terrane (e.g., Wells et al., 2000). Tyee Formation strata were deposited across the suture onto the Siletz terrane in a new forearc basin system by north-directed (modern coordinates) flow (e.g., Heller et al., 1985; Ryu et al., 1996). Rapid deposition of 1.5–2 km of Tyee sediments occurred between 49.4 and 46.5 Ma. Most Tyee sandstones contain abundant detrital muscovite that has yielded multi-grain K-Ar ages of 66–68 Ma, evidence of sediment sources near the Idaho Batholith, which includes large areas of two-mica granitoids (Heller et al., 1985, 1987). Paleomagnetic data indicate that the Tyee Basin has rotated ~67° clockwise since deposition (Simpson and Cox, 1977; Wells et al., 2000).

In northern California, the Franciscan Complex is divisible into three major units: the Cretaceous Eastern and Central belts and the younger Coastal belt, the unit of interest here (e.g., Underwood and Bachman, 1986; McLaughlin et al., 1994, 2000; Ernst and McLaughlin, 2012). The Coastal belt has been further subdivided into the Yager terrane, Coastal terrane, and a few other smaller units. Coastal belt rocks are chiefly marine sandstones and mudstones that have been pervasively faulted and folded. Age control is somewhat problematic, but the Yager and Coastal terranes are probably mostly Lower to Middle Eocene (56–36 Ma). Detrital muscovite is common in some Yager and Coastal terrane sandstones.

Mildly deformed Upper Jurassic to Neogene strata of the Great Valley forearc basin underlie much of the modern Great Valley of California. Most of these marine sediments were shed from the Sierra Nevada and highlands to the east (e.g., DeGraaff-Surpless et al., 2002). The Middle Eocene Markley Formation crops out near Mount Diablo and is curious for unusually abundant detrital muscovite compared to other Great Valley units.

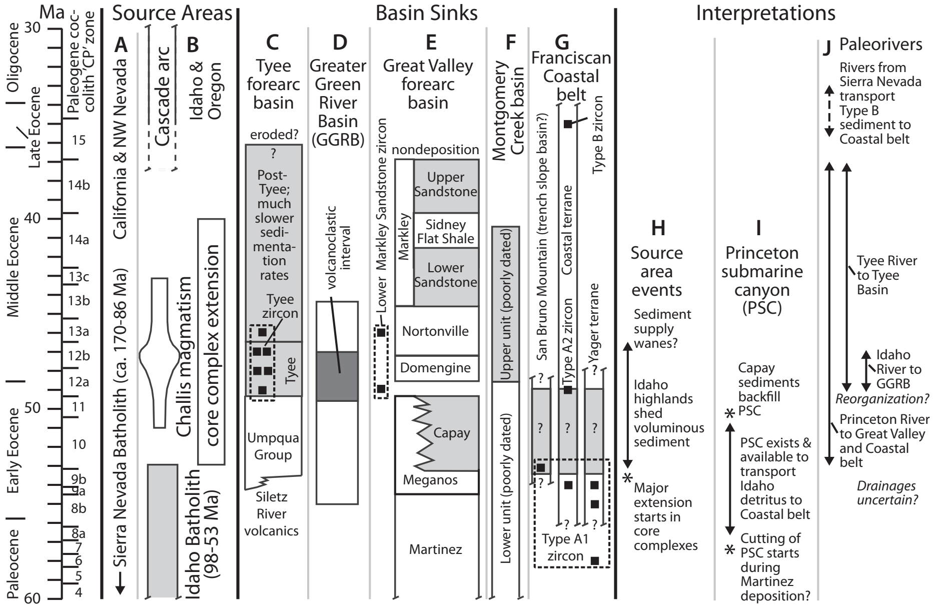

Figure 2. Comparative timing of events, 60–35 Ma. Light shading indicates units with anomalously large concentrations of muscovite. Square dots indicate youngest detrital zircon population in each sample. See Table DR1 (see footnote 1) for details.

POTENTIAL SEDIMENT SOURCE AREAS

The Sierra Nevada Batholith lies east of the Franciscan Complex and is an obvious potential source for Eocene Coastal belt and Great Valley sediments. Cretaceous Franciscan and Great Valley sandstones yield detrital zircon ages compatible with Sierran sources (DeGraaff-Surpless et al., 2002; Ernst et al., 2009; Snow et al., 2010; Dumitru et al., 2010). Muscovite-bearing rocks are quite rare in the Sierra Nevada (Heller et al., 1985). Sierran plutons range in age from older than 170 Ma to ca. 86 Ma, with small volumes of 86–80 Ma plutons (Irwin and Wooden, 2001). At ca. 80 Ma, the Sierran arc died, apparently in response to shallow subduction attending the Laramide orogeny, but to the northeast, magmatism continued in the Idaho Batholith (IB).

The IB is divisible into five plutonic suites, with a combined age range from 98 to 53 Ma (Fig. 2B), and was emplaced in a contractional setting during Sevier–Laramide orogenic thrusting (Gaschnig et al., 2011). IB magmatism was then abruptly superseded by major extensional exhumation in the Bitterroot, Anaconda, Clearwater, and Priest River metamorphic core complexes (53–40 Ma; Foster et al., 2007) and major magmatism in the Challis volcanic-plutonic field (starting 51 Ma, peaking 47 Ma, ending 43 Ma; Gaschnig et al., 2011; Chetel et al., 2011). After the Challis event, arc magmatism was reestablished in the new Cascade arc to the west, becoming moderately voluminous by ca. 35 Ma (du Bray and John, 2011).

NEW DETRITAL ZIRCON AGES

Figure 3 and Table DR2 present detrital zircon U-Pb ages from sandstones from the three depocenters. Maps and petrographic data for the Coastal belt samples are available in Ernst and McLaughlin (2012).

Tyee sandstones shows a strong zircon age peak ca. 49 Ma, essentially identical to peak Challis magmatism (Figs. 3A, 3B), plus numerous IB-age zircons. Substantial numbers of pre–98 Ma zircons were probably sourced from older rocks in Idaho, Oregon, and vicinity (cf. LaMaskin et al., 2011). The proportion of Challis-age zircons is high; this might reflect temporary burial and shielding of older outcrops by a widespread Challis volcanic blanket.

Coastal belt zircon age patterns plot into three distinct groups (Figs. 3C–3E). Type A1 comprises five (of seven) samples and exhibits these features: (1) most zircons are ca. 52–85 Ma; (2) only smaller numbers of zircons yield the ca. 86–170 Ma ages expected from Sierran sources; (3) the youngest zircon population in a given sample yielded ages of ca. 53, 54, 54, 55, and 58 Ma (pre-Challis). Type A2 (one sample) is similar to A1, but the youngest population is ca. 49 Ma. Types A1 and A2 were apparently derived largely from the Idaho Batholith region rather than from the Sierra Nevada. Although the 86–170 Ma zircons could have come from the Sierra Nevada, zircons of such ages are also present in Oregon and Idaho (Gaschnig et al., 2011; LaMaskin et al., 2011) and that area is likely their main source. Tagami and Dumitru (1996) reported very limited detrital zircon fission track ages from three Coastal belt samples that are similar to Types A1 and A2. Only our seventh sample (Type B) is dominated by Sierran-age zircons, with a paucity of zircons indicative of an Idaho source. This sample also

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[1] GSA Data Repository item 2013046, Table DR1 (depositional age data and detrital muscovite concentrations of Eocene sedimentary rock units), Table DR2 (detrital zircon U-Pb age data and methods), is available online at www.geosociety.org/pubs/ft2013.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

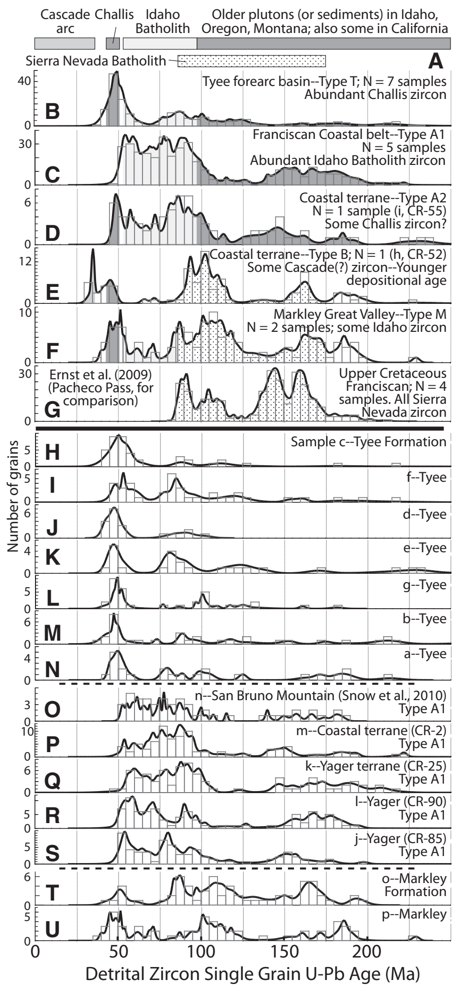

Figure 3. A: General ages of magmatic rocks in potential sediment source areas. B–G: Composite detrital zircon age distributions from different sedimentary units. Plots are shaded to indicate our interpretation of primary source area. H–U: Plots for individual samples composited in B, C, and F.

contains a robust population of 35 Ma zircons, probably derived from the new Cascade arc, suggesting that its depositional age is younger than Types A1 and A2 and reflects a later provenance shift.

Figure 3F shows data from muscovite-bearing sandstones of the Markley Formation, deposited ca. 45–40 Ma (Table DR1). The Markley Formation appears to contain a mixture of ~80%–90% Sierra Nevada–age zircons and 10%–20% Challis- and IB-age zircons. This suggests that a river from Idaho debouched into the northern end of the Great Valley forearc basin during Markley Formation deposition.

DISCUSSION

Figure 1 reconstructs the Early to Middle Eocene paleogeography between the Green River Basin and the Coastal belt trench. Based on north-directed paleocurrents, Tyee sediments would appear to be derived from the adjacent Klamath Mountains. However, Heller et al. (1985, 1987) demonstrated that the general Idaho Batholith area was the likely source, consistent with the ~67° clockwise rotation of the Tyee Basin. Before rotation and Basin and Range extension, the Tyee Basin and IB were closer together and an Eocene Tyee River apparently drained the IB region and debouched into a major Tyee delta (Dickinson et al., 1988). This river first reached the Tyee area ca. 49.4 Ma, as pre-Tyee strata lack detrital muscovite and IB-age zircons (Ryu et al., 1996; our preliminary data). The huge delta and very rapid sedimentation rates suggest that a single, large Tyee River fed the basin, rather than numerous smaller rivers like the Eocene to modern Sierra Nevada–Great Valley system to the south.

Chetel et al. (2011) documented detrital material with Challis $^{40}Ar/^{39}Ar$ ages and isotopic signatures in an anomalous 49.6–47.0 Ma volcaniclastic interval in the greater Green River Basin in Wyoming and reconstructed an Eocene Idaho River that transported Challis detritus ~500 km from the northwest. They also pointed out that depositional ages of Tyee and volcaniclastic Green River strata are virtually identical and that the major core complex event detailed by Foster et al. (2007) likely caused Tyee Basin sedimentation (Figs. 2B–2D).

Based on sandstone compositions, Underwood and Bachman (1986) tentatively concluded that the Franciscan Coastal belt was also partly sourced from the IB region (see also McLaughlin et al., 1994, 2000). Our new U-Pb data indicate that the IB region was the main source, and surprisingly little Sierra Nevada–derived zircon is apparent in our Type A1 and A2 samples. Of 10 studied samples, nine are Type A1 and A2 (including the 3 fission-track samples), so Idaho-sourced material appears to make up most of the Coastal belt.

Tyee samples yielded subequal numbers of Challis-age and IB-age zircons. In contrast, Type A1 Coastal belt samples yielded abundant IB-age zircons but no resolvable Challis-age zircons. From this, we make the key inference (admittedly debatable) that Type A1 Coastal belt sediments were probably deposited slightly earlier than Tyee sediments, after extension commenced in the core complexes but before Challis magmatism peaked. Three of our Type A1 samples are from the Yager terrane, one is from the Coastal terrane, and one is from a possible trench slope basin at San Bruno Mountain (Fig. 1). Limited microfossil data suggest that the Coastal belt is mostly Eocene (56–34 Ma; Table DR1); our interpretation suggests that the much of deposition, particularly in the Yager, was concentrated between ca. 53 and 49 Ma (perhaps extending somewhat later if transport lag times were significant). A less likely scenario is that the Type A1 samples were sourced from a part of the IB characterized by few Challis rocks. Our Type A2 sample does appear to contain Challis zircons (ca. 49 Ma), but we defer interpretation of this one sample pending more data.

The Eocene Tyee and Idaho Rivers carried sediments west and southeast to the Tyee and greater Green River Basins, starting at 49.4 and 49.6 Ma, respectively. Another river, here named the Princeton River, apparently transported sediments toward the Coastal belt trench. Its path (Fig. 1) probably started in the Idaho Batholith, transited the poorly understood, muscovite-bearing Montgomery Creek fluvial basin east of the Klamath block (Renne et al., 1990; Table DR1), debouched into the northern Great Valley, then exploited the Princeton submarine canyon to supply sediment to the Coastal belt. Princeton canyon is very large (200 km long), and canyon cutting probably started ca. 60–55 Ma, during deposition of the Martinez Formation (Fig. 2I; Redwine, 1984; Dickinson et al., 1979). The canyon was later backfilled by the Lower Eocene Capay Formation [ca. 51(?) to 49.4 Ma; Table DR1]. The canyon fill comprises conglomerate plus mudstone and sandstone with common detrital muscovite (Redwine, 1984; our observations, see Table DR1), strong evidence of a connection to the IB. Backfilling of the canyon suggests a possible reduction in sediment input from the Princeton River in early Challis event time, perhaps coincident with a reorganization of drainage patterns in Idaho that gave birth to the Tyee and Idaho Rivers. However, some IB and Challis material did continue to reach the Great Valley until at least ca. 37 Ma, partially sourcing the Markley Formation.

In some respects, a good modern analog for the Coastal belt depocenter may be the Astoria Fan off the mouth of the Columbia River (Fig. 1), where fan sediments and underlying older strata have filled trench slope basins and the Cascadia trench and then spread far out onto the subducting Juan de Fuca plate. At Deep Sea Drilling Project Hole 174, near the edge of the fan, 630 m of sediments have accumulated since perhaps 2.5 Ma (Prytulak et al., 2006). Geochemical data show that these sediments are strongly dominated by detritus from far in the North American interior rather than from the nearby Cascade arc, similar to the Coastal belt situation. In the Astoria Fan, however, rapid sedimentation reflects Pleistocene glacial-fluvial erosion (climatic control), rather than extensional processes as for the Coastal belt (tectonic control).

It is often tempting to ascribe events in ancient subduction zones to the tectonics of the plate margin, such as changes in plate motions or the accretion of allochthonous terranes. However, in modern subduction zones, the highly variable volume of sediment supplied to the trench appears to be strongest control on rates of sediment accretion and accretionary prism growth (e.g., Cloos and Shreve, 1988; Clift and Vannucchi, 2004; Dumitru et al., 2010). The Coastal belt crops out over ~3500 km^2, ~15% of the total outcrop area of the Franciscan Complex, and much of it apparently reflects a relatively brief surge of sediments sourced from a major core complex extensional episode in Idaho. Therefore, the Coastal belt appears to be an instructive example of a major accretion event ultimately controlled by continental tectonics far within the interior of the overriding plate, rather than by some tectonic change at the plate margin itself. As such, it illustrates the importance of considering sediment transport pathways and sedimentation rates in reconstructing the growth of ancient accretionary prisms.

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