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Does the Great Valley Group Contain Jurassic Strata? Reevaluation of the Age and Early Evolution of a Classic Forearc Basin

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Does the Great Valley Group contain Jurassic strata? Reevaluation of the age and early evolution of a classic forearc basin

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ABSTRACT

The presence of Cretaceous detrital zircon in Upper Jurassic strata of the Great Valley Group may require revision of the lower Great Valley Group chronostratigraphy, with significant implications for the Late Jurassic–Cretaceous evolution of the continental margin. Samples ($n = 7$) collected from 100 km along strike in the purported Tithonian strata of the Great Valley Group contain 20 Cretaceous detrital zircon grains, based on sensitive high-resolution ion microprobe age determinations. These results suggest that Great Valley Group deposition was largely Cretaceous, creating a discrepancy between biostratigraphy based on *Buchia* zones and chronostratigraphy based on radiometric age dates. These results extend the duration of the Great Valley Group basal unconformity, providing temporal separation between Great Valley forearc deposition and creation of the Coast Range Ophiolite. If Great Valley forearc deposition began in Cretaceous time, then sediment bypassed the developing forearc in the Late Jurassic, or the Franciscan subduction system did not fully develop until Cretaceous time. In addition to these constraints on the timing of deposition, pre-Mesozoic detrital zircon age signatures indicate that the Great Valley Group was linked to North America from its inception.

Keywords: Great Valley, detrital zircon, *Buchia*, biostratigraphy, Jurassic.

INTRODUCTION

The Great Valley Group has been regarded as Upper Jurassic through Cretaceous for the past century (e.g., Diller and Stanton, 1894), and as the world's archetypal ancient forearc basin for the past three decades (e.g., Dickinson and Seeley, 1979; Ingersoll, 1982; Ingersoll and Busby, 1995). However, the Great Valley Group may contain few, if any, Upper Jurassic strata. Here we report new detrital zircon ages that may prompt revision of lower Great Valley Group chronostratigraphy and reevaluation of the early development of the Great Valley forearc basin and its role in the evolution of the continental margin.

GEOLOGIC SETTING

Great Valley sedimentation began in a narrow deep-marine trough south of the Klamath Mountains and west of the northern Sierran terranes that developed into a broad bathyal forearc basin with an extensive system of submarine fans by the Early Cretaceous (e.g., Ingersoll, 1982; Bertucci, 1983). Excellent outcrops of the Great Valley Group along the western margin of California's Sacramento Valley (Fig. 1), combined with extensive subsurface data, permit documentation of Mesozoic subsidence and sedimentation in the Great Valley basin, coeval with Franciscan subduction and accretion and Klamath-Sierran arc magmatism (e.g., Ingersoll, 1983; Williams, 1997).

Petrographic studies divide the northern Great Valley Group into six sandstone petrofacies (Dickinson and Rich, 1972; Ingersoll, 1983), with the Stony Creek, Lodoga, and Platina petrofacies forming the lowermost section (Fig. 2). The Stony Creek petrofacies contains sandstone with abundant basaltic and andesitic lithic grains, indicating derivation from an active arc (Ingersoll, 1983). The Platina petrofacies occurs only at the northern limit of the Sacramento Valley and was apparently derived directly from metamorphic terranes of the southern Klamath Mountains (Ingersoll, 1983; Short and Ingersoll, 1990). The Great Valley Group has been linked to the Klamath Mountains from its earliest depositional history by south-directed paleocurrent indicators (Ingersoll, 1983), Klamath-derived chert-rich conglomerate (Bertucci, 1983), and distinctive sandstone compositions (Ingersoll, 1983; Short and Ingersoll, 1990).

BIOSTRATIGRAPHY

The ''Upper Jurassic''–Lower Cretaceous stratigraphic age of the Stony Creek petrofacies (we refer to the basal section as ''Upper Jurassic'' to indicate uncertainty in the Jurassic age assignation raised by our data) is based on six zones of the pelecypod *Buchia*, including two Tithonian zones (*B. piochii* and *B.* aff. *B. okensis*; Jones et al., 1969). The *Buchia* occur in deep-water deposits (e.g., Bertucci, 1983) of the lower Great Valley Group, presumably transported from their living environment in the shallower waters of the continental shelf and slope by turbidity currents.

The *Buchia* zone ages are based primarily on their association with less abundant ammonites, as well as on the similarity of the Great Valley Group *Buchia* succession to that in western Canada (Imlay and Jones, 1970). Lower Cretaceous calcareous nannofossils provide age calibrations for ammonite stratigraphy and are generally consistent with the age assignments of the Lower Cretaceous *Buchia* zones, but indicate that the *B.* aff. *B. okensis* zone is actually Berriasian, not Tithonian (Bralower, 1990). Foraminifera (Dailey, 1973) and two tuff horizons (U-Pb zircon age of 137.1 Ma $+1.6/-0.6$ Ma; Bralower et al., 1990) confirm an Early Cretaceous age for the section defined by Cretaceous *Buchia* zones. Radiolarians recovered near the base of the Great Valley Group were assigned to the Tithonian (Pessagno, 1977) based on the *Buchia* zones of Jones et al. (1969), and thus do not represent an independent age designation.

DETRITAL ZIRCON METHODS AND RESULTS

We analyzed seven samples collected from the full thickness of the Tithonian strata along 100 km of strike in the Sacramento Valley (Fig. 1) using the sensitive high-resolution ion microprobe–reverse geometry (SHRIMP-RG) at Stanford University and following the analytical and statistical protocols outlined in DeGraaff-Surpless et al. (2002) (Data Repository Appendix 1[1]). The detrital zircon age data were plotted as histograms with superposed probability density curves to represent both the age measurement and associated uncertainty (Fig. 1; only Mesozoic portions of the plots are shown). We use the 145.5 ± 4 Ma Jurassic-Cretaceous boundary age estimate of Gradstein et al. (2004), which is consistent with the more recent minimum Jurassic-Cretaceous boundary age estimate of

[1]GSA Data Repository item 2006004, Appendix 1, description of analytical methods and data tables is available online at http://www.geosociety.org/pubs/ft2006.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

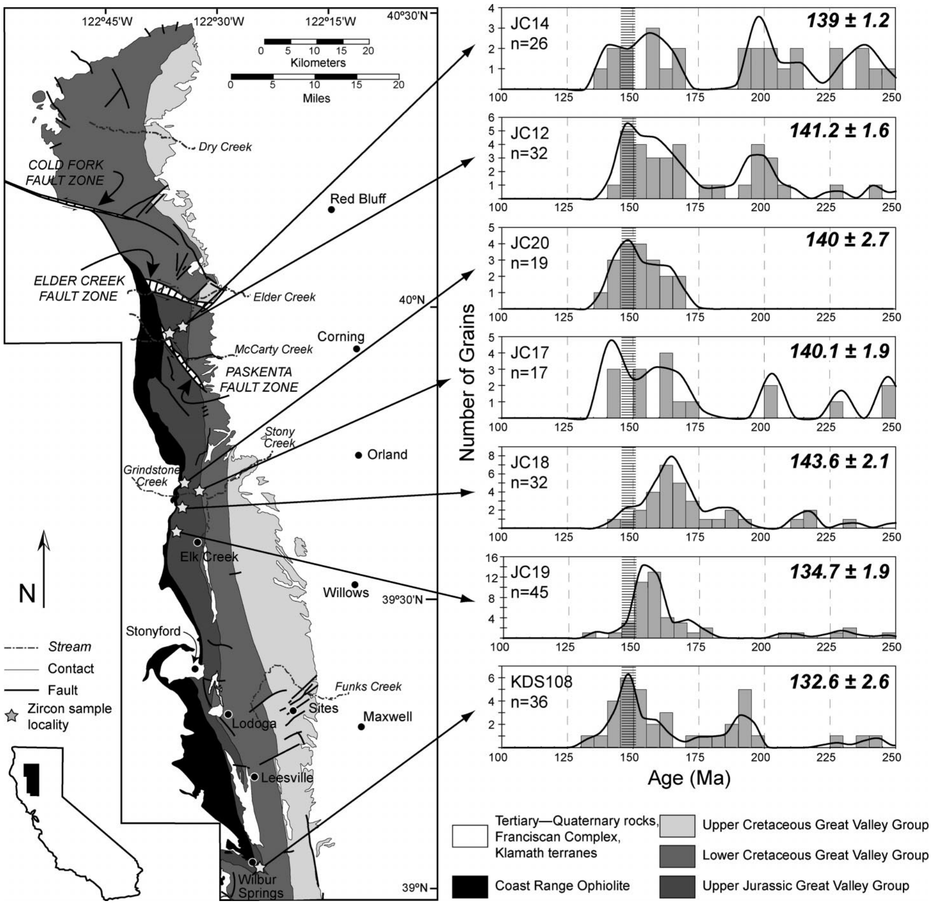

Figure 1. Detrital zircon data are keyed to sample locations in Sacramento Valley outcrop belt and stacked by geographic location. Each sample is shown as a histogram of ages with superposed probability density curve; only Mesozoic age distributions are shown. Horizontal stripes in each plot indicate Tithonian biostratigraphic age and bold italicized number is youngest detrital zircon age present in each sample. Map is modified from Jennings and Strand (1960), Strand (1962), and Wagner and Bortugno (1982).

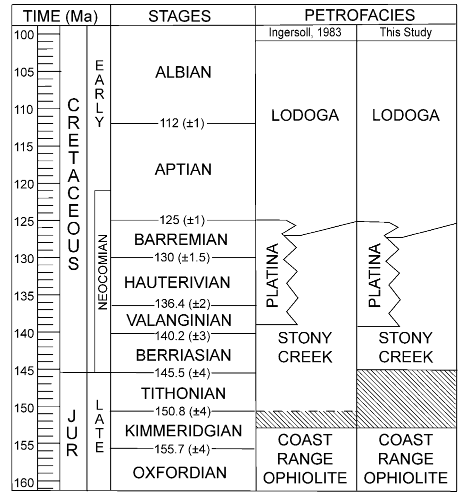

Figure 2. Revised chronostratigraphy for Great Valley Group in the Sacramento Valley, showing extended unconformity at base of Great Valley Group. Petrofacies are from Ingersoll (1983) and time scale is from Gradstein et al. (2004).

144.6 ± 0.8 Ma derived from radiometric dating of sills injected into the earliest Berriasian sediments of the Shatsky Rise (Mahoney et al., 2005).

Each of the 7 samples contains Cretaceous zircon, with 20 Cretaceous ages in the combined 7 samples making up 5% of the total zircon age population and 10% of the Mesozoic age population. In samples JC14 and JC17, clusters of Cretaceous grains form separate age groups, but more typically, the small number of Cretaceous grains in each sample is overwhelmed by larger Jurassic peaks. A high proportion of Jurassic grains is expected if these strata were deposited in the earliest Cretaceous, before abundant Cretaceous igneous rocks were exposed to erosion.

Samples were collected and processed in 4 separate sampling trips and analyzed during 4 separate SHRIMP-RG runs over a 26 month period. We used a ^{207}Pb rather than ^{204}Pb correction for common lead to eliminate possible bias toward young ages, and we assessed discordance using Tera-Wasserburg Concordia plots following DeGraaff-Surpless et al. (2003), removing from further consideration any ages more than ±5% discordant. For all data presented, ^{204}Pb-corrected ages are within error of ^{207}Pb-corrected ages.

To verify Cretaceous ages and check for possible systematic analytical bias, we reanalyzed detrital zircon with ages near the Jurassic-Cretaceous boundary in three of the seven samples. The second analysis of these grains involved six instead of four scans through all mass stations and longer counting times through critical isotope masses to improve precision and reduce uncertainty in calculating Mesozoic ages (Appendix 1; see footnote 1). The original ages determined for 9 of the 16 reanalyzed grains were duplicated by the second analysis. Of the seven grains whose original ages could not be reproduced, three grains were younger on the second analysis, four grains were older, and all seven grains showed complex zoning visible under cathodoluminescence that likely accounts for variability in the age analyses. These results, together with the consistency of data over several analytical runs, indicate that there is no systematic bias in the analyses.

We checked for possible Pb loss in the young ages by plotting uranium concentration against age and visually assessing the grain size and crack/inclusion density of the younger grains. The Cretaceous zircons do not have elevated uranium concentrations (Fig. 3) and are similar in size to the rest of the detrital zircon population, suggesting that Pb loss was not a factor. Although some grains are complexly zoned, none of the young grains analyzed has inclusions or cracks visible under cathodoluminescence.

Detrital zircon samples JC12, JC14, and JC17 were collected from reported fossil localities of Jones et al. (1969) to provide direct comparison with biostratigraphic zones, and samples JC20, JC18, JC19, and KDS 108 were collected from near the base of the Great Valley Group to better assess the maximum depositional age of Great Valley strata using the ages of the youngest detrital zircon present (Fig. 1). The presence of 20 Cretaceous zircon grains in these samples conflicts with the Ti-

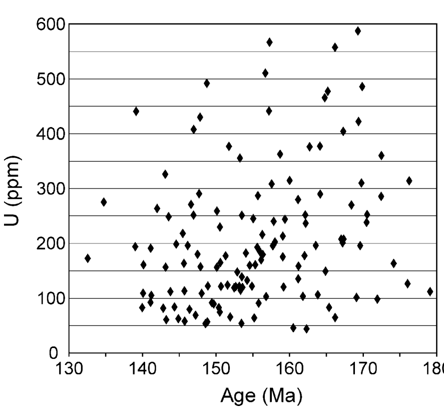

Figure 3. Uranium concentration plotted against age for Jurassic and Cretaceous zircon.

thonian age assignment based on *B. piocchi* and associated ammonites in these strata (Jones et al., 1969; Imlay and Jones, 1970) and indicates that the Stony Creek petrofacies, previously considered Tithonian to Neocomian, may be entirely Neocomian (Fig. 2). These zircon data do not alter the well-documented Lower Cretaceous assignment of the upper Stony Creek, Platina, or Lodoga petrofacies, which is based on *Buchia*, ammonites, calcareous nannofossils, foraminifera, and two Lower Cretaceous tuff horizons, or the pre-Tithonian age of the underlying Coast Range Ophiolite and its pelagic cover (e.g., Shervais et al., 2005).

DISCUSSION

Because the Sacramento Valley outcrop exposes the most complete stratigraphy deposited in the deepest preserved part of the eroded forearc basin (i.e., approximately the eastern half of the original basin; Ingersoll, 1982; Williams, 1997), the presence of Cretaceous zircon grains at the base of the exposure suggests that the currently accepted Late Jurassic–Cretaceous age range of the Great Valley Group is incorrect. This chronostratigraphic revision nearly doubles the thickness of Lower Cretaceous strata in the basin from 4 to 7 km to as much as 13 km, extends the duration of the unconformity between the Coast Range Ophiolite and the Great Valley Group by at least 5 m.y., and dramatically increases the inferred sedimentation rates in the developing forearc through the earliest Cretaceous, with attendant implications for rates of arc unroofing.

The traditional *Buchia*-based age assignments of the lower Great Valley Group may need reevaluation, either because the age significance of *Buchia* fossils is misunderstood or because Great Valley Group *Buchia* fossils are reworked. Previously, calcareous nannofossils in the Lower Cretaceous section illuminated a major discrepancy between nannofossil stratigraphy and *Buchia*-based zones: *B.* aff *B. okensis* is actually Berriasian in age (Bralower, 1990). *B. piochii* has been used to date and correlate Tithonian strata found in basins of British Columbia (e.g., MacLeod and Hills, 1990), Alaska (e.g., Brew et al., 1988), and Russia (e.g., Sey and Kalacheva, 1999), as well as California, but perhaps it, too, extended into Cretaceous time.

Alternatively, reworking of megafossils in the Great Valley Group has resulted in erroneously old age designations in the past (e.g., Brown and Rich, 1960; Ingersoll, 1979), and may be a factor where microfossils are not present to verify Tithonian deposition. For example, if Upper Jurassic shelf deposits of the North American continental margin were uplifted and eroded before forearc subsidence and development of a Cretaceous shelf, then Upper Jurassic fossils could have been incorporated into Cretaceous deep-water turbidite deposits. Submarine canyons cutting nearly a kilometer into underlying strata have been recognized recently in Upper Cretaceous Great Valley strata (e.g., Williams et al., 1998; Lowe, 2004), and similar features may remain unrecognized in less well-known Lower Cretaceous strata.

Revision of the timing of early Great Valley Group deposition bears on the evolution of the North American convergent margin system. The newly developing accretionary wedge associated with Franciscan subduction may not have thickened enough to pond sediments in a forearc basin (cf. Dickinson and Seely, 1979; Ingersoll, 1982) until near the Jurassic-Cretaceous boundary. Until western ponding of the forearc basin, sediment shed from the magmatic arc may have bypassed the forearc and been deposited in trench basins or on the subducting Farallon plate. These sediments likely were incorporated into the developing accretionary wedge and may be represented by Jurassic graywacke in the Franciscan Complex. Thus, Upper Jurassic Franciscan graywacke may not be coeval with Great Valley Group sandstone but may actually predate Great Valley deposition. Alternatively, the initiation of Franciscan subduction may have been nearer the Jurassic-Cretaceous boundary, postdating accretion of the Smartville complex of oceanic crust (e.g., Schweickert and Cowan, 1975; Godfrey and Dilek, 2000) in the Sierra Nevada foothills.

A Cretaceous age for the beginning of Great Valley deposition nearly doubles the duration of the hiatus between the radiolarian cherts intercalated with volcanic glass (dated as 164 Ma; Shervais et al., 2005) capping the Coast Range Ophiolite and the overlying Great Valley Group. The duration of this hiatus may require reevaluation of the three conflicting models for the origin of the Coast Range Ophiolite: (1) intraarc and backarc spreading (Dickinson et al., 1996), (2) open-ocean seafloor spreading (Hopson et al., 1996), and (3) forearc oblique rifting (Saleeby, 1996). For example, the first model closely links a jump in subduction caused by Nevadan collision orogeny to the initiation of the Great Valley Group forearc basin (162–155 Ma; Schweickert and Cowan, 1975; Schweickert et al., 1984; Ingersoll and Schweickert, 1986), but a temporal separation of the events by 10 m.y or more permits the possibility of greater allochthoneity of Coast Range Ophiolite. However, any model proposing an allochthonous origin for the Coast Range Ophiolite (i.e., Hopson et al., 1996) must account for 10 m.y. of missing pelagic cover represented by the unconformable contact between the volcano-pelagic succession of the Coast Range Ophiolite and the siliciclastic strata of the Great Valley Group.

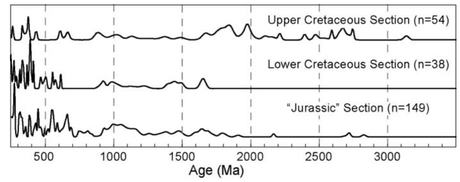

Figure 4. Comparison of pre-Mesozoic detrital zircon age distributions from Tithonian and Lower Cretaceous strata (this study) and Upper Cretaceous strata (DeGraaff-Surpless et al., 2002) of the Sacramento Valley. Distributions from all samples in each section were combined into one probability density curve and normalized for comparison.

The Great Valley forearc basin has long been considered autochthonous to the western margin of North America (e.g., Hamilton, 1969), but recent suggestions that the Great Valley Group was deposited in a translational forearc basin posit that Jurassic and Lower Cretaceous strata were deposited in a basin located much farther south than the basin receiving Upper Cretaceous sediment (Wright, 2004). Pre-Mesozoic detrital zircon age signatures from the entire Great Valley Group (Fig. 4) demonstrate that the Great Valley Group received zircon ultimately derived from North American cratonal sources throughout its history. The primary difference among the age signatures of the ''Jurassic,'' Lower Cretaceous, and Upper Cretaceous strata is that Lower Cretaceous strata contain fewer pre-Mesozoic zircon grains than either the Upper Cretaceous or ''Jurassic'' strata. This difference likely reflects changing sediment dispersal paths during geomorphic evolution of the convergent margin. The detrital zircon age signatures of the ''Jurassic'' and Lower Cretaceous strata do not appear sufficiently distinct from the Upper Cretaceous strata to substantiate a different, more southerly, source region for the older portion of the basin.

CONCLUSIONS

Our preliminary revision of the depositional age of the Great Valley Group necessitates reevaluation of the early history of the Great Valley forearc basin and its role in the evolution of the continental margin. A Cretaceous depositional age for the entire Great Valley Group would extend the duration of the basal unconformity, which bears on the timing of initiation of Franciscan subduction, the relationship between the Nevadan orogeny and Great Valley forearc deposition, and evolutionary models of the Coast Range Ophiolite. This age revision would also expand the thickness of the Lower Cretaceous portion of the Great Valley Group, with attendant implications for increased rates of forearc sedimentation and arc unroofing. Our new detrital zircon geochronology data call into question the utility of *Buchia*-based biostratigraphy in the deep-water Great Valley Group, where downslope reworking was ubiquitous. The presence of pre-Mesozoic zircon grains throughout the Great Valley Group suggests that the basin received sediment derived from the North American craton throughout its history.

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