CONTRASTING CRATONAL PROVENANCES FOR UPPER CRETACEOUS VALLE GROUP QUARTZITE CLASTS, BAJA CALIFORNIA

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ABSTRACT

Late Cretaceous Valle Group forearc-basin deposits on the Vizcaino Peninsula of Baja California Sur are dominated by first-cycle arc-derived volcanic-plutonic detritus derived from the adjacent Peninsular Ranges batholith. Craton-derived quartzite clasts are a minor but ubiquitous component in Valle Group conglomerates. The source of these clasts has implications for tectonic reconstructions and sediment-dispersal paths along the paleo-North American margin. Three strongly contrasting types of quartzite are recognized based on petrology and detrital zircon U-Pb geochronology. The first type is ultramature quartz arenite with well-rounded, highly spherical zircon grains. Detrital zircon ages from this type are nearly all >1.8 Ga with age distributions that closely match the distinctive Middle-Late Ordovician Peace River arch detrital signature of the Cordilleran margin. This type has been previously recognized from prebatholithic rocks in northeast Baja California (San Felipe quartzite). A second quartzite type is subarkosic sandstone with strong affinity to southwestern North America; important features of the age spectra are ~1.0-1.2 Ga, 1.42 and 1.66 Ga peaks representing cratonal basement, 500-300 Ma grains interpreted as recycled Appalachian-derived grains, and 284-232 Ma zircon potentially derived from the Early Permian-Middle Triassic east Mexico arc. This quartzite type could have been carried to the continental margin during Jurassic time as outboard equivalents of Colorado Plateau eolianites. The third quartzite type is quartz pebble conglomerate with significant ~900-1400 Ma and ~450-650 Ma zircon components, as well as mid- and late Paleozoic grains. The source of this type of quartzite is more problematic but could match either upper Paleozoic strata in the Oaxaca terrane of southern Mexico or a southwestern North America source. The similarity of detrital

zircon spectra in all three Valle Group quartzite types to rocks of the adjacent Cordilleran margin support previous interpretations that Valle Group forearc basin sediments were deposited in proximity to rocks on the mainland of northwest Mexico and southwestern United States.

INTRODUCTION

Baja California plays a central role in the debate over Cretaceous paleogeography and terrane translation models for the western North American Cordillera. This debate, fueled by uncertainties and conflicts between models based on geologic versus paleomagnetic data (Cowan et al., 1997), can be resolved into two separate issues: 1) the displacement history of the main part of the Baja Peninsula which is cored by crystalline basement of the Cretaceous Peninsular Ranges batholith (PRB), and 2) the displacement history of Vizcaino terrane forearc basement on the western outboard edge of Baja California.

Butler et al. (1991) observed that anomalously shallow paleomagnetic inclinations from the PRB and overlying sedimentary strata (e.g. Teissere and Beck, 1973, Beck 1980, 1991; Hagstrum et al., 1985; Lund and Bottjer, 1991), which require ~1200 km of northward transport, might be reconciled by a combination of westward tilting of the batholith together with compaction-induced inclination shallowing in sedimentary units. This idea has gained strong support from subsequent paleomagnetic studies on the batholith (Dickinson and Butler, 1998; Böhnel and Delgado-Argote, 2000; Böhnel et al., 2002) and overlying upper Cretaceous strata (Tan and Kodama, 1998; Kodama and Ward, 2001). The most recent paleomagnetic interpretations for Baja thus require minimal tectonic transport and are supported by independent lines of geologic evidence that indicate simply closing the Gulf of California by ~300 km restores Baja to its original position against northwestern Mexico (e.g., Gastil, 1993; Gehrels et al., 2002).

The translation/accretion history of the Vizcaino terrane has been harder to resolve. Paleomagnetic data (Smith and Busby, 1993a) and unusual peraluminous Jurassic granite clasts in Aptian-Albian conglomerates (Kimbrough et al., 1987) suggest that the Vizcaino terrane may have been displaced by margin parallel strike-slip faulting relative to the Baja California Peninsula. However, the newest paleomagnetic data indicate that the Vizcaino terrane has moved little with respect to the Peninsular Ranges batholith and cratonic North America since the late Early Cretaceous (Vaughn et al., 2005). These data are consistent with geologic evidence that links an enormous influx of PRB-derived Cenomanian to Turonian coarse-grained sediment into the Vizcaino terrane Valle Group forearc basin (Kimbrough et al., 2001).

On the other hand, an increasingly large body of evidence indicates that the Cretaceous was a period of major margin parallel dextral strike-slip faulting along the western U.S. Cordillera driven by oblique subduction and strain partitioning (e.g. Wright and Wyld, 2006 and references therein). Northward from the Vizcaino terrane in the submerged borderland region of Baja and southern California, western remnants of the Valle Group forearc basin have been dismembered and tectonically removed. Crouch (1979) suggested that dismemberment of the forearc was associated with late Cenozoic strike-slip tectonics associated with initiation of the San Andreas system, and that fragments of the basin are preserved in the northern borderland on San Miguel Island (e.g. Bartling and Abbott, 1983), and also in the Transverse Ranges and Coast Ranges farther north. Cowan et al. (1997) however suggests that the missing forearc basin strata were removed during the Late Cretaceous-Early Cenozoic and translated to northern Washington and British Columbia (the Baja British Columbia hypothesis). The Baja BC hypothesis has gained renewed support from a recent paleomagnetic study that indicates Cretaceous forearc basin strata of the Nainamo Group in British Columbia originated adjacent to the Baja California margin during the Late Cretaceous (Housen and Beck, 1999; Krijgsman and Tauxe, 2006).

This paper provides a test for Baja California terrane translation models and the Baja BC hypothesis via analysis of detrital zircon from minor but ubiquitous quartzite conglomerate clasts in Cretaceous Valle Group strata. Quartzite is durable and can withstand long-distance transport in sediment dispersal systems. Motivation for this work is provided by existing and rapidly expanding detrital zircon data sets from the southwestern United States and elsewhere (e.g. Gehrels and Stewart, 1998; Gillis et al., 2005) that provide a basis for testing possible connections between the Valle Group quartzite clasts and ancestral North America, as well as with potentially correlative displaced units such as the Nainamo Group in British Columbia.

VALLE GROUP STRATIGRAPHY

Forearc basin strata of the Peninsular Ranges of southern and Baja California comprise two main belts of rock; the Rosario Group and the Valle Group (Fig. 1). Along the western margin of the Peninsular Ranges batholith from the Santa Ana Mountains to El Rosario, the Rosario Group comprises relatively thin (1-2 km) sequences of Turonian to Maastrichtian fluvial and shallow- to deep-marine strata that unconformably onlap the eroded western flank of the batholith.

The Valle Group comprises thick successions (3-12 km) of Aptian-Albian to Eocene, mainly deep-marine strata overlying Triassic to Lower Cretaceous ophiolite/volcanic arc basement (e.g., Patterson, 1984; Barnes, 1984; Moore, 1985; Busby-Spera and Boles, 1986; Smith et al., 1993; Smith and Busby, 1993b; Busby et al., 1998; Kimbrough et al., 2001; Kimbrough and Moore, 2003). It can be divided longitudinally along the 200-km-long outcrop belt into at least three distinct sub-basins, including northern and southern sub-basins on the Vizcaino Peninsula that are separated by a paleo-basement high, and a third sub-basin centered on Cedros Island (Figs. 1, 2).

Each sub-basin contains a thick, early Cenomanian to middle Turonian coarse clastic sequence that represents a rapid and regionally extensive progradation of coarse clastic detritus into the deep-marine portion of the forearc basin. The thickest and most complete record of the Cenomanian -Turonian progradation is provided by the Campito and Los Indios sections in the northern Vizcaino sub-basin where a basal 150-300-m-thick broad apron of granule to pebble conglomerate overlies basin-plain shales of the Los Chapunes Formation (Patterson, 1984). These deposits are overlain by a thick succession of turbidites that in turn, coarsen upward into channelized sandstone and conglomerate deposited in a slope-proximal submarine fan setting. These deposits may be located in an inner fan valley or distal submarine canyon environment.

Valle Group conglomerate are typically channelized weakly stratified pebble-cobble clast supported conglomerates with outsized boulder clasts. Debris flow conglomerate beds exhibit inverse grading at the base and outsized boulders “float” near the top. Average conglomerate clast size in the Campito section increases upward reaching a maximum in the middle Cenomanian. The coarsest interval contains numerous boulder beds (maximum size of 2.5 m) that we interpret as having been deposited within a steep-gradient inner-fan channel or possibly a submarine canyon axis. This observation indicates that the fan apex had prograded into the basin axis by middle Cenomanian time. Rapid unroofing rates are required to generate high-gradient sediment-transport systems capable of delivering abundant meter-sized boulders and great volumes of sand and gravel to the axis of the deep-marine basin.

Clast Petrology

Valle Group sediments are dominated throughout by first-cycle arc-derived volcanic-plutonic detritus. Table 1 presents conglomerate clast-count data on 2114 clasts from 9 localities in the Valle Group that range from Aptian-Albian to Coniacian in age. Two clast counts are presented for each locality; the first represents the pebble cobble fraction, the second represent the boulder fraction.

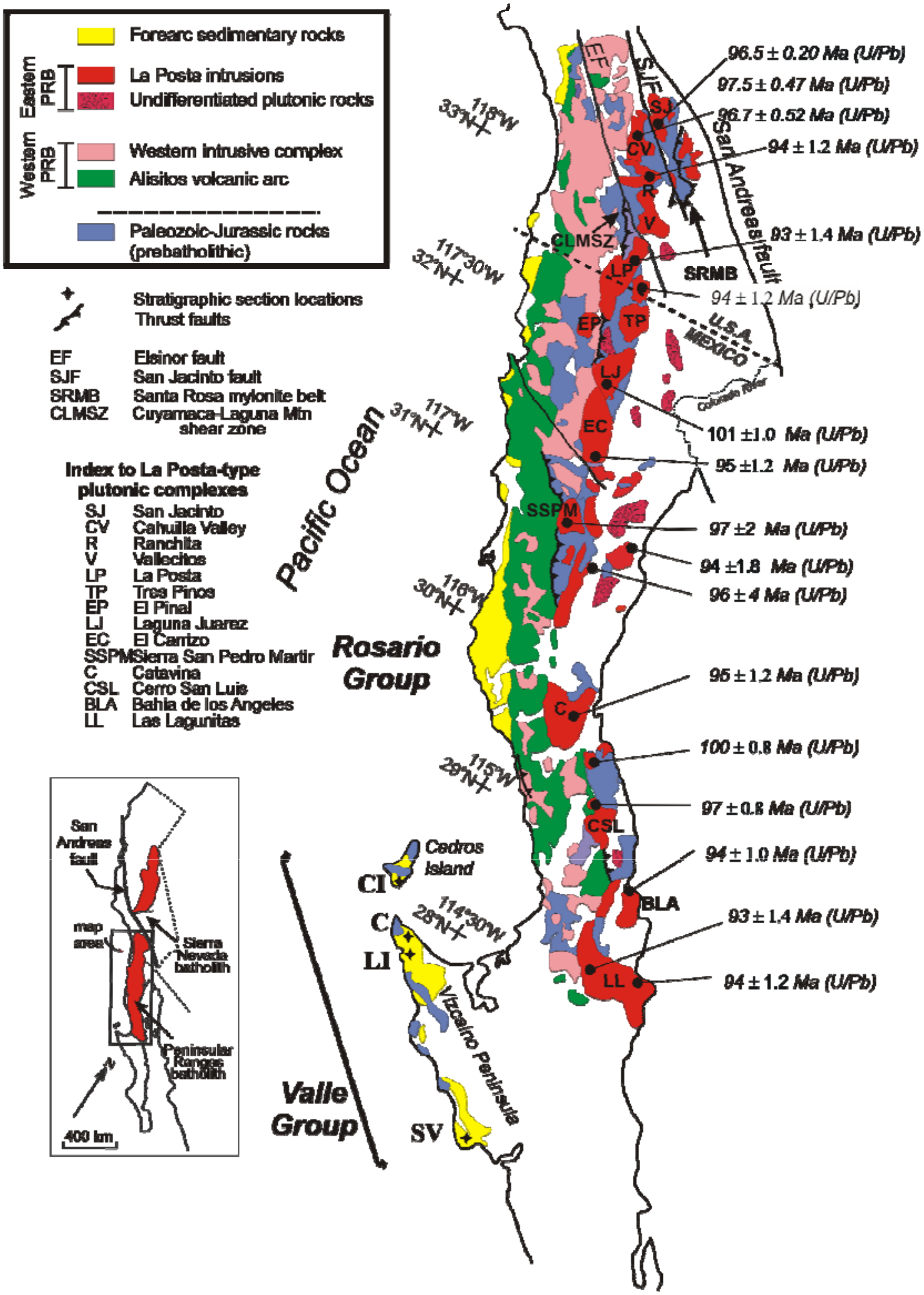

Figure 1. Schematic geologic map of Peninsular Ranges batholith (PRB) and Valle and Rosario Group forearc sedimentary strata. Location of Valle Group stratigraphic columns in Figure 2 are indicated. The inferred source of quartzite clasts in Valle Group strata are prebatholithic units of the PRB shown in blue. Zircon U-Pb ages and uncertainties (2SE) are also shown for La Posta suite intrusions that make up about half the surface exposure of the batholith. The La Posta magmatic flareup is related to rapid batholith erosional denudation and delivery of coarse-grained deep marine sediment into the forearc which carried the quartzite clasts.

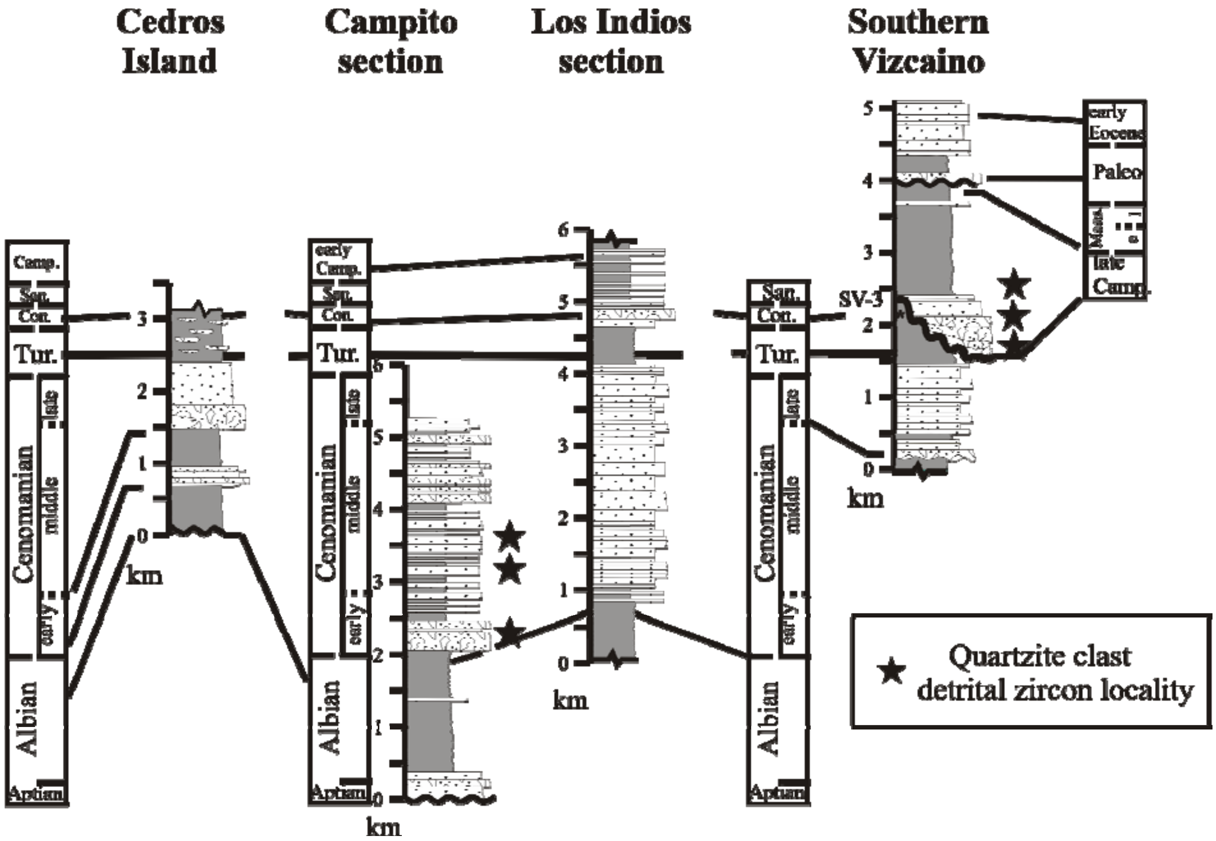

Figure 2. Stratigraphic sections of Valle Group showing quartzite detrital zircon sample localities. Section names refer to Cedros Island, northern (Campito and Los Indios) and southern Vizcaino subbasins the locations of which are shown in Figure 1.

Clast counts document mainly volcanic (73%) and plutonic (13%) rock types. Volcanic types are volcaniclastic and effusive with andesite, dacite and rhyodacite compositions dominating. Plutonic rocks are mainly biotite ± hornblende tonalite, granodiorite and monzogranite. Dioritic and gabbroic compositions are uncommon.

The volcanic-plutonic assemblage is consistent with a continental or mature island arc derivation, supporting earlier sandstone petrology studies (Patterson, 1984; Barnes, 1984). There is no obvious ‘batholith unroofing’ trend evident from these data. The clast category labeled “chert” consists mainly of a dark grey “cherty argillite” lithology. Minor quartzite clasts occur throughout the Valle Group but are locally abundant in the Aptian-Albian Perforada Formation, and conspicuously abundant in Campanian submarine channel deposits around Punta Abreojos. The largest quartzite clasts encountered were meter-sized boulders in the mid-Cenomanian Campito section.

METHODS

U-Pb geochronological analyses of 328 detrital zircon grains from six Upper Cretaceous Valle Group quartzite clasts are reported here. Sample locations and details are presented in Table 2. Analytical results are presented in Table 3 and plotted in Figure 3. Table 3 can be obtained from the Data Repository link on the Pacific Section, SEPM website (http://www.sci.sdsu.edu/pacsepm).

Zircons were separated from quartzite clasts by standard crushing, density and magnetic separation techniques at San Diego State University. Aliquots from bulk zircon separates were mounted along with standards

Table 1: Valle Group conglomerate clast count data

conglomerate locality	depositional age	latitude[1] longitude	clast size	volcanic	plutonic	quartzite	sedimen-tary	chert	total clasts counted (n)	mean clast size (cm)	max clast size (cm)	1 stdev clast size (cm)
Canon Malarimo	Coniacian	27.647750	pebble-cobble	64.0%	17.5%	5.9%	3.6%	8.9%	303	6	19	2.4
Los Indios section		-114.46303	boulder	18.2%	81.8%	0.0%	0.0%	0.0%	11	33	42	6.2
Arroyo Los Juncos	Campanian	26.817444	pebble-cobble	62.6%	2.4%	16.3%	11.4%	7.3%	123			
Southern Vizcaino		-113.51931	boulder	58.0%	34.0%	0.0%	8.0%	0.0%	50	18	30	4.9
Campo Enmedio	Campanian	26.803055	pebble-cobble	79.8%	1.9%	8.9%	3.3%	6.1%	213			
Southern Vizcaino		-113.55008	boulder	70.0%	22.0%	8.0%	0.0%	0.0%	50	17	26	3.8
Arroyo Pitahaya	late Cenomanian	26.907666	pebble-cobble	77.6%	15.1%	0.0%	1.8%	5.5%	219	6	20	3.7
Southern Vizcaino		-113.76567	boulder	70.0%	28.0%	0.0%	2.0%	0.0%	50	13	28	14.4
Campito Lighthouse	middle Cenomanian	27.826666	pebble-cobble	79.5%	12.7%	1.3%	4.4%	2.2%	229	5	15	2.3
Campito section		-114.85367	boulder	74.0%	22.0%	2.0%	0.0%	2.0%	50	72	150	19.3
Sierra Campito	early Cenomanian	27.789555	pebble-cobble	77.2%	9.6%	1.8%	7.9%	3.5%	114	10	20	4
Campito section		-114.89261	boulder	66.7%	33.3%	0.0%	0.0%	0.0%	9	28	32	3.14
Sierra Queen	early Cenomanian	27.737305	pebble-cobble	79.0%	18.0%	1.2%	0.6%	1.2%	167	8	24	3.8
Campito section		-114.72258	boulder	67.9%	25.0%	0.0%	0.0%	0.0%	28	55	110	22.5
Arroyo El Porsen	early Cenomanian	27.790944	pebble-cobble	82.0%	8.5%	2.0%	2.5%	5.0%	200	5	15	5.3
Campito section		-114.75211	boulder	70.0%	26.0%	0.0%	4.0%	0.0%	50	41	95	14.5
Perforada Fm	Aptian-Albian	27.761194	pebble-cobble	61.5%	3.0%	14.5%	16.0%	5.0%	200	8	60	7
Campito section		-115.01592	boulder	81.3%	0.0%	0.0%	18.8%	0.0%	48	39	120	17.9

[1] NAD27 datum

Table 2: Valle Group quartzite clast, detrital zircon sample descriptions

sample	depositional age	[1]latitude longitude	clast size (cm)	clast color (GSA chart)	clast description	stratigraphic details
CRENE 95-98	late Campanian	26.824444 -133.505555	15	brownish gray 5YR 4/1	fine grained quartzite - qtz sandstone w/ qtz overgrowths; zircons are a mix of very well rounded spherical & more prismatic subrounded grains	uppermost part of Los Juncos submarine cglm channel - late Campanian ammonites bracket cglm bed
CKR94-9	Campanian	26.803055 -113.550083	21	medium bluish gray 5B 5/1	qtz pebble cglm clast - poorly sorted 0.2-2.0 cm subrounded to subangular white & gray gangue qtz, dark chert pebbles & possible silicic volcanics; zircons are a mix of very well rounded & prismatic subrounded grains	basal part of Los Juncos submarine cglm channel - coastal outcrops 3 km NE of Punta Abreojos - weakly stratified pebble-cobble cglm w/ outsized boulder clasts
CKR 94-8	Campanian	26.803055 -113.550083	17	yellowish gray 5Y 8/1	qtz pebble cglm clast - poorly sorted 0.5-2cm rounded to subrounded white gangue qtz and darker chert pebbles, matrix is yellowish gray xtalline qtz; zircons are a mix of very well rounded & prismatic subrounded grains	same as for CKR94-9
CSP94-1	mid-Cenomanian	27.83425 -114.865222	15	light brownish gray 5YR 6/1	fine grain sugary textured quartzite sandstone; homogeneous zircon population of well sorted very well rounded spherical grains	poorly sorted close-packed boulder rich pebble-cobble-boulder cglm
CSC 94-19	early Cenomanian	27.790944 -114.752111	11	dark gray N3	fine grained quartzite w/ white qtz veins - subangular moderately sorted grains; zircons are a mix of spherical & prismatic subrounded grains	basal Cenomanian cglm deposited across basin-plain turbidites of the Los Chapunes Fm
CSC94-11	early Cenomanian	27.790944 -114.752111	11	pale yellowish brown 10YR 6/2	fine-grained qtzite ss w/ qtz veining; homogeneous zircon population of well sorted very well rounded spherical grains	same as for CSC 94-19

[1] NAD27 datum

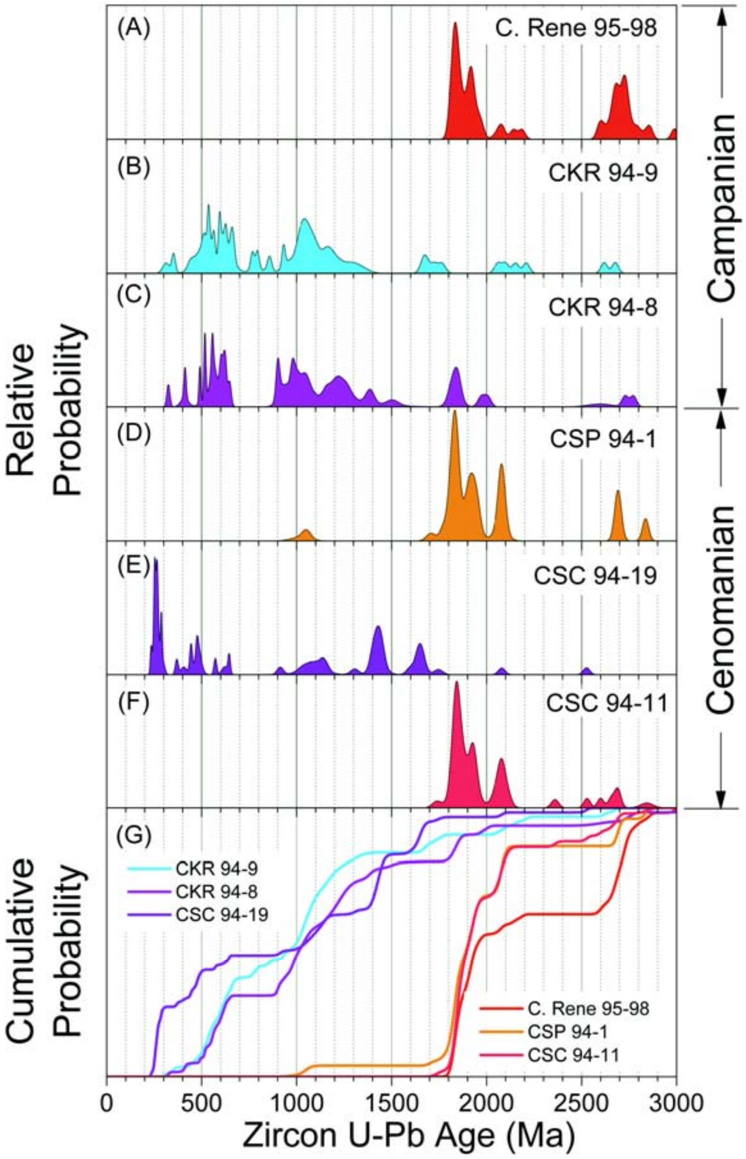

Figure 3. Zircon U-Pb relative age probability plots and cumulative probability plot for Valle Group quartzite clasts.

in 1" diameter epoxy plugs and polished with 3000 grit sandpaper.

Zircons were analyzed at the University of Arizona LaserChron Center using a Multicollector Inductively Coupled Plasma Mass Spectrometer (GVI Isoprobe) coupled to a 193 nm Excimer laser ablation system (New Wave Instruments). Analyses were conducted in static mode with a laser beam diameter of 35 microns. Inter-element fractionation was monitored by reference to a concordant Sri Lanka zircon standard with a known (ID-TIMS) age of 564±4 Ma (Gehrels, unpublished data). The standard zircon was analyzed once for every five unknowns. A protocol was established to ensure random selection of grains. In this study, interpreted ages are based on $^{206}Pb/^{207}Pb$ ratios for grains >1000 Ma, and $^{206}Pb/^{238}U$ ratios for grains <1000 Ma. Refer to Dickinson and Gehrels (2003) and Gillis et al. (2005) for additional analytical details.

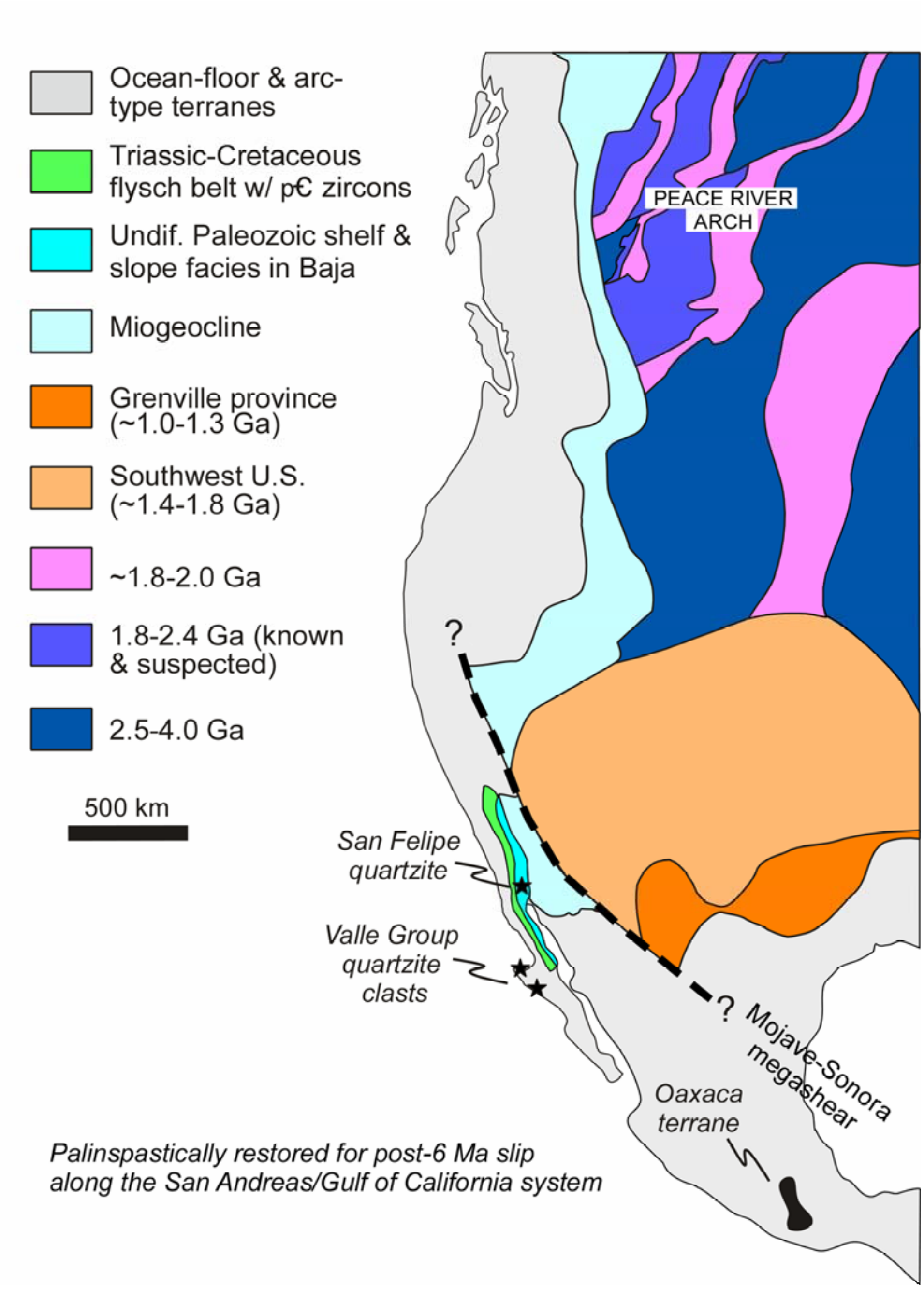

Figure 4. Schematic map showing Baja California in its restored pre-Neogene position along the southwestern Cordilleran margin. Base map adapted from Hoffman (1989), Stewart et al. (1990) and Gastil (1993).

DISCUSSION

The enormous influx of Cenomanian to early Turonian coarse-grained Peninsular Ranges volcanic-plutonic debris into the Valle forearc basin indicates that significant uplift and erosion of the Peninsular Ranges batholith was virtually synchronous with massive intrusion of the eastern PRB at this time (Kimbrough et al., 2001). Rapid unroofing rates are required to generate high-gradient sediment-transport systems capable of delivering abundant meter-sized boulders and great volumes of sand and gravel to the deep-marine axis of the basin. High relief and steep gradients must have persisted for at least 5 million years. Sustained Cenomanian to early Turonian denudation at mean rates of 1.0 km/m.y. is also evident in the northern Peninsular Ranges batholith (Lovera et al., 1999; Grove, 2003); clearly indicating that magmatic inflation of the batholith at 95±3 Ma was strongly coupled with arc exhumation and sediment delivery to the forearc basin.

Whatever the ultimate origin of quartzite clasts in the Valle Group strata may be, during the Late Cretaceous they must have been derived from erosional denudation of Peninsular Ranges batholith wallrock sequences. To date, there is no evidence for extra-regional sediment dispersal systems feeding into the Valle basin.

Peace River arch type clasts

Three clasts analyzed in this study match the distinctive age spectra for Middle-Late Ordovician Eureka quartzite of the Cordilleran miogeocline (Fig. 3). The Eureka quartzite represents a blanket of mature sand eroded from Cambrian sandstone formerly covering the Peace River-Athabaska arch in northern Alberta (Ketner, 1968). The sand was swept southward by longshore currents along the length of the Cordilleran margin (Fig. 4).

A good local match for the Valle Group ‘Peace River arch-type’ quartzite is the San Felipe quartzite exposed on the northeastern margin of Baja California (Fig. 4). The San Felipe quartzite was previously correlated with basal Cambrian strata of the mainland (Proveedora Quartzite of Sonora, Zabriskie Quartzite of California and Nevada) based on stratigraphic similarities (Anderson, 1993; Gastil, 1993). However, Gehrels et al. (2002) demonstrated that the detrital zircon age distribution from the San Felipe quartzite is a close match to both the miogeoclinal and eugeoclinal Middle-Late Ordovician ‘Peace River arch’ detrital signature. The zircon spectra for Valle quartzite sample CSP94-1 (Fig. 3D), as well as the San Felipe quartzite, matches best with the “higher” Ordovician eugeosynclinal reference spectra which contain a small Grenville age component. This match is consistent with accumulation of these rocks in either outer-shelf or off-shelf basins along the Cordilleran margin (cf. Gehrels et al., 2002). The zircon spectra for Valle quartzite samples CSC94-1 and CRene95-98 (Fig. 3A, F) appear to match better the Ordovician miogeoclinal reference curve.

Southwest North American clast type

A single clast of subarkose (CSC 94-19; Fig 3E) analyzed from the basal Cenomanian progradational package represents a southwest North American clast type in the Valle Group. Grenville age, 1.42 and 1.66 Ga spikes in the detrital zircon spectra indicate a strong affinity to southwestern North America basement sources. Early Paleozoic grains may reflect an Appalachian provenance transported westward across the Laurentian craton by Permian and Triassic transcontinental river systems (Dickinson and Gehrels, 2003). The distinct Late Permian peak suggests derivation from a circum-Pacific arc sequence such as the Early Permian-Middle Triassic (284-232 Ma) east Mexico arc (Torres et al., 1999) which may extend into southern California (Barth et al., 2001). Four grains with well-determined ages clustering between 251-253 Ma represent a solid maximum depositional age for the sample; the youngest grain is 234 Ma. Most clastic detritus in arc-type terranes in the Cordillera was generated during contemporaneous or slightly older magmatism so we assume an early Mesozoic stratigraphic age for this sample.

This lithology may have reached the continental margin during early Mesozoic time as outboard marine equivalents of the well known Colorado Plateau eolianites where they now reside as part of the Peninsular Ranges prebatholithic “flysch belt” (Gastil, 1993).

Quartz pebble conglomerate clasts

Detrital zircons from the two quartz pebble conglomerate clasts collected from the

Campanian submarine canyon at Punta Abreojos yield similar distinctive age distributions. Large components of Pan African (515-750 Ma), Grenville (1000-1350 Ma), and late Mesoproterozoic (800-1000 Ma) zircon dominate, accompanied by smaller early to mid-Paleozoic peaks and older Meso- and Paleoproterozoic peaks. The source of these clasts is more problematic. They may represent a North American source, or alternatively, Paleozoic cover of the Oaxaca complex in Mexico. The Oaxaca complex of southern Mexico is the largest exposure of Precambrian and Paleozoic rocks in Mexico and is believed to represent part of the Oaxaquia terrane basement that underlies most of eastern Mexico (Keppie et al., 2001).

CONCLUSIONS

Reconnaissance U-Pb detrital zircon dating of quartzite clasts in the Late Cretaceous Valle Group of Baja California defines three different clast types. Two of these clast types are firmly linked to local southwestern North American basement sources based on detrital zircon age distributions. Distinctive Middle-Late Ordovician ‘Peace River arch’ type quartzite is locally known from wall rock sequences in the northeastern Peninsular Ranges batholith (San Felipe quartzite). Early Mesozoic quartzite sands have a detrital signature that can be related to the southwestern Cordillera and could represent equivalents of Colorado Plateau early Mesozoic fluvial and eolian deposits transported into offshore basins as turbidites. This clast type was presumably derived from the prebatholithic flysch belt of the Peninsular Ranges batholith. A third type is more problematic but can be related to either southwestern Cordilleran Laurentian basement sources or perhaps Paleozoic cover of Gondwana Oaxaquia terrane basement that underlies most of eastern Mexico.

The similarity of detrital zircon spectra in the Valle Group quartzite clasts to rocks of the adjacent Cordilleran margin support previous interpretations that Valle Group forearc basin sediments were deposited in proximity to rocks on the mainland of northwest Mexico and southwest US, and have not experienced significant Late Cretaceous to early Eocene offset relative to the Peninsular Ranges batholith. These data further provide a basis for testing possible connections between the Valle Group forearc basin succession with potentially correlative displaced units such as the Nainamo Group in British Columbia.

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