Earliest delivery of sediment from the Colorado River to the Salton Trough at 5.3 Ma: evidence from Split Mountain Gorge

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Introduction

Recent debate has focused on the timing of events that initiated the Colorado River and first delivered sediments to fault-bounded basins in the Salton Trough. Any successful model for integration of this system must include regional linkages from the Colorado River source to the basinal depocenter in the Salton Trough. The Bouse Formation is a regionally extensive, latest Miocene or earliest Pliocene sedimentary sequence along the lower Colorado River trough that represents this link. It includes a thin basal limestone that was deposited in either a marine estuary (Metzger, 1968; Metzger et al., 1973; Smith, 1970; Buising, 1988, 1990) or nonmarine lakes (Spencer and Patchett, 1997; Poulson and John, 2003; House et al., 2005, 2008), or both (McDougall, 2008), overlain by deltaic and fluvial claystone and sandstone. Recent studies document deposition of the basal Bouse limestone in lake waters that were delivered suddenly to the lower Colorado River corridor by large floods, thus heralding the earliest flows of the Colorado River (House et al., 2005, 2008; Spencer et al., 2008, 2011).

Despite recent advances, age constraints from two locations challenge our current understanding of how the Colorado River system first formed and became regionally integrated. According to any model for the Bouse Formation (lake, marine-estuary, or mixed), the earliest through-going Colorado River should post-date deposition of the basal Bouse limestone. A tuff near Buzzards Peak, which was recently correlated to the 4.83-Ma Lawlor Tuff based on major-element geochemistry (Sarna-Wojcicki et al., 2011), is interbedded with and overlain by basal limestone of the Bouse Formation. This predicts that the Colorado River should have first delivered sediment to the Salton Trough after 4.83 Ma. However, a well-dated section in the Fish Creek – Vallecito basin (FCVB), western Salton Trough, records first arrival of Colorado River sands there ~0.5 million years earlier, at 5.3 Ma (Fig. 1; Dorsey et al., 2007, 2011). An alternate route for the early Colorado River has not been fully tested, but seems unlikely.

The oldest Colorado River sands in the FCVB section are found at Split Mountain Gorge (Fig. 1), in the lower part of a 5.5-km thick section that has extremely tight age control based on multiple datasets (Dorsey et al., 2007, 2011). Below I review the data that provide a definitive age of 5.3 Ma for the first arrival of Colorado River sand at Split Mt. Gorge, and discuss some aspects of the problem raised by contradictory ages at Buzzards Peak and the FCVB.

Stratigraphy and age controls

Figure 2 shows the 5.5-km thick stratigraphic column for the FCVB in the western Salton Trough (Dorsey et al., 2007, 2011), with the Wind Caves member of the Latrania Formation highlighted in the lower part of the section. The age of this section has been determined from extensive study of paleomagnetism, microfossil biostratigraphy, and high-precision U-Pb dating of zircons in two ash beds (Dorsey et al., 2007, 2011). The dated ash beds high in the section unambiguously establish correlation of our magnetic-reversal chronology to the geomagnetic polarity time scale (GPTS). Dense sample

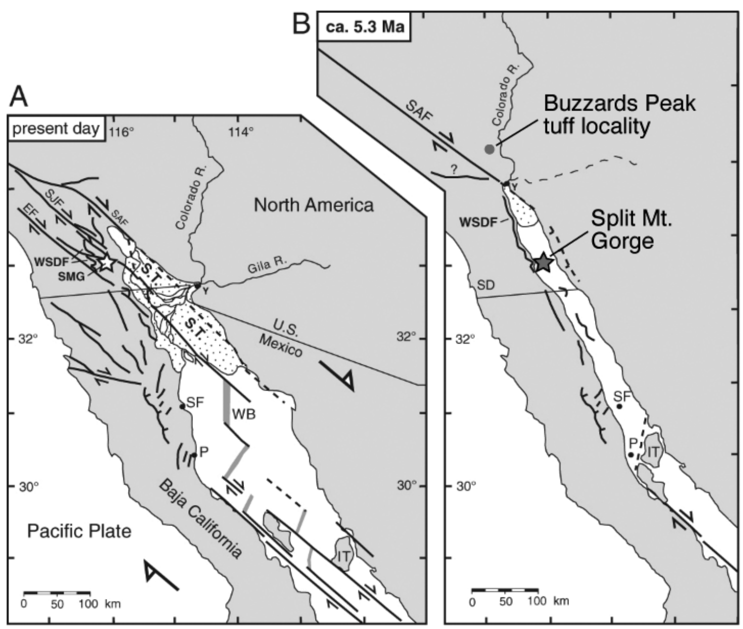

Figure 1. A. Regional tectonic map showing major faults in SE California and northwestern Mexico, and location of Split Mountain Gorge (SMG, star) in the western Salton Trough. B. Reconstruction for 5.3 Ma, restores ~250 km of dextral offset on the San Andreas fault. Note location of Buzzards Peak tuff locality. Stipple pattern shows area of subaerial Colorado Delta deposition, observed in the present-day and inferred for 5.3 Ma. Modified from Dorsey et al. (2007).

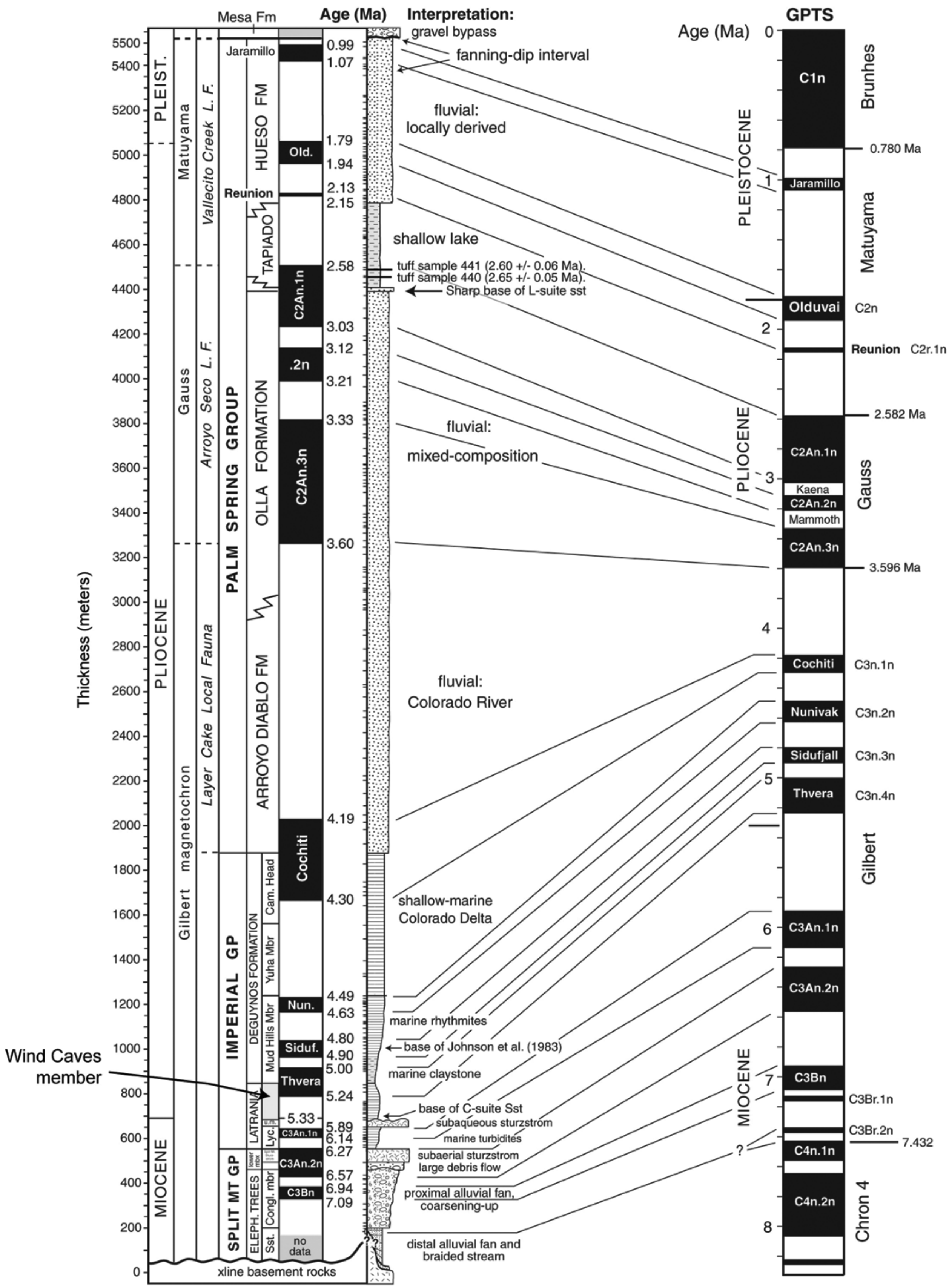

Figure 2. Stratigraphic column for the Fish Creek - Vallecito basin (modified from Dorsey et al., 2011). Tick marks on left side of column indicate locations of paleomagnetic sample sites.

spacing below that level ensures that we captured all of the magnetic reversals in the section. Tests of other possible correlations to the GPTS show that this is the only age model that does not impose unrealistic extreme anomalies in sediment-accumulation rates (Dorsey et al., 2011). Our preferred correlation to the GPTS is further confirmed by the 5.33-Ma Miocene-Pliocene boundary, which was identified using microfossil biostratigraphy by K. McDougall (in Dorsey et al., 2007).

The Wind Caves member is cut by several strike-slip and normal faults that add some uncertainty to the stratigraphic thicknesses and sedimentation rates in this part of the section. These faults deform a well-known stratigraphy. The Wind Caves member fines up-section into the lower claystone of the Mud Hills member of the Deguynos Formation, and the Mud Hills member coarsens gradually up into marine rhythmites that are capped by the base of the Yuha member (Winker, 1987; Winker and Kidwell, 1996; Dorsey et al., 2007, 2011). If the offset on these faults was large enough to juxtapose a younger magnetochron into the lower part of the measured section, it would be clearly revealed in the geology because the offset would produce an abrupt change to a different part of a well-known stratigraphy. Thus, although the section is cut by some faults, my mapping shows them to have rather small offset. Moreover, based on stratigraphic arguments it is highly unlikely that unidentified large faults could have

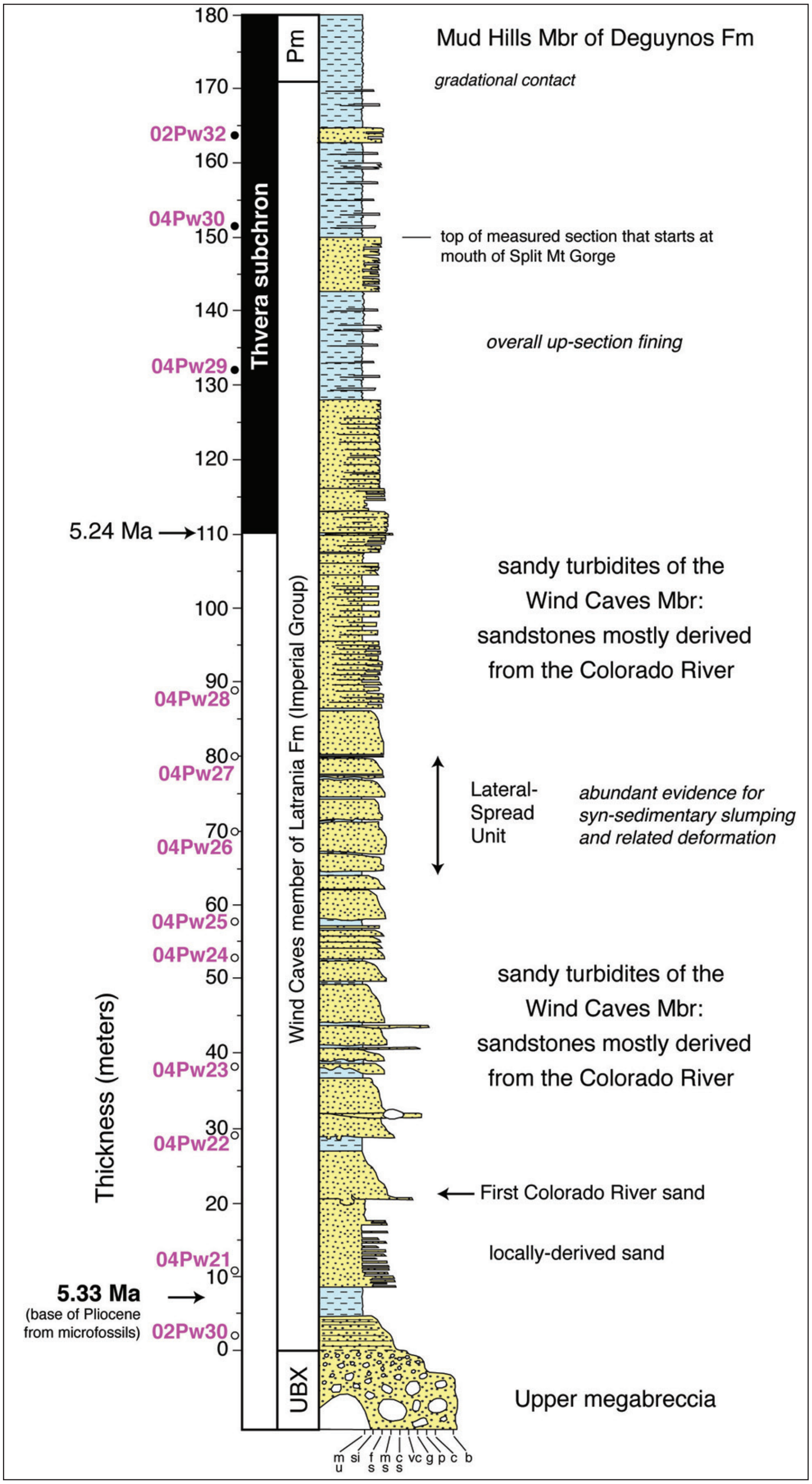

Figure 3. Measured section for the Wind Caves member of the Latrania Formation. Paleomagnetic sample sites (colored numbers) are from Dorsey et al. (2011).

caused us to misidentify the reversals and magnetochrons shown in Figures 2 and 3.

Figure 3 is a detailed measured section of the Wind Caves member (Pw) that shows the main variations in grain size and sedimentary structures. The continuous section starts at the southern mouth of Split Mountain Gorge (UTM 582,449 E; 3,651,021 N; WGS84, zone 11S) and ends on a ridge above the wash (582,151 E; 3,650,875 N). The upper 30 m of the section in Figure 3 was constructed by visual correlation of a sandstone bed south across an intervening ridge and into the main FCVB section (see map in Dorsey et al., 2007 Data Repository). The base of Pw is marked by a gradational contact with the underlying upper megabreccia, or "sturzstrom", which formed from a large rock avalanche (Kerr and Abbott, 1996; Winker and Kidwell, 1996; Abbott et al., 2002) (Figs. 2, 3). The lowest sandstone in Pw likely was deposited from a dilute turbidity current that trailed behind or was somehow related to subaqueous emplacement of the sturzstrom. Above that is ~5 m of mudstone overlain by well bedded turbidites composed of locally-derived sand (described below).

Starting ~21 m above the base of Pw, a normally graded thick sandstone bed (single-event turbidite) contains a 5-10 cm thick concentration of locally derived pebbly granule conglomerate that grades into sandstone composed of distinctive Colorado River sand (described below) mixed with locally-derived sand (Fig. 3). Sand in the upper part of this bed is mainly of Colorado River origin. Above that, thick-bedded turbidites are composed of Colorado-River sands with some basal concentrations of local pebbly sand with angular clasts of metamorphic rock similar to that of the megabreccia. Geologic mapping shows that the lower part of Pw onlaps irregular paleotopography on top of the megabreccia, suggesting that the concentrations of metamorphic pebbles and coarse locally derived sand may have been reworked from the breccia deposit before it was buried by the large influx of Colorado River sand and mud.

Sand compositions

As documented by Winker (1987), Colorado River-derived sands are easily distinguished from locally-derived sands through visual inspection with a hand lens and binocular microscope, and by observation of thin sections with a petrographic microscope. Locally-derived sands are lithic arkose composed of angular to subrounded feldspar, quartz, and detrital biotite, all eroded from nearby plutonic and metamorphic rocks. In contrast, Colorado River-derived sands are sublitharenites dominated by fine- to medium-grained, moderately to well rounded pink quartz, with lesser amounts of lithic fragments and feldspar. This difference is easy to see with a hand lens. In thin section, quartz grains display characteristic hematite coatings and syntaxial quartz overgrowths. The thin hematite coatings often are encased between the core grains (which are very well rounded) and attached quartz overgrowths that are in optical continuity with the core grains (and are less well rounded). These features are attributed to derivation from the Colorado Plateau (Buising, 1988, 1990), but this inference has not been rigorously tested.

Detrital zircon evidence

A recent study by Kimbrough et al. (2011) shows that Colorado River sands have a remarkably similar detrital zircon age signature through time, remaining statistically constant from the oldest sandstones dated at 5.3 Ma (Wind Caves member), through the Late Cenozoic stratigraphic section, into modern sands of the present-day Colorado river and delta system. Because of the geological dilemma posed by the published 4.83-Ma age of Bouse Formation at Buzzards Peak (as summarized above), Kimbrough suggested that perhaps the older sands of the Wind Caves member were derived from the Gila River instead of the main stem of the Colorado River. While this explanation has rapidly gained popularity among people who worry about these things, I believe that the idea is not supported by the existing data. This hypothesis is also contradicted by my recent visual inspection of a modern sand from the Gila River.

Several points are worth elaborating. (1) Figure 2 of Kimbrough et al. (2011) shows that detrital zircon ages of the Wind Caves sample fall well within the statistical variation of detrital zircon ages seen in all modern Colorado River and Delta sand samples, as defined by the 2 sigma envelope on a cumulative probability plot. An excursion produced by a relatively small age peak at ~1.1 Ga (Grenville age) deviates from the Colorado Delta reference curve less than another sample higher in the section that is ca. 3.0 Ma and nobody questions is from the Colorado River. (2) When compared to the Colorado River reference curve (Fig. 3 of Kimbrough et al., 2011), Gila River sand strays well outside of the 2 sigma error envelope, due primarily to a paucity of grains between ~500 and 1,300 Ma. This shows that Gila River sand has detrital-zircon ages that are statistically unlike those of Colorado River sand. (3) Sands in the Wind Caves member and all other Colorado River sands contain a small but distinctive population of grains dated between ~500 and 700 Ma. In contrast, modern sand from the Gila River lacks analyzed zircon grains of this age (Kimbrough et al., 2011). (4) I recently collected a modern sand from the Gila River main channel, well upstream of any detectable influence of Colorado River sediments. This is a well sorted medium-grained sand with abundant lithic fragments, some feldspar, and much less quartz than Colorado River sands (including sands from the Wind Caves member). None of the quartz grains contain the distinctive pink color produced by hematite coatings, and they do not display the well developed rounding and frosted appearance typical of Colorado River sands.

Thus, although it would be convenient if sandstones in the Wind Caves member were derived from the Gila River, I believe this hypothesis is unlikely for the reasons explained above.

Summary

Sand compositions and detrital zircon data for the Wind Caves member indicate that it was derived from the main stem of Colorado River, not the Gila River, starting at 5.3 Ma. While further tests of the sandstone provenance are needed, the age is firm and it seems unlikely that the Colorado-River source will be overturned. Geochemical data from the Buzzards Peak tuff support correlation to the 4.83-Ma Lawlor tuff (Sarna-Wojcicki et al., 2011), but the Buzzards Peak tuff has not been successfully dated using modern geochronological methods. Damon et al (1978) obtained an age of 5.47 ± 0.2 Ma from K-Ar dating of glass in the tuff, and Spencer et al. (2001) got perturbed age spectra using the $^{40}Ar/^{39}Ar$ method that yielded a best estimate of 5.01 ± 0.09 Ma, also from glass. This leaves us with an interesting and as-yet unresolved problem.

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