Chronology of Miocene–Pliocene deposits at Split Mountain Gorge, Southern California: A record of regional tectonics and Colorado River evolution

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ABSTRACT

Late Miocene to early Pliocene deposits at Split Mountain Gorge, California, preserve a record of basinal response to changes in regional tectonics, paleogeography, and evolution of the Colorado River. The base of the Elephant Trees Formation, magnetostratigraphically dated as 8.1 ± 0.4 Ma, provides the earliest well-dated record of extension in the southwestern Salton Trough. The oldest marine sediments are ca. 6.3 Ma. The nearly synchronous timing of marine incursion in the Salton Trough and northern Gulf of California region supports a model for localization of Pacific–North America plate motion in the Gulf ca. 6 Ma. The first appearance of Colorado River sand at the Miocene-Pliocene boundary (5.33 Ma) suggests rapid propagation of the river to the Salton Trough, and supports a lake-spillover hypothesis for initiation of the lower Colorado River.

Keywords: California, stratigraphy, tectonics, Miocene, Pliocene, Salton Trough, Colorado River.

INTRODUCTION

The Salton Trough is a large fault-bounded basin that occupies the Pacific–North America plate boundary in Southern California and northwestern Mexico (Fig. 1). Late Cenozoic subsidence resulted from combined slip on the dextral San Andreas fault on the NE and the oblique-normal West Salton detachment fault on the SW (Axen and Fletcher, 1998; Kairouz, 2005; Shirvell, 2006; Steely, 2006). Age estimates for the southern San Andreas fault range from 10–13 Ma (Matti and Morton, 1993) to 5–6 Ma (Ingersoll and Rumelhart, 1999). Recent work provides evidence for rapid localization of plate motion in the Gulf of California ca. 6 Ma (Oskin and Stock, 2003a, 2003b), but analysis of total extension suggests that dextral shear may have started in the Gulf as early as ca. 12 Ma (Fletcher et al., 2004). Improved dating of crustal deformation is needed to reconstruct the kinematic evolution of the plate boundary and test models for lithospheric rupture in the Gulf of California.

This paper presents a high-resolution stratigraphic study of late Miocene to early Pliocene sedimentary rocks at Split Mountain Gorge in the southwestern Salton Trough (Figs. 1 and 2). The timing of earliest extension in this area was previously not well known (Kerr, 1984; Winker, 1987; Winker and Kidwell, 1996; Axen and Fletcher, 1998), and the age of marine transgression has been widely but inaccurately cited as 4.3 Ma on the basis of existing magnetostratigraphy (Johnson et al., 1983). Data presented here provide precise new controls on the age of these deposits, allowing us to address long-standing questions about the timing and significance of regional tectonic and geomorphic transitions in southwestern North America.

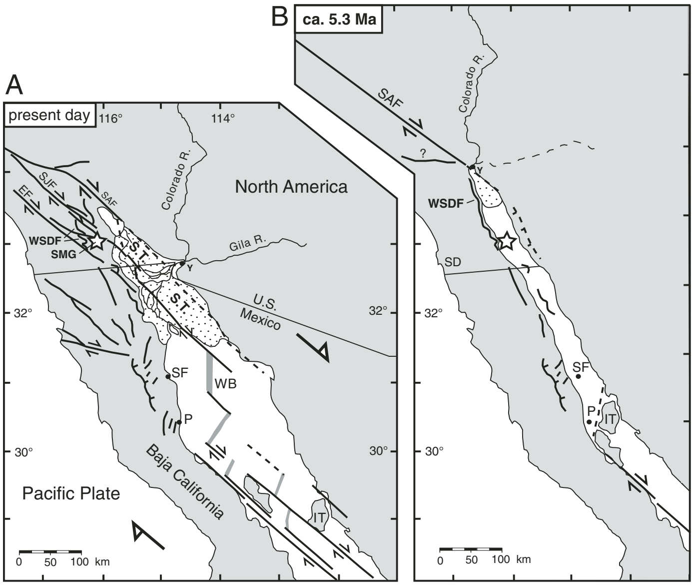

Figure 1. A: Regional tectonic map showing major faults in southeastern California and northwestern Mexico, and location of Split Mountain Gorge (SMG, star) in western Salton Trough. B: Reconstruction for 5.3 Ma restores ca. 250 km of dextral offset based on data of Oskin and Stock (2003b). EF—Elsinore fault, IT—Isla Tiburón, P—Puertecitos, SAF—San Andreas fault, SF—San Felipe, SJF—San Jacinto fault, S.T.—Salton Trough, WB—Wagner basin, WSDF—West Salton detachment fault, Y—Yuma. Stipple pattern shows area of subaerial Colorado Delta deposition, observed in the modern setting and inferred for 5.3 Ma.

TECTONIC SETTING

Split Mountain Gorge is a narrow canyon incised into late Cenozoic sedimentary rocks near the southwest margin of the Salton Trough (Fig. 1). These deposits occupy the lower part of a thick Miocene to Pleistocene sedimentary section that accumulated in a large rift basin (Johnson et al., 1983; Kerr, 1984; Winker, 1987; Winker and Kidwell, 1996). The basin formed largely in the upper plate of the oblique, dextral-normal West Salton detachment fault (Axen and Fletcher, 1998; Kairouz, 2005; Shirvell, 2006; Steely, 2006). The Split Mountain Group includes early to middle Miocene basalts of the Alverson Formation and rift-related alluvial

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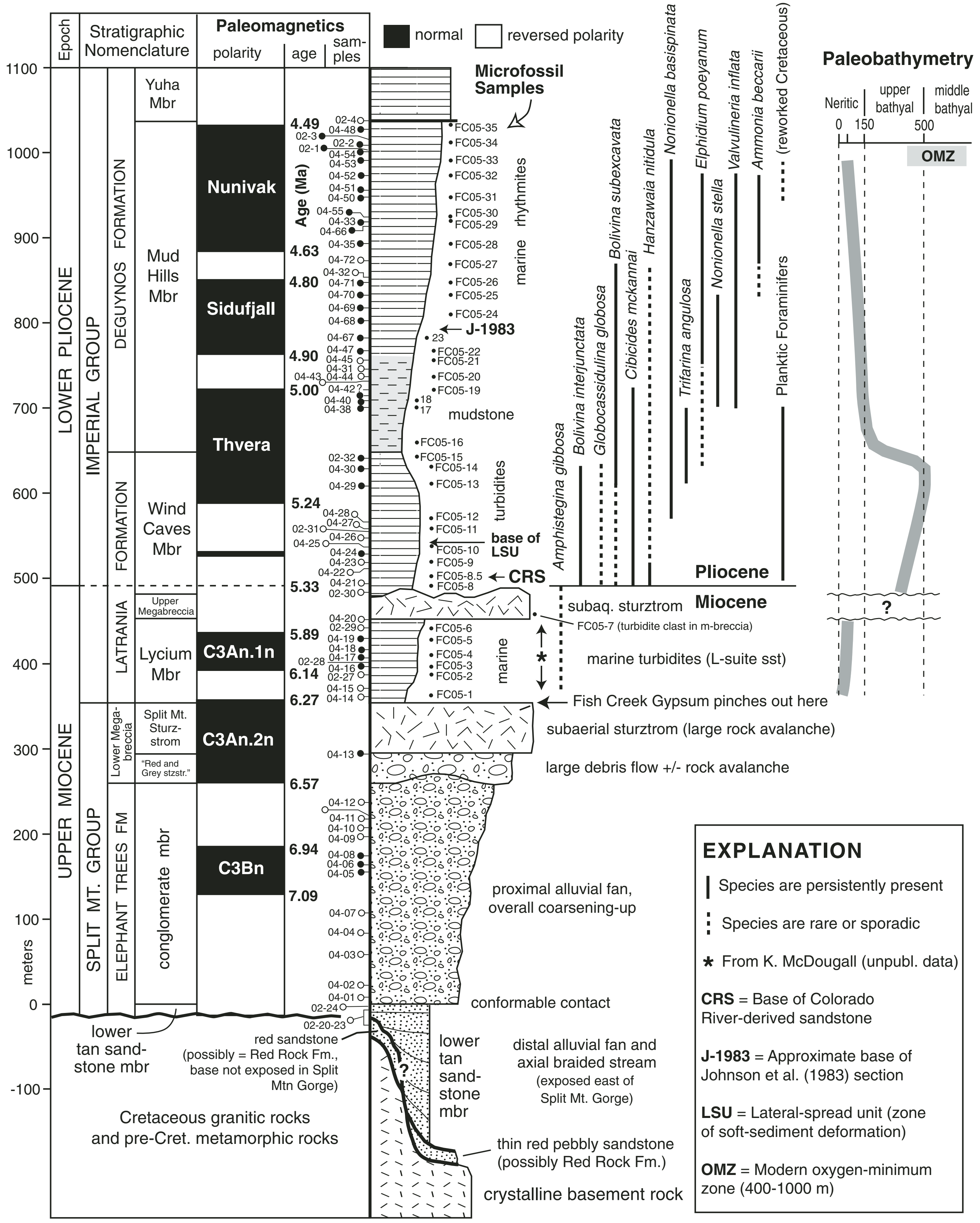

Figure 2. Measured section at Split Mountain Gorge showing results of stratigraphic, paleomagnetic, and micropaleontologic analysis. Species indicated are benthic foraminifers. m-breccia—megabreccia.

deposits of the Elephant Trees Formation, and is overlain by marine deposits of the Imperial Group. Sediment from the Colorado River accumulated first in a marine setting (Imperial Group) and later in a large fluvial-deltaic system (Palm Spring Group) that prograded into the basin during translation along the San Andreas fault (Winker and Kidwell, 1986, 1996).

METHODS

We measured, described, and sampled the section at Split Mountain Gorge using the geologic map of Winker (1987; we revised the map in areas of structural complexity [see Data Repository Fig. DR1[1]]) and stratigraphic nomenclature of Winker and Kidwell (1996) (Fig. 2). We collected samples for paleomagnetic analysis at 70 sites (5–7 samples per site), with an average sampling interval of 14 m (Table DR1; see footnote 1). Paleomagnetic measurements were conducted on a 2-G 755 Cryogenic magnetometer using stepwise thermal or alternating-field demagnetization. We collected 36 mudstone samples for micropaleontology analysis at intervals of 5–40 m (Table DR2; see footnote 1). Samples were processed with water on a 263 mesh screen. We examined 300 benthic foraminifers, or all specimens if fewer than 300, in each sample.

RESULTS

Paleomagnetic study revealed two components of magnetization: a first-removed component interpreted to be a recent viscous overprint, and a second-removed component interpreted to represent an ancient magnetization (Fig. DR2; see footnote 1). The second-removed component was resolved with variable quality, but in all cases the polarity was easily discerned, and series of normal and reverse polarity zones are thus defined (Fig. 2). Correlation of this section to the magnetic polarity time scale (Cande and Kent, 1995; Lourens et al., 1996) is based on overlap with the overlying Fish Creek–Vallecito section (calibrated using an ash dated as 2.3 ± 0.4 Ma [Opdyke et al., 1977, Johnson et al., 1983; Dorsey et al., 2006]) and on placement of the Miocene-Pliocene boundary using micropaleontology (this study).

A moderately diverse assemblage of foraminifers is present at Split Mountain Gorge (Fig. 2; Table DR2 [see footnote 1]). Rare benthic foraminifers in the Lycium member suggest deposition at inner neritic depths. These microfossils are similar to those observed in the northern Salton Trough, considered coeval with warm interval W10 (6.5–6.3 Ma) or W11 (5.6–5.5 Ma) (McDougall et al., 1999). The Miocene-Pliocene boundary is placed at sample FC05–8 based on the last appearance of *Amphistegina gibbosa* and first appearance of other foraminifers (cf. McDougall et al., 1999). Foraminifers in the Wind Caves member indicate upper bathyal water depths, with a possible abrupt deepening above the upper megabreccia. Poorly preserved Cretaceous planktic foraminifers reworked from the Colorado Plateau (e.g., Merriam and Bandy, 1965) are present near the top of the Mud Hills member (Fig. 2).

Cretaceous tonalite at the base of the section is overlain by a thin (~0–40 m) reddish pebbly sandstone that in turn is overlain along a progressive unconformity by southeast-thickening (~0–200 m) pale tan sandstone that we assign to the lower Elephant Trees Formation (Fig. 2). Previous workers assigned both sandstone units to the Red Rock Formation, which is overlain in Red Rock Canyon (8 km SE of the gorge) by basalts of the Miocene Alverson Formation (not present at Split Mountain Gorge) (Kerr, 1984; Winker and Kidwell, 1996). Because Alverson volcanics are dated as ca. 14–22 Ma, correlation of the tan sandstone to the Red Rock Formation would mean it is older than 15–20 Ma. However, contacts above this unit are conformable or represent short hiatuses, so we conclude that all reversed sites below the base of C3Bn and above the progressive unconformity are within the Gilbert magnetochron (younger than 7.43 Ma). Using a sedimentation rate of 0.2–0.5 mm/yr (nondecompacted, calculated between 0 and 450 m in Fig. 2) and a maximum age of 7.43 Ma for site 02–23, we extrapolate through 140–190 m of sandstone below that level and calculate an age of 8.1 ± 0.4 Ma for the base of the thickest part of the tan sandstone member.

The catastrophically emplaced lower megabreccia is overlain by marine turbidites of the Latrania Formation along a sharp contact that coincides with pinch-out of the Fish Creek Gypsum (Fig. 2). The megabreccia is absent and upper Elephant Trees sandstone is gradationally overlain by Latrania turbidites 2 km north of this exposure, indicating that no subchrons are missing due to erosion. Because the megabreccia directly overlies site 04Lbx13 (normal polarity) and represents very little time, we infer that the top of subchron C3An.2n (6.27 Ma) is located between the top of the megabreccia and site 04MPl14 (reversed polarity). The base of the Latrania Formation is thus assigned an age of ca. 6.3 Ma.

Turbidites of the Lycium member and lower 20 m of the Wind Caves member are composed of locally derived sand with quartz, feldspar, plutonic lithic fragments, and detrital biotite (Winker, 1987; this study). Sand composition changes abruptly to Colorado River–derived (C-suite) sand 9 m above the Miocene-Pliocene boundary (Fig. 2). C-suite sandstone contains abundant well-rounded quartz with hematite coatings, syntaxial quartz overgrowths, and distinctive chert and metavolcanic lithic fragments. At a locality 3.3 km NW of the northern entrance to Split Mountain Gorge, mudstone with late Miocene microfossils occurs near the base of a 14-m-thick transition from L-suite to C-suite sandstone. The base of C-suite sand thus coincides closely with the Miocene-Pliocene boundary, and is dated as ca. 5.3 Ma. Our paleogeographic reconstruction for this time shows that Split Mountain Gorge was located in the northern part of a narrow marine basin in a releasing stepover between the San Andreas fault in the north and other transform faults to the south (Fig. 1B). The Colorado River entered the north end of the basin, consistent with southward transport of turbidites in the Wind Caves member (Winker, 1987).

DISCUSSION AND CONCLUSIONS

The base of the Elephant Trees Formation, dated here as 8.1 ± 0.4 Ma, represents the earliest well-dated record of crustal extension or transtension in the southwestern Salton Trough. While this resolves uncertainty about the age of normal faults at Split Mountain, the significance of these faults remains uncertain: they could be coeval with early slip on the West Salton detachment fault, or they could predate the detachment fault and be related to late Miocene extension documented in northeastern Baja California (e.g., Stock and Hodges, 1989). In either case, the onset of normal faulting at Split Mountain Gorge may be related to a change in relative plate motion ca. 8 Ma (Atwater and Stock, 1998).

The base of the Imperial Group is dated here as ca. 6.3 Ma, similar to late Miocene marine deposits documented in a large region from the northern Salton Trough (McDougall et al., 1999) to the Gulf of California (Oskin and Stock, 2003a) (Fig. 1). Oskin and Stock (2003a, 2003b) inferred that marine incursion resulted from rapid localization of the Pacific–North America plate boundary in the Gulf of California ca. 6 Ma. Alternatively, marine flooding could have resulted from a latest Miocene global sea-level highstand superimposed on long-term extension and subsidence, an idea that is supported by the presence of reworked middle Miocene marine microfossils in the Fish Creek Gypsum (K. McDougall, unpublished data), northern Salton Trough (McDougall et al., 1999), Yuma (McDougall, 2005), and northern Gulf of California (Gomez, 1971). We favor a model for latest Miocene rapid focusing of plate motion in the gulf, but cannot rule out other hypotheses at this time.

Two hypotheses for initiation of the lower Colorado River involve: (1) headward erosion and capture of streams on the Colorado Plateau (Lucchitta, 1989; Lucchitta et al., 2001); or (2) downward-propagating lake-spillover events (Meek and Douglass, 2001; House et al., 2005). The Colorado River arrived after 6.0 Ma at Lake Mead (Spencer et al., 2001), after

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[1] GSA Data Repository item 2007020, Table DR1 (paleomagnetic sample positions and results), Table DR2 (micropaleontology sample positions and data), Figure DR1 (geologic map with sample locations), and Figure DR2 (orthogonal vector plots), is available online at www.geosociety.org/pubs/ft2007.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

5.5 Ma in the Davis Dam area (House et al., 2005), and ca. 5.3 Ma in Split Mountain Gorge (this study), so it apparently propagated 350–400 km to the Salton Trough in <200 k.y. This supports a rapid, top-down lake-spillover model for initiation of the lower Colorado River, but does not inform the debate over a marine-estuary versus lacustrine origin for the Bouse Formation. A poorly dated tuff in the Bouse Formation that predates arrival of the Colorado River near Yuma (Spencer et al., 2001) has been correlated to the 4.83 Ma Lawlor Tuff (McLaughlin et al., 2005; M. Perkins and A. Sarna-Wojcicki, 2006, personal commun.). A 4.83 Ma age for the Bouse tuff is puzzling because the Colorado River should have flowed past Yuma before arriving in the Salton Trough. Nevertheless, our chronology agrees with prior results (Johnson et al., 1983), and is the only solution that yields reasonable sedimentation rates between 3.5 and 2.0 Ma (Dorsey et al., 2006). This problem thus remains unresolved and requires further work.

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