**Geosphere**
geosphere.gsapubs.org
Expand

**First published online May 13, 2015, doi: 10.1130/GES01073.1**
**v. 11 no. 3 p. 660-682**

# Importance of groundwater in propagating downward integration of the 6–5 Ma Colorado River system: Geochemistry of springs, travertines, and lacustrine carbonates of the Grand Canyon region over the past 12 Ma

L.C. Crossey[1], K.E. Karlstrom[1], R. Dorsey[2], J. Pearce[3], E. Wan[4], L.S. Beard[5], Y. Asmerom[1], V. Polyak[1], R.S. Crow[1], A. Cohen[6], J. Bright[6] and M.E. Pecha[6]

⊞ Author Affiliations

## Abstract

We applied multiple geochemical tracers ($^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$, [Sr], $\delta^{13}\mathrm{C}$, and $\delta^{18}\mathrm{O}$) to waters and carbonates of the lower Colorado River system to evaluate its paleohydrology over the past 12 Ma. Modern springs in Grand Canyon reflect mixing of deeply derived (endogenic) fluids with meteoric (epigenic) recharge. Travertine (<1 Ma) and speleothems (2-4 Ma) yield $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ and $\delta^{13}\mathrm{C}$ and $\delta^{18}\mathrm{O}$ values that overlap with associated water values, providing justification for use of carbonates as a proxy for the waters from which they were deposited. The Hualapai Limestone (12 -6 Ma) and Bouse Formation (5.6-4.8 Ma) record paleohydrology immediately prior to and during integration of the Colorado River. The Hualapai Limestone was deposited from 12 Ma (new ash age) to 6 Ma; carbonates thicken eastward to ~210 m toward the Grand Wash fault, suggesting that deposition was synchronous with fault slip. A fanning-dip geometry is suggested by correlation of ashes between subbasins using tephrochronology. New detrital-zircon ages are consistent with the "Muddy Creek constraint," which posits that Grand Wash Trough was internally drained prior to 6 Ma, with limited or no Colorado Plateau detritus, and that Grand Wash basin was sedimentologically distinct from Gregg and Temple basins until after 6 Ma. New isotopic data from Hualapai Limestone of Grand Wash basin show values and ranges of $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$, $\delta^{13}\mathrm{C}$, and $\delta^{18}\mathrm{O}$ that are similar to Grand Canyon springs and travertines, suggesting a long-lived spring-fed lake/marsh system sourced from western Colorado Plateau groundwater. Progressive up-section decrease in $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ and $\delta^{13}\mathrm{C}$ and increase in $\delta^{18}\mathrm{O}$ in the uppermost 50 m of the Hualapai Limestone indicate an increase in meteoric water relative to endogenic inputs, which we interpret to record progressively increased input of high-elevation Colorado Plateau groundwater from ca. 8 to 6 Ma. Grand Wash, Hualapai, Gregg, and Temple basins, although potentially connected by groundwater, were hydrochemically distinct basins before ca. 6 Ma. The $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$, $\delta^{13}\mathrm{C}$, and $\delta^{18}\mathrm{O}$ chemostratigraphic trends are compatible with a model for downward integration of Hualapai basins by groundwater sapping and lake spillover.

The Bouse Limestone (5.6-4.8 Ma) was also deposited in several hydrochemically distinct basins separated by bedrock divides. Northern Bouse basins (Cottonwood, Mojave, Havasu) have carbonate chemistry that is nonmarine. The $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ data suggest that water in these basins was derived from mixing of high-$^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ Lake Hualapai waters with lower-$^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$, first-arriving "Colorado River" waters. Covariation trends of $\delta^{13}\mathrm{C}$ and $\delta^{18}\mathrm{O}$ suggest that newly integrated Grand Wash, Gregg, and Temple basin waters were integrated downward to the Cottonwood and Mojave basins at ca. 5-6 Ma. Southern, potentially younger Bouse basins are distinct hydrochemically from each other, which suggests incomplete mixing during continued downward integration of internally drained basins. Bouse carbonates display a southward trend toward less radiogenic $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ values, higher [Sr], and heavier $\delta^{18}\mathrm{O}$ that we attribute to an increased proportion of Colorado River water through time plus increased evaporation from north to south. The $\delta^{13}\mathrm{C}$ and $\delta^{18}\mathrm{O}$ trends suggest alternating closed and open systems in progressively lower (southern) basins. We interpret existing data to permit the interpretation that the southernmost Blythe basin may have had intermittent mixing with marine water based on $\delta^{13}\mathrm{C}$ and $\delta^{18}\mathrm{O}$ covariation trends, sedimentology, and paleontology. [Sr] versus $^{87}Sr/^{86}Sr$ modeling suggests that southern Blythe basin $^{87}Sr/^{86}Sr$ values of ~0.710-0.711 could be produced by 25%-75% seawater mixed with river water (depending on [Sr] assumptions) in a delta-marine estuary system.

We suggest several refinements to the "lake fill-and-spill" downward integration model for the Colorado River: (1) Lake Hualapai was fed by western Colorado Plateau groundwater from 12 to 8 Ma; (2) high-elevation Colorado Plateau groundwater was progressively introduced to Lake Hualapai from ca. 8 to 6 Ma; (3) Colorado River water arrived at ca. 5-6 Ma; and (4) the combined inputs led to downward integration by a combination of groundwater sapping and sequential lake spillover that first delivered Colorado Plateau water and detritus to the Salton Trough at ca. 5.3 Ma. We propose that the groundwater sapping mechanism strongly influenced lake evolution of the Hualapai and Bouse Limestones and that groundwater flow from the Colorado Plateau to Grand Wash Trough led to Colorado River integration.

Received 16 May 2014.
Revision received 17 January 2015.
Accepted 19 March 2015.

© 2015 Geological Society of America

## Articles citing this article

**Middle Jurassic landscape evolution of southwest Laurentia using detrital zircon geochronology**
Lithosphere, April 1, 2016, v. 8, p. 185-193
Abstract Full Text Full Text (PDF)

**DID A CATASTROPHIC LAKE SPILLOVER INTEGRATE THE LATE MIOCENE EARLY PLIOCENE COLORADO RIVER AND THE GULF OF CALIFORNIA?: MICROFAUNAL AND STABLE ISOTOPE EVIDENCE FROM BLYTHE BASIN, CALIFORNIA-ARIZONA, USA**
PALAIOS, March 1, 2016, v. 31, p. 81-91
Abstract Full Text Full Text (PDF)