Rifting in the BR in the Late Jurassic and Early Cretaceous was accompanied by uplift of parts of the TZ and erosional removal of lower Mesozoic and upper Paleozoic strata. This uplift event is recorded by a pre-Late Cretaceous unconformity, where sedimentary rocks of the Cretaceous Interior Seaway were deposited on successively older rocks, from the Four Corners region southward to east-central Arizona. A similar uplift history, although not well documented, may have also affected the TZ of western Arizona, to explain Proterozoic clasts in Late Mesozoic conglomerates (McCoy Group) and the deposition of Late Cretaceous volcanic rocks directly on Proterozoic basement at Bagdad.

In the Late Cretaceous and early Tertiary, Laramide compression and magmatism affected all three provinces, but not equally. The BR was the most affected, being subjected to widespread intermediate to felsic magmatism, basement-involved thrusting, and associated folding and metamorphism. The TZ contains only scattered Laramide stocks and dikes, and the dominant Laramide structures are monoclines, which trend north-south, northwest, and east-west. Monoclines locally uplifted the TZ relative to the CP, such as along the north-facing Diamond Rim / Christopher Mountain monocline and the east-facing Canyon Creek monocline. During and after this uplift, large canyons were cut into the uplifted blocks, such as the Salt River paleocanyon and canyons in the western part of Grand Canyon. Gravels (Mogollon Rim Formation and correlatives) derived from the uplifted blocks were transported north and east down the canyons and deposited onto the topographically lower CP. A major drainage divide evidently existed within or southwest of the TZ, separating these north- and east-flowing drainages from

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Mapping of Miocene hydrothermal systems in the Marysvale Volcanic Field, west-central Utah, using AVIRIS High-resolution remote sensing data.

SCHMIDT, DWIGHT L.

Late Miocene aquifer beneath southwestern Colorado Plateau, a precursor to the Grand Canyon reach of the Colorado River. Part I, apparent evidence

Major discharge from springs issuing from a large carbonate-rock aquifer beneath the southwestern Colorado Plateau in the vicinity of the modern Grand Canyon, north western Arizona, deposited the Hualapai limestone along Grand Wash Cliffs at the Colorado Plateau-Basin Range boundary (herein proposed). Deposition of the limestone ended at 5 Ma, concurrent with the first appearance of surface water of the Colorado River at Grand Wash Cliffs. The River deposited its earliest gravel conformably on top of the Hualapai limestone. The spatial coincidence and chronologic succession of these events and deposits strongly suggests that the aquifer was a precursor of the modern Colorado River in its Grand Canyon reach. Evidence that a Late Miocene aquifer preceded the cutting of Grand Canyon is as follows:
(1) The Hualapai limestone, 11-5 Ma (M. A. Wallace, 1999), has the sedimentary characteristics of a carbonate, supersaturated, spring-discharge deposit. (2) Preliminary Sr isotope data suggest a similarity between the high radiogenic Sr content of the Hualapai limestone and that of modern aquifer water transmitted through Paleozoic carbonate rocks in and near the Grand Canyon (see abstract Part II, Schmidt, this volume). (3) Oxygen isotope data suggest a nonevaporative deposition of the Haulapai limestone. (4) In contrast, gypsum and halite, normally expected in solution in the paleoaquifer and spring discharge, are found as large evaporative salt deposits downslope from the Hualapai limestone.
(5) A large potential gradient favored a west-flowing aquifer after about 16 Ma when extensional deformation greatly lowered the Basin-Range relative to the Colorado Plateau. By about 11 Ma, this gradient was fully utilized by the paleoaquifer that deposited the Hualapai limestone, and at 5 Ma, its average gradient was a measurable 3-4 m/km over a distance of 200 km between the Kaibab Upwarp-Bidahochi basin and Grand Wash Cliffs. 6) Fractures and joints in the thick Paleozoic-carbonate strata of the southwestern Colorado Plateau seem adequate for efficient, fracture-controlled aquifer flow. (7) An adequate fracture network is also suggested by the probable existence of older regional aquifers that had previously utilized most fractures used by the Late Miocene aquifer. (6) By about 11 Ma after Oligocene-Miocene reversal of surface drainage on the southern Colorado Plateau, abundant new surface water from the upper Colorado River Basin flowed into the Bidahochi basin and recharged into the Kaibab limestone, earlier on the east side, and later on the west side of the Kaibab Upwarp.

SCHMIDT, DWIGHT L.

Late Miocene aquifer beneath southwestern Colorado Plateau, a precursor to the Grand Canyon reach of the Colorado River. Part II, Sr isotopes

Voluminous limestone in the Hualapai member of the Muddy Creek Formation, 11-5 Ma (M.A. Wallace, 1999), was deposited entirely by spring-discharge along the Grand Wash Cliffs at the Basin Range-Colorado Plateau border, northwestern Arizona (see abstract, Part I, Schmidt, this volume). The spring water discharged from a large, Late Miocene carbonate-rock aquifer beneath the southwestern Colorado Plateau between the Kaibab Upwarp and the Grand Wash Cliffs.

The Hualapai limestone has a high radiogenic Sr 87/86 of 0.7145 ‰, the same as the Sr ratio of the paleoaquifer water from which it was deposited. Along a 30-km reach of Grand Canyon below South Rim, strontium ratios in present-day spring discharges are also radiogenic, 0.711 to 0.715 (Margot Truini, written commun., 2000). These ratios suggest that the Paleozoic carbonate rock of much of the Grand Canyon region may contain abnormally high radiogenic Sr, and that ground water flowing through this altered rock acquires high radiogenic Sr. By comparison, normal Paleozoic marine limestone has Sr ratios of 0.708-0.709. Probably, the Paleozoic rocks beneath the Grand Canyon region were inconspicuously altered by low-temperature, hydrothermal solutions enriched in highly radiogenic Sr derived from the underlying Precambrian igneous and metamorphic rocks. This unrecognized alteration might have coincided with uranium and other mineralization of some of the hundreds of large breccia