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 %o, 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 pipes located in and near Grand Canyon. Mineralization age is uncertain and ranges from Laramide-Sevier to Mississippian age.

The Sr alteration of the Paleozoic limestone of the Grand Canyon region is also affirmed by a large increase of the Sr-isotope ratio of the modern surface water of the Colorado River; Upstream of Grand Canyon the Sr ratio of river water is about 0.7092, but downstream it is about 0.7106 (P. J. Patchett, written commun., 2000). For a large river, this radiogenic Sr increase is pronounced, but seems generally proportional (1) to the ground-water volume and (2) to the above-suggested widespread Sr-isotope content of the present-day spring discharge into the river in Grand Canyon. Modern upper Colorado River surface water within the Grand Canyon presumably mixes with discharging ground water having a high radiogenic Sr content derived from altered Paleozoic carbonate rock adjacent to the Grand Canyon. In a similar situation, some of the Late Miocene, ancestral upper-Colorado-River water was recharged and flowed through the same altered Paleozoic carbonate rock and became the high radiogenic-Sr ground water of the paleoaquifer that deposited the Hualapai limestone.

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A preliminary assessment Of the glacial geology and geomorphology of Great Basin National Park, east-central Nevada.

Great Basin National Park (GBNP) is located in east central Nevada approximately 286 miles north of Las Vegas. The park includes much of the southern Snake Range rising to a maximum elevation of 3,982 meters at the summit of Wheeler Peak. The park is located in the Great Basin, a portion of the Basin and Range physiographic province that drains internally. Centered on the state of Nevada and extending from southern Oregon to western Texas, the Basin and Range Province is an immense region (~ 200,000 mi.2) of alternating, north-south trending, faulted mountains and flat valley floors. Topographically high regions like the Snake Range are found throughout the Great Basin and produce drastically different microclimates from the surrounding low lying valleys. For example, the high peaks of the Snake Range provide refuge for the only remaining active rock glacier in the interior Great Basin. Thus, the climate of GBNP is the closest modern analog we have for Late Quaternary climatic conditions.

It has long been recognized that the southern Snake Range in GBNP was glaciated during the last Ice Age. Early explorers (Gilbert, 1875; Simpson, 1876; and Russell, 1884) first described glacial features in the Snake Range and subsequent authors have continued to substantiate their reports (Weldon, 1956 and Kramer, 1962). However, little research had been conducted on the glacial history and paleoclimate of GBNP since this early reconnaissance work. There have been numerous studies on glaciation and paleoclimate throughout the Great Basin but to prior to this study, there had not been a formal investigation into the glacial geology and paleoclimate of the Snake Range and GBNP (Osborn and Bevis, 1997 and Osborn, 1988).

This study presents a preliminary map of glacial deposits and landforms in Great Basin National Park. The general surficial geology and glacial geomorphology has been mapped at a scale of 1:24,000 including the location and extent of cirques, moraines, and an active rock glacier. Relative age constraints have also been developed for prominent glacial deposits following the guidelines of Blackwelder, 1931; Sharpe, 1938; Birkeland, 1964, 1974; and Wayne, 1984.

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New Geologic Mapping in Utah's Dixie, St. George Basin and Zion National Park, Southwest Utah

The St. George basin is experiencing some of the most rapid urban growth in Utah. Because of its setting in a tectonically active area with extensive shallow and exposed bedrock, many geologic concerns have arisen. These include an unusually large variety of geologic hazards, limited industrial minerals needed for construction, water supply issues, unique geologic features that merit preservation, and conflicting land management plans that generally have a geologic component.

As a result of these concerns, in 1994 the Utah Geological Survey (UGS) Mapping Program began an extensive geologic mapping effort in the basin. Currently, we have completed ten 1:24,000-scale quadrangles that were funded with a 50:50 cost share under the National Cooperative Geologic Mapping Program. In 1996, the UGS Mapping Program expanded its efforts and began a project to map the eight quadrangles encompassing Zion National Park. This project is nearing completion and was funded in part by the National Park Service (NPS).

Thus, since 1994, the UGS has published or is nearing completion of 18 1:24,000-scale geologic maps in the greater St. George basin area. These maps provide unprecedented geologic map coverage of over 2,700 km2 across the western margin of the Colorado Plateau and adjacent transition zone with the Basin and Range Province. Already, the maps have served as the basis for a GIS-based geologic hazards map folio of the burgeoning St. George basin; as a guide to ongoing paleoseismic investigations of the Hurricane fault zone; as the foundation for general-interest geologic reports on Zion National Park, and Quail Creek and Snow Canyon State Parks; and will form an important GIS layer in the NPS's Zion National Park Resource Management Area database. The maps have also been a critical resource in ongoing efforts to set aside habitat for the endangered desert tortoise, and to delineate scarce sand and gravel resources before they are covered by construction.

These geologic maps provide a wealth of new data, but like any good maps they raise as many questions as they solve. We know, for example, that long-term downcutting rates vary systematically along the Virgin River, yet river terraces remain poorly dated and poorly correlated across the region. We have mapped the extent of debris-flow deposits high on the Kolob Terrace, but the age and significance of these deposits are imperfectly understood. At the base of the Cretaceous section, we have identified strata of late Early Cretaceous age that have affinities with the Cedar Mountain Formation of central