tinct element of the Cordillera. During the Phanerozoic Era, areas surrounding the Colorado Plateau have been subjected to repeated tectonism, including contraction, extension, and magmatism while the plateau has been little affected by these processes. Deformation and magmatism mostly wrap around the Colorado Plateau, suggesting the plateau is a rigid body that has often transmitted forces across itself. Compiled geophysical and petrologic evidence indicates that the lithosphere of the Colorado Plateau has a higher strength than regions to the east, south and west. Strength differences may be attributed to a mafic crustal composition and long-term lower crust and mantle geothermal gradients, especially relative to the Basin and Range Province. Estimates of crustal and lithospheric thickness indicate that the ratio of the thickness of mantle to crust in the northern Basin and Range Province ranges from 0.8 to 1, whereas the same value in the Colorado Plateau is about 1.2. Given that mantle rocks are stronger on average than crustal rocks, the ratio of crust to mantle and the greater total thickness of the Colorado Plateau lithosphere also make it inherently strong.

Some evidence suggests that fertile or hydrated mantle may exist beneath the Colorado Plateau. Rock strength data show that mafic rocks in the crust and high pyroxene and amphibole contents in the upper mantle may enhance lithospheric strength, or, at a minimum, provide no reason to presuppose that a fertile, hydrated mantle should be weak.

The Colorado Plateau, although inferred to be stronger than regions to the west, south, and east, may not be as strong as the Archean Wyoming Province to the north. Higher seismic velocities in the lower crust and upper mantle north of the Cheyenne belt imply a higher strength in the middle Rocky Mountains. In this context, the Uinta aulacogen, which separates the Wyoming Province and the Colorado Plateau, developed as a "pop up" structure during Mesozoic to early Tertiary contraction. Thus, in understanding the tectonic history of the western U.S., or any region for that matter, it is important to assess the relative compositional and thermal structure of the lower crust and upper mantle. These factors have exerted considerable control over the partitioning of strain and magmatism throughout the Cordillera in the Colorado Plateau region during the last 1 Ga. Similar factors play an important role in the architecture of mountain systems throughout the world.

QUIGLEY, MARK C., and KARL E. KARLSTROM,
DEPARTMENT OF EARTH AND PLANETARY SCIENCES, UNIVERSITY OF NEW MEXICO, ALBUQUERQUE, NM, 87131

Tectonic inheritance at the Colorado Plateau - Basin and Range margin – Miocene uplift of the Virgin Mountain anticline influenced by reactivation of Proterozoic and Laramide structures

TheVirgin Mountain anticline (VMA) is a NE-trending basement-cored uplift that straddles the Colorado Plateau – Basin and Range margin in southeast Nevada and northwest Arizona, approximately 15 km south of the Utah border. Our hypothesis is that this region has been an important zone of weakness from the Paleoproterozoic through to the present, and that Miocene extension and uplift was significantly influenced by inherited structures and tectonic boundaries. Two processes: 1) reactivation of basement structures, and 2) utilization of lower Paleozoic rheologic heterogeneities, influenced were the Colorado Plateau margin was originally defined and how Miocene extension was made manifest at this margin from ~20 to 5 Ma. Intense 1.7 Ga fabrics and the presence of exotic lithologies (ultramafics, pillow volcanics, chert) suggest that this structure may have been part of a Paleoproterozoic province boundary. NE-trending upper greenschist grade dextral-transpressional mylonites are ubiquitous throughout the VMA, suggesting that this area was a high strain zone during Mesoproterozoic (~1.4 Ga) transpressive deformation. N to NW-trending "monoclinal-type" geometries in the Paleozoic and Mesozoic sections, and the position of the VMA between the thin-skinned Sevier thrust belt and thick-skinned monoclines of the Colorado Plateau, suggest a Laramide (~65 Ma) component of deformation. Miocene extension was generally exhibited by brittle oblique dip-slip fault reactivations of strongly fissile mylonitic foliations in the basement, steep and shallow normal faulting in the Tapeats sandstone, basal-glide and westward tectonic thinning in the Bright Angel shale, and steep to moderate normal and antithetic normal faulting in the overlying Paleozoic carbonates. Highly angular (>60°) relationships are observed in the Lower Paleozoic section on the west limb of the VMA. This structural-rheological partitioning and deflection of strain may give insights into the complex Miocene strain field observed at the Colorado Plateau - Basin and Range margin.

REYNOLDS, S. J., POTOCHNIK, A., and LEIGHTY, R. S.

Tectonic Evolution of the Arizona Transition Zone

The Transition Zone (TZ) of Arizona lies between the Colorado Plateau (CP) and Basin and Range (BR) Provinces, and shares some physiographic, stratigraphic, and structural aspects with each. The oldest rocks in all three provinces are Proterozoic metavolcanic and metasedimentary rocks, which record the evolution from oceanic to continental environments from >1.75 to 1.65 Ga. These rocks were strongly deformed, mostly between 1.7 and 1.6 Ga, and structurally are dominated by north- to northeast-trending folds, cleavage, high-strain zones, and shear zones. The rocks were intruded by Proterozoic granites before, during, and after deformation, and subsequently overlain in places by sedimentary and volcanic rocks of the mid- to late Proterozoic Grand Canyon Supergroup and Apache Group. All three provinces then received a similar, ~1 km-thick cover of platformal Paleozoic clastic and carbonate rocks.

With the onset of subduction beneath the southwestern edge of North America in the Triassic, the stratigraphic and structural histories of the three provinces began to diverge. Triassic and Jurassic rocks are not preserved in the TZ, but sequences of these rocks in the BR and CP have stratigraphic ties and some commonalities, indicating that the TZ originally contained similar Lower Mesozoic sequences and did not block sediment transfer between neighboring provinces at this time. In the Early to Middle Jurassic, for example, the TZ evidently contained the facies change between volcanic-dominated sequences of the BR and sediment-dominated ones of the CP.

The Geologic Transition, High Plateaus to Great Basin – A Symposium and Field Guide (The Mackin Volume) (2001)

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

ROCKWELL, B.W., CUNNINGHAM, C.G.*, CLARK, R. N., SUTLEY, S.J., GENT, C.A., and ROWLEY, P.D.

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