Abstracts

The New Mexico Geological Society annual spring meeting was held at New Mexico Institute of Mining and Technology (Socorro) on April 12, 1996. Following are the abstracts from all sessions given at that meeting.

GEOCHRONOLOGY I SESSION

GEOCHRONOLOGY AS IT PERTAINS TO THE PUBLIC, by *M. T. Heizler,* New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology Socorro, NM 87801

Radioactivity is not something that endears itself to the public. Aside from specialized medical uses, irradiation for food sanitation and gemstone coloration, and for production of nuclear power, radioactivity is generally perceived in a negative light.

Almost all absolute geochronologic methods are based on the radioactive decay of a parent nuclide to a stable daughter product. The decay rate is known as the half-life, and varies from less than seconds to tens of billions of years. The geologic situation generally dictates which dating method is most appropriate for understanding the absolute time, duration, and/or episodicity of a geologic processes. To the public as a whole, geochronology is an obscure concept and is perceived as having little or no practical uses. Although geochronology is a primary tool used by almost all academic geologic disciplines, it can also provide important information that is directly applicable outside campus walls.

The New Mexico Geochronological Research Laboratory (NMGRL) is a $^{40}Ar/^{39}Ar$ dating facility operated within the New Mexico Bureau of Mines and Mineral Resources. The laboratory is clearly a state facility and thus has an obligation to provide information and resources to the citizens of New Mexico. Application of argon geochronology is relatively far reaching with respect to the New Mexican public, but its contribution is not always obvious. Argon geochronology is a primary method of determining how long and how high temperatures (known as paleotemperatures) have persisted in environments such as sedimentary basins and geothermal systems. Paleotemperature data in sedimentary basins has direct impact on the potential of oil, gas, and coal resources and can be used to predict the longevity of geothermal resources. Geochronologic data also provides vital information on how, when, where, and why precious- and base-metal deposits form. The NMGRL works closely with industry to enhance exploration potential by identifying rock units of characteristic age that produce economically important mineral deposits. Also, understanding the temporal evolution of a specific mineral district or deposit provides models that can be used in wildcat drilling programs to help determine possible economic resources. Assessment of earthquake recurrence rates, water transport and recharge rates in hydrologic systems, and volcanic hazard information are just a few additional applications for geochronologic methods.

An equally important resource that directly and indirectly benefits the citizens of New Mexico are the human resources associated with the facility. The laboratory obtains a significant amount of funding from outside the State of New Mexico, which gets funneled into the state and local economy. The NMGRL currently employs two, nearly full-time staff members and three undergraduate students without state-appropriated funds. Also, several graduate-student research projects are supported by the laboratory, thus enhancing the enrollment at New Mexico Tech, which ultimately provides resources for the state and the city of Socorro.

GEOCHRONOLOGIC STUDIES IN THE GRANTS URANIUM DISTRICT, NEW MEXICO, by *W. R. Berglof,* University of Maryland, Asian Division, Unit 5060 Box 0100, APO AP 96328-0100; and *V. T. McLemore,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Geochronologic studies of Colorado Plateau uranium deposits began around 1950 during the early years of the "uranium boom," but detailed studies in the Grants district were not published until more than thirty years later, after most mining had ended. Early work in Utah and Colorado yielded mostly discordant U-Pb ages; these nevertheless suggested a late Cretaceous to early Tertiary (Laramide) age for several deposits, similar to the vein-type deposits of the Colorado Front Range. This idea was influential throughout the 1950s and early 1960s. Geologic studies in Grants and other districts, and slowly accumulating new geochronologic data, then suggested that many Plateau deposits are in reality much older, often approaching the age of their host rocks. Subsequent work has supported this latter interpretation.

The following conclusions have been reached for the Grants district from geochronologic studies published since around 1980. At Ambrosia Lake and Smith Lake, primary (trend) ore formed early in the history of the host sandstones of the Upper Jurassic Morrison Formation, at 130 Ma or earlier, on the basis of U-Pb data and Rb-Sr and K-Ar ages of clay minerals penecontemporaneous with uranium minerals. Redistributed (stack) ore and an oxidized uranium mineral (uranophane) at Ambrosia Lake have late Tertiary U-Pb ages of 3 to 12 Ma, consistent with geologic evidence on remobilization of uranium. Redistributed Morrison ore in the Church Rock area is as young as Pleistocene; redistribution was not extensive at Smith Lake. Primary deposits in the Morrison at Laguna may be younger than at Ambrosia Lake, but limited age data are inconclusive. The age of primary deposits in the Middle Jurassic Todilto Limestone is 150–155 Ma, close to the age of the Todilto; these deposits are older than those in the Morrison. Secondary Todilto uranophane yields U-Pb ages of 3 to 7 Ma, confirming Tertiary redistribution of uranium in this formation as well.

Most U-Pb ages from all ore-bearing horizons are discordant, attributed mainly to open-system behavior involving migration of radiogenic Pb and relatively long lived, intermediate daughter isotopes in the ^{238}U decay chain. In this interpretation the $^{207}Pb/^{235}U$ age is the most reliable, and generally yields a minimum age. However, some ages are concordant. In addition, concordia diagrams provide meaningful conclusions from discordant age data. Migration of ^{238}U daughters and subsequent decay to ^{206}Pb produces anomalous radiogenic $^{207}Pb/^{206}Pb$ ratios and resulting apparent ages in many samples. Some $^{207}Pb/^{206}Pb$ "ages" are greater than 1,000 Ma in Morrison and Todilto samples that are deficient in ^{206}Pb. By contrast, excess ^{206}Pb produces a negative or "future" age of −840 Ma for one Todilto sample; four ages ranging from −19 to −580 Ma for Ambrosia Lake, Smith Lake, and Church Rock samples; and an extreme of −13,000 Ma for one Ambrosia Lake sample ($^{207}Pb/^{206}Pb$ = 0.008). Such anomalies were not observed in early studies and provide especially strong evidence of complex open-system behavior.

AGE AND GEOLOGY OF THE MINERAL DEPOSITS IN THE ORGAN MOUNTAINS DISTRICT, DOÑA ANA COUNTY, NEW MEXICO, by *V. T. McLemore, T. C. Pease,* and *V. W. Lueth,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The Organ Mountains form a west-tilted block exposing rocks ranging in age from Proterozoic through Quaternary. In the Oligocene, the Organ batholith and volcanic rocks associated with the Organ caldera were emplaced. The Organ batholith is a complex pluton made up of three major phases: the granite of Granite Peak, Sugarloaf Peak quartz monzonite and Organ Needle quartz syenite (Seager, 1981). Mineralization in the Organ Mountains district was discovered in the 1830s and perhaps as early as 1797. Production in 1869–1962 amounted to 25 million lbs of Pb, 2.7 million lbs of Zn, 4,636,000 lbs of Cu, 820,000 oz of Ag, and 11,500 oz of Au worth $2.7 million. It is the sixth-largest lead-producing district in New Mexico, although there is no current production.

Six types of mineral deposits are found in the district and are within or centered around the Sugarloaf Peak quartz monzonite. Three centers of disseminated Cu-Mo minerals (porphyry Cu-Mo deposits?) are surrounded by innermost Cu skarns and breccias, Zn-Pb skarns, Pb-Ag replacements, Au-Ag veins, and an outermost barite-fluorite zone (Dunham, 1935; Seager, 1981). The relationship of the barite-fluorite zones to the mineralization centers is inconclusive; they are similar to the Rio Grande rift barite-fluorite-galena deposits that are thought to be associated with extension along the rift. This district-wide zoning is best preserved in the north part of the district where disseminated Cu-Mo minerals, representing a faulted portion of a larger porphyry Cu-Mo deposit, were found in drill holes northwest of Organ. Copper-breccia and Cu skarn deposits are found adjacent to the porphyry deposit (Excelsior mine) and grade outward from the pluton to Zn skarns (Merrimac mine), to Pb-Zn replacement deposits (Hilltop mine), to distal Pb-Ag-Mn replacement deposits (Black Prince mines). Adjacent to a second center of mineralization near San Augustin Pass are Cu breccia deposits at the Torpedo, Zn skarns at the Memphis, Zn-Pb replacement deposits at the Homestake, Pb-Zn replacements at the Philadelphia and Stephenson–Bennett mines, and Au-Ag pegmatites and veins in the Mineral Hill area. The Modoc Pb-Zn skarn and replacement deposits and Ruby fluorspar deposits are related to the third center of mineralization near Organ Peak. All of these gradational changes occur along faults associated with the Organ caldera and/or batholith margin. Mineralization style, metal zoning, and fluid inclusion data indicate that these deposits are related and they could have formed by mixing of magmatic and meteoric fluids.

The Sugarloaf Peak quartz monzonite was dated by K-Ar as 32.8±0.5 Ma by Loring and Loring (1980). Several dikes north of Organ intruding the Sugarloaf Peak quartz monzonite were also dated, and some of these dikes had age dates that were older than the age date obtained of the older pluton (32.1–34.4, Loring and Loring, 1980). Therefore, relatively unaltered samples of the Sugarloaf Peak quartz monzonite and a pegmatite at San Augustin Pass were collected and dated by $^{40}Ar/^{39}Ar$ methods at NMBMMR.

Biotite from the Sugarloaf Peak quartz monzonite yielded a flat spectrum with a well-defined plateau at 33.1±0.1 Ma. K-feldspar yielded a saddle-shaped spectrum, with flat segments centered at approximately 33 and 41 Ma. The shape of the age spectrum, which is in part older than the biotite plateau, indicate excess Ar in this K-feldspar. Hornblende yielded a disturbed age spectrum. Low radiogenic yields coupled with anomalously high K/Ca ratios indicate alteration and/or contamination by K-bearing phases. The biotite age of 33.1±0.1 Ma is considered the best estimate for when the pluton cooled through the biotite closure temperature of ~300°C.

K-feldspar from the Quickstrike pegmatite yielded a rising spectrum with flat segments averaging 30.8±0.1 and 32.2±0.1 Ma. The form of the spectrum suggests that the K-feldspar closed at 32.5 Ma and was reheated and partially reset at 30.8 Ma. The younger age suggests that hydrothermal fluids were mobile and reset the age date. The isochron plot yields an age of 30.8±0.1 Ma, although the MSWD (mean standard weighted deviation) of the isochron is high (20.4). The $^{40}Ar/^{39}Ar$ for those steps is close to atmospheric, suggesting no trapped ^{40}Ar component is present. From these data, the maximum age of the mineral deposits in the Organ Mountains is 33.1 Ma; mineralization probably continued through at least 30.8 Ma.

^{40}AR/^{39}AR DATING OF FLUID INCLUSIONS IN QUARTZ FROM THE CAPITAN PLUTON, NEW MEXICO, by *A. R. Campbell, M. T. Heizler,* and *N. W. Dunbar,* Dept. of Earth and Environmental Science and New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The 300-km^3 Capitan pluton in central New Mexico hosts small REE-bearing zones of mineralization that contain high-temperature (up to 600°C), high-salinity (up to 80 wt%) fluid inclusions. The hydrothermal veins contain quartz, fluorite, adularia plus a number of REE-bearing phases. Based on the microthermometry of fluid inclusions, stable isotope composition of host minerals, and spatial distribution of veins in the outer carapace of the pluton, this mineralization has been interpreted to be the result of magmatic fluids. In contrast to many magmatic/hydrothermal systems, there are few inclusions produced by late-stage meteoric fluids. The primary, high-temperature inclusions contain daughter minerals of halite, sylvite, and other phases, and the high-K content of the inclusions allows determination of their ages of entrapment using the $^{40}Ar/^{39}Ar$ technique. Furthermore, the presence of hydrothermal potassic feldspar (adularia) in the veins allows independent determination of the age of mineralization.

Two samples of adularia, from prospects MTE and CPU-2, were analyzed with the $^{40}Ar/^{39}Ar$ incremental heating technique. MTE reveals a flat age spectrum and an isochron age of 28.2±0.09 Ma. The CPU-2 adularia age spectrum is suggestive of minor argon loss and gives an isochron age of 28.0±0.09 Ma. The isochrons define a trapped $^{40}Ar/^{39}Ar$ component that is essentially atmospheric (~298) for both samples. Four samples of hydrothermal vein quartz were analyzed from the MTE, CMX, FN, and CPU prospects. Two types of degassing behavior were noted during the incremental heating runs. MTE and CMX-1 yielded isochron ages of 26.5±4 Ma and 38.6±9.5 Ma respectively. Both samples yielded Cl/K ratios of about 5 and K/Ca ratios of 1.8 and 1.9. FN and CPU-2 yielded isochron ages of 28.8±0.09 Ma and 29.5±0.07 Ma respectively. For these two samples the Cl/K ratios were very low and the K/Ca ratios increased relative to MTE and CMX-1.

The Cl/K and K/Ca ratios of MTE and CMX-1 are very similar to the elemental ratios determined for the inclusion fluid determined by the bulk crush-leach technique. Therefore, we conclude that dates from these two samples are from K trapped within the inclusions. In contrast, the Cl/K and K/Ca ratios from FN and CPU-2 are more similar to those from the vein adularia. For these samples we believe that small (as of yet unseen) crystals of adularia trapped within the quartz are responsible for the age spectra. Although FN and CPU-2 do not represent direct dating of fluid inclusions, they do provide a mechanism for obtaining spectra from unaltered vein adularia.

The $^{40}Ar/^{39}Ar$ ages of hydrothermal quartz from the Capitan pluton closely match those determined from hydrothermal adularia, suggesting that this technique yielded true depositional ages. However, the Ar-release spectra were complicated because of the trapped Ar component and were therefore not straightforward to interpret. Recognizing and correcting for the excess argon associated with Cl, and use of standard isochron techniques, allows determination of the fluid-inclusion age and thus mineralization age. Further work on Capitan pluton samples may help us understand the Ar systematics in hydrothermal/mineralizing systems.

GROUND-WATER DATING AND OTHER USES OF ENVIRONMENTAL ISOTOPES IN GROUND-WATER STUDIES, by *P. S. Johnson,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Naturally occurring isotopes that exist in water in the hydrologic cycle have been used in investigations of ground water for decades. The application of environmental isotopes in hydrologic studies (Isotope Hydrology) makes use of two main properties of isotopes: (1) some decay radioactively; and (2) the relative mass difference of common to rare isotopes results in fractionation during physical, chemical, and biochemical reactions. These properties permit ground-water age estimation, "fingerprinting" of ground water from different sources, and tracing of ground water in the subsurface. By determining the distribution of environmental isotopes in ground water, one can establish ground-water residence and travel times, ground-water flow paths, leakage between aquifers, definition of recharge areas, stream-aquifer interactions, and aquifer hydraulic conductivity.

The isotopes most commonly measured in ground water are the radiogenic isotopes tritium (^3H or T) and carbon-14 (^{14}C), and the stable isotopes deuterium (^2H or D), oxygen-18 (^{18}O), and carbon-13 (^{13}C). Tritium and ^{14}C are used to estimate the "age" or residence time of ground water and to solve related problems of ground-water travel time, flow-path definition, and rates of recharge. The apparent age (t_a) of ground water is: $t_a = t_{1/2} \ln(A/A_o)$, where $t_{1/2}$ is the half-life, A is the activity of the isotope at the time the water entered the subsurface, and A_o is the measured activity. If age and distance traveled are known, ground-water velocity can be determined. Added knowledge of ground-water gradient and estimates of effective porosity can then provide information on aquifer hydraulic conductivity. The stable isotopes ^{18}O and D are used as indicators of ground-water source areas, and because these isotopes reflect the environmental conditions at the time they entered the subsurface, they can also distinguish modern ground water (derived directly from modern precipitation) from paleowater (recharged under conditions different from the present day).

Tritium and ^{14}C are produced naturally by interaction of cosmic rays with the upper atmosphere and have also been artificially injected into the hydrosphere in large quantities by above-ground thermonuclear testing from 1952 to 1963. Because ^3H becomes a constituent of the water molecule, and has a half life of 12.3 years, it is an ideal tracer for ground water recharged since 1954. However, its use is limited because atmospheric concentrations vary over space and time, and it is difficult to reconstruct ^3H input concentrations for specific geographic areas. An analytical advance of the ^3H method uses combined measurements of ^3H and helium-3 (^3He), the stable tritium decay product, to determine more precisely the "age" of the ground water.

Carbon-14 is introduced into ground water through the dissolution of atmospheric CO_2 in rain and surface water and of gaseous soil CO_2 in water percolating through soil. The $^{14}CO_2$ equilibrates with the dissolved inorganic carbonate species in ground water. Carbon-14 "ages" are calculated based on the 5,730-yr half-life and the ratio of $^{14}C/^{12}C$ in a barium or strontium carbonate precipitate derived from a representative ground-water sample. Carbon-14 activities are expressed in "pmc," or percent of modern carbon, where 100 pmc is the approximate mean pre-bomb atmospheric ^{14}C activity and about 130 pmc is the average post-bomb activity. Several natural processes occur in the subsurface that affect the ratio of $^{14}C/^{12}C$, the most important of which is the dissolution of carbonates devoid of ^{14}C (referred to as "dead" carbon). This process dilutes or reduces the natural ratio of $^{14}C/^{12}C$ and increases the apparent age of the ground water. After accounting for dilution by dead carbon using correction methods based on concentrations of ^{13}C, modern pre-bomb ^{14}C activities in ground water are typically 60 to 80 pmc. Carbon-14 activities greater than 80 pmc are most likely due to input of "bomb" ^{14}C and represent water less than about 40 years old. Because of the complexities of ground-water flow paths, and the potential for changes in the total mass of dissolved carbon in the subsurface, ^{14}C often provides only a semi-quantitative estimate of ground-water age.

AR-AR EVIDENCE FOR MESOPROTEROZOIC (1.45–1.0 GA) REGIONAL METAMORPHISMS IN NEW MEXICO: IMPLI-

CATIONS FOR THERMAL EVOLUTION OF LITHOSPHERE IN THE SOUTHWEST, by *K. E. Karlstrom*, Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; and *D. A. Dallmeyer*, Dept. of Geology, University of Georgia, Athens, GA 30602

Ar-Ar dating of hornblende and muscovite separates from 47 samples from Proterozoic rocks of northern New Mexico documents a complex Mesoproterozoic thermal history for northern New Mexico. In most areas of northern New Mexico, hornblendes give plateau ages of 1.43–1.35 Ga, indicating cooling through about 500°C at this time. This suggests that the well-documented regional triple point metamorphism (500–550°C, 3–4 kbar) occurred at ca 1.4 Ga. This metamorphism was superposed on previous Paleoproterozoic amphibolite-grade rocks that were residing at 3–4 kbar (10–15 km), as suggested by (1) disturbed hornblende Ar spectra (nearly one-third of samples) that contain pre-1.4 Ga age increments and are interpreted to reflect partial resetting of Paleoproterozoic minerals; (2) numerous 1.4 Ga U-Pb mineral ages in high-grade blocks; and (3) field studies of syntectonic 1.7–1.65 Ga plutons.

Aureoles of 1.4 Ga plutons that were emplaced at 3–4 kbar in the Sandia and Manzano Mountains show nearly concordant 1.4 Ga hornblende and muscovite dates, suggesting rapid cooling to ambient conditions of about 300°C at depths of 10–15 km. This corresponds to a 1.4 Ga geothermal gradient of about 25–30°C/km. Somewhat younger, 1.37–1.31 Ga, dates on muscovite throughout much of the region and on hornblende in high- grade blocks could represent a second "event" associated with 1.35 Ga magmatism. However, no 1.35 Ga plutons are known in New Mexico, and spread of dates seems better explained by cooling because of erosional unroofing following 1.4 Ga plutonism. The 1.1–0.9 Ga (Grenville) tectonism locally reset or perturbed muscovite ages and may record further (Grenville) unroofing of middle crustal rocks combined with variable reheating.

Different tectonic blocks record different apparent thermal histories suggesting differential Mesoproterozoic uplift and/or thermal histories. Blocks with the highest metamorphic grades (both P and T) have the youngest mineral ages for both hornblende and muscovite, suggesting that Ar resetting and resulting apparent ages are at least in part due to differential unroofing (1.4–1.0 Ga) of different levels of the middle crust with its Mesoproterozoic (post-1.4 Ga) thermal structure. Regional metamorphism at 1.4 Ga was probably driven by heat from fluid and magma advection into the crust because of upwelling of asthenosphere in southern Laurentia. This metamorphic event was regional in character and enhanced by plutons, but not restricted to pluton aureoles. Variable cooling ages suggest that the 1.4 Ga magmatic/thermal event initiated protracted regional (differential) denudation and cooling of middle crustal rocks of the Southwest.

THERMOCHRONOLOGIC CONSTRAINTS ON PROTEROZOIC DEFORMATION AND METAMORPHISM IN THE MANZANO MOUNTAINS, CENTRAL NEW MEXICO, by *J. R. Marcoline, M. T. Heizler*, S. Ralser,* and *L. Goodwin,* Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, *New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Detailed structural mapping and microstructure studies indicate rocks in the Capilla Peak area of the Manzano Mountains, central New Mexico, are multiply deformed. Thermochronologic studies have been focused on minerals from the Blue Springs schist and the microstructurally complex amphibolite layers within the Sevilleta metarhyolite. Inclusion-rich anhedral actinolitic amphiboles are overgrown and are crosscut by foliation-forming blue-green amphiboles. The blue-green amphiboles define a strong tectonic foliation, the youngest fabric in the amphibolite, which is parallel to the regional foliation trend. Our studies show that the ductile deformation and associated mineral growth that formed this foliation overprint an older, probably ca 1,650 Ma ductile fabric.

The $^{40}Ar/^{39}Ar$ geochronologic analyses on multiple minerals were conducted to constrain the timing of the observed deformation events. Along with a bulk amphibole concentrate, an actinolitic amphibole and a blue-green amphibole were individually separated from amphibbolite samples ML 10-8 and ML 14-18. The anhedral actinolitic amphiboles and bulk separates yield complex $^{40}Ar/^{39}Ar$ age spectra characterized by age gradients increasing from ~200 Ma to 1,600 Ma. These samples have total gas ages ranging from ~1,110–1,290 Ma. The euhedral blue-green amphiboles have less-complex spectra and overall older ages. In particular, ML 14-18 blue-green amphibole is less plagued by young apparent ages and yields a plateau age for 80% of the gas release of 1,406 ± 16 Ma (2σ). Based on this result, it is proposed that temperatures at ca 1,400 Ma were sufficiently high to reset the actinolitic amphiboles with respect to argon (at least 400°C), and this blue-green amphibole grew ca 1,400 Ma.

Six muscovites from the Blue Springs schist and two biotites from amphibolite layers within the Sevilleta metarhyolite also were separated and analyzed. The muscovite separates show variable age spectra with age gradients ranging from ~200 Ma to 1,400 Ma. The muscovite samples were collected over a vertical section of greater than 1.5 km (35–50°C, assuming a geotherm of 25°C/km). Assuming samples within the traverse have similar argon closure temperatures, apparent ages can be used to estimate uplift and/or cooling rates. For instance, the structurally deepest sample yields an age of ~1,320 Ma, whereas the structurally highest sample yields an age of ~1,380 Ma. This 60 Ma age discordance thus corresponds to an average cooling rate of (0.3–1)°C/Ma.

Biotite from ML 10-8 yields a plateau age of 1,277±8 Ma whereas ML 6-10 biotite gives an age of ~1,400 Ma. This age discordance probably reflects variation in closure temperature coupled with apparent slow cooling because the two samples are located at the same structural level.

Taken together, the geochronologic and structural data are interpreted to support a model where regional deformation, metamorphism, and mineral growth occurred at ca 1,400 Ma. These data suggest that regional temperatures of at least 400°C existed ca 1,400 Ma followed by a period of protracted cooling. The deformation associated with this metamorphism is clearly an event not confined to the margins of the 1,400 Ma Priest pluton in the Manzano Mountains.

COOLING HISTORIES OF MOUNTAIN RANGES IN THE SOUTHERN RIO GRANDE RIFT BASED ON APATITE FISSION-TRACK ANALYSIS: A RECONNAISSANCE SURVEY, by *S. A. Kelley*, Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *C. E. Chapin*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Forty-nine apatite fission-track (AFT) and two zircon fission-track ages were determined during a reconnaissance study of south-central New Mexico in order to investigate the cooling and tectonic history of uplifts associated with the southern Rio Grande rift. Mack et al. (1994) proposed that the southern rift has been affected by four episodes of extension beginning at about 35 Ma. The main phases of faulting started in the early Oligocene, the late Oligocene, the middle Miocene, and the latest Miocene to early Pliocene, with each phase disrupting earlier rift basins, and in some cases, reversing the dip of the early rift half-grabens found in the vicinity of the southern Caballo Mountains. The timing of denudation derived from AFT data in the Caballo, Mud Springs, San Diego, and Doña Ana Mountains are consistent with the episodes of uplift and erosion preserved in the Oligocene to Miocene Hayner Ranch and Rincon Valley Formations in the southern Caballo Mountains.

Each mountain block studied in the southern rift has a unique history. AFT ages in the Proterozoic rocks on the east side of the San Andres Mountains record cooling of this mountain block at 21 to 22 Ma in response to the phase of extension that began in the late Oligocene. Younger AFT ages of 7 to 8 Ma related to the middle Miocene episode of extension are exposed on the upthrown side of high-angle faults cutting the Proterozoic rocks. AFT ages from the eastern Organ Mountains are 10 to 17 Ma and the mean track lengths are long, whereas the ages on the west side are 20 to 29 Ma and the mean track lengths are shorter. A westward-tilted partial annealing zone for apatite that formed during protracted cooling of the Organ batholith in the late Oligocene to early Miocene is preserved in this mountain block. Rapid denudation (200 to 400 m/m.y.) and tilting of the range occurred in the middle Miocene. The base of an apatite partial annealing zone that formed during burial of southern New Mexico in the Mesozoic is preserved in the Sacramento Mountains. The earliest phase of extension is recorded in the AFT data from Proterozoic rocks exposed at the base of the Sacramento escarpment. Evidence for significant denudation related to Laramide deformation, or late Oligocene and middle Miocene extension is not observed in the AFT data from the Sacramento Mountains. AFT data derived from high-elevation samples in Oligocene to Miocene intrusions (Capitan, Sierra Blanca, and Black Range) record rapid cooling of these shallowly emplaced plutons.

The AFT data from the northern and southern Rio Grande rift are similar in many respects. The trend of young AFT ages and greater denudation on footwall blocks adjacent to the master faults controlling the geometry of the half-grabens that was observed in northern New Mexico is also found in southern New Mexico. Horst blocks in the rift that are bordered by normal faults on two or three sides invariably have young (<12 Ma) AFT ages and high (>10°C/Ma) cooling rates. In the places where Mesozoic AFT ages are preserved, the estimated cooling rates are low (<2°C/Ma) in both the northern and southern rift. The primary difference in the cooling histories of mountain ranges in the northern and southern rift is the paucity of AFT ages that are older than 30 Ma in the southern rift. Part of this trend may be a function of sampling bias.

Zircon FT and K-Ar data are used to examine the distribution of late Mesozoic to Eocene volcanism in southern New Mexico. A previously unrecognized Cretaceous intrusion was identified southeast of Hillsboro using zircon FT dating. The porphyry from this intrusion was the source of volcanic clasts in the late Cretaceous to early Tertiary McRae Formation located in the northeastern Caballo Mountains. In addition, a zircon FT age of 49.6± 3.8 a for the rhyolite sill capping Salinas Peak at the north end of the San Andres Mountains, and K-Ar ages for the Orogrande, Cuchillo, and Tres Hermanos stocks are used to constrain the northern limit of 40 Ma volcanism in south-central New Mexico.

QUATERNARY GEOLOGY AND GEOMORPHOLOGY SESSION

PLIOCENE AND PLEISTOCENE DISPLACEMENT HISTORY OF THE SOCORRO CANYON FAULT, CENTRAL RIO GRANDE RIFT, New Mexico, by *R. M. Chamberlin,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; and *B. Harrison,* Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Socorro Canyon fault (SCF) is a major active normal fault of the central Rio Grande rift. This north–northwest-trending, high-angle, down-to-the-east normal fault can be traced for 40 km along the west flank of the Socorro Basin. North and west of Socorro, the SCF has the appearance of a large-displacement range-bounding fault where it transects the east toes of west-tilted blocks that form the Lemitar and Socorro Mountains. Southwest of Socorro the SCF horsetails and splays into a 7-km-wide zone of distributed Quaternary scarps. These scarps locally outline closely spaced horsts and grabens that cut across the piedmont slope below the east-tilted Chupadera Mountains. The intrabasinal south segment of the SCF (most-active Quaternary trace) dies out near San Antonio, about 11 km south of Socorro Canyon.

Recent mapping near the mouth of Socorro Canyon shows that the "main" (most-active) trace of the SCF locally displaces four geomorphic surfaces of middle to late Pleistocene age in addition to the early Pliocene basalt of Socorro Canyon. Recurrent displacement is demonstrated by progressively increasing offset of Quaternary surfaces with increasing age. The oldest Quaternary surface is capped by a stage IV laminar calcrete that projects 98 m above the Rio Grande. It is correlative with the Las Cañas surface, which marks the top of the Santa Fe Group (maximum level of aggradation) in the Socorro Basin. Correlative surfaces in the Albuquerque and Mesilla Basins have been dated at 0.5 and 0.7 Ma, respectively. The main trace of the SCF displaces the Las Cañas surface 21–24 m, thereby yielding an average upper Pleistocene displacement rate of 39±9 m/Ma. Preliminary estimates based on younger surfaces suggest the "short-term" displacement rate has been relatively constant since 0.7 Ma. The longer-term displacement rate, however, was clearly not constant. The main trace of the SCF displaces the basalt of Socorro Canyon (4.1±0.3 Ma) approximately 46–49 m, which yields an average Plio–Pleistocene displacement rate of 11.7±1.2 m/Ma. This significant increase in average displacement rate, from Pliocene to Pleistocene time, could be interpreted as the result of episodic rifting or accelerated rifting. Available map data, however, indicate the most probable scenario is one of constant rifting (in Plio–Pleistocene time) associated with nonuniform partitioning of strain within the adjacent four strands (splays) of the SCF. Three strands of the SCF that lie west of the "main" trace show a cumulative post 4.1 Ma displacement of approximately 162 m, which adequately compensates for the "missing" 144 m of Pliocene displacement that should be present on the main trace (projecting present rate backward over long term). These Pliocene splays of the SCF, observed north of Socorro Canyon, show only minor displacement where they project across the middle Pleistocene piedmont slope south of Socorro Canyon.

TECTONIC GEOMORPHOLOGY OF THE SANDIA MOUNTAINS AND EASTERN PIEDMONT OF THE ALBUQUERQUE BASIN, New Mexico, by *H. Gustafson,* Dept. of Earth & Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The middle Rio Grande valley is presently experiencing a rapidly growing population. Large cities in the western interior, such as Albuquerque, face two serious problems: water resources and potential seismic hazards related to active tectonics. Following from the initial work of Connell (1995), this study performs a tectonic geomorphologic analysis and field mapping of specific portions of the Sandia mountain front and piedmont (Pino embayment) east of Albuquerque, NM. Results are used to understand better the structural and hydrostratigraphic setting of the Albuquerque Basin. Drainage basins on the west facing Sandia mountain front suggest highly variable rates of offset, both in time and space, on the range front fault. A detailed field map (1:12,000) of the Pino embayment helps corroborate these morphometric results. Quaternary stratigraphy in the Pino embayment is composed of five allostratigraphic fan and terrace deposits. Field and laboratory soil analysis helps to constrain the relative ages of the Quaternary deposits at a resolution higher than initially proposed by Connell (1995). In summary, the stratigraphy of the Pino embayment is dominated by a large alluvial fan designated as the Q2 deposit, which is estimated to be middle Pleistocene in age. Progressively younger deposits are inset into the proximal regions of Q2 but bury distal regions. The mapping clearly shows only a thin veneer of Quaternary deposits burying a granitic bedrock pediment that locally is exposed at the surface. These results demonstrate that the Pino embayment is not underlain by an alluvial aquifer. However, vegetation lines, natural surficial springs, low scarps cutting Q2, and highly fractured bedrock all suggest movement of groundwater through Quaternary fault systems. Further work will better constrain the role of the structural setting and Quaternary stratigraphy in determining potential recharge from the Sandia mountain front to the Albuquerque aquifer.

Connell, S. D., 1995, Quaternary geology and geomorphology of the Sandia Mountain piedmont, Bernalillo and Sandoval Counties, central New Mexico: Unpublished MS thesis, Dept. of Earth Sciences, University of California at Riverside, 390 pp.

ORIGIN AND SPATIAL DISTRIBUTION OF EARLY VADOSE AND PHREATIC CALCITE CEMENTS IN THE ZIA FORMATION, ALBUQUERQUE BASIN, NEW MEXICO, USA, by *J. R. Beckner* and *P. S. Mozley,* Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Zia Formation (Miocene) consists of sandstones and mudrocks deposited in fluvial, eolian, and playa lake environments. Although much of the formation is poorly consolidated, resistant zones of calcite cementation are common. These zones range in size from isolated nodules to tabular cemented zones several meters thick that extend more than 2 km laterally. The calcite-cemented zones are highly complex, exhibiting a wide range of macroscopic and microscopic textures and geometries. Isolated or groups of nodules and rhizocretions with micritic fabrics and alveolar structures are inferred to be vadose carbonates. Individual or groups of ovoid or elongate concretions, characterized by blocky spar cements, and preservation of primary sedimentary structures are inferred to be phreatic carbonates. Most cemented units in the Zia reflect characteristics of both phreatic and vadose zone cementation (e.g., preservation of sedimentary structures plus rhizocretions and alveolar microtextures). The $\delta^{13}C$ values for vadose cements tend to be heavier and $\delta^{18}O$ values tend to be lighter than values for phreatic cements. The $\delta^{13}C$ and $\delta^{18}O$ values for units with mixed features tend to have intermediate values. Most cementation types that exhibit a mixture of features may reflect past fluctuations of the water table where vadose cements were moved into the phreatic zone. Vadose-zone cementation occurred principally in association with soil development, whereas phreatic-zone cementation occurred preferentially in zones of high primary permeability. In many cases early vadose cements provided nucleation sites for later phreatic cementation. Tabular units in the Zia are often laterally extensive, decreasing potential reservoir/aquifer quality by forming significant barriers to vertical fluid flow. These barriers could result in compartmentalization of the reservoir/aquifer and extensively reduced production if wells were screened on only one side of a cemented layer.

MODULATION OF SOUTHWEST NORTH AMERICAN SUMMER PRECIPITATION BY SNOWPACK IN THE AMERICAN ROCKIES, by *J. Preston* and *D. Gutzler,* Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Much of Arizona and New Mexico receive most of their precipitation during the summer months (late June through late August/early September) as a result of a monsoonal flow centered over northwest Mexico. The monsoon is triggered by the reversal of middle and lower tropospheric winds between June and July, which is directly related to the land-ocean temperature/pressure gradient. During the cooler seasons the winds blow from the landmass (higher pressure) to the ocean (lower pressure); however, during the warmer seasons, the land heats up faster than the ocean, and the winds blow from the ocean (higher pressure) to the landmass (lower pressure).

The Mexican monsoon is strikingly similar to the Indian summer monsoon in all of these respects. One aspect of the Indian monsoon that has been studied for more than 100 years is its inverse relationship to the snowpack and snow cover of the Himalayas and Tibetan Plateau. The Indian monsoon following winters with greater than average snow cover tends to have less precipitation than normal and affect a smaller area than normal. The increased soil moisture from melting and runoff in the spring and summer following a winter with above-average snowfall prevents the land from heating up as efficiently, thereby suppressing the land-ocean temperature/pressure gradient.

We hypothesize that this is also the case with the Mexican monsoon and that summer precipitation over the southwest United States might thereby be predictable. As an initial step in examining this hypothesis, we have obtained time series of monthly mean precipitation data from 21 stations in New Mexico, focusing the analysis on July precipitation. Interannual fluctuations of July precipitation from these stations are positively correlated with each other and with the statewide average for New Mexico.

As indices of snow variability we have used Principal Component Analyses of the interannual variability of snow cover in North America (derived from satellite observations) from the winter of 1970–71 through the winter of 1992–93 obtained from the Canadian Climate Centre. Specifically, the Spring and Annual PCs describing variability in the Central–Southern Rocky Mountains were correlated with the July precipitation data from New Mexico stations. Most of these correlation coefficients are negative, confirming that average July precipitation in New Mexico tends to be inversely related to the amount of antecedent snow cover in the Rockies to the north. The correlation coefficients are approximately –0.4, satisfying a one-tailed *t*-test for statistical significance.

SOIL TOPOSEQUENCES AND SOIL CATENAS, by *B. Harrison* and *M. Eppes*, Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

A soil toposequence is a sequence of soils located on different positions down a slope profile. A soil catena is a subset of a soil toposequence where individual soil properties are determined strongly by their position on the slope. The linkage between soils in a catena indicates a continuity of slope processes, such as soil creep or throughflow, which result in a continuum of soil variability from the top to the bottom of the slope. Catenary relations take time to develop, so their presence indicates a period of slope stability. Identification of these relations can aid in determining the age of fault scarps and terrace risers and can also indicate the extent of throughflow and surface runoff off hillslopes.

Recent work on hillslope soils in the Sevilleta and near Escondida have identified three situations where catenary relations have not developed. Study of these toposequences allows us to identify situations in which other factors, apart from slope position, strongly influence soil forming processes.

On the Sevilleta, two sequences of soils were described down opposing slopes. The southwest-facing slope is formed on Capirote quartz monzonite bedrock, which weathers to gruss. The gruss is easily transported off the slope, and only a very thin soil forms in bedrock. There is little variation in soil properties down the slope. The opposing northeast-facing slope is formed on Ladron quartz monzonite, which weathers to form a coarse colluvium. Zones in this monzonite weather much faster than the surrounding bedrock, appear to have formed topographic lows at some stage of slope development, and are now in the process of being filled in. Soil chemistry indicates that there is no significant throughflow on this slope.

The soils described on opposing slopes cut into upper Santa Fe Formation near Escondida show a strong influence of the underlying sediments rather than a systematic variation in soil properties downslope. Catenary relations will not develop on these slopes until the underlying variation in sediments has been masked by the development of a thick colluvial layer.

The soils forming the toposequences in the Sevilleta have been forming for several thousands of years judging by the amount of calcium carbonate that has accumulated in these soils. This should be sufficient time for catenary relations to develop. In this case the bedrock lithology has an overriding influence on slope processes. The Escondida sequences, on the other hand, have not been forming long enough for the establisment of a complete cover of colluvium down the entire slope, and thus no catenary soil sequences have been developed.

A CLIMOSEQUENCE ON EARLY HOLOCENE FLUVIAL TERRACES ON THE SOUTH EDGE OF THE ALBUQUERQUE-BELEN BASIN IN THE RIO GRANDE RIFT, New Mexico, by *M. Fronterhouse,* Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Climate is one of several important variables that influence the formation of soils. Recent documented increases in desertification threaten to significantly alter the environment of many soils, probably on a global scale. Therefore, it is important to understand how anticipated climate change (e.g. global warming) will specifically affect soil environments. The evaluation of soils along the elevation gradient is one effective way to study climate's influence on soil formation. The transitional climate regime of the semiarid Southwest in south-central New Mexico on the southeast edge of the Rio Grande rift provides an opportunity to examine closely a soil climosequence following the "state factor" strategy of Jenny (1941, 1980). Studies of two soils forming on fluvial terraces in the Palo Duro drainage basin, estimated to be of early Holocene age, help determine the effect of a spatial change in climate on soil development. One site is at an elevation of approximately 1,830 m where mean annual precipitation (MAP) is 29.35 mm and mean annual temperature (MAT) is 19.14°C. The second site is at an elevation of approximately 1,422 m, and here MAP is 18.65 mm and MAT is 21.95°C. The soil profile associated with the site at the highest elevation is characterized by the presence of a noncalcareous argillic horizon from a depth of 5 cm to 30 cm, and calcium carbonate begins to accumulate at a depth of 30 cm and continues to the bottom of the pit at 136 cm. In contrast to this soil, pedogenic carbonate has accumulated throughout the soil profile starting at the lower elevation site; its morphology is stage II (Gile et al., 1966) and no argillic horizon is present.

It is unlikely that the small difference in the present-day climate at the two sites can account for the observed differences in these two soils. There are many alternative explanation for the differences. It is possible that the time period of the meteorological data collected does not clearly establish the longer-term contrast in climate between the two sites. There have been many climate changes in the Holocene that could be responsible for the observed changes. A stronger climatic gradient could produce greater temperature and precipitation differences. A greater difference in the climatic gradient could account for the differences in the depth of calcium carbonate, clay accumulations, and soluble salts. Climate depends on many complex responses and invokes many dependent relationships, for example, the positive feed back between vegetation and climate and the effect of the amount of vegetation and the production of carbonic acid. It is possible that the contrasts observed are due to the positive vegetation feedback because the "higher" elevation site has 70% vegetation cover and the "lower" site has 20% vegetation cover. The influx of dust also should be investigated to determine its influence on the water balance in the soils. Future studies investigating the possible complex responses should also be conducted to aid in future studies of the influences of climate changes on soil development.

LATE QUATERNARY PALEOCLIMATE INDICATED BY STABLE ISOTOPIC ANALYSES OF PEDOGENIC CARBONATE, SOUTHERN NEW MEXICO AND WEST TEXAS, by *B. J. Buck* and *H. C. Monger,* Pedology Lab, Dept. of Agronomy and Horticulture, New Mexico State University, Las Cruces, NM 88003

An understanding of paleoclimate and its effect on past ecosystems is important in understanding and predicting future responses of ecosystems to climatic shifts. The goal of this research was to determine (1) the latest Pleistocene and Holocene vegetational history and paleoclimate of the Hueco Basin in the northern Chihuahuan Desert; (2) how other factors within the ecosystem, primarily sedimentation and erosion rates, respond to changes in vegetation types and densities; and (3) how the above changes may have affected past human populations and/or the preservation and integrity of the archaeological record.

The method used to determine past vegetation types was analyses of stable isotopes in pedogenic carbonate. This method is a particularly useful tool in environments where packrat middens and fossil pollen may not be preserved. In addition, buried calcic soils within fault troughs in the Hueco Basin are ideal because these soils have formed in noncalcareous parent materials and in an aggrading environment, which protected older pedogenic carbonates from contamination by younger fluids. Approximately 140 profiles were excavated and described throughout the Hueco Basin to determine the eolian stratigraphy. Five trenches within two fault complexes were sampled at 10-cm intervals for carbon and oxygen isotopes. In addition, three lateral transects were sampled at 10, 20, and 30 cm apart and analyzed to determine the lateral variability of the isotopic signatures.

The $\delta^{13}C$ analyses indicate an abrupt shift from C_4 grasses to C_3 desert scrub during the Altithermal, at approximately 8 ka. This change is also found in the alluvial fans adjacent to the basin indicating that this event was significant enough to affect both the higher and lower elevations throughout southern New Mexico and west Texas. In addition, this vegetational shift resulted in a basin-wide deflational event, which eroded Pleistocene paleosols in many areas within the central basin, created a paleolag similar to the one on the surface today, and eventually resulted in the deposition of the Organ I unit. In contrast, $\delta^{18}O$ values remain comparatively constant during the 8 ka shift in $\delta^{13}C$ values, suggesting that a decrease in precipitation was the major driving factor contributing to this vegetational shift, rather than temperature change. An increase in atmospheric CO_2 may have also contributed.

The largest enrichment of $\delta^{18}O$ values begins at approximately 4 ka and suggests an increase in mean annual temperature and/or a shift from winter precipitation to summer monsoons. This increase in $\delta^{18}O$ values is coupled with increasing $\delta^{13}C$ values from approximately 4 to 2 ka. This indicates an increase in C_4 grasses and is reasonable because summer monsoonal precipitation favors their development.

Isotopic signatures from soils younger than 2 ka are rare. However, $\delta^{13}C$ values from the only profile containing carbonate of this age indicate an increase in aridity and C_3 desert scrub between 2,120 and 1,550 yr B.P. This corresponds to the Fairbanks Drought and the Formative period of cultural evolution. A corresponding shift in $\delta^{18}O$ values is not present. The stable isotopic data indicate major vegetational shifts during the latest Pleistocene and Holocene and correspond to periods of eolian erosion and deposition within the Hueco Basin. These processes may have affected both the cultural practices of indigenous people in this area as well as the preservation and stratigraphic integrity of their artifacts.

HYDROLOGY AND STRATIGRAPHY SESSION

SECULAR VARIATION OF COSMOGENIC NUCLIDE PRODUCTION AS A GROUND-WATER TRACER, by *M. A. Plummer* and *F. M. Phillips,* Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, mplummer@nmt.edu and phillips@nmt.edu.

Since the advent of ^{14}C dating in the early 50s, there has been a continuing effort to assess the effect of secular variation of production of cosmogenic nuclides on atmospheric ^{14}C activity. It is now widely accepted that long-term variations in production of cosmogenic nuclides are caused by fluctuations in the strength of the earth's magnetic field. The secular variation of production of one of these nuclides, ^{36}Cl, could provide an excellent tool for soil moisture and ground-water tracing because Cl^- is conservative in the subsurface. If a recharge system is advection dominated, ^{36}Cl concentration variations along a flow path should preserve the record of production of the isotope. To test this hypothesis, we have measured $^{36}Cl/Cl$ ratios in 23 ground-water samples from the San Juan Basin in northern New Mexico. Results are compared to a hypothetical reconstruction of production variations over the last 35 ka based on global paleointensity records or Tric et al. (1992).

After eliminating samples believed to have been affected by in situ addition or dilution of chloride, the pattern of $^{36}Cl/Cl$ variation appears to agree well with the paleointensity-based signal. This supports the hypothesis that long-term variations in production of cosmogenic nuclides are caused by variations in the strength of the earth's magnetic field. Moreover, the preservation of this signal in the ground-water archive suggests that it may, indeed, prove a useful ground-water tracer for aquifers with residence times on the order of tens of thousands of years.

For comparison with other archives of cosmogenic nuclides, we summarize the results of previous investigations of secular variation, including atmospheric ^{14}C, ^{10}Be in polar ice, and our recent study of the $^{36}Cl/Cl$ ratios preserved in fossil middens of packrats in Nevada.

HYDROGEOLOGIC CHARACTERIZATION OF THE FLOODPLAIN ON THE URANIUM MILL TAILINGS REMEDIAL ACTION SITE AT SHIPROCK, NEW MEXICO, by *B. Tsosie* and *B. Harrison,* Dept. of Earth and Environmental Sciences, New Mexico Institute of Mining and Technology, Socorro, NM 87801

A contaminant plume has been identified in the floodplain below the U.S. Department of Energy's Uranium Mill Tailing Remedial Action site at Shiprock, New Mexico. Movement of the plume is controlled by behavior of the unconfined aquifer within the floodplain. To characterize the unconfined aquifer we used geologic data from monitoring well water-level measurements, electrical conductivity (EM), and reflection seismic data. Lithologies from monitoring well logs and seismic reflection were used to define the floodplain stratigraphy and the paleotopography map. Water-level measurements were collected on a monthly basis to determine the interaction of the San Juan River on the floodplain. A seismic reflection survey defined the alluvium, gravel, and shale interfaces, fractures and offsets in the floodplain stratigraphy. The stratigraphy consists of alluvial gravels overlying coarser outwash gravels that are deposited on an erosional terrace cut into Mancos Shale. Paleochannels can be identified by fluctuations in lithology elevations from the monitoring well log data. The larger outwash gravels are currently a major factor in controlling the water and contaminate flow directions in the floodplain. The outwash gravels contain larger pore space than the alluvium. The preferential flow pattern is in the outwash gravels. Movement of the contaminant plume was determined from chemical analysis of water from existing wells over several years. The EM-31 and EM-38 surveys traversed the floodplain to determine the vertical and horizontal extent of a salt contaminant plume. Comparison of chemical analysis and EM-31/38 readings were used to determine if movement of the plume varies with flows in the San Juan River. Correlation of all four results indicates the general direction of flow of ground water and how the lithology influences the ground-water and contaminant movements in the floodplain.

GROUND-WATER FLOW AND IMPLICATIONS FOR MICROBIAL TRANSPORT IN THE DEEP SUBSURFACE NEAR CERRO NEGRO, NEW MEXICO, by *M. Walvoord*[1], *T. Kieft*[2], *P. Pegram*[1], *M. Person*[3], and *F. M. Phillips*[1]; [1]Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; [2]Dept. of Biology, New Mexico Institute of Mining and Technology, Socorro, NM 87801; [3]Dept. of Geology and Geophysics, University of Minnesota, MN

The Cerro Negro Microbial Origins Project is part of the Deep Microbiology Subprogram of the DOE's Subsurface Science Program, which is ultimately aimed at improving bioremediation techniques for contaminant cleanup and waste disposal. A large-scale, multi-disciplinary research effort at Cerro Negro, New Mexico is investigating the origins of microorganisms in the deep subsurface and their behavior, in situ survival potential, and long- distance transport in subsoils and ground water over thousands of years. Cerro Negro, a volcanic neck in the southeast San Juan Basin, intruded approximately 3.39 million years ago presumably producing a sterile zone, free from microorganisms, because of the associated heat of volcanism. Recent drilling and sampling in Cretaceous sediments near Cerro Negro address the questions of whether or not microorganisms have recolonized the previously sterilized area and if so, by what means.

Microorganisms and evidence for microorganisms have been detected at depth in the sterilized zone. Preliminary results suggest that both ground-water transport and in situ survival are responsible for present-day microbial populations in the thermal aureole of Cerro Negro. Ground-water transport is probably the predominant mode of microbial origin.

The focus of this study is to describe the ground-water flow pattern and flow rates from the recharge area, Mount Taylor region, to Cerro Negro in order to constrain microbial transport rates and recolonization potential. Horizontal and vertical flow rates were estimated through geochemical modelling and radiocarbon dating along the flow path. Carbon-14 analyses indicate that ground-water samples near Cerro Negro are more than 38,000 years old. Regional flow rates based on radiocarbon ages yield a conservative ground-water travel time of 91,000 years from Mount Taylor to Cerro Negro at 0.11 m/yr. These rates suggest that relatively rapid microbial recolonization of the thermal aureole by transport was possible.

A northeast-southwest cross-sectional model, extending 10 km from the recharge area, Mount Taylor region, to Cerro Negro, integrates horizontal and vertical flow rates determined in the isotopic study, available water-level data, and subsurface geology of the Mesozoic sediments. Particle tracking is used to illustrate quantitatively the potential for microbes to be transported in ground water in the past 3.39 million years to reestablish themselves in the previously sterilized zone. The model supports the microbial transport theory and constrains the timing of recolonization subsequent to the intrusion.

A THREE-DIMENSIONAL VIEW OF WATER QUALITY IN THE ALBUQUERQUE BASIN, by *D. A. Romero,* Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, darom@nmt.edu

With the ever-growing need for water in the City of Albuquerque, much recent work has been conducted to characterize the physical characteristics of the Albuquerque Basin. Although knowledge of the permeability distribution in an aquifer is vital to exploiting ground-water resources, it is also extremely important to examine the chemical processes related to the lithological and hydrological flow pattern of a hydrologic system. A three-dimensional conceptual model of the water-quality distribution in the Albuquerque–Belen Basin was constructed by using (1) a previous hydrogeological characterization of the basin (Hawley and Haase, 1992), (2) water-quality data for City of Albuquerque municipal wells, and (3) basic hydrogeochemical principles. Chemical analyses were plotted on six cross-sections of the basin, defined by Hawley and Haase (1992), which led to the following conclusions: (1) total dissolved solids (TDS) increase from north to south on the east side of the basin; (2) TDS decrease from the basin edges toward the Rio Grande; (3) ground water in the west basin tends to be high in sodium and sulfate, yet relatively soft and low in alkalinity; (4) ground water in the east basin is relatively hard yet low in sodium and sulfate; (5) the northwest part of the City of Albuquerque may have higher water quality and larger supply than previously believed; (6) water-chemistry patterns suggest much more complex flow patterns than previously thought; (7) ground-water quality does not always decrease with depth in the Albuquerque Basin; and (8) aquifer permeability and rock type may be the dominant factors in determining water quality in the basin.

This model differs from earlier versions (Romero, 1994) in that isotopic data was incorporated to examine the relative residence times of water in certain parts of the Albuquerque Basin. This model may prove valuable to the City of Albuquerque in its future efforts to manage and develop the basin's ground-water resources.

REGIONAL LITHO- AND SEQUENCE STRATIGRAPHY OF THE LOWER CHINLE GROUP, WEST-CENTRAL NEW MEXICO AND EASTERN ARIZONA, by *A. B. Heckert,* Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Lower Chinle Group strata in west-central New Mexico and eastern Arizona comprise a 70–150-m-thick tectonosequence consisting of (ascending) the "mottled strata," Shinarump and Bluewater Creek Formations, and the Blue Mesa Member of the Petrified Forest Formation. The Mesa Redondo Formation laterally replaces the Bluewater Creek Formation in parts of Arizona, and the San Pedro Arroyo Formation replaces the Bluewater Creek Formation in the southern Lucero uplift in central New Mexico. This tectonosequence rests disconformably on the Moenkopi Formation and is disconformably overlain by the Sonsela member of the Petrified Forest Formation. These surfaces represent the Tr-3 and Tr-4 unconformities, respectively.

Mottled strata are color-mottled, pedogenically modified sandstones, conglomerates, siltstones, and mudstones that represent a cumulative pedon developed on pre-Chinle strata during a time of lowered base level. Shinarump Formation deposits consist of extrabasinal conglomerates and conglomeratic sandstones dominated by Paleozoic limestone and Precambrian chert and quartzite clasts. These coarse-grained clastics overlie either the mottled strata or, in places, the Moenkopi Formation and represent localized channel-drowning in response to rising base level. Thus Shinarump Formation deposits are the nonmarine reflection of the onset of a transgressive systems tract (TST).

Although dissimilar in the exact distribution of sediment types, the Bluewater Creek Formation and its lateral equivalents, the San Pedro Arroyo and Mesa Redondo Formations, are all red-bed-dominated units deposited in response to continued base-level rise. These units consist of sheet flood and lenticular channel sandstones and siltstones with abundant red-bed mudstones and minor paleosols. Where the Shinarump is absent, these strata mark the only TST equivalent in the sequence. Throughout eastern Arizona and west-central New Mexico the Blue Mesa Member overlies the Mesa Redondo and Bluewater Creek Formations with apparent conformity. The Blue Mesa Member thins across the outcrop belt from 77.7 m thick at the Petrified Forest National Park to 44.5 m thick at Fort Wingate (western Zuni Mountains) and 22 m at Prewitt (eastern Zuni Mountains). The Blue Mesa Member does not crop out in the Lucero uplift and instead appears to have been removed during the Tr-4 unconformity, after which the Sonsela member was deposited. Where present, the Blue Mesa Member consists of highly bentonitic mudstones that represent a series of stacked paleosols and floodplain deposits. These low-energy deposits comprise the nonmarine equivalent of a high-stand systems tract (HST). Biochronology, including palynology and tetrapod biochronology, indicates that this tectonosequence was deposited over a relatively brief interval (<3 m.y.) of late Carnian time.

STRATIGRAPHY OF PROBLEMATIC PERMIAN AND CRETACEOUS ROCKS IN THE LITTLE HATCHET MOUNTAINS, SOUTHWEST NEW MEXICO, by *S. G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; *O. J. Anderson,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; and *J. Utting,* Geological Survey of Canada, 3303-33rd St., Calgary, Alberta, Canada T2L 2A7

In 1970, Robert Zeller (NM Bureau of Mines Bulletin 96) identified as "unnamed Cretaceous? beds" strata exposed east of Hatchita Peak in the Little Hatchet Mountains, especially in sec. 25 T28S R16W, Hidalgo County. He claimed these strata have a maximum thickness of 500 m and "could [even] represent a northern remnant of a Mexican marine Jurassic formation." Detailed stratigraphy of these rocks indicates a much thinner section (<250 m) composed of four distinct stratigraphic units. The lowest unit is at least 140 m thick and is mostly olive-gray and yellowish-brown micritic limestone and dolomite strikingly similar to strata of the Permian Epitaph Dolomite that crop out in the nearby Big Hatchet Mountains. The second unit is about 1 m of yellowish-gray metaquartzite that in lithology, thickness, and stratigraphic position can be correlated to the Permian Scherrer Formation in the Big Hatchet Mountains. The third unit is approximately 80 m thick and consists of dark-gray micritic limestone and calcareous sandy shale. The fourth unit is the Lower Cretaceous Hell-to-Finish Formation, with its base chosen at the stratigraphically lowest Paleozoic limestone-cobble conglomerate. The lower 40 m of the Hell-to-Finish Formation are interbeds of this kind of conglomerate with limestones of unit 3 lithology.

Unit 3 lacks macrofossils, and efforts to extract palynomorphs proved unsuccessful. The lack of chert and brachiopod fossils makes it highly unlikely that unit 3 is the Permian Concha Limestone, which overlies the Scherrer in the Big Hatchet Mountains. Furthermore, as Zeller noted, unit 3 is interbedded with the lower part of the Lower Cretaceous Hell-to-Finish Formation. This suggests unit 3 may be of Early Cretaceous age, and we consider it a lower, unnamed member of the Hell-to-Finish Formation. Therefore, most of the rocks near Hatchita Peak that Zeller termed Cretaceous? are Permian, but a relatively thin (80 m or less), apparently Lower Cretaceous marine unit is present at the base of the Hell-to-Finish Formation.

STRUCTURALLY DEPENDENT SOURCE-ROCK MATURITY AND KEROGEN FACIES, ESTANCIA BASIN, NEW MEXICO, by *R. F. Broadhead,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The Estancia Basin of central New Mexico is an asymmetric, north–south-trending structural depression that originated during the Pennsylvanian. The present-day basin covers 1,600 mi^2 (4,100 km^2). It is bounded on the east by the late Paleozoic Pedernal uplift, on the west by the Tertiary Manzano and Los Pinos Mountains, on the north by the Española Basin, and on the south by Chupadera Mesa. Depth to Precambrian basement ranges from 9,000 ft (2,700 m) in a narrow graben in the east part of the basin to less than 1,500 ft (460 m) on a shelf to the west. Basin fill consists primarily of Pennsylvanian and Wolfcampian sandstones and shales in the graben and sandstones, shales, and marine limestones on the shelf.

Mature to marginally mature dark-gray to black Pennsylvanian shales are probable source rocks. Thermal Alteration Index ranges from 2.0 to 3.2. Shales become thermally mature with depth in the east graben. On the west shelf, shales become mature to the west as a result of increased heating from the Rio Grande rift. Total organic carbon exceeds 0.5% in many shales, sufficient for hydrocarbon generation. Kerogen types are mixed algal, herbaceous, and woody, indicating that gas, or possibly gas mixed with oil, was generated. Kerogens in the shales of the east graben are entirely woody, gas-prone types. In limestones and shales of the west shelf, kerogens have a mixed marine and continental provenance, indicating that both oil and gas may have been generated in thermally mature parts of the shelf.

LATE CRETACEOUS CORALS FROM SOUTH-CENTRAL NEW MEXICO, by *S. G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *O. J. Anderson,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Fossil corals are extremely rare in the Upper Cretaceous deposits of the Western Interior epicontinental seaway, with fewer than 10 documented reports in the published literature. We add to this record an occurrence of the ahermatypic coral *Archohelia dartoni* Wells from Mescal Canyon in the north Caballo Mountains of Sierra County, New Mexico. The coral fossils occur at a single horizon over approximately 1 km of strike east of the creek in the W½ sec. 36 T13S R3W. The fossiliferous horizon is in the Rio Salado Tongue of the Mancos Shale 30 m below the base of the Atarque Sandstone and thus is of middle Turonian age. The corals display features characteristic of *Archohelia dartoni,* including circular individual branches with persistent axial corallites and small, circular corallites that branch at right angles from the axial corallite and ascend the branch in spirals. The coral fossils are isolated and broken branches that occur in lenticular masses of sedimentary breccia as long as 100 cm and as thick as 25 cm. Coral branches are concentrated near the top of each breccia mass and show no preferred orientation. Clearly, these corals are not an in situ thicket but represent reworked and redeposited debris, probably reflecting a Turonian storm event.

GEOCHRONOLOGY II SESSION

PROGRESS ON THE ^{40}AR/^{39}AR DATING OF THE TAOS PLATEAU VOLCANIC FIELD, TAOS, NEW MEXICO AND SOUTHERN COLORADO, by *R. M. Appelt*, Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM, 87801

Twenty-seven ^{40}Ar/^{39}Ar age determinations yield a refined geochronologic framework for the Taos Plateau volcanic field (TPVF) in northern New Mexico and southern Colorado. The age determinations are from plateaus in spectra produced by step-heating ground-mass concentrates and range in age from 2.14 to 17.45 Ma with average errors of less than ±0.1 Ma. The TPVF is one of several dominantly basaltic fields erupted in New Mexico during the last 10 m.y. The volcanism of the TPVF is volumetrically dominated by the eruption of the Servilleta Basalt, a series of highly fluid olivine tholeiites. Intermixed spatially and contemporaneously with the Servilleta Basalt is a volumetrically lesser suite of andesites, dacites, and akalic basalts. Also present is a scattering of older pre-TPVF units exposed by tectonic and erosional processes in the area.

The samples were primarily collected from eruptive centers of the TPVF, with a smaller amount consisting of sequences through exposed sections of the Servilleta Basalt where multiple flows are present. These results are part of an in-progress thesis study for which a suite of 111 samples have been collected: [location, unit, age (Ma)] La Segita Peaks, Servilleta Basalt, 3.28±0.06, 3.29±0.11, 3.32±0.12; US–285, Servilleta Basalt, 3.61±0.13, 3.82±0.03; Dunn Bridge, Servilleta Basalt, 3.95±0.05, 4.00±0.3, 4.33±0.01; N of San Antonio Mt., Servilleta Basalt, 3.21±0.08; Cerritos de la Cruz, basalt, 3.31±0.08, 3.82±0.03; Los Mogotes, basalt, 3.96±0.06; San Antonio Mt., akalic basalt, 2.43±0.04, 2.72±0.07; La Segita Peaks, akalic basalt, 2.14±0.03; No Agua roadcut, akalic basalt, 3.52±0.02; N of Cerro Chiflo, akalic basalt, 17.45±0.04; San Antonio Mt., dacites, 2.99±-0.03, 3.30±0.06; Tres Orejas, dacite, 4.60±0.5, 4.77±0.13, 4.85±0.06, 4.85±0.03; San Antonio Mt., andesite, 2.49±0.06; Pinatabosa Peaks, basaltic andesite, 2.83±0.02; Cerro del Aire, andesite, 3.52±0.05; Cerro de Taos, andesite, 4.56±0.11.

The ages presented here for the TPVF are within the range of 1.5 to 5.0 Ma seen in previous studies. Although no ^{40}Ar/^{39}Ar age determinations younger than 2.14 Ma have yet been measured, K-Ar dates for the area suggest that the younger limit for the TPVF is still valid. The ages given for the San Antonio Mountain area are in close agreement with previous K-Ar dates, as is the age for Cerro del Aire. The age range for the Servilleta Basalt however differs at its youngest end member from previously published dates. The age determinations for the Dunn Bridge area show good agreement with previous K-Ar ages for the same sequence. Overall the TPVF shows a fairly well distributed range of ages starting at 4.85 Ma and lasting until 2.14 Ma with no major breaks or hiatus in activity. Non-basaltic activity in the field appears to be well distributed throughout the eruptive sequence. The alkalic basalts in the field seem to have the narrowest range of ages, from 2.83 to 2.43 Ma, although this may an artifact of the small population measured to date.

THE VOLCANIC HISTORY AND LANDSCAPE EVOLUTION OF THE RATON–CLAYTON VOLCANIC FIELD, by *J. R. Stroud*, Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Recent ^{40}Ar/^{39}Ar data obtained in the Raton–Clayton volcanic field has provided a concise record of the eruptive history and landscape evolution in the field. Previous workers have completed extensive field work in examining the petrology and the geochemistry of the field, but only a limited effort has been made to date the volcanic rocks. One use of the data was to follow the development of the volcanic field through time. Forty-three selective whole- rock samples were analyzed by the ^{40}Ar/^{39}Ar geochronologic dating method. The results indicate that there are three phases of volcanic activity in the field. The Raton phase consists of activity from 8.77 to 7.52 Ma, with sporadic activity to 3.60 Ma; the Clayton phase lasted from 3.51 to 2.24 Ma and the Capulin phase from 1.68 Ma to 30 Ka. Eruption activity at Sierra Grande overlaps the Raton and Clayton phases from 3.80 to 2.67 Ma. Each phase is characterized by differing petrology and geochemistry established from previous studies. Another application of the data was used to estimate the amount of erosion that has occurred in the volcanic field, especially in the west part. This erosion represents continuous post-emplacement erosion around these flows, possibly caused by intense precipitation events (Chapin, pers. comm.). Because the oldest flows are on top of the local mesas, by simply calculating the vertical distance of the flows from the current surface and the age of the flows, an erosional rate can be established. Erosion rates have been calculated that range from as high as 120 m/Ma at the Raton Pass to zero in the east part of the field. This provides information that can be used in conjunction with other data to estimate the paleoclimatology of the region.

SUBSURFACE GEOLOGY OF THE PAJARITO PLATEAU, JEMEZ VOLCANIC FIELD, NEW MEXICO, by *G. Woldegabriel*[1], *A. W. Laughlin*[2], *D. Broxton*[1], *M. Heizler*[3], and *J. Bloom*[1], [1]EES-1/D462, Los Alamos National Laboratory, Los Alamos, NM 87545; [2]ICF Kaiser Engineers Inc., Los Alamos, NM 87544; [3]New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Pajarito Plateau is an east-dipping ignimbrite terrain between the Jemez Mountains on the west and the Española Valley on the east. Voluminous deposits of the Bandelier Tuff form the uppermost bedrock units. Older rock units including Miocene Santa Fe Group sedimentary rocks and interbedded volcanic rocks, Pliocene volcanic fanglomerates and conglomerates of the Puye Formation, and Pliocene Cerros del Rio and Pajarito Plateau volcanic rocks are exposed in east-trending deep canyons that merge with White Rock Canyon of the Rio Grande. This study uses borehole information to determine the distribution and structural setting of pre-Bandelier units in the Pajarito Plateau area. Geochronology and geochemistry are used to correlate mafic flows intercalated in the Santa Fe Group and the Puye Formation.

Selected basaltic samples dated by the ^{40}Ar/^{39}Ar method indicate that volcanism in the Pajarito Plateau was episodic. The volcanic rocks erupted during the Miocene (11.7–12.9 Ma and 8.4–10.9 Ma) and late Pliocene (2.3–≥2.75 Ma) periods. Major- and trace-element analyses of the drillhole cuttings yielded variable geochemical results typical of tholeiite, hawaiite, and mugearite compositions. The oldest Miocene and most of the late Pliocene flows are tholeiitic in composition, whereas the late Miocene flows are dominated by evolved rocks of mugearite affinity. Some of the late Pliocene rocks are hawaiite in compositon. The Miocene and late Pliocene tholeiites, hawaiites, and mugearites in the subsurface of the Pajarito Plateau are temporally and geochemically similar to flows exposed in White Rock Canyon and may be genetically related. The thickness of the subsurface volcanic rocks of the Pajarito Plateau are variable and appear to be confined to a marginal graben east and parallel to the present-day Pajarito fault zone.

The Miocene basaltic rocks of the Pajarito Plateau erupted contemporaneous with early magmatic and tectonic activities in the adjacent Jemez volcanic field (13–7 Ma). The Pliocene mafic volcanism was rift bound and overlaps with the late culminating stage of silicic eruptions in the Jemez volcanic field. The volcanic rocks of the Pajarito Plateau are interbedded with fluvial and lacustrine sedimentary rocks suggesting that episodes of intense tectonic activity, subsidence, and sedimentation overlapped during evolution of the Española Basin of the Rio Grande rift.

^{40}AR/^{39}AR DATING OF THE CERRO TOLEDO RHYOLITE, JEMEZ VOLCANIC FIELD, NEW MEXICO: TIMING OF ERUPTIONS BETWEEN TWO CALDERA COLLAPSE EVENTS, by *T. Spell*, Dept. of Geosciences, University of Houston, Houston, Texas 77204; and *I. McDougall*, Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia.

The Cerro Toledo Rhyolite (CTR) comprises domes and tephra erupted during the interval between two caldera-forming ignimbrites, the Tshirege Member (TM or upper) and Otowi Member (OM or lower) of the Bandelier Tuff, in the Jemez volcanic field, New Mexico. As such, they record important petrogenetic information regarding the evolution of the Bandelier magma system during this interval. Data were collected in two ^{40}Ar/^{39}Ar laboratories, and intercalibration was secured by using the same standard (Fish Canyon Tuff sanidine) and running repeated analyses of a sample from the OM Bandelier Tuff, for which identical ages were obtained. Crystal populations from 20 samples range from essentially homogenous juvenile material to populations with significant components of both juvenile and xenocrystic assemblages. In most cases dominant groups of juvenile sanidine crystals define ^{40}Ar/^{39}Ar ages that agree with stratigraphic constraints. Reliable isochron ages were obtained for most of these sanidine analyses. In contrast, plagioclase analyses are distinctly more scattered and do not define reasonable ages. The $^{40}Ar/^{39}Ar$ ages for the OM Bandelier Tuff (1.608±0.010 Ma) and the TM Bandelier Tuff (1.225±0.008 Ma) yield a repose interval of 380±20 ka between caldera collapse events. The $^{40}Ar/^{39}Ar$ dates on pumice fall units in the CTR tephra indicate that eruptive activity occurred at 1.59, 1.54, 1.48, 1.37 and 1.22 Ma. The $^{40}Ar/^{39}Ar$ dating of CTR domes indicates these were also being erupted in the caldera at 1.54, 1.45, 1.38–1.34, and 1.27 Ma. The dates obtained indicate that CTR eruptive activity producing both tephra and domes occurred during discrete intervals at approximately 1.54 Ma, 1.48–1.45 Ma, 1.35–1.37 Ma, and 1.27 Ma. The interval from 1.379±0.012 Ma to 1.336±0.018 Ma was particularly active as 7 of 16 units dated were erupted during this interval. These $^{40}Ar/^{39}Ar$ data in some cases confirm suspected differentiation sequences suggested by geochemical relationships among domes and tephra whereas in others they show that apparently related samples are of distinctly differing ages and cannot be comagmatic.

$^{40}AR/^{39}AR$ DATING OF MIOCENE SILICIC LAVAS OF THE SOCORRO–MAGDALENA AREA, by *H. H. Newell, P. R. Kyle,* and *W. C. McIntosh,* Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Miocene silicic volcanic rocks in the Socorro–Magdalena area have been dated by the high-precision $^{40}Ar/^{39}Ar$ dating method to determine their eruptive history. The silicic lavas are located on the Morenci lineament, an accommodation zone associated with the Rio Grande rift. The distribution of the silicic lavas is arbitrarily divided into the Socorro Peak, the Pound Ranch, the Magdalena Peak, and the Squaw Peak eruptive centers. Previous studies by Bobrow et al. (1983) identified sporadic volcanism from 18 to 7 Ma and discussed the petrographic, geochemical, and petrologic evolution of the lavas.

The $^{40}Ar/^{39}Ar$ dates on mineral separates have been obtained by single-crystal laser fusion and incremental furnace-heating procedures. Many of the silicic lavas contain sanidine, which is ideal for dating. Plagioclase, biotite, and hornblende separates allow for the comparison of ages on two or more minerals from a single rock sample. SOCORRO PEAK CENTER: "Signal Flag Hill," sanidine, 8.61±0.02 Ma; biotite, 8.84±0.12 Ma; "Grefco Dome," sanidine, 7.85±0.02 Ma; "Jejenes Hill East," sanidine, 7.52 ±0.09 Ma; "6633 Peak," sanidine, 7.08±0.01 Ma; biotite, 8.56±0.12 Ma; "Tripod Peak," sanidine, 7.02±0.01 Ma; biotite, 9.20±0.30 Ma. POUND RANCH CENTER: L. Pound Ranch unit, sanidine, 11.55±0.07 Ma. SQUAW PEAK CENTER: Alameda Springs unit, sanidine, 14.89±0.07 Ma.

The ages on biotite pairs from the same samples are problematic. All of the biotite separates analyzed by $^{40}Ar/^{39}Ar$ and the previously reported K/Ar dates are older than the more-precise sanidine dates. Excess argon, chloritization, and xenolithic contamination are possible explanations for the older apparent ages of the biotites. Additional $^{40}Ar/^{39}Ar$ sanidine and biotite dates from all of the eruptive centers will be reported later.

The Miocene silicic rocks of the Socorro–Magdalena area are younger than previously determined. An episode of rhyolitic volcanism from 7.0 to 8.6 Ma is preserved in the Socorro Peak area. The other silicic centers progressively increase in age to the southwest with conventional K/Ar ages from 10 to 18 Ma.

CHRONOLOGY OF TEPHRA DEPOSITS IN RIO GRANDE BASIN-FILL SEQUENCES, CENTRAL AND SOUTHERN NEW MEXICO, by *W. C. McIntosh* and *N. W. Dunbar,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The combination of $^{40}Ar/^{39}Ar$ geochronology and microbeam geochemical analyses is aiding development of a chronologic framework for numerous tephra layers in Rio Grande basin-fill sequences from northern New Mexico to El Paso. Tephra layers are intercalated with Miocene, Pliocene, and Quaternary sediments and can be divided into three typical lithologies: (1) coarse, proximal, pyroclastic-fall deposits; (2) fine, distal, pyroclastic-fall deposits; and (3) fluvially transported concentrations of pumice. Many of the coarse and fine pyroclastic-fall deposits have been fluvially reworked. Previous work using bulk geochemical fingerprinting methods had identified the sources for some of the Quaternary fine, distal, pyroclastic-fall deposits.

Advances in $^{40}Ar/^{39}Ar$ methods have made possible direct dating of many of the coarser and some of the finer tephra deposits. Laser fusion of single sanidine crystals as small as 0.25 mm allows identification and rejection of older contaminant grains. In ashes containing tinier sanidines, laser fusion of small (1 mg) groups of crystals also aids in assessment of contamination. Step heating of biotite separates allows assessment of alteration. Even in samples that are not presently dateable by $^{40}Ar/^{39}Ar$ methods, electron and ion microbeam techniques allow precise geochemical fingerprinting of major and trace elements in individual glass shards as small as 20 μm.

Coarse pumice deposits intercalated with axial river facies primarily represent reworked ignimbrite and plinian pumice derived from Jemez eruptions. The coarsest and most extensive pumice deposits include catastrophic flood deposits at sporadic locations extending from Isleta to Rincon and fluvial pumice concentrations extending as far south as El Paso. These deposits have been dated at 1.6 Ma and geochemically correlated by microbeam techniques with the lower Bandelier ignimbrite. They apparently formed after damming of the Rio Grande by the lower Bandelier ignimbrite and subsequent dam failure. Other pumice concentrations in southern Rio Grande basin-fill sequences have $^{40}Ar/^{39}Ar$ ages of 3.1 and 1.3 Ma, probably derived, respectively, from Puye and Cerro Toledo eruptions.

Sequences of coarse pyroclastic fall deposits intercalated with basin-fill deposits have been successfully dated ($^{40}Ar/^{39}Ar$) in the San Lorenzo Canyon area (14.5 Ma), in the Silver Creek area (15.6–14.6 Ma), in the Albuquerque Basin (15.6–13.6 Ma), and in the Chamita Formation in the Española Basin (6.95–6.75 Ma). The San Lorenzo and Silver Creek ashes were apparently produced by eruptions associated with rhyolite domes in and near the Magdelena Mountains, and the Chamita Formation ashes were produced by eruptions associated with the Bearhead Rhyolite.

The $^{40}Ar/^{39}Ar$ dating of fine-grained (<0.25 mm) ashes has proven problematic because many contain older contaminant feldspars but are too fine for single-crystal analysis. In at least one case, a non-reworked ash exposed west of Socorro in Blue Canyon, it is clear that the contaminant feldspars were incorporated at the time of eruption. Successfully dated fine ashes include White ash #2 (15.6 Ma) and White ash #4 (15.4 Ma) in the Española Basin and a Quaternary ash west of Luis Lopez (1.2 Ma). Successful dating of other fine ashes will require either improved separation techniques to remove very fine K-feldspar contaminant grains or improvements in mass spectrometry to allow single-crystal dating of silt-sized grains.

Microbeam geochemical fingerprinting has been much more successful in correlating, and thereby indirectly dating, fine ashes. Ashes in the Luis Lopez and Socorro areas have been geochemically linked with lower Bandelier plinian and other Jemez eruptions. Some of the fine ashes in the Española Basin represent distal fall facies of eruptions in Nevada and Idaho.

CHRONOLOGY AND THERMAL HISTORY OF POTASSIUM METASOMATISM IN THE SOCORRO, NEW MEXICO, AREA: EVIDENCE FROM $^{40}AR/^{39}AR$ DATING AND FISSION-TRACK ANALYSIS, by *N. W. Dunbar* and *D. Miggins,* New Mexico Bureau of Mines and Mineral Resources and Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Argon 40/39 dating and fission-track analysis of K-metasomatized rocks have provided insight into the timing and thermal regime of this geochemical alteration in the Socorro area. During K-metasomatism, which is thought to be caused by alkaline-saline brines in a closed-basin playa system, the rocks of the basal Popotosa Formation and underlying ignimbrites underwent alteration that resulted in selective replacement of non-K-bearing phases, such as plagioclase, by a combination of adularia, clay, and quartz. The $^{40}Ar/^{39}Ar$ dating was carried out on material selectively hand-picked from altered plagioclase crystals in basaltic-andesite units as well as plagioclase-bearing silicic ignimbrites and allows resolution of the alteration age from the eruption age of the original unit. Isochron ages for hand-picked rhyolitic material and a mafic clast from the basal Popotosa conglomerate in the Box Canyon area are 8.7±0.1 and 7.4±0.1 Ma respectively. A rhyolitic clast from an underlying lithic-rich tuff at a nearby location yields a plateau age of 10.4±0.1 Ma. An ignimbrite sample collected from the metasomatized Water Canyon area yields a plateau alteration age of 14.1±0.1 Ma. The $^{40}Ar/^{39}Ar$ ages determined on sanidine crystals from the above-mentioned samples are slightly younger than true eruption age, suggesting that the sanidine has been chemically affected by alteration.

Fission-track analysis of apatite and zircon in ignimbrites from the areas mentioned above have also been performed. One clast of crystal-rich tuff collected from an intensely metasomatized outcrop of Popotosa Formation in the Box Canyon area contained apatite and yielded an apatite fission-track (AFT) age of 8.7±5.1 Ma. Zircon FT ages determined for other two other clasts yielded ages of 23.3±1.4 (Hells Mesa Tuff) and 23.9±2.2 Ma (upper Lemitar Tuff). These ages are slightly younger than true eruption ages and suggest that the clasts may have been exposed to temperatures on the order of 170 to 200°C. Two clasts of crystal-rich tuff were collected from the Popotosa Formation in Water

Canyon area. A clast tentatively identified as upper Lemitar Tuff has an AFT age of 15.0 ± 3.3 Ma and a clast of Hells Mesa Tuff has an AFT age of 18.0 ± 3.6 Ma. The AFT results can be used to infer that temperatures were above 120°C in this area, and cooling occurred rapidly in the middle Miocene.

The combination of ages determined by $^{40}Ar/^{39}Ar$ and FT analysis suggests that both techniques are dating the same thermal/alteration event, and we would infer that this event is the K-metasomatism. The dates suggest that alteration began at least 15 Ma and continued until approximately 7 Ma. This chronological information is consistent with the inferred timing of playa deposition from independent geological evidence. We believe that metasomatism in the Box Canyon area may have been caused by fluids from the deepest and most central part of the playa system, an interpretation consistent with the high temperatures shown by FT analysis, high degree of K enrichment, and youngest date of metasomatism. The Water Canyon area may represent a more distal part of the playa where alteration occurred earlier and at lower temperature. This pattern of alteration would be consistent with that of paleolake T'oo'dichi (Turner and Fishman, 1991).

A CHRONOSEQUENCE STUDY OF SOILS DEVELOPING ON BASALT FLOWS IN AN ARID ENVIRONMENT, THE POTRILLO VOLCANIC FIELD, DOÑA ANA COUNTY, NEW MEXICO, by *M. C. Eppes* and *B. Harrison*, Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

One of the most widely referenced soil-geomorphic studies in the US is the Desert Project, near Las Cruces, New Mexico, in which Gile et al. defined stages of calcic horizon development in soils of arid environments. Each stage of calcic horizon development incorporates an age range of several thousands of years. To place better age constraints on these stages of development in the Desert Southwest, soils forming on well-dated basalt-flow surfaces in the Potrillo volcanic field, Doña Ana County, New Mexico, were examined.

Soils were described on four basalt flows (Aden, AD; Afton, AF; and two flows from Little black mountain, LBM & LBMX). Surfaces were dated using $^{40}Ar/^{39}Ar$ and He surface dating methods, and their ages are AD, ~20 ka; AF, ~90 ka; LBM, ~188 ka; and LBMX, >200 ka. Basalt flow surfaces evolve topographically through time as depressions are filled with basalt rubble and eolian dust. Young flows have as much as 4 m of relief whereas the surfaces of older flows are virtually flat. Soil development on the surfaces varies according to where the soil is forming in relation to highs and lows in the flow topography. Soils developing in low areas where more eolian material has accumulated show cummulic profiles and more apparent development than the soils of higher areas. Separate chronofunctions for soils developing on highs and lows are therefore required to adequately describe soil evolution through time.

Chronofunctions of profile carbonate accumulation suggest a break in slope around 150 ka. Carbonate percentages increase more rapidly with age in the LBM and LBMX soils, and they have significantly higher pH and conductivity levels in depth profiles than AD and AF soils. The LBM and LBMX soils are also sandier in texture than the AD and AF soils.

The sandier texture of LBM and LBMX soils could be influencing carbonate precipitation, pH, and conductivity. Higher sand and carbonate components of LBM surfaces can be explained in at least two ways or a combination of both: (1) a change in dust composition, i.e. to more sandy and/or more $CaCO_3$-rich, around 150 ka. (2) Dust size decreases across the Potrillo volcanic field with increasing distance from the Rio Grande. A change in dust composition in this area has climatic change implications for the Southwest, suggesting increasing aridity during the Quaternary.

STRUCTURE, METAMORPHISM, AND VOLCANOLOGY SESSION

EVIDENCE FOR 1.4 GA METAMORPHISM AND DEFORMATION IN THE AUREOLE OF THE SANDIA PLUTON, MONTE LARGO HILLS AREA, NEW MEXICO, by *J. M. Timmons*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The Monte Largo Hills preserve outcrops of the roof and southeast aureole of the Sandia pluton. Recorded in deformed phases of the Sandia granite and thermally softened aureole is evidence of a dynamic interaction of pluton emplacement, metamorphism, and deformation. Deformation associated with the intrusion is recorded by variably developed high-temperature solid-state deformation of both megacrystic (Sandia) and medium-grained (Cibola) granites, including S-C fabrics and dynamically recrystallized sigma feldspar porphyroclasts in the granite. In the aureole, syn-plutonic deformation is recorded by shallow lineations and reorientation of foliation surfaces relative to contact metamorphic porphyroblasts. Recent 1:12,000 mapping in the Sandia Park quadrangle supports the interpretation that the roof of the pluton is shallowly dipping to the southeast truncating the steeply dipping country-rock foliation. The country rock exposed in the study area consists of a bimodal metavolcanic package consisting of intimately interlayered rhyolite (60%), greenstone (25%), quartzite (10%), and pelitic schist (5%). Metamorphic grade in the 2-km-wide aureole increases toward the pluton from greenschist faces (kyanite, actinolite), reflecting pre-pluton metamorphic conditions, to sillimanite grade proximal to granite exposures. Final crystallized melts of the granite appear relatively strain free suggesting emplacement of the Sandia pluton took place during the waning stages of some deformational event. A recent discovery in the Monte Largo Hills is the presence of a highly sheared granite that appears unrelated to the Sandia intrusion and may represent an earlier intrusion possibly correlative with the Manzanita granite. The presence of the roof and aureole of the Sandia pluton in the Monte Largo Hills with the same orientation as outcrops on the northwest side of the Tijeras–Gutierrez fault system suggests a relatively small strike-slip component (less than several kilometers) on this Laramide fault system.

1.7–1.4 GA POLYMETAMORPHIC HISTORY OF THE BIG THOMPSON CANYON, NORTHERN COLORADO FRONT RANGE, by *M. Hodgins* and *J. Selverstone*, Dept. of Earth & Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, mhodgins@unm.edu

Recent work in the Proterozoic of southwest North America suggests that the ca 1.4 Ga metamorphic and deformational events are more important and more widespread than previously thought (Nyman et al., 1994; Kirby et al., 1995; Karlstrom et al., 1996). These ca 1.4 Ga events involved regional heating at low to moderate pressure (3–5 kbar), large-scale, widespread granitoid intrusions and movement on some shear zones, and deformation localized around some 1.4 plutons. The Big Thompson Canyon region of the Yavapai province in the northeastern Colorado Front Range was previously thought to have experienced one low-pressure, high-temperature metamorphism ca 1.7 Ga during the collision of this region with the Archean Wyoming province. Recent workers (Selverstone et al., 1995; Shaw et al., 1995) in this area have found abundant evidence for a more-complex polymetamorphic history that includes an early high-pressure, high-temperature metamorphism ca 1.7 Ga and a later low-pressure, high-temperature metamorphism ca 1.4 Ga.

Metamorphosed Proterozoic supracrustal rocks are exposed approximately 100 km south of the suture with the Archean Wyoming province in the Front Range of Colorado. This region, centered on the Big Thompson Canyon, consists of subvertical, polydeformed metaturbidite sequences that still preserve relict graded bedding. The metasedimentary rocks range in grade from biotite zone to the onset of partial melting and are concordantly intruded by ~1.7 Ga trondhjemites parallel to foliation. The high-grade rocks of this region are intruded by discordant bodies of ~1.4 Ga granite. This is the only area in the Front Range of Colorado where a complete progression from low to high grades is preserved, and it therefore presents the opportunity to determine the P-T-t deformation history of Proterozoic tectonism uncomplicated at lower grades by the effects of diffusional reequilibration. The 1.7 Ga metamorphism reached garnet-staurolite grade over a large part of the area following isoclinal folding and development of axial planar foliation and prior to the development of steep, asymmetric crenulation cleavages. The initial prograde metamorphic assemblages were retrogressed to chlorite+white mica±cordierite pseudomorphs by post-deformational fluid-rock interaction. New euhedral garnet and staurolite growth in some of these pseudomorphs indicates a subsequent, short-lived heating event. Ar-Ar age spectra from hornblende, muscovite, and biotite indicate that this reheating event reached temperatures of about 500 to 550°C ca 1.4 Ga followed by rapid cooling (Shaw et al., 1995). The isograd pattern of this region is interpreted as a combination of 1.7 and 1.4 Ga metamorphism rather than just 1.7 Ga tectonism, as previously thought. The isograds and locations where Ar age spectra indicate 1.4 Ga resetting are not spatially related to 1.4 Ga plutons and therefore may represent a widespread mid-crustal heating event. PT data indicate that both the 1.7 and 1.4 Ga metamorphic events occurred at pressures of 2 to 4 kbar; however, some samples preserve earlier pressures of 8 to 10 kbar that probably predate the emplacement of the 1.7 Ga intrusions. These data are interpreted to indicate that the early metamorphism involved deep burial of the sedimentary sequences during the collision with the Wyoming craton ca 1.8 Ga. The rocks were then transported to shallower depths and intruded by 1.7 Ga trondhjemites, metamorphosed to gt-st grade, and further deformed. The region experienced pervasive post-deformational hydration and metamorphism to T>500°C ca 1.4 Ga. Field relations and geochronologic data are incompatible with a model of early, ca 1.7 Ga metamorphism followed by slow cooling and indicate that the 1.4 Ga metamorphic event is more significant in this area than previously thought. Many observations made in the Front Range are similar to those made in the Proterozoic rocks of New Mexico and Arizona. This relationship indicates that similar processes occurred throughout the southwest U.S. ca 1.4 Ga and that the heating event of that age is a widespread, regional metamorphism.

SUB-HORIZONTAL FLOW AND FOLDING FACILITATED BY PLUTONISM WITHIN THE MIDDLE CRUST: RINCON RANGE, MORA COUNTY, NEW MEXICO, by *A. S. Read*, Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131
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The Proterozoic rocks exposed in the Rincon Range (north of Mora, New Mexico) display progressive north to south changes in structural style that reflect depth and proximity to syntectonic granitoid plutons. At the north end of the range, overturned sections of the 1-km-thick quartzite of the Ortega formation are repeated several times by north-vergent thrusts. In the vicinity of the town of Guadalupita farther south, the quartzite defines the limbs of a large-scale synformal anticline cored dominantly by fine-grained foliated felsic gneiss. This felsic gneiss is complicated internally by smaller-scale folding and contains layers of amphibolite and quartzite. Farther south, in the vicinity of the small village of El Turquillo, the quartzite limbs of the synformal anticline become drastically attenuated and entirely surrounded by gneiss. This suggests that the quartzites are screens in an intrusive fine-grained granite gneiss. Additional evidence for an intrusive relationship comes from the existence of ~10-cm-diameter 'nodules' of musc-sill±kspar in the gneiss that are interpreted to be xenoliths of nearby quartzite in the felsic gneiss. A transition exists from thin tabular foliated quartzite layers to blocky nodules to more equant nodules. Similar 'nodules' are seen in both the Cimarron and Taos Ranges in the regionally extensive felsic gneiss in contact with quartzite.

Still farther south, along La Cañada del Carro, a Phanerozoic fault marks a fairly abrupt change in the character of the granitic gneiss. The gneiss south of the fault, and on to the town of Mora, is much more homogenous, and the foliation is regionally subhorizontal over some 40 km^2. In the gneiss, particularly in the vicinity of Tierra Amarilla canyon, considerable volumes of pegmatites are dominantly concordant with S1 but are locally seen to crosscut S1 and, in one case, intrude the axial plane of an F2 fold. In these southern gneisses is an S1 parallel zone of musc-kspar±grt schist that is several meters thick and is traceable over most of the area of gneiss exposure. This zone contains high proportions of muscovite, oxides, and zircon in addition to quartz and remnant kspar that define highly strained ribbons separated by muscovite layers. This muscovite-rich rock likely represents a shear zone and fluid conduit that experienced metasomatic alteration in the parent gneiss.

From north to south, this progression can be summarized as follows: moderately steeply dipping north-vergent thrust duplex structures, more open folding, areas where supracrustal rocks are caught up in the intrusion as screens and xenoliths, to a more homogeneous fine-grained granite gneiss with subhorizontal foliation cut by concordant pegmatites and subhorizontal high-strain fluid conduits.

The favored model is that pluton emplacement apparently thermally eroded the mechanical strength of the middle crust near the brittle-ductile transition and localized subhorizontal flow, both magmatic and solid state, along and within granitoid sills. Differences in metamorphic grade (~500° vs 700° at ~4–6 kb) reflect steep field gradients around the pluton. The granite gneiss displays microtextural evidence for high-temperature solid-state deformation such as grain boundary migration in kspar. This is in apparent contrast with Al_2SiO_5 triple-point metamorphic conditions in the nearby quartzite. Additionally, the presence of a thick quartzite in the north part of the range may accentuate the structural style changes and metamorphic grade contrast because of the high thermal conductivity of quartzite.

ROTATED AND NONROTATED PORPHYROBLASTS, by *B. R. Ilg*, Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131
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Metamorphic porphyroblasts in supracrustal rocks of the Granite Gorge Metamorphic Suite exposed in the Upper Granite Gorge of the Grand Canyon have responded variably to noncoaxial heterogeneous shortening deformation; some rotated, others remained fixed with respect to geographic coordinates. Thin-section-scale domains of rotated versus nonrotated garnets are developed adjacent to one another in garnet-staurolite schist, demonstrating endmember behavior on a millimeter scale. However, in spite of local domains of rotation, inclusion trails within porphyroblasts in most samples consistently strike either northwest or northeast, in keeping with regional trends and indicating that most porphyroblasts did not significantly rotate across the 70-km-long transect. Porphyroblasts with northwest-striking inclusion trails are interpreted to have overgrown a regionally penetrative, northwest-striking foliation (S1) pre- to early-S2 development. Porphyroblasts with northeast-striking inclusion trails are interpreted to have overgrown the northeast-striking S2 late during S2. Nonrotated porphyroblasts yield insights about both the early geometry of S1 throughout the transect and the timing of their growth with respect to S2-related deformation. Rotated porphyroblasts yield information about the local finite-strain history. These methods provide a powerful tool for evaluating the tectonic evolution of middle crustal rocks in an orogen and for understanding the complex behavior of porphyroblasts during ductile deformation.

CAMBRIAN PLUTONISM IN SOUTHERN NEW MEXICO: THE FLORIDA MOUNTAIN INTRUSIONS, by *S. D. Ervin* and *N. J. McMillan*, Dept. of Geological Sciences, New Mexico State University, Las Cruces, NM 88003
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Late Cambrian plutonic rocks, dated by U-Pb zircon at 503±10 Ma (Evans and Clemons, 1988), located in the Florida Mountains south of Deming, New Mexico, present an intriguing problem in interpreting the tectonic history of southern New Mexico. Alkali-feldspar granites and syenites in the Florida Mountains have been mapped by Clemons (1982, 1984, 1985) and Clemons and Brown (1983) as two distinct bodies, separated by the South Florida Mountains fault (SFMF). The plutonic rocks are overlain by the Late Cambrian Bliss Sandstone, which was locally derived from the intrusions. During the Late Cambrian, southern New Mexico is thought to have been a passive continental margin, a tectonic setting commonly devoid of igneous activity. The presence of Cambrian-age intrusions in the Florida Mountains and the rapid unroofing implied by the Bliss Sandstone suggests a more-active tectonic setting. This study uses detailed petrographic and geochemical analyses to indicate depth of emplacement, to model magmatic processes that occurred during magma genesis, to estimate the amount of unroofing necessary to expose the pluton, to determine source regions for the intrusion, and to identify the structural relationship between the igneous bodies north and south of the SFMF.

All Florida Mountain igneous rocks are hyper-solvus, one-feldspar plutons containing potassium feldspar with exsolved plagioclase, indicating that the intrusion crystallized at $P_{H_2O}<5$ kb (<16.5 km). Low-pressure textures, such as miarolitic cavities, are absent. Thus, the pluton was probably emplaced in the upper crust but not at extremely shallow depth. Exsolution laminae are broader and more well developed in rocks south of the SFMF; north of the SFMF, the rocks contain orthoclase, but south, orthoclase has partially inverted to microcline. This indicates that the alkali-feldspar granites in the south have cooled more slowly than the syenites and alkali-feldspar granites in the north. Mafic enclaves with chilled margins and potassium feldspar xenocrysts (1–3 cm) identical to phenocrysts in the alkali-feldspar granites are abundant south of the SFMF. These enclaves are interpreted as partially mixed mafic magmas injected in the lower part of the chamber. Cenozoic movement along the fault thrust the southern alkali-feldspar granites over the upper part of the pluton. The presence of Late Cambrian magmatic activity and evidence for up to 16 km of erosion between 503±10 Ma and deposition of the Late Cambrian–Early Ordovician Bliss Formation (ca 505 Ma) suggest that this continental margin was atypical. Whole-rock major- and trace-element analyses are in progress to identify magma sources and mechanisms of melting, which should aid in the re-interpretation of Late Cambrian tectonics of the region.

LARAMIDE CONTRACTIONAL DEFORMATION IN THE SANDIA MOUNTAINS, by *K. E. Karlstrom*, Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, 87131; and *C. A. Ferguson*, Arizona Geological Survey, Tucson, Arizona, 85701

Recent mapping of the Placitas and Sandia Park quadrangles sheds new light on the geometry of contractional features of probable Laramide age in the Sandia uplift. Although faults were reactivated in the Tertiary, the Laramide history was a major factor in producing the present geometry of the Sandia uplift. Two main contractional zones control the geometry of the eastern margin of the Sandia uplift: (1) the north–south-trending, east-vergent faults and related small- to large-amplitude folds of the San Antonio fault system and

(2) the northeast-trending, northwest-verging reverse faults and monoclines of the Tijeras–Gutierrez fault zone. The interaction of these two features, oppositely verging contractional features, produced the prominent Tijeras synclinorium, which is one of the few places on the east flank of the Sandia–Manzano Mountains where Mesozoic rocks are preserved. The San Antonio fault zone is a series of en echelon faults that form an east-verging fault system analogous to the Montosa fault of the Manzano Mountains to the south. The Sandia Park quadrangle contains numerous small-scale north–south- to northwest-trending folds and incipient axial planar cleavage associated with a network of high-angle east-side-down, north-striking reverse faults and monoclinal warps. Small-scale folds are disharmonic and most common in thinly bedded Madera Formation near La Madera. This system can be traced north to the Placitas quad where east-vergent contractional deformation is preserved in one segment of the Tertiary-reactivated (west-side-down) East Las Huertas fault, indicating a Laramide ancestry. Tertiary west-side-down movement along all these faults has diminished and often reversed the throw, making it impossible to estimate original extent of contraction along this system. Nevertheless, we think it was an important zone in controlling the geometry of Laramide Sandia uplift.

Although also overprinted by Tertiary movements, the geometry along the Tijeras–Gutierrez fault system was produced mainly by east-west contractional deformation in the Laramide. The bulk of the movement was northwest vergent with offset partitioned onto different fault segments linked by the southwest-dipping monoclinal warp of the Frost Arroyo. To the south of the Frost Arroyo, the Gutierrez fault accommodates about 1 km of southeast-side-up throw and related large-scale drape folding to produce the Tijeras synclinorium and its fault-truncated anticline pair. Throw on the Gutierrez fault decreases rapidly northeastward, toward Frost Arroyo, where it changes sense to (more minor) southeast-vergent sense along the northern segment. Major southeast-side-up displacement is transferred to the Tijeras fault across the Frost Arroyo monocline. Southeast-side-up throw of about 1 km across the Tijeras fault juxtaposes Proterozoic rocks with the San Pedro syncline. Both the Tijeras and Gutierrez are scissors faults with associated folds that have axial plane and vergence consistent with an origin as "drape" folds associated with the contractional faults.

Possible strike-slip displacement along the Tijeras–Gutierrez system remains controversial, and evidence is sparse. Shallowly plunging slickenlines are present, but age and magnitude of slip(s) are unknown. A closely spaced set of north- to north–northwest-striking vertical faults with sinistral stratigraphic separation was mapped along the west side of the Tijeras fault. These faults may have initiated as Laramide contractional fractures and later acted as synthetic R-shears during sinistral Tertiary movement. An earlier (Laramide) component of dextral slip on the Tijeras is inferred from the transfer zone across the Frost Arroyo (a restraining bend) and the geometry of the Monte Largo uplift (a flower structure). Magnitude of strike slip is probably minor (less than a few kilometers) as there is little strike separation of markers that can be mapped across the Tijeras–Gutierrez fault. These markers include the shallowly southeast dipping surfaces of the roof of the Sandia pluton and associated isograds.

EVOLUTION OF IGNEOUS VEINS INTRUDING BASANITE AT EL PORTICITO, QUEMADO, NEW MEXICO, by *R. R. Horning, N. W. Dunbar, P. R. Kyle,* Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *W. S. Baldridge,* Los Alamos National Laboratory, Los Alamos, NM 87545

Field relationships, mineralogical, and geochemical studies are used to explain the origin of a complex network of light-colored, igneous veins that intrude dark, fine-grained basanite at El Porticito and the adjacent Tejana Mesa, located approximately 8 km north-northwest of Quemado, N. M. Subhorizontal veins, ranging in thickness up to 2 m, form anastomosing patterns across the faces of El Porticito. In places, subvertical veins suggest 'tap roots' appearing to feed the higher-level networks of subhorizontal veins. Veins similar to those in El Porticito intrude the nearby lowermost Tejana Mesa lava. Thin (≤0.2 mm), subhorizontal veinlets are common in host rock at both locations and occasionally penetrate host rock/vein interfaces. Beneath the Tejana Mesa lavas, a few hundred meters southeast of El Porticito, scoria and bombs are exposed.

The veins are holocrystalline and coarse grained. Titaniferous pyroxene, the dominant phenocryst in veins, displays two crystal habits. The first consists of euhedral, fractured, sometimes offset, grains that apparently grew to near their final size (up to about 2 cm long) prior to final vein emplacement, as indicated by the absence of further growth after fracturing. Many other pyroxene phenocrysts nucleated on vein walls. Vein textures suggest that entrainment of these elongate phenocrysts into flowing vein magma was common. The elongate habit of these pyroxene phenocrysts and the skeletal and dendritic habits of other phenocrystic phases, particularly magnetite and alkali feldspar, are consistent with growth during rapid cooling of veins. Vein groundmass consists of Ba-rich alkali feldspar, analcite, leucite, and minor phases. The mineralogy of the thin, subhorizontal veinlets is similar to vein groundmass. In contrast to the veins, the host rock exhibits a fine-grained igneous texture typical of an extrusive mafic rock. It consists of small, sparse to common phenocrysts of olivine, augite, and magnetite enclosed in a groundmass consisting primarily of euhedral clinopyroxene crystals. Acicular apatite is ubiquitous in both veins and host rock. Virtually all phenocrysts longer than 1 mm, except apatite, in both host rock and veins are fractured.

The lavas of El Porticito and nearby Tejana Mesa have similar compositions. Major-element compositions of bombs, host lavas, and veins form a coherent basanitic trend. Bombs contain about 40% SiO_2 and 2–3% total alkalis, host lavas 41–43% SiO_2 and 2–4.5% total alkalis, and veins 41–47% SiO_2 and 4.5–8.5% total alkalis. Various component pairs, notably TiO_2 vs. MgO, V vs. Ni, and K_2O vs. Ni, form a second trend within the veins. These trends in host and vein rocks are tentatively interpreted to be the result of fractional crystallization, first within the magma source, and then within the veins as they were emplaced.

Lithologic relations seen in outcrop indicate that at least some of the veins were intruded into fractures in the host rock. Possibly the host rock was passing through the 'critical crystallinity' cooling phase (about 50% crystals) and thus exhibited brittle deformation in response to stress. The rarity of volcanic exposures that exhibit the structure of El Porticito is tentatively attributed to the low probability that significant strain occurs as the magma passes through the range of critical crystallinity. When this does occur, development of brittle fractures in the cooling magma mush allows segregaton, transport, and/or emplacement of more-evolved magma to form veins. This evolved magma may be derived entirely in situ, or it may be differentiated from a hidden magma chamber and intruded into the present location. In either case, the formation and emplacement of veins may be a consequence of the stress field that allowed the crystallizing mush to fracture.

P-T HISTORIES OF METASEDIMENTARY XENOLITHS FROM THE NAVAJO VOLCANIC FIELD: IMPLICATIONS FOR PROTEROZOIC CRUSTAL STRUCTURE BENEATH THE COLORADO PLATEAU, by *J. Selverstone, K. Karlstrom,* and *A. Pun,* Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, selver@unm.edu

Preliminary examination of 85 crustal xenoliths from six diatremes in the Navajo volcanic field provides information on crustal compositions in basement beneath the Colorado Plateau. Each of the diatremes brought up mafic granulites, felsic orthogneisses, and granitoids. In addition, the three northwest diatremes (Moses Rock, Garnet Ridge, and Red Mesa) brought up abundant paragneisses and garnet amphibolites that are lacking in the xenolith suites from the southeast diatremes (Shiprock, The Thumb, and Mitten Rock). This observation indicates either a fundamental difference in lower to midcrustal makeup between the two suites or an inherent sampling bias by the different diatremes.

The metasedimentary rocks of the north diatremes fall into two categories, both of which are represented at all three sites: (1) garnet-sillimanite-perthite-qtz±plag±kyanite±hercynite gneiss and (2) isoclinally folded biotite-sillimanite-Fe-oxide gneiss. The latter rock type occurs at musc+qtz grade in the Red Mesa suite and at 2nd sillimanite grade in the Moses Rock suite; both metamorphic grades are represented in the Garnet Ridge suite. Approximately half of the Type (2) metasedimentary xenoliths experienced pervasive low-T, moderate-P hydration, as documented previously by Broadhurst (1986) and confirmed in this study; Type (1) xenoliths were largely unaffected by this hydration.

P-T calculations carried out on the Type (1) metasedimentary xenoliths indicate that a thermal peak of ~700–850°C was attained at pressures between ~6 and 10 kbar (~20–35 km), followed by prolonged cooling to temperatures of ≤500°C at unknown depths. The extensive diffusional cooling profiles indicate that the "peak" conditions were attained prior to Tertiary entrainment in the host kimberlite and most likely represent part of the Proterozoic metamorphic history. Numerous petrographic observations in single samples place further constraints on the PTt path shape: (a) inclusions of intergrown sill+kspar in garnet indicate initial garnet growth around mus grains, followed by the reaction musc+qtz=sill+kspar+H_2O at $2<P<10$ kbar. (b) Herc inclusions in the outer portion of garnets and as discrete grains in the presence of quartz in the matrix indicates continued garnet growth up to high T followed by the reaction gar+sill=herc+qtz at P>3 kbar. (c) Partial transformation of sill to kya in the presence of kspar indicates T>750–800°C at P>9–10 kbar. (d) Extensive perthitic exsolution of kspar implies slow cooling at high T. (e) A few samples show retrogression of kspar+Al_2SiO_5 to musc. These observations are consistent with counterclockwise PTt paths that reached granulite grade followed by slow cooling at depth; such paths are typical of pluton-enhanced metamorphism in collisional settings.

Paragneisses with similar bulk composition and metamorphic grade occur in Proterozoic exposures in the Cimarron Range (Grambling & Dallmeyer 1993) and the Grand Canyon (Williams 1991) but have not thus far been reported from rocks farther to the south. Model Nd ages of 1.8–2.0 Ga (Wendlandt 1992) obtained on Type (1) xenoliths are in agreement with model ages determined from the Yavapai province to the north. Broadhurst (1986) argued that hydration of the type (2) xenoliths might represent Tertiary devolatilization of the Farallon slab, but the lack of scatter in the model ages argues against such a young event and the lack of similar hydration features in the south diatremes is also difficult to explain by this model. An alternative hypothesis is that the hydration was related to underthrusting and devolatilization of hydrous material in the Proterozoic. Eclogite xenoliths with Proterozoic Nd model ages (Wendlandt 1992) are also confined to the north diatremes. This geographic restriction of Proterozoic metasediments, hydration, and eclogites to the north diatremes supports the existence of a major crustal boundary in the Four Corners region, as postulated from other lines of evidence by Bennett and DePaolo (1987) and Karlstrom and Bowring (1988). The locus of crustal hydration and restricted occurrence of eclogitic mafic rocks further suggest an original northward dip along this boundary.

PALEONTOLOGY SESSION

LATE PENNSYLVANIAN MARINE FAUNAS OF THE MADERA FORMATION, JEMEZ SPRINGS AREA, NORTH-CENTRAL NEW MEXICO,

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Although Upper Pennsylvanian (Missourian–Virgilian) strata near Jemez Springs are profusely fossiliferous, these diverse faunas have been little studied; only the brachiopods of the uppermost unit (Jemez Springs Shale Member) are well known. Extensive collections (7,000+ specimens) of marine invertebrates were made from three shale units west of Hummingbird Music Camp, 7.8 km north of Jemez Springs town. The lowest fauna, from a yellow-brown shale unit (HC-1) about 65 m below the base of the Abo Fm., is dominated by a high-spired, large (25 mm high), probable new species of the gastropod *Stegocoelia (Hypergonia)*, by the bivalve *Myalina (Orthomyalina) slocombi*, and by dense rhomboporoid bryozoan fragments. Snails (*Goniasma*, several bellerophontids), the bivalve *Nuculopsis girtyi*, and the brachiopods *Composita subtilita* and *Crurithyris planoconvexa* compose important subsidiary elements of this fauna, which is dominated by molluscs and overall of relatively low taxonomic diversity.

A higher shale unit (HC-11, 27–33 m below the Abo, about at the Missourian–Virgilian boundary) is reddish gray with minor limestone beds. It contains a much more diverse, mollusc-dominated fauna, including about 20 species each of gastropods and bivalves, 18 species of brachiopods, and low to moderate numbers of scaphopods, echinoid and crinoid remains, small, solitary rugose corals, trilobites, and bryozoans. Among gastropods, bellerophontids (e.g. *Bellerophon* n.sp., *Euphemites* n.sp., *Retispira eximia, R. tenuilineata, Knightites* n.sp.), *Glabrocingulum (G.)* n.sp., *Trepospira* aff. *illinoisensis*, and *Amphiscapha subrugosa* are most abundant. No single bivalve species is unusually common; characteristic taxa are *Astartella, Polidevcia arata, Septimyalina perattenuata*, and *M. (O.) slocombi*. About 50% of the brachiopods are *C. subtilita* and *C. planoconvexa*, but *Neospirifer, Derbyia, Antiquatonia, Linoproductus, Neochonetes*, and *Juresania* are moderately common.

The Jemez Springs Shale Member, within the uppermost 15 m of the Madera Formation, contains abundant brachiopods with fewer gastropods, bivalves, bryozoans, echinoderms, rugose corals, fusulinids, and trilobites. Sutherland and Harlow (1967) described the 18 species of brachiopods, of which *Hystriculina armata, Composita subtilita, Neospirifer pattersoni*, and *Antiquatonia jemezensis* are most abundant. At least one thin interval of dense *M. (O.) slocombi* shells occurs in this unit, but bivalve diversity is restricted to only a few species. Gastropods mainly include species (chiefly bellerophontids and *Glabrocingulum*) that are present in unit HC-11, but total diversity is much lower.

Each of these shale units represents early phases of marine transgressions, but with somewhat different faunal assemblages. These differences reflect both varied nearshore marine depositional environments and temporal changes in some elements of these marine communities. Although Late Pennsylvanian brachiopod/bryozoan/echinoderm/fusulinid faunas in limestones are conspicuous in the Jemez Springs area, careful examination of shale units also reveals rich molluscan faunas. Most of these bivalve and gastropod species also occur in the Midcontinent and eastern U.S., but some are endemic to the Rocky Mountains region or are new species.

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VERTEBRATE PALEONTOLOGY, BIOSTRATIGRAPHY, AND BIOCHRONOLOGY OF THE LOWER CHINLE GROUP, ZUNI MOUNTAINS, NEW MEXICO, AND ST. JOHNS AND PETRIFIED FOREST NATIONAL PARK, ARIZONA,

by *A. B. Heckert*, Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Prolific quarries in Arizona have produced extensive collections of Late Triassic (late Carnian) tetrapods. These quarries include numerous vertebrate collections from the Blue Mesa Member of the Petrified Forest Formation in the Petrified Forest National Park (PFNP), such as "Dying Grounds," "Crocodile Hill," "Wizard Wash," and many others. The other famous late Carnian quarry in Arizona is the *Placerias* quarry south of St. Johns, Arizona, long thought to be correlative to the PFNP quarries. Recent lithostratigraphic work in western New Mexico and eastern Arizona indicates instead that these localities are separated by as much as 100 m of stratigraphic section, even though they produce nearly identical fossils, including the phytosaur *Rutiodon*, the metoposaur *Buettneria*, the aetosaurs *Stagonolepis* and *Desmatosuchus*, and the dicynodont *Placerias*. *Stagonolepis* and *Rutiodon* are index fossils of the Adamanian land-vertebrate faunachron, which is of latest Carnian age. This lithostratigraphic succession indicates that biostratigraphic subdivision of the Adamanian remains elusive as all common tetrapod taxa occur throughout the section.

The Shinarump Formation is generally assigned an Otischalkian (late Carnian) age based on palynology and the metoposaurid amphibian *Buettneria*, which is common in strata of late Carnian age. The Bluewater Creek Formation and the Blue Mesa Member in Arizona have produced a diverse fauna of Adamanian (latest Carnian) age. In New Mexico the Blue Mesa is relatively unfossiliferous, but the Bluewater Creek Formation produces an Adamanian fauna consisting of cf. *Rutiodon, Stagonolepis, Desmatosuchus*, and *Buettneria* near Fort Wingate. A occurrence of the aetosaur *Paratypothorax* low in the Bluewater Creek Formation extends the range of that taxon into the early Adamanian.

Two late Triassic microvertebrate localities are known from this outcrop belt, the *Placerias* quarry and the Fort Wingate dinosaur site. Litho- and biostratigraphic evidence indicates that both of these quarries lie at or near the base of the Bluewater Creek Formation, and thus are of equivalent age. Both quarries produce dinosaurs, with the Fort Wingate dinosaur quarry producing extensive fossils of at least two dinosaurs and numerous other previously undescribed taxa.

THE CERATOPSIAN DINOSAUR *TOROSAURUS* FROM THE MCRAE FORMATION, SOUTH-CENTRAL NEW MEXICO,

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Red-bed mudstones and lenticular, trough-crossbedded sandstones of the Hall Lake Member of the McRae Formation east of Elephant Butte Reservoir produce ceratopsian fossils from six new localities. These localities are in a 100-acre outcrop area and occur at five stratigraphic levels over a 25-m-thick interval of the middle? part of the Hall Lake Member. Previously reported ceratopsian fossils from the McRae Formation have been of generically indeterminate specimens referred to *Triceratops* without justification in the older literature. The newly collected fossils include a partial skull, vertebrae and ribs, a scapula-coracoid, ilium, femur, and phalanges. The partial skull consists of the base of the paired parietals, a partial squamosal, the quadrate, and the jugal. It can be identified as *Torosaurus* because of its fenestrated frill with relatively large parietal fenestrae, lack of epoccipitals, and smooth lateral margin of the squamosal. This new record of *Torosaurus* is significant because (1) it supports assigning a Lancian (late Maastrichtian) age to the Hall Lake Member; (2) it represents a rare association of cranial and postcranial material of *Torosaurus*; and (3) it suggests that previously reported large ceratopsian fossils from the McRae Formation may all belong to *Torosaurus*.

A PRELIMINARY REPORT ON A NEW SKULL OF *PARASAUROLOPHUS* FROM THE UPPER CRETACEOUS KIRTLAND FORMATION, SAN JUAN BASIN, NEW MEXICO, by *T. E. Williamson,* New Mexico Museum of Natural History and Science, 1801 Mountain Road, NW, Albuquerque, NM 87104-1375; and *R. M. Sullivan,* Section of Paleontology and Geology, The State Museum of Pennsylvania, Third and North Streets, Harrisburg, PA 17109-1026

Parasaurolophus is one of the more rare and unusual of the crested duck-billed dinosaurs. A new skull of *Parasaurolophus* (long-crested form), from the Upper Cretaceous De-na-zin Member, Kirtland Formation, represents the most complete skull of this genus to be collected from New Mexico. It also has the most complete narial crest of any specimen collected to date. The specimen (New Mexico Museum of Natural History P-25100) is well preserved and consists of the skull roof and braincase, a nearly complete narial crest, the left cheek region, and left mandible.

The crest of the new skull differs from those of other described specimens of *Parasaurolophus*. The external crest morphology is unusual in that the dorsal surface is marked by numerous "vascular grooves." Computerized tomography (CT) scans, the first reported for *Parasaurolophus*, reveal that the internal morphology of the crest in the new specimen is much more complex than has been previously documented for this dinosaur. Previous workers described a maximum of only three pairs of internal chambers within the crest based on broken sections of the crests in other specimens. Our CT scans reveal nine to eleven distinct chambers within certain areas of the crest in NMMNH P-25100. The discrepancies between morphology of the crest of the new *Parasaurolophus* skull and previously described specimens remain unexplained at this time. Forthcoming detailed analysis of the CT scan data will reveal the distribution and shape of these chambers.

A TYRANNOSAURID SKELETON FROM THE UPPER CRETACEOUS KIRTLAND FORMATION, SAN JUAN BASIN, NEW MEXICO, by *T. E. Williamson,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

A partial skeleton of a tyrannosaurid is referred to *Albertosaurus* and represents the most complete skeleton of a theropod dinosaur to be collected from Upper Cretaceous deposits of New Mexico. Archer and Babiarz (1992) provided a preliminary description of this specimen (NMMNH P-25049) that was collected illegally from lands of the Navajo Nation and now resides at the New Mexico Museum of Natural History and Science. In May, 1995, the collection site of NMMNH P-25049 was relocated (NMMNH locality L-3097) in a fine-grained sandstone in the Farmington Sandstone Member of the Kirtland Formation. Additional portions of the skeleton, including a large articulated segment of the tail, were recovered.

NMMNH P-25049 includes parts of a disarticulated skull and many elements of the postcranial skeleton. Preserved skull elements include both frontals, both nasals, part of the left maxilla with several teeth, part of the left lachrymal, the left jugal, the right quadratojugal, part of the right quadrate, and a portion of the premaxilla as well as several isolated teeth and a portion of a premaxillary tooth. Parts of a mandible preserved include a partial dentary with several teeth, and the left articular. The postcranial skeleton includes a complete left scapula, the distal part of the right scapula, a partial humerus and fragments of other forelimb elements, a partial ilium, fragments of the pubis?, a nearly complete right hindlimb, and parts of the left hindlimb. The right hindlimb was found largely articulated. The axial skeleton includes parts of a few cervical vertebrae, part of the centrum of a dorsal vertebra, several ribs, a stomach rib, and a large articulated segment of the tail.

NMMNH P-25049 is referred to *Albertosaurus* based on the shape of the frontals and the presence of serrations on a premaxillary tooth. The relatively small size and the relative proportions of the hind limb bones suggest that it represents a sub-adult.

TAPHODACIES AND EARLY DINOSAUR EVOLUTION: AN EXAMPLE FROM THE BULL CANYON FORMATION (UPPER TRIASSIC: NORIAN), EAST-CENTRAL NEW MEXICO, by *A. P. Hunt,* Mesalands Museum, Mesa Technical College, 911 South Tenth St., Tucumcari, NM 88401; and *A. J. Newell,* British Geological Survey, Exeter, England

The Norian Bull Canyon Formation of east-central New Mexico yields the most diverse Late Triassic dinosaurian fauna in the world: (1) two new large herrerasaurids; (2) a new large ceratosaur and a small indeterminate form; (3) a new *incertae sedis* theropod; (4) the ornithischians *Revueltosaurus* and *Lucianosaurus*; and (5) an indeterminate prosauropod. In west Texas the Bull Canyon Formation also includes the ?theropod *Protoavis*, the ornithischian *Technosaurus,* and an indeterminate prosauropod.

Three vertebrate taphofacies are present in the Bull Canyon Formation: (1) channel sandstone; (2) floodplain mudstone; and (3) paleosol. Channel-sandstone assemblages are characterized by isolated and abraded fragments, principally of phytosaurs. Floodplain-mudstone assemblages represent the majority of fossils and include skulls and rare, articulated skeletons of large tetrapods (femoral length >30 cm), principally phytosaurs and aetosaurs. Paleosol assemblages are depauperate in aquatic/semiaquatic taxa (e.g. phytosaurs) and include articulated skeletons of small tetrapods (femoral length <30 cm).

All dinosaurian specimens derive from paleosol-hosted assemblages. Thus, it appears that dinosaurs were an element of a community living in well-drained environments and were absent from floodplain communities. Taphonomic studies in the Petrified Forest Formation at Petrified Forest National Park show similar distributional patterns for dinosaurian specimens—restricted to the paleosol taphofacies. The rarity of Late Triassic dinosaurs in western North America is mainly a function of the predominance of fossil localities that only sample the floodplain community. The few localities that sample the paleosol taphofacies contain abundant dinosaurian specimens.

POSTER SESSION

A LITHOLOGIC STUDY OF XENOLITHS FROM THE KILBOURNE HOLE MAAR, SOUTHERN NEW MEXICO, by *E. C. French, IV,* and *N. J. McMillan,* Dept. of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, efrench@nmsu.edu and nmcmilla@nmsu.edu

A representative collection of crustal and mantle xenoliths has been obtained from the Kilbourne Hole maar, New Mexico. In spite of the site's international fame, no previous comprehensive study has been done on these xenoliths. This suite of xenoliths will be compared to other xenolith suites from around the world to understand more fully the crustal structure and how xenoliths become entrained in basaltic eruptions.

Xenoliths from Kilbourne Hole fall into eight broad categories. In order of decreasing abundance, these are (1) ultramafic peridotites, (2) mafic granulites, (3) pyroxenites, (4) intermediate and silicic volcanic rocks, (5) clastic sedimentary rocks, (6) basalts and basaltic andesites, (7) limestones, and (8) pelitic granulites. Collectively, these represent samples of the entire lithospheric section. The peridotites were entrained in the upper mantle. Mafic and pelitic granulites represent the lower crust. Pyroxenites represent either the mantle or lower crust. All other lithologies have not been metamorphosed and thus represent the middle to upper crust. The basalts and basaltic andesites are coarser grained than the coatings of juvenile basalt on the xenoliths and thus could represent upper crustal lava flows through which Kilbourne Hole erupted. Lithologic correlations with exposed formations are in progress.

Most xenolith studies focus on specific lithologies, especially lower crustal granulites and upper mantle peridotites. The Kilbourne Hole data will be compared to other xenolith studies worldwide in which the entire spectrum of lithologies have been collected. For instance, the crustal xenolith suite from Hill 32 in the McBride volcanic province, north Queensland, Australia, is dominated by lower crustal lithologies; upper crustal xenoliths constitute only a few percent of the population, and no sedimentary or volcanic xenoliths are reported (Rudnick and Taylor, 1987, JGR, 92:13,981–14,005). In contrast, the Kilbourne Hole crustal suite contains a more diverse and abundant selection of upper crustal lithologies.

A NEW DATABASE OF PHANEROZOIC ISOTOPIC AGES IN NEW MEXICO, by *M. Wilks,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The New Mexico Bureau of Mines and Mineral Resources is compiling Phanerozoic isotopic ages for New Mexico. The data, entered into an ACCESS database, comprises 2,100 published and unpublished radiometric ages of Phanerozoic rocks in New Mexico.

Nine isotopic methods have been used to determine the above radiometric ages: Potassium/Argon, $Argon^{40}/_{39}$, Rubidium/Strontium, Uranium/Lead, Uranium/Thorium-disequilibrium, $Chlorine^{36}/_{35}$, $Helium^{3}$, $Carbon^{14}$, and fission track. An age is entered into a Main table where the sample is assigned a unique number. In the Main table there are thirty fields common to every data point including: method, age, material dated, rock, formation, region, location (more specific than region), latitude and longitude, quad, county, and two references.

The unique sample number links the Main table to specific isotopic system tables where analytical data can be reported. There are nine separate analytical tables, one for each of the above mentioned isotopic systems.

In the Main table a maximum of two references can be reported. The first reference is the reference where the age was first reported. The second reference often gives more detailed analytical data or sample location. The two reference fields are followed by abbreviations that link to the Bibliographic table where one can search for the authors' names in full, the title, and journal where the article was published. As of 2/9/96, 330 references have been cited.

The search capabilities of ACCESS allow searches to be made on any field or combination of fields.

The first step in data entry is to produce a hard copy; individual forms have been designed for each isotopic system. The data is then entered into database. One of the main problems encountered in compiling this database was the lack of geographic location for many data points. Of the 2,100 ages only 60% reported latitude and longitude locations, 10% had locations reported by Section, Township, Range. For the remaining 30% Lat./Long was determined from published maps and location descriptions and are therefore not as accurate as the reported Lat./Long data.

We hope to have this database accessible to the public by the end of the year. To aid maintaining this database we would request that authors publish Lat./Long data or make it available to us. At the present time we are working on expanding the analytical data that can be presented. The newer isotopic systems require that more analytical data be reported if the dates are to be evaluated. Formats for reporting Ar/Ar, $Cl^{36}/_{35}$, and He^{3} are being developed so that authors can send analytical data to us on disc or via email.

A separate but linked database is being developed for ages determined by other methods such as ESR (Electron Spin Resonance) dating.

CORRELATION AND RELATIVE AGES OF QUATERNARY PIEDMONT SURFACES WEST OF SOCORRO, NEW MEXICO, by *B. Harrison, *R. Chamberlin, E. Shearer,* and Soils Class, Fall 1995, Dept. of Earth and Environmental Science, New Mexico Tech, and *New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Geologic mapping of the Socorro area identifies four major piedmont units of Quaternary age(Qlc, Qvo1, Qvo2, Qvy) modified after McGrath and Hawley, 1987. Recent detailed mapping and correlation of surfaces using soil characteristics has indicated that these piedmont units can be further subdivided. Two major types of landforms are recognized in the piedmont west of Socorro, (1) those that grade to past levels of the Rio Grande, and (2) those landforms that have not been influenced by past levels of the Rio Grande. The first set of landforms are moderate-gradient fans and terraces associated with the larger streams flowing primarily from the Magdalena Mountains, whereas the second set of landforms are those found along the foot of Socorro Peak, and consist of steep, coarse, debris-flow fans. In some places there is an apparent tectonic control on the development (age) of fan surfaces where Quaternary faults are down-to-the-west (against slope) causing small segments of the upthrown block to be bypassed by streams.

Landforms related to levels of the Rio Grande consist of two fans (at Socorro Canyon and Nogal Canyon) and a series of inset terraces. The oldest fan surface, forming the southern boundary of Socorro Canyon, has been correlated to the Las Cañas (Qlc) surface, which marks the top of the Santa Fe Group and the top of the Sierra Ladrones Formation. It has a stage IV carbonate horizon and is probably several hundred thousand years old. The next oldest fan surface (Qvo1) is north of Nogal Canyon; it has a Stage II carbonate horizon. The surface (Qvo1) has been stripped and probably had a more strongly developed soil prior to erosion. At a minimum, this surface (Qvo1) is late Pleistocene in age.

Both the Socorro Canyon and Nogal Canyon fan surfaces have been incised by tributary streams of the Rio Grande, resulting in nested terrace sequences. Both terrace sequences consist of three terraces. In the Socorro Canyon sequence, terrace soils have stage III, stage II, and very weakly developed stage I calcic horizons, respectively. In the Nogal Canyon sequence, the highest terrace has a stage II calcic horizon, and the youngest terrace has no calcic horizon. Only a few remnants exist of an intermediate surface between the two terraces in this sequence.

The debris fans along the Socorro piedmont (Qpu, piedmont-slope deposits undifferentiated) have a range of soils with different degrees of development. Of the six soils described on this area, three had stage II calcic horizons, and one of these had been stripped.The other three surfaces all had soils of different degrees of development on them. One of the soils was developed on a sand sheet and had stage I calcic horizon.

The two major types of surfaces respond to different geomorphic conditions, the first set of surfaces are formed as the tributary streams respond to drops in the level of the RioGrande, whereas the second set of surfaces probably form in response to climatically wetter periods in the late Pleistocene and Holocene. It is possible that there has been almost continuous deposition of the debris fans since the middle to late Pleistocene, which has implications for recognizing the top of the Santa Fe Group in these sediments.

DINOSAUR FOOTPRINTS FROM THE JURASSIC SUMMERVILLE FORMATION, NORTHERN NEW MEXICO, by *S. G. Lucas* and *J. W. Estep,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

The only Jurassic dinosaur footprints known from New Mexico are from the Summerville Formation. Lucas et al. (1990 NMGS Guidebook) reported two footprints of a theropod dinosaur (*Grallator* sp.) from Romeroville near Las Vegas in San Miguel County. They identified the track-bearing horizon as lowermost Morrison Formation, but it is actually Summerville Formation below the disconformable base (J-5 unconformity) of the Salt Wash Member of the Morrison Formation.

We document here a second theropod-dinosaur-footprint locality in the Summerville Formation of New Mexico. This locality is just west of the Chama River at Navajo Peak, Rio Arriba County at UTM 13 346460E, 4037151N. The tracks are concave imprints in a yellowish-gray to very light gray, fine-grained micaceous litharenite of the Summerville Formation about 13 m above the Todilto–Summerville contact. Fifteen tridactyl tracks are present. All are longer than wide, and some preserve claw impressions at the digit tips. These tracks are those of a large theropod and closely resemble large theropod tracks reported from European Jurassic strata.

AN ADDITION TO THE VERTEBRATE ICHNOFAUNA OF THE REDONDA FORMATION (UPPER TRIASSIC: RHAETIAN), EAST-CENTRAL NEW MEXICO, by *W. D. Cotton,* National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903-2475; *A. P. Hunt,* Mesalands Museum, Mesa Technical College, 911 South Tenth Street, Tucumcari, NM 88401; *J. E. Cotton,* Charlottesville High School, 1400 Melborne Road, Charlottesville, VA 22901; and *M. G. Lockley,* Dept. of Geology, University of Colorado at Denver, Denver, Colorado 80217-3364

The Redonda Formation (Upper Triassic: Rhaetian) is widely exposed in east-central New Mexico and represents lacustrine and lacustrine-margin deposition. Laterally continous beds of ripple-laminar micrite are common in more easterly exposures in Quay County. These strata represent carbonate mudflats on the lacustrine margin and yield a significant ichnofauna. The vertebrate component of the ichnofauna was first collected in 1934 by E. C. Case. The vertebrate ichnofauna includes *Pseudotetrasuropus, Tetrasauropus, Grallator,* and *Rhynchosauroides.* In 1995 we found several specimens of a new ichnotaxon in the thinly bedded upper portion of one of the micrite beds.

The new tracktype is pentadactyl and represents a quadrupedal trackmaker. A typical pedal imprint is 5 cm long and about 5 cm wide. Digit impressions IV-I exhibit decreasing length or are subequal in length and are incurved. The impression of digit V is always shallow; it diverges from the other digit impressions and is much shorter. A short, narrow heel imprint is deep and has an acute posterior margin.

This ichnotaxon shows morphological similarities to tracks assigned to *Rhynchosauroides,* such as those from the lower Petrified Forest Formation (Upper Triassic: late Carnian) of Petrified Forest National Park, northeastern Arizona. It differs from most *Rhynchosauroides* tracks in the depth and shape of the heel impression and in the large size. Most *Rhynchosauroides* tracks are exhibit pedal lengths less than 5 cm, although some European species compare in size to the Redonda tracks. The ichnogenus *Rhynchosauroides* is apparently a "wastebasket" taxon that includes all "lizard-like" tracks from the Triassic and is in need of taxonomic revision. The Redonda tracks appear to represent an ichnotaxon similar, but not identical, to *Rhynchosauroides.*

EVIDENCE OF GREGARIOUS BEHAVIOR IN DINOSAURS FROM A NEW TRACKSITE, MESA RICA SANDSTONE (LOWER CRETACEOUS), NORTHEASTERN NEW MEXICO, by *A. P. Hunt* and *B. R. Watts,* Mesalands Museum, Mesa Technical College, 911 South Tenth St., Tucumcari, NM 88401

A new tracksite has been located near Mills, Harding County, New Mexico, in the Mesa Rica Sandstone (Lower Cretaceous: late Albian). The tracksite is located on the rim of Mills Canyon in the upper portion of the Mesa Rica

Sandstone. Isolated and poorly preserved tracks occur in nearby outcrops. The main tracksite preserves portions of about 12 trackways of a large bipedal dinosaur. The pedal tracks are wider than long, have bilobed heels, and average 30–40 cm in length; they represent the iguanodontid ichnogenus *Caririchnium*.

The new tracksite is an extension of the Dakota megatracksite (DM), which extends from Boulder, Colorado to Mosquero, New Mexico. All DM tracksites are in the upper Mesa Rica Sandstone or lower Pajarito Formation, or their nomenclatural equivalents. These tracksites formed on the western margin of an epeiric seaway.

The trackways at the new tracksite exhibit parallel orientation, which is suggestive of gregarious behavior. The only other DM site in New Mexico to show this feature is near Mosquero. At Mosquero, the tracks trend north-northeast and roughly parallel the shoreline trend, but those at the new site trend east.

Late Triassic tracksites in eastern New Mexico indicate gregarious behavior in prosauropods (*Pseudotetrasauropus:* Redonda Formation) and theropods (*Grallator:* Sheep Pen Sandstone). The new tracksite and the one at Mosquero are the only to exhibit gregarious behavior in ornithischian dinosaurs in New Mexico.

TRIASSIC STRATIGRAPHY AROUND THE NACIMIENTO AND JEMEZ UPLIFTS, NORTHERN NEW MEXICO, by *A. B. Heckert,* Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico, 87131; and *S. G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

Triassic strata exposed along the flanks of the Nacimiento and Jemez uplifts (Sandoval County, northern New Mexico) represent two tectonosequences. The lower tectonosequence is a relatively thin (up to 39 m) package of red-bed sandstones assigned to the Middle Triassic Anton Chico Member of the Moenkopi Formation. The upper tectonosequence disconformably overlies the Moenkopi Formation or older Permian strata and is assigned to the Chinle Group (Agua Zarca, Salitral, Poleo, and Petrified Forest Formations).

The Moenkopi Formation includes strata previously assigned to the Permian Bernal Formation by most workers, and it consists mostly of grayish-red sandstone, siltstone, and intraformational conglomerate, with minor mudstones as thick as 39 m. The Anton Chico Member of the Moenkopi Formation disconformably overlies the Permian Glorieta Sandstone and is disconformably overlain by the Agua Zarca Formation.

Chinle Group strata around the Nacimiento and Jemez uplifts are a thick (up to 400 m) sequence of red-bed mudstones with a relatively thick basal unit of sandstone and extrabasinal conglomerate. The Agua Zarca is as thick as 61 m and is mostly white-to-brown, trough-crossbedded quartzose sandstone and siliceous, extraformational conglomerate. The overlying Salitral Formation is as thick as 102 m and is mostly purplish smectitic mudstone. The Poleo Formation disconformably overlies the Salitral and is as thick as 41 m of mostly grayish-yellow, trough-crossbedded litharenite, subarkose, and intrabasinal and siliceous conglomerate. Above the Poleo, the Petrified Forest Formation is as thick as 340 m and is dominated by reddish-brown smectitic mudstone. South of San Miguel Canyon (T19 R1W) the Poleo Formation essentially pinches out, although thin (<20m) lenticular equivalents of the Poleo are locally present as far southeast as Vallecito Creek (T16N R2E). Furthermore, throughout Sandoval County, the lower portion of the mudstone-dominated interval above the Agua Zarca Formation, even where the Poleo Formation is absent, is dominated by purplish mudstone characteristic of the Salitral Formation. Therefore, to the south of San Miguel Canyon, the Salitral and Poleo Formations can be recognized locally, but the thick, mudstone-dominated section above the Agua Zarca is assigned to the Petrified Forest Formation. The Correo Sandstone Bed crops out as a bench-forming sandstone up to 15 m thick at the top of the Petrified Forest Formation along the south flank of the Nacimiento uplift. Fossil vertebrates indicate the Petrified Forest Formation ranges in age from Adamanian to Revueltian (latest Carnian–Norian) and support lithostratigraphic correlation of the Triassic strata exposed in Sandoval County to nearby Triassic outcrops in the Chama Basin, Lucero uplift, and Hagan Basin.

EVIDENCE FOR HERDING BEHAVIOR IN ORNITHOPOD DINOSAURS FROM THE DAKOTA SANDSTONE OF NORTHEAST NEW MEXICO, by *J. E. Cotton,* Charlottesville High School, 1400 Melbourne Rd., Charlottesville, VA 22901; *W. D. Cotton,* National Radio Astronomy Observatory, 520 Edgemont Rd, Charlottesville, VA, 22903-2475; and *A. P. Hunt,* Mesalands Museum, Mesa Technical College, 911 South Tenth St., Tucumcari, NM 88401

Studying the trackways of extinct animals is one of the few ways to study social behaviors, especially herding, in these animals. Lockley and Hunt (1995, Dinosaur tracks: Columbia University Press, New York) discuss a tracksite at Mosquero Creek, New Mexico, that shows many individuals of ornithopod ichnogenus *Caririchnium* (a presumed iguanodontid) moving in apparently organized groups that they interpreted as herds. The tracks are all assigned to *Caririchnium,* but different groups had different size footprints. In addition, the consistency of the track depths indicated that the tracks were made in a relatively short time span. We have further studied one of these groups, analyzing the direction and speed of motion for consistency with the herding hypothesis. Speeds were determined using the method of Alexander (1989, Dynamics of dinosaurs and other extinct giants: Columbia University Press, New York). Although there are large uncertainties in the absolute speeds determined using this method, the relative speeds should be accurate. We measured positions, sizes, and direction of motion of footprints in 16 trackways that were unambiguous and consisted of three or more consecutive pes imprints. These trackways have a relatively narrow distribution of pes impression lengths indicating a rather narrow age distribution. Lockley and Hunt (1995) interpret these tracks as those of yearling iguanodontids.

Most of the trackways measured had dimensionless speeds (as defined by Alexander, 1989) in the range of 0.3 to 0.5, which is significantly slower than the division between walking and running of 0.7 given by Alexander (1986). The trackmakers were moving at a deliberate but not fast pace. The measured speeds and directions of motion cluster around a well-defined central value with significant dispersions in speed and direction. At this slow speed, some variation in speed and direction is expected, and the observed distribution is consistent with herding behavior. In addition, there is a correlation (correlation coefficient = –0.67) between footprint size and dimensionless speed in the sense that the larger animals were exerting less effort than the smaller animals but moving at approximately the same physical speed. We believe these trackways represent a herd of yearling iguanodontids.

A REEVALUATION OF THE VERTEBRATE ICHNOFAUNA OF THE MESA RICA SANDSTONE AND PAJARITO FORMATIONS (LOWER CRETACEOUS: LATE ALBIAN), CLAYTON LAKE STATE PARK, NEW MEXICO, by *A. P. Hunt,* Mesalands Museum, Mesa Technical College, 911 South Tenth Street, Tucumcari, NM 88401; and *S. G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

The extensive vertebrate ichnofauna at Clayton Lake State Park, northeast New Mexico, has been the subjective of several publications. Tracks here occur in the upper Mesa Rica Sandstone and lower Pajarito Formation (Lower Cretaceous: late Albian) in the dam spillway. Early studies suggested the presence of a diverse ichnofauna, including half a dozen ichnotaxa representing ornithischians, theropods (including web-footed theropods), and pterosaurs. Recent work indicates that only three vertebrate ichnotaxa are present: (1) more than 90% of the tracks are tridactyl ornithischian tracks assigned to *Caririchnium* sp. (including putative web-footed theropod tracks); (2) tridactyl theropod tracks; and (3) crocodilian swimming traces (putative pterosaurian tracks).

The Clayton Lake tracksite (CLT) is one of the largest individual sites in the Dakota megatracksite (DM; popularly called the "Dinosaur Freeway"). CLT is similar to other DM tracksites in having a preponderance of iguanodontid tracks and relatively few theropod tracks. It differs from several other DM tracksites by including crocodilian tracks and in having tracks on multiple bedding planes. It differs from all DM sites in exhibiting a large range of track preservation as a result of variability in substrate saturation. A new map of the site is being prepared, and this will provide inferences on individual and group behavior. □